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Hydrosocial research for better understanding, managing, and modeling human-nature interactions

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Introduction

Traditional water management based on simple, linear growth optimization strategies overseen by command-and-control approaches has failed to resolve the inherent unpredictability and uncertainty of water systems, but also increasing tensions over freshwater use (Furlong et al., 2016). Beyond potential technical solutions, it is crucial to provide solid institutional settings and mechanisms for conflict resolution in water management. In most circumstances, water crises tend to go beyond hydrology, infrastructure, and financing; it is about who does what, at which scale, how, and why (Akhmouch and Clavreul, 2017). Assuming water has different physical, social, political, and symbolic value(s) both individually and collectively, it becomes necessary to reinforce stakeholders' involvement to better understand the motivations for conflict and potential solutions coexisting in multi-scalar water crises (Ricart, 2020). This suggests the need for holistic and systemic approaches to comprehend the complex and interlinked nature of water management and governance (Megdal et al., 2017). We concur there is an urgent need to promote the benefits of stakeholder engagement in reducing water conflicts, acknowledging the shift from "government" to "governance" that marked a transition from hierarchical decision-making to bottom-up and network-based forms of participation by promoting diffusion of boundaries between private and public, individual and collective actors (Swyngedouw, 1999; Akhmouch et al., 2018; Skrydstrup et al., 2020).

Researchers have begun exploring inter- and transdisciplinary approaches that seek to address the social side of water management. Two perspectives with similar terminology have been devised: socio-hydrology and hydrosocial research (Wesselink et al., 2017; Ross and Chang, 2020). Hydrological scientists developed the term "socio-hydrology" in recognition that social relations alter water systems. The aim of socio-hydrology was to capture the full range of human-behavior narratives and patterns and to fit them in a quantitative model, trying to reconcile numerical data with descriptive histories (Troy et al., 2015). On the other side, social scientists from human geography and the political ecology opted for the term "hydrosocial" research which encompasses concepts such as hydrosocial cycle, hydrosocial territories and waterscapes (Boelens et al., 2016; Flaminio et al., 2022) to address power relations in human-water or social-nature systems. Hydrosocial research also includes a dialectical approach to "water" meaning and symbolism (Linton and Budds, 2014; Cantor, 2021). Both approaches point out how socially, naturally, and politically constituted spaces are (re)created through the interactions amongst human practices, water flows, hydraulic technologies, biophysical elements, socioeconomic structures and cultural-political institutions (Hommes et al., 2020). However, hydrosocial perspectives are where scholars specifically ask "who controls, who acts, and who has the power" in water management (Qi et al., 2021). In many locations, governments continue to dominate these decision-making processes, but there is growing recognition of the role stakeholders from the private sectors, communities, and other entities have in freshwater management (Handayani et al., 2022).

Stakeholder engagement for system transformation

Stakeholder engagement has become a central requirement for water-related projects in many different contexts. For example, Sustainable Development Goal (SDG) 17 explicitly recognizes multi-stakeholder partnerships as important vehicles for mobilizing and sharing knowledge, expertise, technologies, and financial resources to support countries' SDG commitments, while encouraging and promoting effective public–private–civil society partnerships (Sigalla et al., 2021). A stakeholder is usually defined as someone having an interest in a particular situation, even if this interest is not recognized or acknowledged by others (Wehn et al., 2018). Stakeholders' participation is mandatory in many international legal documents, and it is realized in different ways (e.g., water committees, water user associations, community participation, workshops for selected pre-screened participants, advisory groups, citizens juries) (Srdjevic et al., 2022).

Ruiz-Villaverde and Garcia-Rubio (2017) state several benefits of stakeholder involvement, including: the contribution of ideas, thoughts, and experiences from different stakeholders; an increase in accountability and community trust in the policies and implemented program; and the reduction in risks and problems in the implementation process. However, there are issues regarding time, cost, replicability, and adequate representation (Reed et al., 2018; Anggraeni et al., 2019). Interestingly, stakeholder engagement is often fraught with conflict when different interests result in mistrust and non-cooperation; ergo, a significant component of stakeholder engagement is to develop techniques for conflict reduction (Furber et al., 2016).

