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# The water science communication problem: Water knowledge and the acceptance or rejection of water science

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ABSTRACT

A "science communication problem" exists when scientifically-supported, policy-relevant fact is disputed because it conflicts with political perspectives or other culturally-relevant influences. This study evaluates whether such a problem exists on water topics, where it could obstruct productive discourse as new water policies are introduced. To identify water topics on which partisan individuals reject water science, we developed and applied a Rasch-modeled scale of "ordinary water science knowledge" (OWSK) and an associated assessment of beliefs. Our sample, consisting of 806 Florida and Georgia residents, indicated personal beliefs that aligned with their perceptions of scientists' beliefs so long as the information did not activate partisan positioning. Partisan positions were easily activated, however, with some politically right-leaning individuals indicating personal water beliefs contrary to their perceptions of scientists' beliefs (i.e., a water science communication problem). This divergence occurred in response to statements on the effects of climate change on water availability and on the adequacy of water supply to meet demand 20 years in the future. These topics have relevance far beyond the study area, suggesting a water science communication problem may exist at broader regional and national scales.

## 1. Introduction

Water policy is a normative topic and, as such, is suitable for public debate. Decisions on water allocation and quality standards benefit from public discourse and even some measure of conflict, so long as it serves to balance communities' ecological, economic, and social needs (Fielding and Hornsey, 2016; van Zomeren et al., 2008). Yet this benefit can be undermined when the subject of debate includes scientific facts on which there is broad scientific consensus. Established facts should be neutral tools referenced in the service of policy decisions, but partisan interpretation can turn scientific facts into points of contention that overwhelm normative discourse. This is what Kahan calls the "science communication problem" – "the failure of valid scientific evidence to quiet disputes over policy-relevant facts" (2017a, p. 36). Topics that demonstrate the science communication problem include fracking, gun possession, and most notably climate change, where disputes regarding the existence of global warming and its anthropogenic origins have detracted from consideration of adequate societal responses (Kahan, 2015b, 2017a; Nisbet, 2016).

Water topics can also exhibit the science communication problem, but it has been assumed that where clean, affordable water flows predictably from the faucet, the public does not give water much consideration (for instance, Handwerk, 2012; Tobin, 2017). If this presumption is accurate, water may be largely free of the science communication problem, at least among those who live in relatively water-rich regions. However, there are at least three reasons this could change. First, climate change is altering the geographic and temporal availability and predictability of water supplies (Hoegh-Guldberg et al., 2018), adding to the ongoing stresses of population change and economic expansion. Second, as water supplies are stressed or as unexpected crises ensue, environmental inequalities and injustices may be exposed (Butler et al., 2016), prompting reconsideration of existing water policies. Third, subpopulations of stakeholders, such as agricultural and environmental interests exhibit partisanship on water topics (Hundemer and Monroe, 2020; Paolisso and Maloney, 2000) and can influence public perspective.

The above social and natural pressures, alone and in combination, will likely necessitate new prioritization decisions for limited water supplies and thus heighten the public's awareness of water challenges. How the water supply is managed is a high stakes decision, particularly for those with large economic or ideological interests in water outcomes (Dunlap and Brulle, 2020); therefore, multiple actors with competing

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motivations may assert to the public their perspective on water challenges and what should be done to address them. Individual residents, most of whom have limited scientific background, are then faced with a decision, *who to believe*? Do they accept the words of scientists, or do they base their personal water beliefs on alternative narratives?

As more communities approach potentially contentious water futures, one objective of policy makers and communicators should be to limit the science communication problem so that whatever water debate ensues is focused on the advantages and disadvantages of normative concerns (which can be a basis for productive discourse), rather than the veracity of scientific facts. As the US climate change debate has demonstrated, once the science communication problem is established, it can be difficult to reverse (McCright and Dunlap, 2011; Wong-Parodi and Feygina, 2020). Before a potential escalation of water issues, proactive investments should be made in the proverbial ounce of prevention to stave off a pound of cure, by taking steps to prevent a water science communication problem. An initial step toward this objective is determining whether a water science communication problem already exists on regionally and nationally relevant topics, which is the objective of this study. Specifically, we aim to determine what the public knows about water and if individuals reject their scientific knowledge in favor of partisan beliefs. Equipped with this information, water communicators can better design interventions to prevent the potentially debilitating effect of a water science communication problem.

### *1.1. Cultural conception of water risk*

If a water science communication problem emerges in regions where water issues have thus far been publicly obscure, the likelihood that an individual possesses beliefs that contradict their scientific knowledge may be correlated with their position along the political spectrum. This pattern has been observed on other topics that exhibit the science communication problem (Kahan, 2017a). In these cases, one political ideology asserts scientific knowledge as evidence to support their policy preferences, while the opposing political ideology rejects the science, effectively saying that policy action is not needed (Campbell and Kay, 2014). The denial of valid scientific evidence by those possessing ideologies incompatible with the stated or implied solution is what Campbell and Kay (2014) call “solution aversion.” The science is rejected as a means to invalidate the implied need for policy action. While one group is averse to the environmental conditions reflected by scientific evidence, the other group is averse to the interventions that could result if the scientific evidence were accepted as true.

Conceptions of which environmental conditions are “problems” and which solutions are “problematic” are influenced by culture. Culture has been defined in many ways including common values, beliefs, attitudes, and behaviors (Kroeber and Kluckhohn, 1952; Strauss and Quinn, 1998). By these broad definitions, the United States has two dominant political cultures: the political left (which may be identified as liberal or Democrat) and the political right (identified as conservative or Republican). As occurs with other types of culture, American political cultures have become conventionalized over time, creating consistencies within the political left and political right in the way information is processed, interpreted, and used (Douglas and Wildavsky, 1982; Higgins and Bargh, 1987; Oliveira, 2007; Trompenaars, 1994).

Differences in information processing across political ideologies is associated with their alternative visions for how the world “should be”. The political left idealizes a society that promotes equality and helps even the most vulnerable members succeed (Douglas and Wildavsky, 1982; Kahan and Braman, 2006). In accordance with this perspective, the left tends to prioritize social welfare and ecosystem protection (among other values) (Douglas and Wildavsky, 1982; Kahan and Braman, 2006). The worldview of the political right idealizes a society that promotes tradition and in which government is minimized and individuals succeed on their own (Douglas and Wildavsky, 1982; Gauchat, 2012; Kahan and Braman, 2006). In line with this vision, conservatives prioritize freedom from regulation and protection of established industries (among other values) (Douglas and Wildavsky, 1982; Kahan and Braman, 2006). These two worldviews and policy preferences have been strongly associated with divisiveness on climate and other environmental topics. Studies find that because environmental issues put at risk things that liberals deeply value, specifically social welfare and ecosystems, the political left tends to support action that abates the threat; however, the solutions often target things of great value to conservatives, such as freedom from regulation, generating strong opposition from the political right (Day et al., 2014; Kidwell et al., 2013; Wolsko, 2017; Wolsko et al., 2016).

Similar value tradeoffs weave throughout water challenges, potentially dividing individuals of opposing political orientations on future water policy. Based on their cultural value priorities, right-leaning individuals, who may oppose increased water regulation, could demonstrate solution aversion by rejecting the validity of scientific evidence that indicates water quality or quantity have declined. Alternatively, left-leaning individuals, who may believe water regulation is too weak, could reject the validity of scientific evidence that indicates water conditions have improved. If either of these scenarios were observed, it would signify a water science communication problem.

Notably, the water science communication problem can spread within a political culture even if most individuals are not personally solution averse. For the average person, it is a difficult and time consuming task to weigh the merits of policy options (Kahan, 2017a). In place of this investment, many simply adopt the positions of those they trust, and people typically trust those who are similar to them, such as those who share their political identities (Oliveira, 2007). If partisan influencers are solution averse, others may unwittingly adopt science incongruent positions.

### *1.2. Public knowledge of water science*

Before we proceed with our assessment of a potential water science communication problem, it is necessary to establish what people know about water science. Only then will we be able to determine whether beliefs that run contrary to scientific fact reflect a rejection of science, a lack of topical awareness, or both. Likewise, measurement of water science knowledge enables us to determine if a person’s science-conforming beliefs reflect an acceptance of science or simply a fortuitous alignment of belief with scientific reality. These are critical differences because an intervention designed to instill new scientific knowledge among individuals motivated to align their beliefs with water science would necessarily be quite different than an intervention designed to change the predispositions of individuals who reject scientific evidence.

Prior studies, though limited, find low levels of water science knowledge among Americans (Robelia and Murphy, 2012). National surveys conducted in 1998 and 1999 found 24 percent of Americans could correctly identify the most common source of surface water pollution (NEETF, 1999), and 41 percent could correctly select the definition of a watershed (NEETF, 1998). Other studies report low to moderate levels of self-reported familiarity with terminology related to water resources (Hubbard, 2020) and water policy (Lamm et al., 2015). Though these findings are narrow in scope, they suggest an American public that lacks the scientific knowledge to accurately inform water beliefs (Kunda, 1990). There should be no expectation that science knowledge is the sole determinant of water beliefs (Bucchi, 2008), but to the extent that the public is motivated to ground their water beliefs in scientific evidence (Kunda, 1990), many are unlikely to possess the requisite knowledge to do so.

