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Technical knowledge and water resources management: A comparative study of river basin councils, Brazil

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[1] Better understanding of the factors that shape the use of technical knowledge in water management is important both to increase its relevance to decision-making and sustainable governance and to inform knowledge producers where needs lie. This is particularly critical in the context of the many stressors threatening water resources around the world. Recent scholarship focusing on innovative water management institutions emphasizes knowledge use as critical to water systems' adaptive capacity to respond to these stressors. For the past 15 years, water resources management in Brazil has undergone an encompassing reform that has created a set of participatory councils at the river basin level. Using data from a survey of 626 members of these councils across 18 river basins, this article examines the use of technical knowledge (e.g., climate and weather forecasts, reservoir streamflow models, environmental impact assessments, among others) within these councils. It finds that use of knowledge positively aligns with access, a more diverse and broader discussion agenda, and a higher sense of effectiveness. Yet, use of technical knowledge is also associated with skewed levels of power within the councils.

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1. Introduction

[2] Scarcity and the degradation of freshwater resources are two of the greatest problems facing societies today. The predicted negative effects of climate change on water resources further exacerbate the need for innovative and adaptive management institutions to simultaneously address current levels of stresses and to build systems that are more resilient for the future. Scholars point to different kinds of knowledge use, including technical, lay, and indigenous, as a crucial ingredient for the successful management of natural resources and adaptive capacity building [*Berkes et al.*, 2000; *Brooks et al.*, 2005; *Dietz et al.*, 2003; *Lemos and Agrawal*, 2006; *Smit et al.*, 2000]. In decentralized water resources management, for example, technical knowledge can inform managers and stakeholders about physical and environmental aspects of river basins as well as contribute to conflict resolution and reduce transaction costs. By enabling better-informed decisions, it can also encourage stakeholders' sense of effectiveness, participation, and ownership. Conversely, lack of knowledge can lead to shortsighted, unsustainable use of resources. And insulated use of technical knowledge can reinforce traditional patterns of technocratic decision making, undermining good governance goals. Indeed, when technical knowledge is unavailable or inaccessible and is used in an insulated manner, it can alienate stakeholders, invite demobilization, and encourage noncompliance with management decisions [*Lemos*, 2008]. Moreover, all types of knowledge have been theorized to be a critical resource for implementing adaptive water resources management and for building the adaptive capacity and resilience of vulnerable water systems [*Pahl-Wostl*, 2007]. However, there has been relatively little empirical research assessing the role of technical knowledge in water management and even less exploring how it relates to broader institutional mechanisms within the context of emerging adaptive and integrated water governance approaches. In this article, we analyze these factors within and across 18 river basin councils in Brazil.

[3] Water resources management around the world is characterized by great diversity of knowledge use and comanagement schemes. For instance, decentralization and the democratization of water management to the river-basin level have received significant attention through renewed calls for Integrated Water Resources Management (IWRM) and similar approaches [*Blomquist et al.*, 2005]. Historically, Brazilian water agencies and decision makers in charge have relied heavily on technical knowledge to manage the country's public water resources. Engineers, cloaked in their technical expertise, have traditionally dominated and insulated decision making in the water sector, leaving little room for broader societal input [*Formiga-Johnsson*, 2001]. However, for the past 15 years, Brazil's water resources management sector has undergone an extensive reform that includes many of the mechanisms for good governance prescribed within the IWRM paradigm. These include the creation of stakeholder-driven river basin

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councils (committees and consortia), the integration across policies for sustainable management, and the adoption of the river basin as the managing jurisdiction. The implementation of this paradigm to such a wide-ranging extent is what makes Brazil unique among its reform counterparts throughout the world. In the wake of Brazil's water reform, we discuss how the use of technical knowledge is changing in the context of the new management institutions and how participants in the process perceive and value its use.

[4] Since the early 1990s, over 100 river basin committees and consortia, formed by representatives from the government, organized civil society, and water users, have been created [*SRH*, 2006]. Their mandate includes design and implementation of basin management plans, conflict resolution, and implementation of a bulk water permit and charge system. Broadening societal participation in water management is also included [*Abers*, 2007; *Abers et al.*, 2009; *Brannstrom et al.*, 2004; *Formiga-Johnsson et al.*, 2007].

[5] In principle, the advantages of the use of technical knowledge in participatory and advisory councils are twofold. In material terms, knowledge can improve and facilitate decision making by supporting better-informed decisions. For example, in river basin committees, reservoir models can inform stakeholders of water availability, recharge and discharge, potential water shortages, and exposure to climate-related events such as the El Niño–Southern Oscillation (ENSO) or future climate change. In adaptive water resources management, knowledge networks can influence and enable learning that supports adaptive response as problems emerge [*Olsson et al.*, 2004]. In normative terms, knowledge can empower participation by decision makers and increase their sense of effectiveness and inclusion, which, in turn, should encourage further participation [*Lemos*, 2008]. It can also democratize the production of science through the creation of arenas (such as river basin councils) where expertise can be picked apart and questioned in the context of multiple interests [*Blok*, 2007] (for an alternative view, see also *DuPuis and Gareau* [2006]). In other words, if council members have access to technical knowledge, then they will be able not only to participate more meaningfully in decision-making negotiations but also make better informed decisions. In this context, a better understanding of the factors that shape knowledge use contributes to the growing scholarship in water management and democratization of science. This research can also inform institutional design and governance of water resources on a practical level.