Some authors have identified a lack of evidence-based assessment on how effective engagement processes have enabled water objectives to be achieved (Lacroix and Megdal, 2016). Developing a common language represents one of the primary challenges. For example, the way stakeholders are involved has changed and is progressively moving away from mere "participation." Likewise, various degrees of engagement, priority levels and typologies of participation have been discussed in the literature (Sharpe et al., 2021) since the "ladder of citizen participation" developed by Arnstein (1969), which has been critiqued for considering participation as an end in itself rather than as a value itself (Pigmans et al., 2019). Another issue is that stakeholder engagement is not usually measured in terms of realistic expectations about the process and its potential outcomes (Markouzi et al., 2022) because the participation process tends to be limited in space and time.

Social-learning in water management and governance

Social learning has been acknowledged by researchers in recent decades as a fundamental feature of water governance, with past experiences helping people to perceive changes and deal with future challenges (Johannessen et al., 2019). The approach can be summarized as learning together to manage together. Typically, no one person or organization has all the legal competencies, funds, information and other resources necessary to manage these issues to his or her satisfaction. Consequently, stakeholders need to cooperate and pool resources (Mostert et al., 2008). Social learning is also a means to analyze and enhance the current natural (hydrological and geographical conditions) and social (governance, cultural and economic systems) contexts affected by pressure or change (Benhangi et al., 2020).

Social learning is a process centered around multi-stakeholder collaboration (Figure 1), which goes beyond consultation or deliberation to also involve concerted action monitored at different iterations (Hovardas, 2021). Stakeholders learn by observing others and by their social interactions to promote cognitive feedback. Imitation games and role models are classic examples of individual social learning (Ananda et al., 2020).

Reflective practice, experimentation, shared understanding, knowledge exchange, and confronting opposing points of view are key issues in social learning (Rodela et al., 2012). Social learning can contribute to outcomes such as changes in the system performance, structural changes in institutions, improving socio-ecological systems, shared vision for collective actions, or changing the features and variables characterizing the system performance (van der Wal et al., 2014). Additionally, the process leads to new knowledge, shared understanding, trust, and collective actions (Eriksson et al., 2019).

