Advanced Review

Socio-hydrology and hydrosocial analysis: toward dialogues across disciplines

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In this study, we review the ways in which water has recently been conceptualized by both natural and social scientists as either hydro-social or socio-hydrological. We do this in order to discuss whether and how they can be compatible, in order to enable dialogue across disciplines that seek to address the ecological and social challenges related to the complex human/water interactions. Through our review, we document the emergence of these specific terminologies, identify how these terms—and the conceptualizations they represent—relate to each other, and suggest what opportunities there are for building further interdisciplinary approaches to understanding water and society. Specifically, we review the recent rise in socio-hydrology amongst natural scientists/hydrologists to put this in discussion with a much longer tradition in social sciences of seeing water as both natural and social. We identify what the paradigms are in both conceptualizations in order to assess what their respective focus is, and what they omit. Our purpose is not to judge competing claims. Rather we want to assess the knowledge claims made in both paradigms: what can we learn when we employ these different approaches, what different rationales for action do they suggest, and what scope exists for collaboration. We conclude that there is scope in combining both approaches without a need to antagonistically question their respective fundamental assumptions, and playing to the strengths of each: the rich case study narratives produced by hydrosocial research can be the basis for the conceptual and quantitative modeling of socio-hydrology. © 2016 The Authors. *WIREs Water* published by Wiley Periodicals, Inc.

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INTRODUCTION

Interdisciplinary approaches to water research have been on the rise over the past decades. The launch of this interdisciplinary review journal itself in 2014 is but one reflection of the degree to which different disciplines are now interested in each other's water research. Much of the motivation to combine disciplinary approaches to study water from humanities, social science and natural science perspectives has been driven by the need to understand and address complex, interdependent water related societal challenges. The scale and magnitude of these challenges are reflected in the impact of climate change on water, the increased frequency and severity of water-related disasters, impact of growing population on water consumption, more water-intensive patterns of growth, increasing rainfall variability, water pollution, and lack of access to water for hundreds of millions of people. In response to these global challenges, water scientists are increasingly adopting an interdisciplinary or transdisciplinary approach in order to understanding water problems, make predictions, and produce information on which society makes future decisions.[1,2]

Notably, this recognition of the need for combining analyses of social and natural systems has come from both natural and social water scientists. But, as is amply discussed in existing literature on the complications of interdisciplinary research[3–5], there are barriers. Specifically, the different sciences base their understanding on fundamentally different knowledge paradigms, which can be difficult to align. Thus, often water scientists across disciplines are using similar words, but understand different things. These difficulties in communicating across disciplines can be related to differences in paradigms, although disciplinary definitions and jargon can also play a role. A research paradigm includes ontology ('what does the world look like?'), epistemology ('what can we know about the world?'), methodology ('how should we gather this knowledge?'), and axiology ('why should we gather knowledge/what should we do with the knowledge?').[6,7] Even when paradigms are discusses explicitly, axiology is often forgotten while it should play a major role in the assessment of paradigms for their societal relevance, as well as in scientists' reflexivity about their own work.

In this context of an increasing need for, and response of scientists to, water research to cut across disciplinary boundaries, and the inherent challenges in these combinations, we discuss the recent research in geography and beyond, where we see two distinct paradigms developing: one that talks of socio-hydrological systems, and one that uses 'hydrosocial' to describe the same systems. Researchers from both social and natural sciences perspectives who address global challenges increasingly acknowledge the need to see water—and the systems within which it flows—as both social and natural. These sentiments have come from both directions. The hydrological program Panta Rhei (meaning 'everything flows,' after the Greek philosopher Heraclitus) launched by the International Association Hydrological Sciences embodies this recognition of hydrological systems as fundamentally altered by social relations and processes. Scientists driving this program have coined the term socio-hydrology to reflect this new direction in hydrological science.[8] On the other side, social scientists have found their own new term 'hydrosocial,' to encapsulate a longer tradition within human geography of understanding natural systems in relation to the social world.[9] Interestingly, Heraclitus' quote to illustrate how nothing is permanent except change, 'no man ever steps in the same river twice, for it's not the same river and he's not the same man,' could be interpreted to refer to socio-hydrological or hydrosocial examples.

What do these two, seemingly parallel, movements toward understanding relations between water and society mean for each other? Are we using two different words to do the same things, or are there differences between them? These are the questions we seek to answer in this paper. We do so through a review of literature self-identified as socio-hydrology, and a more diverse literature that can be labeled as 'hydrosocial.' Unlike Blair and Buytaert,[10] we do not consider hydrosocial research to be a development of socio-hydrology, but locate it in another, distinct research tradition. The sequence of the terms 'hydro' and 'socio' and the presence or absence of a hyphen is highly significant, as we will show.

Through our review, we examine the compatibilities and the differences between these two concepts by identifying their research paradigms: what do they think the world looks like (ontology), what do they think they can know about the world (epistemology), how do they set about to gather the knowledge required (methodology), and how do they see their role vis-à-vis society (axiology)? Through this classification, we identify the scientific origins of these two moves, and their relationship with more general scientific debates on Earth System Science (ESS). As we go on to describe, the general research lineages out of which these concepts have emerged carry certain implications for research. However, the paradigmatic choices are equally if not more important from a societal or policy perspective. Paradigms are characterized as much by what they omit as by what they include, and some omissions give rise to doubts about the usefulness of the resulting findings.