[6] This article examines the factors shaping the use of technical knowledge (specifically, climate and weather forecasts, reservoir streamflow models, environmental impact assessments, hydrological models, water quality information, planning, and management studies, and early warning studies) in water resources management in Brazil. In particular, it explores their use by river basin councils created by the Brazilian reform. While the new management system might amplify the opportunity for the use of different kinds of nontechnical knowledge (practical, lay, local knowledge), this analysis is limited to technical knowledge. We examine a number of variables that influence knowledge use in the context of river basin councils' decision making (see Table 1). The study uses data collected through a census survey of 626 members of river basin councils across 18 river basins in different regions of Brazil. In the next sections, we discuss these factors, using both quantitative and qualitative approaches. First, we explore a few of the theoretical underpinnings that inform this analysis, including the role of science-generated knowledge in decision making and more specifically in IWRM. Second, we briefly describe Brazil's water reform and contextualize the river basin councils and their role in Brazil's new water governance. Next, we explain in further detail the empirical analysis and report our main results. We conclude with a brief summary of our main findings and a few suggestions for further research.

2. Technical Knowledge and Decision Making

[7] The importance and criticality of knowledge in water resources have been repeatedly recognized, both in traditional and in emerging innovative models of water management, albeit with different outcomes. In traditional water resources management, technical knowledge use often seeks to rationalize or optimize decision making and increase efficiency. Its deployment, in an insulated manner, can lead to the concentration of power in the hands of experts at the expense of other stakeholders' inputs. Indeed, rather than an unintended consequence, part of the desirability of technical knowledge can be explained precisely by its ability to insulate decision making from "irrational" actors. From a policymaker's point of view, there may be many advantages to gain from a technocratically insulated model of decision making. First, because policy tools originate in "hard" research science, therefore requiring technical expertise for their use, they can insulate policymakers from political meddling and efforts by powerful interest groups to influence policy implementation and outcomes [*DuPuis and Gareau*, 2006; *Lemos and Oliveira*, 2004]. Second, technocratic decision making is also understood as increasing legitimacy and feasibility and reducing dissent [*Ezrahi*, 1990; *Jasanoff*, 1990]. Third, technocrats believe technical insulation will decrease policies' vulnerability to criticism from nontechnical people and politicians [*Steel et al.*, 1993]. Finally, scientific decision making may hold the promise of value-free decisions about public policy and therefore bypass the messiness of dialog and negotiation [*Jamieson*, 2000]. Here, many of the essential qualities people associate with science, thoroughness, objectivity, the search for truth, and rationality, to name just a few, are also the most desirable characteristics of efficient and effective policymaking sought after by policymakers [*Ezrahi*, 1990; *Jasanoff*, 1990; *Lemos*, 2003]. Although this model may be attractive to decision makers hoping to keep political meddling or undue influence of particular interest groups at bay, in reality, decision making is often messy and fraught with uncertainty [*Kingdon*, 1985; *Lindblom*, 1959; *Stone*, 1988].

[8] Technocratic decision making, however, may defy basic precepts of democracy by limiting the number of participants and policy alternatives and by rendering technocrats unaccountable to elected officials and clients [*Etzioni-Havely*, 1983; *Nunes and Geddes*, 1987]. Indeed, when trying to gain political advantage, groups may be tempted to exaggerate or distort information when that information serves to support the interests of one group over another. In this process, information is neutral neither in terms of power relationships nor in institutional structures

[*Lemos*, 2008]. As technical analysis becomes more prominent than other informational input (including opinions and interests of nontechnical sources), it may "squeeze out other forms of information, decision-making routines, and claims" [*Healy and Ascher*, 1995, p. 13].

