Investigating the Complex Nature of Power in Water Governance: A Framework for Incorporating Typologies of Power Into the Study of Socio-Hydrological Systems

by

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Dedication

To my parents, Flavia and Amando, as a testament to the fruits of your perseverance and sacrifice. Your struggle and love provided me with the opportunities and capacity to thrive and live a life of my own choosing.

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Para mis padres, Flavia y Amando, como testamento al fruto de su sacrificio y perseverancia. Su lucha y amor me otorgaron las oportunidades y la capacidad de florecer y forjar mi propio camino.

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Abstract

Climate change disruptions on water systems increasingly jeopardize our ability to satisfy current and future water needs of society and the natural environment. Fostering adaptive and resilient water systems will require a transition away from inflexible governance approaches. The organizations tasked with governing water continue to face challenges implementing bold climate adaptation strategies that can mitigate the negative impacts of climate change for most water users. Several factors limiting transitions to adaptive and sustainable water governance include centralized decision-making systems and path-dependencies that lock policy makers into unsustainable approaches. Additional challenges arise from the uncertainty and complexity inherent to human-water systems.

Substantial transitions to adaptive governance approaches have failed to materialize, despite progress establishing collaborative and participatory governance systems. Researchers in the environmental governance and climate adaptation literature are increasingly paying attention to issues of power and how it curtails adaptation efforts. Existing research has typified the power dynamics that occur within specific governance systems. However, there is little research exploring how different types of power influence system-wide environmental outcomes as they cascade through the complex links of human-water systems.

This dissertation describes an interdisciplinary approach to analyzing the role of power dynamics on climate change adaptation strategies pursued by the collaborative river basin organization (RBO) of the Piracicaba, Capivari, and Jundiaí (PCJ) Rivers in South-East Brazil. Here I lay the groundwork for systematically exploring how different types of power deployed

within water governance organizations may impact system-wide social and environmental outcomes. The second chapter provides a theoretical framework for investigating the complex effects of power in water governance by combining existing frameworks for studying socio-ecological systems with theories of power.

Chapter three describes how decision-makers' knowledge and worldviews play an important role in determining the strategies considered to tackle pressing challenges. I analyzed qualitative data from semi-structured interviews with members of the PCJ RBO discussing their views on the basin's primary challenges and potential solutions. Results show that RBO members associated with engineering backgrounds view insufficient water supply as the basin's primary issue and large infrastructure investments as the only viable solution.

In Chapter four, I use a mixed-methods approach combining semi-structured interviews and short behavioral experiments to estimate water rationing patterns and relate said patterns with the PCJ RBO's overarching investment policies. Results identify municipal users as water recipients and industrial users as water donors as total availability decreases. This pattern, combined with future investments focused on sanitation projects, raises questions about the increased vulnerability of water users who will donate water during times of scarcity.

Finally, chapter five outlines avenues for future research translating the empirically derived insights about water rationing patterns and preferences over policy alternatives into typologies of power. These typologies of power can, in turn, define the decision rules guiding water allocation and investment decisions used to model policy implications on socio-ecological systems.

This dissertation provides a framework for explicitly analyzing the subtle connections between power and agency in water governance and the strategies deployed to cope with climate change impacts. Moreover, it presents an example of the interdisciplinary work required to inform research analyzing complex dynamics and provide a theoretical framework to guide empirical research on power in water governance.

Chapter 1. Introduction

1.1. Research Overview

Water governance decisions have consequential impacts on the survival of ecosystems and the equitable distribution of water among its users. Some of the challenges associated with sustainable water governance stem from the complex nature of human-water systems. Water governance decisions can have a multitude of unanticipated consequences that cascade through time and socio-ecological scales. The transition to systems thinking and the use of socio-ecological systems (SES) frameworks to analyze human-nature interactions have provided important insights on the complex connections between humans and their natural environment (Cumming & Peterson, 2017; Österblom & Folke, 2013). However, significant challenges remain for the successful implementation of sustainable water governance policies, especially in terms of climate change adaptation and mitigation. Recently, there has been increased attention on the need to understand issues of power in natural resource governance as a key factor curtailing the transition to sustainable governance systems (Voss & Bornemann, 2011).

Power is present in all aspects of water governance, influencing which users have access to water, the amounts available for use, and the efforts made to prevent disruptions caused by climate change impacts, to provide a few examples. Regardless of the structure of a water governance system (e. g. centralized, collaborative, or polycentric), power will be exercised by participants based on different individual priorities, worldviews, and relative influence. The exercise of power will also vary based on the structure of the governance system itself. A water governance system determines which individuals are allowed to participate in decision-making processes, defines the spaces where decisions will take place, and the rules and practices guiding decision-making. Analyzing system-wide effects of power can be challenging given its ubiquitous presence in water governance and the multiple ways power can be exercised within any given system. Existing typologies of power, such as the one proposed by Morrison et al. (2017) defining three salient categories of power (i.e. power by design, pragmatic power, and framing power), provide a theoretical foundation for systematically analyzing the outcomes of different types of power being deployed in water governance.

This dissertation provides an interdisciplinary framework for studying the cascading effects of power dynamics in environmental governance. The dissertation builds upon existing combined frameworks for analyzing power in environmental governance, see (Brisbois, Morris, & de Loë, 2019), and current efforts for formalizing aspects of the SES research that can facilitate comparative analysis of empirical research, see (Hinkel, Bots, & Schlüter, 2014). The proposed framework adds to current research approaches by providing a direct link between formal definitions of power and the complex socio-environmental outcomes that are the focus of SES research and modelling. In sum, this framework provides an avenue for systematically incorporating issues of power, based on theoretically rather than *ad hoc* definitions of power, into SES modelling. In this sense, the proposed framework may facilitate ongoing efforts to connect theoretical research on environmental governance with the empirical research of SES taking place worldwide.

It is worth noting that the typologies of power presented by Morrison et al. (2017) are not proposed as the only formal definitions of power that could be combined with SES research frameworks, rather as an example of the possibilities held by relying on formal definitions of power. Ultimately, theoretically grounded typologies of power provide a guide for empirical research investigating power dynamics within specific governance systems. Discerning relevant types of power affecting governance outcomes requires an in-depth knowledge of decision-makers' policy priorities, perceptions of key issues, water allocation strategies, general attitudes towards risk, along with any relevant biases or preferences for certain governance approaches. A realistic understanding of a governance system can be derived using qualitative and quantitative research methods such as interviews, participant observation, and behavioral experiments.

This dissertation presents research conducted with the aim of identifying relevant power dynamics influencing governance outcomes at the Piracicaba, Capivari, and Jundiaí River Basin (PCJ River basin) and mapping them onto formal typologies of power. Results from empirical research conducted in the Piracicaba, Capivari, and Jundiaí River basin Committees (PCJ Committee), the collaborative organization in charge of the PCJ River basin, provide the foundation for explicitly incorporating power dynamics into the analysis of the decisions made by collaborative river basin organizations. This dissertation presents a case study example of the research on the power dynamics influencing water allocation and climate adaptation policies in the PCJ River basin. The PCJ River basin provides a clear example of the disruptive and multifaceted impacts that climate-driven extreme events can trigger. The PCJ River basin in the South-Eastern State of Brazil, São Paulo, has experienced extreme drought events twice in the previous decade. The extreme drought of 2014-2015 resulted in significant disruptions to economic activities, energy production, fish die-offs, and jeopardized water access for millions of people, including approximately 5 million people along the PCJ basin and 9 million people in the São Paulo Metropolitan Region. Given the high stakes associated with future water disruptions in the region, we must explore and understand how existing power dynamics at play in the PCJ Committee may be curtailing climate adaptation efforts and unintendedly reinforce the vulnerability of certain water users to climate change impacts.

1.2. Summary of Dissertation Chapters

Chapter two presents an interdisciplinary framework for exploring the influence of power in socio-hydrological systems. I incorporate the typologies of power recently developed by (Morrison et al., 2017) with the well-established action-arena and SES frameworks first presented by (Ostrom, 2007, 2009). This combined framework provides a foundation for exploring the cascading effects of different types of power across its social and ecological spheres using recent approaches to explore complexity in SES using ABMs (Schlüter et al., 2019), see Figure 1.

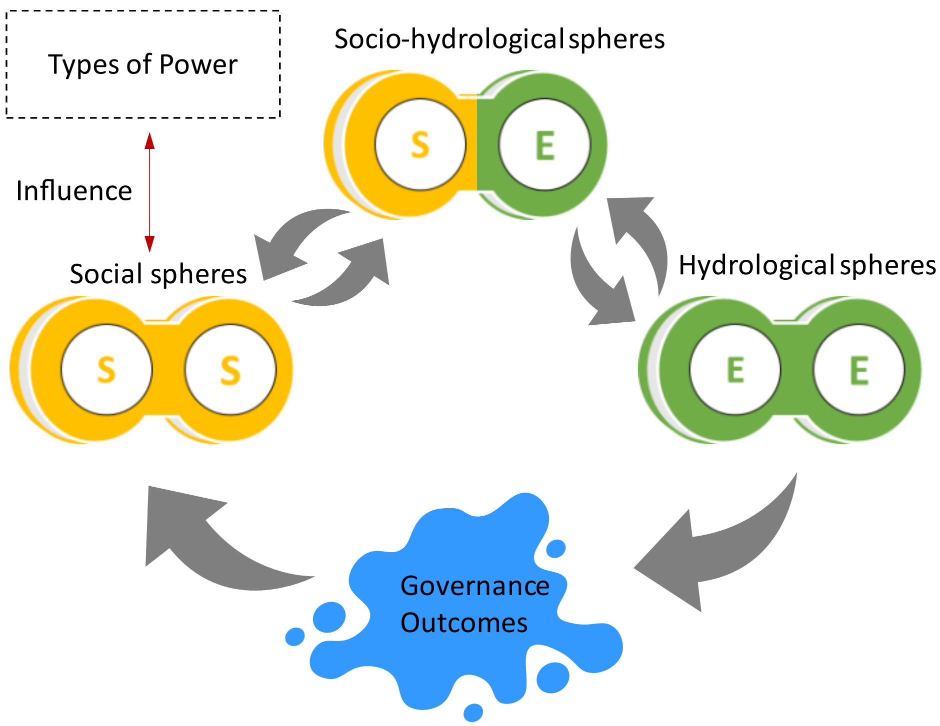

Figure 1. Exploring power dynamics using a combined IAD and SES framework.

Chapter three explores how the ways-of-knowing (WoKs) of technical experts participating in the PCJ Committee may be contributing to the PCJ basin's overreliance on grey-infrastructure approaches for dealing with climate change issues. In this sense, this chapter provides insights on the invisible, and subtle, dynamics that hamper climate change adaptation efforts in river basins across the world. A decision-maker's WoKs are the combination of values, beliefs, perceptions, and backgrounds that individuals draw from to assess issues at hand (Ingram, 2006). WoKs can have an important influence on overall planning strategies as they affect how individuals frame issues and advocate for certain courses of action, thereby limiting the range of options considered. I use qualitative data from 27 semi-structured interviews with active PCJ Committee members inquiring about interviewees' perceptions about the basin's main priorities, the impacts of climate change, and the best solutions to deal with these issues. I highlight the connection between the prevalence of Committee members with engineering WoKs and the overall perception of grey- infrastructure projects as the only viable solution to the basin's water security issues.

Chapter four explores the connections between water rationing strategies, planning policies, and the vulnerability to extreme events of different water users in the PCJ River basin. Brazilian law mandates the provision of drinking water for humans and cattle as the number one priority in times of water scarcity. Brazilian legislation, however, does not specify a water rationing order for other water users. The responsibility of defining water rationing policies falls onto river basin committees and their technical experts. I perform a mixed-effects model using results from short behavioral experiments about the water allocation strategies chosen by PCJ Committee members to estimate a water rationing order for the basin's water users. Results let us identify water users who function as primary water recipients and water donors as water availability decreases. Furthermore, I relate the implications of these water rationing patterns in terms of vulnerability to extreme events with the expected benefits of the basin's planned investments for the next 15 years. Overall, I found that the existing focus on traditional infrastructure projects is consistent with Brazil's approach to guaranteeing water security for municipal users. However, the focus on traditional infrastructure may result in an increased vulnerability of industrial, agricultural, and environmental users if extreme events become a more frequent occurrence and estimated water rationing patterns remain constant. Overall, shedding light on the implicit tradeoffs associated with water governance decisions can assist researchers and practitioners assess the unexpected costs associated with climate adaptation and risk mitigation strategies in river basins.

Finally, chapter five includes a short discussion on the limitations of the empirically derived data and presents an overview of future research. Information about prevalent WoKs and perceptions about the validity of certain management approaches (e. g. traditional infrastructure vs. nature-based solutions) will inform not only the likelihood with which a specific project will be implemented but whether certain projects will be considered at all. These empirically derived insights set the stage for exploring the cascading effects of the practice of power, interpreted as the ability to shape policy strategies and the ability to avoid water rationing measures, in the PCJ River basin's ability to mitigate the worst effects of climate-driven disruptions.

Chapter 2. Unraveling Power Dynamics in Water Governance

2.1. Abstract

Governing water resource sustainably requires balancing the needs of the environment with those of social and economic actors constantly exercising power to secure resources. Power dynamics present challenges for equitable and sustainable water governance as current decisions may have unforeseen ramifications across social, geographical, ecological, and temporal scales. In this review we argue that capturing the complexity surrounding power and water systems can be done with assistance from computational tools such as agent-based models (ABMs). ABMs are particularly well suited for this task due to their flexibility, which facilitates the study of power's influence on governance outcomes under different governance structures (e.g., centralized, decentralized, or polycentric), across geographical scales, and varying degrees of participation from social actors. We present a framework for incorporating power dynamics to ABMs that explore the cascading social and ecological outcomes of power in water systems.

2.2. Introduction

Society derives countless benefits from natural systems. These benefits range the material, such as food, water, and energy, to the intangible such as creating and building on the means for achieving well-being, and ecosystem health. The key role of natural systems for our survival highlights the importance of understanding the intricate ways in which human and natural systems are connected. Our actions can foster the protection of natural systems (Gerst, Raskin, & Rockström, 2014; Otto et al., 2020; Springmann et al., 2018) or their degradation (Clift et al., 2017; Rockström et al., 2014; Steffen et al., 2015). For the past few decades, empirical studies of socio-ecological systems (SES) have provided important insights on the complex dynamics that connect humans to their natural environment and vice versa (Cumming & Peterson, 2017; Österblom & Folke, 2013). This focus aligns with the emergence and consolidation of systems thinking in environmental research and has been instrumental in transcending the pursuit of "simple solutions" to embrace the complexity inherent to environmental problems (Ostrom & Cox, 2010). Despite significant advancements in our understanding of SES, we continue to face great challenges in stopping environmental degradation, depleting freshwater resources, reducing carbon emissions, and implementing climate change adaptation and mitigation strategies. While many challenges are at play, researchers are increasingly focusing on power as a key factor contributing to enabling or precluding necessary changes for sustainable governance (Voss & Bornemann, 2011).

A fundamental way in which power materializes in natural resources governance is by determining access to natural resources. Access to natural resources, or lack thereof, has a tremendous impact on the ability of individuals and countries to satisfy their needs and pursue economic development. Given their importance, different social groups (at local, national, or global scales) have strong incentives to control or influence the process through which natural resources are allocated, enhancing the importance of power. Power in natural resource governance is constantly being deployed both by those within and without the jurisdictional and organizational mandate to govern natural resources. Power in complex SES, however, can impact socio-ecological dynamics that go well beyond the direct or short-term control of a natural resource. Governance decisions today may have effects across time and scale that may not be fully realized until decades into the future. Governance decisions have the potential to alter the broader power structures and balance between groups actively trying to influence the governance process. The iterative and dynamic relationship between power and SES emphasize the importance of understanding the main mechanisms through which power is deployed in governance systems and generates system-wide dynamics. To explore these mechanisms, this paper focuses on how we can study the influence of power on the governance of water.

Freshwater plays a vital role in sustaining human societies and ecosystems. A wide range of human activities such as food production, sanitation, economic activities, and energy production depend on access to water. Hence, understanding how power can affect society's efforts to ensure more sustainable and equitable water management is crucial, especially as climate change threatens freshwater supplies worldwide. The exercise of power in water governance is a key factor determining societies' access to water now and in the future. Those participating in a governance system are constantly making consequential decisions over water storage, quality, distribution among social groups, and the mechanisms necessary to deal with water crises. Decisions can be made in decentralized, participatory, or collaborative governance systems by decision-makers with different individual priorities, worldviews, and relative power. As decision-makers try to advance their agendas, i.e. exercise power, their interactions may result in unexpected system behavior, such as, for example, increased costs of wastewater treatment associated with water conservation policies (Schwabe, Nemati, Amin, Tran, & Jassby, 2020). In this sense, power is a social component intricately linked with the complex dynamics of water systems. To explore this complexity, computational modelling tools such as agent-based models (ABMs) can help tackle research challenges associated with understanding cross-scale impacts of ever-evolving social phenomena like power in governance (Lippe et al., 2019). ABMs have helped make significant contributions to the study of ecological systems, both in disciplinary studies (DeAngelis & Diaz, 2019; Grimm et al., 2005; Matthews, Gilbert, Roach, Polhill, & Gotts, 2007) and in the field of socio-ecological systems (An, 2012; Kremmydas, Athanasiadis, & Rozakis, 2018). ABMs are particularly well-suited for analyzing power dynamics between agents within governance systems, as they were designed to explore issues of "complex causation, emergence, and socio-ecological intertwinedness" (Schlüter et al., 2019).

Here, we present a framework for investigating the role of power dynamics across different arenas of a hydro-social system. In the following sections, we provide an overview of research approaches to power and governance identifying useful frameworks to inform the design of ABMs. We briefly review how ABMs have been used to explore water governance issues and provide a conceptual model for explicitly modelling power within a governance system. We highlight some of the key relationships that can be explored with ABMs of this nature and conclude with some final considerations for advancing the study of power in water governance using ABMs.

2.3. An Interdisciplinary Framework to Research Power in Water Governance

2.3.1. Characterizing water governance systems and their power structures

Power is a relational phenomenon through which individuals or groups within society exhibit agency in response to their desires, interests, and behavior. Power is exercised in the personal sphere, in political arenas, and public life. As an intrinsically social phenomena, power in environmental governance is highly context dependent. Structures of power will vary within and across regions, cultures, and even the type of natural resource being governed. Despite contextual variations, power can be systematically analyzed using well-established theoretical frameworks. A wealth of studies have investigated power with a focus on the means through which people or groups exercise power over one another (Bourdieu, 1977; Collier, 2009; Foucault, 1995; Foucault, Senellart, Ewald, & Fontana, 2007; Hedström & Swedberg, 1998; Lukes, 1974, 2005). These studies have developed typologies of power that describe the mechanisms for the exercise of power (Foucault, 1995; Lukes, 1974, 2005), and the dynamics that determine who participates, and to what degree of success, in decision spaces (Gaventa, 2006).

One main criticism of investigations of power through an individual lens, however, is that it neglects the role of social structures in facilitating the exercise of power. In response, the realist approach to the study of power focuses on the interactions between individuals and social structures. A strength of this approach is that it engages with the tension between individual agency and the social structures that curtail it (Raik, Wilson, & Decker, 2008). Research following this this school of thought highlights the lack of a strict dichotomy between agency and social structures (Giddens, 1984) and the fact that individuals can change social structures over time (Isaac, 1987). Despite this strength, (Agrawal, 2005) cautions against overestimating the importance of people's interactions with social structures by highlighting the artificial nature of the identities and interests assigned to people for research or analytical purposes. In doing so, he points out the need to tease out the different ways in which individual or social aspects of power influences water governance outcomes, a process that requires frameworks that can provide nuance to the analysis. For instance, scholars of biopolitics emphasize the role of narratives deployed by government and multi-national organizations in determining who gets access to critical resources like water (Bakker, 2012). Meanwhile, several scholars have expanded on Elinor Ostrom's (2005; 2011) influential Institutional Analysis and Development

(IAD) framework to incorporate notions of power. For example, Whaley and Weatherhead (2014, 2015) incorporated definitions of power presented by Lukes (1974) with Clement's (2010) politicized IAD to analyze the co-management of water for farming in England. Meanwhile, Brisbois et al. (2016; 2019) argue for incorporating theories of power, such as notions of instrumental, structural, and discursive power proposed by Lukes (2005) to investigate issues of power in collaborative governance. Finally, Morrison et.al (2017, 2019) propose a framework that builds on an institutional approach to power highlighting the interconnections between rules, norms, and practices with individual behavior in the exercise of power.

The rationale for combining multiple frameworks, particularly the IAD and SES frameworks, when analyzing the complexity of environmental governance is to mitigate the analytical limitations of using each framework individually. The IAD framework defines action-situations as the locus of governance analysis. Action-situations can refer to the spaces where actors' choices impact outcomes, the spaces where actors' choices determine the rules that guide the practice of decision-making, and the spaces where who is a legitimate actor to engage in the decision-making process is determined (Cole, Epstein, & Mcginnis, 2019). Meanwhile, the SES framework focuses on understanding the dynamics underpinning the relationships between the social and ecological components of a system. In the case of water governance, Kadirbeyoglu and Özertan (2015) used a combined IAD-SES framework to explore the influence of power in decentralization of irrigation in Turkey. Meanwhile, Garrick et al. (2018) also used a combined IAD-SES framework to incorporate risk for drought adaptation in transboundary river basins. Scholars have recently argued that transcending the limitations of any individual framework is key to understanding nuanced and overlapping dynamics, such as the co-evolution of institutions

(Epstein et al., 2020) and the effectiveness of regimes in polycentric governance systems (Tiffany H Morrison, 2017).

Using frameworks capable of systematically analyzing polycentric governance systems is key given the explosion of Integrated Water Resource Management (IWRM) initiatives and other decentralization process that have occurred worldwide in the past half century (Commission, Bsik-ccsp, Systems, Resilience, & Uk, 2021). Polycentric governance systems are characterized by multiple autonomous decision centers with overlapping jurisdiction over the subject they govern (E Ostrom, 2005). Based on their structure and functioning, polycentric governance systems are intended to foster policy innovation and diffusion, increase capacity to adapt to social and environmental change, and provide a good platform for governing complex natural systems (Carlisle & Gruby, 2017; Jordan, Huitema, Schoenefeld, van Asselt, & Forster, 2018; Lebel et al., 2006). Despite their increasing prevalence, the elements determining successful polycentric systems are not straightforward (Carlisle & Gruby, 2017). This can be partly driven by the generality of the polycentric governance framework, but it is also due to the complex nature of human-natural systems. The exact structure of a polycentric governance system is highly context dependent, making it difficult to identify causal relationships between a governance structure and environmental outcomes that will be common across different contexts. Of particular interest are the problems associated with identifying the causal mechanisms between social behavior (like exercising power) and environmental outcomes. We argue that Morrison et.al. (2017, 2019)'s framework is well suited to be coupled with a SES systems approach to explore the intertwined interactions between the individual and social aspects of power in water governance.

The exercise of power determines who, when, and how people receive water. It also determines who gets excluded from access to water (Hellberg, 2018). Existing research on water governance and power provide useful theoretical insights for incorporating these dynamics into ABMs. For example, scholars of biopolitics emphasize the Foucauldian nature of water governance where control and use of water resources is guided both by formal regulations and by self-policing practices braided into society (Bakker, 2012, 2013). At the same time, power dynamics influence who participates in decision-making, which issues are priorities, and which solutions are implemented (Almazán-Casali, Puga, & Lemos, 2021; Gaventa, 2006). From an institutional perspective, power affects the practice of governance by informing the rules, norms, and practices of those participating in governance systems (T. H. Morrison et al., 2017, 2019). Three categories of power are defined by Morrison et.al (2017) as follows:

1. Power by design constitutes the "[f]ormal authority with capacity to make rules, allocate resources, undertake structural adjustment, redesign markets and administrative structures, to tax, and regulate resource use and externalities."
2. Pragmatic power refers to the "[p]rimarily informal authority with capacity to interpret, certify, and monitor rules, influence other actors, control information, to 'govern by doing' through the day-to-day implementation of governance mechanisms."
3. Framing power consists of the "[o]ften invisible authority with capacity to develop codified rules and knowledge, to frame problems, construct issues and set norms."

Among these categories, pragmatic power and framing power are particularly relevant when trying to understand the subtle ways in which participants in decision-making bodies can have large or unexpected influence over governance outcomes. Power by design, although it can also have an unexpected influence on governance outcomes, is generally more explicit and easier to identify than pragmatic and framing power. Examples of power by design include governance arrangements granting authority over natural resources to specific government agencies or legislation that grants certain groups or populations priority for the use and access to natural resources. Meanwhile, framing power relates to the ability of individuals, institutions, or organizations to direct conversations about problems and the process to address them while pragmatic power is deployed through influence on day-to-day decisions (T. H. Morrison et al., 2017).

Notions of pragmatic and framing power can be related to decision-biases and worldviews in the sense that the worldviews held by those with the ability to exercise these types of power may become the dominant in a governance system. For example, framing power can determine the type of knowledge considered valuable or credible by those governing natural resources and therefore used to make decisions (Lejano & Ingram, 2009). Framing power can also directly inform which issues are deemed as most pressing along with the best available solutions to address them. This implicitly assigns a comparative advantage to those who hold the knowledge and abilities closely associated to the narratives informing problems and solutions. In this sense, framing and pragmatic power are intricately related as individuals who can present themselves as experts will have more opportunities to influence day-to-day decisions and continue to place their expertise and group interests at the forefront of governance decisions.

A key aspect of Morrison et.al (2017, 2019)'s power framework that makes it well suited for coupling with a complex system approach is its emphasis on the relational and iterative notions of power. Power balances can shift, sometimes dramatically, among the actors participating in environmental governance systems. The systemic and long-term effects of such shifts can be unpredictable, making them excellent candidates for scenario analysis and "in silico" experiments (i.e., computer simulations) using complex system approaches like ABMs. This is of particular importance if we consider the potential effects on governance outcomes arising from sudden changes in dominant narratives and power shifts between people with contrasting worldviews and priorities. Thus, ABMs that seek to explore issues of water governance need to consider the role of power and institutions in determining who becomes a decision-making agent.

2.3.2. Current use of ABMs in governance research

ABMs are an extremely flexible computational tool for modeling systems (Bonabeau, 2002). Their flexibility stems in part from the simplicity of its building blocks. As the name reveals, ABMs model the behavior of agents: independent individuals with agency who interact with their environment following a series of decision rules. The focus on agents facilitates model scaling by simply adding or removing the number or types of agents interacting in a model. This focus also facilitates incorporating heterogeneity, as agents can be assigned a wide range of characteristics or independent decision rules. ABMs' greatest strength, however, are their ability to capture system emergence (i.e., the outcomes that cannot be predicted by analyzing individual decision rules in isolation). ABMs have been widely used over the past two decades to explore system dynamics in a wide range of scientific fields including biology, epidemiology, the social sciences, geography, and ecology.

Within water SES research, there are several examples of ABMs being used to analyze issues of water access, risk management, governance structure or the influence of social norms and practices. For example, Schlueter & Pahl-Wostl (2007) used an ABM to explore the effects of a centralized vs decentralized decision-making regime on the resilience of a semiarid river basin. The authors found that although neither model outperformed the other in all scenarios, a decentralized model was more resilient when assumptions about behavior and resource availability were relaxed. Bellaubi & Pahl-Wostl (2017) used an ABM based on principle-agent theory to explore the influence of corruption and water management practicies on the performance of municipal water delivery systems in Ghana and Kenya. Their research highlighted the influence of strong social ties between relevant agents in the water systems and increased risk of corrpution and opportunistic management practices. De Caro et al. (2017) provide a framework for analyzing environmental governance through a lens of social cognition and decision-making, with a particular focus on adaptive governance in response to climate change. Meanwhile, researchers have used Bayesian inference to model agents risk perceptions in water decisions at the San Juan River basin in New Mexico, USA (Hyun, Huang, Yang, Tidwell, & Macknick, 2019). Some models include participatory components to calibrate or validate models. For instance, Shelton et al. (2018) modeled household behavior regarding water access in an underserved neighborhood of Mexico City. Their research took a participatory approach to validate their model, including a role-playing game with modeled households to assess the performance of the model and ways to improve it. Meanwhile, Daré et al. (2018) used a participatory agent-based model on river bank management. Others developed theoretical ABMs exploring the resilience of social norms as drivers for cooperation in water allocation decisions under climate change stressors such as increased water scarcity (Nhim, Richter, & Zhu, 2019).

ABMs also provide insights into the complex effects of individuals as they access and use water. A significant portion of ABMs are used as decision-support tools. As such, they focus on increasing the quality of information available to decision-makers or improving decisions by reducing the influence of decision-biases and providing opportunities to practice decision-making under uncertainty. However, researchers emphasize the need to improve the reliability of depictions of human decision-making by using more accurate cognitive and decision-making rules (Conte & Paolucci, 2014; Scalco, Ceschi, & Sartori, 2018), and relying on established theoretical models about decision-making rather than ad hoc rules specific to each ABM (Groeneveld et al., 2017). Most of existing research in water governance using ABMs focuses on modelling individual decision-making over water access (Shelton et al., 2018), irrigation decisions (Nhim et al., 2019), fisheries management (Lindkvist et al., 2020), and management of exposure to risks such as flooding or erosion (Daré et al., 2018), to name a few. As such, these models focus on the outcomes of decisions taken within a given governance system rather than the mechanisms underpinning the governance system itself.

Researchers have begun modelling how the structure of water governance systems determine a variety of system-wide outcomes. Qin et al. (2019) used an asymmetric bargaining model incorporating information on social, economic, and political aspects to investigate water distribution decisions in the Euphrates River basin. Bitterman and Koliba (2020) explored how different collaborative governance structures affect non-point pollution control outcomes in the Lake Champlain Basin. These examples highlight ABMs' potential for modelling the intricate, and oftentimes subtle, dynamics of governance systems including power.

2.3.3. Integrating power into water governance research using ABMs

Figure 2 presents a power-centric framework for studying water systems. Our framework incorporates recent conceptualizations of power in governance (Morrison et al., 2017) with the well-established action-arena framework (Ostrom, 2007, 2009) and recent approaches to explore complexity in SES (Schlüter et al., 2019). The combination of these frameworks provides a foundation for exploring how different expressions of power influence the complex dynamics of a SES across its social and ecological spheres. Our framework considers the usual four components of a SES: governance, systems, actors, resource units, and resource system. For illustrative purposes, we describe a hypothetical river basin as the resource system and the water volumes associated to different water uses as the resource units.