Our emphasis on water science knowledge may suggest that addressing water knowledge deficits is our primary goal. While scientific knowledge is a critical component in the assessment of a potential water science communication problem, and a water science literate public is more able to democratically engage (Dewey, 1916; Fischer, 2000), scientific knowledge on its own is not necessarily a cure-all for water challenges. When discussing culturally contentious scientific issues, the assumption is often incorrectly made that if people had more information they would make the "right" decisions. There are two issues with this line of thinking. First, there are no objectively "right" decisions (Lackey, 2007; Nisbet, 2016). Water degradation is only a "problem" if people's values cause them to perceive it as such. For example, while degraded water may have negative implications for wildlife or human health, it may have a positive impact on a community's economy if the degradation is a result of industrial or agricultural production. Science can help quantify the tradeoffs but is unable to determine the "right" policy decision.

The second issue is the assumption that water decisions are made primarily on the basis of scientific fact. A wealth of literature illustrates that scientific knowledge is just one (often minor) factor in decision making (Owens, 2000; Sturgis and Allum, 2004). In addition to their scientific knowledge, people make decisions based on their values (Douglas and Wildavsky, 1982; Haidt, 2012; Kahan and Braman, 2006), guidance from opinion leaders (Chong and Druckman, 2007; Kahan, 2017a), and communication frames (Chong and Druckman, 2007; Entman, 1993; McCombs and Reynolds, 2008). Moreover, scientific literacy does not reliably correlate with trust in science. Studies have identified a weak, positive correlation between scientific literacy and generalized trust in science, but not between scientific literacy and attitudes on specific science controversies (Allum et al., 2008; Gauchat, 2012).

While the notion of scientific knowledge as a cure-all is unsupported, so too is the idea that scientific knowledge is an insignificant determinant of behavior and belief (Owens, 2000). Water science knowledge can make people aware of environmental conditions that threaten the things they value, and can enable them to engage in the discourse on threats and tradeoffs (Dewey, 1916; Fischer, 2000). Additionally, without water science knowledge, people may be more easily misled by false claims that cause them to adopt positions contrary to their interests (Sharon and Baram-Tsabari, 2020). Critically, a measure of the public's scientific knowledge informs communicators about the appropriate level at which to discuss water challenges so that the public can participate (Nickerson, 1999). In short, while scientific knowledge is not a cure-all, lack of scientific knowledge can be a crucial barrier (Owens, 2000; Sturgis and Allum, 2004), and if water science is actively rejected, these problems may be compounded.

### 1.3. Knowledge versus belief

To accurately assess a potential water science communication problem, it is also imperative that a clear distinction is made between scientific knowledge and belief, concepts often confounded both in scientific discourse and research. Kahan (2015a) demonstrated this error with the dilemma faced by a survey respondent who understands the scientific consensus on evolution but chooses not to believe it. How is such a person to respond to the true/false question, "Humans evolved from an earlier species of animal" (2015a)? If the respondent replies with scientific knowledge, the answer will be "true;" if the respondent replies with personal belief, the answer will be "false." Water science knowledge could be vulnerable to this type of mismeasurement as well, particularly on subtopics that associate water with more polarized issues, such as the sectors responsible for water contamination and potential changes in water availability resulting from climate change.

As defined for the purpose of this paper, scientific knowledge is an individual's understanding of what scientists think is true. Belief, in contrast, is what an individual personally accepts as true (Schwitzgebel, 2019). Beliefs may reflect an individual's understanding of science or they may reflect another socially relevant construct, such as a religious tenet or partisan position. Which of these foundations provides the basis (or bases) for one's beliefs depends on the individual's motivations (assuming they are motivated to invest in the topic at all) (Petty and Cacioppo, 1986). An individual may be motivated by a desire to arrive at an accurate conclusion or, alternatively, by a desire to arrive at a specific, directional conclusion (Kunda, 1990). The decision to adopt a position that matches one's political party line, regardless of accuracy, is an example of directional decision making.

Decisions motivated by accuracy goals and directional goals can yield similar belief outcomes. For example, a fully informed Democrat who is motivated to adopt beliefs reflective of scientific consensus would conclude that climate change is largely anthropogenic in origin, just as they would if they were motivated to adopt beliefs in line with party position. In this circumstance, both scientific consensus and party position yield the same belief. Similarly, a fully informed Republican would arrive at the belief that genetically modified foods are no risker to human health than foods from conventional breeding (Snell et al., 2012) regardless of whether they are motivated by political positioning (directional) or scientific consensus (accuracy). Yet, there are many other instances in which partisan positioning conflicts with perceived scientific consensus. In those cases, if a person's beliefs are dominated by partisan directional goals, they will reject science, and the science communication problem emerges.

Importantly, even those individuals motivated by accuracy may not align their beliefs with scientists if they do not trust scientists to provide objective information. Since the 1970 s, conservatives' trust in organized science has progressively declined, a trend not observed among the public at large (Gauchat, 2012). In part, the reduction in trust may be due to the increased role of science in regulatory activity (to which conservatives are adverse) and the political power scientific institutions have gained in this role (Gauchat, 2012; Gross et al., 2011; Jasanoff, 1990). Conservatives have challenged the legitimacy of this conferred power, citing a perceived lack of neutrality among the organizations producing and funding scientific research (Barnes, 1977; Bloor, 1976; Gieryn, 1999; Jasanoff, 1990; Latour and Woolgar, 1979). On climate change, these challenges and science denial have been promoted by corporations, conservative foundations, conservative think tanks, contrarian scientists, and conservative media among others (Dunlap and Brulle, 2020).

We refer to climate change here, and throughout the paper, because it is the most studied case of science denial. But the public may develop opinions on climate science quite differently than they do on water science. With climate change, the science debate cannot be avoided by anyone who moderately engages news media. Therefore, partisans know and can easily adopt the culturally expected positions of their political ideology. Moreover, on climate change, political positions have become powerful symbols of group membership and self-identity (Fielding and Hornsey, 2016), making it psychologically difficult for individuals to stray from political alignment. On water topics, however, we currently lack the empirical evidence to determine whether a partisan public experiences conflict between political positioning and science. Unlike climate change, water is not among the top issues of national political concern (Pew Research Center, 2020). Though water can be divisive locally and regionally, most people engage with politics primarily at the national level, and define their political identities by national issues (Hopkins, 2018). Since water is not widely discussed on the national stage, individuals may not associate water topics with partisan stances, potentially making it easier to accept perceived scientific consensus. However, if partisans possess ample consistency of underlying beliefs or the political savvy to anticipate party positions on novel topics, a water science communication problem could be primed for activation when water issues emerge more prominently on the public stage.

Although water is not a prominent national issue, there is persistent risk that the public could broadly associate water issues and water policies with partisan politics. At the time of this writing, in 2021, the American West is experiencing a severe drought that has led to federal cuts in water allocations and the need for water management collaboration across US states and between the US and Mexico (Flaccus, 2021; Naishadham, 2021). These government-directed water distribution decisions yield no winners and many losers, which can prompt political backlash, escalate political rhetoric, and boost national media attention. Similarly, President Obama's "Waters of the United States" rule (US EPA, 2017), expanding wetland and stream protections, and Trump's "Navigable Waters Protection Rule" (US EPA, 2018), rescinding these protections, cast water policy as a political "us vs. them" battle that, with increased media attention, could cause the public to view other water issues through a partisan lens. These constant partisan threats increase the urgency for evaluating the public's susceptibility to the water science communication problem.

## 2. Regional context

For this study of scientific knowledge, belief, and the science communication problem, we concentrate on Georgia and Florida, two states substantially dependent on the Floridan aquifer system (depicted in Fig. 1) (Hodges et al., 2014; Marella and Berndt, 2005). Of particular importance to the quality and quantity of the system's waters are the geologically unconfined regions located in southwest Georgia and north Florida. In these areas, many rivers and springs are fed by the upper portion of the aquifer system. As a result, the effects of aquifer decline are seen above ground, particularly when rainfall is low. The tradeoffs between groundwater use and surface water availability have become increasingly apparent over the past 50 years as withdrawals substantially increased due to population growth, tourism, and agricultural production (Marella and Berndt, 2005). Though recent data show some declining use trends (Lovelace et al., 2020), the impact of water withdrawals continues to affect property values, recreation, and tourism, as well as the availability of water for residential, agricultural, industrial, and ecosystem use.

The aquifer system's vulnerability to contamination further threatens economics and ecosystems (Rath et al., 2021). While well-drained soil in the unconfined regions has supported agricultural investment, it has also introduced large amounts of applied fertilizer. As a result of agricultural intensification, municipal fertilizer use, and other nutrient contributors, Florida springs exceed the state's ecosystem-protective numeric nutrient criteria (FDEP, 2010; Katz, 2004; Katz et al., 2009). Exceedances have also been recorded in Florida's rivers, and high nutrient concentrations have been observed in the rivers of Georgia where there are fewer nutrient regulatory standards (Allums et al., 2012; FDEP, 2010, 2012; Hallas and Magley, 2008).


**Fig. 1.** Extent of the Floridan aquifer system (latitude 29, longitude −84). Area south of the black line is underlain by the aquifer system. Credit: U.S. Geological Survey, Department of the Interior/USGS.

If new water policies are proposed to enhance protection of the Floridan aquifer system through actions taken in the unconfined regions (e.g., incentives to farmers to adopt new land management practices), the policies would likely be funded at the state level. Accordingly, their adoption would be affected by the scientific knowledge, beliefs, and attitudes of residents across the entirety of both Florida and Georgia. What these individuals know and believe about water conditions in the unconfined regions could affect the future of the aquifer system overall. This premise influenced the selection of water topics assessed throughout this research. Though we sampled individuals from throughout the two states, the questions to which they responded emphasized water considerations of particular importance in the unconfined areas.

## 3. Research questions

The extent to which a water science communication problem exists in Georgia and Florida was examined though two research questions:

RQ1: What is the public's level of scientific knowledge on regional water topics?

RQ2: On what water topics do people's water beliefs reflect their perception of what scientists think is true? Are there variations across political orientations?

