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Applying Place-Based Social-Ecological Research to Address Water Scarcity: Insights for Future Research

Jodi Brandt
Boise State University

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Applying Place-Based Social-Ecological Research to Address Water Scarcity: Insights for Future Research

Antonio J. Castro [1,2,*], Cristina Quintas-Soriano [1,3], Jodi Brandt [3], Carla L. Atkinson [4], Colden V. Baxter [1], Morey Burnham [5], Benis N. Egoh [6,7], Marina García-Llorente [8], Jason P. Julian [9], Berta Martín-López [10], Felix Haifeng Liao [11], Katrina Running [5], Caryn C. Vaughn [12] and Albert V. Norström [13]

[1] Department of Biological Sciences, Idaho State University, 921 South 8th Avenue, Pocatello, ID 83209, USA; quincris@isu.edu (C.Q.-S.); baxtcold@isu.edu (C.V.B.)

[2] Centro Andaluz para la Evaluación y Seguimiento del Cambio Global (CAESCG), Departamento de Biología Vegetal y Ecología, Universidad de Almería, La Cañada de San Urbano, 04120 Almería, Spain

[3] Human-Environment Systems Center, Boise State University, Boise, ID 83725, USA; jodibrandt@boisestate.edu

[4] Department of Biological Sciences, University of Alabama, 300 Hackberry Lane, Tuscaloosa, AL 35487, USA; carlalatkinson@gmail.com

[5] Department of Sociology, Idaho State University, Social Work, and Criminology, 921 South 8th Avenue, Pocatello, ID 83209, USA; burnmore@isu.edu (M.B.); runnkatr@isu.edu (K.R.)

[6] Council for Scientific and Industrial Research, Natural Resources and the Environment, P.O. Box 320, Stellenbosch 7599, South Africa; begoh@csir.co.za

[7] School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, 27 Private Bag X01, Scottsville 3209, South Africa

[8] Department of Applied Research and Agricultural Extension, Madrid Institute for Rural, Agricultural and Food Research and Development (IMIDRA), Finca Experimental "El Encín"Ctra N-II, Km 38,200, 28800 Alcala de Henares, Spain; marinaglloren@gmail.com

[9] Department of Geography, Texas State University, 601 University Drive, ELA 139, San Marcos, TX 78666, USA; jason.julian@txstate.edu

[10] Institute for Ethics and Transdisciplinary Sustainability Research, Leuphana University of Lüneburg, Faculty of Sustainability, Universitätsallee 1, 21355 Lüneburg, Germany; martinlo@leuphana.de

[11] Department of Geography, University of Idaho, University of Idaho, 875 Perimeter Drive, Moscow, ID 83844, USA; hliao@uidaho.edu

[12] Oklahoma Biological Survey and Department of Biology, University of Oklahoma, 111 E Chesapeake St, Norman, OK 73019, USA; cvaughn@ou.edu

[13] Stockholm Resilience Centre, Stockholm University, Kräftriket 2B, SE-10691 Stockholm, Sweden; albert.norstrom@su.se

* Correspondence: castroresearch@gmail.com

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Abstract: Globally, environmental and social change in water-scarce regions challenge the sustainability of social-ecological systems. WaterSES, a sponsored working group within the Program for Ecosystem Change and Society, explores and compares the social-ecological dynamics related to water scarcity across placed-based international research sites with contrasting local and regional water needs and governance, including research sites in Spain and Sweden in Europe, South Africa, China, and Alabama, Idaho, Oklahoma, and Texas in the USA. This paper aims to provide a commentary on insights into conducting future solutions-oriented research on water scarcity based on the understanding of the social-ecological dynamics of water scarce regions.