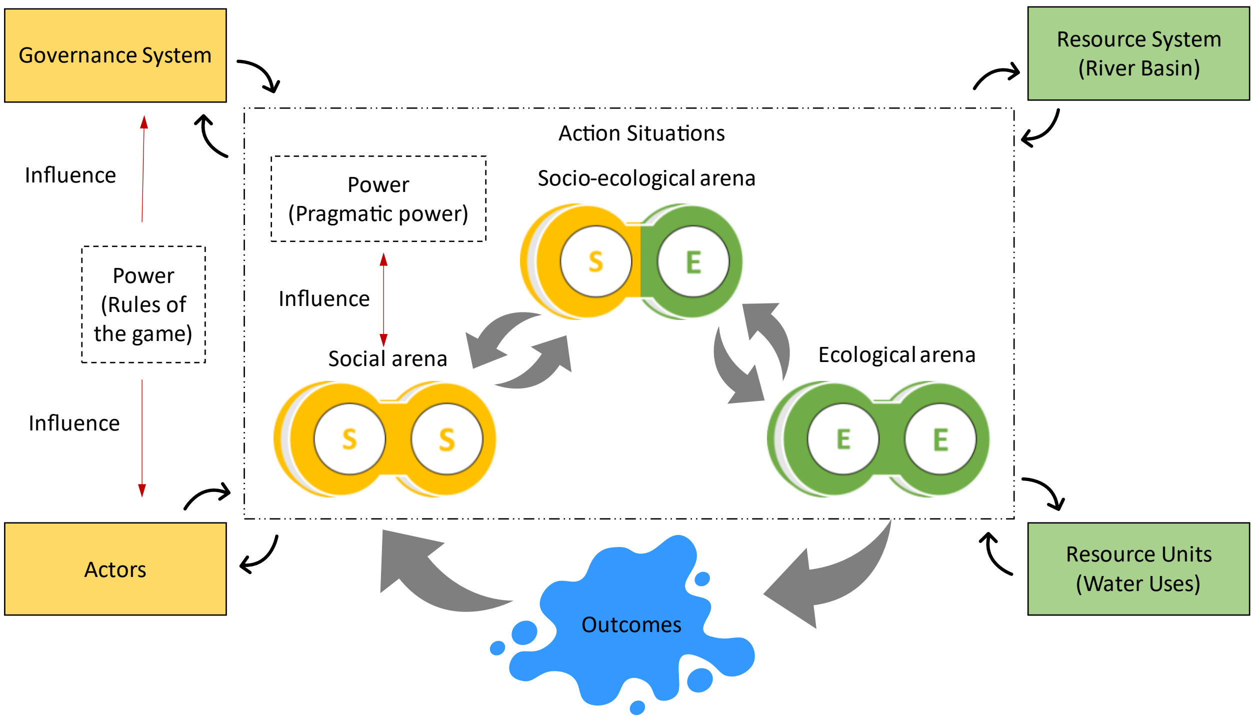

Figure 2. A power-centric framework for modelling water governance using agent-based models

In this system, interactions take place in three types of arenas: a purely social arena, a socio-ecological arena, and a purely ecological arena. The social arena is the space were actors advance their interests by participating in the organizations established by governance systems. Purely social arenas are the governance spaces where most of the high-level decision-making takes place. Actors attempt to advance their interests in the governance organizations and structures they can access by using available resources, formal or informal, to influence policy and overarching governance goals.

Socio-ecological arenas refer to the spaces where the human and ecological systems interact directly. In the case of river basins, these arenas may refer to large physical structures or economic activities and sectors (usually the aggregate of small individual interactions). Examples of large arenas include dams, hydropower plants, large irrigation infrastructure, municipal water sanitation and treatment plants, natural protected areas, or protected springs. Socio-ecological interactions associated with economic activities are usually the aggregate result of individual interactions such as municipal water use, water transportation, industrial activities, small-scale agricultural water withdrawals, or fishing. Purely ecological arenas refer to the spaces where the biophysical components of a river basin interact with one another. This includes aquatic species, floodplains, precipitation, river flows, water chemistry, or riparian buffer zones, to name some examples.

As in any SES, interactions in one arena impact the dynamics of the others and the actors in charge of the system's governance will track outcomes comparing them to their overall goals and objectives. Our framework focuses on two ways in which power influences the system: by determining eligible actors and the rules for participating in the decision-making process, and by granting specific actors more influence in the social arenas where decisions take place.

The influence of power on governance systems and actors

The governance system provides crucial information about the structure of the decision-making process, like who is considered a decision-maker, the organizational spaces where decisions are made, and how decision-makers relate to each other. For example, a centralized governance system will potentially include a restricted set of decision-makers considering a narrow agenda. Meanwhile, a polycentric governance system will be characterized by a diverse set of decision-makers that interact with each other in decentralized, yet overlapping, decision spaces. Power exercised in this space influences the act of governance by determining the rules and the structures where decisions take place. In this space, power can refer to legitimacy or authority to participate in governance or developing the procedures and designating authority to make decisions. Power differentials are expressed as different capacities to fully participate in decision spaces, and the extent to which participation can be fruitful. In this way, power at the intersection of governance system and actors can grant certain groups a disproportionate ability to affect the overall governance outcomes before any debate or discussions occur in the social arena.

The influence of power on the social arena

Power in the social arena is exercised by individual agents trying to advance their individual or group interests. Individuals can have varying degrees of power based on agent-specific characteristics such as their professional expertise or membership in a certain group or social sector. For example, Morrison et al.(2019) argue that, individuals can attempt to influence governance outcomes by deploying pragmatic or framing power. As discussed earlier, pragmatic power can be understood as an agent's capacity to influence how programs or regulations are implemented, or whether a new rule is deemed legitimate at all. Indeed, varying degrees of pragmatic power can result in some policies or regulations to have a diluted or even belated effect on specific groups. Framing power, meanwhile, relates to an agent's ability to influence how information is interpreted, which issues are deemed important, and which solutions are considered viable or legitimate.

2.3.4. Exploring the Indirect influence of power on SES through ABMs

An ABM based on a power-centric framework models the governance processes that take place in the purely social arena and tracks their cascading impacts throughout the socio-ecological, and purely ecological arenas. The agents in such ABMs are not the individual water-users, but the decision-makers responsible for achieving system-wide governance objectives that will ultimately provide water for individual users. Depending on the characteristics of the governance system (centralized, decentralized, or polycentric, decisions will be made collectively by a heterogenous group of decision-makers with a diverse set of objectives. We assume that decision-makers consider their governance objectives in tandem with information derived from the environment to determine their governance decisions. Governance objectives can encompass regulatory mandates, policy objectives in planning documents, or collaboratively agreed objectives. Decision makers will regularly gather information related to their governance objectives from the environment. The environment provides information on biophysical indicators such as precipitation, water quality, stream flows, reservoir levels, and climate change disruptions. The environment can also provide information on social indicators like water users' demands and responses to governance decisions.

ABMs explicitly modelling power in water governance can provide a robust foundation to analyze the effects of governance changes. Such ABMs can help model system-wide impacts of decentralization reforms, the expansion of stakeholders participating in decision-making, or changes in the rules and norms guiding the practice of governance. They can also provide a platform to analyze how power dynamics contribute to reform processes that fail to generate the expected changes in governance outcomes. This is done by providing a plausible, and systematically analyzed, representation of a governance system in action. Computational experiments can simulate changes ranging from small shifts in power differentials to a substantial restructuring of the decision-making process altering the heterogeneity of agents, the objectives they consider and the filters they use to process information. Simulations can focus on identifying the main mechanisms through which the power held by individual agents affect system outcomes. They can also provide insights into the robustness and flexibility of a governance system based on whether a sudden change in power differentials results in a significant realignment of key governance outcomes.

ABMs can help address some of the difficulties researching power in water governance by providing a platform to analyze counterfactuals of a system's reaction to changes in power among its participants. Plausible counterfactuals are generated by modelling autonomous decision-makers and analyzing how their use of different types of power affect independently the system's governance structure. The capacity for ABMs to model the boundedly-rational or irrational behavior helps capture the complexity of human decision-making (Schlüter et al., 2017; Smith & Conrey, 2007). ABMs can explore plausible causal mechanisms that lead to observed outcomes from empirical research. In other words, they provide a way of evaluating plausible mechanisms that lead to equifinal outcomes observed in empirical studies (Schlüter et al., 2019). It is worth highlighting, as Morrison et.al. (2019) note, that not all power deployed in a governance system will result in negative outcomes. Future work should leverage progress on ABMs of SES governance and the theoretical robustness of power theory in environmental governance. The ABMs generated with this approach should focus on relating notions of power with concrete policy outcomes within a particular system. For example, power differentials between participants in a collaborative governance system should be connected to governance decisions such as planning goals, investment decisions, and resource allocations among users. More complex ABMs can couple governance models with ecological models tracking biological and hydrological indicators, or social models tracking equity in access to resources, social vulnerability, and resilience to crises.

2.3.5. Final considerations

It is important to remember that, like all models, ABMs are an abstract representation of a real-world system. They are not predictive models but rather a tool to make sense of a complex system. This is a key distinction from other modelling tools frequently used in social sciences, that are designed to make predictions or forecasts about specific real-world outcomes of the systems they are modelling (Janssen & Baggio, 2017). ABMs focus on analyzing the system-wide processes that arise from individuals' behavior with the intent of detecting emergent behavior. Such emergent behavior cannot be predicted by simply looking at the individual parts of a system and determining how that part behaves (e.g., sardines swimming together in a swarm cannot be predicted by simply looking at how an individual sardine swims).

ABMs are a platform where painstaking efforts to model agency can be taken. Some researchers like Smith & Conrey (2007) argue that ABMs should focus on using cognitive models to truly explore SES instead of using ad hoc decision rules as this prevents linking insights to the general understanding of human decision-making. There are trade-offs, however, to attempting such models to analyze power dynamics in SES. Modelling human decision-making accurately implies a significant amount of time and carries the risk of building overly complicated decision rules. ABMs are designed to understand the role of individual and independent agents and identify plausible or "accurate" explanations for the dynamics present in a modelled system. Therefore, models using highly sophisticated decision-rules to mimic power dynamics between a system's agents run the risk of missing the balance between a simple model that can capture complexity (a characteristic of the system) and a model that is merely complicated in its construction (Sun et al., 2016).

The appropriate selection of decision-rules that capture the exercise of power for ABMs can be supported by gathering information on the practice of decision-making from decision-makers themselves. Qualitative and quantitative research methods such as interviews, participant observation, and behavioral experiments can be used to provide researchers with a more realistic understanding of how the modelled system works on a day-to-day basis. For example, a combination of these methods can be used to determine a system's policy priorities, decision-makers perceptions of key issues, general attitudes towards risk, identify key participants, ascertain the presence of cognitive biases, and identify pertinent cognitive models. The chance to observe a decision-process firsthand can allow the researcher to model a more accurate decision-making process than can perhaps be gleaned from official documents of how the process is supposed to work. More importantly, observing the practice of governance can provide a researcher the opportunity to test hypothesis over whether a decision-making process ascribes to what a theoretical framework predicts for such a system.

Creating such a system representation is not without challenges. Part of the reluctance to expand the use of ABMs, in general, may come from some of their limitations as tools for empirical research. Frequent criticism levied against ABMs has revolved around the difficulty replicating results, difficulties scaling up models to large systems, and an inability to make predictive conclusions (Conte & Paolucci, 2014). These issues continue to be actively addressed by the ABM community with considerable improvements (Grimm et al., 2006, 2010; Sun et al., 2016) by providing protocols to describe ABMs in a standardized way and guidance on their structure to enhance replicability (Grimm et al., 2020). Despite these criticisms, ABMs can be an excellent tool when designed and used in tandem with other research approaches, as proposed by Schlüter et al. (2019). Following these methodological guidelines, ABMs of water governance systems focusing on power can be used as generative models through which interdisciplinary research teams can explore hypothesis that can then be tested and refined using empirical research.

The complex nature of social interactions derived from power make it difficult to assess power dynamics within a system without observing the system first-hand. Comparing the outcomes produced by the model with what well established theoretical frameworks would predict is a good way of providing insights as to why some proposed dynamics that ignore the influence of power or decision-biases fail to come to fruition. When used in this fashion, ABMs can also contribute to the theoretical understanding of how power influences governance to produce unanticipated outcomes given certain governance structures. More importantly, perhaps, ABMs can provide a platform for engaged research as a scenario building tool that can help both researchers and practitioners understand potential unintended consequence of governance structures or explore potential outcomes of changes to those structures in a hypothetical setting. Overall, ABMs of power in SES will require following an iterative and collaborative process where models provide hypothesis and counterfactuals to be empirically tested. Determining the plausibility of outcomes will depend on insights derived from existing literature (theoretical frameworks, empirical studies, case studies, meta-analysis), researcher knowledge about the specific system modeled, and stakeholders' knowledge and expertise of their day-to-day decision-making process.

Chapter 3. Who Governs at What Price? Technocratic Dominance, Ways of Knowing, and Long-Term Resilience of Brazil's Water System[1]

3.1. Abstract

Technocratic decision making has been long criticized for dampening participation and limiting the range of adaptive choices through its overreliance on infrastructure-based solutions. There has been growing attention to how technocratic approaches shape long-term resilience of water systems, especially under the threat of climatic change impacts. In Brazil, even under its highly decentralized and participatory water management system, technical expertise and science-based decisions have been often promoted as a desirable mechanism to insulate governance outcomes from the country's prevailing clientelistic and rent-seeking politics. Yet, Brazilian river basins continue to struggle with long-standing problems (such as universal access to sanitation) and increasing challenges for guaranteeing water provision under recurrent drought.

In this study, we examine how technocratic insulation, different ways of knowing (WoKs), and participatory governance shape long-term resilience in one of Brazil's most important river basins, the Piracicaba-Capivari-Jundiai (PCJ). By taking an in-depth look at how

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the PCJ River Basin's governance system responded to the 2014 Brazilian water crisis, we seek to understand how planning decisions in the aftermath of the crisis were influenced by different actors, and how the outcomes of those decisions are likely to shape long term resilience. Based on 27 in-depth interviews with members of the PCJ River Basin Committees, we show how a distinct preference for infrastructure-based solutions to deal with on-going and upcoming challenges may be unsustainable under climate change as the basin's traditional technocratic approach failed both to insulate its decisions from politics and to explore adaptive water management solutions that might be key to shape long-term resilience.

3.2. Introduction

While Brazil has plenty of freshwater, more than 70% of the country's runoff is concentrated in the Northern region, home to a small part of the population (ANA, 2017). In contrast, the southeast, where 40% of the population lives, is endowed with only 7% of total runoff (Getirana, 2016). As a result, megacities such as São Paulo invest large amounts of resources in the procurement and management of water but are often under water stress (Kelman, 2015). Historically, metropolises worldwide have followed the 'hydraulic paradigm' in which access to water and sanitation mostly relies on built infrastructure to store, treat and move water to where it serves both the population and industry (Bakker, 2014; François Molle, Mollinga, & Wester, 2009). In São Paulo, the crown jewel of this system is the Cantareira System, a set of four reservoirs and tunnels responsible for providing water to more than 10 million people in the São Paulo Metropolitan Region (SPMR) (Leão & De Stefano, 2019). This model has ensured a relatively good level of water security for the metropolitan region, relying on water transfers from other basins especially the Piracicaba-Capivari-Jundiaí River Basin (PCJ) and more recently from the Paraíba do Sul River Basin (PDS) (Lemos, Puga, Formiga-Johnsson, &

Seigerman, 2020). However, the existing infrastructure and management practices are no guarantee for satisfying the metropolis' increasing demand for water, nor is the process of water allocation accomplished without conflict. Tensions between the SPMR and the PCJ came to a head during the 2014-2015 water crisis when the region experienced the worst drought on record. Conflict arose over water storage in Cantareira reservoirs when several downstream cities ran out of water. Cities dependent on water released from the Cantareira system suffered significantly more than those relying on water from smaller tributaries or their own water storage infrastructure. Moreover, the participatory river basin committees in the PCJ were powerless to stop the São Paulo State government from invoking emergency measures that re-centralized decision-making and rationed water at high social costs in a process widely recognized as lacking transparency, participation, and legitimacy (Empinotti, Budds, & Aversa, 2019). These extraordinary measures were a painful reversal of a decades-long process of decentralization started in the 1990s with the Brazilian water reform.

Extreme events pose significant challenges to any governance system, exposing its gaps and flaws. The 2014-2015 water crisis is a salient example of the hydraulic paradigm's limitations for dealing with increased uncertainty about the timeliness and magnitude of precipitation in the region (Getirana, 2016; Gleick, 2003). The overlap of low rainfall with high temperatures led to a rapid depletion of water in the Cantareira System and threatened to collapse the system. The crisis also exposed the limitations of existing operational rules and management practices controlling water flows across the PCJ basin. Because extreme events may sometimes create a window of opportunity for institutional innovation to change an established political pathway (Biggs, Breen, & Palmer, 2008; Kingdom, 1995; Meijerink, 2005), a possible consequence of the 2014-2015 extreme drought could have been a significant change in the water management approach in the region. These changes could have included, for example, favoring alternatives related to ecosystem services, nature-based solutions, water-demand management, and cultural measures, all options already existing in small scale across the system. Rather, the water crisis led to renewed efforts to expand the dominant hydraulic model instead of embracing innovations or pursuing options akin to an adaptive governance approach.

One explanation for this outcome is that water policy is characterized by periods of continuity rather than dramatic changes (Ingram & Fraser, 2008). Once a particular policy begins to follow a specific route, the political cost of reversing it becomes too high, generating a hard path-dependence almost impossible to overcome (Marshall & Alexandra, 2016). Indeed, some choices along the path reduce the range of future choices, making alternative paths less likely over time and possibly creating lock-ins (Crow-Miller, Webber, & Molle, 2017). Large, high-cost, infrastructure projects such as dams, tunnels, canals, and water transfer systems are good examples of decisions that anchor water management paths for decades at a time. Another related explanation is that different ways of knowing (WoKs) can critically affect water policy decisions by limiting the pool of policy alternatives deemed appropriate and desirable, creating a different kind but not less intractable path-dependence as decision-makers continuously choose alternatives from a restricted set of options.

WoKs can be defined as a dynamic process in which actors interpret the different components and relationships within a policy realm and make sense of them (Schneider & Ingram, 2007). A WoK influences how a decision-maker perceives an issue, determines whether the issue is a priority, and what are possible solutions to address it. For example, under a certain WoK, a decision-maker may deem water scarcity as a priority issue that is best addressed by investing in large infrastructure projects, rather than reducing water demand. Different WoKs can foster or constrain policy changes by influencing the perceived level of ambiguity surrounding the issues considered as important and the range of solutions contemplated to address them (Brugnach & Ingram, 2012). It is therefore important to understand the WoKs held by those who make water policy decisions and how those WoKs influence responses to extreme events. This paper examines how different WoKs held by Brazilian water managers, combined with the historical hierarchies of different types of technical expertise, contribute to perpetuating a technocratic governance model to address water challenges. First, we provide our theoretical framework highlighting how WoKs interconnect and shape governance outcomes. Next, we present the example of the PCJ basin in the aftermath of the 2014-2015 water crisis, and how different WoKs in the basin have shaped decision-making and outcomes. Lastly, we discuss the challenges faced by this prevailing model and offer some reflections about what can be done.

3.3. An Overview of Brazilian Water Governance

Like most Latin American countries, in the 1990s Brazil transitioned from a state-centered to a more decentralized water governance approach (Formiga-Johnsson & Kemper, 2005). The Brazilian Water Law (1997) enacted a governance system based on Integrated Water Resources Management (IWRM) principles aimed at balancing water resources protection with achieving ecological, social, and economic needs through the integrated management of water and land use (Engle, Johns, Lemos, & Nelson, 2011). The new law designed a system encompassing the multi-level characteristics of water management, introducing new tools, organizations such as river basin organizations (RBOs) and water agencies. It also introduced new integrated scales of governance at the sub-regional and intra-state levels to tackle the challenges of water availability and use in Brazil. The new participatory and decentralized governance system succeeded at introducing a new diversity of technical experts with different WoKs to the water governance space.

Historically, in Brazil, water governance has relied mostly on the expertise of engineers (Barraqué, Formiga Johnsson, & de Paiva Britto, 2008; Marques, 2000). Brazilian engineers are the biggest supporters of large infrastructure and public works as the primary strategy for dealing with longstanding and emerging water governance issues (Roman, 2017). Preference for infrastructure-centered solutions constitutes the core of an engineering WoK that has dominated Brazilian water governance for decades. The great level of influence enjoyed by engineers, locally and generally known in Brazil as *técnicos*, can be partially attributed to the technocratic insulation process created by major political and administrative reforms starting in the 1950s but reaching their apex in the 1970s and 1980s (Buckley, 2017; Nunes & Geddes, 1987). Through these processes, the Brazilian government presumably sought to insulate decision-making from the irrationality and rent-seeking of party politics (Lemos et al., 2020; Nunes & Geddes, 1987) in favor of a new model based on scientific evidence and expertise.

While the outcomes of technocratic insulation can at times be positive (Lemos & de Oliveira, 2004; Nunes & Geddes, 1987), in Brazil's natural resource governance it fundamentally depended on the values and frames espoused by these technocrats and the diverse networks of which they were part (Lemos, 1998). The creation of the modern Brazilian state combined elements of authority, hierarchy, control, and patrimonialism shaped by the belief the government should promote the isolation of its political decisions in favor of greater rationality (Nunes & Geddes, 1987). This belief was widespread during the military dictatorship and incorporated the modernist ideas of planning and policymaking (Lemos, 1998). Technocratic bureaucracies emerged from this process, which, by invoking the "neutrality" of technical knowledge, shaped distinct sectoral policies (Abers & Keck, 2013; Marques, 2000).

However, critics of technocratic governance highlight its political and operational implications. For example, Radaelli (1999) argues that the denial or repulsion of politics does not necessarily mean more efficient decisions. The politicization of issues may generate more conflicts, but "frees policies from the trap of technocracy and makes room for a more benign utilization of expertise" (Radaelli, 1999, p. 770). Scholars also highlight the fundamental incompatibilities between technocratic approaches and facing the complexity of natural resource governance (Pahl-Wostl, Holtz, Kastens, & Knieper, 2010). In Brazil's water governance, dislike of political interference at times negatively interacted with popular participation and transparent decision-making in RBOs, often characterizing decisions from government and technical agencies as superior to all others (Abers & Keck, 2013; Lemos et al., 2020). Favoring technocratic decisions, however, failed at producing evidence-based policies, and rather gave rise to politics-based evidence. Using politics-based evidence, policy opponents often tried to influence policy outcomes by disguising their political preferences as technical issues. As a result, "political struggles over different substantive outcomes are waged as if they were conflicts over technical issues" (Abers & Keck, 2013, p. 43).

In the case of Brazilian water governance, technical experts akin to an engineering WoK found natural allies in politicians who favored visible and politically profitable infrastructure solutions. The strength of this alliance, however, depends on the issue at hand, where temporary alliances may arise or dissolve with changing political circumstances (Lemos, 1998). As mentioned before, the outcomes of technocratic insulation in great part depend on the values and networks created to push for different solutions (Blyth, 2002; Lemos & de Oliveira, 2004). In this context, technocratic insulation can yield both positive and negative outcomes relative to water governance. During the 2014 crisis, for example, although *técnicos* prevailed in many of the decisions on what to do, they failed to insulate the process from political intervention as the crisis progressed. Rather, during the crisis, politics challenged both the participatory and the technocratic systems, at times opening the opportunity for contestation even if in the end technical approaches prevailed.

3.4. Ways of knowing, adaptive management and solving crises.

Ways of knowing. Actors in a governance setting have different values, beliefs, perceptions, backgrounds and use different heuristics and rationale to assess issues at hand (Ingram & Fraser, 2008). Understanding how water problems and solutions are framed, assessed, and proposed by water managers is crucial to assess governance outcomes (Brugnach, 2017; Feldman, Khademian, Ingram, & Schneider, 2006; Ingram & Fraser, 2008). Actors can portray an issue in a certain way to advocate a given course of action, thereby limiting options to be considered. Through politics, actors can use their framing power to select which aspects of the problem to focus on and which should be set aside (T. H. Morrison et al., 2017). Thus, how each problem is defined, framed, and represented, is inherently linked to the different WoKs of actors involved in decision-making and can significantly affect policy outcomes. Usually, different WoKs are associated with an implicit set of values and priorities that inform the different narratives actors use to explain the phenomena they experience. People can have multiple WoKs as social interactions reinforce or challenge certain elements of a particular WoK (Gerlak & Mukhtarov, 2015). As issues emerge and are interpreted, some WoKs might gain more traction than others, creating a shared dominating understanding or marginalizing others (Lejano & Ingram, 2009). Not surprisingly, different WoKs might lead to different proposed solutions to a given problem or challenge. However, the pool of solutions considered might not be drastically different had another WoK become dominant, but the way in which alternatives are weighted will vary. Those discrepancies can result in markedly different policy preferences when, for example, choosing between solutions such as a bold reforestation program or expanding water transfer systems. Other factors that play a determinant role in advancing a WoK include power asymmetries and the epistemic legitimacy of actors, both of which are receiving growing attention in environmental governance literature (Brisbois & de Loë, 2016; Meijerink, 2005; T. H. Morrison et al., 2019).

Assessing the different discourses through the WoKs lense is useful to understand the different values and concepts shaping policy outcomes (Gerlak & Mukhtarov, 2015). Figure 1 presents an actor-centric framework of how WoKs inform efforts to tackle climate change issues. An actor’s WoK serves as a filter through which climate issues are perceived and interpreted, identifying the most and least pressing issues. Although an actor may hold different WoKs at the same time, some WoKs may hold more sway over an actor’s decisions at any given time (see preferred WoKs in Figure 3). For example, an individual favoring a WoK akin to IWRM may perceive changes in rain patterns as a major threat to the steady and reliable provision of water. The appropriate ways of tackling priority issues will also be influenced by the actor's WoK. Actors using an IWRM WoK may deem increasing overall water storage capacity as the best way of tackling uncertainty over rains. Alternatives that reduce water demand or increase water storage capacity through spring protection programs may be deemed too slow or insufficient to deal with the magnitude of challenges related to reliable water supply. In this sense, different WoKs help determine overarching policy preferences. Policy preferences, in turn, can greatly impact a system's ability to cope with climate issues, either increasing its resilience or vulnerability (Kallis, Kiparsky, & Norgaard, 2009).

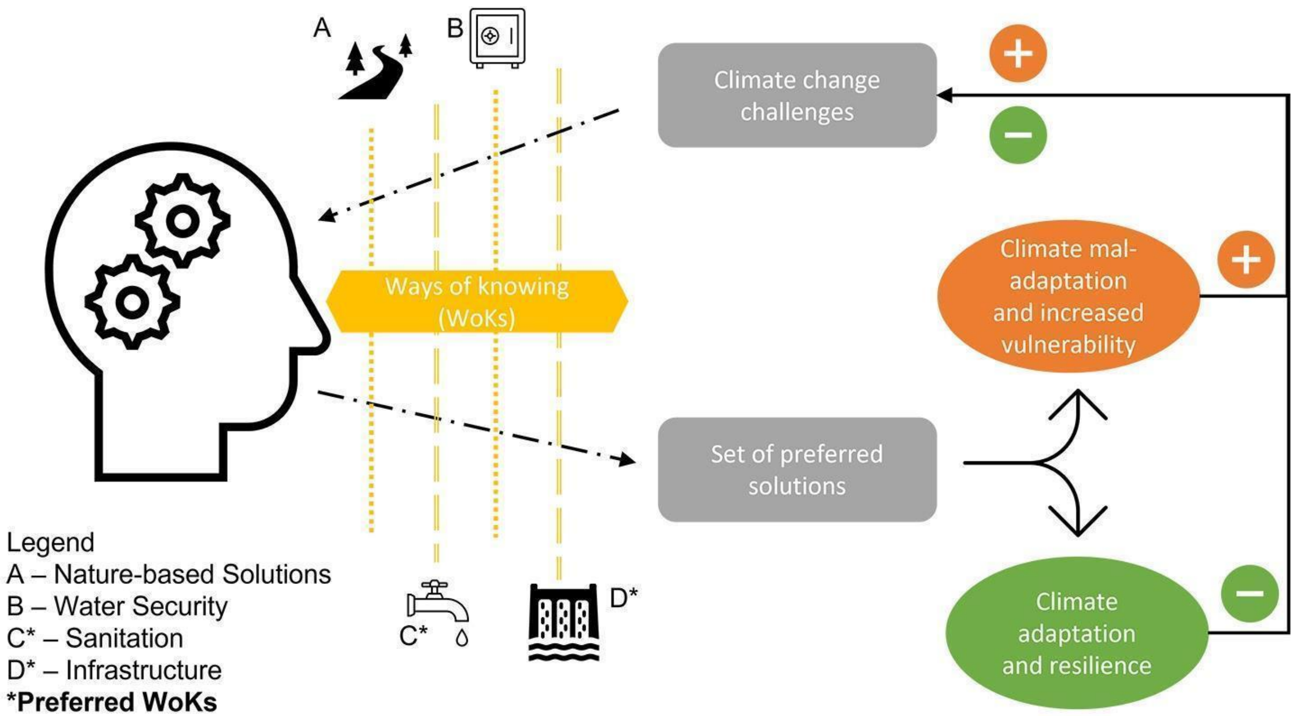


Figure 3 Framework for understanding the influence of WoKs in climate adaptation and resilience efforts

3.5. Ways of Knowing, adaptive management and building adaptive capacity

Different scholars advocate for more adaptive governance systems, such as those established by the Adaptive Management (AM) approach, both as a superior way to govern natural resources and as particularly adept to respond to uncertain climate change impact. According to Folke et al. (2005) AM is a systematic process of continuous improvement of management policies and practices through learning the results of implemented practices. The process incorporates uncertainty through social learning and knowledge co-production between policymakers and scientists (Walters, 1997). Adaptive frameworks also emphasize the need of including a broad range of stakeholders, including different perspectives beyond the technical and scientific, especially when these stakeholders are the ones likely to shoulder the brunt of negative impacts in these highly uncertain contexts (Funtowicz & Ravetz, 1991).