## 4. Methods

A survey was administered to a Qualtrics-recruited sample of 806 voting age residents of Florida (n = 402) and Georgia (n = 404) between 13 November 2020 and 8 December 2020. For Florida and Georgia populations of 21.5 and 10.6 million respectively (US Census Bureau, 2019), this sample provides 95 percent confidence that estimates from the survey sample are within 10 percentage points of the true population value (Dillman et al., 2014). Due to the manner in which survey participants were recruited, a traditional response rate cannot be reported; however, of the 526 Florida participants and 536 Georgia participants who began the survey 402 (76%) and 404 (75%) completed it, respectively.

Sample selection was based on three requirements: relatively even participation from the two states of interest; relatively even participation across three age groups (18–34, 35–55, and 56+); and, within the Georgia sample, a minimum of 20 percent participation from individuals residing in the less populous southern counties. Qualtrics recruits their survey participants from a variety of sources including website intercepts, member referrals, and targeted email lists, then verifies their names, addresses, and birth dates. When asked to take part in a specific survey, potential participants receive generic invitations or are prompted from within a survey platform. The invitations and prompts do not indicate the topic of the survey.

The survey consisted of demographic questions, political orientation questions, scales of perceived water quality and availability risk, a knowledge assessment, and a belief assessment. With the demographic questions at the beginning of survey, participants were asked how much risk they personally believe water quality and availability pose to human health, economic prosperity, ecosystems, and quality of life (measured separately on five-point scales from "none" (0) to "much risk" (4)). At the end of the survey, political orientation was measured with the following three questions, the results of which were combined into a single index that identified individuals as politically left-leaning, right-leaning, or moderate.

1. Which of the following best describes your views? [*Very liberal, Liberal, Moderate/Independent, Conservative, Very conservative, Other ___, I don't know*]
2. How often do your positions on issues align with the positions of DEMOCRATS? [*Always, Often, Occasionally, Rarely, Never, I don't know*]
3. How often do your positions on issues align with the positions of REPUBLICANS? [*Always, Often, Occasionally, Rarely, Never, I don't know*]

The index gave equal weight to question 1 and the combination of questions 2 and 3. Therefore, the assignment of political orientation equally reflected participants' self-applied political labels and their self-identified issue alignments. Also at the end of the survey, perceived differences were assessed between the political left and the political right in their perception of water risk. Participants were asked to score, to the best of their knowledge, how much of a problem Republicans and Democrats believe water quality and availability are in their states (0 = not a problem, 1 = little problem, 2 = moderate problem, 3 = big problem).

### 4.1. Scientific knowledge assessment

Modeled after Kahan's (2015a) "ordinary climate science intelligence" (OCSI) instrument, an "ordinary water science knowledge" (OWSK) instrument was developed to measure recognition of water facts and scientific consensus to a level that would enable an ordinary resident of Florida or Georgia to competently participate in water discussions and make citizen-level voting decisions on water topics. This knowledge level includes familiarity with fundamental vocabulary, understanding of basic water processes, awareness of regional water challenges, and recognition of major regional water policies.

Development of the OWSK began with stakeholder and expert consultation to determine what the public should know about regional water science and related topics. Experts were recruited from a USDA-funded project currently underway in the Floridan aquifer region (FACETS: Floridan Aquifer Collaborative Engagement for Sustainability) in which regional water stakeholders and university scientists collaboratively examine alternative water scenarios and the associated trade-offs for economics, ecosystems, and other societally valued outcomes. Though not all water interest groups were represented, we aimed to include a broad range of water perspectives, particularly those with unique sets of water science knowledge.

To begin, the FACETS project's advisory committee was asked via a survey to identify those water topics they believe the public should know. Respondents included leaders in agriculture, forestry, and environmental organizations. Their responses (n = 7) served as preliminary input for focus groups on the same topics. Focus group participants (n = 32) included project representatives from agriculture, environmental organizations, community leaders, economists, and water scientists familiar with water challenges in the Floridan aquifer regions. Using the collected information and literature as a guide, preliminary OWSK assessment questions and answers were developed to reflect scientific consensus. The determination of scientific consensus was based on a literature review and confirmation from university scientists.

In accordance with test specifications, preliminary OWSK questions encompassed topics and a question difficulty range reflective of the above-stated goals of an ordinary water science knowledge assessment. Question formats included multiple choice and multiple true–false. Common misconceptions were included in answer options where applicable. To reduce the potential for measurement error from the confoundment of scientific knowledge and belief, questions were written to specifically elicit knowledge-based responses (Kahan, 2015a). For example, on water topics where respondents could possess beliefs that differ from their perception of scientific consensus, questions began with a phrase such as "According to water scientists…".

Questions were also written to prevent over-inflation of the scores of individuals who generally perceive greater levels of environmental risk. This was accomplished by balancing questions that such individuals would likely guess correctly based on their affective risk orientation, with questions they would likely guess incorrectly due to the same affective bias (Kahan, 2015a). For instance, on the question "Why are algae sometimes described by water scientists as harmful?," respondents with a high affective risk orientation may be predisposed to see all negative outcomes as true. Therefore, they may be more likely than the average respondent to *correctly* guess "Algae can produce toxins that are dangerous to humans and animals." To offset the influence of correct answers resulting from this predisposition, we included the response option, "Algae can increase oxygen to a level that is unsafe for fish," which these individuals may be predisposed to *incorrectly* believe is true due to the risk implied.

Our initial set of 53 questions (with each option of multiple true–false items counted as a separate question) was initially administered to a Qualtrics-recruited sample of 285 voting age residents of Florida (n = 133) and Georgia (n = 152). The results were assessed using Rasch modelling (Rasch, 1960) and Winsteps software (Linacre, 2020c) with the aim of reducing the preliminary question pool to a final OWSK scale. Our sample size of 285 individuals is in accordance with Crocker and Algina's (1986) recommended minimum sample for Rasch models of 200 participants, which enables measurement with 95 percent confidence.

Rasch modeling enabled the development of a standard measurement metric while ensuring items were sufficiently unidimensional (correlation among items can be explained by a single latent factor, regional water science knowledge) and cover the latent construct continuum (question difficulty spans a suitable range of citizen-level water science knowledge). The partial credit Rasch model was used to reduce the impact of local dependence that could have been introduced through the use of multiple true-false items. Fit discrepancies between items and the Rasch model were measured using INFIT and OUTFIT mean-square residual summary statistics, which range from 0 to infinity with 1 indicating ideal fit. Items were included in the final assessment only if item INFIT and OUTFIT were between 0.7 and 1.3, which is considered a reasonable range for run-of-the-mill testing (testing that is not high stakes) (Wright and Linacre, 2020). A principal component analysis of residuals indicated sufficient uni-dimensionality, with a first contrast eigenvalue of 1.85 (<2.0, which is the smallest eigenvalue that can be considered a dimension) (Linacre, 2020a). Uniform differential item functioning (DIF) was used to determine if assessment items functioned in the same manner across gender, race, and political identification. Based on identity plots, items that did not conform to the model expectation of item difficulty invariance were removed from the assessment. Rasch results guided the reduction of the question set to the final OWSK instrument of 40 items. With the sample of 285 individuals, the OWSK yielded a model item separation of 4.48 and reliability of 0.95. Person model separation was 1.98 with a reliability of 0.80.

Scientific facts and methods questions from Kahan's (2017b) "ordinary science intelligence" (OSI_2.0) instrument, which measures individuals' capacity to interpret and use scientific evidence in everyday decisions, were administered alongside the preliminary OWSK to evaluate external validity. Responses to OSI questions were found to be moderately positively correlated with person measures on the final 40 OWSK items, $r(283) = 0.54$, $p < 0.001$. This correlation is not high enough to raise concerns that the OWSK and OSI measure the same thing, yet is high enough to support our expectation that participants with more water science knowledge also have more general science knowledge.

### 4.2. Belief assessment

In the belief portion of the assessment, we aimed to discern the role that scientific knowledge plays in water belief. Specifically, on which topics does the public accept what they perceive water scientists to believe? Likewise, on which topics does the public reject what they perceive water scientists to believe in favor of other belief determinants?

Participants indicated their personal beliefs and their perception of scientists' beliefs on four water topics. As an example, item 1 below assesses participants' beliefs about fertilizer as a water pollutant and item 2 assesses their understanding of what scientists think.

1. *Which statement most accurately reflects your thoughts?*
 o I think fertilizer IS a source of water pollution in my state.
 o I think fertilizer IS NOT a source of water pollution in my state.
 o I don't know enough to answer.
2. *Which statement is most accurate?*
 o Most WATER SCIENTISTS think fertilizer IS a source of water pollution in my state.
 o Most WATER SCIENTISTS think fertilizer IS NOT a source of water pollution in my state.
 o I don't know enough to answer.

This question format was utilized with the following four water topics, presented in random order:

Fertilizer [IS or IS NOT] a source of water pollution in my state.

Septic systems [ARE or ARE NOT] a source of water pollution in my state.

Climate change [WILL or WILL NOT] impact the availability of water in my state.

In 20 years, there [WILL or WILL NOT] be enough surface and ground water to meet demand throughout my state.

Our interest in this section was not participants' ability to answer the question correctly, but rather the consistency between participants' perceptions of scientists' beliefs and their personal beliefs. By water topic and political orientation, the percentage of respondents selecting as their personal belief the affirmative (IS, ARE, WILL) or contradicting perspective (IS NOT, ARE NOT, WILL NOT) was charted against the percentage of respondents selecting each perspective as their perception of scientists' beliefs. The resulting alignment or misalignment provided a visual indicator of the acceptance or rejection of scientists' beliefs. To illustrate that the differences observed across political orientations were not due to variations in water science knowledge across political groups, similar charts were developed comparing the personal beliefs and perceived scientists' beliefs of high OWSK scorers (above the mean) and low OWSK scorers (below the mean).