We therefore conduct this classification to highlight the consequences of the (often implicit) paradigms employed. Which consequences do different paradigmatic perspectives have for empirical research? Which values are implied in these paradigmatic choices? The objective is not to judge competing paradigms, but to assess them in the light of pragmatic questions: what can we learn when we employ these different approaches, what different rationales for action do they suggest, and what scope exists for complementarity? We do not set out to answer all of these questions, but focus in our concluding section of the paper on the scope for complementarity with a proposal for fruitful collaboration between the different branches of enquiry. However, we first present our review.

SOCIO-HYDROLOGY RESEARCH

Socio-hydrology has recently been launched by the hydrological sciences community as the research theme for the current decade (2013–2022) which will 'advance the science of hydrology for the benefit of society' (Ref 11, p. 1257). According to its proponents, 'it is evident that societal actions are now conditioning hydrology in many countries at a tremendous and increasing rate' and 'water is becoming a major limiting factor to the sustainable development of society' so that 'strategic and efficient efforts for water management, within an interdisciplinary approach, are needed' (Ref 11, p. 1259). Although parallels with socio-ecological systems modeling can be discerned (see *ESS and Its Critics* section), socio-hydrology has largely developed its own conceptualization of how water interacts across biophysical and societal processes, and subsequent methodologies to identify and analyze these interactions.

In our review of publications self-identified as 'socio-hydrological,' a large proportion of papers (approximately one third of a total of 69) argues for, rather than provides examples of, socio-hydrological research.[8,12] This is perhaps not surprising given its recent launch. However, when preceding research agendas are included, water resources research has for a long time sought to understand the human impact on hydrological systems, as well as the opportunities and constraints faced by societies due to low or high water quantities and inappropriate quality. This is generally problem-focussed research into specific interactions in specific locations. For a long time many of these studies have followed an 'integrated' approach, advocating 'integrated water (resources) management'.[13]

What distinguishes socio-hydrology from problem-focussed water resources research is the attempt to capture all human-nature interactions in a mathematical, holistic system model by means of mathematical expressions.[14,15] At the same time, socio-hydrology also endeavors to go beyond the conceptual models pioneered in Falkenmark's research.[16,17] According to one prominent proponent, socio-hydrology could therefore be labeled 'the scientific justification for integrated water resources management' (M. Sivapalan, personal communication, 2015). Indeed, the orientation toward societal goals such as sustainability is often stated in published papers. However, in socio-hydrology's axiology it is assumed that such goals are self-evident and unproblematic. For example, O'Connell and O'Donnell (Ref 18, p. 159) posit that 'managing the future evolution of tightly coupled human and natural systems will require the development of a capability to rationally "engineer" them through new management and engineering approaches that accommodate the balance between social, economic, and environmental capital.' In their study, this means the evaluation of flood investment strategies not purely on the grounds of a stochastic flood model, but coupling this with costs-benefit analysis and/or agent-based modeling of societal decision making. This is at the same time a nice illustration how 'old style' research is now relabeled as socio-hydrology.

Moving beyond the promotion of socio-hydrology as an approach, socio-hydrological case studies have also been published. Some of these case studies present a narrative of patterns of historical changes in human-water relations.[19,20] Socio-hydrological narratives are sometimes illustrated by a simple quantitative analysis, for example of a historical analysis of catchment water balance.[21,22] In many socio-hydrology case studies, the emphasis lies with the development of a conceptual mathematical model, mostly as coupled, nonlinear differential equations.[23] Some papers aim to study the behavior of the models by inputting imaginary or real time series and/or using different parametrizations to produce scenarios of possible behavior.[24] Within the set of self-identified research on socio-hydrology, analyses of human responses to flooding comprise examples of all above types of research (Box 1).

The ontological aspiration of scholars in socio-hydrology is to capture the full range of human behavior in the interaction with the natural systems. However, in the methodological implementation of these ideas both the natural and the human dimensions are reduced to fit in a quantitative model. This presents epistemological problems: humans differ from other constituents of socio-hydrological models because they can choose how to act on their perception and preferences, and their opportunities for individual and collective agency is affected by socio-political contexts, so no single truth will be found. This is duly recognized, and flagged as concern, within socio-hydrology community. Di Baldassarre et al. (Ref 27, p. 3301) recognize that 'this conceptualisation unavoidably neglects some potentially significant aspects related to the heterogeneity