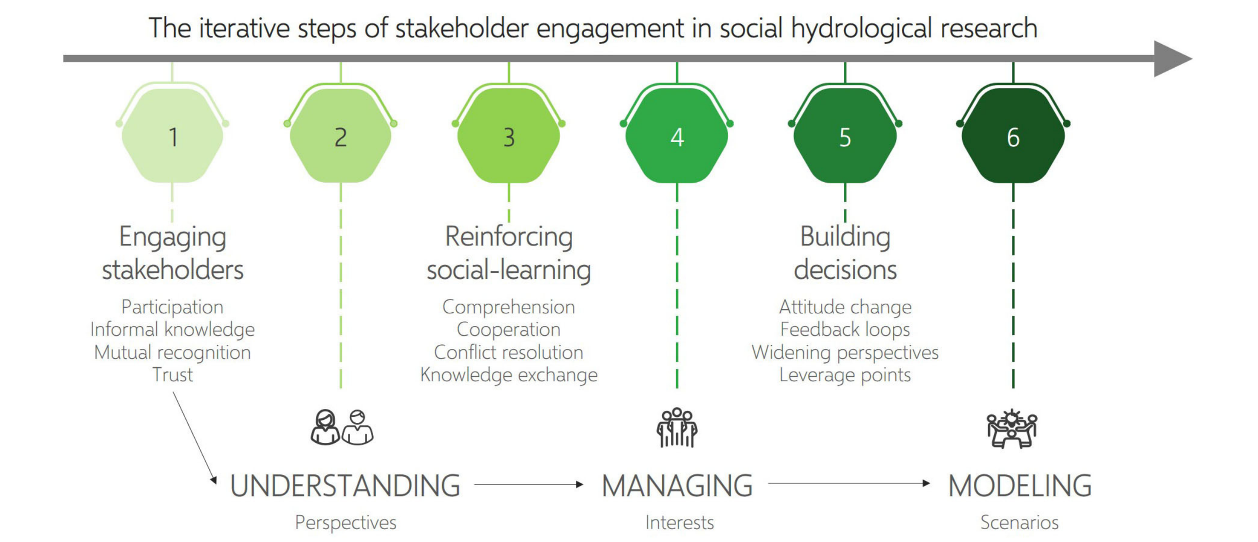

FIGURE 1
The iterative steps of stakeholder engagement in social hydrological research.

System thinking and system dynamics to modeling biophysical and social data

Despite a vast literature on stakeholder and modeling processes, the fundamental questions of "who's in" and "why" are not always explicit and remain a difficult issue (Voinov and Bousquet, 2010). Conventional hydrological models are based on linear causal thinking that struggles to integrate the complexity of social and natural systems (Zomorodian et al., 2018). But increasingly researchers are using approaches informed by system thinking and system dynamics to devise integrated social hydrological models (e.g., considering human impacts on global resources as a boundary condition; involving particularly long timescales considering changing values and norms; or combining system understanding, forecasting and prediction, and policy and decision-making) (Blair and Buytaert, 2016). Systems thinking has its roots in von Bertalanffy's (1971) General Systems Theory and Holling's (1973) work on ecological system resilience, and has evolved to understand complex systems since 1960s. It can be viewed as a language of communicating processes and interrelationships to aid effective decision-making processes (Ram and Irfan, 2021). There are many different systems thinking approaches, with system dynamics being particularly influential in the development of social hydrological models. System dynamics is an approach to systems that examines relationships and behaviors over time, conceiving of all systems having elements of accumulation, flow, feedback, and delay that change through time, altering the characteristics of hydrological and social systems over time (Elsawah et al., 2017). System dynamics enables modelers to use insights from pure hydrological models and to combine them with parameters like economics, values, or social network connectivity to explore different future scenarios (Beall et al., 2011). However, social characteristics of stakeholders (including power and interests) have been rarely incorporated in the system dynamics-based models (Moghaddasi et al., 2022).

One method for collecting and integrating social data is through collaborative modeling, where invited experts, stakeholders, and interested parties and partners are invited to develop a model in collaboration with researchers (Beall-King and Thornton, 2016). These types of modeling approaches typically attempt to develop a shared vision, rather than making firm predictions. Researchers can collaboratively develop a view of the system and its characteristics through engaging these invited guests in the development of a causal loop diagram (CLD), for example, a model that can combine qualitative and quantitative data to describe causation and connection between different elements of the system. In an early example of collaborative modeling using CLD, Stave (2003) argued that collaborative model development helped stakeholders understand the complexity of the system, while shifting narratives away from blame toward solutions. Easy-to-view CLDs help to engage stakeholders during the modeling process and facilitate their mind maps. However, modelers have difficulties in identifying which stakeholders should be approached, what to do when stakeholders perceive variable relationships in the CLDs differently, and how this affect the robustness of systems dynamics (Dhirasasna and Sahin, 2019). A recent paper has reviewed system dynamics modeling in water resources planning and management (Phan et al., 2021). The authors reviewed 169 papers and noted that only 14% of the reviewed papers included examples of collaboratively developing models with stakeholders, leading the authors to argue that the full potential of qualitative tools and thinking in system dynamics-informed socio-hydrological modeling has not yet been achieved.