In addition, belief was regressed on OWSK scores to identify topics where water science knowledge emerged (or failed to emerge) as a significant factor in water belief. Multinomial logistic regression was utilized because the outcome variables (personal beliefs and perceived scientists' beliefs) are nominal, while OWSK is continuous. Because the significance of OWSK could vary across water topics, separate regression models were created for each personal or perceived belief. Results were split by political leaning to enable across groups assessment of the relationship between OWSK and beliefs. All statistical analyses for this portion of the assessment were conducted with SPSS Version 26 (IBM Corp., 2019).

## 5. Results

As detailed in Table 1, demographic characteristics were similar for Florida and Georgia. Using our index of political orientation, 38.1 percent (FL: 40.8%; GA: 35.4%) of the sample was identified as politically left-oriented, 30.0 percent (FL: 26.9%; GA: 33.2%) as right-oriented, and 32 percent as politically neutral. In accordance with our sampling criteria, participants were almost evenly split across three age categories (18–34, 35–55, and 56 + ). Both states had more female (FL: 57.7%; GA: 60.6%) participants than male (FL: 41.3%; GA: 39.1%), and a broad range of education levels were represented. The sample consisted primarily of individuals identifying their race as "White" (FL: 75.4%; GA: 66.3%) or "Black or African American" (FL: 15.4%; GA: 24.3%). For Florida and Georgia respectively, 17.4 percent and 6.7 percent identified their ethnicity as "Hispanic or Latinx." State-specific demographics are provided for sample transparency and to aid in the interpretation and use of OWSK results; however, assessment of the water science communication problem is conducted for the sample as a whole, not by state.

Based on participants' county of residence, 85.2 percent (FL: 93.3%; GA: 77.2%) resided in metropolitan areas and 14.8 percent (N = 119) in nonmetropolitan areas (USDA Economic Research Service, 2020). For comparison, 91.3 percent of the overall, combined population of Florida and Georgia resides in a metropolitan county (per 2010 census data) (USDA Economic Research Service, 2020). The percentage of participants residing in metropolitan areas was similar across political orientations with 86.6 percent of left-leaning participants residing in metropolitan areas (13.3 percent non-metropolitan) and 83.9 percent of right-leaning participants residing in metropolitan areas (16.1 percent non-metropolitan). The percentage of metropolitan and non-metropolitan participants is provided to aid in interpretation of the results; we have not directly compared the two groups due to the relatively

**Table 1**
Demographic characteristics of survey participants.

| Demographic | Overall | | Florida | | Georgia | |
|---|---|---|---|---|---|---|
| | % | N | % | N | % | N |
| State of primary residence | | | | | | |
| Florida | 49.9% | 402 | | | | |
| Georgia | 50.1% | 404 | | | | |
| Political orientation* | | | | | | |
| Left | 38.1% | 307 | 40.8% | 164 | 35.4% | 143 |
| Right | 30.0% | 242 | 26.9% | 108 | 33.2% | 134 |
| Neutral | 31.9% | 257 | 32.3% | 130 | 31.4% | 127 |
| County category | | | | | | |
| Metropolitan | 85.2% | 687 | 93.3% | 375 | 77.2% | 312 |
| Non-metropolitan | 14.8% | 119 | 6.7% | 27 | 22.8% | 92 |
| Age | | | | | | |
| 18–34 | 33.0% | 266 | 32.6% | 131 | 33.4% | 135 |
| 35–55 | 33.0% | 266 | 33.3% | 134 | 32.7% | 132 |
| 56+ | 34.0% | 274 | 34.1% | 137 | 33.9% | 137 |
| Gender | | | | | | |
| Male | 40.2% | 324 | 41.3% | 166 | 39.1% | 158 |
| Female | 59.2% | 477 | 57.7% | 232 | 60.6% | 245 |
| Prefer not to say | 0.2% | 2 | 0.5% | 2 | 0.0% | 0 |
| Prefer to self-describe | 0.4% | 3 | 0.5% | 2 | 0.2% | 1 |
| Education (highest completed) | | | | | | |
| Less than high school | 3.6% | 29 | 3.5% | 14 | 3.7% | 15 |
| High school or GED | 20.3% | 164 | 20.9% | 84 | 19.8% | 80 |
| Some college | 23.8% | 192 | 23.1% | 93 | 24.5% | 99 |
| Associate degree | 10.2% | 82 | 12.4% | 50 | 7.9% | 32 |
| Bachelor's degree | 21.2% | 171 | 19.7% | 79 | 22.8% | 92 |
| Some graduate school | 3.1% | 25 | 3.2% | 13 | 3.0% | 12 |
| Completed graduate school | 17.7% | 143 | 17.2% | 69 | 18.3% | 74 |
| Ethnicity | | | | | | |
| Hispanic or Latinx | 12.0% | 97 | 17.4% | 70 | 6.7% | 27 |
| Not Hispanic or Latinx | 82.9% | 668 | 77.6% | 312 | 88.1% | 356 |
| Prefer not to say / No response | 5.1% | 41 | 5.0% | 20 | 5.2% | 21 |
| Race | | | | | | |
| American Indian or Alaska Native | 0.4% | 3 | 0.0% | 0 | 0.7% | 3 |
| Asian or Asian American | 1.9% | 15 | 1.5% | 6 | 2.2% | 9 |
| Black or African American | 19.9% | 160 | 15.4% | 62 | 24.3% | 98 |
| Native Hawaiian or Pacific Islander | 0.6% | 5 | 1.0% | 4 | 0.2% | 1 |
| White | 70.8% | 571 | 75.4% | 303 | 66.3% | 268 |
| Prefer not to say | 2.5% | 20 | 3.0% | 12 | 2.0% | 8 |
| Other / No response | 4.0% | 32 | 3.7% | 15 | 4.2% | 17 |

* Based on our political orientation scale.

small number of non-metropolitan participants.

Left-leaning and right-leaning participants alike believed that Democrats perceive water as a bigger problem than do Republicans. Specifically, as depicted in Table 2, the political left's mean scores of Democrats' perception of the scale of water problems was 0.55 points higher (on a four-point scale ranging from 0 to 3) than that of Republicans. The political right's mean scores of Democrats' perceptions of the scale of water problems was 0.60 points higher than that of Republicans. Not only did participants perceive a partisan gap on water concern, but they did so with relative accuracy. The political left perceived levels of health, economic, ecosystem, and quality of life risk from water on average 0.52 points higher, $t(547) = 5.2$, $p < 0.001$, than the political right. Notably, neither group's water risk perceptions were particularly high.

### 5.1. RQ1: what is the public's level of scientific knowledge on regional water topics?

Participants' performance on the OWSK assessment is detailed in Table 3, with the percentage of correct responses displayed by state and for the sample overall. Interpretation of correct answer percentages should be made with recognition of the effect of guessing. For example, if participants selected from the answer options at random, we would expect a 25 percent correct answer rate for those questions with four answer choices.

The questions in Table 3 are ordered by difficulty from high to low. This difficulty rating is mirrored in the left column of the item person map provided in Fig. 2. The item person map illustrates the relationship between question difficulty and participants' OWSK. Because measurement was conducted with a Rasch model, the difficulty of questions is measured on the same scale as the OWSK of participants, simplifying score interpretation. In other words, the measures on the left side of the figure apply to both the difficulty of questions and the water science knowledge of participants (each "#" represents four individuals; each "." represents one to three individuals). For any given individual, their position on the item person map indicates their expected performance on each question. For example, an individual receiving a score at the mean would have approximately a 50–50 chance of accurately answering Q21, a<50 percent chance of accurately answering the questions appearing below Q21, and a greater than 50 percent chance of accurately answering the questions appearing above Q21.

Preliminary testing of OWSK assessment questions enabled us to select questions within an appropriate range of difficulty based on participants' range of water science knowledge, thereby increasing the accuracy of measurement. As can be observed in Fig. 2, question difficulties approximate the same normal curve around the mean as participants' OWSKs. The OWSK assessment of Florida and Georgia residents yielded a model item separation (capacity to distinguish between high and low performers) of 7.79 and reliability (reproducibility of item measures) of 0.98. Person model separation (confirmation of item difficulty hierarchy) was 1.96 with a reliability (reproducibility of person measures) of 0.79. These measures indicate reliability and validity are appropriate for run-of-the mill testing (Linacre, 2020b). Participants' OWSK measures had a weak, positive correlation with right political orientation, $r(804) = 0.162$, $p = 0.000$.

The OWSK results indicate that Florida and Georgia participants (the majority of whom reside in metropolitan counties) have higher levels of scientific knowledge on water topics that they may have encountered in their daily lives and through local news. These topics include urban environments, water conservation, climate change, and algae. For example, 67 percent of participants correctly indicated that it is more difficult for rain to soak into the ground in urban environments than other land use types. Likewise, at least 60 percent of respondents were able to correctly identify each of a series of potential steps that cities can take to reduce water use. A majority of participants correctly identified each of a series of predicted climate change effects. Seventy-one percent of participants correctly identified algae as an indicator of high nutrient levels, and a majority correctly identified harms that can result from algal blooms.