BOX 1

SOCIO-HYDROLOGY OF FLOODPLAINS

Di Baldassarre et al.[25–29] and Viglione et al.[30] state their objective /purpose to investigate 'how different sociotechnical approaches in floodplains are formed, adapted, and reformed through social, political, technical, and economic processes; how they require and/or entail a reordering of social relations leading to shifts in governance and creating new institutions, organizations, and knowledge; and how these societal shifts then impact floodplain hydrology and flooding patterns' (Ref 28, p. 137). Some of the publications qualitatively identify historical patterns in the coevolution of settlement patterns and technological choices, partly based on a case study of the Po floodplain.[26,28] They find two patterns, the 'adaptation effect,' when the use of flood defense technology is limited, resulting in frequent flooding which is in turn associated with decreasing vulnerability; and the 'levee effect' when flood protection structures lead to less frequent but more severe flooding, associated with increasing vulnerability.[30] Moving toward a quantitative model, Di Baldassarre et al.[27,30] construct a mathematical conceptual model of human–nature interactions in a floodplain using differential equations. The input of fictive time series and an assumed decision model on when to construct levees or move away 'shows that the conceptual model is able to reproduce reciprocal effects between floods and people as well as the emergence of typical patterns [the adaptation effect and the levee effect, authors]' (Ref 27, p. 3295). Using the same conceptual model of human-flood interactions, Viglione et al.[31] explore how the size and wealth of settlements will change over time with six different ideal-types of risk-coping cultures, loosely based on Cultural Theory.[31] The representation of human-nature interactions is more limited in the case study in Bangladesh[29] which focuses on statistical relationships between the occurrence of flooding and patterns of human settlements by performing a spatially distributed analysis of the interactions between the dynamics of human settlements and flood inundation patterns.

of human societies' [so] 'this conceptualisation should be considered as an educated hypothesis of how human-flood systems work in a generalised way, rather than as a predictive tool for a particular location.' Vogel et al. (Ref 12, p. 4420) assert that 'the primary and perhaps most formidable challenge involves a quantitative description of the behavior of individuals (e.g., stakeholders and decision makers) as well as social institutions and communities.' As Troy et al. (Ref 24, p. 3677) point out, 'this poses numerous oppositional challenges: the desire to be quantitative but to incorporate (often qualitative and specific) knowledge from social science disciplines; the challenge of reconciling numerical data with descriptive histories; the need to base analyses on empirical facts but to develop generalizable understanding; and the desire to observe and predict the behavior of a system while being a part of that system.' Looking for an answers to some of the challenges, Troy et al.[24] suggest that approaches such as agent-based modeling and scenario-building can capture the above-mentioned 'heterogeneity among agents' to some extent.

However, the desire to capture human behavior in a model remains when they warn that 'incorporating human behavior in models is difficult [because] human behavior is often unpredictable.' There are indeed several examples of human behavior that exacerbate rather than reduced flood risk (Ref 24, p. 4813). Di Baldassarre et al. capture the latter by 'the levee effect' (Box 1). Troy et al.[24] conclude that 'for sociohydrologic models, using the traditional mode of calibration may not be feasible [...] as the social system and its coupling to the physical system may preclude universal dynamics. In addition, it is possible that how the two systems coevolved is one plausible path among many, or it is also possible that the nature of the social dynamics (i.e., economic, demographic, cultural) that are represented in the model may result in different trajectories and model behaviours' (Ref 24, p. 4811) and 'some system components will be critical to one system while irrelevant in another' (Ref 24, p. 4812).

Fundamental reasons for this difficulty to include 'society' in socio-hydrological models are the plurality of human values, differing human agency, and path dependency of societal (power) relations. For example, 'societal values and experiences with flooding can lead to diverging policy responses, such as the differences seen in U.S., UK, and Canadian flood policy. [...] the media shapes much of society's flood risk perception, such that floods taking place in one place may affect flood risk perceptions in another. [...] The historical and cultural drivers and processes of social systems may pose further challenges for socio-hydrologic modelling' (Ref 24, p. 4813). On a pragmatic level, though not unimportant, Troy et al.[24] also point out the massive data requirement for socio-hydrological models if they are to capture enough variables and details, something they assess is unlikely to be satisfied in reality.

The approaches of, and justification for, socio-hydrology are very similar to those used by Earth Systems Science (ESS), particularly socio-ecological systems modeling (SES), which are fields of research with a much longer history. It could be argued that socio-hydrology is no more than a recent incarnation of SES, one that focusses on, or starts with, the water system. In SES, the quest to incorporate human dimensions has been on-going for a longer period, which provides learning opportunities for socio-hydrology. In the next section, we therefore proceed to put socio-hydrology in the wider context of ESS.

ESS AND ITS CRITICS

Efforts to consider social and ecological systems in their entirety are not new. Already in 1939 Angyal[32] argued that a whole system could not be captured by its constituting elements and their relationships, and Ablowitz[33] used the term 'emergence' to describe how the whole displays new characteristics unrelated to the parts—in turn tracing this idea back to earlier writing. The quest to connect human and physical research, both conceptually but also practically (in research activities) is therefore a long-standing one, especially but not solely in geography. ESS originates from the work done at IIASA in the late 1970s by Walters and Holling, initially on structural change and ecosystems functioning.[34,35] The scope was later expanded to include societal behavior[36], evolving into SES. Modelers have worked to include feedback mechanisms between human society and the global environment in order to capture the 'co-evolution of human and natural systems' (Ref 37, p. 4). It could be identified as 'a holistic super-discipline that tries to embrace all processes in nature and society as one interlinked system' (Ref 38, p.7). The ESS paradigm has acquired much prestige and influence, which can be traced in part to its 'Enlightenment promise of human self-realization, autonomy and control' (Ref 36, p. 8). Its success is also based on a (post)positivist axiology that a better understanding of the effects of human actions on the Earth will lead to more responsible behavior, an assumption shared by socio-hydrology.