[9] In emerging paradigms such as IWRM and adaptive management of water systems, knowledge also figures prominently if in a less insulating format. IWRM and adaptive management many times involve devolution of decision making to the watershed scale and the inclusion of stakeholders in the decision-making process [*Kemper et al.*, 2007; *Leach et al.*, 2002; *Medema et al.*, 2008]. In the case of adaptive management models, decision makers and institutions not only respond to changes as they emerge but also learn while doing it [*Arvai et al.*, 2003]. Adaptive management mechanisms are flexible, responsive, and inclusive and use knowledge, networks, and social learning as the basis for decision making at the natural resource level. It accepts the system as dynamic and unpredictable and promotes flexible coordination among diverse stakeholders, various levels of actor–organizational networks, self-organization from the ground up, and experimentation and learning [*Folke et al.*, 2005]. Proponents of these approaches argue that recognizing the different interests, the interwoven nature of the problems, and the dynamics and flows of information, learning, and adaptation represents a model much more aligned with the inherent complexity (both social and natural) of the water system. Indeed, in this context, knowledge is an intrinsic part of management that interactively shapes and informs decision making and, in principle, leads to better decisions. As mentioned above, knowledge use influences and is influenced by levels of participation. It may also shape deliberation and consensus formation [*Elliott*, 1999] and perceptions of power distribution [*Lemos*, 2008]. The mere creation of decentralized, stakeholder-driven councils enhances the opportunity for knowledge use and distribution in a markedly different way from traditionally centralized and insulated models of natural resource management [*Brannstrom et al.*, 2004; *Ribot*, 2002].

[10] However, both the IWRM and adaptive management literatures tend to look at knowledge as an independent variable affecting the performance of water governance approaches rather than an outcome whose nature and characteristics need explanation themselves. In effect, these studies mostly assume that knowledge is available and plays a positive role (or not) in influencing the quality of water governance. Often, knowledge, including local and indigenous knowledge, is treated as one of the factors shaping the success or failure of decentralized natural resources management [*Leach et al.*, 2002; *Lubell et al.*, 2002; *Pahl-Wostl and Hare*, 2004; *Ribot*, 2002]. Moreover, many of its findings are based on single case studies in which knowledge use is examined within the context of unique, place-based processes [*Lemos*, 2008; *Olsson and Berg*, 2005; *Pahl-Wostl and Hare*, 2004]. In this study, we look at knowledge use as the dependent variable and examine it against various aspects of the characteristics, organization, and modus operandi of river basin councils. Because we use data collected within the river basin committees themselves, we do not take into consideration broader institutions affecting knowledge use beyond the council's activities. Hence, rather than an exploration of knowledge use in water management in Brazil as a whole, this study is an examination of knowledge use within water councils.

3. Water Reform in Brazil

[11] As mentioned above, several characteristics of the water reform process in Brazil provide an excellent opportunity to study comparatively the institutional factors that influence both the use of technical knowledge by river basin councils and council members' perception of how it shapes decision making and relations within these councils. First, the reform is mainly regulated by a national law enacted in 1997 (Law 9,422 also know as "Water Law"). This law instituted the National Policy for Water Resources and created the National System for the Management of Water Resources and the National Water Agency (Agência Nacional de Água, ANA), which oversees the application of the law and has jurisdiction over the management of interstate rivers' watersheds. Although implementation has varied substantially between states as well as between river basins within the same state, the basic organizing framework, especially in terms of the creation of river basin councils, has followed the same model of triparty representation between public officials, water users, and representatives of organized civil society (mostly nongovernment organizations and professional associations) [*Brannstrom et al.*, 2004]. Stakeholders are organized through both river basin committees and consortia. River basin committees are legally constituted organizations for IWRM; their responsibilities are the design and approval of river basin plans, the establishment of water quality goals, the creation and implementation of water permitting and charging mechanisms (including the establishment of priorities of how to spend revenues), and arbitration over conflicts [*Abers*, 2007; *Abers et al.*, 2009]. Consortia, in turn, are not legally established but have very similar responsibilities as those of the committees although not the same range and enforcement capabilities. Committees and consortia (collectively referred to as councils in this article) generally have a presidency, a deliberative body (the plenary), and a secretariat. A few councils also have technical chambers, working groups, or both that create, organize, and-or synthesize technical knowledge to support the plenary decision making. Even fewer councils have a more robust developed structure that includes an executive agency to implement decisions at the river basin level [*Formiga-Johnsson et al.*, 2007; *Lemos and Oliveira*, 2004]. Figure 1 shows a map of all river basins included in the study.

[12] Second, the new legislation completely overhauled the old system, introducing mechanisms for the management of water resources more in tune with the democratization of state–society relations after the demise of the Brazilian military dictatorship in the mid-1980s. These included (with variations in regulations across different states) (1) the organization of management at the watershed level, replacing a previous system that favored municipal, state, and federal jurisdictions; (2) the creation of specific regulation to protect water resources at the watershed level; (3) the decentralization of decision making and resources; (4) the design of a new system of water concession rights; (5) the creation of different instances of public participation, especially the organization of watershed committees and State and National Water Councils; (6) the insertion of water resources