In water governance, especially under the uncertainty of climate change impact, AM involves transforming the way water managers view problems and act, focusing on the learning process as a crucial element for promoting adaptive capacity while embracing uncertainty (Kochskämper, Koontz, & Newig, 2021). The IPCC defines adaptive capacity (AC) as 'the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities or to respond' (IPCC, 2014, p. 118). AC includes the resources needed to cope with disturbances, such as infrastructure, information, institutions, and capital (economic, social, and environmental) (Nelson, Adger, & Brown, 2007). Adaptive capacity is core to both vulnerability and resilience paradigms, but scholars still struggle with creating and implementing metrics to access it (Engle, 2011; Siders, 2019). Both AM and AC frameworks posit that technical knowledge-use through water governance is likely to build more adaptive capacity and to increase the resilience of governance systems (Medema, McIntosh, & Jeffre, 2008). Those adaptive forms of management aim to overcome failures of traditional regimes by integrating multiple resource uses and governance levels with a dynamic decision-making process that considers uncertainty and various forms of knowledge (Bell, Engle, & Lemos, 2011). However, while the conceptualization of these new forms has advanced, their practices and implementation are still lacking (Brugnach, 2017; Medema et al., 2008; Pahl-Wostl, 2009). Scholars have also discussed the compatibility and relationship between existing IWRM and AM (Engle et al., 2011; Fritsch, 2017), with a few proposing a broader interpretation of the IWRM framework that expands the role of alternative narratives and WoKs as an avenue to balance the weight of technical experts and a focus on technocratic solutions (Mukhtarov & Gerlak, 2014).

In this conceptualization, increasing the role of alternative WoK in decision-making may facilitate effective transitions to AM practices.

Moreover, several authors have explored the role of knowledge and technical experts in upholding existing practices and blocking the introduction of AM practices (Kehler & Birchall, 2021). There is also growing attention paid on how different processes of knowledge co-production may enhance collaboration (Mach et al., 2020), especially connecting multiple WoKs (Brugnach, 2017). For example, research on subsiding deltas across Asia, Europe, and the U.S. emphasizes, among other factors, the role of technical experts in maintaining a path-dependence on technocratic approaches that exacerbate, rather than mitigate, delta subsidence (Seijger, Ellen, Janssen, Verheijen, & Erkens, 2017). However, in post-socialist Uzbekistan, attempts from technocrats to introduce IWRM were received with distrust by the central government who perceived the move as an attempt to hollow out their power to manage water (Hamidov, Kasymov, Salokhiddinov, & Khamidov, 2020). In addition to knowledge, empirical research has documented how differing perspectives on uncertainty between scientists and practitioners of different sectors have influenced decision-making and contributed to tensions between actors engaged in water management (Höllermann & Evers, 2017). Acknowledging the tensions created by the interaction of different WoKs and expertise is key for building agreements that reflect common collective goals and mutually acceptable solutions (Brugnach, 2017). In this context, finding common solutions is challenging given the ambiguity surrounding issues and possible solutions (Brugnach & Ingram, 2012), which can be attested by the relative lack of robust empirical evidence of expected outcomes of adaptive water management, either positive or negative.

In such contexts, a few frameworks have emerged that acknowledge that water governance should embrace uncertainty rather than try to repeal it (Döll & Romero-Lankao, 2017). Many of these frameworks also highlight the benefits of learning and experimentation in situations of crisis (Farrelly & Brown, 2011). For example, emergency situations may align a need for change with an increased willingness of policymakers and the general population to accept new ideas and the creation of new political channels and arenas (Lach, Rayner, & Ingram, 2005). Moreover, although built infrastructure is necessary, it is often not enough; under the threat of climate change impact, it is very likely that coping with either uncertain or non-stationary scenarios will require a more flexible approach to water management (Milly et al., 2008). Such approaches should explicitly consider current path-dependence and allow for experimentation to foster adaptive management solutions. Some scholars suggest that handling extreme events and hydrological variability should involve three 'I's: institutions, infrastructure and information (Hall et al., 2014). For instance, there is a growing recognition that nature-based solutions (green infrastructure) can be a good complement (or alternative) to grey infrastructure in water-related issues, including because of the flexibility they offer when compared to public works (Cohen-Shacham, Emmanuelle, Gretchen Walters, Christine Janzen, 2016; Seddon et al., 2020).

3.6. Methods

Our analysis relies on primary and secondary documentary data to understand the structure and general functioning of the planning process at the PCJ Committees: the unified decision-making body grouping the river basin committee in charge of each river in the PCJ basin. We comprehensively reviewed and coded information available on the PCJ Committees official website (Comitês PCJ, 2021), the PCJ Executive Agency's official website (PCJ, 2019), the State of São Paulo's Water Plan (Plano Estadual de Recursos Hídricos) for 2016-2019 and 2020-20230, and the PCJ Committee's master planning documents (Plano de Bacias) for 2010-2020 and 2020-2035 (see Appendix A for a list of reviewed documents). Our analysis of the Plano de Bacias focused on the investment projects defined as priority for the basin in the past and for the next few decades. We also participated, as observants, of dozens of committee and technical group meetings throughout 2014 to 2016, and between October and December 2018. Data and observations collected from these meetings helped us to understand how the Committees and its institutional bodies work and supported our background description of how different WoKs interact with each other in setting up and making decisions within the Committees. We also identified, downloaded, and coded news articles and other media from national and local news outlets such as Folha de São Paulo, Estado de São Paulo and Correio Popular to document the water crisis and the political machinations influencing decision-making at the PCJ basin level.

The PCJ Committees comprise a deliberative body, a Secretariat, an Executive Agency, and several technical chambers (Comitês PCJ, 2021; PCJ, 2019). The technical chambers and the Executive Agency play a crucial role in informing planning decisions at the Committees. Technical chambers are also the main arenas where members of the Committees analyze, debate, and elaborate policies or programs to address basin issues before presenting them to the deliberative body of the Committees. Meanwhile, the Executive Agency functions as the Committees' knowledge producer, being responsible for creating and diffusing technical knowledge and providing technical assistance for program implementation (Member of the Executive Agency, personal communication, 2018). When first created, the PCJ Committees faced great challenges in terms of sanitation infrastructure, flood control, pollution, and water flow disruptions. In the past 20 years, the basin has achieved remarkable progress in terms of sanitation infrastructure and sanitation access. However, there are still increasingly pressing challenges, both in terms of water quantity and quality. Defining the strategies to address these issues falls primarily on the technical chambers most closely related to each individual issue (Comitês PCJ, 2021). When issues fall within the jurisdiction of multiple technical chambers, the Committee tends to form ad hoc groups to work collaboratively across technical chambers (PCJ Committee Member, personal communication 2018).

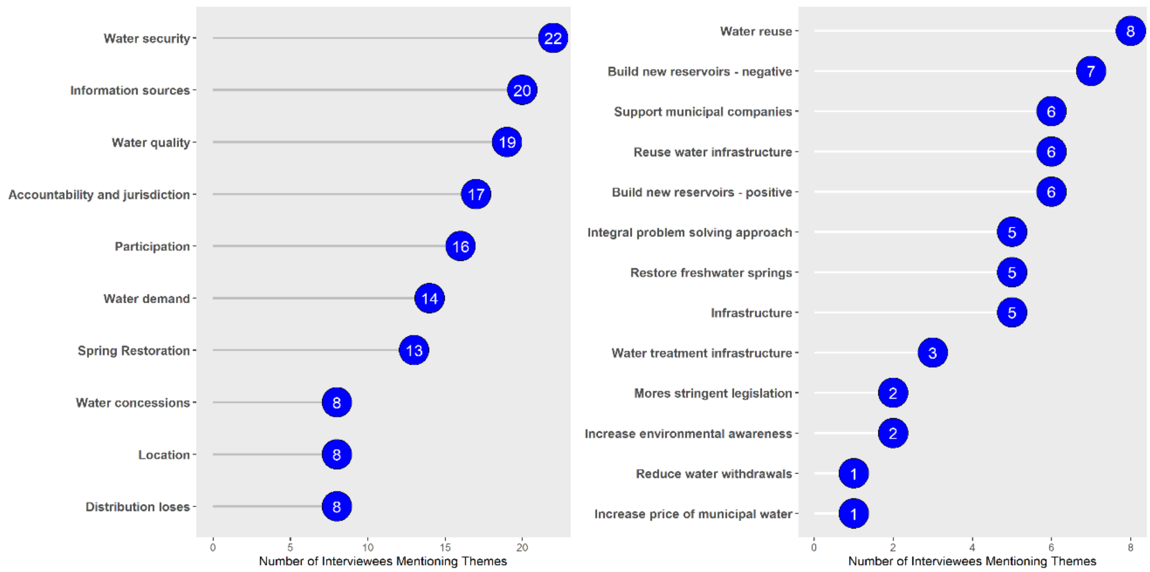
We collected information about Committee members' perceptions of the planning process and governance priorities through in-depth semi-structured interviews with members of the PCJ Committees and Technical Chambers between September to December 2018. The PCJ governance bodies currently have 600 members representing government agencies, local governments, water users, and representatives of civil society. However, only a minority of current members actively participate during regular meetings organized by the twelve different technical chambers or the Committees' Plenary sessions (Member of the Secretariat, personal communication, 2018). Interviewees were selected snowballing from introductory interviews with key informants at the PCJ Committees and Chambers until no new names were suggested. We invited 35 potential interviewees representing the different water users and types of technical experts active in the Committees, with 27 accepting the invitation. Our interviewees were highly active in the PCJ Committees, and some have been involved since the Committees' creation. Twenty of our respondents are male and seven are female. We interviewed 14 water users, five government representatives, four representatives of civil-society, and four unaffiliated members. We believe the interviewees spoke candidly about interview topics. They were generous in sharing their experiences at the PCJ Committees, their opinions on how the Committees are tackling challenges, and their perceptions of the decision-making process at the Committees. Out of the 27 interviewees, 11 have engineering backgrounds while 16 have training in a variety of disciplines including biology, social sciences, and education. In section 3.7 below, we compare how participants at the PCJ Committees perceive the basin's challenges and their potential solutions based on different WoKs.

All interviewees were transcribed, translated, and coded using NVivo software. Interviews focused on committee members' perceptions on the basins' primary challenges faced currently, potential solutions to those challenges, perceptions about the 2014-2015 water crisis, flexibility of the Committees' planning process, primary sources of information guiding interviewee's decisions, perceptions about influential groups and individual participating in the Committees, and general perceptions about climate change. We performed a two-stage content analysis of in-person interviews. In the first stage of analysis, we coded interviews to identify the main themes arising from our conversations with PCJ Committee members. We used a deductive approach to develop a set of coding categories broadly corresponding to our interview protocol topics. We then added coding categories to reflect the richness and specificity of topics available in the data taking advantage of the flexibility of the deductive coding approach (Saldaña, 2009). Our interview protocol is presented in Appendix B. During the second stage of our analysis, we reviewed coded interviews to identify the narratives that reflect interviewees' WoKs, particularly in terms of how the basin's issues should be addressed. For this analysis, we focused primarily on the themes relating to the 2014-2015 water crisis, perceptions of climate change, and potential solutions to the basin's challenges.

3.7. Results

Figure 4 presents the sub-themes identified as the basin's main challenges and potential solutions, other relevant themes can be found in Appendix C. Throughout our interviews, water security came up as the most critical challenge for the basin. Other relevant issues include an expressed need to improve the basin's meteorological monitoring and information systems, issues of water quality, the appropriate distribution of responsibilities, and issues with increasing participation at the Committees. However, there was no general agreement on which solutions have the largest potential to address the issue coupled with persistent challenges and broader governance goals.

Table 1 summarizes identified WoKs in terms of their main proponents in the PCJ Committees, the kind of solutions they gravitate towards, the level of influence each WoK holds in the Committees, and ancillary narratives that support the use of each WoK. Several interviewees, primarily those from large sanitation companies, industrial users, and government agencies favored the construction of new reservoirs and the water transfer system from other basins as the best, and potentially only, solutions. Meanwhile, interviewees from local municipalities, researchers, environmental education projects, rural and natural water resources expressed concerns about the effectiveness of new reservoir systems. We also encountered divided opinions about climate change, its relation to the 2014-2015 water crisis, and potential ways of coping with it (see details below). These topics are all deeply intertwined with one another and clearly informed by individuals' WoKs. Appendix D provides a detailed summary of the qualitative data supporting these findings.



(A) (B)

Figure 4. Interview themes related to the basin's challenges (A) and potential solutions (B)

WoK	***Integrated Water Resources Approach***	***Environmental Approach***
Advocates	Primarily engineers, local politicians, water state agencies	Ecologists, environmentalists, biologists, social scientists, NGOs.
Water	Water as a commodity	Nature as water producer
Preferred solutions	Grey infrastructure: reservoirs, water transfer systems	Green infrastructure, experimentation through pilot programs, nature- based solutions
Kind of knowledge	rational / cartesian / engineering approach	multiple sources of knowledge
Level of influence	High overall	Low overall, except for the rural/environmental sector
Frameworks	IWRM, Water Security (narrow view)	Water security (broader view),

		Adaptive management, Nature-Based Solutions
Ancillary narratives	Infrastructure as only reliable way to achieve water security	Infrastructure is necessary but not sufficient. Water should be seen as an outcome from ecological processes.

Table 1. Ways of Knowing and their main features

Data from the interviews overwhelmingly support the importance of WoKs for selecting solutions to deal with challenges currently affecting the PCJ basin. The PCJ Committees are a space where different WoKs coexist, and different actors can participate in all areas of the Committees. Yet, participation does not translate to all ideas having the same weight or credibility. During the meetings, it became increasingly clear that there is an unspoken hierarchy for which kinds of solutions are considered as the most legitimate in terms of water management, with engineering solutions ranked highly (see Appendix D for more detail).

"We are perhaps one of the largest and most active groups in the public sphere. Not all groups have the same spotlight and media presence. In general, we work elaborating public policy recommendations for local governments, representatives, and other high-level decision makers." -Member of Professional Association of Sanitation Engineers

"The group of technical experts from SABESP is very strong. The group from the water sanitation company in Campinas is strong too. They have an office with experts dedicated to their water sustainability plans. They have political influence that we cannot even dream off."- Water Sanitation Company Employee

The prevalence of the hydraulic solution is often noted by members of the PCJ Committees that hold other WoKs. For example, an interviewee pointed to the predominance of engineering approaches as part of the culture of the water sanitation company they collaborate with.

"The issue of climate change now emerged from the crisis of 2014. It is recently perceived here as a limiting factor of water resources. That's because the water company is an engineering company, 99% of the coaching staff are engineers, mainly civil engineers. You do not have the mindset and vision to relate engineering, the environment, and water resources. In the company's long history, I am the first biologist to assume the position of environmental manager at the company. It is one thing I'm breaking that paradigm." - Water Sanitation Company Employee

The dominance of engineers does not imply that environmental ideas are absent from the Committees. In general, the members of the Committees publicly support initiatives for water resources conservation and restoration (see Appendix D). Nuances over the extent of this support arise in the different technical chambers. Members of the Committees more connected to the rural and environmental education sectors have an agenda closely linked to conservation and environmental initiatives, placing great emphasis on programs such as payment for ecosystem services and nature-based solutions.

Regarding climate change perceptions and its influence on the decisions taken by members of the PCJ Committees, all of them acknowledge that climate change impact projections imply the basin will face more extreme events and more uncertainty. However, interviewees' opinions differ regarding the cause of climate change disruptions and its connection to the water crisis, with some expressing disbelief in anthropogenic climate change. When talking about climate change, most interviewees referred to expected uncertainty about rain patterns, and lamented the loss of stable or "predictable" rain. The overall perception is that climate change will make rain patterns more or less intense throughout the years, with the expectation that it will cause disruptions to water supply. Although interviewees shared a sense of being unable to alter the causes of climate disruptions, they disagree on how best to cope with them.

"Weather events are our major challenge. The great challenge is understanding climate change. What we know is that here, in the PCJ, rain patterns are different, more intense or less intense, and we are losing that average that existed throughout the years. Now we are always at the extremes of too much or too little rain. This is forcing us to revise our planning, but because we have not yet managed to accurately identify changes, we still don't have metrics to monitor these extreme conditions." - Member of Executive Agency

"Noting the extreme weather events in the world, what are they doing? Dams, dams for you to offset the climate anomalies." - Water Sanitation Company Employee

Meanwhile, members in charge of water allocation and monitoring decisions are staunch supporters of infrastructure-based initiatives, including to deal with climate change. These preferences are heavily informed by professional expertise and its accompanying WoK. As a result, disagreements arise over the priority and potential benefits associated with different solutions, greatly affecting the likelihood that a particular solution will be pursued. Everyone participating in the PCJ Committees agrees that nature-based solutions have a place in the portfolio of management strategies at the Committees' disposal. However, environmental approaches are rarely considered as the best solution, particularly against the big challenges like climate change. For some, environmental solutions can provide, at best, marginal gains. Therefore, they cannot be the main strategy pursued by the Committees. The following quote from a large sanitation company employee perfectly sums up this perspective.

"Climate change is happening, but my opinion is very different from many others. What we must do is prevention and that means infrastructure. Because with the changes, the reservoirs are not only for drought mitigation but also for flood control. The engineering vision imposes itself a bit because engineers are very pragmatic. We (engineers) need to be a little more like poets and social engineers. Solutions cannot be at either extreme. Neither do away with all the infrastructure nor just only plant trees. We have to find a balance to address the environmental issues and also the infrastructure issues. Environmentalists are here to stay, so you have to find that balance. We still have eco-chatos2 on the PCJ Committees, as well as very Cartesian3 engineers. I think there has been a change of vision in the Committees and now we need to find the balance between the environmental and the pragmatic." - Water Sanitation Company Employee

It is worth noting the association the informant makes between an environmental agenda and poetry, evoking a sense of idealism, in contrast with an engineering agenda and pragmatism. This contrast exemplifies how environmental solutions are construed as less appropriate from a problem-solving perspective. Under the engineering WoK, infrastructure projects aimed at increasing water production capacity will fare better than environmental solutions despite their potential for water retention. Preference for engineering solutions is reinforced by a positive feedback loop between existing built infrastructure and the increasing complexity of new projects. Existing infrastructure requires technical experts capable of managing it. In turn, these technical experts will pursue solutions they are familiar with to address existing and arising

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[2] Eco-chato is a disparaging term for someone who constantly directs the conversation to environmental issues similar to the English common expression "broken record".
[3] Cartesian is an adjective used in Brazilian Portuguese to describe an individual who is extremely rational and methodical.

issues, creating the need for more technical experts like them to handle infrastructure in the future. This dynamic creates barriers for technical experts associated with other WoKs as they seek to advance their agendas. In the interviews, these barriers are cited as one of the reasons for the lack of innovation and out-of-the-box thinking in the Committees as different perspectives can rarely gather enough support and resources to establish large scale projects.

Despite these barriers, alternatives to engineering approaches continue to gain recognition and support in the Committees, at least in terms of brainstorming. Financial resources for projects implemented by the Committees in the foreseeable future are still expected to primarily fund infrastructure projects. Those advancing alternative perspectives view the increased ability to propose their ideas as the result of a long engagement process on their part that is slowly, but surely, changing the dominant perspectives and culture at the PCJ Committees. Respondents highlight the cultural change in terms of the creation of dedicated technical chambers and increasing resources for nature-based projects. Several interviewees commented on the difficulty of convincing who they described as "traditional engineers." However, they also highlight that through constant participation in technical chambers focused on rural and natural resource issues they have been able to create a space for different agendas to gain a foothold.

"It was a turning point, a quiet revolution within the Committees. We now have working groups focused on stream restoration that include different Committee members. They are addressing deeper issues within each area of expertise related to reforestation, sewage treatment, watershed recovery. We elaborated the first master plan for water springs. The approach of the group: our reservoir is not the Cantareira, but here on the ground." - Member of Agricultural Water Users

The water crisis was a tipping point towards recognizing the seriousness of future water availability challenges. Not surprisingly, Committee members tend to rely on their technical expertise when thinking of potential solutions. About half of interviewees (14) mentioned the need to increase built infrastructure to tackle climate change, a kind of solution with which they are very familiar. Those advocating for expanding built infrastructure consistently mentioned the need to increase water storage and transfer capacity as the obvious and most reasonable strategy. In this sense, responses to the water crisis and the acknowledgment of climate change are consistent with the planning culture at the PCJ Committees, which is deeply informed by the WoKs of the engineers that populate it.

Data from participant observation of Committee meetings and the interaction between participants supports our finding that overreliance on one type of technical expertise (or one WoK) may ultimately increase vulnerability to climate change as it limits the experimentation and active learning required for adaptive management. During meetings despite the participatory nature of the PCJ Committees, which provides opportunities for different technical experts, and their WoKs, to introduce new perspectives, potential solutions, and alter how an issue's priority is determined, there was little evidence that such ideas have a path to take hold. Although the work and engagement from actors advancing different WoKs continue to gain footholds in the PCJ Committees, the tension between traditional and emerging WoKs can be observed in the day-to-day activities of the PCJ Committees, during long-term planning processes, and in the aftermath of a crisis. For now, discussions observed during these meetings suggest that the engineering WoK will continue to prevail in the foreseeable future.

3.8. Discussion

The multiple WoKs identified during our analysis are consistent with WoKs previously described in the broader water management literature. One particularly prominent WoK corresponds to traditional management strategies with a focus on engineering solutions akin to the IWRM framework. This WoK tends to dominate water management spaces focused on technical and economic solutions (Brugnach, 2017; Gerlak & Mukhtarov, 2015; Giordano & Shah, 2014). In partial opposition to the first WoK, we identified another WoK that grants a larger emphasis to environmental solutions and pays more attention to broader concepts of water security (Mukhtarov & Gerlak, 2014) and the social value of water in line with the work of Ingram and Oggins (1990), which highlights water's relevance as a community good vital for security and self-determination.

Throughout Brazil's drive to decentralize water governance, technical experts, and their WoKs have critically participated and influenced RBOs. However, basin organizations have struggled to foster broad participation and balancing power asymmetries that favor technical solutions (Lemos et al., 2020). As a result, WoKs attuned to engineering solutions remain prominent throughout Brazilian basin organizations. Part of this prominence stems from the fact that a large percentage of Committee members are engineers and they have consistently been part of the Committees since their creation. In the PCJ basin, the main proponents of the engineering WoK are the technical experts from water sanitation companies and some government agencies. Water sanitation companies, especially the state-owned companies, hold a great deal of influence and power despite just being a water user. The heuristics used to categorize issues into technical chambers are, to a great extent, informed by the WoKs held by Committee members. This is one mechanism through which WoKs contribute to reinforcing established patterns, a dynamic in line with common criticisms levied at technocratic IWRM approaches (Mukhtarov & Gerlak, 2014). Technical experts that have a large presence or influence at the Committees will have a greater capacity to designate the basin's most pressing issues as challenges that fall primarily under their jurisdiction. Key issues are then discussed primarily in technical chambers dominated by these technical experts, where proposed solutions will likely correspond to their WoK: a lock-in process similar to the one observed in delta subsidence (Seijger et al., 2017). Likewise, having jurisdiction over priority issues grants technical experts an advantage to secure most of the Committees' financial resources to implement solutions.

Water sanitation company employees occupy leadership roles in the Committees' deliberative body and key technical chambers. Meanwhile, most high-level actors in state agencies have a lot of practical authority, ensuring that their agendas are followed as a state policy (Abers & Keck, 2013). Technical experts from other areas of expertise have progressively become more engaged at the PCJ Committees, but there are still significant barriers for greater participation. These experts are usually affiliated with NGO's, Civil Society, and Municipal governments, groups that tend to have smaller budgets and capacity to participate in multiple arenas of the PCJ Committees.

Yet, because of the dominance of the engineering WoK, the extent to which solutions stemming from relatively new WoKs will impact the basin's overall policy approaches is limited. Success will partly depend on the extent to which recent events and perceptions of climate change continue to influence Committee members' approach to the basin's challenges. For example, pilot nature-based projects have been recently funded by the PCJ Committees.

Similarly, discussions about rural water production, spring restoration, and small-scale water reservoirs, to name a few, have become more common.

As a participatory body, the PCJ Committees provide ample opportunity for actors holding different WoKs to engage with each other as they try to advance their preferred management approaches and solutions. These debates influence what is ultimately included in the basin's planning documents as priority policies. It is therefore important to understand the links between the different WoKs present in the Committees and current perceptions about the basin's challenges and the long-lasting effects of the water crisis. For example, despite the challenges, technical experts akin to other WoKs have managed to establish some projects. The PCJ RBO runs a modest watershed restoration and protection program, and is developing others addressing water demand reduction, nutrient load reduction, and environmental education. These programs are a testament to the hard work and perseverance from technical experts holding WoKs akin to environmental issues and adaptive management. Arguably, part of these experts' success would lie in their ability to frame initiatives as a different kind of infrastructure (green infrastructure) that can effectively complement existing infrastructure, particularly in rural or otherwise underserved areas of the basin. Interviewees representing alternative WoKs often referred to the need and difficulty of convincing more established members of the PCJ Committees of the benefits of new approaches. Part of this difficulty stems from the perception that alternative approaches to water management, particularly nature-based approaches, are not only less effective but idealistic. The characterization of environmental approaches as idealistic puts them at a disadvantage when trying to convince technical experts focused on finding pragmatic solutions under considerable financial constraints.

Different perceptions regarding the efficacy of environmental solutions also helps understand why, despite agreement over the risks and uncertainty presented by climate change, technical experts double down on their preferred approaches. For those holding an engineering WoK, the water crisis appears to have reinforced the belief in the need to expand the built infrastructure in the basin as the only viable option to increase water security. The tendency to rely on familiar solutions highlights the limitations of learning opportunities supposed to be facilitated by polycentric governance systems (Walters, 1997) and the role of technocratic approaches in limiting AM (Kehler & Birchall, 2021). Nonetheless, the crisis seems to have helped broaden the acceptance of nature-based and adaptive management approaches with groups that are not traditionally associated with an engineering WoK. With time, the modest rural, environmental education, and nature-based programs included in the 2020-2035 basin plans may provide valuable proof-of-concept to increase the respect and credibility of these approaches. Setting the PCJ basin on a path towards adaptive management depends on recognizing the ambiguity around policy options (Brugnach & Ingram, 2012) and achieving a greater balance between the different agendas and WoKs coexisting in the PCJ River Basin. Preventing catastrophic consequences of future rain pattern disruptions may well depend on the basin's capacity to understand the complementarity of different approaches, a challenging feat. Helping non-traditional understandings of the basin's problems achieve equal footing with established views is one of the key steps to achieve this. Increasing the importance of non-sanitation water agendas in the PCJ could create opportunities for proposing, designing, and planning for flexible solutions that address multiple agendas at the same time. This can come from the recognition that the problems assailing the PCJ River basin have consequences for all water users and that solutions for these problems can address more than one agenda at a time.

This would be in line with advancing a more holistic view of the IWRM framework that can lead to implementing successful AM practices (Fritsch, 2017; Medema et al., 2008; Mukhtarov & Gerlak, 2014). Expanding the pool of viable solutions, both in political and technical terms, can give rise to new approaches. For example, nature-based solutions can address needs in the sanitation sector as well as environmental ones and are gaining adherents in different parts of the world.

3.9. Conclusions

The 2014-2015 water crisis failed to ignite the changes many hoped would transform the governance of the PCJ river basin's water management strategy towards long-term resilience. Rather the hydraulic WoK once again prevailed. The PCJ Committees have not deployed ambitious nature-based solutions programs and social marketing campaigns, or programs aimed at reducing water consumption greatly depend on the Committees' partners, particularly municipalities, for success. Rather, many members of the PCJ Committees look towards the construction of large new reservoirs, an inter-basin water transfer system, more sophisticated water treatment plants, and water loss reduction programs as the main avenues to increasing water security. This reliance on traditional infrastructure solutions is a common feature of a narrow view of IWRM.

Decision-makers in water governance tend to choose strategies they are familiar with and feel confident about having the technical expertise required to manage them. This is understandable given the high stakes and perceived risks posed by climate change. Incentives to invest in experimental approaches are lower when infrastructure solutions have generally proved successful at achieving a narrow definition of water security understood simply as maximizing water supply. In this sense, the way in which the most influential technical experts conceptualize problems and judge potential solutions, or their WoK, is one of the pillars upholding the overreliance on traditional infrastructure solutions. Although it is true that river basins worldwide need to expand their water supply to deal with current and future demand, there are potential risks associated with these projects when considering climate change impacts. For example, climate change erodes our ability to estimate future water availability based on historical data alone. In the case of the PCJ basin, decision-makers may be under or overestimating rain pattern disruptions, potentially increasing rather than decreasing their vulnerability to climate change. Some potential risks include increased flooding risk for the cities near new reservoirs, intensification of nutrient load pollution issues, water supply disruptions and intraregional conflict that arise from extreme events jeopardizing water transfers between the PCJ and the Paraiba do Sul basin. The focus on infrastructure solutions may prove to be an example of maladaptation if and when another water crisis (either extreme floods or drought) occurs.

Planning in a deeply uncertain world requires flexibility to adjust for changing conditions, giving more room for adaptation in an iterative process of social learning. Arguably, decentralized and participatory institutions facilitate social learning by creating arenas where different actors and different WoKs can interact with each other. However, the introduction of new WoKs and the increased participation of different technical experts and social actors have not translated into the implementation of a diverse set of strategies to deal with the basin's challenges. Members of the PCJ Committees perceive low participation from less dominant voices as an issue that requires immediate attention. We argue that the PCJ Committees need not only increase the variety of voices and expertise in the Committees but actively elevate the validity of alternative WoKs and fight bias and misconceptions about non-engineering water management strategies.

Our research also contributes to the literature that advocates overcoming the prescription that participation alone is sufficient for fostering AM. Exchanging information and co-creating knowledge does not influence governance outcomes without recognizing the different asymmetries (structural, institutional, and power) that permeate such relationships. In the case of the PCJ, problems and issues are framed, voices heard, and solutions considered in an institutional environment that reflects historical and structural asymmetries reinforcing them in an institutional lock-in. Challenges faced by the PCJ River Basin, although informed by the Brazilian context, are a familiar story for many regions of the world. Climate change will increase the pressure drivers over freshwater resources, requiring new WoKs. Breaking the infrastructure path-dependence will require additional measures, in addition to increasing participation and decentralizing governance systems. Close attention needs to be paid to the voices and expertise that hold sway over the decisions that will determine future adaptation strategies.