SES models have a holistic ontology and consider earth's socio-ecology as self-organising complex system, thus implementing Angyal's[30] and Ablowitz'[31] propositions. Climate change impact (CC) modeling is another example of such linked socio-physical systems research. Methodologically, both SES and CC models are based around a well-developed core of physical modeling, which is combined with a selection of social science knowledge that can be made commensurate with the physical sciences' paradigm.[39,40] The main epistemological presumption is that society and the biophysical world can best be analyzed and modified using similar concepts and protocols; for society this could for example be agent-based models. As Castree et al.[37] argue, a single, seamless concept of integrated knowledge is thereby posited by ESS as both possible and desirable, one focused on complex systems.

Like in socio-hydrology, in ESS social dynamics of environmental change are downplayed, which can lead to incorrect or incomplete solutions. ESS's incomplete understanding stems from ESS' epistemological assumptions, i.e., how ESS thinks it can know human values and agency and societal (power) relations. Humans have different perceptions of and preferences for their environment, and have different abilities upon which to act on their perception and preferences. Such opportunities for individual and collective agency are shaped by the socio-political contexts, which is not taken into account by ESS. In turn, the ESS approach 'also runs the risk of producing a post-political narrative that invites techno-managerial planning and expert administration at the expense of democratic debate and contestation' (Ref 38, p. 217). This practice of using a quantification process to 'screen out' pluralistic perspectives and to obscure how power plays a role in the status quo occurs in many approaches to assessment, such as the representation of biodiversity by the Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES)[41] or the assessment of the Millennium Development Goals.[42]

Some of the most vocal critics of ESS and its ways of knowing, representing, and intervening in earth-society relations come from (critical) human geography, where there is a long tradition of focusing on the topics that ESS backgrounds: to expose the role of power and value choices in the history of human interaction with earth systems. However, this central focus on the very things ESS omits—human agency, and the ways social/political contexts shape choices in how to respond to environmental changes—has, historically, been combined with insufficient attention to the 'material roots' of the resulting socio-environment, i.e., the role(s) played by the physical environment in societal changes.[43–45] Reflecting an awareness of this imbalance, a 'material turn' or 'renaturalization' in the social sciences in general[46] and critical human geography in particular has been unfolding since the early 1990s as an attempt to redress the lack of attention to the physical environment. Nevertheless, in a review of attempts to take 'the material' into account in critical human geography, Engel-Di Mauro[47] observes that 'there is a general lack of attention to the things soil scientists and other geoscientists are good at revealing; namely, the material specificities of a differentiated, yet connected, biophysical environment' (as summarized in Ref 48, p. 676). Instead, much time is often spent on abstract theoretical debates on the appropriate ontology and epistemology[49], the application of which in case studies is often not convincing: no new insights on how to address global challenges are gained compared with accounts not based in such advanced theorizing.

Recent discussions on and research activities around a proposal for 'critical physical geography' (CPG) may change this situation. The proponents of CPG see their endeavor as part of the quest to give both natural and social elements due attention.[42,43,50] They start from the perspective that 'socio-biophysical landscapes are as much the product of unequal power relations, histories of colonialism, and racial and gender disparities as they are of hydrology, ecology, and climate change. CPG is thus based in the careful integrative work necessary to render this co-production legible' (Ref 42, p. 2–3). It thus retains the critical outlook proposed by critical human geographers, without necessarily engaging in their advanced theoretical debates.[42]

Moreover, CPG not only proposes another way of seeing the world, or ontology, it also asks the axiological question how researchers could engage with the world differently in order to achieve societal goals such as justice or democracy. It proposes a 'reflexive intellectual practice that acknowledges the social and political shaping of research agendas and practices, calling into question claims to universal and value neutral research findings' (Ref 42, p. 3). Recent research by Lane and coauthors[51,52] and Tadaki et al.[47] stress the need for researchers to be explicit about the values involved in making methodological choices such as classifications[47] or whose knowledge is included.[48,49] In his most recent publication, Lane[53] argues that CPG means that researchers should engage more fully with people affected by the subjects studied. He acknowledges that in the current research evaluation culture, this position may have negative repercussions for the scientific prestige of the researcher, in spite of the professed importance of societal impact in assessment schemes.

Brown[54] traces this 'need for physical geographers to engage with philosophical debates on the status of knowledge in geography and to demonstrate critical self-reflection at the level of methodology' back to at least to the 1990s. These general critiques and developments in research on human-nature systems are manifested also in the critical study of water systems discussed next.

HYDROSOCIAL RESEARCH

The study of human-water systems as hydrosocial systems is an example of human geography (see above). As an explicit label it has a relatively short history within geography: most of the publications[a] labeled as 'hydrosocial' appeared in special issues of *Environment and Planning D* in 2013[55] and in *Geoforum* in 2014.[56] In both cases, the 'hydrosocial cycle' is a key concept. However, as a field of research on power relations in human-water or social-nature systems its pedigree is much longer.[57–60] Much of this tradition known as critical, or radical, human geography is grounded in Marxist theory and employs historical and materialist analyses. A conceptually diverse collection of 'political ecology' has emerged from critical human geography (feminist political ecology; urban political ecology; southern political ecology) which is aligned more by its concern with environmental inequalities, than through common analytical frameworks or theory. Because there is no common label it is not possible to draw a sharp boundary around this field; its shared characteristics are described below.