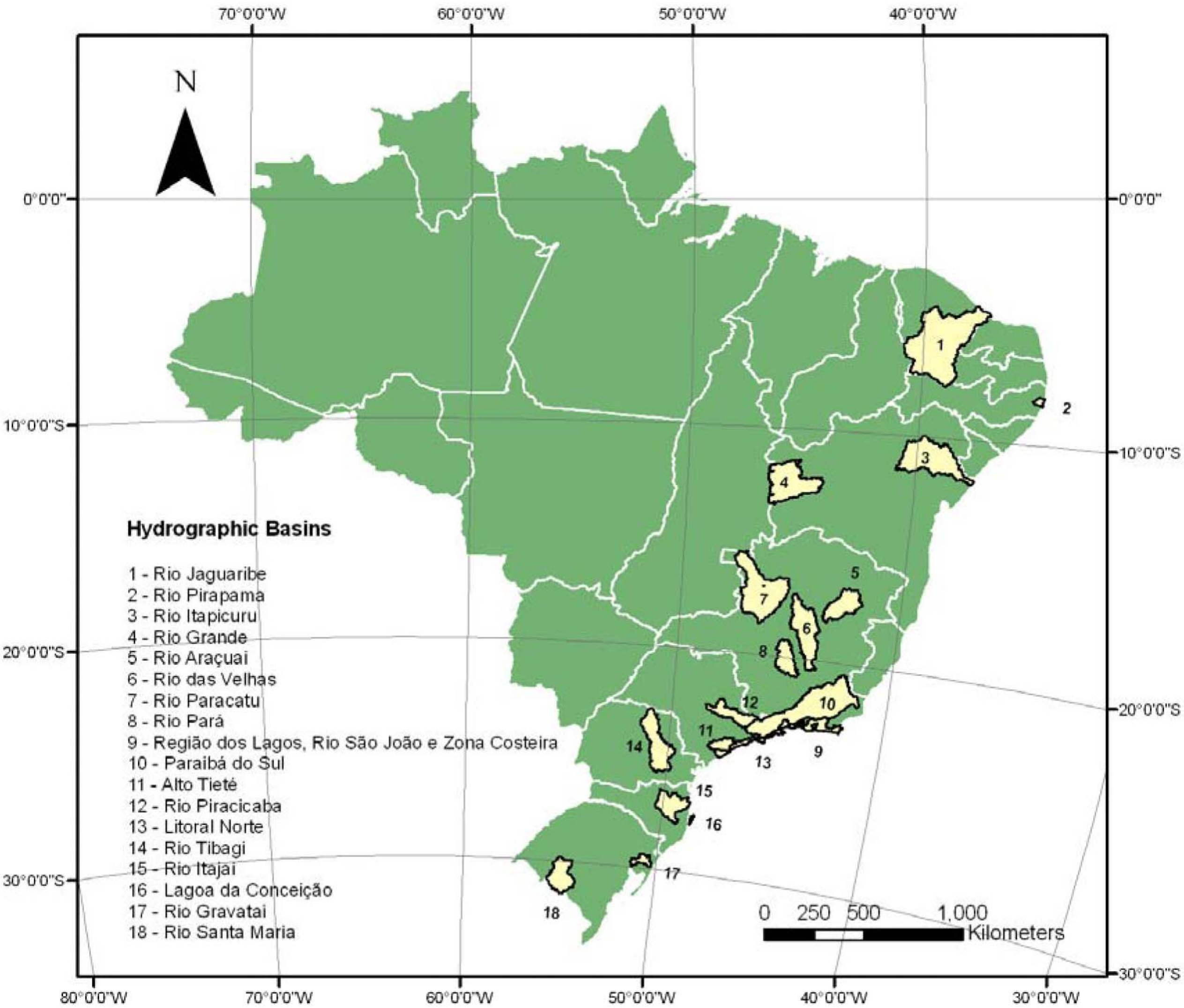

Figure 1. Map of Brazil showing river basins studied.

management within a larger realm of environmental concerns that challenged the traditional supremacy of economic criteria in water management; and, most controversially, (7) the implementation of a user's fee system at the river basin level. These reforms, in principle, not only democratized decision making by creating stakeholder-driven watershed councils but also introduced new patterns of knowledge use with the creation of water resources management agencies and technical support groups that work with the committees [*Abers*, 2007; *Brannstrom et al.*, 2004; *Formiga-Johnsson et al.*, 2007; *Lemos and Oliveira*, 2004].

[13] Third, in spite of this national framework, the structure of councils varies from state to state and even within states. They differ in size and in the allocation of seats among users, public servants, and civil society groups. In some states the minutia of council rules and procedures are regulated by law, while in others the law provides a framework within which a council may design by-laws and create technical support groups as it sees fit. Some of the design differences are in response to Brazil's enormous regional diversity in socioeconomic conditions, political cultures, natural environments, range of water uses, and institutional resources. Furthermore, a strong federal system allows state governments to modify the national model, for example, by giving priority to intermunicipal consortia over river basin committees [*Brannstrom et al.*, 2004]. These sources of variation represent a valuable opportunity to study the factors that influence knowledge use.