Keywords: PECS; water governance; ecosystem service; place-based research; social-ecological system; sustainability; transdisciplinary science

1. Introduction

Global demand for freshwater sources combined with a declining water supply and quality translates in an issue for approximately two-thirds of the global population and nearly every regional-scale watershed experiences severe water scarcity for at least one month of the year [1–5]. Developing equitable and effective governance solutions for water scarcity is a global priority [6–8] to achieve global sustainability [9–11]. Governance solutions for water scarcity are defined as the social and political processes of fixing goals for the management of water scarce social-ecological systems (SES). SES are complex, adaptive systems in which social and bio-geophysical components interact at multiple temporal and spatial scales [12,13]. Here, among different SES frameworks, we adopt the SES concept as a broad framework that is useful for understanding the interlinked dynamics of environmental and societal change [14,15]. Though interactions between ecological and social components exist across spatial scales in different SES [2], water governance solutions to address water scarcity associated with cross-scale and cross-sectoral interdependencies have not yet been developed [7,8]. Therefore, advancing equitable water governance solutions requires place-based approaches, solutions based on the co-production of knowledge [3,4,8], and the existence of institutional diversity and multi-level governance that considers cross-scale and cross-sectoral interdependencies [4]. Such cross-scale approaches that include local to broader scales may have the potential to provide a generalizable framework capable of being translated across different socio-ecological systems [9–11].

Over previous decades, various research networks have emerged to facilitate the synthesis of SES research conducted at the local scale [12]. In particular, the Programme on Ecosystem Change and Society (PECS) was launched in 2011 with the goal of synthesizing insights that may contribute to global sustainability [16–18]. PECS evolved from explicit recommendations made by the Millennium Ecosystem Assessment to establish a global effort to foster coordinated, place-based research for understanding the dynamic relationship between humans and ecosystems. The principal approach of PECS research is based on comparisons of place-based, long-term, social-ecological case studies [19]. Place-based SES research can explore the interplay between physical and social dynamics that both cause water problems, and it may guide future governance solutions by recognizing the distinctiveness of local entities, while also addressing the impacts of external forces [20–22]. Place-based SES science on water scarcity is taking place in numerous locations around the world, but the impact of these efforts is limited because of the following reasons:

- Every region does not have the resources to generate its own place-based SES science. Not only is interdisciplinary expertise needed, but a great deal of social capital and research funding is also required.
- While effective and equitable solutions are often best generated at a local/regional level, many regions require additional research and institutional infrastructure to enable solution development.
- Changing environmental and social conditions demand rapid scientific solutions. This often results in insufficient time to independently create new place-based solutions in specific places.

Thus, generating solutions for particular regions could be facilitated by communicating and sharing experiences and lessons from regions across the world that are coping with related challenges [17,23]. WaterSES (www.pecswaterses.com) is an international, interdisciplinary research team within PECS that promotes placed-based comparative research to study the SES dynamics that cause, and are caused by, water scarcity across international research sites in Sweden, Spain, China, South Africa and the USA (Oklahoma, Alabama, Texas, and Idaho) (Figure 1). Water scarcity across all WaterSES place-based research sites is produced by both different climates and socio-ecological dynamics, but all sites are experiencing new human demands on water resources that require effective and equitable governance solutions. Therefore, the SES framework is a useful approach for understanding the interlinked dynamics of environmental and societal change and providing insights for addressing water scarcity. Table 1 presents the different social-ecological dynamics that are producing water scarcity across all sites. WaterSES research sites presented here correspond to (1) cases where long-term research has been conducted, such as the Kiamichi Watershed (Oklahoma) and the watershed in the Almería region of Spain, Las Vegas Rural and Agrarian District-Madrid and the Portneuf and Treasure Valleys regions of Idaho; and (2) new cases, such as the Loess Plateau (China), the Norrstrom B., (Sweden), and the Breede-Gouritz (South Africa) where we are in the process of collecting data that can help us establish further comparisons and sharing of experiences and lessons. In order to provide solutions to address water scarcity, WaterSES embraces sustainability science principles related to complex and systemic thinking [24] and is comprised of a research team with expertise in ecology, hydrology, environmental justice, climate change, economics, land change science, rural sociology, resilience thinking, social-ecological system science and ecosystem services.