Experiences to bring the gap

Despite the lack of co-development and participation in social hydrological models, there are examples from research of this working well in practice. Tidwell et al. (2004) is an early example of how participatory modeling approaches can inform freshwater decision making and planning. The authors helped create a system dynamics model to assist community-based water planning in New Mexico. The model development helped the community recognize the potential consequences of a "business as usual" management strategy, demonstrating the impact of time delays and feedback within the system. However, the authors also acknowledge some disadvantages to participatory modeling approaches, such as disparity between the researchers and stakeholders regarding the purpose of the model and what it should do, limits in regards to time, resources, and data, and certain important metrics not being simulated by the model, such as how specific pricing or conservation programs will affect economic growth.

The ability of participatory modeling to reduce social conflict was articulated by Karamouz et al. (2006). These authors highlight how system dynamics modeling, similar to the approach used in Tidwell et al. (2004), can be used as a conflict resolution strategy. The scenarios highlighted by the final model created an option that suited all parties, where over 90% of the time the receiving water bodies for waste load allocations will meet water quality standards.

More recently, Kotir et al. (2017) reflect on the development of CLDs with stakeholders in the Volta River Basin in West Africa to assist with sustainable agricultural development. The conceptual model that was built collaboratively with stakeholders communicated the importance of feedback loops in the system, and how governing those feedback loops could provide strategic leverage points for decision makers. Analysis after the collaborative model development confirmed that a majority of participants enjoyed the process and it contributed to a greater understanding of the importance of feedbacks in the function of the water basin.

Zare et al. (2019) reflect on the use of system dynamics modeling as a decision support and learning tool for water management in North-Eastern Iran. In this case, stakeholder engagement was conducted informally to elicit qualitative data which was integrated with more quantitative models. The researchers admit there is more room to add in formal and systematic engagement of stakeholders throughout the modeling process.

Discussion

Stakeholder participation in social hydrological modeling has developed over the last 20 years, however, the review conducted by Phan et al. (2021) confirms a need to highlight the benefits of these engagements to encourage further participation. We have derived the following lessons from our reading of the literature on participant engagement in hydrosocial modeling.

Lesson 1: Addressing conflicts through recurring participation

Social hydrological modeling will often start by defining the problem, and it is this stage where stakeholders are often seen as potential participants. However, this relegates participants as inputs in the modeling process, rather than co-developing the model and sharing decision-making with researchers about relevant connections, loops, delays, and feedbacks. The lived experience of participants in catchments can be critical to developing accurate models. Given this, we argue stakeholder engagement ought to be promoted throughout the modeling process, from problem definition, data collection, model development, to model verification.

Lesson 2: Resolving conflicts through mutual understanding

The co-development of models between stakeholders and researchers can help both groups better understand the complexity of water systems and water management. Building this understanding and social learning amongst a broad variety of participants helps reduce conflict between participants who may have brought competing interests to the process (Markouzi et al., 2022). A benefit of socio-hydrological modeling is that participants recognize complexity and learn about multiple values, highlighting that a "one-size-fits-all" approach is unlikely to succeed.

We think there is an opportunity for innovative and engaging participatory approaches to play a key role in reducing conflict and water use competition, as well as identifying catchments with a particular need for more holistic water management. Hydrosocial imaginaries explicitly connect water with society and, in so doing, drive actions, shape outcomes, and allow collectives of people to recognize a common purpose (Berry and Cohn, 2022). Such imaginaries can be understood as the socioenvironmental world views and aspirations held by particular social groups, often in confrontation with the contrasting images adhered to by competing subject groups (Molden and Meehan, 2018). This calls for a non-static view of water management and urges adaptive planning, which includes multiple perceptions from multiple stakeholders in a participatory planning process, (Viera and Malekpour, 2020). Thus, planning needs to be geared toward accommodating multiple futures when responding to different scenarios. Contestation, however, arises when planners adaptively plan without integrating stakeholders' perspectives on future development and setting clear signpost to trigger deviating paths together (Butsch et al., 2022).