4. Exploring Factors That Affect Knowledge Use

[14] Our analysis uses data from a survey carried out in Brazil in 2005 by the Watermark project, a broad research collaboration created in 2001 by U.S. and Brazilian researchers and water management practitioners. The survey queried 626 members of 18 river basin councils (14 river basin committees and 4 consortia) in various parts of Brazil. To select the survey sample, the river basin councils were stratified according to four characteristics: region of the country (northeast, central, southeast, and south), main

water-related problem (scarcity, quality, and flooding), type of river basin (rural, urban, coastal, or combination rural-urban), size of river basin (in square kilometers). Because councils were intentionally selected within each stratum, with preference for ones that had been previously studied by the Watermark Project since 2001, the findings are not representative and are limited to refer specifically to the sample basins. Only one committee included in the survey, the Sapucaí Mirim Grande Committee in São Paulo had not been the object of such previous qualitative research. Hence, our findings refer only to the councils examined.

[15] In each council under study, all full members (*membros titulares*) were selected to be interviewed and substituted for by their alternates when unavailable. Thus, for each council an effective census of members (86% of members or their alternates) was interviewed. In two councils, Itajaí and CEIVAP, the members of the technical chambers were also interviewed. In addition, to interpret and complement the findings from the quantitative analysis, this study takes advantage of the extensive qualitative database collected across these river basins since 2001 by the Watermark Project.

[16] We selected one focal question from the Watermark survey to serve as the dependent variable explored in our regression models regarding reported technical knowledge and information use. From the responses, we derived five dependent variables:

[17] D1, reported use of weather forecasts;

[18] D2, reported use of climate forecasts;

[19] D3, reported use of environmental information systems, water quality information, and management planning studies;

[20] D4, reported use of models, forecasts, and disaster alert systems; and

[21] D5, reported use of all forms of technoscientific knowledge.

[22] For the independent variables, we first selected questions that we theorized could offer plausible explanations or provide some insight into the dependent variables. These included both questions that related to governance and institutional mechanisms and those that related to various demographic variables. We then removed from this list the questions that were not significantly correlated to our dependent variables at $\alpha = 0.05$. Next, we clustered the remaining questions into 20 categories of questions that we qualitatively inferred to be gauging similar concepts (i.e., variables). The categories had from 1 to 9 questions gauging each of the 20 variables (see Table 1, Appendix A).

[23] We aggregated the individual responses for our independent and dependent variables to the river basin committee and consortium level; that is, the 626 individual responses were aggregated for each basin to produce $n = 18$ data points characterizing "river basin water management." For questions where we were interested in a particular response (e.g., those responding yes or those responding b), the variable was coded as the proportion of committee members giving the response of interest. For questions where responses could be converted to a cardinal number (e.g., a scale from 1 to 10, age, income, etc.), we coded the variable as the mean value for the basin. For questions where we were interested in the differences among members within the committee, we calculated the entropy of the variable. We used the concept of entropy to measure the disorder or diversity among responses, that is, the range of agreement or disagreement between committee members when expressing their opinion (measured in a scale of 1 to 10) regarding different aspects of the committee functioning. Entropy is calculated as

$$E = \frac{\sum_{i}^{10} -p_i \ln(p_i)}{-\ln(1/10)}, \qquad (1)$$

where p_i is the proportion of committee members responding i to the particular question. Entropy scales from 0, when all committee members give the same response to a question, to 1, when the responses to a question are evenly spread across the given scale. We use the level of entropy as a proxy to measure agreement and disagreement among the members of any given committee. This entropy calculation was applied to the questions regarding committee performance, how democratically the committee made decisions, for example, where one might reasonably expect responses within a committee to be similar. In this context, the entropy calculation provides a measure of "cohesiveness" within the committee, describing how much or how little committee members agree with each other and perceive the committee similarly.

[24] These three categories of variables (proportions, mean responses, and entropies) make up the set of variable types used in this analysis. Each variable was measured across 18 points for the 18 committees and consortia included in this study (for a detailed explanation of the model and aggregation of variables, see Table 2 and Appendix A). It is important to emphasize that the results spring from a data set of 18 points, a small but significant sample of the basin council population (139 for rivers under state jurisdiction in 2005). While there is disagreement over whether the data set should be larger [*Maxwell*, 2000] or smaller [*Wampold and Freund*, 1987], a common rule-of-thumb is that the ratio data points:predictors should not be less than 10:1 [*Maxwell*, 2000]. By selecting for models with at most two terms, we remain at or above this ratio. We gain further confidence in the regression results by noting that our P values for the F tests of the regression models against null models are extremely low (Table 2). The small number of model terms and the low P values also give us confidence that the stepwise regression is not unduly weighting random variation, another point of caution when using this technique [*Menard*, 2002]. However, as mentioned above, because of the small sample, findings should not be broadly generalized beyond the studied basins.