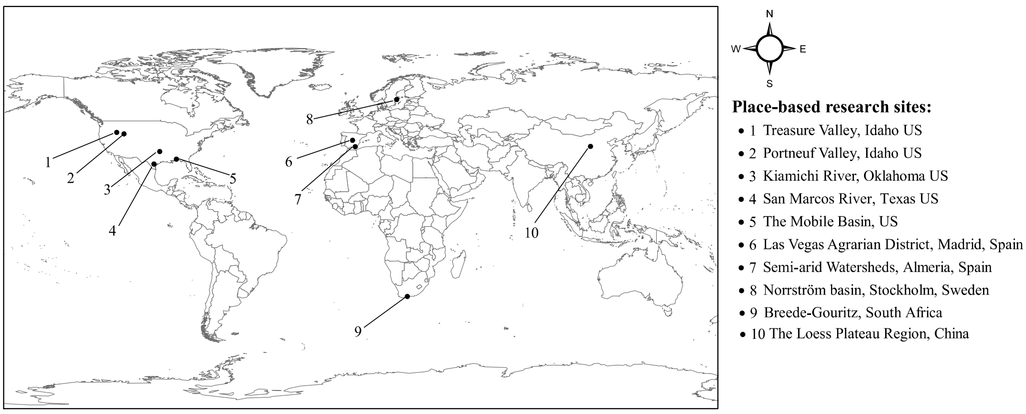

Figure 1. Geographic locations of WaterSES place-based social-ecological research sites.

Multidisciplinary expert workshops are commonly-used platforms to identify research challenges in sustainability science [25]. Here, we report on our implementation of the PECS approach to provide insights for solutions-oriented research on water scarcity by (1) characterizing SES characteristics and water supply and demand across WaterSES research sites; and (2) reporting the outcomes of a subsequent WaterSES workshop to identify key sustainability challenges for regions experiencing water scarcity.

Table 1. Description of social-ecological dynamics across WaterSES research sites caused by and/or causing water scarcity and water governance issues.

WaterSES Research Site	SES Dynamics Influencing Water Scarcity and Governance
Treasure Valley, Idaho, USA	In the Treasure Valley, industrial-scale agriculture is responsible for nearly all of the region's current water use and contributes to extensive water quality degradation. In addition, the Treasure Valley is home to Idaho's largest metropolitan area, Boise, the fastest growing city in the USA. Rapid urban expansion coupled with climate change is driving conflicts related to the quality and quantity of water supplies.
Portneuf River Valley, Idaho, USA	In the Portneuf River Valley, agricultural land use and irrigation water withdrawals in the upper drainage, combined with flood control management in the lower drainage via levees and a concrete channel, has reduced water quantity and quality. This has limited ecosystem health, recreational opportunities, and river-community connections, all of which are increasingly desired by residents, especially those in the midsize city of Pocatello, the only urban center in the valley.
Kiamichi River watershed, Oklahoma, USA	The Kiamichi River is a relatively pristine, rural river known for its high aquatic biodiversity. The river lies within a Native American jurisdictional area and is at the center of intense, regional conflict over water use and governance. The river is influenced by two impoundments, which supply water for urban areas over 100 miles away. Water availability to these reservoirs is predicted to decrease over the next 25 years because of increased drought from climate change and an increasing human population. Concurrently, drought and poor water management have already led to large declines in biodiversity and ecosystem services provided by the river. These problems are exacerbated by the fact that there are no established environmental flows to protect aquatic life.