Chapter 4. Planning for The Past or The Future? How Governance Priorities and Investment Decisions Can Reinforce Climate Change Vulnerabilities in a Brazilian River Basin

4.1. Abstract

Climate change is expected to increase pressure on freshwater resources worldwide. As uncertainty over future water availability increases, water managers face enormous pressure to find effective strategies to balance present and future water needs. Understanding the implicit tradeoffs associated with water security strategies can provide key insights for evaluating potential outcomes of climate adaptation efforts. We present results for a mix-methods study on the water allocation and planning strategies of water managers at the Piracicaba, Capivari, and Jundiaí (PCJ) River Basin Committee in São Paulo, Brazil. We highlight the implicit tradeoffs associated with strategies that focus primarily on protecting municipal water users instead of pursuing strategies that would mitigate risks for several water users in the basin. First, we explore changes to water allocation patterns among all water users based on decreasing water availability, previous extreme events, and decision-makers' values and worldviews. Second, we examine how long-term planning strategies relate to decision-makers' perceptions of the main challenges affecting the river basin, beliefs about climate change impacts, and the need to increase water security for priority users. Finally, we discuss how strategies chosen to protect municipal water users, mainly large investments in traditional infrastructure projects, may

increase the vulnerability of all water users when dealing with extreme events such as the 2014-2015 water crisis.

4.2. Introduction

Climate change forces water managers to adjust their governance and planning strategies to cope with reduced water availability and higher uncertainty. Extreme events can precipitate drastic changes, often with high economic, social, and environmental costs (Curtis, Fair, Wistow, Val, & Oven, 2017; Frame et al., 2020; Greenough et al., 2001). For example, disruptions to municipal water services have negative impacts on health and well-being. Similarly, aquatic species die-offs and habitat degradation are associated with severe disruptions to river flows. In addition, water scarcity can have cascading negative economic and social impacts for regions by disrupting energy production, industrial, and agricultural activities. As a result, decision-makers implement a variety of strategies to mitigate the negative impacts associated with water scarcity. Rationing water during times of scarcity has been proposed as one policy strategy that can alleviate economic and social impacts (Gómez-Limón, Gutiérrez-Martín, & Montilla-López, 2020). However, rationing water raises concerns over equity in water access among water users, such as agricultural users and cities (Francois Molle & Berkoff, 2009), and between the rich and poor in urban areas (Gerlach & Franceys, 2009).

Much like efforts to adopt adaptive or sustainable water governance strategies, efforts to minimize the negative impacts of rationing decisions are hindered by multiple factors associated with the complex nature of water systems. For example, issues of water scarcity can be intricately connected to other natural systems outside of the jurisdiction of water governance institutions, see (Lerner, Eakin, Tellman, Bausch, & Hernández Aguilar, 2018) for an analysis of the policy gaps linking water scarcity and land-use in Mexico City. Issues can also be related to fragmented governance institutions, see (Caniglia, Frank, Kerner, & Mix, 2016) the challenges posed by fragmented governance in the Oklahoma, USA. Similarly, challenges managing water scarcity are linked with difficulties in defining relevant scenarios for decision-makers to evaluate (Withycombe Keeler, Wiek, White, & Sampson, 2015), differing perspectives among key stakeholders about the availability and water access rights (Lopez Porras, Stringer, & Quinn, 2018), and the willingness of key stakeholders to adopt adaptive approaches (Salajegheh, Jafari, & Pourebrahim, 2020).

The central role of decision-makers' perceptions and attitudes hold towards managing water scarcity emphasizes the importance of understanding not only how people make decisions, but how their decision-making criteria determine the strategies considered as potential solutions. The connection between decision-making criteria and management and planning strategies is particularly relevant when considering the implications of both short-term water rationing strategies and long-term investments aimed at improving water security. Long-term policy strategies, such as traditional infrastructure investments, nature-based solutions, and demand-reduction programs contribute to alleviating water scarcity. However, benefits derived from such investments usually come to fruition after long periods of time, benefit water users in different ways, and have varying degrees of flexibility to cope with crises. Identifying the tradeoffs associated with current management strategies, and whether planning strategies are consistent with broader governance objectives like mitigating vulnerabilities for all water users, is a crucial step towards determining which water users are more likely to experience the negative impacts of water scarcity.

This study explores how individual decision-making criteria influence the policy preferences and investment decisions for water allocation and climate change adaptation of the collaborative river basin organization in charge of the Piracicaba, Capivari, and Jundiaí (PCJ) River basin in São Paulo, Brazil. Our study provides an example of how individual perceptions about previous water crises, preferences over management approaches, along with the regulatory and implicit priorities favoring various water users can unexpectedly reinforce existing vulnerabilities to water scarcity. First, we identify how decision-makers adjust water allocations for the basin's water users under hypothetical water availability scenarios. Second, we explore how expressed governance priorities align with perceived challenges and investment priorities from official planning documents for the PCJ River basin. Third, we reflect on how current management strategies and stated investment plans may reinforce existing water allocation patterns among the basin's users. The paper concludes with a brief discussion on how discrepancies between expressed governance priorities, preferred management strategies, and planned investments may be revealing a gap that could increase the vulnerability to extreme events for the most vulnerable users.

4.3. Case Study Background

Brazil's abundant water resources are unevenly distributed with most densely populated regions located in areas with low water availability. A prime example is the State of São Paulo, home to about 22% of Brazil's population but only 1.6% of available surface waters (Soriano et al., 2016). Historically, water managers in the State of São Paulo have relied on large infrastructure projects and inter-basin water transfers to cope with cyclical water scarcity, especially for the city of São Paulo and its 12 million inhabitants (Leão & De Stefano, 2019; Lemos et al., 2020). The PCJ River basin is one of the main water donors supporting the city São Paulo using water stored at the basin's headwaters in the large reservoir system called the Cantareira System. The Cantareira System diverts approximately 30% of total water available in the PCJ river basin based on a concession agreement established in the 1970s. The concession agreement, and the completion of the Cantareira System itself, was done during a period of centralized water governance in Brazil. Under this governance system, Brazil's energy authority the Departamento de Águas e Energia Elétrica (DAEE) and the city of São Paulo's water company (SABESP) exercised complete control over water in the Cantareira system and has constituted a constant source of tension with downstream water users along the PCJ River basin.

Starting in the 1970s, Brazil embarked on a water reform process to modernize their water governance system. The new governance system was heavily influenced by the political and historical circumstances in Brazil. These conditions created overlapping institutions with varying degrees of political power and authority (Abers & Keck, 2013). During the 1980s, several water committees were established within this structure. One of the first water committees founded was the PCJ Committees (referred to as the PCJ Committee for simplicity). The PCJ Committee is the combined participatory body that jointly manages the Piracicaba, Capivari, and Jundiaí rivers at the State and Federal level. The PCJ Committee's creation constituted a successful process through which municipal governments increased their control over a basin's water resources in opposition to DAEE and SABESP. The PCJ Committee now includes a strong network of municipalities, members of government organizations and members of the agricultural, industrial, and NGO water users.

Overall, members of the PCJ Committee who identify themselves as part of the PCJ basin frequently present a unified front in opposition to representatives of SABESP regardless of their affiliation to different sectors of society (personal communication, November 2018, Member of Sanitation Company). In this sense, the historical and political dynamics that led to the creation of the PCJ Committee remain relevant today. Water users along the PCJ basin need to pool their resources as downstream users to mitigate the power exercised by SABESP and their control of the basin’s headwaters through the Cantareira System and the 1970s water concession. The differences between the agendas pursued by PCJ Committee members come to the forefront when discussing the distribution of water and financial resources downstream from the Cantareira System.

Differences between PCJ Committee members may lie not only on representing different sectors of society, government agencies, or interest groups, but also on their location along the basin, proximity to large cities, and dependence on water from the basin’s three main affluents. For example, frictions between small cities like Atibaia and larger downstream cities like Campinas and Piracicaba are heightened during extreme events as incentives to store large amounts of water to satisfy demand for larger cities increase the risk of flooding in upstream cities. In addition, large urban areas demand significant volumes of bulk water to satisfy municipal water demands of their population while increasing water treatment costs for downstream cities. The city of Campinas, roughly midway along the Piracicaba River, is an excellent example of this dynamic. As the third largest city in the State of São Paulo, Campinas requires large amounts of water released from the Cantareira System to provide for its municipal water users. In times of crisis, this dependence on river flows from the Piracicaba River puts Campinas’ water sanitation company at odds with upstream cities based on competition over water flows or difficulties in managing water levels in upstream reservoirs. Similar tensions over reservoir and river flow management arise between small upstream and large downstream cities along the entire PCJ River Basin.

Differences and tensions observed between representatives of small and large cities are echoed across other identities present in the PCJ Committee. For example, there is an inherent affinity between large sanitation companies in opposition to smaller sanitation companies, government representatives from small municipalities, and water users with fewer Committee members such as rural users or environmental NGOs. The combination of affinity between PCJ Committee members based on professional expertise and size of the group represented has granted large sanitation companies a great amount of influence in the PCJ Committee. Contesting this influence is, at times, difficult for other groups present in the PCJ Committee as alliances between groups needs to reconcile different identities, interests, and type of technical expertise.

Extensive research documents how, in Brazil, technical experts tend to command authority in river basin committees (Abers & Keck, 2006; Formiga-Johnsson, Kumler, & Lemos, 2007; Lemos & de Oliveira, 2005). The creation of the PCJ Committee provided an opportunity for technical experts more closely associated with water users along the river basin to exercise more control over water resources, in opposition to the technical experts closely related to the city of São Paulo. It is worth highlighting that the inclusion of different technical experts after the creation of the PCJ Committee did not necessarily result in the inclusion of different technical approaches to the basin's governance. The newly included technical experts, like most Brazilian water managers, have shown a preference for traditional engineering approaches to govern water resources (Roman, 2017).

The technical experts participating in the PCJ Committee play a crucial role defining the strategies that determine how water access is restricted in times of scarcity and the policies and investments aimed at ensuring long-term water security. Brazilian Law codifies water as a human right and mandates guaranteeing drinking water for people and animals during times of scarcity as water governance's top priority (LEI Nº 9.433 Política Nacional de Recursos

Hídricos, 1997). However, current legislation does not codify a priority order for all water users, nor does it specify how water should be rationed when necessity arises. The flexibility afforded by Brazilian legislation highlights the need to identify which water users are more likely to bear the brunt of water rationing measures and whether planned investments are likely to mitigate or increase their vulnerability to climate change disruptions.

Currently, decisions regulating water flows and electricity generation at the Cantareira System are made by two different bodies depending on the time of the year. Unless water levels are extremely low during the dry season, May to September, SABESP can withdraw water volumes at their discretion up to the maximum amount stated in the water concession agreement. During the rainy season, October to April, decisions are made collaboratively by SABESP and the PCJ Committee's technical chamber of hydrological monitoring (TC-HM). Management of the Cantareira System is just one arena through which technical experts from the PCJ Committee manage the river basin's resources. The PCJ Committee consists of several technical chambers that elaborate planning documents and design policies to address the different challenges facing the basin, Figure 5 presents an overview of the planning process at the PCJ Committee. Technical chambers are discussion spaces open to all Committee members and the public led by Committee members with expertise in the chamber's focus area. The plans and policies designed by technical chambers are approved by the Plenary chamber. The Plenary is considered a political rather than a technical arena. Members of government agencies, water users, and civil society are entitled to equal representation across the PCJ Committee. Neither the technical chambers nor the Plenary experience equal levels of representation from each sector. Although technical chambers supposedly have the same hierarchy within the Committee, some technical chambers are perceived as more active or important. Some influential technical chambers (TC) include the following: hydrological monitoring (TC-HM), planning (TC-PL), water concessions (TC-C), sanitation (TC-SA), and basin planning (TC-BP) in charge of defining the basin's guiding governance documents every 10 years. Their most recent plan covers the years 2020-2035. As other river basin committees in Brazil, the PCJ Committee is comprised of a plenary, several technical chambers, an executive secretariat, and an executive agency.

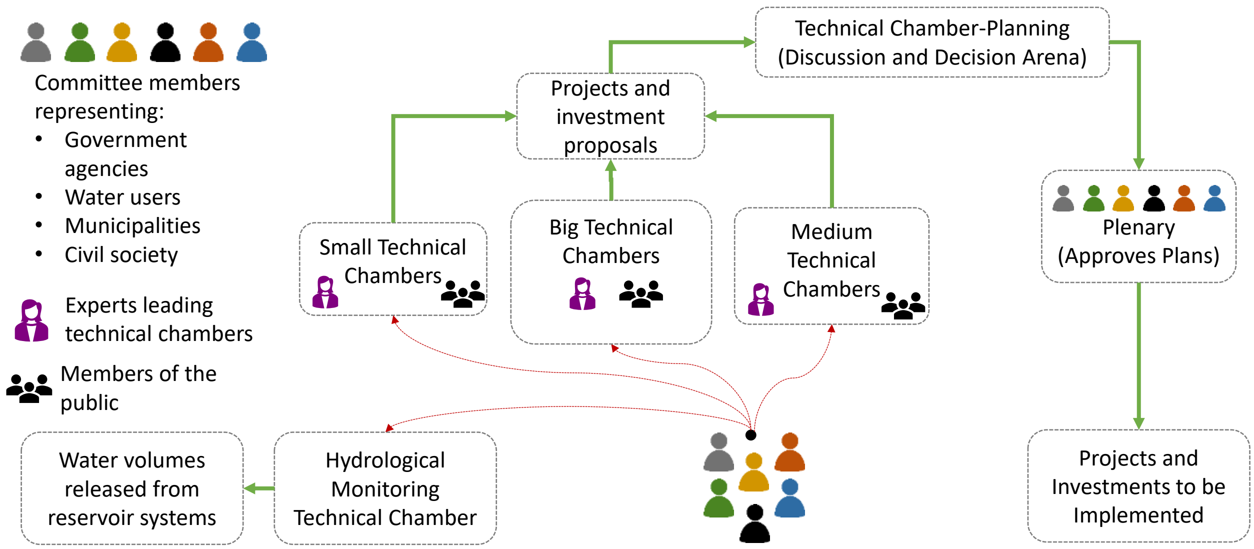


Figure 5. Overview of the PCJ Committee's water allocation and planning process

Characterization of technical chambers as small, medium, or large refers to the level of participation from Committee members and the public. Large technical chambers are those that enjoy high degrees of participation and may also oversee tackling several issues in the basin. Small technical chambers are those that were established more recently and are still building attendance, from both Committee members and the public, and are expanding the issues they discuss.

Despite adopting a decentralized and more collaborative approach to water governance in the PCJ basin, issues surrounding water scarcity persist today. Urbanization, population growth, economic development, and climate change in the PCJ river basin have increased concerns over water security. The water crisis experienced in South-East Brazil in 2014 presented significant challenges for all those depending on the PCJ basin for water (Jacobi, Cibim, & Leão, 2015; Martirani & Peres, 2016). In addition, evidence suggests that, at least for South-East Brazil, the 2014 crisis may be part of a decades-long trend of decreasing water availability (Nobre, Marengo, Seluchi, Cuartas, & Alves, 2016). As a result, the PCJ Committee must define management and planning strategies that will allow them to satisfy existing water needs and cope with the impacts of future water disruptions.

4.4. Methods

Our study analyzes empirical data derived from semi-structured interviews and an online survey engaging active PCJ Committee members during late 2018 and early 2019. The semi-structured interviews focused on exploring Committee members' main governance priorities, perceptions about recent extreme events, perceived challenges, and potential solutions. The survey instrument collected data on respondents' general beliefs and values and included short behavioral experiments regarding water allocation strategies under different water availability scenarios. In addition, the researchers participated, as observants, in three public Committee meetings between October and December 2018 to further understand the day-to-day decision-making process at the PCJ Committees.

Semi-structured interviews were conducted with highly active members of the PCJ Committees. Potential interviewees were identified using the snowball method during informal meetings with key informants at the Committee's Executive Agency and an influential water user group, the Consórcio PCJ. Based on input from these key informants, the list of potential interviewees was paired down based on their current or previous role in the Committee. Overall, we identified a list of 34 potential interviewees. Potential interviewees received a formal letter of invitation to participate in the research study. The letter of invitation contained a general description of the research study, its voluntary nature, and the approval of the Executive Secretariat for the performance of the study. In total 27 Committee members responded to the invitation and 26 interviews were scheduled. To get a geographically relevant sample, interviews took place in several cities along the river basin. We interviewed at least one member of the three sectors of society participating at the Committee. Conversations with members of the PCJ Executive Secretariat and Executive Agency were facilitated through a formal letter of introduction provided by the coordinator of the technical chamber of research and development (CT-ID), a co-author of this research study.

The interview protocol asked respondents about their perceptions on current challenges, climate change impacts, and potential future problems faced by the basin. It also inquired about the perceived flexibility of the committee's decision-making process; sources of information consulted to make decisions; and members of the committee contacted to discuss issues of concern. The interview protocol was originally designed in English and then translated to Portuguese following a three-way translation process with the help of native Portuguese speakers fluent in English. Interviews were transcribed and analyzed following a structural coding approach to identify common topics and perspectives among respondents. We compared commonalities and differences among responses based on respondent affiliation. Respondents were grouped based on affiliation to one of the following groups: water user, member of government agency, or member of civil society. A preponderance of evidence criteria was used to categorize the level of confidence over relevant topics identified from the coding process. We consider there is evidence for a topic's relevance when it is mentioned by at least three different interviewees, regardless of their affiliation, while we consider there is strong evidence for a topic's relevance if three people from different affiliations mention it.

The PCJ Committee is perceived as one of the most organized and engaged in Brazil. The PCJ Committee's official website listed approximately 1200 active members in the summer of 2018. However, not all listed members actively participate in Committee activities at any given time. During the period we collected data, the Committee's Executive Secretariat estimated the

PCJ Committee had 600 active members (personal communication, October 2018, Executive Secretariat Member). Based on this information, the online survey was sent to the list of 600 active Committee members in January 2019 gathering responses during the first quarter of 2019.

The online survey was accompanied by an email invitation describing the study's main objectives and the voluntary nature of participation. The survey was originally developed in English and translated to Portuguese following a three-way translation process with the help of native Portuguese speakers fluent in English. From the approximately 600 listed Committee members, over 110 people initiated to the survey, 3 people opened the survey link and declined to participate, and 74 respondents completed the survey. Although this represents an approximate 11% response rate, there is uncertainty around the exact size of the total sample. The Committee member list does not necessarily capture all members actively engaging in Committee. Rather, the list includes all people who are registered as members, regardless of whether they participate in any technical chamber or attend public meetings and Plenary sessions. It is likely we received responses from a subset of the most active Committee members, but we cannot accurately estimate a response rate for our survey. Survey results are compared and contextualized with information provided from key informants during semi-structured interviews.

The survey included two behavioral experiments directed at understanding respondent's water allocation choices under i) different water availability scenarios and ii) the effects of previous water crises, see Figure 6. Participants were asked to complete the tasks using their personal values, beliefs, and technical expertise. The first experiment aims at identifying if managers significantly alter water allocations destined for each type of water user in the basin as total water availability increases or decreases. Respondents were tasked with distributing the total amount of water available among the four main categories of water users existing in the basin: municipal, agricultural, industrial, and environmental users. Water was allocated equitably (25% of total water available for each user) as the baseline in all scenarios. We used a within-subjects experimental design presenting respondents with three water availability scenarios: high, average, and low. Scenarios were presented randomly to respondents to avoid ordering bias.

The second experiment explores respondents' water storage preferences after recalling extreme water availability events. The experiment followed a between-subjects design to avoid confounding effects of prompting different events. All respondents were asked to decide the operational band of a hypothetical Cantareira system that was currently operating at 60% of total storage capacity. Operational bands determine the amount of water (in m3/sec) that are released from the reservoir system for downstream users. One group of respondents were prompted to recall the extreme drought suffered in the PCJ river basin in 2014-2015 prior to deciding on an operational band for the reservoir system. Another group was prompted to remember the severe flooding events of 2010-2011 in the areas surrounding the Cantareira system, while a control group was simply asked to decide the operational band of the hypothetical Cantareira system.

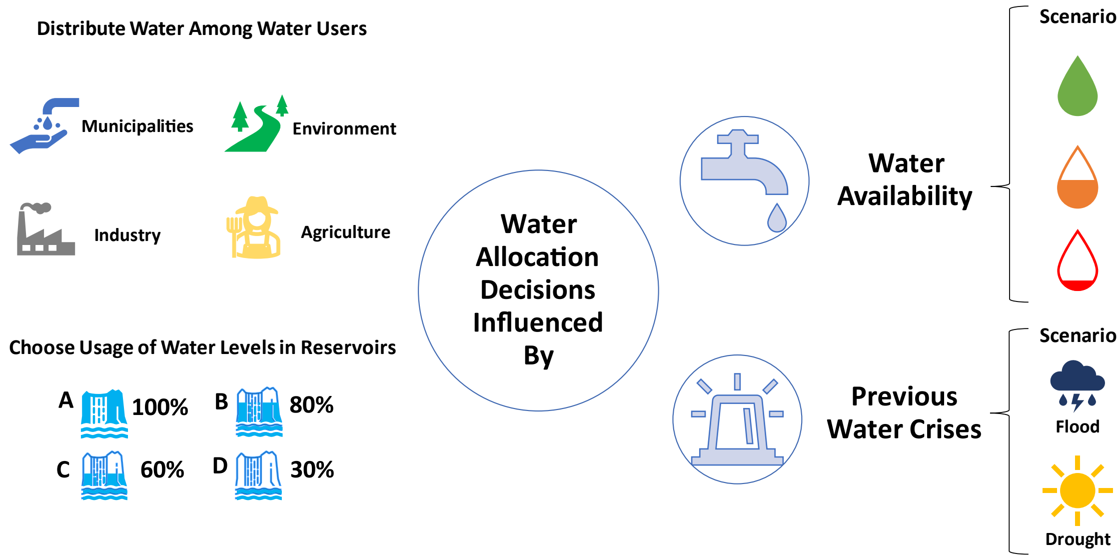


Figure 6. Design of water allocation experiments presented to survey respondents

The survey also applied the 12-item value orientation scale presented by De Groot and Steg (2008).The scale measures participants' agreement with three hypothetical value-orientations: *egoistic*, *altruistic*, and *biospheric* value orientations and is used as a measure of agreement with individualistic, pro-social, or pro-environmental behaviors. The purpose of the value-orientation instrument is to help ascertain the influence of PCJ Committee members' personal values on their water allocation decisions in hypothetical scenarios. Each value orientation (*egoism*, *altruism*, *biospherism*) is hypothetically associated with four specific statements, out of the total 12 items. Respondents reported their level of agreement with each statement on a Likert-scale ranging from "opposing to my values" through "extremely important". A respondents' overall agreement with an egoistic value-orientation scores higher (i.e., reports statements as important) on statements that reflect ideas of: influence over others, authority, wealth, and social power. Meanwhile, altruistic value-orientations are associated with higher scores on statements about: a world in peace, social justice, equality, and service to others. Finally, agreement with biospheric value-orientations is associated with higher scores for statements about preventing pollution, environmental protection, respect of Earth, and unity with nature. We performed a confirmatory factor analysis (CFA) to test the correspondence between our hypothetical value-orientations and survey responses. We considered the hypothetical value-orientations of *egoism, altruism,* and *biospherism* as the latent variables to be estimated based on observed values of individual value statements (Mueller & Hancock, 2001).

The next section presents results from both our online survey and semi-structured interviews. Highlights from semi-structured interviews revolve around the influence of previous extreme events and evolving governance priorities on perceptions of the main challenges faced by the river basin. Survey results highlight adjustments to water allocation among water users given decreasing water availability. Survey results also provide a profile of respondents based on agreement with pro-environment, pro-social, and individualistic tendencies. Finally, we compare the insights gained from our empirical research with the ranking and expected budget of future investments at the PCJ Basin included in the basin's master planning document for 2020-2035 (Plano de Bacias 2020-2035).

4.5. Results

4.5.1. Characterizing research participants

Interview respondents participate in the PCJ Committee as coordinators (or former coordinators) of technical chambers, high ranking members of the Executive Agency, or high-ranking members of the Executive Secretariat. Interviewees range between long-standing members of the Committee (participating since the Committee's foundation) and relatively new participants (less than five years). Meanwhile, survey respondents skewed towards new participants. Almost half of the respondents have been participating in the Committee for five years or less. The remaining half of respondents were similarly split between those with a medium or long tenure of more than 5 or 10 years of experience, respectively. Higher rates of short tenure respondents may be a function of the survey format (online and distributed by email). In terms of gender distribution, most respondents identify as male with about one third of respondents who provided an answer identifying as female. In terms of sector representation, members of water user groups correspond to 31% of our sample, followed by local municipal governments (28%), federal governments (22%), and NGOs (19%). Although we received responses from participants engaged with almost every technical chamber in the Committee, the natural resources TC had the highest representation (receiving 11 responses) followed by the basin planning TC (receiving 9 responses). The environmental education TC, the industry TC, and the sanitation TC each received 8 responses, followed by the water concession TC, the groundwater TC, the hydrological monitoring TC, and the environmental health TC with 7 responses each. Finally, we received less than three responses each for the rural TC and the scientific research TC. The relative distribution of responses may be a function of the survey topic (focused on perceptions of climate change, water crisis, and how to allocate water among users). The two most represented TCs work directly with environmental and planning issues. Supplementary Tables A through D in Appendix E present a summary of demographic information of survey participants.

In terms of categorizing survey respondents based on their beliefs and values, a CFA supports the classification of survey responses regrading attitude-value statements into the three hypothesized categories of egoistic, altruistic, and pro-environment attitudes. The CFA aggregate model is statistically signficant at a 0.01 confidence level, leading to the conclusion that there is a significant correlation between the statements included in each category opposed to statements excluded from each category. Although the *altruism* and *biospherism* categories are highly correlated ($r=0.95$, $p<0.01$), the CFA analysis confirms they are distinct categories. The correlation between *egoism* and *altruism* categories was $r= 0.24$ ($p<0.05$), and $r=0.27$ ($p<0.01$) between *egoism* and *biospherism.* In terms of scale reliability, all categories have high Crohnbach alphas: 0.81 for *egoism*, 0.96 for *altruism*, and 0.98 for *biospherism*. Despite our smaller sample size, we obtained results consistent with those of De Groot and Steg (2008), providing additional evidence for the general validity of their instrument. The average scores (s.d.) across all survey respondents for each category are as follows: 1.61 (1.21) for *egoism*, 4.35 (1.38) for *altruism*, and 4.4 (1.49) for *biospherism*. Based on these scores, respondents qualified statements associated with pro-social and pro-environmental behaviors as more important or aligned with their personal values than statements associated with egoistic behaviors. These results are, perhaps, unsurprising for survey respondents actively participating in a collaborative water governance organization.

4.5.2. Understanding water allocation trade-offs: water user hierarchies

The focus of the online survey is to understand changes to water allocation patterns as water availability decreases. Supplementary Figures A and B in Appendix F present the water allocation and water storage experiments presented to respondents. A total of 71 respondents provided information for the water storage experiment. A Fisher's exact test of the association between scenarios and restrictions on water allocation showed no statistical significance between the two. This means, we found no statistical evidence that priming respondents to recall previous extreme events had any impact on the water storage levels they choose to enact today. Given our relatively small sample size, we do not have enough information to make any inference about the impacts of previous events on current decisions.

A total of 78 respondents provided responses for the water allocation experiment. Figure 7 shows average water allocations to each user under high, medium, and low water availability scenarios. Results are presented as changes over percentages of total water availability to identify the trade-offs arising from water restrictions. Overall, the data suggests relatively stable water allocation patterns across high, medium, and low water availability for each type of user. Municipal water users appear to consistently receive more than a quarter of total water available, between 26% and 30%, showing a slight upward trend as water availability decreases and generally staying above 20%. Agricultural users and environmental water flows received a stable share of water through all scenarios hovering around 25%. Industrial users received the least amount of water with respect to other users, around 20% in all scenarios, exhibiting a slight downward trend as water availability decreases. It is worth highlighting that baseline water allocations were set at 25% (an equitable distribution across all users) and deviations from a perfectly equitable distribution may point to underlying preferences over water users.

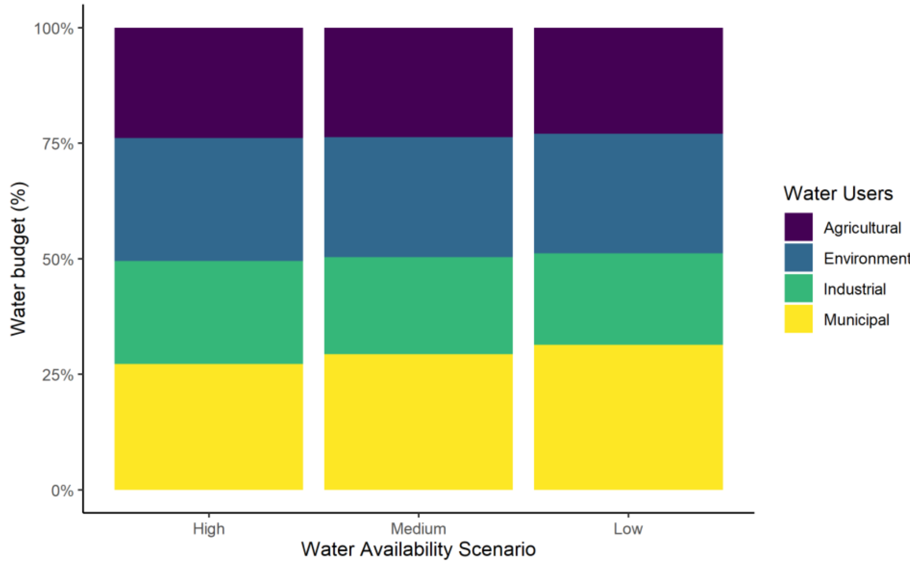


Figure 7. Average water allocations to each type of water user under decreasing water availability

Figure 8 provides additional information on allocation patterns. Overall, respondents chose allocations concentrated around 25% for all users in the high water-availability scenario. However, municipal water users and environmental flows experienced the largest variability both above and below 25% for this scenario. Agricultural users, industrial users, and environmental flows received relatively constant water allocations across scenarios with allocations clustering around a slightly wider range as water availability decreased. This can be seen by the slightly widening boxes in the box and whisker plots. The most pronounced change, however, was experienced by municipal users, whose allocation shares show an increasing trend as water availability decreases (observed in the wider boxes as water decreases).