5. Regression Model Search

[25] We reduced the data one final time by creating regression models that pulled a single variable from each of the 20 independent variable categories (for a total of 20 independent variables) to create a "gene" and performed stepwise regressions of this set of independent variables against each dependent variable. The resulting models retained from 1 to 17 of the independent variable terms. We

Table 1. Variables and Survey Questionnaire Questions[a]

Variable	Question
AI (actor influence)	Which sectors or organs of the committee are the most influential in deciding the agenda of the committee's plenary meetings? [Those answering "the officers."]
CR (conflict resolution)	What grade would you give to the committee on attempting to negotiate conflicts among members in a democratic fashion?
D (level of democratization)	What grade would you give to the committee regarding communication with the population at large?
E (education)	How far did you go in school? [Graduate degree]
ET (entropy)	Sum of various questions, gauging members' opinions (in a 1–10 scale) regarding different issues such as level of democracy, conflict, effectiveness, equity, etc.[b]
F (flexibility)	In relation to issues discussed in the committee, did you ever change your mind about something because of discussions that took place in the committee?
I (income)	Indicate for us please your total monthly household income, adding up all your income, wages, rents, etc., over the last month. [Those answering "over 40 Minimum Wages (over R$ 10.400,00)."]
LP (level of participation)	Assess your involvement in this committee…how often do you participate in a majority of plenary meetings, a few meetings, or none? [Those answering "present proposals."][c]
P (performance)	What grade would you give to the committee as to its success in influencing the decisions of governmental organs?
PI (perception of information value)	How much relevance you would attribute information about water quality for solving the basin's problems?
TR (Trust)	Which (people-groups-organizations) on this list do you have the most confidence for producing and distributing technical information in your committee? [Those answering "organs of government."]
PW (power)	In some committees, there are distinctions among members that can make a democratic decision-making process difficult. In your view, which of these distinctions have gotten in the way of democracy in your committee? [Those answering "unequal political power among members."]
S (stake)	Is your agency, firm, or municipality located in the basin?
TE (technical experiences)	Do you have experience in law, political institutional issues, economics?
TI (technocratic insulation)	In your opinion, are most decisions negotiated before the plenary meeting takes place ?
TN (technical networks)	Have you been to any meetings of Brazilian Association of Sanitary Engineers (ABES)?
U (understanding)	Speaking now of the dissemination of technical information among the members-associates of the committee, would you say that the presentations are made in a way that facilitates understanding on the part of all members?
AA (access)	Speaking now of the dissemination of technical information among the members-associates of the committee, would you say that they are available and accessible to all members-associates?
AP (access to participation)	In some cases, committee members find it difficult to come to meetings. If this is true for you, which obstacle is the main difficulty you encounter?[d]
OA (outreach activities)	What do you do in relation to the committee's activities in addition to the plenary meetings; tell us how often you represent the committee in other forums?

[a]Some questions are coded as the proportion of respondents that give the answers included in brackets.
[b]The concept of entropy is based on the level of agreement between members regarding these issues.
[c]Answer is coded according to an assigned mean having three points (0, 0.5, 1).
[d]Choice of obstacles: (1) distance and travel time, (2) transportation cost, (3) difficulty of travel (e.g., bad or dangerous roads), (4) lack of time, (5) difficulty in getting employer to grant time off, (6) no difficulty, and (7) other.

used a "genetic" algorithm to create many such models and selected among them to maximize the fitness function (see Appendix A for details concerning the genetic algorithm):

$$F = \sum_{j}^{5} \frac{R_j^2}{n_j}, \quad (2)$$

where j is the number of dependent variables across those that we evaluated, R_j^2 is a standard measure of how much variance in the dependent variable is explained by the regression model, and n_j is the number of terms in the model. This function thus selects for models with high variance explanation per model term, rather than high overall variance explanation. To further simplify our model, we built a simple genetic algorithm to find the "fittest" regression model for our study, leading to five simple expressions for our dependent variables:

$$D1 = -0.23 + 0.47(\pm 0.24)\mathrm{TI} + 0.65(\pm 0.32)U, \quad (3)$$

$$D2 = 3.79 - 4.17(\pm 1.25)\mathrm{ET} + 0.66(\pm .29)S, \quad (4)$$

$$D3 = -1.94 + 5.38(\pm 2.83)\mathrm{PI}, \quad (5)$$

$$D4 = 1.92 + 2.48(\pm 1.58)\mathrm{TI}, \quad (6)$$

$$D5 = -1.84 + 7.61(\pm 3.02)P + 4.66(\pm 2.32)\mathrm{PW}, \quad (7)$$

Table 2. Aggregated Responses

Basins	D1	D2	D3	D4	D5	AI	CR	D	E	ET[a]	F	I	LP
Rio Paraíba do Sul	1.57	1.49	−0.41	1.37	0.73	0.09	0.02	−0.39	0.54	**−3.01**	1.17	0.87	−0.38
Rio Itajaí	1.06	0.97	0.49	1.04	0.80	0.74	−0.05	0.94	0.04	**−1.38**	−0.22	0.07	−0.28
Alto Tietê	−0.38	−0.41	0.00	0.31	0.06	1.32	−1.25	−1.91	0.31	**0.48**	0.99	1.43	−0.16
Rio Araçuaí	−1.39	−1.43	−2.50	−1.53	−2.24	−0.46	−0.02	−0.42	−2.43	**0.01**	−1.13	−1.43	1.53
Rio das Velhas	−1.23	−0.84	−0.08	−0.99	−0.95	−0.54	0.50	0.81	−0.04	**0.35**	1.11	−0.37	0.75
Rio Pará	0.22	0.21	0.18	0.48	0.26	−0.56	−0.26	1.09	−0.28	**−0.34**	−0.65	−0.21	−0.78
Rio Pirapama	−0.29	−0.31	0.43	0.30	0.21	0.17	0.21	0.02	0.37	**−0.14**	1.75	0.05	0.48
Rio Sapucaí Mirim Grande	−0.08	−0.65	0.24	0.14	0.02	1.31	−0.21	−0.71	0.24	**−0.01**	1.06	0.80	−1.59
Litoral Norte	0.28	−0.05	0.05	−0.47	−0.52	1.66	0.72	−0.09	−0.52	**−0.37**	0.90	−0.09	0.06
Baixo Jaguaribe	1.24	1.10	−1.03	1.23	0.39	−0.34	0.53	0.73	−1.66	**−0.15**	−0.68	−0.74	−0.06
Rio Paracatu	−0.76	0.05	−2.90	−1.46	−2.32	−1.07	−2.44	−1.23	−0.91	**1.68**	−1.91	−0.05	2.32
Lagoa da Conceição	−1.59	−1.35	−0.31	−1.53	−1.45	−0.39	−0.69	−0.17	−0.26	**0.38**	0.00	0.16	0.20
Rio Gravataí	−0.76	−0.42	0.00	−0.34	−0.43	−0.09	0.93	−0.15	0.92	**−0.27**	−0.19	0.87	0.82
Rio Santa Maria	0.99	1.53	0.54	0.23	0.20	−0.20	0.77	1.53	−1.58	**−0.07**	0.59	−0.51	0.63
Rio Piracicaba	1.82	2.10	0.18	1.34	0.92	1.90	1.15	1.62	0.92	**0.34**	0.61	2.71	−0.69
Rio Tibagi	−0.17	−0.62	−0.26	−0.39	−0.56	0.48	−1.08	−0.02	0.77	**0.93**	−1.42	0.39	−0.68
Alto e Médio Itapicuru	0.34	0.33	−1.23	−1.45	−1.72	−1.07	−0.11	0.59	−1.78	**0.78**	0.00	−1.43	−0.47
Região dos Lagos, Rio São João e Zona Costeira	0.08	0.39	0.72	−0.14	−0.02	2.09	1.97	1.81	0.13	**0.87**	−0.10	−0.62	1.88
Maximum	1.82	2.10	0.72	1.37	0.92	2.09	1.97	1.81	0.92	**1.68**	1.75	2.71	2.32
Minimum	−1.59	−1.43	−2.90	−1.53	−2.32	−1.07	−2.44	−1.91	−2.43	**−3.01**	−1.91	−1.43	−1.59