Table 1. *Cont.*

WaterSES Research Site	SES Dynamics Influencing Water Scarcity and Governance
San Marcos River, Texas, USA	Located in one of the fastest growing regions in the USA which is also a water-limited environment, the San Marcos River is experiencing increasing demands on its water resources, particularly due to recreational demands. This increased development and usage of the river is affecting its water quality and sensitive aquatic ecosystem.
Mobile River Basin, Alabama, USA	In the Mobile River Basin, more frequent and extreme droughts in conjunction with human water demand, which is anticipated to increase in the future, is culminating in increased demands on water supply and potential declines in aquatic biodiversity and ecosystem function in this species rich area.
Las Vegas Agrarian and Rural District, Madrid, Spain	This region, known as "the orchard of Madrid" due to its fertile valleys, has a long tradition of agriculture and related agri-food industries. While the area has not been subject to significant urbanization or loss of agricultural land, commercial agriculture has increased the total irrigated area, replacing traditional practices and crops with crops with higher water demands. This has compromised the maintenance of cultural values and decreased freshwater availability, leading to social-ecological conflict.
Spanish watersheds, Almeria, Spain	The Spanish watersheds are the most arid region in Europe and have little surface water availability for much of the year. Despite this, groundwater use for greenhouse horticulture development (the largest concentration of greenhouse agriculture on the planet) has made this region the largest producer of vegetables in Europe, and the over-exploitation and salinization of aquifer systems is amplifying water scarcity issues.
Norrstrom Basin, Sweden	The Norrstrom drainage basin is heterogeneous in terms of land cover and land use and includes two of Sweden's largest lakes, Lake Malaren and Lake Hjalmaren. Lake Malaren is crucial for the water security of more than a fourth of the Swedish population, and the region is growing rapidly. Interestingly, the human-dominated landscapes in the region remain highly multifunctional with no major tradeoffs between agricultural and water-related ecosystems services. However, there is a looming risk of drinking water contamination due to climate change-related salt water intrusion. Climate change will also lead to drier summers and milder winters with more and higher intensities of precipitation.
Breede-Gouritz, South Africa, Africa	In the Breede-Gouritz basin, limited rainfall over the last three years has led to drought in the Western Cape province of South Africa where this region is found. This recent drought, coupled with over-exploitation of water resources for irrigation purposes, has led to severe water scarcity in the region. As a result, water use restrictions are already in place to curb water use.
The Loess Plateau, China, Asia	The Loess Plateau Region, home to more 50 million people, has been identified as one of the most agriculturally vulnerable regions to climate change in China. Climate change is predicted to cause increases in the average annual temperature and drought frequency, changes in the timing of rainfall, decreased water availability, and increased soil erosion. Additionally, intense precipitation events are likely to increase, while decreased runoff from the Yellow River is expected to lead to water shortages that will be made worse by a growing population. Compounding these problems are water quality issues caused by industrial pollution and soil erosion from agriculture practiced on the steep and highly erodible Loess slope land.

2. Workshop for Identifying Sustainability Challenges

In the Spring of 2017, the WaterSES team met for a workshop at the Idaho State University (USA) with the goal of synthesizing research conducted across WaterSES sites. The main goal of the workshop was to collaboratively identify the social-ecological dynamics caused by, and causing water scarcity and to discuss the key sustainability challenges across water scarce SES. Based on existing data and research on water supply and demand for WaterSES sites, we first collectively characterized the social-ecological characteristics of each WaterSES site. Then, in cases where water supply is not meeting water demand, we identified the causing economic hardships, degraded ecosystem health, and/or potential derived environmental injustices.

Prior to the workshop, the WaterSES team completed an online questionnaire (see Supplementary S1). The purpose of the online questionnaire was to synthesize research conducted across WaterSES sites and individually identify key challenges limiting sustainability based on WaterSES sites [17]. The workshop brought together 12 scientists from different disciplines as a way to learn from each individual site. The workshop was organized into three dynamics (Figure 2, see workshop agenda in Supplementary S2) [26]. First, presentations were given for each WaterSES site to get a deeper understanding of all WaterSES sites. Then, we collectively discussed the sustainability challenges collected in the online questionnaire, grouped them into different categories, and reached consensus as to which three were the most important (dynamic 1, Figure 2). Next, workshop participants were divided into three groups based on their backgrounds to characterize each challenge based on data needs, data availability and knowledge gaps (dynamic 2, Figure 2). Finally, each group defined and identified key actions to overcome their respective challenge (dynamic 3, Figure 2).