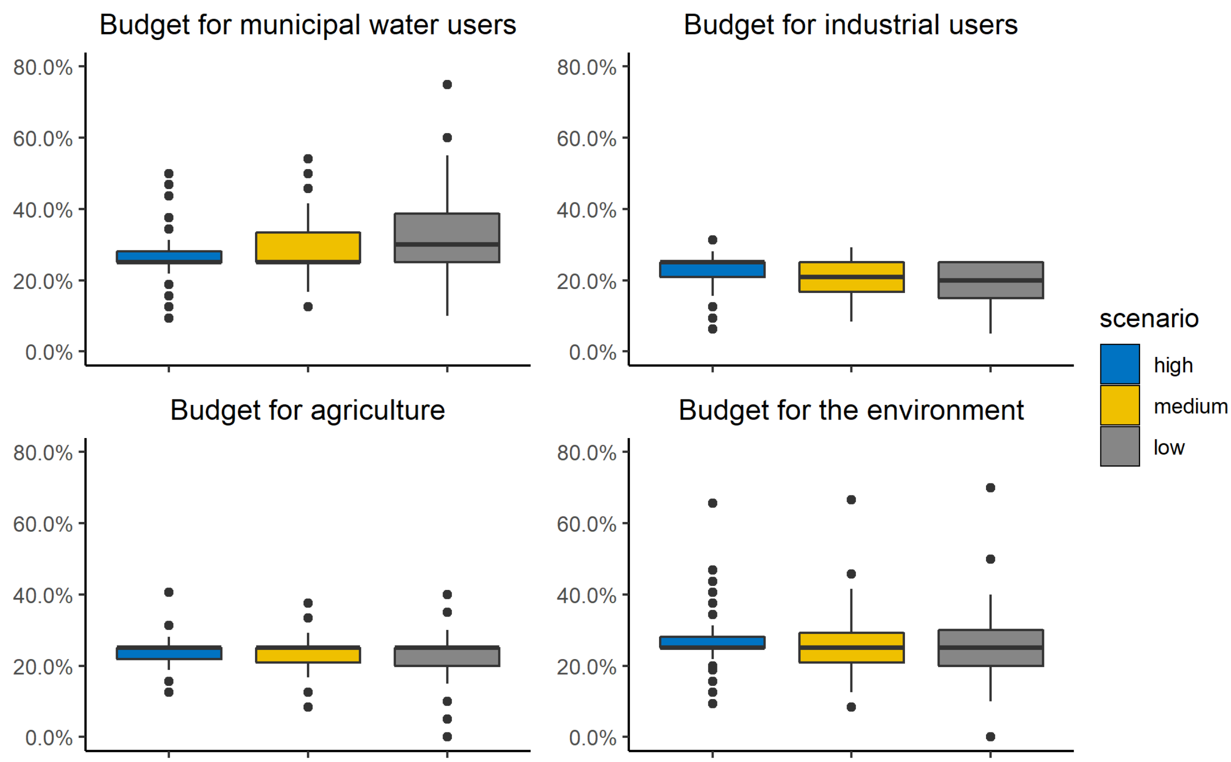


Figure 8. Distribution of water allocation for all users under decreasing water availability

We performed a MANOVA analysis of water allocation across water users to assess the statistical significance of potential allocation differences. The model compares water allocations decisions among users across scenarios using environmental water flows as the benchmark. We fitted two MANOVA model specifications. The first model compares water allocations based only on water availability scenarios. The second model compares water allocations based on availability scenarios and respondent's average scores for *egoism*, *altruism*, and *biospherism*. Both models were statistically significant at a high confidence level with respect to differences across scenarios. Model results also suggest there is some influence on allocation decisions based on respondents' pro-environmental attitudes (*biospherism* index). Table 2. Output of MANOVA model of water allocation choices summarizes model results.

Variable	Df	Pillai	Approx F	Num Df	Den Df	Pr(>F)
egoism	1	0.056	1.421	3	72	0.244
altruism	1	0.027	0.661	3	72	0.579

biospherism	1	0.117	3.184	3	72	0.029
Residuals	74	-	-	-	-	-
scenario	2	0.301	8.675	6	294	0
scenario.egoism	2	0.018	0.457	6	294	0.84
scenario.altruism	2	0.007	0.182	6	294	0.982
scenario.biospherism	2	0.1	2.582	6	294	0.019
Residuals	148	-	-	-	-	-

Table 2. Output of MANOVA model of water allocation choices

We then fitted a mixed-effects model to tease out changes in water allocation for each user, across all scenarios, given water manager's values and attitudes. Mixed models are frequently used to analyze data from a between-subjects design like our water allocation experiment. Mixed models account for the correlation arising from having multiple responses by the same individual. In our case, each survey respondent provided three water allocation responses, one for each water availability scenario presented to them. A mixed model includes fixed (water-availability driven) and random (user-specific) effects. We specified a mixed model that accounted for the potential effects of water availability (represented by the variable *scenario*), and other unobserved individual characteristics (represented by the variable *userid*).

For model specification purposes, environmental water allocations were excluded from the sample and agricultural users were determined as the benchmark for model comparison. Model coefficient estimates are interpreted as percentages of water allocated to one user in relative terms of another. For example, a negative correlation between municipal and industrial water allocations, and a positive correlation between municipal and agricultural users, indicates that an increase in water allocation to municipal users is associated with a decrease in water allocation to industrial users and an increase in water allocation to agricultural users. We estimated changes in environmental water allocations by comparing aggregate shares for the other three users and subtracting from 1 (since water allocation shares cannot exceed 100% of water available, the remainder corresponds to environmental flows). We also specified a mixed model considering the potential effects of respondents' values and attitudes (represented by the average value-index scores for *egoism*, *altruism* and *biosphersim*). This model, however, did not improve the overall goodness of fit to our data (although it resulted in a higher Log-likelihood, it had lower AIC and BIC scores) and was therefore discarded.

Unlike MANOVAs, mixed models provide information beyond aggregate direction of changes in water allocation averaged across all water availability scenarios. We used pair-wise comparisons of marginal effects to identify overall water allocation differences between users, differences between users within each water availability scenario, and differences for each user across availability scenarios, see Table 3. As can be seen in Table 3 a) environmental users receive, on average, 5.1% more water than industrial. Agricultural users receive 5.7% less than municipal users and 2.5% more than industrial users. Industrial users, in turn, receive 8.3% less water than municipal users.

Table 3 b) presents the means and standard deviations for water allocation differences among users in each of the three water availability scenarios. For the most part, model results show statistically significant differences among water users, especially when water availability is low. The environment, agricultural, and industrial users receive less water than municipal water users (5.5%, 8.4%, and 11.5%, respectively) when water availability is low. The pattern holds true for agricultural and industrial users under average water availability, and only remains true for industrial users when water availability is high. The rates at which users gain or lose water also varies across scenarios. Overall, the proportion of water assigned to agricultural users and the environment does not vary in a statistically significant manner as water availability decreases. The reverse is true for industrial and municipal users, see Table 3 c).

a) Water Allocation Differences Averaged Across Water Availability Scenarios

Differences in Proportion of Water Allocations to Users	Estimate (S.E)
agriculture share - industrial share	0.025***
	(0.006)
agriculture share - municipal share	-0.058***
	(0.013)
industrial share - municipal share	-0.083***
	(0.011)
environmental share - industrial share	0.051***
	(0.012)
environmental share - municipal share	-0.031
	(0.017)
agriculture share - environmental share	-0.026+
	(0.012)

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Degrees-of-freedom method: Kenward-Roger
P-value adjustment: Tukey method for comparing a family of 3 estimates

b) Water Allocation Differences By Water Availability Scenario

Differences in Proportion of Water Allocations to Users by Scenario	Estimate (S.E)		
	High	Medium	Low
agriculture share - industrial share	0.016+	0.027***	0.031***
		(0.007)	
agriculture share - municipal share	-0.033+	-0.056***	-0.084***
		(0.014)	
industrial share - municipal share	-0.049***	-0.083***	-0.115***
		(0.012)	
environmental share - industrial share	0.043**	0.050***	0.061***
		(0.013)	
environmental share - municipal share	-0.006	-0.034	-0.054**
		(0.018)	
agriculture share - environmental share	-0.027+	-0.022	-0.029+
		(0.013)	

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Degrees-of-freedom method: Kenward-Roger
P-value adjustment: Tukey method for comparing a family of 3 estimates

c) Water allocation Differences by Water User

Differences in Proportion of Water Allocations by Scenario	Estimate (S.E.)			
	Share for agricultural users	Share for industrial users	Share for municipal users	Share for the environment

High - Medium	0.002	0.013*	-0.021***	0.006
			(0.005)	
High - Low	0.01	0.025***	-0.041***	0.007
			(0.005)	
Medium - Low	0.008	0.012*	-0.020***	0.001
			(0.005)	

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001
Degrees-of-freedom method: Kenward-Roger
P-value adjustment: Tukey method for comparing a family of 3 estimates

Table 3. Pairwise comparisons of marginal effects for water allocation changes for each type of water user under high, medium, and low water availability scenarios

The data clearly shows respondents prioritize municipal water users, as established in Brazilian law, while also providing information on which users will donate water in times of need, see Figure 9. Not only do municipal users receive a higher percentage of total water available than all other users, but the proportion of water allocated to them increases as total water availability decreases. By the same measure, industrial users can be considered the lowest priority water user. They receive the lowest share of water in general and lose the highest amount of water as availability decreases.

While there are no statistically significant changes as water availability decreases, environmental users appear to be the second priority as they receive higher shares of water than agricultural and industrial users. Meanwhile, agricultural users position themselves as the third priority in this experimentally derived ranking. It is worth noting that changes in overall percentage of water allocations may be small in relative terms but translate into larger or more considerable differences when transformed into water volumes (in m3) and flows (in m3/s) available to users. More importantly, these hypothetical scenarios provide information on the tradeoffs and implicit hierarchies that water managers at the PCJ Committee may consider when confronting fluctuations in water availability. Our data strongly suggests that in situations of water scarcity, water managers will divert water towards municipal users, curtailing water access to industrial users first.

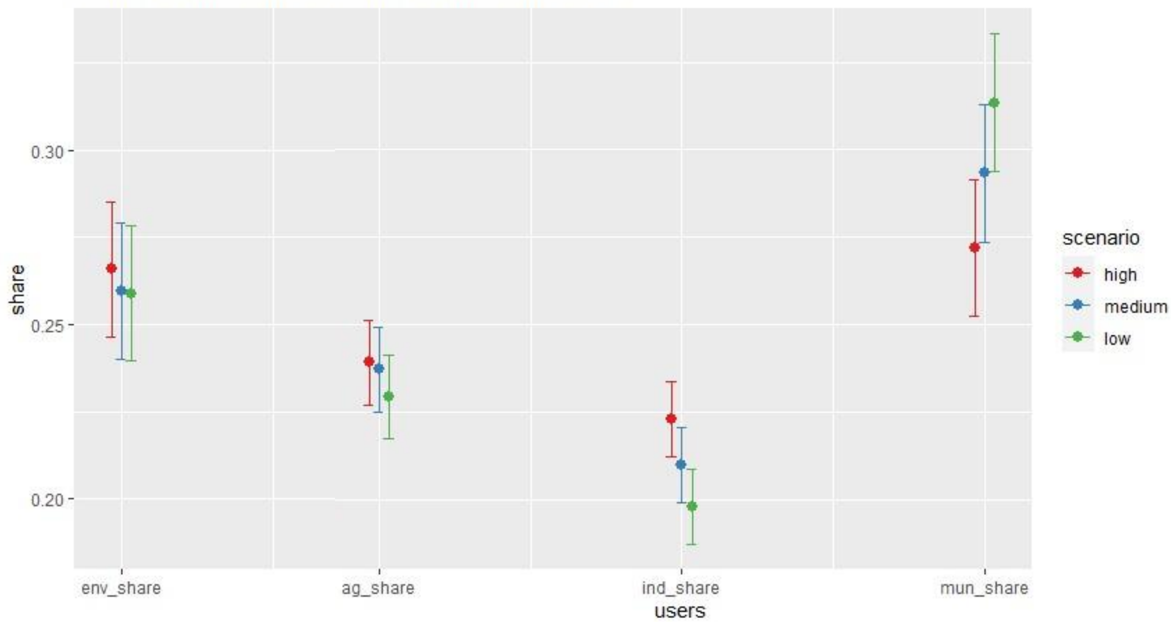


Figure 9. Predicted shares of water allocated to water users in each water availability scenario

4.5.3. Linking water allocation strategies to broader governance strategies at the PCJ Committee

Survey data shows that Committee members will ration water to industrial users to prioritize municipal water users, and the environment to some degree, when water scarcity arises. Qualitative data from semi-structured interviews help situate water allocation preferences within the broader set of governance strategies pursued by the PCJ Committee. Perceptions about previous water crises, the basin's priorities, and preference over potential solutions are some of the key components related to how often allocation strategies need to be deployed. We highlight qualitative data that summarize interviewees' points of view on these key components. Figure 10 presents the general themes coded from interviews regarding the main challenges faced by the PCJ River basin, the 2014-2015 water crisis, main governance priorities, and preferred solutions for tackling challenges. Issues of water scarcity, improving information systems, and water quality emerged as the top three challenges faced by the river basin. The importance of these issues echoes through the emerging themes relating to the water crisis and governance priorities, though these topics were discussed by fewer interviewees. In contrast, themes regarding potential solutions have a narrower focus around infrastructure and municipal water use. A summary of relevant themes ordered based on the preponderance of evidence criteria can be found on Supplementary Tables E through G of Appendix G.

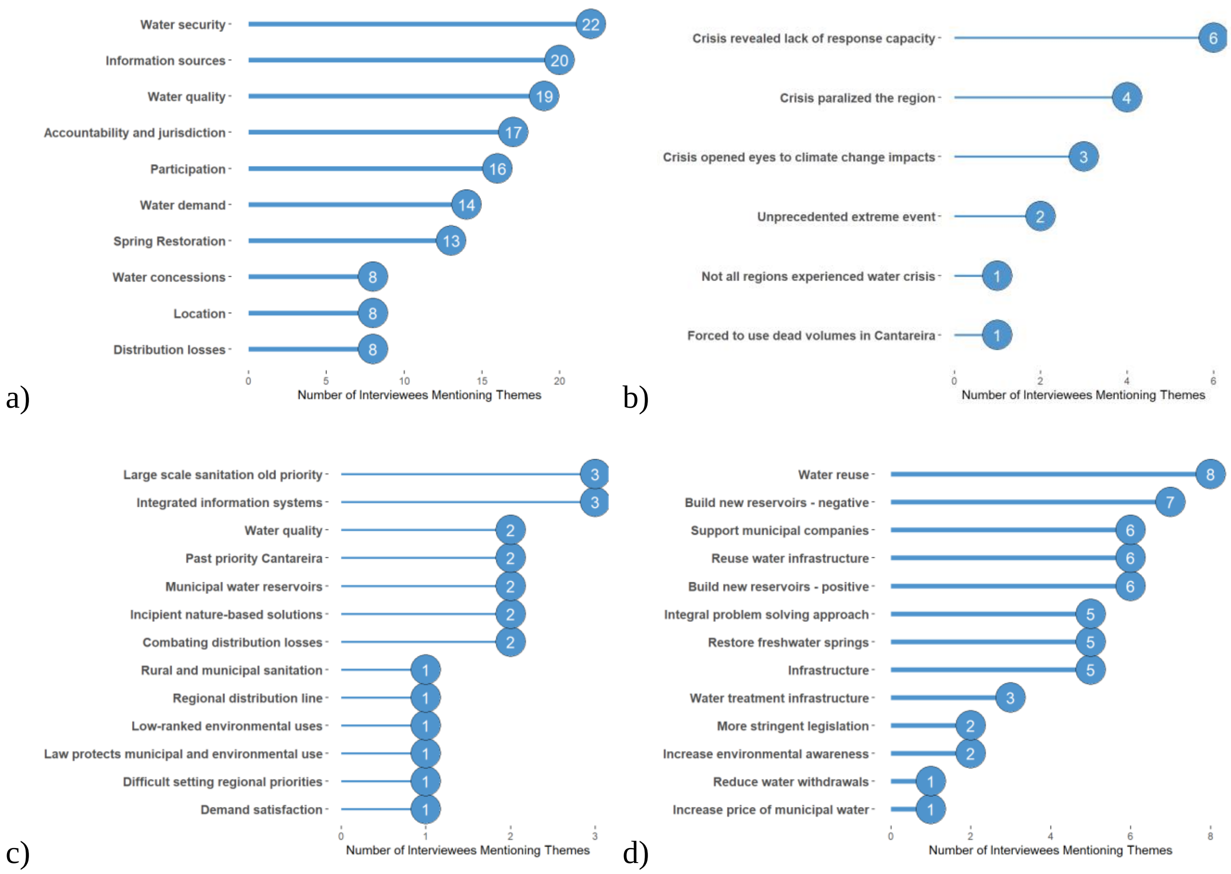


Figure 10. Overview of themes derived from semi-structured interviews regarding a) main challenges faced by the PCJ River basin, b) the 2014-2015 water crisis, c) main governance priorities, and d) preferred solutions for tackling challenges

4.5.4. Taking stock of extreme events

The water crisis had significant impacts on life along the PCJ basin. Economic activities and energy production were disrupted. Municipal water supply experienced difficulties throughout the region, with some cities being forced to find emergency sources after running out of water. There were also reports of considerable fish die-offs as river flows reached critically low levels. The stark negative social and well-being impacts of the crisis and its handling is still fresh in interviewees' minds. Some interviewees recalled particularly shocking impacts from the crisis. For example:

The crisis had terrible impacts throughout the region in terms of public health. There was an increase in diarrheal disease and hepatitis, among others. There were also massive fish die-offs. – ***Member of Public Prosecutor's Office***

During the crisis, we saw the largest economic engine for the ceramics industry in Latin America grind to a halt. Some hydropower plants had to stop operations because cities ran out of water and had to take it from those reservoirs. – ***State Agency Member***

Almost all interviewees recalled the crisis as a moment of shock and profound dismay. Several portrayed it as a moment of reckoning that initiated significant changes in the planning culture for the basin.

We were at fault for thinking a crisis like this one was impossible. We learned a lot during the crisis of 2014. It opened our minds, and we now have dedicated chapters in the Basin Plan to include the rural aspects, water supply, water quality classification, and groundwater. Those and climate change are now part of the discussion about water supply and water quality. We can now talk about an issue that is happening worldwide. – ***Member of Water Sanitation Company***

Interviewees expressed that PCJ Committee, and even the general population, learned from the crisis. Those emphasizing lessons learned frequently referred to the public being more aware of water scarcity and reducing their consumption (at least during the crisis). Lessons for the Committee revolved mainly around the need to diversify water supply sources, increase capacity at small municipal systems, and exploring nature-based solutions. However, not everyone agreed that the crisis created lasting changes in decision-making. Skeptics of long-term learning qualified water conservation efforts and emergency water supply sources as temporary adjustments.

People's memory is very short. We experienced the 2014-2015 water crisis and people have already forgotten the problem. We almost went through the same situation in 2018. We did not learn. You could feel the sense of desperation because no one prepared themselves. For example, a city that was left without water during the crisis and had to take water from other sources and improvise how to store and bring water stopped using, maintaining, even sold some of that infrastructure after the crisis. Cities like that one did not build new reservoirs, they did not control water losses, they did not search for new springs. It would be a different story if they had prepared. No one was ready for a similar crisis. – ***State Agency Member***

The water crisis added new dimensions to concerns about water security and incorporated climate change as a new fixture in the Committee's agenda. Most interviewees expressed concerns about rain pattern fluctuations and their implications on maintaining the already precarious balance between water supply and demand. In that sense, climate change is a disruptor making their already difficult job more complicated.

My perception is that we'll have more frequent extreme events. We'll have extreme drought, issues with flooding, equitable water access issues, and other events related to extreme scarcity. The problems with drought are important, yes, but it is my understanding that problems around scarcity are more dramatic. – ***Executive Agency Member***

During the dry season, it is my responsibility to establish the water volumes to be released from the Cantareira system. I consider the meteorological models, users' current *demands, and potential future scenarios to determine the amount of water that can be released from the reservoirs. I must always have a water conservation perspective, that is the challenge. There is a lot of uncertainty, and I am always trying to conserve water for next year. Given uncertainty about rains, if I release a certain amount of water thinking that rain will come, and it doesn't, then we'll have insufficient water in the rivers. That is a challenge for planning. –* ***Member of Industrial Users***

4.5.5. Shifting water governance priorities

From 2018 to 2020, the PCJ Committee engaged in an overarching planning process to define their master plan for the 2020-2035 period. As a result of this process, they published the 2020-2035 Basin Plan. Our interviews took place while discussions were taking place about the issues to be included in the Plan and the resources destined to address them. Overall, some issues have remained a priority for decades like improving wastewater collection rates in the basin. Another longstanding priority relates to procuring, storing, and managing water volumes to satisfy the basin's demand. This priority is currently shifting from a historical focus on managing the Cantareira system to increasing reservoirs along the basin and building water transfer infrastructure with other river basins. Other priorities fluctuate in importance depending on the changing conditions in the river basin. For example, combating water losses through updates to the water distribution system is experiencing a resurgence. Emerging priorities include tertiary water treatment infrastructure to remove nutrient pollution along with water spring protection and reforestation efforts. See Supplementary Table H in Appendix G for some of the qualitative evidence highlighting these shifting priorities.

4.5.6. Dealing with current and future challenges

To some extent, all interviewees agree that the PCJ Committee need to implement a combination of different strategies to deal with existing and emerging challenges. Disagreements lie on how much emphasis or resources should be allocated to each type of solution and whether the Committee should prioritize increasing available water or a more holistic approach. For fifteen interviewees (56%), infrastructure solutions represent an important component of the basin's efforts to deal with existing water scarcity issues and the threat of climate change. Infrastructure solutions frequently mentioned include the construction of two large new reservoirs along the basin, a large water transfer system connecting with the Paraiba do Sul River basin, large sewage infrastructure upgrades, small reservoirs for local water supply, and water retention projects near existing reservoirs. Interviewees holding positive views about increasing the built infrastructure of the PCJ basin emphasized their perceived potential for water flow regulation during the dry season, mitigate risk from drought, and satisfy increasing demand for sanitation services. Interviewees highly supportive of increasing built infrastructure framed it as the best solution to cope with climate change disruptions.

We need to reduce uncertainty about climate change and water supply. The solution is infrastructure for water storage, restoring riparian zones, and do water retention work. Right now, we don't have that. We have just started, these were not so necessary before, they are now. We cannot fight climate change; we can only build. – ***Member of Water Sanitation Company***

Not all interviewees agree with the view that built infrastructure is the best solution to the basin's challenges. Those skeptical of the purported benefits of increasing infrastructure, particularly new reservoirs, highlight challenges with eutrophication, land disputes, and increased risk of flooding in areas near the reservoirs. One interviewee focused on the time and resources sink represented by reservoirs, along with their vulnerability to changing rain patterns.

They explained how built infrastructure projects are resource intensive that not only take several years to be completed but can also crowd out other projects and take time before being fully operational. In addition, reservoirs may fail to provide expected benefits if changes in rain patterns either significantly decrease water available for capture or result in higher costs from increased flooding.

"[…] I am not very optimistic about it. We have observed that the rain periods, particularly in October are changing. Temperatures are rising, demand is rising, and we will consume more. Until we have the reservoirs, we are waiting for rains to behave. We have nothing in terms of public policy for dealing with the issue directly or that dictate what to do during extreme cases. Today when we have normal water levels everything works well, but we need a strategy for when we have a water deficit. People believe that any rain is enough to build a reservoir; then you hear the news that a reservoir is overflooding and water goes downstream but out of the river channel, and you lose all that water. For water to infiltrate, it needs to remain in place for a while; you need plants and roots to retain water otherwise water just runs off." – ***State University Researcher***

Infrastructure solutions to capture, store, and transport water are not the only strategy discussed by PCJ Committee members. Other infrastructure-related strategies mentioned include the construction of tertiary water treatment plants, the creation and regulation of a water reuse system across the basin, and investments in increasing the technical capacity of municipalities and small sanitation companies. Interviewees also mentioned the need for nature-based solutions such as spring restoration programs, investments in improving the Committee's monitoring and information systems, and policy or operational rules to change how the Committee responds to water stress. Given the uncertainty presented by climate change, it is unclear whether efforts taken by the PCJ Committee will be successful at preventing a crisis like that of 2014-2015. It is likely that decision-makers in the PCJ Committee will face difficult decisions about water rationing and trade-offs between the well-being of the basin's users. As one interviewee expressed regarding the water crisis:

I think we were already arriving at a critical state before the crisis. We had high rates of water consumption for all possible uses, then we arrived at a situation where you cannot use water. So, who should reduce their consumption? Where do you start? What should be the water use limit? These are very important questions. – ***State University Researcher***

4.5.7. Connecting past and future investments in the PCJ river basin

The focus on municipal water is also reflected on the basin's investment plans. Figure 11 shows historical investments in the PCJ river basin from three main funding sources: federal water collection fees, state water collection fees, and the State of Sao Paulo's Water Resources State Fund (FEHIDRO from its name in Portuguese). Investments performed between 1994-2018 show that over 60% of resources from all sources were destined to infrastructure directly related to municipal water users (primarily through sanitation and loss control infrastructure). Categories such as data collection, environmental education, reforestation, and water resources management received between 1% and 7% of total available funds.

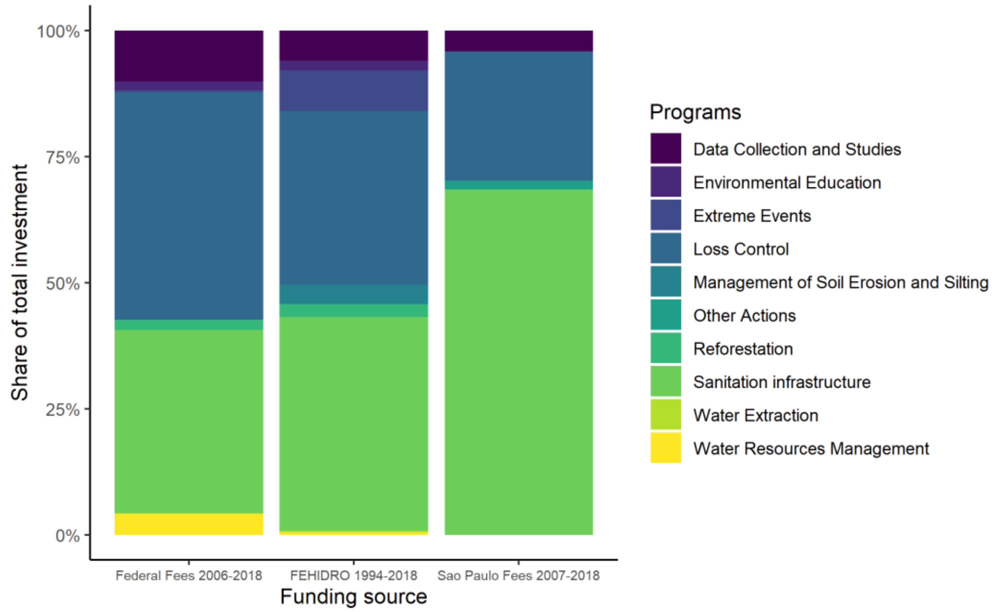


Figure 11. Historical investments by general category undertaken in the PCJ basin from 1994-2018

The historical preference for grey infrastructure remains present in the 2020-2035 PCJ River Basin Plan. The Plan contains 115 priority actions that the PCJ basin hopes to implement in the next 15 years. Each action is associated to a specific planning category (e.g. classification of surface water, water supply and drainage, environmental education) and ranked from very low to very high priority. Table 4 categorizes planned actions by theme and assigned priority. The table shows a cluster of medium, high, and very high priority actions associated with sanitation and water treatment infrastructure. At the same time, the expected costs of all actions shows a marked burden from infrastructure projects, see Table 5. Approximately 90% of expected costs correspond to the sanitation and water treatment actions.

Ranking of Proposed Management Actions in 2020-2035 Basin Plans

Category	Priority	Share of Estimated Cost (%)
Data	High	0.01
	Very High	0.85
Environmental Education	Very Low	0.02
	Low	0.11
	Medium	0.04
	High	0.08
	Very High	0.24
Environmental Programs	Very Low	0.01
	Low	0.03
	Medium	0.09
	High	0.35
	Very High	1.26
Groundwater	Very Low	0.18
	Medium	0.93
	High	0.13
	Very High	0.27
Sewage	Very Low	0.01
	Low	0.21
	Medium	1.32
	High	85.27
	Very High	5.84
Water Fees	Very High	0.02
Water Management	Low	0.01
	Medium	0.00
	High	0.01
	Very High	0.01
Water Supply & Drainage	Very Low	0.02
	Low	0.11
	Medium	0.42
	High	1.98
	Very High	0.15

Table 4. Actions established in the 2020-2035 PCJ River Basin Plan by category and assigned priority

Estimated Cost of Planned Investments by Thematic Category

Theme	Program	Estimated Cost (BRL)	Share of Estimated Cost (%)
Surface Water Quality Classification			
Thematic Axis 1	Universal collection and treatment of sewage	3,618,525,224.3	47.49
Thematic Axis 2	Strategies for tertiary treatment deployment	3,092,847,716.4	40.59
Thematic Axis 3	Strategies for removing polluting loads of diffuse origin	273,451,406.6	3.59
Thematic Axis 4	Training in Sanitation	400,000.0	0.01
Water Supply and Drainage			
Thematic Axis 1	Institutional strengthening, planning and management of water resources	9,945,480.0	0.13
Thematic Axis 2	Special projects of regional character	13,185,024.4	0.17
Thematic Axis 3	Support to municipalities of PCJ Basins	94,680,161.2	1.24
Conservation, Land Use, and Water in Rural and Forest Areas			
Thematic Axis 1	Watershed Protection Forest and recomposition	90,683,489.0	1.19
Thematic Axis 2	Efficient Use of Water and Soil Conservation in Rural Areas	8,827,904.8	0.12
Thematic Axis 3	Rural Sanitation	11,205,129.4	0.15
Groundwater			
Thematic Axis 1	Information on water resources	4,776,250.0	0.06
Thematic Axis 2	Planning and scientific development on a regional scale	20,550,000.0	0.27
Thematic Axis 3	Planning and scientific development in urban scale	28,900,000.0	0.38
Environmental Education, Integration and Dissemination of Research and Technology			
Thematic Axis 1	Institutional strengthening, planning and management of water resources	12,950,000.0	0.17
Thematic Axis 2	Institutional communication of the PCJ Committees and dissemination of research and technology in water resources	15,289,962.9	0.20
Thematic Axis 3	Technical training related to planning and management of water resources	5,683,914.6	0.07
Thematic Axis 4	Environmental education focused on conservation of water resources in rural areas and protected areas	386,309.7	0.01
Water Resources Management			
Thematic Axis 1	Operational Support and Technical Support	176,850,000.0	2.32
Thematic Axis 2	management tools	139,766,240.2	1.83
Thematic Axis 3	The relationship between Basin Committees	1,390,000.0	0.02

Table 5. Expected costs of planned actions by category included in 2020-2035 PCJ River Basin Plan

4.6. Discussion

Deciding which water users will experience water restrictions during times of scarcity is one of the most difficult tasks faced by members of the PCJ Committee. Our research shows that given high water-availability, distribution among water users in the PCJ River basin is fairly equitable. Municipal users and the environment receive slightly more than 25% of total water available, while industrial and agricultural users receive slightly less. Results also show that, faced with hypothetical decreases in water availability, decision-makers in the PCJ River basin will allocate more water to municipal users, often at the expense of industrial and, potentially, agricultural users. This could stem from a greater ease of enforcing water reduction for industrial users with respect to agricultural users. In Brazil, agricultural users are notoriously hard to monitor in terms of water use, while industrial users are more heavily regulated. The reflection of this pattern in the hypothetical situation presented by the survey's scenarios may indicate decision-makers at PCJ Committee have internalized this oversight and enforcement difference into their day-to-day decision-making. However, given survey respondents high level of agreement with pro-social and pro-environmental attitudes, along with a tendency for equitable water allocations under normal conditions, we assume that water allocation strategies that consistently jeopardize the well-being of industrial or agricultural users is not the PCJ Committee members' preferred alternative.