Like socio-hydrologists, hydrosocial researchers also start with the recognition that human and water systems are closely related. However, they make two essential differences in the conceptualization of the resulting socio-natural system. First, on an ontological level the aspects of society that are highlighted are different, and thereby also the cause–effect relationships that are included and excluded. While socio-hydrology considers societal features such as settlement patterns and economic prosperity, much hydrosocial research focuses on 'the articulation of water and social power relations' (Ref 61, p. 173), i.e., how, and therefore whose, decision making shapes the hydrosocial system and what impact this has on political and material inequity. Other hydrosocial research focuses on context-specific and nonscientific social and cultural meanings of water and how they result in different relationships with water and choices for water management.[62,63]

Second, on a more fundamental ontological level hydrosocial research proposes a conceptual model very different from the coupled human-natural systems that socio-hydrology uses. Rather than postulating that interaction of social and natural systems leads to a socio-hydrological system (hyphenated in this article, although in the socio-hydrological literature this is not always the case), hydrosocial researchers assert that 'it is not just society's relationship with water that is at stake, but the social nature of water itself.' This means that 'the components of the process—water and social power—are related internally rather than externally, and should thus be considered as hybrids rather than pregiven entities that fall within the realm of either nature or society'; 'it defines and mobilizes a relational-dialectical approach to water' (quotes from Linton and Budds[58]). The hybridity between water and humans is indicated here, and in much hydrosocial research, by the omission of the hyphen in 'hydrosocial.' As defined in this literature, in a socio-natural system the two elements 'socio' and 'natural' cannot be separated or even distinguished. 'Understanding things as related internally means that the properties that constitute them emerge as a function of their relations with other things and phenomena. It implies a shift from thinking of relations between things—such as the impacts of humans on water quality—to the relations constituting things—such as the cultural, economic, and political processes that constitute the particular character of desalinated water, treated drinking water or holy water. *Considering internal relations thus means that things do not relate to each other as preformed entities (like 'water' and 'society'), nor do they emerge from these relations as independent entities*' (Ref 58, p. 173, italics added). Many hydrosocial cycle researchers employ the analytical toolbox of Actor Network Theory (ANT) developed by Latour and others[64–66] because ANT proposes the equal (symmetrical) ontological treatment of human and nonhuman actors and their coconstitution. We return to the difficulty of the concepts used by hydrosocial researchers shortly; first we describe a few examples of the research performed in this field.

The peer-reviewed published work that uses the conceptual framing and reflexivity of hydrosocial research in case studies (though not always using this explicit label) shows a great variety in topics and locations. To give just a few examples: science, policy and politics in water resources management in Chile[59]; the colonial and post-colonial history of 'French' hydraulics in France and North Africa[67]; control and use of water in the Upper Jordan[68]; water and culture in the Andean highlands[60]; definitions of water in the European Water Framework Directive[69]; science-policy interactions in the Seine and the Rhône catchments, France[70]; canal irrigation and contested water control in the Tungabhadra Left Bank Canal, South India[71]; and urban water governance in Durban, South Africa.[72] In most of these publications, the emphasis on theoretical framing is noteworthy. Much attention is paid to explaining the foundational assumptions, e.g., that 'the act of defining water is not only a deeply social and political process, but that it often privileges specific worldviews',[66] or that 'the resulting 'waterscape' is understood as the outcome of the interaction of actor coalitions and their power relations, discourses and knowledges, technologies and infrastructures, which are embedded in multiple spaces that come together simultaneously'.[69]

As these quotes show, many hydrosocial publications use Marxist or ANT-derived jargon that is difficult to follow to the noninitiated. Socio-hydrologists, and also nonacademics, who may wish to engage with this work probably find the concepts used a barrier to understanding its relevance. Conversely, it is often not clear how this theoretical positioning actually affects the case description and analysis, especially since most of these papers are very brief on the methodology employed. The reader is expected to believe the interpretation provided by the authors, and it is not clear whether the researched subjects would agree with the analyses. At the same time, the case descriptions are mostly rich and in-depth with ample attention to the diverse elements of the situation, including history and wider context. However, the natural system and technical interventions are often under-emphasized. Therefore, while its advocates assert that 'the hydrosocial cycle offers a critical approach that prompts us to consider how water internalizes and reflects social and power relations that might otherwise remain invisible' (Ref 58, p. 178), it is not always clear how the case descriptions would be different if less advanced theoretical weaponry had been deployed. Put differently: we contend that asking the simple question 'how did the situation become as it is, and why?' with an open mind to all possible factors, including one's own biases, would yield the same rich and critical case descriptions without the need for sophisticated theorising. Pertinent questions to be answered in such a rich case description could be summarized as 'the social circumstances of water circulation': how water, social structures, power relations, and technologies are related and materialize in the actual waterscape, including institutions and culture.