Perhaps the most fundamental indicator of the public's inability to understand regional water challenges was proper identification of "underground water" as the region's primary drinking water source – an answer selected by only 54 percent of participants in Georgia and 59 percent of participants in Florida. Fifty-four percent of the overall sample correctly selected the definition of an aquifer. Other topics on which participants possessed relatively low levels of water science knowledge included natural water processes, nutrient pollution, and current water policy, all of which could be highly relevant to future water policy in the region. For example, the natural processes that affect aquifer water levels and water quality will likely influence determinations of which activities should be curtailed or promoted by water policy, and where in the region such changes should occur (e.g., the unconfined region). Yet, it appears the public may not understand the scientific basis for such determinations. Only 44 percent of respondents correctly identified rainwater seeping through the soil as the primary way water levels increase in the Floridan aquifer. This is the same percentage that correctly indicated that easily infiltrated soils carry the risk of increased groundwater pollution. Nitrogen and phosphorous were correctly identified as the two primary nutrients of concern by only 30 and 35 percent of participants respectively, and the key contributors of those nutrients, fertilizers and septic tanks, were correctly selected by 50 and 20 percent of participants respectively. When asked the reasons why aquifer levels decline during droughts, 54 percent of respondents correctly indicated that less rain falls on the land above the aquifer and only 40 percent correctly indicated that more

**Table 2**
Perceived water risk and perceptions of Democrats' and Republicans' water risk beliefs, by political orientation.

| Question | Left-oriented | | Right-oriented | | Comparison | | |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Diff | $t$ | $p$ |
| To the best of your knowledge, how much of a problem do < DEMOCRATS OR REPUBLICANS > believe water quality and availability are in your state? *[Four point scale ranging from 0 to 3]* | | | | | | | |
| Democrats | 1.98 | 0.92 | 1.80 | 1.00 | 0.180 | 1.871 | 0.062 |
| Republicans | 1.43 | 0.99 | 1.20 | 1.06 | 0.235 | 2.295 | 0.022* |
| In your state, how much risk do you believe water quality and water availability pose to each of the following? *[Five-point scale ranging from 0 (no risk) to 4 (much risk)]* | | | | | | | |
| Human health | 2.48 | 1.34 | 1.96 | 1.34 | 0.517 | 4.483 | 0.000* |
| Economic prosperity | 2.32 | 1.30 | 1.84 | 1.24 | 0.476 | 4.361 | 0.000* |
| Ecosystems | 2.46 | 1.33 | 1.96 | 1.30 | 0.496 | 4.394 | 0.000* |
| Quality of life | 2.48 | 1.31 | 1.88 | 1.81 | 0.600 | 5.307 | 0.000* |

* $p$-value < 0.05.

**Table 3**
OWSK assessment correct answer percentages by question difficulty.

| Question *(Note: Answer choices randomized)* | Type* | Category | Difficulty** | % Correct overall | % Correct Florida | % Correct Georgia |
|---|---|---|---|---|---|---|
| **Q20.** According to water scientists, which of the following is a source of **nutrient** pollution? [Septic tanks; Automotive fluids; Pesticides; Nuclear power plants] | MC | Quality | 1.61 | 20% | 21% | 20% |
| **Q25 (GA).** In 2012, consideration of new irrigation permits in southwest Georgia was suspended for which of the following uses? [Agriculture; Urban lawns and landscapes; Industry; Power generation] | MC | Quantity | 1.02 | 29% | NA | 29% |
| **Q18.** According to water scientists, which of the following is one of the two primary nutrients of concern in your state's waters? [Nitrogen; Mercury; Chlorine; Sulfur] | MC | Quality | 1.01 | 30% | 34% | 26% |
| **Q19.** According to water scientists, which of the following is one of the two primary nutrients of concern in your state's waters? [Phosphorous; Arsenic; Lead; Fluorine] | MC | Quality | 0.74 | 35% | 38% | 33% |
| **Q13.** What defines the boundaries of a watershed? [The elevation of the surrounding land; The size of rivers and streams; Political borders; The land use type (agricultural, urban, etc.)] | MC | General | 0.57 | 39% | 42% | 35% |
| **Q26.** According to water scientists, which of the following is a challenge for agencies trying to limit pollution in streams, rivers, and lakes? [It can be difficult to determine where the pollution came from; Tests for measuring water quality are often unreliable; State and local authorities lack the authority to regulate public water bodies; It can be difficult to determine the chemical makeup of the pollutants] | MC | Quality | 0.48 | 41% | 42% | 39% |
| **Q24 (FL).** Florida law references minimum flows and levels (MFLs). What does this mean? [The minimum water flow rate and level needed to prevent significant harm to a water resource; The lowest water flow rate and level on record for a water resource; The depth to which a well must be dug to pump groundwater that flows at a minimum rate; The lowest speed at which surface water in an area moves downward to the level of groundwater] | MC | Quantity | 0.40 | 43% | 43% | NA |
| **Q7.** What is the **primary** way the amount of water in the Floridan Aquifer increases? [Rainwater seeps through the soil; Water flows downward through sinkholes and cracks in the ground surface; Treated wastewater is pumped underground; Water soaks in from lakes and rivers] | MC | Quantity | 0.34 | 44% | 47% | 41% |
| **Q10.** What do reservoirs, desalinization, and aquifer storage and recovery have in common? [They can all be used to provide supplemental water; They can all be used to improve water quality; They are all cost effective approaches to water management] | MC | Quantity | 0.33 | 44% | 45% | 43% |
| **Q27.** Some types of soil make it easy for water on the surface to trickle downward and become groundwater. According to water scientists, what risk is most commonly associated with these soil types? [Increased groundwater pollution; Constantly decreasing groundwater levels; Freshwater being pushed out by saltwater; Difficulty pumping water to the surface for human use] | MC | Quality | 0.33 | 44% | 44% | 44% |
| **Q6.** According to water scientists, which of the following are reasons that the water level in the Floridan Aquifer declines during droughts? Select all that apply. | MTF | Quantity | 0.17 | | | |
| Q6_1. [More water than usual is pumped from the aquifer] | | | | 40% | 44% | 37% |
| Q6_2. [Less rain falls on the land above the aquifer] | | | | 54% | 54% | 53% |
| Q6_3. [Water from the aquifer is given to other regions that don't usually use the aquifer] | | | | 69% | 68% | 69% |
| **Q9.** Which of the following best describes a spring? [An area where groundwater flows to the surface; A well for extracting fresh water; A lake with clear water; A water source free of impurities] | MC | General | 0.15 | 48% | 46% | 49% |
| **Q21.** According to water scientists, which of the following is a source of **nutrient** pollution? [Fertilizer; Coal-fired power plants; Herbicides; GMOs] | MC | Quality | 0.02 | 50% | 53% | 48% |
| **Q4.** Which of the following best describes an **aquifer**? [An underground layer where space between rocks and sediment is filled with water; A drainage basin where rain water moves toward a common outlet; An area where underground water bubbles or flows to Earth's surface] | MC | General | −0.15 | 54% | 56% | 52% |
| **Q15 (GA).** Below is a watershed map of Georgia. The red flag marks the location of Lake Oconee. Pollution from which point is most likely to enter the lake?[Watershed map with four points labeled A, B, C, D] | MC | Quality | −0.16 (GA) | 54% | NA | 54% |
| **Q2 (GA).** What is the primary source of drinking water in South Georgia? [Underground water; Rainfall collected in cisterns; Surface water; Ocean water with the salt removed] | MC | General | −0.19 (GA) | 54% | NA | 54% |
| **Q3.** What term is used to describe water that moves across the land surface without soaking in? [Runoff; Drawdown; Base flow; Groundwater] | MC | General | −0.31 | 58% | 58% | 57% |
| **Q1 (FL).** What is the primary source of drinking water in North and Central Florida? [Underground water; Rainfall collected in cisterns; Surface water; Ocean water with the salt removed] | MC | General | −0.36 (FL) | 59% | 59% | NA |
| **Q22.** According to water scientists, which of the following steps can cities take to reduce water use? Select all that apply. | MTF | Quantity | −0.37 | | | |
| Q22_1. [Repair leaks in pipes] | | | | 60% | 58% | 62% |
| Q22_2. [Provide low-flow water fixtures] | | | | 62% | 61% | 63% |
| Q22_3. [Encourage residents to increase the amount of turf grass] | | | | 64% | 63% | 65% |
| **Q14 (FL).** Below is a watershed map of Florida. The red flag marks the location of Lake Okeechobee. Pollution from which point is most likely to enter the lake?[Watershed map with four points labeled A, B, C, D] | MC | Quality | −0.41 (FL) | 60% | 60% | NA |
| **Q12.** What are the terms "reclaimed water" and "recycled water" typically used to describe? [Wastewater treated so it can be used for other purposes; Water transferred by humans from one geographic area to another; Excess surface water stored in the aquifer for later use; Ocean water treated to remove salt for human use] | MC | General | −0.48 | 61% | 60% | 62% |
| **Q16.** Why are algae sometimes described by water scientists as harmful? Select all that apply. | MTF | Quality | −0.63 | | | |
| Q16_1. [Algae can produce toxins that are dangerous to humans and animals] | | | | 60% | 64% | 56% |
| Q16_2. [Algae can block sunlight from reaching other plants] | | | | 50% | 52% | 49% |

(*continued on next page*)