Results from our behavioral experiments are partially consistent with emergency allocation decisions taken during the water crisis of 2014-2015. At the height of the crisis, industrial users and hydropower generation stopped to preserve water for human consumption. Restrictions were also implemented to restrict water for irrigation, but it is unclear if those measures were fully enforced. The discrepancy between behavioral experiment and measures taken in 2014-2015 arises in the topic of water for environmental flows. Contrary to what respondents expressed in a hypothetical scenario, the 2014-2015 crisis resulted in particularly intense fish die offs due to low water flows in rivers across the basin. Although fish die offs are not a rare occurrence at the PCJ basin, they are an extreme example of the high costs of water rationing measures, particularly for users with very limited capacity to find alternative water sources. This result highlights the importance of relating planning strategies and their potential outcomes in terms of reducing the need to take extreme water rationing measures in times of water scarcity.

Water rationing is not the only tool available to PCJ Committee members for coping with uncertainty and water scarcity. The analysis of semi-structured interviews, and the review of the PCJ's Master Planning documents, provide a glimpse of the investment and policy tools being considered by the PCJ Committee to face the basin's water security challenges. The PCJ

Committee is considering strategies ranging from investments in inter-basin water transfers, the expansion of water storage capacity for small municipalities, and more sophisticated water treatment facilities, to water loss reduction programs, and nature-based solutions restoring and protecting water springs. Among available strategies, there is a preference for options associated with traditional grey infrastructure in the shape of reservoirs, sewage system improvements, and large water transfer investments. The pursuit of these strategies is consistent with having municipal water use, and increasing water security for this sector, as a top policy priority.

It is unclear if pursuing grey infrastructure strategies will indeed guarantee water security for municipal users, especially when faced with similar extreme events to those of 2014-2015. Grey infrastructure projects are expensive in nature and are forecast to take up most of the PCJ's future financial resources. Pursuing these investments may preclude the PCJ Committees from pursuing a broader set of strategies, including hybrid infrastructure projects or nature-based solutions, with lower costs and more moderate benefits enjoyed by multiple water users. Ultimately, efforts to protect municipal users may fall short if chosen strategies fail to withstand extreme events or effectively ration water consumption from industrial or agricultural users.

Although our statistical models suggest that industrial and agricultural users are the preferred water donors in cases of water scarcity, there is no guarantee that this would be the outcome outside the realm of hypothetical scenarios, particularly in terms of reducing water for agriculture. Water managers at the PCJ river basin may have a difficult time monitoring water for agriculture, which is primarily sourced from groundwater in the PCJ basin and informal wells are hard to locate and difficult to monitor constantly. Water managers may be more capable of monitoring water use compliance by industrial users along the basin, but the economic costs of these disruptions eventually translate to negative social outcomes. In addition, the increasing presence and engagement by PCJ Committee members representing industrial users, agricultural users and the environment may provide an increasingly stronger obstacle to implementing water rationing measures that conceive industrial and agricultural water users as the primary water donors in the basin.

4.7. Conclusion

Insights from the PCJ River basin can help practitioners and policymakers both in Brazil and other regions worldwide understand the links between water rationing strategies and long-term planning strategies when dealing with water scarcity. The PCJ River basin is not the only basin around the world that prioritizes municipal water users, has invested heavily in grey infrastructure solutions, and is expected to continue these investments in the future. There is no intrinsic fault in such a preference, but the trade-offs associated with prioritizing one type of water user without mitigating the potential risks for others may prove unsustainable as climate change impacts intensify. In the case of the PCJ basin, the reliance on grey infrastructure projects for bolstering water security in a highly urbanized region may increase vulnerability of industrial and agricultural users if increased water supply capacity is unable to deal with extreme drought and decreasing water quality. The participatory nature of the PCJ Committee has created spaces for exploring alternative strategies. However, this process has not yet translated into an aggressive pursuit of alternative strategies (Almazán-Casali et al., 2021).

Our results show that PCJ Committee members perceive municipal users as the priority user but disagree on how to tackle future water scarcity to protect these and other water users. Although the desire for pursuing both nature-based solutions projects is already present at the PCJ Committee, this desire remains aspirational and is not supported by budgeting decisions that favor traditional infrastructure investments. This discrepancy, combined with other social factors like power and authority, may result in investment strategies that exacerbate existing inequalities and reinforce the vulnerability of water users considered water donors in times of scarcity. Grey infrastructure has well-known limitations for dealing with climate change disruptions with an increasing consensus that hybrid infrastructure approaches integrating grey, green, and blue infrastructure is necessary for dealing with future challenges (Depietri & McPhearson, 2017). Green and blue infrastructure approaches fall in the category of infrastructure focused on preserving, restoring, or mimicking the functionalities of natural ecosystems along with other approaches such as nature-based solutions, ecosystem-based adaptation, and ecosystem services (Nika et al., 2020). At their core, all these approaches are characterized by striving for multifunctionality adjusting human infrastructure to both reduce its impact on ecosystems and better integrate with remaining natural systems to restore some of the functionality of now degraded ecosystems (Pauleit, Zölch, Hansen, Randrup, & Konijnendijk van den Bosch, 2017).

The benefits derived from each type of infrastructure varies across different water users, changing the relative appeal that each option has for decision-makers. However, the focus on priority users when comparing potential benefits of future investments may overlook potential gains in protecting water users that will bear the brunt of rationing decisions. Making implicit water user hierarchies explicit can help decision-makers evaluate the tradeoffs associated with their planning strategies and whether expected outcomes are compatible with individual values and overall water allocation goals. Insights derived from the PCJ basin can provide a useful example for practitioners hoping to identify potential unexpected links and tradeoffs of the criteria used to guide water allocation practices. Being cognizant of the implicit tradeoffs may also help decision-makers break existing path-dependences as areas where decision-makers' strategies are in odds with their expressed priorities become clear. In this sense, our research provides an example of relevant information that can help both researchers and practitioners evaluate the tradeoffs associated with water governance strategies. In terms of contributing to future research and practice, our results can inform scenario analysis and the evaluation of different governance strategies based on their impacts over different water users and expected water rationing strategies. This information can contribute to establishing management practices that are more consistent with managers' broader governance objectives and reduce the risk of requiring costly water rationing measures.

Chapter 5. Conclusion

The dissertation establishes a general framework for analyzing the effects of power in water governance systems. The power-centric framework I proposed links existing theoretical frameworks for analyzing the complex dynamics of environmental governance, mainly the IAD and SES frameworks, with recently developed typologies of power. As such, it carves an interdisciplinary research approach that will facilitate using theories of power in applied research and modelling of SES. This dissertation also presents a case study example of the preliminary research necessary for establishing solid modelling foundations of power dynamics in SES. The insights derived from qualitative and quantitative research on the PCJ Committee’s water allocation and planning strategies highlights the advantages of leveraging mixed-methods research approaches. Results presented in chapter three and four provide concrete examples of different types of power currently deployed in the PCJ Committees. More importantly, results provide an example of how the exercise of power relates to climate adaptation efforts in the PCJ River basin.

5.1. Summary of Findings

The framework presented in Chapter 2 provides a foundation for connecting investigations of power to empirical research of SES trying to ascertain the system-wide impacts of governance decisions. Research conducted in the PCJ basin provides an example of how researchers can operationalize theoretical definitions of power in empirical research of water governance systems. In terms of specific contributions to our understanding of Brazilian water governance, results from the empirical research presented in chapters three and four of this dissertation contribute to our understanding of the processes and power dynamics that influence how the PCJ River basin responds to climate change impacts and selects policy and planning strategies for the future. Chapter three highlights the importance of technical experts' WoKs in informing the issues considered as priorities and the set of strategies deemed suitable to address them. In this sense, WoKs, considered an expression of framing power, are another aspect of decision-making that uphold path-dependencies locking water governance into traditional approaches. The disproportionate influence that some WoKs have on governance approaches is explained when considered in tandem with the hierarchy and respect, an expression of pragmatic power, enjoyed by individuals who hold them. In the PCJ Committee, the respect enjoyed by technical experts with an engineering background, and its associated WoK, may represent one of the most important hurdles for transitioning to adaptive governance approaches in the PCJ river basin. The prevalence of an engineering WoK contributes to the path-dependence that locks the PCJ basin into traditional infrastructure projects as the primary strategy for increasing water security, despite the growing presence of WoKs more akin with green-infrastructure and nature-based solutions.

Chapter four provides insights on the implicit tradeoffs associated with water allocation priorities defined by Brazilian legislation, and followed by managers at the PCJ Committee, that place municipal water use as priority users. Our results emphasize how strategies designed to protect municipal users, both via investment plans and water rationing strategies, may increase vulnerability of other water users, particularly industrial users. In addition, these results need to be contextualized within the larger governance system of the PCJ Committee. The polycentric nature of Brazil's water governance system implies that different levels of government and sectors of society have representation in its river basin committees. Therefore, we must assume that the PCJ basin's water users, and their representatives, will deploy the power they possess to either alter or maintain existing governance strategies. The dynamic nature of the PCJ's governance system highlights the value of research approaches that can explore plausible outcomes of the interplay of different agendas, interests, and power differentials in the PCJ Committees. The ability to explore unexpected, or emerging, governance outcomes derived from power dynamics in the PCJ basin is of great importance given increased uncertainty about water availability and different coping capacities of the basin's water users.

5.2. Case Study Limitations

As is frequently the case in empirical research, this dissertation could have benefited from a larger data collection process both in terms of case study locations and sample size of data collected. Research results may have been more generalizable, at least for the broader Brazilian context, had interviews and surveys been deployed in multiple river basin organizations in Brazil. In addition, the statistical analysis may have benefited from a larger sample size in terms of perhaps being able to perform a more robust statistical analysis of the within-subjects' behavioral experiments about the impact of previous water crises on water decisions today.

Although the survey was sent to 600 potential participants, only 110 Committee members started the survey, and only 74 of them completed it. Although this sample size presented no problems for the analysis of two of the behavioral components of the survey (i. e., the value-attitude index and the water allocation experiment), it may have limited our ability to perform a robust statistical analysis of the third component: the water storage and previous water crises experiment. This limitation arose from the nature of the experiment's design. As is standard practice for experiments priming respondents to certain information, we followed a between-subjects to avoid confounding effects and bias in survey responses. As a result, despite having more than 70 overall responses, there were between 22 and 26 responses for each of the three scenarios included in the experiment. The limited sample size may have made it impossible to discern any systematic difference in water storage decisions based on the recollection of previous extreme water events. This dynamic will need to be explored further in future research.

Another limitation of this study relates to limited stakeholder engagement. The researcher performed a 3-month long visit in the Fall of 2018 for initial data collection. The original research plan contemplated presenting initial results to Brazilian stakeholders and the deployment of focus groups running role-play water allocation games. Unfortunately, the Covid-19 health crisis made a return trip to Brazil impossible. Continued engagement with Brazilian stakeholders would have helped corroborate the insights and understanding of the decision-making process at the PCJ Committees. Despite these limitations, this dissertation provides a valuable contribution to our understanding of the influence of power dynamics on system-wide water governance outcomes.

5.3. Future Research

As previously mentioned, this dissertation provides the foundations for analyzing the effects of power dynamics in SES. Future research consists of categorizing research insights based on theoretically informed types of power like those presented by Morrison et al. (2017, 2019). For example, the observed correlation between PCJ Committee members' WoKs and planning preferences can be interpreted as an expression of framing power. Framing power, in this case, is closely related to the exercise of pragmatic power through which PCJ Committee members wield the hierarchy and respect they enjoy to further advance their planning preferences. As such, the ability of PCJ Committee members to establish priority issues for the basin, and how best to tackle them, has a significant impact on the type of solutions considered in participatory decision spaces. The impacts of framing and pragmatic power extend even further by indirectly affecting the outcomes of water rationing strategies. I hypothesize that one mechanism through which these two types of power affect water rationing strategies is by influencing investment portfolios which, in turn, influence total water availability in the PCJ basin. Investments and planning strategies greatly determine water storage capacity and the quality of stored water. Different management approaches (i.e., grey infrastructure, green-blue infrastructure, and nature-based solutions) provide different benefits in terms of water storage capacity and water quality improvements. This way, investment and planning preferences influence the total water available to distribute among water users in times of scarcity.

The PCJ River basin and the PCJ Committee, however, are not static systems. The participatory nature of the PCJ Committee, a quality inherent to all polycentric systems, holds the seeds to push-back against the status quo. My research shows that, although engineering WoKs and management approaches are prevalent in the PCJ Committee, Woks associated with environmental and rural agendas (along with the respect enjoyed by technical experts who hold them) are slowly, yet surely, gaining ground. The lack of a complete water rationing order stipulated by Brazilian law, outside of the protection of municipal users, further opens the possibility for other users to wield their framing and pragmatic power as they attempt to avoid the worst outcomes of water rationing. The potential outcomes of these interactions cannot be fully anticipated given the complex nature of the PCJ River basin. However, my dissertation provides enough background information to systematically explore plausible outcomes of these interactions using SES modelling tools focused on the planning and water allocation process of the PCJ Committee.

Other avenues for future research include coupling SES models of power in decision-making processes with hydrological models that can assess ecosystem impacts of changes in water quality, average river flows, and concentrations of key pollutants associated with changes in planning strategies. Similarly, the application of the framework presented to other river basin organizations can contribute to the comparative analysis of system-wide impacts of power dynamics in different governance systems. Multi-site analyses are possible given the flexibility of our theoretical framework and the fact that is grounded on theories of power, environmental governance, and SES frameworks that provide a basis of comparison for very context-specific dynamics.

Appendices

Appendix A. List of Reviewed Policy Documents Related to Brazilian Water Governance

Level	Title	Type	URL
State	Plano Estadual de Recursos Hídricos de 2016 a 2019	State Water Planning	https://sigrh.sp.gov.br/public/uploads/ckfinder/files/PERH%202016-2019%20INTERNET%20225%20dpi.pdf
State	Plano Estadual de Recursos Hídricos - PERH 2020 - 2023	State Water Planning	https://drive.google.com/drive/folders/1qtDMW_xpyrdvjuT8D_dDjcTfioyaW0M_?usp=sharing
Regi	Plano	Region	http://www.comiteps.sp.gov.br/noticias/plano-diretor-de-

onal	Diretor de Aproveitamento dos Recursos Hídricos para a Macrometrópole Paulista	al Water Planning	aproveitamento-dos-recursos-hidricos-para-a-macrometropole-paulista
Basin	Plano de Bacias PCJ 2020-2035	Water Basin Plan	https://www.comitespcj.org.br/index.php?option=com_content&view=article&id=957:pb-pcj-2020-2035&catid=148:plano-das-bacias&Itemid=332
Basin	Plano de Bacias PCJ 2010-2020	Water Basin Plan	https://www.comitespcj.org.br/index.php?option=com_content&view=article&id=341:plano-de-bacias-pcj-2010-2020&catid=148:plano-das-bacias&Itemid=332
Basin	Resolutions of the PCJ Committe	Water Basin Resolutions	https://www.comitespcj.org.br/index.php?option=com_content&view=article&id=181&Itemid=223

	e		
Basin	Meeting Minutes of Technical Chamber of the PCJ Committe e (CT-MH, CT-RN, CT-Rural, CT-PL, CT-PB)	Meetin g Minute s	https://www.comitespcj.org.br/index.php?option=com_content &view=article&id=279&Itemid=192
Basin	Relatório Institucion al da Agência de Bacias PCJ 2020	Execut ive Agenc y Report	https://agencia.baciaspcj.org.br/institucional2020/

Appendix B. Informed Consent Form and Interview Protocol Used During Semi-Structured Interviews With Members of the PCJ Committees

Informed Consent Read to Study Participants

You are invited to participate in a research study about the decision-making and planning process at the Piracicaba, Capivari, and Jundiaí Basin Comittees (Comitês PCJ). The research study focuses on three topics. 1) How are issues of concern for different stakeholders incorporated into the Comitês PCJ agenda. 2) How do Comitês PCJ determine priority water issues to be addressed by the Planos de Bacias and 3) How do challenges associated to climate change affect planning and management priorities for the Comitês PCJ.

If you agree to be part of the research study, you will be asked to answer several questions as part of a semi-structured interview and provide your perspective on the topics addressed by questions. By participating in this research study, you authorize researchers to audio-record interviews. You also authorize researchers to use excerpts from interview transcripts as de-identified quotes.

Benefits of the research relate to increased understanding of how different perspectives, interests, and priorities relating to water management and response to climate change influence planning decision in the Comitês PCJ.

There are no significant risks and discomforts expected as part of this research.

There is no compensation associated with participation in this research study.

Participating in this study is completely voluntary. Even if you decide to participate now, you may change your mind and stop at any time. You may choose not to continue with the interview or answer any particular question during the interview for any reason.

We will protect the confidentiality of your research records by storing collected data in secure servers. We will protect your identity by conducting data analysis using de-identified data. Information collected in this project may be shared with other researchers, but we will not share any information that could identify you.

A) *I consent to participate in the research study and for the interview to be recorded.*

B) *I consent to participate in the research study, but I do not consent for the interview to be recorded.*

Interview Protocol

Note: Text in *italics* corresponds to prompts and cues for the interviewer.

Introduction:

Thank you for taking some of your time to participate in our research study. We are interested in learning about the planning process at the Comitês PCJ, how issues of concern are brought to the attention of the Comitês PCJ, how issues are discussed and actions taken. We also want to know about the water challenges faced by the PCJ basin and expected challenges in the future, particularly those associated with climate change.

Before we begin, do you have any questions about the purpose of the interview?

Let's begin. Please,

1. Tell us your role in the Comitês PCJ.
    a. *Represented sector (government, municipalities, civil society)*
    b. *Represented organization*
    c. *Main responsibilities*

1.1. Are you a member of other organizations that interact with the Comitês PCJ (Câmaras Técnicas, Agência PCJ, Consórcio PCJ, other)
- *If yes, tell us about role in other organization*
- *Tell us about the relation between your role in different organizations and the Comitês PCJ*

Topic 1: Perception of main issues faced by the PCJ basin

Tell us a bit about current water issues here in the PCJ basin.

2. In your opinion, what are the issues currently faced by the Piracicaba, Capivari, and Jundiaí river basin?
3. Out of the issues you mentioned, which ones do you identify as the most pressing?

Topic 2: Climate change and risk perception

Now, we want you to think about the future of the PCJ basin.

4. From your perspective, how do you think the current issues faced by the river basin will differ from those of 2030 (end of planning horizon for upcoming Plano de Bacias)?

5. Describe the ways in which you expect changes associated with climate change to affect water users in the PCJ basin.
6. Based on your previous response, which would you consider to be the most impactful changes associated with climate change?

<u>Topic 3: Role and sources of knowledge</u>

Thinking about the issues you just mentioned, tell us:

7. Which are the main sources that you consult to get information about the status of the PCJ basin?
    - *a. Technical data*
    - *b. Past experience or professional judgement*
    - *c. Experiences from other members at your organization*
    - *d. Academic research*
    - *e. Other*

    7.1. Please provide examples of the sources of information you have mentioned. E.g.
    - *i. Hydrological data from telemetry system*
    - *ii. Information from the Sala de Situação*
    - *iii. River Basin Plans*
    - *iv. Technical reports from government agencies (ANA, INPE)*
    - *v. State or Federal reports*
    - *vi. Scientific publications*
    - *vii. Institutional reports/operation manuals*
    - *viii. Traditional knowledge (refers to collective experiences passed down from generation to generation, understandings of physical phenomena not collected through the scientific method)*

8. When you need to make a management or planning decision, which sources of information do you rely on the most to inform your decision?

<u>Topic 4: Perception of stakeholder-specific issues</u>

Let's focus on the issues relevant for the group or organization you represent at the Comitês

PCJ.

9. From your perspective, what are the most pressing water issues faced by your group?
    - *a. Water quantity/Access to outorgas*
    - *b. Water quality*
    - *c. Water delivery issues*
    - *d. Consistency in water access*
    - *e. Cost of water access*
    - *f. Funds for required investments*
    - *g. Not a priority in planning process*

Topic 5: Preferred solutions to perceived issues

We would like to know your thoughts on how to address the issues you have mentioned. Please tell us,

10. From your perspective, what concrete actions can the Comitês PCJ take to address the issues of most concern to you?

Topic 6: Power dynamics in decision-making process

Now we want to talk about how you try to raise your group's issues at the Comitês PCJ.

11. Which section of the Comitês PCJ or associated organizations (CTs, Agência PCJ) do you approach when you (or the group you represent) want to submit a particular issue for consideration by the Comitês PCJ?
12. From your perspective, which individuals or groups play a crucial role in determining the issues discussed and evaluated by the group you specified?
13. Which other groups or participants at the Comitês PCJ do you reach out to when trying to raise attention upon an issue of concern to you?
    - f. Groups in same sector (government, municipalities, civil society)
    - g. Groups in other sectors

Topic 7: Flexibility of decision-making process

Let us take a step back and think of the general decision-making process at the Comitês PCJ and dealing with crisis or changing conditions.

14. How would you characterize the Comitês PCJ's ability to adapt management priorities and plans in response to changes in water availability or water requirements in the basin?
15. What are the main challenges preventing the Comitês PCJ from effectively responding to a changing climate?

Definitions

Issues faced by basin: Refers to characteristics, processes, or circumstances, experienced in the basin, associated to less than ideal conditions of water quality, quantity, distribution (in time and space) that impede satisfaction of human and environmental needs and interests (currently and in the future).

Sources of information: Refers to any source that interviewees consult to inform their understanding of the issues faced by the basin. E.g. hydrological data from telemetry system, technical reports from PCJ, academic research, traditional knowledge, experiences from constituents).

Perception of the basin: Subjective evaluation of the status of the basin in terms of its ability to satisfy the needs and interests of those living in it. May include environmental needs and interests.

Appendix C. Interview Codebook Corresponding to Relevant Themes Identified During Interview Analysis

Theme	Coding
Challenges	Accountability and jurisdiction over issues
	Distribution losses
	Information sources
	Location
	Participation
	Spring Restoration
	Water concessions
	Water demand
	Water quality
	Water security
Participation	Active and vocal members are agenda setters
	Challenging to address everyone's interests and priorities
	Civil society does not feel heard or participants of decision making
	Committees need new people, fresh ideas and

	innovation
	Experienced participants have important historical knowledge
	Financial cost as deterrent to participation without a backing organization
	Governor imposition of water use during crisis disincentivized participation
	High positions in Committees always on municipalities and state agencies
	More participation in Committees brings more resources
	Outreach required to attract smaller municipalities
	Participation is very susceptible to changes in personnel at public agencies
	Partnerships between Committees, its members, oversight agencies, and municipalities
	Sanitation companies are very active
	Some CTs have low participation, people only go to comply, not really engaged
	Universities no longer allowed to participate as civil society
	Very local NGO participation
Potential Solutions	Build new reservoirs - negative
	Build new reservoirs - positive
	Increase environmental awareness

	Increase price of municipal water
	Infrastructure
	Integral problem solving approach
	More stringent legislation
	Reduce water withdrawals
	Restore freshwater springs
	Support municipal companies
	Water reuse infrastructure and practices
	Water treatment infrastructure
Priorities	Cantareira System is a past priority
	Combating distribution loses
	Demand satisfaction
	Difficult setting regional priorities
	Incipient nature-based solutions
	Integrated information systems
	Large scale sanitation is an old priority
	Law protects municipal and environmental use
	Low-ranked environmental uses
	Municipal water reservoirs

	Regional distribution line
	Sanitation rural and small municipality
	Water quality
Water Crisis	Crisis opened eyes to climate change impacts
	Crisis paralyzed the region
	Crisis revealed lack of response capacity
	Forced emergency measures for water in Cantareira System
	Not all regions experienced water crisis
	Unprecedented extreme event

Appendix D. Qualitative Evidence From Interviews With PCJ Committee Members on Topics Relating to Woks

WoKs	***Integrated Water Resources Approach***	***Qualitative evidence***	***Environmental Approach***	***Qualitative evidence***
Advocates	Primarily engineers, local politicians, water state agencies	"The issue of climate change now emerged from the crisis of 2014. It is thought recently here as a limiting factor of water resources. That's because the water company is an engineering company, 99% of the coaching staff are engineers, mainly civil engineers. You do not have the mindset and vision to relate engineering, the environment, and water resources. In the company's long	Ecologists, environmentalists, biologists, social scientists, NGOs.	"The State's agenda for water resources relies only on engineering. The more environmental-oriented agenda emerged recently but has its days numbered. Unfortunately, the focus is much more on engineering: on building new reservoirs and interconnecting river basins. We have to be much more than this engineering agenda. We need to have an environmental recovery agenda in

		history, I am the first biologist to assume the position of environmental manager at the company. It is one thing I'm breaking that paradigm. It is cultural exactly, it was a cultural shock to get someone who brings an environmental vision from the PCJ Committees, which are important management reports and participate in committees and networking. It has been a challenge; it is difficult to get there. And we will move a little glimpse of something fully developer-oriented to something else, it is a painstaking task." Water Sanitation Company Employee		dam areas around the Cantareira system." - State Agency Employee

Water	Water as a commodity	"The Committee itself is not interested in environmental services; it is only interested in producing water." - State Agency Researcher "Noting the extreme weather events in the world, what are they doing? Dams, dams for you offset the climate anomalies. We live in an eternal conflict, because we are a donor water basin for the Metropolitan Region of Sao Paulo. Sao Paulo also demands and needs this water." Water Sanitation Company Employee	Nature as water producer	"When I arrived eight years ago, there was no CT-Rural. We were simply rural water users, now we are considered water producers. There's been a shift in the prioritization of resources. We showed to the PCJ that the farmer is a producer of water, that yes, we are users but also producers because we use very little water since most infiltrates and returns to the river. With these conversations and discussions, we managed to change the conversation. It was worth the effort. Before, the work was mainly urban, they did not focus on rural problems. Then we started having people at the PCJ Committees, then came our agenda. Today we have

				enough support at PCJ."- Member of Rural Syndicate
Preferred solutions	Grey infrastructure: reservoirs, water transfer systems	"It is not known whether the drought will be longer and more intense, if it will be a shorter period of more heavy rain showers. That's a scenario but say it may be that the amount of water is the same, only with a different distribution throughout the year. In that case, engineering solutions work because the solution is to build reservoirs." State Agency Employee	Green infrastructure, experimentation through pilot programs, nature-based solutions	"We have now achieved a paradigm shift within the committees and introduced green infrastructure. We have broken the idea that water infrastructure is only gray infrastructure. Until now, we have invested 99% of our resources in gray infrastructure. - State Agency Researcher" "I think we have the conditions to do everything. We could have the dams and do the water capture work, water treatment, alternative water sources, and improve spring protection, reforestation, and roots to help water retention, address agriculture and pollution issues.

				It is a fairly integrated system with many factors, and they are all important. - State University Researcher”
Kind of knowledge	Rational / cartesian / engineering approach	“Climate change is happening, but my opinion is very different from many others. What we have to do is prevention and that means infrastructure. Because with the changes, the reservoirs are not for drought mitigation but also flood control. The engineering vision imposes itself a bit because engineers are very pragmatic. We (engineers) need to be a little more like poets and social engineers. Solutions cannot be at either extreme. Neither do away with all the infrastructure nor just only plant trees. We have to find a balance to address the	Multiple sources of knowledge	"The Committee has a (social) conscience, a critical mass, that also brings the possibility of discussing many topics and sharing (different) realities. This has fostered participation which invariably leads to interaction with stakeholders at the local level." - Employee of Public Prosecutor's Office

		environmental issues and also the infrastructure issues. Environmentalists are here to stay, so you have to find that balance. We still have *eco-chatos** on the PCJ committees, as well as very *Cartesian*** engineers. I think there has been a change of vision in the Committees and now we need to find the balance between the environmental and the pragmatic." - Water Sanitation Company Employee *Eco-chato is a disparaging term for someone who constantly directs the conversation to environmental issues similar to the English common expression "broken record".		