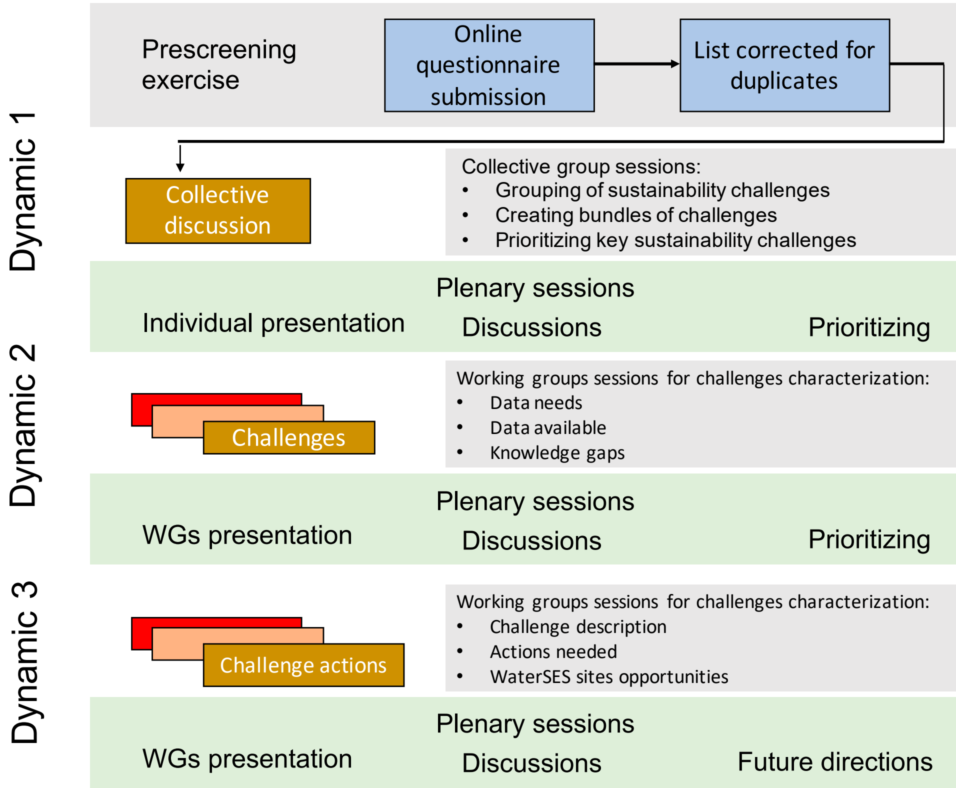

Figure 2. Dynamics of the workshop for addressing sustainability challenges across freshwater socio-ecological systems. Adapted from [20].

3. Challenges for the Sustainability of Water Scarce Social-Ecological Systems

Table 2 summarizes the major social and environmental characteristics of each WaterSES research site, including information about the major water uses and stresses in each site and the important ecosystem services. The three sustainability challenges identified during the workshop corresponded to (Figure 3): (1) bridging the gap between increasing demands for water and declining water supply and quality; (2) using social-ecological knowledge for water scarcity management; and (3) towards transdisciplinary social-ecological research.

3.1. Sustainability Challenge 1: Bridging the Gap between Increasing Demands for Water and Declining Water Supply and Quality

The most tangible solutions to address water scarcity are likely occur at a regional scale, ideally at the watershed scale [27–30]. This challenge corresponded to SES understanding [31] and identified the need to investigate how to best meet the demand for water in an equitable manner (Figure 3). The first step is the determining supply and demand of water resources at a given site. Water supply calculations require empirical hydrologic data, which can be difficult to obtain for the various stores of water in a basin [32]. Projecting future water supplies adds further complexity, given uncertainties in climate and land use changes and cross-scale interactions between both [33–35]. However, as long as reliable environmental data are available (ideally over long periods), then deriving water budgets for both the present and future is feasible. Calculating water demand is more nuanced because water use changes over time, and this occurs in response to interrelated, dynamic external factors including (but not limited to) climate, land management, personal tastes, and economic factors. Determining the social demand of water resources (beyond water consumption) requires in-depth survey questionnaires from a relatively large sample of diverse stakeholders to document water needs for recreation, aesthetics, tourism, and other cultural uses of water [28]. For environmental justice, data on income, health impacts, water allocation, access, human well-being, and ecosystem health is needed. In addition, assessments of how varying governance arrangements either cause or solve environmental justice problems related to water access are needed to develop a better understanding of equitable place-based solutions.