These ontological differences between socio-hydrology and hydrosocial research obviously lead to different research methodologies in terms of data collected and choice of analysis. However, hydrosocial research also differs from socio-hydrology in its reflexivity. Although socio-hydrology has an explicit societal and therefore political goal (usually along the lines of improving sustainability), socio-hydrology researchers do not usually reflect on, or make explicit, the politics of their paradigmatic choices. For example, the choice of model algorithms and variables is value-based and therefore political. To make explicit and discuss such modeling assumptions with nonspecialist, socio-hydrologists would need to translate mathematical expressions, in comparative terms the equivalent of hydrosocial jargon, into human language. At the same time, socio-hydrologists offer solutions for what are essentially political problems of choice and priorities. Overall, they therefore lack reflexivity. Conversely, hydrosocial researchers discuss axiological issues at length, often explicitly stating a pro-poor objective. However, in contrast to socio-hydrologists they do not usually engage in discussions about solutions to the problems they find. The prioritization of theory and the weak treatment of physical elements are at the detriment of a potential focus on supporting transformations by water users, water managers and water regulators. This means that they have failed, until now, to substantively develop their analyses to clearly and cogently help with the diagnosis and potential solutions to the problems and crises so often used to frame the introduction and context sections of their papers.

In their quest for reflexivity, hydrosocial researchers posit that concepts such as the hydrological cycle are not merely neutral scientific concepts, but can be regarded as a social construct with political consequences: how you know something affects how you may treat it. In his well-known example of explicating the political motivation of knowledge construction, Linton[9] shows how the conception and use of the hydrological cycle is historically and politically closely related to state interventions in water management in the USA. According to Linton[9] the hydrological cycle makes water visible for the purpose of controlling it, which in turn 'helped structure an understanding of water for which large-scale engineering solutions may be seen (literally) as the norm' (Ref 9, p. 637). The control of water through engineering is built into hydrology as a science and 'sustaining the modern hydrologic cycle might actually do more harm than good for the protection of aquatic ecosystems and the provision of water services for more people—goals that are often pursued in its very name' (Ref 9, p. 638).

According to Linton[9] some of the reasons for these problematic effects of hydrological research originate in the 'temporate bias' built into hydrological theory, leading to a quest for permanent water availability in arid regions since this is the norm (without it being explicitly labeled as such) in the hydrological cycle. The failure to account for a large sediment load is another 'temporate bias' identified by Lahiri-Dutt.[73] Hydrologists may object that this bias may, and is, overcome by more hydrological research in nontemporate regions, but this is not the point of Linton and other hydrosocial researchers. Instead, they show how such research is not a neutral and universal endeavor, but is shaped by the disciplines and research interests of different scientists, as well as the administrative and political contexts. Both these assertions are anathema to hydrology's supposed value-neutralness.[67]

In the context of this paper, an important message from hydrosocial researchers is that in order to imagine different solutions, a different conceptualization of water is required, with different causal relationships and patterns. Thinking about how to think about, or conceptualize, water and societal systems is therefore very important. We believe this requires meaningful conversations between proponents of socio-hydrology and hydrosocial research.

TOWARD MEANINGFUL CONVERSATIONS ABOUT WATER

The above discussions of ESS, its branch socio-hydrology, and their critics in the social sciences and CPG reveals many seemingly incompatible paradigmatic choices, although both fields of research share an ontological understanding of the world as complex. Table 1 summarizes these respective paradigmatic choices, focussing on the mainstream in socio-hydrology and hydrosocial research respectively. The categories and the classification are inspired by Guba and Lincoln[6,7] and Patterson and Williams.[74] Castree[45] argues that critical human geographers adopt a position in between both fields: ontological objectivity and epistemological subjectivity. In socio-hydrology social processes are reduced to (quantitative or qualitative) measurable variables; in hydrosocial research natural factors are viewed as (political) constructs and contextual to societal developments. In contrast to socio-hydrology, hydrosocial research demands full recognition of human agency and power and a reflexive attitude. This also requires explicit attention to axiology. Propositions for collaboration therefore raise issues of potential (in)compatibility between socio-hydrology's (post)positivist paradigm and the paradigms grounding most

TABLE 1 | Comparison of Socio-Hydrology and Hydrosocial Research

	Socio-Hydrology	Hydrosocial Research
Paradigms	Positivist; postpositivist	Constructivist; critical theory
Ontology	Objectivist; holistic; parts can be separated; interaction gives emergent properties	Holistic; parts constitute each other and cannot be separated
Epistemology	Objective	Subjective
Main methodology	Quantitative modeling	Historical materialist analysis
Starting point	Natural system	Society (and technology)
Keyword	Interaction	Power
Axiology	(Post)positivist; researchers are & should be neutral	Critical or interpretivist; researchers cannot be and should not be neutral

enquiries into issues of interpretation, power and values. Indeed, Lave et al. (Ref 42, p. 6) state that 'conducting CPG [critical physical geography] research is challenging because it integrates substantively different epistemologies.' However, Miller et al.[75] conclude that epistemological differences can be overcome by way of epistemological pluralism. For them, 'integrating epistemologies result in a more complete understanding' (Ref 72, p. 4), thus assuming complementarity rather than conflict between epistemologies. However, whether or not this proposition may work in practice, we believe that issues at stake relate to several elements of the paradigms used, not just to epistemology.