		** Cartesian is an adjective used in Brazilian Portuguese to describe an individual who is extremely rational and methodical.		
Level of influence	High overall	"We are perhaps one of the largest and most active groups in the public sphere. Not all groups have the same spotlight and media presence. In general, we work elaborating public policy recommendations for local governments, representatives, and other high-level decision makers." -Member of Professional Association of Sanitation Engineers "The group of technical experts from SABESP is very strong. The group from	Low overall, except for the rural/environmental sector	"We need a change in mentality at the Committees. We have a lack of new people that are engaged. Most new people are coming out of obligation, and it is difficult to engage people from all sectors. We find it very difficult to get the population participating and involved in decisions. We have low participation from NGOs with leaving vacant seats for the sector. We need new people because new people bring new

		the water sanitation company in Campinas is strong too. They have an office with experts dedicated to their water sustainability plans. They have political influence that we cannot even dream off."- Water Sanitation Company Employee "Information asymmetry is real. Smaller municipalities have less access and participate less. Some have difficulty attending the meeting. Without participating they do not have access to resources. The larger companies, like SANASA, have many people participating with a high technical expertise. They have access to inside information, mainly at the technical		ideas and perspectives." - RBO Employee "Before, you had few people from rural areas, most of the work at the PCJ was urban, it didn't focus on the rural problems. As representatives from the rural sector started participating at the Committees our agenda started getting considered. Today, we have a lot of resources from the PCJ, and we do activities based on what is available in the yearly planning." – Member of Rural Syndicate

		level. Smaller municipalities have difficulty understanding this articulation as it has several actors and governance is complicated. Municipalities do not understand. It is a very complicated process until you get the resources. It is a skilled process: technical demand, project development, knowledge of the rules of the game, so this is fundamental. So, you have this asymmetry itself, a municipal technical limitation that does not have someone full time." - Water Sanitation Company Employee		
Frameworks	IWRM, Water Security (narrow view)	"At the beginning when I joined the committee, all the focus was on Cantareira, like they have all the water there and everything would work. But	Water security (broader view), Adaptive management,	"Obviously you have a more environmental staff that understands that the solution is nature-based solutions. There are other segments that

		they moved from this obsession to find alternatives since negotiating with SABESP is impossible. Then the focus shifted to trying to increase investments in watershed level, looking for alternatives and we started to prioritize investments at the municipal level and work hard with them to start planning. The Committee itself is not interested in environmental services, but only in producing water. Even the Public Prosecutors Office had difficulty accepting environmental services, but they are now embracing it."- State Agency Researcher "We have cities that have water infrastructure that give scope for	Nature-Based Solutions	are more focused on sanitation, dams, engineering, avoiding, and combating losses, and reduced consumer demand for placing targets. And indeed, everyone has it right. Things are not mutually exclusive." - Member of Executive Agency

		drought. Santa Bárbara d'Oeste, for example, has a chain of small dams, but most cities depend on water catchment. The most that is done is emergency measures to deal with more polluted water, at best, at best. Or reserve treated water and insure the distribution. What we saw are municipalities looking for auxiliary springs. But there it was in the extreme situation of improvisation. It was completely reactive. The rule has already been reactive, and the local action is predominantly delimited by a reactive action."- Member of Executive Agency		
Ancillary narratives	Infrastructure as only reliable way	"This owes much to the mindset of engineers and processes of internal	Infrastructure is necessary but not	"What is missing from my perspective, is to advance environmental

	to achieve water security	environmental education to understand the value of the approach of environmental services and preservation of springs. It has been a labored process. For example, (names a very prominent Committee member) is a traditional engineer and convincing him is complicated. Even within the PCJ Agency. They just created the part of environmental education and environmental services, so they are just beginning to invest in this." -State Agency Researcher	sufficient. Water should be seen as an outcome from ecological processes.	management. That's a big challenge, linking licensing and grants (...). And change that consciousness that people perceive the experience of places like New York. There, the reservoirs are shielded since the springs are preserved as water sources. We should be extremely careful of springs. Here they prefer to invest in treatment technology rather than recover springs." - State Government Employee "It was a turning point, a quiet revolution within the Committees. We now have working groups focused on stream restoration that include different Committee members. They are addressing deeper issues within each

				area of expertise related to reforestation, sewage treatment, watershed recovery. We elaborated the first master plan for water springs. The approach of the group: our reservoir is not the Cantareira, but here on the ground." - Member of Agricultural Water Users

Appendix E. Demographic Information of Online Survey Respondents

Gender	Respondents	Percentage
male	57	64
female	32	36

Supplementary Table A. Gender distribution of survey respondents

Sector Represented	Respondents	Percentage
water users	10	32
municipality	8	26
government	7	23
NGOs	6	19

Supplementary Table B. Sector of society represented by survey respondents

Technical Chamber	Respondents	Percentage
RN	11	15
PB	9	12
EA	8	11
IND	8	11
SA	8	11
AS	7	9
MH	7	9
OL	7	9
SAM	7	9
Rural	2	3
ID	1	1

Supplementary Table C. Tenure of survey respondents participating in the PCJ Committee

Tenure	Respondents	Percentage
long tenure	24	27
medium tenure	22	25
short tenure	42	48

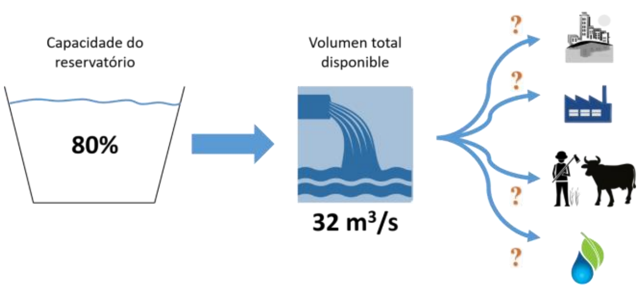
Supplementary Table D. Technical chamber survey respondents participate in

Note: Demographic and other summary statistics presented here use the full dataset of survey responses. We include partial survey responses as it provides information on everyone who kindly donated some of their time to help our research despite perhaps not completing all behavioral experiments or ranking the attitude-value statements. The tables below show the distribution of survey respondents based on characteristics such as gender, sector of society they represent at the Committees, tenure at the PCJ Committees, and technical chamber they engage with primarily. Tenure at the Committees is divided into three broad categories based on how many years a respondent has been involved: long for 10 years or more, medium for engagement between five and ten years, and short for engagement of up to five years.

Supplementary Figure A. Water allocation experiment with three scenarios presented to respondents

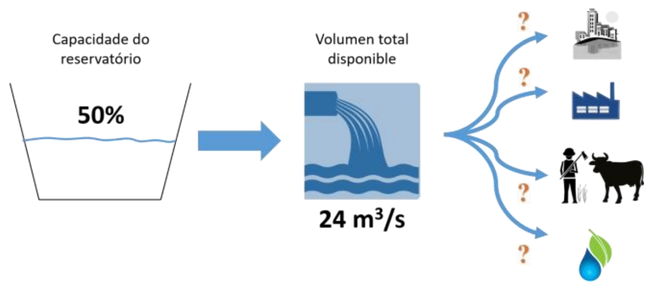
a) High Water Availability Scenario

This year, water levels at the reservoir system are at 80% of total storage capacity. This means that there is enough water to release **32 m3/s** for water users to consume. The default water concession for each user is set at 25% of total water available, equivalent to **8 m3/s**.
Adjust water user concessions as you consider necessary to produce the **highest social well-being**. Keep in mind that an equal distribution of water may not reflect the value that different water users provide to society.



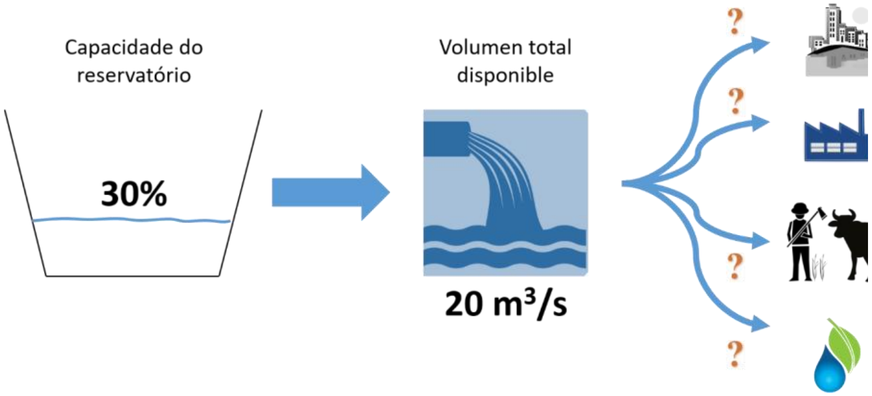
b) Medium Water Availability Scenario

This year, water levels at the reservoir system are at 50% of total storage capacity. This means that there is enough water to release **24 m3/s** for water users to consume. The default water concession for each user is set at 25% of total water available, equivalent to **6 m3/s**.
Adjust water user concessions as you consider necessary to produce the **highest social well-being**. Keep in mind that an equal distribution of water may not reflect the value that different water users provide to society.



c) Low Water Availability Scenario

This year, water levels at the reservoir system are at 30% of total storage capacity. This me
that there is enough water to release **20 m3/s** for water users to consume. The default water
concession for each user is set at 25% of total water available, equivalent to **5 m3/s**.
Adjust water user concessions as you consider necessary to produce the **highest social we**
being. Keep in mind that an equal distribution of water may not reflect the value that differen
water users provide to society.



Supplementary Figure B. Water storage experiment prompting different rain scenarios: a) floods, drought b) and c) average conditions.

Consider the following scenario. The water reservoirs in the hypothetical system are currently at 60% of total storage capacity. Rain forecasts for the next rainy season are uncertain. However, rains in the past three years have been some of the **highest recorded** in recent history. The intense rains resulted in **significant floods** in areas close to reservoirs as the Water Agency had to perform **emergency water releases** in order to preserve the structural integrity of the reservoir system.

Remember that the operational band chosen will determine how much water (in m3/s) is released to downstream users to satisfy current demand and, at the same time, how much water is stored for next year.

Based on this information, select the operational band that is **most likely** to provide a stable supply of water to users downstream.

a)

Consider the following scenario. The water reservoirs in the hypothetical system are currently at 60% of total storage capacity. Rain forecasts for the next rainy season are uncertain. However, rains in the past two years have been some of the lowest recorded in recent history, marking one of the **most extreme drought** seasons in the past 80 years.

Remember that the operational band chosen will determine how much water (in m3/s) is released to downstream users to satisfy current demand and, at the same time, how much water is stored for next year.

Based on this information, select the operational band that is **most likely** to provide a stable supply of water to users downstream.

b)

Consider the following scenario. The water reservoirs in the hypothetical system are currently at 60% of total storage capacity. Rain forecasts for the next rainy season are uncertain. However, rains in the past years have been similar to the **historical average**.

Remember that the operational band chosen will determine how much water (in m3/s) is released to downstream users to satisfy current demand and, at the same time, how much water is stored for next year.

Based on this information, select the operational band that is **most likely** to provide a stable supply of water to users downstream.

c)

Appendix G. Qualitative Evidence From Interviews With PCJ Committee Members on Topics Relating to Governance Priorities, Preferred Solutions, and Climate Change Impacts

Supplementary Table E. Preponderance of evidence for themes related to the 2014-2015 Water Crisis in SE Brazil

Theme	Number of Interviewees Mentioning Theme	Evidence based on Interviewees	Evidence Based on Interviewee Affiliation
Crisis revealed lack of response capacity	6	Yes	Yes
Crisis paralyzed the region	4	Yes	No
Crisis opened eyes to climate change impacts	3	Yes	No
Unprecedented extreme event	2	No	No
Forced to use dead volumes in Cantareira	1	No	No
Not all regions experienced water crisis	1	No	No

Supplementary Table F. Preponderance of evidence for themes related to governance priorities of the PCJ Committee

Theme	Number of Interviewees Mentioning Theme	Evidence based on Interviewees	Evidence Based on Interviewee Affiliation
Integrated information systems	3	Yes	No
Large scale sanitation old priority	3	Yes	No
Combating distribution losses	2	No	No
Incipient nature-based solutions	2	No	No
Municipal water reservoirs	2	No	No
Past priority Cantareira	2	No	No
Water quality	2	No	No
Demand satisfaction	1	No	No
Difficult setting regional priorities	1	No	No
Law places municipal and environment water as priorities	1	No	No
Low-ranked environmental uses	1	No	No
Regional distribution line	1	No	No
Sanitation rural and small municipality	1	No	No

Supplementary Table G. Preponderance of evidence for themes related to preferred solutions for perceived challenges of the PCJ River basin

Theme	Number of Interviewees Mentioning Theme	Evidence based on Interviewees	Evidence Based on Interviewee Affiliation
Water reuse	9	Yes	Yes
Build new reservoirs - negative	7	Yes	Yes
Build new reservoirs - positive	6	Yes	No
Reuse water infrastructure	6	Yes	Yes
Support small municipalities and sanitation companies	6	Yes	Yes
Infrastructure	5	Yes	Yes
Restore freshwater springs	5	Yes	Yes
Use integral approach to solve problems	5	Yes	Yes
Water treatment infrastructure	3	Yes	Yes
Increase environmental awareness	2	No	No
More stringent legislation	2	No	No
Reduce water withdrawals	2	No	No
Increase price of municipal water	1	No	No

Supplementary Table H. Qualitative evidence

Topic	Qualitative evidence
Impacts of 2014-2015 Water Crisis	*The water crisis marks a milestone for our Basin Plans, a BCE and CE so to speak because we reached critical water levels. Now we are working on water security plans. –* ***State Agency Member*** *We were at fault for thinking a crisis like this one was impossible. We learned a lot during the crisis of 2014. It opened our minds, and we now have dedicated chapters in the Basin Plan to include the rural aspects, water supply, water quality classification, and groundwater. Those and climate change are now part of the discussion about water supply and water quality. We can now talk about an issue that is happening worldwide. –* ***Member of Water Sanitation Company*** *The 2014-2015 water crisis was completely unexpected. We were not prepared. We knew about the risks, those who study know, but nobody took precautions. […]. From my perspective, we will live with the climate instability and municipalities that do not prepare will suffer from it. –* ***Member of Municipal Water Users***
Learning from Water Crisis	*Because of the crisis, we learned we must protect springs, we need to make sure that water filters into the ground so that the soil functions as a large reservoir.* ***- Executive Agency Member*** *People's memory is very short. We experienced the 2014-2015 water crisis and people have already forgotten the problem. We almost went through the same situation in 2018. We did not learn. You could feel the sense of desperation because no one prepared themselves. For example, a city that was left without water during the crisis and had to take water from other sources and improvise how to store and bring water stopped using, maintaining, even sold some of that infrastructure after the crisis. Cities like that one did not build new reservoirs, they did not control water losses, they did not search for new springs. It would be a different story if they had prepared. No one was ready for a similar crisis. –* ***State Agency Member***
Governance Priorities	*The problems that are a priority change over time. First it was water loses, then it was water treatment. Now, water loses are a priority again. –* ***Member of Sanitation Company*** *When I joined the Committees, all the focus was on Cantareira, as if having all the water there would make everything work. They [the Committees] have moved on from that obsession to find alternatives, because negotiating with SABESP is impossible. The focus changed to trying to increase investments at the basin level, find alternatives, prioritizing investments at the municipal level and work closely with municipalities to start planning. –* ***State Agency Researcher*** *Before, you had few people from rural areas, most of the work at the PCJ was urban, it didn't focus on the rural problems. As representatives from the rural sector started participating at the Committees our agenda started*

	getting considered. Today, we have a lot of resources from the PCJ and we do activities based on what is available in the yearly planning. – ***Member of Rural Syndicate*** *The other issues were dormant because it was understood that you could not address them without first addressing the wastewater issue. That is what the Committees have focused on for the past 25 years. Today, and for the past 5 years, we have diversified the use of resources, they are no longer all destined for wastewater. –****Executive Agency Member*** *Water quality will be on the agenda because first you need universal wastewater treatment. After that comes removal of nitrogen and phosphates from water. –* ***Member of Sanitation Company***
Governance Challenges	*The truth is, we are finalizing the thematic planning documents of the Basin Plan and we know that we will not achieve some of the water quality goals by 2035. The water quality issue is a recurring issue. For water quantity, we have the reservoirs that give us some protection, but the issue of water quality is problematic." –* ***Executive Agency Member*** *Another important topic for the basin is the issue of water balance. That and reuse water because even with available treatment technology, one must consider what to do with return flows. Otherwise, you may have and increase in water withdrawals and river channels drying out in sections. More specialized water treatment does not imply that you can use more water, rather you need to account for the water that you need to let flow and reduce withdrawals. –* ***Executive Agency Member*** *We have insufficient financial resources to implement all the projects targeting spring restoration, conservation, and payment for ecosystem services. At least they are included in the plans. –****State Agency Member*** *My perception is that we'll have more frequent extreme events. We'll have extreme drought, issues with flooding, equitable water access issues, and other events related to extreme scarcity. The problems with drought are important, yes, but it is my understanding that problems around scarcity are more dramatic. –* ***Executive Agency Member*** *During the dry season, it is my responsibility to establish the water volumes to be released from the Cantareira system. I consider the meteorological models, users' current demands, and potential future scenarios to determine the amount of water that can be released from the reservoirs. I must always have a water conservation perspective, that is the challenge. There is a lot of uncertainty, and I am always trying to conserve water for next year. Given uncertainty about rains, if I release a certain amount of water thinking that rain will come, and it doesn't, then we'll have insufficient water in the rivers. That is a challenge for planning. –* ***Member of Industrial Users***

Positive Views on Infrastructure Solutions	*Water resource management done in terms of water quantity. I see the possibility of building two new reservoirs plus the transposition system as a positive thing. It would allow us to regulate water flows in drier periods. –* ***State Agency Member*** *Another challenge is water availability. For example, the two new reservoirs being built are an example of what we want to mitigate the effects of not having water. The reservoirs are a key part of guaranteeing water availability and security in the region. –* ***Member of Professional Association of Sanitation Engineers*** *We need to reduce uncertainty about climate change and water supply. The solution is infrastructure for water storage, restoring riparian zones, and do water retention work. Right now, we don't have that. We have just started, these were not so necessary before, they are now. We cannot fight climate change; we can only build. –* ***Member of Water Sanitation Company*** *We now need to make small dams and water retention areas, along with reservoirs. Beforehand, the PCJ Committees were very focused on financial planning, now they are focusing on water retention. That is a good thing. –* ***Rural Syndicate Member*** *Economic development is a fundamental issue. The economy is expected to grow. That is why building reservoirs is vital. If we manage to build the two new reservoirs and the transposition system, then we'll have a balance. The city of Sao Paulo will increasingly need to import water from other areas. –* ***Member of Water Sanitation Company*** *In this context we need more macro-investments, for example, in large sewage systems. This is not possible without coordination. We have tried inducing best practices and provide resources to show municipalities that water loss reduction is a priority and that it pays off to invest in efficiency. –* ***Executive Agency Member***
Negative Views on Infrastructure Solutions	*Regarding water reservoirs, are they a good idea? Because now they also have problems with eutrophication.* ***- Member of Public Prosecutor's Office*** *Things depend on the timelines of political actions and public policy. They want to build reservoirs, but the projects haven't started. They have other reservoirs in construction, but it will be a long time until they finish them and the reservoirs fill up for use. I don't know when, maybe 10 years from now. I am not very optimistic about it. We have observed that the rain periods, particularly in October are changing. Temperatures are rising, demand is rising, and we will consume more. Until we have the reservoirs, we are waiting for rains to behave. We have nothing in terms of public policy for dealing with the issue directly or that dictate what to do during extreme cases. Today when we have normal water levels everything works well, but we need a strategy for when we have a water deficit. People believe that any rain is enough to build a reservoir; then you hear the news that a reservoir is overflooding and water goes downstream but out of the river channel, and you lose all that water. For water to infiltrate, it needs*

	to remain in place for a while; you need plants and roots to retain water otherwise water just runs off. – ***State University Researcher*** *For example, the topic of reservoirs for cities is not a controversial topic within the PCJ Committees. They were considered a good idea and were unanimously supported within the Committees. The problem arose when land appropriations were required to be flooded. That opposition grew during public hearings. That is where it became a controversial topic, and that is normal, people will oppose losing their lands so they will create controversy. –* ***Local Government Official***
Other Solutions	*The Committee itself is always trying to foster self-sufficiency at the municipal level, seeking alternative water provision strategies, spring restoration and reuse water. The PCJ Committees are an example for the rest of the country in supporting their municipalities with planning. The Committees focus on municipalities because they are the level at which projects are implemented.* ***- Member of Public Prosecutor's Office*** *Another important thing to consider is that we have 61 municipalities across the basin: large, big, and small. What we must think about is providing technical assistance for municipalities. To be able to guide municipalities and small water sanitation companies. Having a center that helps them solve their problems, not solve problems for them. The SA-TC developed a capacity building program for small sanitation company technicians because just as a doctor is valued because they save a life, so should be a drinking water professional that provides water for 30, 50, or 100 thousand people. –* ***State Agency Member*** *Spring protection falls onto the grey area of what is and isn't the Committees' jurisdiction. The fact is that we have advanced this issue and the understanding that we must mount a strategy and spend money on spring protection, especially in municipalities that take water from smaller catchments. We are not thinking about those who take water from the main rivers but those who take it from a stream, a dam, or a reservoir. They have priority for investments in this category. –* ***Executive Agency Member*** *In terms of challenges for 2030, I would list issues of tertiary water treatment. Reuse water will help but it does not solve all the problems. –* ***State Agency Researcher*** *I don't think future problems will be different. I think we have advanced a lot, but we will need tertiary treatment for all effluents. We will need a lot of money. We need a more centralized organization to coordinate projects. We also need to structure projects such that the cost also falls upon the final user, for example, increasing the cost of municipal water since they are the largest consumers.* ***- Member of Agricultural Water Users*** *The first part is integrating our information systems. We are talking about understanding and recognizing problems. It is difficult to recognize a problem and plan solutions without an information foundation. From my point of view, this is an obvious need. Integrated sources of information are critical for water resource management. At our scale,*

	*the problems of disjointed information systems intensify. I think the solution goes through integrating our information systems. –**Executive Agency Member*** *I think we are somewhat changing our relationship to water scarcity. It may not always be a fully conscious thing, but people are changing how they coexist with scarcity. This is directly associated with climate change. We had to make a rule that when we detect a drought all water users will reduce their water withdrawals. No one had thought of that, no one. But it did happen that when there was an intense drought, there was a notion that those co-responsible for water had to make a rule for water users during droughts so that they would reduce water withdrawals. We are on an ex-post line of action. We do not prevent. At least now we have a rule that is part of the standard operating procedures of the Cantareira system. –**Executive Agency Member***
Trade-offs between solutions	*Environmental water uses are not a top priority, they are slightly below. – **Member of Sanitation Company*** *We seek coordinated action on all these issues, with a holistic perspective. There have been significant fish die-offs, we have brought all these issues up with the Committees. They have a focus primarily on water quantity, not quality. – **Member of Public Prosecutor's Office*** *I think we were already arriving at a critical state before the crisis. We had high rates of water consumption for all possible uses, then we arrived at a situation where you cannot use water. So, who should reduce their consumption? Where do you start? What should be the water use limit? These are very important questions. – **State University Researcher***

Bibliography

Abers, R. N., & Keck, M. (2006). Muddy waters: The political construction of deliberative river basin governance in Brazil. *International Journal of Urban and Regional Research*, *30*(3), 601–622. https://doi.org/10.1111/j.1468-2427.2006.00691.x

Abers, R. N., & Keck, M. E. (2013). *Practical authority: Agency and institutional change in Brazilian water politics*. Oxford University Press.

Agrawal, A. (2005). Environmentality. *Current Anthropology*, *46*(2), 161–190. Retrieved from https://doi.org/10.1086/427122

Almazán-Casali, S., Puga, B. P., & Lemos, M. C. (2021). Who Governs at What Price? Technocratic Dominance, Ways of Knowing, and Long-Term Resilience of Brazil's Water System . *Frontiers in Water* . Retrieved from https://www.frontiersin.org/article/10.3389/frwa.2021.735018

An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*, *229*, 25–36. https://doi.org/10.1016/j.ecolmodel.2011.07.010

ANA, A. N. de Á. (2017). *Conjuntura dos recursos hídricos no Brasil 2018: informe anual 2017*. Brasilia.

Bakker, K. (2012). Water: Political, biopolitical, material. *Social Studies of Science*, *42*(4), 616–623. https://doi.org/10.1177/0306312712441396

Bakker, K. (2013). Constructing "public" water: The World Bank, urban water supply, and the biopolitics of development. *Environment and Planning D: Society and Space*, *31*(2), 280–300. https://doi.org/10.1068/d5111

Bakker, K. (2014). The Business of Water: Market Environmentalism in the Water Sector. *Annual Review of Environment and Resources*. Annual Reviews. https://doi.org/10.1146/annurev-environ-070312-132730

Barraqué, B., Formiga Johnsson, R. M., & de Paiva Britto, A. L. (2008). The development of water services and their interaction with water resources in European and Brazilian cities. *Hydrology and Earth System Sciences*, *12*(4), 1153–1164. https://doi.org/10.5194/hess-12-1153-2008

Bell, A. R., Engle, N. L., & Lemos, M. C. (2011). How does Diversity Matter ? The Case of Brazilian River Basin Councils, *16*(1).

Bellaubi, F., & Pahl-Wostl, C. (2017). Corruption risks, management practices, and performance in water servicedelivery in Kenya and Ghana: an agent-based model. *ECOLOGY AND SOCIETY*, *22*(2). https://doi.org/10.5751/ES-09205-220206

Biggs, H. C., Breen, C. M., & Palmer, C. G. (2008). Engaging a Window of Opportunity: Synchronicity between a Regional River Conservation Initiative and Broader Water Law Reform in South Africa. *International Journal of Water Resources Development*, *24*(3), 329–343. https://doi.org/10.1080/07900620802127275

Bitterman, P., & Koliba, C. J. (2020). Modeling Alternative Collaborative Governance Network

Designs: An Agent-Based Model of Water Governance in the Lake Champlain Basin, Vermont. *Journal of Public Administration Research and Theory*, *30*(4), 636–655. https://doi.org/10.1093/jopart/muaa013
Blyth, M. (2002). *Great Transformations: The Rise and Decline of Embedded Liberalism*. Cambridge: Cambridge University Press.
Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(SUPPL. 3), 7280–7287. https://doi.org/10.1073/pnas.082080899
Bourdieu, P. (1977). *Outline of a Theory of Practice*. Cambridge, U.K.: Cambridge University Press. Retrieved from http://proxy.lib.umich.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=e000xna&AN=589175&site=ehost-live&scope=site
Brisbois, M. C., & de Loë, R. C. (2016). Power in Collaborative Approaches to Governance for Water: A Systematic Review. *Society & Natural Resources*, *29*(7), 775–790. https://doi.org/10.1080/08941920.2015.1080339
Brisbois, M. C., Morris, M., & de Loë, R. (2019). Augmenting the IAD framework to reveal power in collaborative governance – An illustrative application to resource industry dominated processes. *World Development*, *120*, 159–168. https://doi.org/https://doi.org/10.1016/j.worlddev.2018.02.017
Brugnach, M. (2017). The Space in Between: Where Multiple Ways of Knowing in Water Management Meet. *Journal of the Southwest*, *59*(1), 34–59. https://doi.org/doi:10.1353/jsw.2017.0005
Brugnach, M., & Ingram, H. (2012). Ambiguity: the challenge of knowing and deciding together. *Environmental Science & Policy*, *15*(1), 60–71. https://doi.org/https://doi.org/10.1016/j.envsci.2011.10.005
Buckley, E. E. (2017). *Technocrats and the Politics of Drought and Development in Twentieth-Century Brazil*. UNC Press Books.
Caniglia, B., Frank, B., Kerner, B., & Mix, T. L. (2016). Water Policy And Governance Networks: A Pathway To Enhance Resilience Toward Climate Change. *Sociological Forum*, *31*(S1), 828–845. https://doi.org/https://doi.org/10.1111/socf.12275
Carlisle, K., & Gruby, R. L. (2017). Polycentric Systems of Governance: A Theoretical Model for the Commons. *Policy Studies Journal*, *00*(00). https://doi.org/10.1111/psj.12212
Clement, F. (2010). Analysing decentralised natural resource governance: proposition for a “politicised” institutional analysis and development framework. *Policy Sciences*, *43*(2), 129–156. https://doi.org/10.1007/s11077-009-9100-8
Clift, R., Sim, S., King, H., Chenoweth, J. L., Christie, I., Clavreul, J., … Murphy, R. (2017). The challenges of applying planetary boundaries as a basis for strategic decision-making in companies with global supply chains. *Sustainability (Switzerland)*, *9*(2), 1–24. https://doi.org/10.3390/su9020279
Cohen-Shacham, Emmanuelle, Gretchen Walters, Christine Janzen, S. M. (2016). *Nature-Based Solutions to Address Global Societal Challenges*. Gland: Switzerland.
Cole, D. H., Epstein, G., & Mcginnis, M. D. (2019). Combining the IAD and SES frameworks, *13*(1), 244–275. https://doi.org/10.18352/ijc.864
Collier, S. J. (2009). Topologies of Power: Foucault’s Analysis of Political Government beyond ‘Governmentality. *Theory, Culture & Society*. London, England: SAGE Publications. https://doi.org/10.1177/0263276409347694

Comitês PCJ. (2021). Institucional. Retrieved September 15, 2018, from https://www.comitespcj.org.br

Commission, E., Bsik-ccsp, D., Systems, S., Resilience, B., & Uk, C. (2021). This research was kindly supported by the European Commission (pro- ject NeWater under contract no. 511179 (GOCE)) and the A7-ACER pro- ject funded under the Dutch BSIK-CCsP programme., (2001).

Conte, R., & Paolucci, M. (2014). On agent-based modeling and computational social science. *Frontiers in Psychology*, *5*(JUL), 1–9. https://doi.org/10.3389/fpsyg.2014.00668

Crow-Miller, B., Webber, M., & Molle, F. (2017). Crow-Miller, B., Webber, M., & Molle, F. (2017). The (re) turn to infrastructure for water management?, *10*(2), 195–207.