**Table 3** (*continued*)

| Question *(Note: Answer choices randomized)* | Type* | Category | Difficulty** | % Correct overall | % Correct Florida | % Correct Georgia |
|---|---|---|---|---|---|---|
| Q16_3. [Algae can increase oxygen to a level that is unsafe for fish] | | | | 65% | 67% | 63% |
| Q16_4. [Algae can increase the amount of greenhouse gases in the atmosphere] | | | | 70% | 70% | 69% |
| **Q11.** According to water scientists, which of the following is/are expected to occur this century in the southeastern United States? Select all that apply. | MTF | Quantity | −0.75 | | | |
| Q11_1. [Increase in annual temperatures] | | | | 58% | 63% | 54% |
| Q11_2. [Changes in seasonal precipitation] | | | | 55% | 53% | 57% |
| Q11_3. [Increase in the number of freezing events] | | | | 76% | 74% | 78% |
| Q11_4. [Increase in the amount of sunlight] | | | | 72% | 71% | 74% |
| **Q23.** According to agricultural scientists, which of the following factors affect(s) the amount of water used per acre on a farm? Select all that apply. | MTF | Quantity | −0.76 | | | |
| Q23_1. [Type of irrigation system] | | | | 66% | 67% | 66% |
| Q23_2. [Type of crops being grown] | | | | 55% | 54% | 56% |
| Q23_3. [Regional weather and climate] | | | | 57% | 56% | 59% |
| **Q5.** In which type of area is it most difficult for rain to soak into the ground? [Urban; Agricultural fields; Forest; Pasture] | MC | General | −0.78 | 67% | 66% | 69% |
| **Q8.** Which of following best describes the change in the number of people living in the Floridan Aquifer region over the last ten years? [The number of people has increased; The number of people hasn't changed very much; The number of people has decreased] | MC | General | −0.88 | 69% | 71% | 68% |
| **Q17.** According to water scientists, which of the following typically indicate(s) high levels of nutrients in the water? Select all that apply. | MTF | Quality | −0.97 | | | |
| Q17_1. [Increased algae] | | | | 71% | 71% | 72% |
| Q17_2. [Oil on the water surface] | | | | 70% | 69% | 72% |

*MC = multiple choice; MTF = multiple true false.
**Difficulty measured in units of the latent trait, ordinary water science knowledge. Ordered by difficulty, high to low.
*Note*: Interpretation of correct answer percentages should be made with recognition of the effect of guessing.
*Note*: Descriptive text was provided at several points in the assessment to aid question interpretation.

water than usual is pumped from the aquifer.

On current water policy, a minority of participants correctly identified elements of major policies in their states. Participants also had difficulty identifying the difficulties of water policy. For instance, when asked to identify one of the challenges faced by agencies trying to limit water pollution, 41 percent correctly indicated "it can be difficult to determine where the pollution came from." Furthermore, 44 percent correctly identified "reservoirs, desalinization, and aquifer storage and recovery" (collectively) as ways to provide supplemental water. Calls for aquifer protection in the region are often framed as a means to protect natural springs, yet, only 48 percent of participants correctly identified a spring as "an area where groundwater flows to the surface."

With this information, we can consider whether the public's level of water science knowledge would enable them to competently participate in water discussion and make citizen-level voting decisions on water topics. Given that the OWSK assessment questions were based upon experts' perceptions of what the public should know in order to make good citizen-level water decisions, the results suggest that public water science knowledge is not currently adequate to guide productive water decision making. Moreover, to the extent that individuals are motivated to base their water beliefs on scientific consensus, most lack the capacity to do so.

### *5.2. RQ2: On what water topics do people's water beliefs reflect their perception of what scientists think is true? Are there variations across political orientations?*

Unlike the OWSK assessment, where the objective was to measure the accuracy of participants' water science knowledge, the assessment of beliefs was not concerned with the factual correctness of respondents' choices. Instead, the objective was to determine if people held as their personal beliefs that which they perceived to be the beliefs of water scientists, regardless of accuracy. Whereas many questions in OWSK assessment began with "According to water scientists…" to prompt participants to respond with their scientific knowledge, in this section we explicitly asked participants what they *personally* think.

Participants' personal water beliefs and their perceptions of scientists' beliefs are illustrated in Fig. 3 by topic and political orientation. The gray points in each chart (connected by dotted lines) depict the percentage of individuals who believe the idea posed in the provided statement does or does not reflect what scientists believe. The black points (connected by solid lines) represent the percentage of individuals who accept or reject the concept as part of their personal beliefs. When responding to the questions upon which each chart is based, participants had the option to select "I don't know enough to answer." Therefore, those individuals represented in the charts are only those who had enough confidence in their perspectives to assert a position.

If participants match their water beliefs to what they perceive scientists' think, the two lines in each chart should be roughly parallel. We may also expect some space between the parallel lines with personal beliefs above perceived scientists' beliefs, indicating more confidence in one's own beliefs (less selection of the "I don't know" option) than in their understanding of the beliefs of scientists. If, however, the two lines substantially diverge from parallel, then participants' beliefs reflect a deviation from what they perceive scientists to think – these are the conditions that suggest a water communication problem.

The first two sets of charts in Fig. 3, those depicting perspectives on fertilizer and septic systems as water pollutants, show relative alignment between personal beliefs and perceived scientists' beliefs for the political left, moderates, and the political right. In other words, the full spectrum of political orientations personally accept as their own beliefs that which they perceive to be the beliefs of scientists. (The slope of the lines differs between the two sets of graphs due to differences in the public's knowledge of contamination from fertilizer versus contamination from septic systems, as observed in the OWSK assessment.) However, on topics related to the impact of climate change on water availability and the adequacy of water supply to meet demand in 20 years, the political right shows a misalignment of between their personal beliefs and perceived scientists' beliefs. Though the largest percentage of respondents on the political right indicated that scientists believe climate change will affect water availability in the region and that in 20 years there will not be enough groundwater and surface water to meet regional demand, there is substantial dismissal of this conception in their personal beliefs.

Fig. 4 illustrates the same comparisons as Fig. 3 but divides the sample by OWSK level instead of political orientation. The beliefs and perceptions of those with OWSK measures above the mean are reflected in the "High OWSK" charts, while individuals measured below the

```
MEASURE        INDIVIDUALS               QUESTIONS
               <high OWSK>          |    <more difficult>
   3                     .          +
                                    |
                                    |
                                    |
                         .          |
                                    |
                       .##          |
                                    |
   2                                +
                         #          |
                         #     +2SD|
                       .##          |      Q20
                    .#####          |
                                    |
                  .#######          |+2SD
                   #######          |
   1                  ####          +      Q18     Q25
                      .###     +1SD|
                    .#####          |      Q19
              .###########          |+1SD
                 .########          |      Q13     Q26
              .###########          |      Q07     Q10     Q24     Q27
                .#########          |
   0         #############          +      Q06     Q09
             .############     MEAN| MEAN  Q21
              .###########          |      Q02     Q04     Q15
               ###########          |      Q03
               ###########          |      Q01     Q14     Q22
             .############          |      Q12
             .############          |-1SD  Q16
               .##########     -1SD|      Q05     Q11     Q23
  -1              .#######          +      Q08
                  .#######          |      Q17
                      .###          |
                      ####          |-2SD
                         .          |
                         .          |
                         .     -2SD|
                         .          |
  -2                                +
                         .          |
                                    |
                                    |
                                    |
                                    |
                                    |
                                    |
  -3                                +
                                    |
                                    |
                                    |
                         .          |
                                    |
                                    |
  -4                                +
                <low OWSK>          |    <less difficult>
```

**Fig. 2.** Item person map illustrating the distribution of participants relative to question difficulty. Each "#" equals 4 participants; each "." equals 1 to 3 participants. Individuals are ordered from high to low OWSK. Questions are ordered from high to low difficulty.

OWSK mean are reflected in the "Low OWSK" charts. That line pairs do not substantially deviate from parallel across OWSK levels suggests that the differences observed across political orientations (Fig. 3) are not a result of differences in water science knowledge across groups.

We further evaluated these observations by regressing participants' OWSK measures against their personal beliefs and perceptions of scientists' beliefs. As displayed in Table 4 (which applies a significance threshold of $p = 0.05$), OWSK had a significant effect on participants' perception of *scientists' beliefs* for each of the four topics, and this outcome was true regardless of political orientation. However, the effect of OWSK on *personal beliefs* was not consistently significant across political identities. While OWSK had a significant effect on all four topics of personal belief held by the political left and moderates, it had no significant effect on the political right's personal beliefs about septic systems as a source of water pollution ($X^2\,(2, N = 242) = 2.62, p = 0.27$), the impact of climate change on water availability ($X^2\,(2, N = 242) = 3.93, p = 0.14$), nor the ability of surface and groundwater supplies to meet demand in 20 years ($X^2\,(2, N = 242) = 5.45, p = 0.07$). This suggests that the water beliefs of many on the political right were not substantially connected to their understanding of water science. In these cases, the influence of OWSK may have been overridden by political inclinations that run contrary to perceived scientists' beliefs.