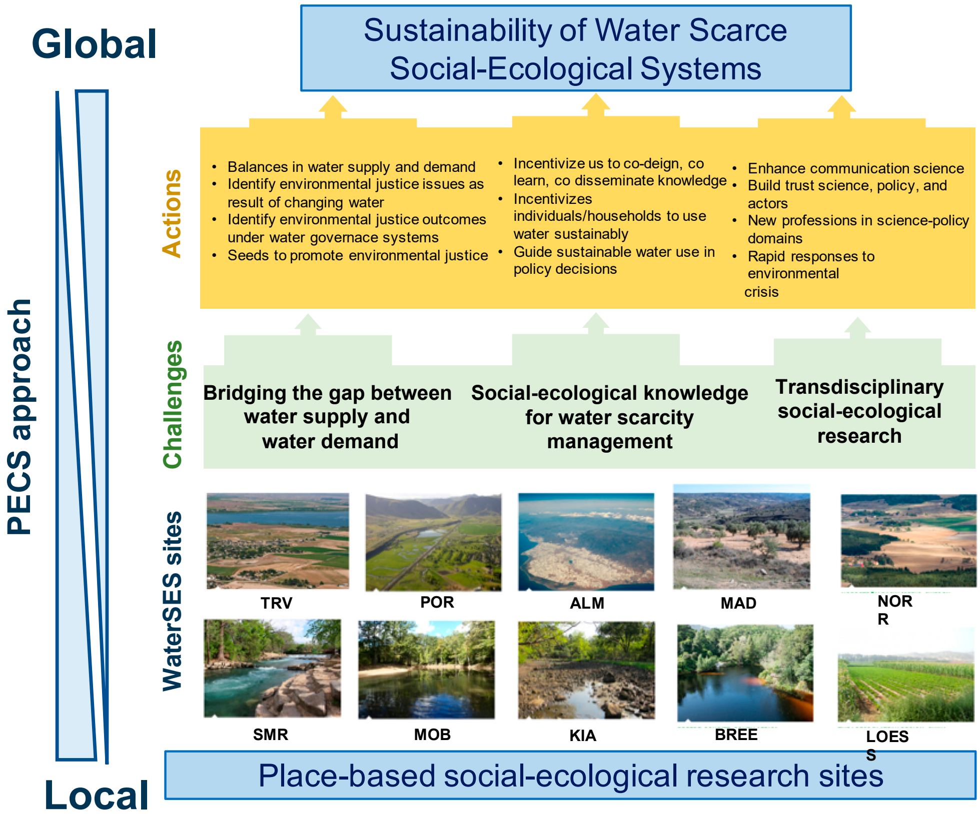

Figure 3. Key challenges and actions for sustainability of freshwater social-ecological systems across water scarce regions. SMR (San Marcos River, Texas, USA), KIA (Kiamichi River watershed, Oklahoma, USA), MOB (Mobile River Basin, Alabama, USA), POR (Portneuff River Valley, Idaho, USA), TRV (Treasure Valley, Idaho, USA), ALM (Almeria, Spain), MAD (Las Vegas Agrarian and Rural District, Madrid, Spain), LOESS (Loess Plateau, China), NORR (Norrstrom B., Sweden), BREE (Breede-Gouritz, South Africa).

Table 2. Social and environmental characteristics of WaterSES place-based research sites.

Study Site	Area (km^2)	Average Annual Rainfall (mm)	2016 Population	Major Land Uses	Major Water Uses	Social-Ecological Stressors on Water Resources	Water-Related Ecosystem Services
Treasure Valley, Idaho, USA	3438	280	575,001	Agriculture; urban	Agriculture; recreation	Farm land conversion; population growth; urbanization	Water quality; river recreation; aesthetic value
Portneuf Valley, Idaho, USA	3436	310	79,747	Agriculture; protected areas; rural; urban	Agriculture; recreation	Agriculture; agricultural runoff and water pollution;	Water quality; flood control; irrigation water
Kiamichi River, Oklahoma, USA	4650	1300	24,214	Pasture; plantation forest; rural	Agriculture; municipal/rural water supply; recreation	Inter-basin water transfers; water regulation and dewatering	Habitat for freshwater species; irrigation water; spiritual values
San Marcos River, Texas, USA	130	860	60,000	Agriculture; industry; urban	Agriculture; recreation; tourism	Land-use change; population growth	Water quality; river-recreation; habitat for freshwater species
The Mobile Basin, Alabama, USA	110,000	1473	3,673,000	Agriculture; rural; urban	Agriculture; endangered species preservation mining; recreation; urban	Habitat fragmentation	Irrigation water; habitat for freshwater species
Las Vegas Rural District, Madrid, Spain	1035	365	54,027	Agriculture	Agriculture	Replacement of traditional crops towards those with more water demand (maize) occupying floodplains	Irrigation water; habitat for species, recreational value, cultural value
Spanish Watersheds, Almeria, Spain	12,207	250	919,405	Agriculture; protected areas; urban,	Agriculture	Agricultural growth; desertification	Groundwater recharge; habitat for freshwater species
Norrström Basin, Stockholm, Sweden	22,650	550	1,500,000	Agriculture, recreation; rural; urban	Agriculture; municipal water supply	Population increase and urban development	Water quality; irrigation water aesthetic value
Breede-Gouritz, South Africa	53,139	400	821,016	Agriculture; mining; urban	Agriculture; recreation	Increasing groundwater use; population growth	Drinking water; habitat for freshwater species
The Loess Plateau Region, China	647,497	140	50,000,000	Agriculture; industry; mining; rural; urban	Agriculture; industry	Agricultural runoff and water pollution; population growth; urbanization	Water quality; irrigation water; hydrological regulation