Consequently, we suggest that the combination of stakeholders' engagement, social learning, and hydrosocial research should be the starting point of a triple-loop analysis to: (i) identify differences in stakeholders' perception and behavior regarding water system management; (ii) raise awareness of synergies and trade-offs regarding water system management; and (iii) resolve potential conflicts by reconsidering future values on relevance and representativeness ("to be"), recognition ("to do"), and collaboration ("to share") among stakeholders (Ricart and Rico-Amorós, 2022).

Conclusion

In this opinion paper, we seek to show the importance of linked hydrological and social research in understanding and resolving complex water management problems. Traditional water management approaches fail to adequate engage in this complexity, which has resulted in the development of socio-hydrology and hydrosocial research approaches. Experiments with joint hydrological and social research and modeling highlights potential benefits of social learning and conflict resolution. However, there remain many challenges to overcome, especially regarding the inclusion of stakeholder input into modeling process. To conclude, we provide four questions which need to be addressed in future social hydrological research:

- How can qualitative data collection (interviews, surveys, focus groups, workshops) more effectively gather stakeholder desires and attitudes and feed this into a water management process?
- How can planners and managers incorporate stakeholder perspectives while simultaneously developing workable, adequate and financially sound "technical" solutions to water conflicts?
- Which techniques can ensure permanent stakeholders' participation, and at what cost?
- Is stakeholder involvement a reactive or proactive measure to resolve water conflicts?

Author contributions

All authors contributed equally to this work and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Akhmouch, A., and Clavreul, D. (2017). "Towards inclusive water governance: OECD evidence and key principles of stakeholder engagement in the water sector," in *Freshwater Governance for the 21st Century*, Ed E. Karar (Cham: Springer), 29–49.

Akhmouch, A., Clavreul, D., and Glas, P. (2018). Introducing the OECD principles on water governance. *Water Int.* 43, 5–12. doi: 10.1080/02508060.2017.1407561

Ananda, J., McFarlane, D., and Loh, M. (2020). The role of experimentation in water management under climate uncertainty: institutional barriers to social learning. *Environ. Policy Gov.* 30, 319–331. doi: 10.1002/eet.1887

Anggraeni, M., Gupta, J., and Verrest, H. J. L. M. (2019). Cost and value of stakeholders participation: a systematic literature review. *Environ. Sci. Policy* 101, 364–373. doi: 10.1016/j.envsci.2019.07.012

Arnstein, S. R. (1969). A ladder of citizen participation. *J. Am. I. Planners* 35, 216–224. doi: 10.1080/01944366908977225

Beall, A., Fiedler, F., Boll, J., and Cosens, B. (2011). Sustainable water resource management and participatory system dynamics. Case study: developing the Palouse Basin Participatory model. *Sustainability* 3, 720–742. doi: 10.3390/su3050720

Beall-King, A., and Thornton, M. (2016). Staying the course: collaborative modelling to support adaptive and resilient water resource governance in the Inland Northwest. *Water* 8, 232. doi: 10.3390/w8060232

Benhangi, S. M., Bagheri, A., Abolhassani, L., and Razi, H. H. (2020). Assessing the learning capacity of water users – adoption a social learning framework. *J. Hydrol.* 590, 125496. doi: 10.1016/j.jhydrol.2020.125496

Berry, K. A., and Cohn, T. C. (2022). Space, time, and hydrosocial imaginaries: water quality governance of the Pyramid Lake Paiute Tribe. *Prof. Geogr.* doi: 10.1080/00330124.2022.2075403

Blair, P., and Buytaert, W. (2016). Socio-hydrological modelling: a review asking "why, what and how?". *Hydrol. Earth Syst. Sci.* 20, 443–478. doi: 10.5194/hess-20-443-2016

Boelens, R., Hoogesteger, J., Swyngedouw, E., Vos, J., and Wester, P. (2016). Hydrosocial territories: a political ecology perspective. *Water Int.* 41, 1–14. doi: 10.1080/02508060.2016.1134898

Butsch, C., Hermans, L. M., Farrelly, M. A., and Zandvoort, M. (2022). Editorial: actors and adaptive planning in water management. *Front. Water* 4, 991338. doi: 10.3389/frwa.2022.991338