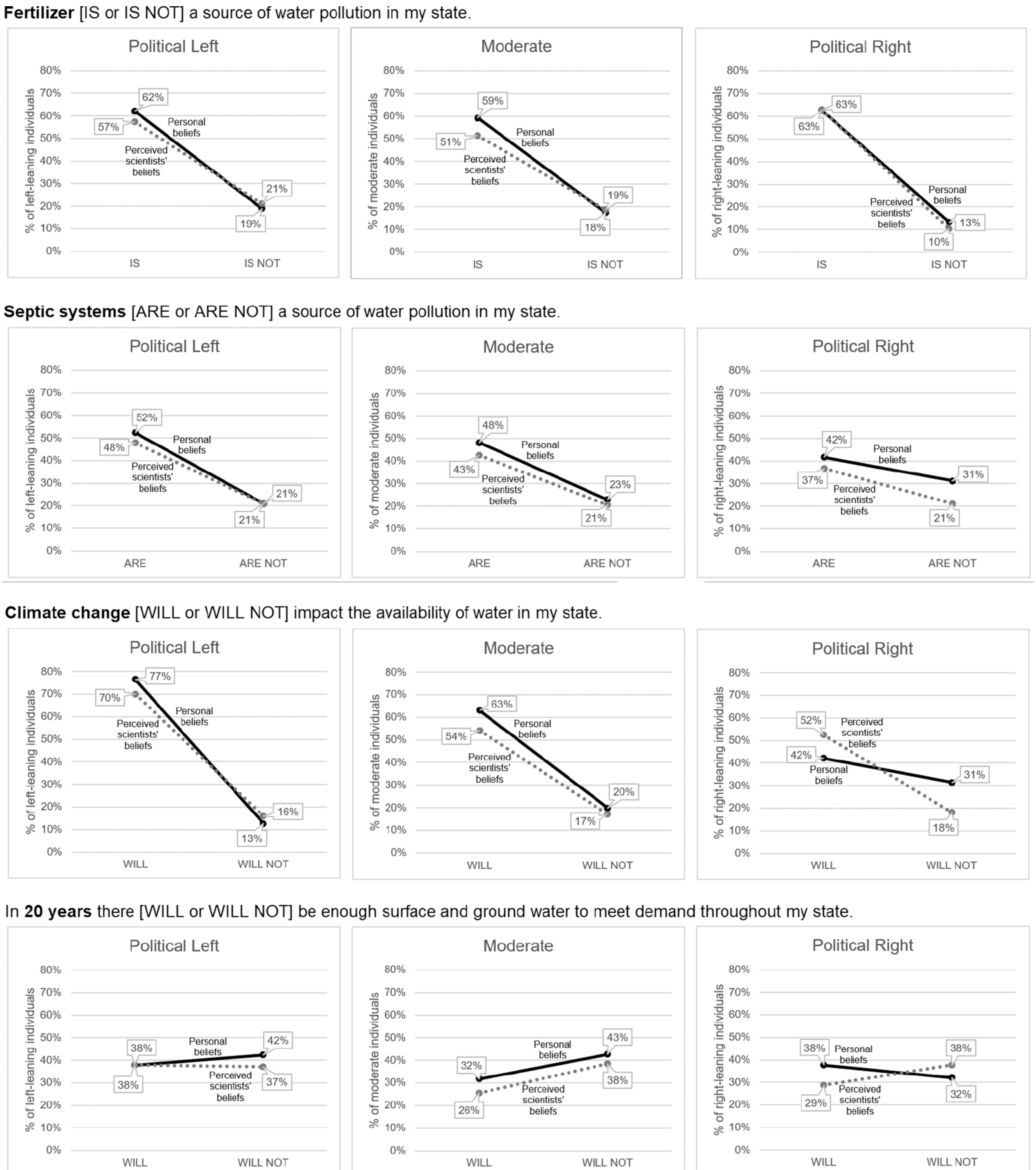


**Fig. 3.** Alignment or misalignment of personal beliefs with perceived scientists' beliefs by political orientation. Not represented are responses indicating, "I don't know enough to answer." Sample sizes: political left, n = 307; moderate, n = 257; political right, n = 242.

Though these results suggest that some on the political right may not rely on OWSK as a determinant of some of their water beliefs, there is evidence that this is not a one-sided phenomenon. The political left may behave in a similar manner even if doing so does not result in a water science communication problem. To illustrate, on the topic of water pollution from fertilizer, OWSK accounts for approximately 2.8% of the variance in personal beliefs of left-leaning participants, but 14.9% of the variance in personal beliefs of right-leaning partisans (Nagelkerke pseudo R-square statistics). In other words, the political right comes to believe that fertilizer is a pollutant by consulting their OWSK, while the political left comes to the same conclusion, but relies more on factors other than scientific knowledge to do so. Since the political left perceives higher levels of water risk, left-leaning individuals can simply follow their environmental predispositions and fortuitously align with water science; they need not rely on scientific knowledge to come to the conclusion that fertilizer is a pollutant. Right-oriented individuals, however, must actively choose scientific knowledge to make the same determination. As indicated by the Nagelkerke pseudo R-square statistics in Table 4, in cases not exhibiting the science communication problem, the political right tends to rely on OWSK more than the political left. As a note, the literature does not provide strong guidance on interpretation of pseudo R-square, therefore, although these statistics

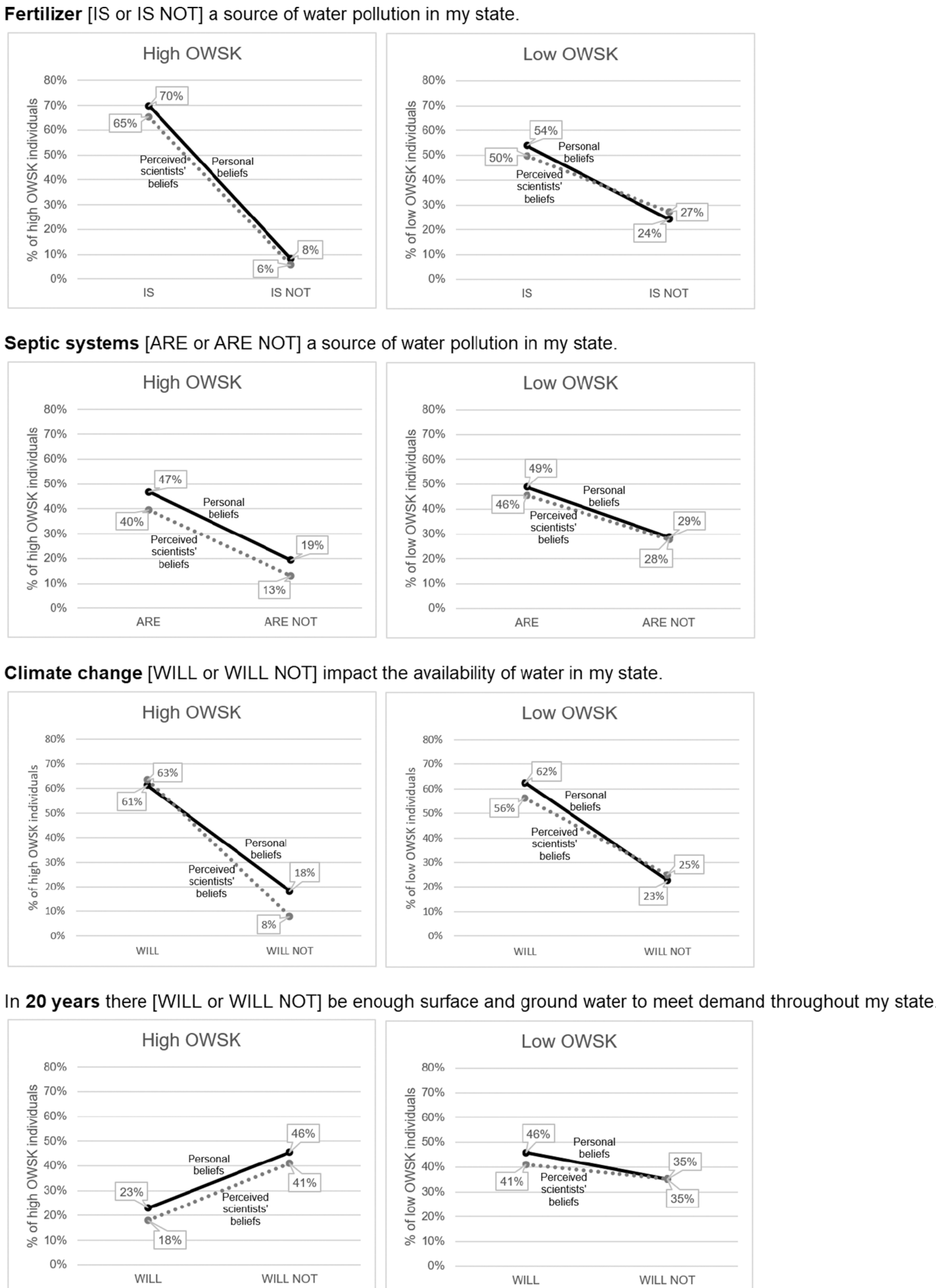


**Fig. 4.** Alignment of personal beliefs with perceived scientists' beliefs by OWSK level. Not represented are responses indicating, "I don't know enough to answer."

provide a measure of relative effect, they should be used with caution.