Given the diverse social and environmental conditions that characterize the different WaterSES sites, investigating the supply vs demand of water resources and questioning environmental justice pose distinct challenges. However, such context-dependency does not necessarily preclude the transferability of approaches and lessons. Table 3 indicates the WaterSES sites where water supply is not meeting demand, causing economic hardships, degraded ecosystem health, and/or environmental injustices. For instance, the Kiamichi River in Oklahoma used long term data on river flow, water quality, and land use to assess water needs to maintain ecosystem health [36], followed by survey-based quantification of social perceptions and willingness to pay for preserving water-related ecosystem services among stakeholder groups [37]. The latter identified some of the roots behind conflicts among stakeholders (e.g., urban vs. rural, Tribal vs. non-native) as well as issues of environmental justice [38,39]. In WaterSES sites such as Texas, Alabama and Idaho, findings related to water scarcity conditions suggest important questions need to be asked regarding stakeholder groups involved in water disputes and socio-economic consequences (Table 3).

Table 3. Water scarcity matrix for WaterSES research sites that plot where water supply (rows) is not meeting water demand (columns), causing economic hardship, degraded ecosystem health, and/or environmental injustices.

WaterWater SupplyDemand	**Intra-Basin Municipal Water Demands**	**Inter-Basin Municipal Water Demands**	**Agricultural Water Demands**	**Recreational Water Demands**	**Aquatic Ecosystem Demands**
Spring-fed river	SMR			SMR	SMR, BREE
Regulated river	LOESS	KIA	MAD, LOESS, NORR	KIA	KIA
Deep groundwater			MAD		
Watershed runoff from rainfall					MOB, BREE
Watershed runoff from snowmelt	TRV		POR, TRV		
Seawater desalination	ALM	ALM	ALM		

Key: SMR (San Marcos River, Texas, USA), KIA (Kiamichi River watershed, Oklahoma, USA), MOB (Mobile River Basin, Alabama, USA), POR (Portneuff River Valley, Idaho, USA), TRV (Treasure Valley, Idaho, USA), ALM (Almeria, Spain), MAD (Las Vegas Agrarian District, Madrid, Spain), LOESS (Loess Plateua, China), NORR (Norrstrom B., Sweden), BREE (Breede-Gouritz, South Africa).

3.2. Sustainability Challenge 2: Using Social-Ecological Knowledge for Water Scarcity Management

While scientists create a substantial amount of knowledge about the social-ecological dynamics of water scarcity, policy-making is rarely guided by this knowledge [40]. Rather, policy decisions are frequently designed to achieve short-term economic or political goals. Additionally, mismatches between the spatial and institutional scale at which ecosystem services are provided and governed frequently lead to loss of SES function or other unintended consequences [41–43].

This challenge corresponds to the phase of sustainability implementation [31] and emphasizes the need to create new structures so that scientific knowledge can influence political decisions that support societal goals, as well as a need to understand why sustainability science is not included in decision-making, and how science can be performed and communicated to ensure its incorporation into policy decision-making (Figure 3). We identified the need to include diverse knowledge sources in research design and policy making, including traditional, experiential, local and indigenous scientific knowledge, as postulated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [10], to facilitate co-learning among stakeholder groups and scientists, and to enable more sustainable governance solutions that incorporate multiple stakeholder needs, values and interests.