Cantor, A. (2021). Hydrosocial hinterlands: an urban political ecology of Southern California's hydrosocial territory. *Environ. Plann. E.* 4, 451–474. doi: 10.1177/2514848620909384

Dhirasasna, N., and Sahin, O. (2019). A multi-methodology approach to creating a Causal Loop Diagram. *Systems* 7, 42. doi: 10.3390/systems7030042

Elsawah, S., Pierce, S. A., Hamilton, S. H., van Delden, H., Haase, D., Elmahdi, A., et al. (2017). An overview of the system dynamics process for integrated modelling of socio-ecological systems: lessons on good modelling practice from five case studies. *Environ. Model. Softw.* 93, 127–145. doi: 10.1016/j.envsoft.2017.03.001

Eriksson, M., van Riper, C. J., Leitschuh, B., Brymer, A. B., Rawluk, A., Raymond, C. M., et al. (2019). Social learning as a link between the individual and the collective: evaluating deliberation on social values. *Sustain. Sci.* 14, 1323–1332. doi: 10.1007/s11625-019-00725-5

Flaminio, S., Rouillé-Kielo, G., and Le Visage, S. (2022). Waterscapes and hydrosocial territories: thinking space in political ecologies of water. *Prog. Env. Geo.* doi: 10.1177/27539687221106796. [Epub ahead of print].

Furber, A., Medema, W., Adamowski, J., Clamen, M., and Vijay, M. (2016). Conflict management in participatory approaches to water management: a case study of Lake Ontario and the St. Lawrence river regulation. *Water* 8, 280. doi: 10.3390/w8070280

Furlong, C., De Silva, S., and Guthrie, L., Considine, R. (2016). Developing a water infrastructure-planning framework for the 20 complex modern planning environment. *Util. Policy* 38, 1–10. doi: 10.1016/j.jup.2015.11.002

Handayani, W., Dewi, S. P., and Septiarani, B. (2022). Toward adaptive water governance: an examination on stakeholders engagement and interactions in Semarang City, Indonesia. *Environ. Dev. Sustain.* doi: 10.1007/s10668-022-02124-w. [Epub ahead of print].

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annu. Rev.* 4, 1–23. doi: 10.1146/annurev.es.04.110173.000245

Hommes, L., Boelens, R., Bleeker, S., Duarte-Abadia, B., Stoltenborg, D., and Vos, J. (2020). Water governmentalities: the shaping of hydrosocial territories, water transfers and rural-urban subjects in Latin America. *Environ. Plann. E.* 3, 399–422. doi: 10.1177/2514848619886255

Hovardas, T. (2021). Social sustainability as social learning: insights from multi-stakeholder environmental governance. *Sustainability* 13, 7744. doi: 10.3390/su13147744

Johannessen, Å., Gerger-Swartling, Å., Wamsler, C., Andersson, K., Arran, J. T., Hernández-Vivas, D. I., et al. (2019). Transforming urban water governance through social (triple-loop) learning. *Environ. Policy Gov.* 29, 144–154. doi: 10.1002/eet.1843

Karamouz, M., Akhbari, M., Moridi, A., and Kerachian, R. (2006). A system dynamics-based conflict resolution model for river water quality management. *Iran J. Environ. Health. Sci. Eng.* 3, 147–160. doi: 10.1061/40856(200)88

Kotir, J. H., Brown, G., Marshall, N., and Johnstone, R. (2017). Systemic feedback modelling for sustainable water resources management and agricultural development: an application of participatory modelling approach in the Volta River Basin. *Environ. Modell. Softw.* 88, 106–118. doi: 10.1016/j.envsoft.2016.11.015

Lacroix, K. E. M., and Megdal, S. B. (2016). Explore, synthesize, and repeat: unraveling complex water management issues through the stakeholder engagement wheel. *Water* 8, 118. doi: 10.3390/w8040118