## 6. Discussion

In Florida and Georgia, we have identified early signs of a potential water science communication problem. The topics exhibiting divergence of participants' personal beliefs from what they perceive scientists to believe are those with the clearest partisan triggers. Climate change is known to exhibit the science communication problem (Fielding and Hornsey, 2016; McCright and Dunlap, 2011) as well as solution aversion (Campbell and Kay, 2014), and we found similar results in this study when climate was invoked in conjunction with water availability. The topic of water supply adequacy 20 years in the future also exhibited the problem, suggesting a similar activation of partisan positioning (Baldwin and Lammers, 2016). One reason this may have occurred is that inadequacy of supply suggests a greater level of environmental risk than the political right may feel is warranted, given their low perception of environmental risk relative to other risk types (Douglas and Wildavsky, 1982; Haidt, 2012) and their low perception of water risk relative to individuals on the political left (though the political left perceived only a moderate level of water risk) (Table 2). Second, inadequacy of supply suggests the need for governmental measures to regulate increasingly strained water supplies, which clashes with the political right's preference for comparatively lower levels of governmental oversight of

**Table 4**
Multinomial regression estimated effect of OWSK on personal belief and perceived scientists' beliefs

| Topic | Condition | Political orientation | Likelihood ratio tests | | Nagelkerke pseudo R-square |
|---|---|---|---|---|---|
| | | | Chi-Square | Sig. | |
| Fertilizer as a source of water pollution | Personal belief | Left | 7.43 | 0.02* | 0.028 |
| | | Moderate | 36.15 | 0.00* | 0.154 |
| | | Right | 32.22 | 0.00* | 0.149 |
| | Perceived scientists' beliefs | Left | 35.26 | 0.00* | 0.126 |
| | | Moderate | 38.06 | 0.00* | 0.158 |
| | | Right | 33.71 | 0.00* | 0.157 |
| Septic systems as a source of water pollution | Personal belief | Left | 18.79 | 0.00* | 0.069 |
| | | Moderate | 14.57 | 0.00* | 0.063 |
| | | Right | 2.62 | 0.27 | 0.012 |
| | Perceived scientists' beliefs | Left | 42.38 | 0.00* | 0.147 |
| | | Moderate | 23.62 | 0.00* | 0.100 |
| | | Right | 6.26 | 0.04* | 0.029 |
| Climate change impact on water availability | Personal belief | Left | 23.39 | 0.00* | 0.097 |
| | | Moderate | 6.97 | 0.03* | 0.032 |
| | | Right | 3.93 | 0.14 | 0.018 |
| | Perceived scientists' beliefs | Left | 19.47 | 0.00* | 0.076 |
| | | Moderate | 21.18 | 0.00* | 0.092 |
| | | Right | 17.70 | 0.00* | 0.081 |
| Ability to meet water demand in 20 years | Personal belief | Left | 44.55 | 0.00* | 0.154 |
| | | Moderate | 10.27 | 0.01* | 0.044 |
| | | Right | 5.45 | 0.07 | 0.025 |
| | Perceived scientists' beliefs | Left | 25.08 | 0.00* | 0.089 |
| | | Moderate | 11.71 | 0.00* | 0.050 |
| | | Right | 23.71 | 0.00* | 0.105 |

* *p*-value $< 0.05$.

resources (Douglas and Wildavsky, 1982; Haidt, 2012).

At present, the observed deviation of personal beliefs from impressions of scientists' beliefs may be of negligible consequence. Based on the OWSK results and the moderate level of perceived water risk across the political spectrum (Table 2), it appears that water issues in the Floridan aquifer region have not yet robustly entered public consciousness; therefore, tendencies toward water partisanship can largely go inactivated. However, as water issues become more intrusive in people's lives, either in ways that are directly observed or through media coverage, it is likely that the public will become increasingly engaged with water topics. Expanded engagement has the potential to activate new water partisanship along with an obstructive water science communication problem.

Though this study was conducted in two states with specific water challenges, the subtopics on which a potential water science communication problem was observed are not region specific. On broader regional and national scales, there is risk that water could take on the stifling characteristics of other issues if and when water discourse and water policy increase in prominence. Despite the risk, there is reason for optimism because positions on water issues do not yet appear to be ingrained in national partisan identities in a manner comparable to the climate science communication problem. Thus, the findings of this study should not be read as a foretelling of a politically divided water future, but rather as early warning signs of the divided future that could develop if intervening measures are not taken. Through the use of communication framing that purposefully associates water security measures with the values and motivations of the political right, it may be possible to alter the automatically triggered positions that, at present, cause the political right to deviate from their perceptions of scientists' beliefs (Feinberg and Willer, 2013; Wolsko et al., 2016).

Lines of research that should be considered in the development of framing interventions include Kahan et al. (2011) theory of cultural cognition and Haidt's (2012) moral foundations theory. Studies using these models have demonstrated, for example, that presenting environmental protection as an act of patriotism or as a means to protect the purity of natural resources can yield relative parity in policy support between the political left and the political right (Feinberg and Willer, 2013; Wolsko et al., 2016). Other studies have found that the identity of the message communicator (a Republican spokesperson, for example) can increase framing effectiveness (Bolsen et al., 2019; Hartman and Weber, 2009). While these approaches have been used in past research primarily with the objective of reducing division on highly polarized topics, the models could prove even more effective as a means to minimize the initial escalation of partisanship. "Inoculation" studies have demonstrated that through preemptive exposure to anticipated persuasive appeals, individuals can guard themselves against polarizing messages (Banas and Rains, 2010; Compton et al., 2021; van der Linden et al., 2017). Moreover, inoculation interventions can have pass-along effects, in which resistance spreads beyond those who directly received preemptive exposure (Compton et al., 2021). If framing interventions are utilized early to limit partisans' association of water science with politically undesirable outcomes, there may not be a need to address severe water partisanship as water issues become more pronounced.

Productive interventions can also be designed to improve water science knowledge. When partisan positioning did not interfere, the public indicated personal beliefs aligned with what they perceived scientists' to think. This tendency was most apparent on the topic of fertilizer as a pollutant, where the vast majority of respondents, across political orientations, accurately identified scientifically endorsed fact and indicated personal beliefs that aligned with that fact. However, the OWSK assessment results indicate that the public does not possess the ability to discern scientific consensus on most water topics.

Environmental issues are distinct from other social issues (such as equal pay and zoning restrictions) in that they are more directly rooted in science (Fischer, 2000). Therefore, a base level of scientific understanding is often necessary for citizens to engage in deliberation about the environmental decisions that affect their lives, such as how water resources are managed. While participation is a democratic ideal, the result of increased participation can be amplified conflict and confusion if attention is not also paid to trust and community building (Jasanoff, 1996). One technique for fostering the simultaneous development of knowledge, trust, and community is the use of inclusive processes that involve stakeholders of all types in knowledge development and decision making (Fischer, 2000; Horlick-Jones, 1998). In contrast to top-down knowledge dissemination approaches, inclusive processes also have the benefit of increasing scientists' awareness and appreciation of the public's experiential knowledge, the incorporation of which can improve the selection, implementation, and acceptance of water policy measures (Burgess et al., 1998; Jasanoff, 1999; Thompson and Rayner, 1998). Participatory processes are not merely a way to demonstrate inclusiveness, but a means to maximize knowledge among scientists and stakeholders alike. Returning to our earlier remarks on culture, Barth argues for "knowledge as a major modality of culture" (2015, p. 66) in which groups of people possess distinct insights into topics such as water challenges. Thinking of culture as knowledge emphasizes openness and inclusion as a way to embrace others as knowledge producers (Barth, 2015).

Studies of the public's mental models of regional water processes and issues may further aid in the development of OWSK interventions. Conceptual Content Cognitive Mapping (3CM) is one approach for revealing how individuals think about complex processes, including the items present and absent in their conceptions, and the connections between those items (Kearney, 2015). With this information, specific water knowledge gaps and scientific misconceptions can be identified. 3CM can also reveal differences between groups that could inhibit effective communication. For example, a 3CM analysis of environmentalists' and agricultural producers' mental models of the relationship between water and economy in the Floridan aquifer region exposed areas of false conflict between the groups (Hundemer and Monroe, 2020). The analysis further suggested how increased exposure to specific topics could improve cross-group understanding and cooperation toward shared goals.

As water science knowledge and belief interventions are developed, additional consideration of the differences between rural and urban audiences may be warranted. Participants in this study, 85.2 percent of whom resided in metropolitan counties, performed best on OWSK topics that have direct relevance to the metropolitan experience, such as water movement in urban environments and residential water conservation. We may, therefore, expect rural residents with different life experiences to exhibit higher than average scientific knowledge on topics such as agriculture and rural living. Residents of rural and urban areas may also be affected in different ways by changes in water quality, water availability, and water regulation, which may influence their water beliefs. The data from this study could be used as a starting point for examination.

Due to geographic location, limited economic resources, and limited access to power, socio-economically vulnerable groups may experience more detrimental impacts from water challenges than the average individual and have more difficulty adequately responding to those challenges (Allen et al., 2006; Weisner et al., 2020; Wescoat et al., 2007). Limited political influence also makes it less likely that the concerns of these groups will be reflected in policy discourse. Therefore, as interventions are developed, particular care should be taken to incorporate the perspectives of those who may be acutely impacted but less heard.

Finally, as steps are taken to combat a potential water science communication problem and to increase the ability of the public to participate in water policy, care should be taken to protect the perceived legitimacy of water science (Keohane et al., 2014; Lackey, 2007; Nisbet, 2016). Science will not be perceived as neutral ground to which all parties can refer if it is used to coax people toward a "right" outcome. It has been suggested that climate science has been rejected, in part, because science rather than social values has been used to justify policy action (Campbell and Kay, 2014). By presenting climate action as the "right" scientific decision and not instead presenting climate policy as a value decision for which society must weigh competing economic, ecological, and altruistic costs and benefits, communicators left little space for those who were solution averse to express their discontent beyond challenging the science itself (Campbell and Kay, 2014). On water topics, communicators can help preserve scientific legitimacy, and thereby reduce the potential for a water science communication problem, by creating space for value debate and situating science as a tool for quantifying and predicting the implications of alternative courses of action.

## 7. Conclusions

Evaluation of the alignment between individuals' personal water beliefs and their perceptions scientists' beliefs indicated a possible water science communication problem in Florida and Georgia that may exist at broader regional and national scales. Sampled residents of Florida and Georgia were generally not well informed on regional water issues; however, they indicated personal beliefs that aligned with their perception of scientists' beliefs on those topics that did not require them to counter inclinations associated with political orientation. Partisan inclinations appeared to be easily triggered and carried the potential to usurp the influence of scientific knowledge. These findings suggest that water has the potential to become an increasingly partisan topic if intervening measures are not taken before water positions become inflexibly associated with partisan identity.

*CRediT authorship contribution statement*

**Sadie Hundemer:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Funding acquisition. **Martha C. Monroe:** Methodology, Writing – review & editing, Funding acquisition. **David Kaplan:** Methodology, Writing – review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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