As explained in the Introduction, our purpose is not to judge these competing claims, but rather to be explicit about them, so that they can be assessed in the light of pragmatic questions: what can we learn when we employ these different approaches, what different rationales for action do they suggest, and what scope exists for collaboration? Having answered the first two questions in our discussion of socio-hydrology and hydrosocial research, we now want to propose some thoughts on the third question: what scope exists for collaboration between researchers from these two schools of thought and practice?

For human-nature systems research more generally, proposals for such collaboration have been recently published.[36–38,45,76,77] In his call for 'a new social contract for global change research,' Castree (Ref 73, p. 1) summarizes these propositions succinctly: 'taking the human dimensions of environmental change seriously requires a new kind of global change research that is at once overtly political and intellectually plural.' Lövbrand et al.[36,38] emphasize the need for reflexivity about and within ESS in order 'to open conceptual and political space where a diversity of green diagnoses, comprehensions and problematizations can be debated and contested' (Ref 38, p. 216). This appears to imply that not just epistemology but axiology should be made plural, too. Related to this suggestion, in their 2009 paper Lövbrand et al.[36] argue that 'Earth System governmentality' research should complement ESS modeling, instead of the current 'Earth System governance' research—which implies an axiological shift away from the supposedly value- and power-free analysis implied in the term 'governance' toward the explicit recognition of power as determining factor. However, how exactly this can be done is still an unanswered question. In the literature we surveyed, the question of how to deal with fundamentally different ontologies has not even been asked yet, while this may be the most intractable.

The two communities do not just have incompatible paradigmatic positions, they also have different societal and scientific prestige. Castree et al.[37] discuss the difficulties likely to be encountered in this realm, which broadly correspond with those identified by Lélé and Norgaard.[3] They posit that it is unlikely that many researchers in the well-established and much larger field of ESS will be willing to question the fundamental assumptions underlying their work, such as value-neutrality, so CPG and similar developments are likely to remain marginal. 'Even assuming our argument for wider and deeper engagement is accepted, it may seem unrealistic to attempt so ambitious a reconfiguration of GEC [Global Environmental Change] research. [...] old intellectual habits can die hard' (Ref 37, p. 766). Personal and disciplinary interests are at stake because 'knowledge in GCR [Global Change Research] and other fields supports particular interests and desires that should not be screened out in any attempt to justify its utility' (Ref 73, p. 13).

Questions of respective societal status and political power thereby greatly affect the relationship between ESS and its critics, the latter generally finding itself in a subordinate position.[78–80] These differences are profoundly anchored in Western societies which are subscribing to Enlightenment ideas on the existence of value-free knowledge. They are reinforced by current drives for so-called Evidence Based Policy making in which allowable evidence is limited to results obtained through (post)positivist research.[81,82] Contrary to what is sometimes suggested, these differences in status and power cannot be assumed to be resolved by building trust through working together[83], nor by open discussion of paradigmatic choices[74] or by reconciling methodologies and developing shared terminology[42] or lexicon.[37] Better understanding of each other's disciplinary cultures, including communication, is a necessary but only first step; negotiation based on respective interests a second.[84] In this negotiation, the most important question to ask is 'whose project interdisciplinarity is and the stakes involved in how it takes place' (Ref 76, p. 367). For the foreseeable future, ESS and its subareas like socio-hydrology is likely to be hegemonic in human-nature systems research, and they are unlikely to change fundamentally when prompted to do so by critical scholars who have much less status or power, especially when they are perceived to appear to want geoscientists to embrace their epistemologies and axiologies, without apparently any efforts in the other direction.[85] We therefore propose a less challenging or profound collaboration, in which each approach can fundamentally pursue its own path, while exchanging useful insights.

After all, recognition of and respect for each other's way of working is a *conditio sine qua non* for collaboration. A productive relationship between socio-hydrological and hydrosocial research would benefit from giving space to either tradition, recognising respective strengths without either party setting out to change the other's paradigms. One of the key shared interest (or boundary object[86–88]) in this collaboration could be 'narrative.' Proponents of narrative analysis define narrative as distinct from story, although both terms could mean the same in everyday language. A narrative is a way for human beings to make sense of random or complex multi-causal experiences by the imposition of a logical structure including causation, climax and ending. In this understanding narratives are more structured than stories, which can have an incomplete, associative character. Narrative has an inherently temporal thread in that current events are understood as rising out of past happenings and pointing to future outcomes.[89,90] Nevertheless, 'narrative' and 'story' are often used interchangeably, as shown in our reference to Phillips[91] below.