Linton, J., and Budds, J. (2014). The hydrosocial cycle: defining and mobilizing a relational–dialectical approach to water. *Geoforum* 57, 170–180. doi: 10.1016/j.geoforum.2013.10.008

Markouzi, A., Mellouli, S., and Daniel, S. (2022). Understanding issues with stakeholders participation process: a conceptual model of SPP's dimensions of issues. *Gov. Inform. Q.* 39, 101668. doi: 10.1016/j.giq.2022.101668

Megdal, S. B., Eden, S., and Shamir, E. (2017). Water governance, stakeholder engagement, and sustainable water resources management. *Water* 9, 190. doi: 10.3390/w9030190

Moghaddasi, P., Kerachian, R., and Sharghi, S. (2022). A stakeholder- based framework for improving the resilience of groundwater resources in arid regions. *J. Hydrol.* 609, 127737. doi: 10.1016/j.jhydrol.2022.127737

Molden, O. C., and Meehan, K. (2018). Sociotechnical imaginaries of urban development: social movements around "traditional" water infrastructure in the Kathmandu Valley. *Urban Geogr.* 39, 763–782. doi: 10.1080/02723638.2017.1393921

Mostert, E., Craps, M., and Pahl-Wostl, C. (2008). Social learning: the key to integrated water resources management? *Water Int.* 33, 293–304. doi: 10.1080/02508060802275757

Phan, T. D., Bertone, E., and Stewart, R. A. (2021). Critical review of system dynamics modelling approaches for water resources planning and management. *Clean. Environ. Syst.* 2, 100031. doi: 10.1016/j.cesys.2021.100031

Pigmans, K., Aldewereld, H., Dignum, V., and Doorn, N. (2019). The role of value deliberation to improve stakeholder participation in issues of water governance. *Water Resour. Manag.* 33, 4067–4085. doi: 10.1007/s11269-019-02316-6

Qi, D., Si, Z., and Scott, S. (2021). Can we be more collaborative? Top-down policies and urban–rural divides in the ecological agriculture sector in Nanjing, China. *Soc. Nat. Resour.* 34, 208–226. doi: 10.1080/08941920.2020.1774951

Ram, S. A., and Irfan, Z. B. (2021). Application of system thinking causal loop modelling in understanding water crisis in India: a case for sustainable Integrated Water Resources Management across sectors. *HydroResearch* 4, 1–10. doi: 10.1016/j.hydres.2021.02.001

Reed, M. S., Vella, S., Challies, E., de Vente, J., Frewer, L., Hohenwallner-Ries, D., et al. (2018). A theory of participation: what makes stakeholder and public engagement in environmental management work? *Restor. Ecol.* 26, S7–S17. doi: 10.1111/rec.12541

Ricart, S. (2020). "Water governance and social learning: approaches, tools, and challenges," in *Clean Water and Sanitation, Encyclopedia of the UN Sustainable Development Goals*, Eds W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, and T. Wall (Cham: Springer), 796–808.

Ricart, S., and Rico-Amorós, A. M. (2022). To be, to do, to share: the triple-loop of water governance to improve urban water resilience – testing the Benidorm' experience, Spain. *Land* 11, 121. doi: 10.3390/land11010121

Rodela, R., Cundill, G., and Wals, A. E. J. (2012). An analysis of the methodological underpinnings of social learning research in natural resource management. *Ecol. Econ.* 77, 16–26. doi: 10.1016/j.ecolecon.2012.02.032

Ross, A., and Chang, H. (2020). Socio-hydrology with hydrosocial theory: two sides of the same coin? *Hydrolog. Sci. J.* 65, 1443–1457. doi: 10.1080/02626667.2020.1761023

Ruiz-Villaverde, A., and Garcia-Rubio, M. A. (2017). Public participation in European water management: from theory to practice. *Water Resour. Manag.* 31, 2479–2495. doi: 10.1007/s11269-016-1355-1