For example, the WaterSES team is conducting research to incentivize the co-design, co-learning, and co-dissemination of SES knowledge in Las Vegas Agrarian District (Madrid, Spain). Historically, this region was commonly referred to as the "orchard" of Madrid due to its agriculture and freshwater availability (Table 1). To support the development of sustainable solutions that deal with emerging water scarcity issues, a participatory strategy is being implemented for agroecosystems beyond market instruments [44,45]. WaterSES is also addressing different institutional settings that govern water resources using cases in Idaho and Texas [46]. These case studies highlight concerns about jurisdictional and political constraints in water management, such as historic water rights [47], and how scientific knowledge has not been fully transmitted to practitioners and policy makers [48]. For example, novel research methods, such as participatory system dynamics, have been used to engage stakeholders and create a nexus of science, policy points, and social concerns as well as local knowledge to describe the issue of water scarcity with an emphasis on groundwater [48].

3.3. Sustainability Challenge 3: Towards Transdisciplinary Social-Ecological Research

As emphasized by the international programme, "Future Earth: Research for Global Sustainability" [49], there is a need for new science to respond to the urgent challenges of global sustainability [50] (Figure 3). This challenge represents the stage of bridging understanding with implementation (challenge 1 and 2) in order to emphasize the need of dialogues between society and scientists [51–53]. Achieving this requires scientists to partner with policy makers and social actors to co-produce knowledge that is useful and credible [50,54]. Coupled with this is the need to develop and encourage new professions that bridge science and policy, such as facilitators and innovation brokers [55–57]. This new, co-produced science needs to be able to be implemented to rapidly respond to environmental crises, such as droughts and floods [58,59]. Finally, more effective tools and strategies for translating and communicating sustainability science are required, including the use of graphics, personal stories, social media, and videos [16]. Addressing this suite of needs would be immediately useful in achieving place-based governance solutions [47].

For instance, in the South African and Chinese WaterSES sites, scientific agendas are emerging that are strongly guided by water societal demands [60,61]. Similarly, in the Spanish semi-arid watersheds (Almeria, Spain) there is a strong body of recent work on the social-ecological issues surrounding water scarcity and the loss of ecosystem services [62–64], much of which has potential applicability to WaterSES sites in the USA, including insights as to the consequences of a future, drier climate. However, in this Spanish site, few scientific recommendations have been implemented because of poor communication and the lack of research co-design between policy makers, scientists, and stakeholders [65,66]. In contrast, at the Portneuf Valley site (SE Idaho, USA), purposeful co-production efforts have led to improved integration of science in policy-making (e.g., with respect to public planning of river restoration) [67,68].

Expert knowledge, as used in this research, provides insight into challenges faced in water-scare social-ecological systems, but it has its limitations [69–71]. Detailed analysis is needed to provide evidence and to make explicit the severity of water scarcity issues as presented by experts and to find possible solutions using social-ecological models [72]. For example, [71] used a hydrological social-ecological model to prioritize areas where investment in ecological infrastructure through restoration action could improve water supply in South African catchments. Such an approach could compliment current policy instruments related to water restrictions being implemented in South Africa. The benefit of balancing water supply and demand including the use of policy instrument directed towards reducing demand has been emphasized by several scientists around the globe [73,74].

4. Conclusions

The PECS approach holds promise for synthesizing insights gained from place-based research sites to inform the global sustainability agenda. WaterSES has begun to realize some of this promise, as our team explores the interplay between physical and social dynamics that cause water scarcity issues and facilitates the identification of effective and equitable governance solutions. Thus far, lessons learned across WaterSES research sites suggest that solutions for particular regions could be facilitated by strategies that foster communication and sharing of experiences and lessons from regions around the world. Finally, experiences and results from WaterSES should be combined with those from the growing list of other PECS projects and working groups to provide feedback to the PECS community and allow adaptive evaluation of the PECS approach itself. In other words, our opinions presented in this paper and through the WaterSES workshop aim to provide a timely commentary on the PECS approach, which we believe has been a more popular way to address challenges of water scarcity across the globe.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/5/1516/s1.

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