Narratives are particularly valuable for dealing with complexity—and as we saw both approaches share an ontological understanding of the world as complex. This shared understanding may be 'a source of [shared] geographical narratives (stories, plots, dramas) describing how the world is and how it might be' (Ref 92, p. 291). In hydrosocial research, narratives on case studies are the main output; it would therefore be reasonable to expect that their contribution to collaborative efforts between socio-hydrologists and hydrosocial researchers would focus on, possibly together and/or with the researched communities, developing narratives of matters of concern. The importance of narratives may not immediately appear obvious as far as socio-hydrology is concerned. However, a socio-hydrological case study has to start with a narrative understanding of the situation and its history, see e.g., the descriptions of flood management and habitation patterns in Di Baldassarre et al.[23,24] Historical patterns are an obvious source of hypotheses, so narratives could be used toward the development of a mathematical model to represent historical changes. In their reflection on uncertainty in socio-hydrological modeling, Di Baldassare et al.[93] recognize this explicitly: 'to develop socio-hydrological theory, there is a need of iterations between historical analyses and formal explanations (e.g., conceptual modeling) of the salient facts, such as the aforementioned levee paradox and adaptation effect' (Ref 86, p. 1753). Any explanatory statement in such narratives also contributes to a conceptual model, which may be formalized through mathematical cause-effect relationships and/or hypotheses. Indeed, Troy et al. (-Ref 21, p. 4809) assert: 'If we take any of these models as an example, we will find a series of equations that link hydrology and social dynamics into a conceptual model. The overall conceptual model is a hypothesis about how different systems interact with each other. Each individual equation may also be considered a hypothesis about how the variable of interest is related to others testing the hypothesis.'

In any of these stages from narrative to mathematical models, different cases may be compared in a search for patterns, which in turn can feed into conceptual or mathematical models on single or multiple case studies. However, research on the relation between water and society has demonstrated that the ways societies organize themselves in response to the need to control and manage water, and the geometries of power that are embedded in this dialectic, are extremely varied.[94] Maybe this variation can be reined in, as done by Srinivasan et al.[95] who assert that a synthesis of many case studies showed that four dominant water patterns existed in regions of water crisis, which they conclude leads credence to the premise that common dynamics may emerge across different regions, and the possibility of modeling the coupled human-water systems. However, to take the contribution of hydrosocial research seriously, socio-hydrology would therefore have to accept that no single model exists that fits all cases, and consequentially to question whether models can be used to predict futures. Whether these limitations are acceptable to socio-hydrologists remains to be seen, since these issues touch upon some of the foundations of the field (Table 1); however, accepting these limitations still leaves other basic assumptions untouched that critical (physical) geographers would question.

The key role of narratives, which he labels stories, in what is generally seen as the securely (post)postitivist domain of geosciences has been recognized by the eminent professor of physical geography, Jonathan Phillips. Phillips[84] recognizes eight basic plots: cause-and-effect, genesis, emergence, destruction, metamorphosis, convergence, divergence, and oscillation. He asserts that storytelling in geoscience is 'another way of tying the local, idiosyncratic stories of specific places, situations, and phenomena together with more broadly (ideally universally) applicable concepts' (Ref 84, p. 154). Not too differently from what interpretivist social scientists would say coming from a subjective epistemology, he further demonstrates that multiple narratives can be told about one situation. Contrary to geosciences' self-declared value-neutral position, this points to the existence of different axiologies, for 'in some cases preference or affinity to different plots results in fundamentally different interpretations and conclusions of the same evidence. In other situations exploration of additional plots could help resolve scientific controversies' (Ref 84, p. 153). The usefulness of narratives to best communicate research findings was also highlighted by Krzywinski and Cairo.[96]

The existence of different values also plays a role in the establishment and use of classifications, which can be considered another type of telling a story. 'Different epistemic communities produce different kinds of classifications, which reveal different 'realities' of rivers to be acted upon by human agents. By emphasizing how river classification practices are productive of environmental governance regimes and rationalities, the roles, responsibilities, and possibilities for environmental science are clarified and expanded. Rather than thinking about classification purely as a realist [representing the truth, authors] scientific project, attention needs to be paid to the ways in which 'classifying mindsets' relate to the production of social and environmental outcomes' (Ref 97, p. 349).

CONCLUSION

A strength of hydrosocial research lies in developing a rich understanding, or narrative, of a situation. In turn, socio-hydrology's strength lies in formalising a conceptual understanding and quantitative testing of derived hypotheses. Such sequencing of individual contributions 'opens up space for thinking in a nonreductionist way about multiple determinations without rejecting the value of single disciplines for uncovering the working of important causalities' (Ref 98, p. 172). In the process of formalization, plurality in the interpretations of the same phenomenon is lost and that it is difficult if not impossible to take account of human agency, chance and path dependency. However, the conscious reduction of rich narratives surely has to be preferable to the automatic and *a priori* selection of knowledge from only those social science research areas that are compatible with quantitative modeling, as is now the usual practice.[37,38] For socio-hydrologists, this collaboration would mean a different starting point for the research, where the problem definition stage is opened up to plural formulations.[99] For hydrosocial researchers, this collaboration would mean to make meaningful and relevant their theoretical posturing and to focus on rich case descriptions.

NOTE

[a] We used Web of Science 2014 to list all papers with 'hydrosocial' or 'waterscape' in keywords or title. Curiously the papers referred here in *Annals of the Association of American Geographers* (Swyngdouw 1999; Linton 2008) were neither included in the WoS search results, nor was the special issue on the hydrosocial cycle in *Environment and Planning D*. We added these to our collection. We do not set out to or pretend to cover the entire body of literature across STS, SSS, rural development, and so on. that could be loosely defined as hydrosocial. We focus here on the literature most closely related to the emerging field of socio-hydrology.

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