Sharpe, L. M., Harwell, M. C., and Jackson, C. A. (2021). Integrated stakeholder prioritization criteria for environmental management. *J. Environ. Manage.* 282, 111719. doi: 10.1016/j.jenvman.2020.111719

Sigalla, O. Z., Tumbo, M., and Joseph, J. (2021). Multi-Stakeholder Platform in water resources management: a critical analysis of stakeholders' participation for sustainable water resources. *Sustainability* 13, 9260. doi: 10.3390/su13169260

Skrydstrup, J., Madsen, H. M., Löwe, R., Gregersen, I. B., Pedersen, A. N., and Arnbjerg-Nielsen, K. (2020). Incorporating objectives of stakeholders in strategic planning of urban water management. *Urban Water J.* 17, 87–99. doi: 10.1080/1573062X.2020.1748204

Srdjevic, B., Medeiros, Y. D. P., and Srdjevic, Z. (2022). Empowering small stakeholders groups in selecting a long-term water management plan. *Water Policy.* 24, 1208–1222. doi: 10.2166/wp.2022.075

Stave, K. A. (2003). A system dynamics model to facilitate public understanding of water management options in Las Vegas, Nevada. *J. Environ. Manage.* 67, 303–313. doi: 10.1016/S0301-4797(02)00205-0

Swyngedouw, E. (1999). Modernity and hybridity: nature, Regeneracionismo, and the production of the Spanish waterscape, 1890 – 1930. *Ann. Am. Assoc. Geogr.* 89, 443–465. doi: 10.1111/0004-5608.00157

Tidwell, V. C., Passell, H. D., Conrad, S. H., and Thomas, R. P. (2004). System dynamics modeling for community-based water planning: application to the Middle Rio Grande. *Aquat. Sci.* 66, 357–372. doi: 10.1007/s00027-004-0722-9

Troy, T. J., Pavao-Zuckerman, M., and Evans, T. P. (2015). Debates—perspectives on socio-hydrology: socio-hydrologic modeling: tradeoffs, hypothesis testing, and validation. *Water Resour. Res.* 51, 4806–4814. doi: 10.1002/2015WR017046 van der Wal, M., De Kraker, J., Offermans, A., Kroeze, C., Kirschner, P. A., and van Ittersum, M. (2014). Measuring social learning in participatory approaches to natural resource management. *Environ. Policy Gov*. 24, 1–15. doi: 10.1002/eet.1627

Viera, O., and Malekpour, S. (2020). An analysis of adaptive planning capacity: the case of Chilean water utilities. *Util. Policy* 65, 101064. doi: 10.1016/j.jup.2020.101064

Voinov, A., and Bousquet, F. (2010). Modelling with stakeholders. *Environ. Model. Softw*. 25, 1268–1281. doi: 10.1016/j.envsoft.2010.03.007

von Bertalanffy, L. (1971). *General System Theory: Foundations, Development, Applications*. London: Allen Lane.

Wehn, U., Collins, K., Anema, K., Basco-Carrera, L., and Lerebours, A. (2018). Stakeholder engagement in water governance as social learning: lessons from practice. *Water Int*. 43, 34–59. doi: 10.1080/02508060.2018.1403083

Wesselink, A., Kooy, M., and Warner, J. (2017). Socio-hydrology and hydrosocial analysis: towards dialogues across disciplines. *WIREs Water* 4, e1196. doi: 10.1002/wat2.1196

Zare, F., Elsawah, S., Bagheri, A., Nabavi, E., and Jakeman, A. J. (2019). Improved integrated water resource modelling by combining system dynamics conceptual modelling techniques. *J. Environ. Manage*. 246, 27–41. doi: 10.1016/j.jenvman.2019.05.033

Zomorodian, M., Lai, S. H., Homayounfar, M., Ibrahim, S., Fatemi, S. E., and El-Shafie, A. (2018). The state-of-the-art system dynamics application in integrated water resources modelling. *J. Environ. Manage*. 227, 294–304. doi: 10.1016/j.jenvman.2018.08.097