Cumming, G. S., & Peterson, G. D. (2017). Unifying Research on Social–Ecological Resilience and Collapse. *Trends in Ecology and Evolution*, *32*(9), 695–713. https://doi.org/10.1016/j.tree.2017.06.014

Curtis, S., Fair, A., Wistow, J., Val, D. V, & Oven, K. (2017). Impact of extreme weather events and climate change for health and social care systems. *Environmental Health*, *16*(1), 128. https://doi.org/10.1186/s12940-017-0324-3

Daré, W., Venot, J. P., Page, C. Le, & Aduna, A. (2018). Problemshed or watershed? Participatory modeling towards IWRM in North Ghana. *Water (Switzerland)*, *10*(6). https://doi.org/10.3390/w10060721

De Groot, J. I. M., & Steg, L. (2008). Value Orientations to Explain Beliefs Related to Environmental Significant Behavior. *Environment and Behavior*, *40*(3), 330–354. https://doi.org/10.1177/0013916506297831

DeAngelis, D. L., & Diaz, S. G. (2019). Decision-making in agent-based modeling: A current review and future prospectus. *Frontiers in Ecology and Evolution*, *6*(JAN), 1–15. https://doi.org/10.3389/fevo.2018.00237

DeCaro, D. A., Arnold, C. A. (Tony), Boamah, E. F., & Garmestani, A. S. (2017). Understanding and applying principles of social cognition and decisionmaking in adaptive environmental governance. *ECOLOGY AND SOCIETY*, *22*(1). https://doi.org/10.5751/ES-09154-220133

Depietri, Y., & McPhearson, T. (2017). Integrating the Grey, Green, and Blue in Cities: Nature-Based Solutions for Climate Change Adaptation and Risk Reduction BT - Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.) (pp. 91–109). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_6

Döll, P., & Romero-Lankao, P. (2017). How to embrace uncertainty in participatory climate change risk management—A roadmap. *Earth's Future*, *5*(1), 18–36. https://doi.org/https://doi.org/10.1002/2016EF000411

Empinotti, V. L., Budds, J., & Aversa, M. (2019). Governance and water security: The role of the water institutional framework in the 2013–15 water crisis in São Paulo, Brazil. *Geoforum*, *98*, 46–54. https://doi.org/https://doi.org/10.1016/j.geoforum.2018.09.022

Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, *21*(2), 647–656. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2011.01.019

Engle, N. L., Johns, O. R., Lemos, M. C., & Nelson, D. R. (2011). Integrated and adaptive management of water resources: Tensions, legacies, and the next best thing. *Ecology and Society*, *16*(1). https://doi.org/19

Epstein, G., Morrison, T. H., Lien, A., Gurney, G. G., Cole, D. H., Delaroche, M., … Cox, M.

(2020). Advances in understanding the evolution of institutions in complex social-ecological systems. *Current Opinion in Environmental Sustainability*, *44*, 58–66. https://doi.org/https://doi.org/10.1016/j.cosust.2020.06.002
Farrelly, M., & Brown, R. (2011). Rethinking urban water management: Experimentation as a way forward? *Global Environmental Change*, *21*(2), 721–732. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2011.01.007
Feldman, M. S., Khademian, A. M., Ingram, H., & Schneider, A. S. (2006). Ways of Knowing and Inclusive Management Practices. *Public Administration Review*, *66*(s1), 89–99. https://doi.org/https://doi.org/10.1111/j.1540-6210.2006.00669.x
Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). ADAPTIVE GOVERNANCE OF SOCIAL-ECOLOGICAL SYSTEMS. *Annual Review of Environment and Resources*, *30*(1), 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511
Formiga-Johnsson, R. M., & Kemper, K. E. (2005). *Institutional and Policy Analysis of River Basin Management: The Jaguaribe River Basin, Ceará, Brazil* (Policy Research Working Paper). Washington, DC. Retrieved from https://openknowledge.worldbank.org/handle/10986/8298
Formiga-Johnsson, R. M., Kumler, L., & Lemos, M. C. (2007). The politics of bulk water pricing in Brazil: Lessons from the Paraíba do Sul Basin. *Water Policy*, *9*(1), 87–104. https://doi.org/10.2166/wp.2006.001
Foucault, M. (1995). *Discipline and punish : the birth of the prison*. *Discipline and punish : the birth of the prison* (2nd Vintag). New York : Vintage Books.
Foucault, M., Senellart, M., Ewald, F., & Fontana, A. (2007). *Security, territory, population : lectures at the Collège de France, 1977-78*. *Security, territory, population : lectures at the Collège de France, 1977-78*. Basingstoke ; New York : Palgrave Macmillan : République Française.
Frame, D. J., Rosier, S. M., Noy, I., Harrington, L. J., Carey-Smith, T., Sparrow, S. N., … Dean, S. M. (2020). Climate change attribution and the economic costs of extreme weather events: a study on damages from extreme rainfall and drought. *Climatic Change*, *162*(2), 781–797. https://doi.org/10.1007/s10584-020-02729-y
Fritsch, O. (2017). Integrated and adaptive water resources management: exploring public participation in the UK. *Regional Environmental Change*, *17*(7), 1933–1944. https://doi.org/10.1007/s10113-016-0973-8
Funtowicz, S. O., & Ravetz, J. R. (1991). A new scientific methodology for global environmental issues. *Ecological Economics: The Science and Management of Sustainability*, (10), 137.
Garrick, D. E., Schlager, E., De Stefano, L., & Villamayor-Tomas, S. (2018). Managing the Cascading Risks of Droughts: Institutional Adaptation in Transboundary River Basins. *Earth's Future*, *6*(6), 809–827. https://doi.org/https://doi.org/10.1002/2018EF000823
Gaventa, J. (2006). Finding the spaces for change: A power analysis. *IDS Bulletin*, *37*(6), 23–33. https://doi.org/10.1111/j.1759-5436.2006.tb00320.x
Gerlach, E., & Franceys, R. (2009). Regulating water services for the poor: The case of Amman. *Geoforum*, *40*(3), 431–441. https://doi.org/https://doi.org/10.1016/j.geoforum.2008.11.002
Gerlak, A. K., & Mukhtarov, F. (2015). 'Ways of knowing' water: integrated water resources management and water security as complementary discourses. *International Environmental Agreements: Politics, Law and Economics*, *15*(3), 257–272. https://doi.org/10.1007/s10784-015-9278-5

Gerst, M. D., Raskin, P. D., & Rockström, J. (2014). Contours of a resilient global future. *Sustainability (Switzerland)*, *6*(1), 123–135. https://doi.org/10.3390/su6010123

Getirana, A. (2016). Extreme Water Deficit in Brazil Detected from Space. *Journal of Hydrometeorology*, *17*(2), 591–599. https://doi.org/10.1175/JHM-D-15-0096.1

Giddens, A. (1984). *The constitution of society : outline of the theory of structuration*. *The constitution of society : outline of the theory of structuration*. Cambridge : Polity Press.

Giordano, M., & Shah, T. (2014). From IWRM back to integrated water resources management. *International Journal of Water Resources Development*, *30*(3), 364–376. https://doi.org/10.1080/07900627.2013.851521

Gleick, P. H. (2003). Global Freshwater Resources: Soft-Path Solutions for the 21st Century. *Science*, *302*(5650), 1524–1528. https://doi.org/10.1126/science.1089967

Gómez-Limón, J. A., Gutiérrez-Martín, C., & Montilla-López, N. M. (2020). Agricultural Water Allocation under Cyclical Scarcity: The Role of Priority Water Rights. *Water* . https://doi.org/10.3390/w12061835

Greenough, G., McGeehin, M., Bernard, S. M., Trtanj, J., Riad, J., & Engelberg, D. (2001). The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. *Environmental Health Perspectives*, *109*(suppl 2), 191–198. https://doi.org/10.1289/ehp.109-1240666

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., … DeAngelis, D. L. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, *198*(1–2), 115–126. https://doi.org/10.1016/j.ecolmodel.2006.04.023

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J., & Railsback, S. F. (2010). The ODD protocol: A review and first update. *Ecological Modelling*, *221*(23), 2760–2768. https://doi.org/10.1016/j.ecolmodel.2010.08.019

Grimm, V., Railsback, S. F., Vincenot, C. E., Berger, U., Gallagher, C., Deangelis, D. L., … Ayllón, D. (2020). The ODD protocol for describing agent-based and other simulation models: A second update to improve clarity, replication, and structural realism. *JASSS*, *23*(2). https://doi.org/10.18564/jasss.4259

Grimm, V., Revilla, E., Berger, U., Jeltsch, F., Mooij, W. M., Railsback, S. F., … DeAngelis, D. L. (2005). Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science*, *310*(5750), 987–991. https://doi.org/10.1126/science.1116681

Groeneveld, J., Müller, B., Buchmann, C. M., Dressler, G., Guo, C., Hase, N., … Schwarz, N. (2017, January 1). Theoretical foundations of human decision-making in agent-based land use models – A review. *Environmental Modelling and Software*. Elsevier Ltd. https://doi.org/10.1016/j.envsoft.2016.10.008

Hall, J. W., Grey, D., Garrick, D., Fung, F., Brown, C., Dadson, S. J., & Sadoff, C. W. (2014). Coping with the curse of freshwater variability. *Science, 346*(6208), 429–430. https://doi.org/10.1126/science.1257890

Hamidov, A., Kasymov, U., Salokhiddinov, A., & Khamidov, M. (2020). How Can Intentionality and Path Dependence Explain Change in Water-Management Institutions in Uzbekistan? *International Journal of the Commons, 14*(1), 16–29. https://doi.org/http://doi.org/10.5334/ijc.947

Hedström, P., & Swedberg, R. (1998). *Social mechanisms : an analytical approach to social theory*. *Social mechanisms : an analytical approach to social theory*. Cambridge : New York : Cambridge University Press.

Hellberg, S. (2018). The power and politics of water. In *The Biopolitics of Water* (1st Editio, pp.

1–24). London: Routledge.
Hinkel, J., Bots, P. W. G., & Schlüter, M. (2014). Enhancing the Ostrom social-ecological system framework through formalization. *Ecology and Society*, *19*(3). https://doi.org/10.5751/ES-06475-190351
Höllermann, B., & Evers, M. (2017). Perception and handling of uncertainties in water management—A study of practitioners' and scientists' perspectives on uncertainty in their daily decision-making. *Environmental Science & Policy*, *71*, 9–18. https://doi.org/https://doi.org/10.1016/j.envsci.2017.02.003
Hyun, J. Y., Huang, S. Y., Yang, Y. C. E., Tidwell, V., & Macknick, J. (2019). Using a coupled agent-based modeling approach to analyze the role of risk perception in water management decisions. *Hydrology and Earth System Sciences*, *23*(5), 2261–2278. https://doi.org/10.5194/hess-23-2261-2019
Ingram, H., & Fraser, L. (2008). Chapter 4. Path Dependency and Adroit Innovation: The Case of California Water. In R. Repetto (Ed.), *Punctuated Equilibrium and the Dynamics of U.S. Environmental Policy* (pp. 78–109). Yale University Press. https://doi.org/doi:10.12987/9780300129748-006
Ingram, H., & Oggins, C. R. (1990). *Water, the Community, and Markets in the West*.
IPCC. (2014). Summary for policymakers. In et al. C. B. Field (Ed.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–32). Cambridge and New York, NY: Cambridge University Press.
Isaac, J. C. (1987). Beyond the Three Faces of Power: A Realist Critique. *Polity*, *20*(1), 4–31. https://doi.org/10.2307/3234935
Jacobi, P. R., Cibim, J., & Leão, R. de S. (2015). Crise hídrica na Macrometrópole Paulista e respostas da sociedade civil. *Estudos Avançados*, *29*(84), 27–42. https://doi.org/10.1590/S0103-40142015000200003
Janssen, M. A., & Baggio, J. A. (2017). Using agent-based models to compare behavioral theories on experimental data: Application for irrigation games. *Journal of Environmental Psychology*, *52*, 194–203. https://doi.org/10.1016/j.jenvp.2016.04.018
Jordan, A., Huitema, D., Schoenefeld, J., van Asselt, H., & Forster, J. (2018). Governing Climate Change Polycentrically. In A. Jordan, D. Huitema, H. van Asselt, & J. Forster (Eds.), *Governing Climate Change: Polycentricity in Action?* (pp. 3–26). Cambridge: Cambridge University Press. https://doi.org/DOI: 10.1017/9781108284646.002
Kadirbeyoglu, Z., & Özertan, G. (2015). Power in the Governance of Common-Pool Resources: A comparative analysis of irrigation management decentralization in Turkey. *Environmental Policy and Governance*, *25*(3), 157–171. https://doi.org/https://doi.org/10.1002/eet.1673
Kallis, G., Kiparsky, M., & Norgaard, R. (2009). Collaborative governance and adaptive management: Lessons from California's CALFED Water Program. *Environmental Science & Policy*, *12*(6), 631–643. https://doi.org/https://doi.org/10.1016/j.envsci.2009.07.002
Kehler, S., & Birchall, S. J. (2021). Social vulnerability and climate change adaptation: The critical importance of moving beyond technocratic policy approaches. *Environmental Science & Policy*, *124*, 471–477. https://doi.org/https://doi.org/10.1016/j.envsci.2021.07.025
Kelman, J. (2015). Water Supply to the Two Largest Brazilian Metropolitan Regions. *Aquatic Procedia*, *5*, 13–21. https://doi.org/https://doi.org/10.1016/j.aqpro.2015.10.004

Kingdom, J. W. (1995). *Agendas, Alternatives, and Public Polic* (2nd ed.). New York, NY: HarperCollins.
Kochskämper, E., Koontz, T. M., & Newig, J. (2021). Systematic learning in water governance: insights from five local adaptive management projects for water quality innovation. *Ecology and Society*, *26*(1). https://doi.org/10.5751/ES-12080-260122
Kremmydas, D., Athanasiadis, I. N., & Rozakis, S. (2018). A review of Agent Based Modeling for agricultural policy evaluation. *Agricultural Systems*, *164*(October 2017), 95–106. https://doi.org/10.1016/j.agsy.2018.03.010
Lach, D., Rayner, S., & Ingram, H. (2005). Taming the waters: strategies to domesticate the wicked problems of water resource management. *International Journal of Water*, *3*(1).
Leão, R. S., & De Stefano, L. (2019). Making concrete flexible: Adapting the operating rules of the Cantareira water system (São Paulo, Brazil). *Water Security*, *7*, 100032. https://doi.org/https://doi.org/10.1016/j.wasec.2019.100032
Lebel, L., Anderies, J. M., Campbell, B., Folke, C., Hatfield-Dodds, S., Hughes, T. P., & Wilson, J. (2006). Governance and the capacity to manage resilience in regional social-ecological systems. *Ecology and Society*, *11*(1). https://doi.org/10.5751/ES-01606-110119
LEI Nº 9.433 Política Nacional de Recursos Hídricos, Pub. L. No. Título I, Capítulo I (1997). Brazil. Retrieved from http://www.planalto.gov.br/ccivil_03/leis/l9433.htm
Lejano, R. P., & Ingram, H. (2009). Collaborative networks and new ways of knowing. *Environmental Science and Policy*, *12*(6), 653–662. https://doi.org/10.1016/j.envsci.2008.09.005
Lemos, M. C. (1998). The Cubatão Pollution Control Project: Popular Participation and Public Accountability. *The Journal of Environment & Development*, *7*(1), 60–76. https://doi.org/10.1177/107049659800700105
Lemos, M. C., & de Oliveira, J. L. F. (2004). Can Water Reform Survive Politics? Institutional Change and River Basin Management in Ceará, Northeast Brazil. *World Development*, *32*(12), 2121–2137. https://doi.org/https://doi.org/10.1016/j.worlddev.2004.08.002
Lemos, M. C., & de Oliveira, J. L. F. (2005). Water reform across the state/society divide: The case of Ceará, Brazil. *International Journal of Water Resources Development*, *21*(1), 133–147. https://doi.org/10.1080/0790062042000316857
Lemos, M. C., Puga, B. P., Formiga-Johnsson, R. M., & Seigerman, C. K. (2020). Building on adaptive capacity to extreme events in Brazil: water reform, participation, and climate information across four river basins. *Regional Environmental Change*, *20*(2). https://doi.org/10.1007/s10113-020-01636-3
Lerner, A. M., Eakin, H. C., Tellman, E., Bausch, J. C., & Hernández Aguilar, B. (2018). Governing the gaps in water governance and land-use planning in a megacity: The example of hydrological risk in Mexico City. *Cities*, *83*, 61–70. https://doi.org/https://doi.org/10.1016/j.cities.2018.06.009
Lindkvist, E., Wijermans, N., Daw, T. M., Gonzalez-Mon, B., Giron-Nava, A., Johnson, A. F., … Schlüter, M. (2020). Navigating Complexities: Agent-Based Modeling to Support Research, Governance, and Management in Small-Scale Fisheries. *Frontiers in Marine Science*, *6*(January), 1–12. https://doi.org/10.3389/fmars.2019.00733
Lippe, M., Bithell, M., Gotts, N., Natalini, D., Barbrook-Johnson, P., Giupponi, C., … Thellmann, K. (2019). Using agent-based modelling to simulate social-ecological systems across scales. *GeoInformatica*, *23*(2), 269–298. https://doi.org/10.1007/s10707-018-00337-8

Lopez Porras, G., Stringer, L. C., & Quinn, C. H. (2018). Unravelling Stakeholder Perceptions to Enable Adaptive Water Governance in Dryland Systems. *Water Resources Management*, *32*(10), 3285–3301. https://doi.org/10.1007/s11269-018-1991-8

Lukes, S. (1974). *Power : a radical view*. London ; New York : Macmillan.

Lukes, S. (2005). *Power : a radical view* (Second exp). New York: Palgrave Macmillan. Retrieved from https://ebookcentral.proquest.com/lib/umichigan/detail.action?docID=296503

Mach, K. J., Lemos, M. C., Meadow, A. M., Wyborn, C., Klenk, N., Arnott, J. C., … Wong-Parodi, G. (2020). Actionable knowledge and the art of engagement. *Current Opinion in Environmental Sustainability*, *42*, 30–37. https://doi.org/https://doi.org/10.1016/j.cosust.2020.01.002

Marques, E. C. (2000). *Estado e redes sociais: permeabilidade e coesão nas políticas urbanas no Rio de Janeiro* (Vol 1.). Rio de Janeiro: Editora Revan.

Marshall, G. R., & Alexandra, J. (2016). Institutional Path Dependence and Environmental Water Recovery in Australia's Murray-Darling Basi. *Water Alternatives*, *9*(3).

Martirani, L. A., & Peres, I. K. (2016). Water crisis in São Paulo: news coverage, public perception and the right to information. *Ambiente & Sociedade*, *19*(1), 1–20. https://doi.org/10.1590/1809-4422asoc150111r1v1912016

Matthews, R. B., Gilbert, N. G., Roach, A., Polhill, J. G., & Gotts, N. M. (2007). Agent-based land-use models: A review of applications. *Landscape Ecology*, *22*(10), 1447–1459. https://doi.org/10.1007/s10980-007-9135-1

Medema, W., McIntosh, B. S., & Jeffre, P. J. (2008). From premise to practice: a critical assessment of integrated water resources management and adaptive management approaches in the water sector. *Ecology And Society*, *13*(2), 29. Retrieved from http://www.ecologyandsociety.org/vol13/iss2/art29/

Meijerink, S. (2005). Understanding policy stability and change. the interplay of advocacy coalitions and epistemic communities, windows of opportunity, and Dutch coastal flooding policy 1945–2003. *Journal of European Public Policy*, *12*(6), 1060–1077. https://doi.org/10.1080/13501760500270745

Milly, P. C. D., Julio, B., Malin, F., M., H. R., W., K. Z., P., L. D., & J., S. R. (2008). Stationarity Is Dead: Whither Water Management? *Science*, *319*(5863), 573–574. https://doi.org/10.1126/science.1151915

Molle, Francois, & Berkoff, J. (2009). Cities vs. agriculture: A review of intersectoral water re-allocation. *Natural Resources Forum*, *33*(1), 6–18. https://doi.org/https://doi.org/10.1111/j.1477-8947.2009.01204.x

Molle, François, Mollinga, P. P., & Wester, P. (2009). Hydraulic Bureaucracies and the Hydraulic Mission: Flows of Water, Flows of Power. *Water Alternatives*, *2*(3), 328–349. Retrieved from http://proxy.lib.umich.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eih&AN=47909019&site=ehost-live&scope=site

Morrison, T. H., Adger, W. N., Brown, K., Lemos, M. C., Huitema, D., & Hughes, T. P. (2017). Mitigation and adaptation in polycentric systems: sources of power in the pursuit of collective goals. *Wiley Interdisciplinary Reviews: Climate Change*, *8*(5), 1–16. https://doi.org/10.1002/wcc.479

Morrison, T. H., Adger, W. N., Brown, K., Lemos, M. C., Huitema, D., Phelps, J., … Hughes, T. P. (2019). The black box of power in polycentric environmental governance. *Global*

Environmental Change, *57*(June), 101934. https://doi.org/10.1016/j.gloenvcha.2019.101934
Morrison, Tiffany H. (2017). Evolving polycentric governance of the Great Barrier Reef. *Proceedings of the National Academy of Sciences*, *114*(15), E3013 LP-E3021. https://doi.org/10.1073/pnas.1620830114
Mueller, R. O., & Hancock, G. R. (2001). Factor Analysis and Latent Structure, Confirmatory. In N. J. Smelser & P. B. B. T.-I. E. of the S. & B. S. Baltes (Eds.) (pp. 5239–5244). Oxford: Pergamon. https://doi.org/https://doi.org/10.1016/B0-08-043076-7/00426-5
Mukhtarov, F., & Gerlak, A. K. (2014). Epistemic forms of integrated water resources management: towards knowledge versatility. *Policy Sciences*, *47*(2), 101–120. https://doi.org/10.1007/s11077-013-9193-y
Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to Environmental Change: Contributions of a Resilience Framework. *Annual Review of Environment and Resources*, *32*(1), 395–419. https://doi.org/10.1146/annurev.energy.32.051807.090348
Nhim, T., Richter, A., & Zhu, X. (2019). The resilience of social norms of cooperation under resource scarcity and inequality — An agent-based model on sharing water over two harvesting seasons. *Ecological Complexity*, *40*(April 2018), 100709. https://doi.org/10.1016/j.ecocom.2018.06.001
Nika, C. E., Gusmaroli, L., Ghafourian, M., Atanasova, N., Buttiglieri, G., & Katsou, E. (2020). Nature-based solutions as enablers of circularity in water systems: A review on assessment methodologies, tools and indicators. *Water Research*, *183*, 115988. https://doi.org/https://doi.org/10.1016/j.watres.2020.115988
Nobre, C. A., Marengo, J. A., Seluchi, M. E., Cuartas, A., & Alves, L. M. (2016). Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015 Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015. *Journal Od Water Resource and Protection*, *8*(February), 252–262. https://doi.org/10.4236/jwarp.2016.82022
Nunes, E. D. O., & Geddes, B. (1987). Dilemmas of state-led modernization in Brazil. In J. D. Wirth, E. D. O. Nunes, & T. E. Bogenschild (Eds.), *State and Society in Brazil: Continuity and Change* (pp. 103–145). Boulder, CO: Westview Press.
Österblom, H., & Folke, C. (2013). Emergence of global adaptive governance for stewardship of regional marine resources. *Ecology and Society*, *18*(2). https://doi.org/10.5751/ES-05373-180204
Ostrom, E. (2005). Understanding Institutional Diversity. In *UNDERSTANDING INSTITUTIONAL DIVERSITY* (pp. 1–355). 41 WILLIAM ST, PRINCETON, NJ 08540 USA: PRINCETON UNIV PRESS.
Ostrom, Elinor. (2007). A Diagnostic Approach for Going beyond Panaceas. *Proceedings of the National Academy of Sciences - PNAS*, *104*(39). https://doi.org/10.1073/pnas.0702288104
Ostrom, Elinor. (2009). A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science (American Association for the Advancement of Science)*, *325*(5939). https://doi.org/10.1126/science.1172133
Ostrom, Elinor. (2011). Background on the Institutional Analysis and. *Policy Studies Journal*, *39*(1), 7–27. https://doi.org/10.1111/j.1541-0072.2010.00394.x
Ostrom, Elinor, & Cox, M. (2010). Moving beyond panaceas: A multi-tiered diagnostic approach for social-ecological analysis. *Environmental Conservation*, *37*(4), 451–463. https://doi.org/10.1017/S0376892910000834
Otto, I. M., Donges, J. F., Cremades, R., Bhowmik, A., Hewitt, R. J., Lucht, W., …

Schellnhuber, H. J. (2020). Social tipping dynamics for stabilizing Earth's climate by 2050. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(5), 2354–2365. https://doi.org/10.1073/pnas.1900577117

Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change*, *19*(3), 354–365. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2009.06.001

Pahl-Wostl, C., Holtz, G., Kastens, B., & Knieper, C. (2010). Analyzing complex water governance regimes: the Management and Transition Framework. *Environmental Science & Policy*, *13*(7), 571–581. https://doi.org/https://doi.org/10.1016/j.envsci.2010.08.006

Pauleit, S., Zölch, T., Hansen, R., Randrup, T. B., & Konijnendijk van den Bosch, C. (2017). Nature-Based Solutions and Climate Change – Four Shades of Green BT - Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice. In N. Kabisch, H. Korn, J. Stadler, & A. Bonn (Eds.) (pp. 29–49). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-56091-5_3

PCJ, F. A. das B. (2019). Institucional. Retrieved September 15, 2018, from https://agencia.baciaspcj.org.br/institucional/

Qin, J., Fu, X., Peng, S., Xu, Y., & Huang Jieand Huang, S. (2019). Asymmetric Bargaining Model for Water Resource Allocation overTransboundary Rivers. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH*, *16*(10). https://doi.org/10.3390/ijerph16101733

Radaelli, C. M. (1999). The public policy of the European Union: whither politics of expertise? *Journal of European Public Policy*, *6*(5), 757–774. https://doi.org/10.1080/135017699343360

Raik, D. B., Wilson, A. L., & Decker, D. J. (2008). Power in natural resources management: An application of theory. *Society and Natural Resources*, *21*(8), 729–739. https://doi.org/10.1080/08941920801905195

Rockström, J., Falkenmark, M., Allan, T., Folke, C., Gordon, L., Jägerskog, A., … Varis, O. (2014). The unfolding water drama in the Anthropocene: Towards a resilience-based perspective on water for global sustainability. *Ecohydrology*, *7*(5), 1249–1261. https://doi.org/10.1002/eco.1562

Roman, P. (2017). The São Francisco inter-basin water transfer in Brazil: Tribulations of a megaproject through constraints and controversy. *Water Alternatives*, *10*(2), 395.

Salajegheh, S., Jafari, H. R., & Pourebrahim, S. (2020). Modeling the impact of social network measures on institutional adaptive capacity needed for sustainable governance of water resources. *Natural Resource Modeling*, *33*(4), e12277. https://doi.org/https://doi.org/10.1111/nrm.12277

Saldaña, J. (2009). *The coding manual for qualitative researchers*. *The coding manual for qualitative researchers*. London ; Thousand Oaks, Calif. : Sage.

Scalco, A., Ceschi, A., & Sartori, R. (2018). Application of psychological theories in agent-based 4 modeling: The case of the theory of planned behavior. *Nonlinear Dynamics, Psychology, and Life Sciences*, *22*(1), 15–33.

Schlueter, M., & Pahl-Wostl, C. (2007). Mechanisms of resilience in common-pool resource management systems: anagent-based model of water use in a river basin. *ECOLOGY AND SOCIETY*, *12*(2).

Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., … Wijermans, N. (2017). A framework for mapping and comparing behavioural theories in models of social-

ecological systems. *Ecological Economics*, *131*, 21–35. https://doi.org/10.1016/j.ecolecon.2016.08.008
Schlüter, M., Orach, K., Lindkvist, E., Martin, R., Wijermans, N., Bodin, Ö., & Boonstra, W. J. (2019). Toward a methodology for explaining and theorizing about social-ecological phenomena. *Current Opinion in Environmental Sustainability*, *39*, 44–53. https://doi.org/10.1016/j.cosust.2019.06.011
Schneider, A., & Ingram, H. (2007). Ways of knowing: Implications for public policy. Proceedings of the 2007 Annual Meeting of the American Political Science Association.
Schwabe, K., Nemati, M., Amin, R., Tran, Q., & Jassby, D. (2020). Unintended consequences of water conservation on the use of treated municipal wastewater. *Nature Sustainability*, *3*(8), 628–635. https://doi.org/10.1038/s41893-020-0529-2
Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190120. https://doi.org/10.1098/rstb.2019.0120
Seijger, C., Ellen, G. J., Janssen, S., Verheijen, E., & Erkens, G. (2017). Sinking deltas: trapped in a dual lock-in of technology and institutions. *Prometheus*, *35*(3), 193–213. https://doi.org/10.1080/08109028.2018.1504867
Shelton, R. E., Baeza, A., Janssen, M. A., & Eakin, H. (2018). Managing household socio-hydrological risk in Mexico city: A game tocommunicate and validate computational modeling with stakeholders. *JOURNAL OF ENVIRONMENTAL MANAGEMENT*, *227*, 200–208. https://doi.org/10.1016/j.jenvman.2018.08.094
Siders, A. R. (2019). Adaptive capacity to climate change: A synthesis of concepts, methods, and findings in a fragmented field. *WIREs Climate Change*, *10*(3), e573. https://doi.org/https://doi.org/10.1002/wcc.573
Smith, E. R., & Conrey, F. R. (2007). Agent-based modeling: A new approach for theory building in social psychology. *Personality and Social Psychology Review*, *11*(1), 87–104. https://doi.org/10.1177/1088868306294789
Soriano, É., Londe, L. de R., Di Gregorio, L. T., Coutinho, M. P., Santos, L. B. L., Soriano, É., … Santos, L. B. L. (2016). Water crisis in São Paulo evaluated under the disaster's point of view. *Ambiente & Sociedade*, *19*(1), 21–42. https://doi.org/10.1590/1809-4422asoc150120r1v1912016
Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., … Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature*, *562*(7728), 519–525. https://doi.org/10.1038/s41586-018-0594-0
Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., … Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223). https://doi.org/10.1126/science.1259855
Sun, Z., Lorscheid, I., Millington, J. D., Lauf, S., Magliocca, N. R., Groeneveld, J., … Buchmann, C. M. (2016). Simple or complicated agent-based models? A complicated issue. *Environmental Modelling and Software*, *86*(3), 56–67. https://doi.org/10.1016/j.envsoft.2016.09.006
Voss, J. P., & Bornemann, B. (2011). The Politics of Reflexive Governance: Challenges for Designing Adaptive Management and Transition Management. *ECOLOGY AND SOCIETY*, *16*(2).
Walters, C. (1997). hallenges in adaptive management of riparian and coastal ecosystems.

Conservation Ecology [Online], *1*(2), 1.
Whaley, L., & Weatherhead, E. K. (2014). An Integrated Approach to Analyzing (Adaptive) Comanagement Using the "Politicized" IAD Framework. *Ecology and Society*, *19*(1). https://doi.org/10.5751/ES-06177-190110
Whaley, L., & Weatherhead, E. K. (2015). Using the politicized institutional analysis and development framework to analyze (adaptive) comanagement: farming and water resources in England. *Ecology and Society*, *20*(3). https://doi.org/10.5751/ES-07769-200343
Withycombe Keeler, L., Wiek, A., White, D. D., & Sampson, D. A. (2015). Linking stakeholder survey, scenario analysis, and simulation modeling to explore the long-term impacts of regional water governance regimes. *Environmental Science & Policy*, *48*, 237–249. https://doi.org/https://doi.org/10.1016/j.envsci.2015.01.006