Basins	*P*[a]	PI[a]	TR	PW[a]	S[a]	TE	TI[a]	TN	U[a]	AA	AP	OA
Rio Paraíba do Sul	**0.26**	**1.08**	0.17	**0.51**	**−0.71**	0.55	**2.69**	1.90	**0.17**	0.14	−0.05	0.04
Rio Itajaí	**−0.15**	**−0.78**	−0.29	**1.24**	**0.31**	0.11	**0.50**	−0.34	**0.46**	0.31	0.49	−0.90
Alto Tietê	**−1.16**	**−0.34**	1.98	**0.81**	**−0.39**	1.14	**1.54**	0.66	**−2.03**	−0.89	1.95	−0.73
Rio Araçuaí	**−1.42**	**−2.66**	−0.03	**0.00**	**−0.05**	−2.14	**−0.27**	−1.48	**−0.35**	−1.37	−1.02	1.91
Rio das Velhas	**0.41**	**0.88**	1.34	**−0.56**	**−0.28**	0.67	**−0.35**	1.28	**−0.94**	−0.74	−0.09	−0.41
Rio Pará	**0.68**	**0.57**	−0.27	**0.00**	**−0.48**	−0.11	**0.52**	−0.19	**0.18**	−0.14	0.32	−0.54
Rio Pirapama	**0.01**	**−0.07**	−0.35	**−0.20**	**0.45**	0.43	**−0.02**	0.23	**0.03**	−0.34	−0.15	1.21
Rio Sapucaí Mirim Grande	**−0.02**	**0.01**	0.03	**1.03**	**−0.16**	−0.29	**0.06**	−0.45	**−0.03**	1.07	−0.55	0.67
Litoral Norte	**0.04**	**0.99**	−0.22	**−1.12**	**−0.28**	0.52	**1.70**	−0.15	**0.53**	0.90	0.91	0.79
Baixo Jaguaribe	**−0.67**	**−1.50**	−1.02	**0.81**	**0.45**	−1.34	**0.02**	−0.90	**0.98**	−1.22	0.05	0.50
Rio Paracatu	**−2.41**	**−1.10**	1.87	**−1.12**	**0.00**	−2.07	**−0.35**	−1.08	**−1.83**	−0.61	−1.24	1.96
Lagoa da Conceição	**−1.56**	**−0.43**	0.71	**0.28**	**−1.13**	0.81	**−0.13**	0.15	**−1.22**	−1.52	1.78	−0.83
Rio Gravataí	**−0.01**	**0.57**	1.19	**−0.26**	**0.00**	−1.23	**−0.55**	1.44	**−0.66**	0.71	1.09	0.27
Rio Santa Maria	**0.18**	**0.01**	−0.49	**−1.30**	**2.27**	−0.89	**−0.44**	−0.45	**0.77**	1.35	−0.38	−0.25
Rio Piracicaba	**1.20**	**1.21**	0.14	**0.42**	**2.27**	0.32	**2.22**	1.55	**−0.08**	1.39	2.02	−0.26
Rio Tibagi	**−1.42**	**−0.01**	0.50	**2.02**	**0.17**	0.29	**0.10**	0.15	**−0.41**	−0.33	−0.60	−2.04
Alto e Médio Itapicuru	**0.20**	**−0.58**	−1.00	**−1.91**	**0.31**	−1.23	**−0.72**	−1.21	**1.09**	0.63	−0.94	0.17
Região dos Lagos, Rio São João e Zona Costeira	**1.35**	**0.55**	−1.82	**−0.42**	**2.27**	−0.79	**−0.07**	0.86	**1.82**	1.64	0.25	−0.04
Maximum	**1.35**	**1.21**	1.98	**2.02**	**2.27**	1.14	**2.69**	1.90	**1.82**	1.64	2.02	1.96
Minimum	**−2.41**	**−2.66**	−1.82	**−1.91**	**−1.13**	−2.14	**−0.72**	−1.48	**−2.03**	−1.52	−1.24	−2.04

All data are shown in standard *Z* scores.

[a]Boldface indicates variable included in regression.

Note. Looking across the aggregated data (Table 3) and drawing on our knowledge of a number of the basins in the study where we carried out extensive qualitative research (i.e., Paraíba do Sul, Itajaí, Jaguaribe, and Pirapama), we find that the values make intuitive sense. In consequence, we are confident that our choice of the basin as the unit of analysis is appropriate. For example, in reference to council members' perception of institutional performance, the below-average aggregate value for Jaguaribe and average aggregate value for the other three basins are consistent with what we know to be true across the four basins. Similarly, we cross-checked the aggregate values for two other variables, access to information and access to participation, and found that they also reflected well the experience of these particular councils.

(Models include only terms significant at 95% confidence; numbers in parentheses represent approximate 95% confidence intervals.)

[26] Because the confidence intervals of the regression terms are relatively broad, the regression equations are more valuable as descriptive rather than predictive tools for the relationships studied across the basins. Within these levels of confidence, the model identified seven factors that influence the use of technical knowledge by river basin councils: perception of information value (PI), performance (*P*), understanding (*U*), technocratic insulation (TI), stake (*S*), entropy (ET), and power (PW) (for further details see Table 3 and Appendix A). We find that, first, the higher the perception among members that their decisions have relevance in terms of water resources management vis-à-vis other sectors of government and society, the higher the level of reported technical knowledge use (the PI term in *D*3). Second, and related to this first factor, the more committee members perceive that their actions in the committee influence decisions of the government, the higher the level of reported technical knowledge use (the *P* term in *D*5). These findings indicate that a member's perception of effectiveness may be influenced by their use of knowledge; that is, members believe either that knowledge use enhances

Table 3. Significant Factors in the Regression[a]

	B	SE	*P* Value	Lower Limit	Upper Limit
		(D1) Weather Forecasts			
AI (actor influence)	0.043	0.15	0.779	−0.251	0.193
CR (conflict resolution)	−0.407	0.373	0.293	−1.138	−0.034
D (level of democratization)	0.333	0.387	0.404	−0.425	0.72
E (education)	−0.006	0.185	0.973	−0.368	0.178
ET (entropy)	−0.123	1.532	0.937	−3.125	1.409
F (flexibility)	−0.179	0.292	0.55	−0.752	0.113
I (income)	−0.337	0.435	0.451	−1.19	0.097
LP (level of participation)	−0.256	0.256	0.333	−0.757	−0.001
P (performance)	−0.067	0.351	0.852	−0.754	0.284
PI (perception of information value)	−0.146	0.586	0.807	−1.296	0.44
TR (trust)	0.977	0.824	0.255	−0.638	1.801
PW (power)	0.087	0.2	0.671	−0.305	0.286
S (stake)	0.253	0.154	0.123	−0.049	0.407
TE (technical experience)	−0.302	0.344	0.395	−0.976	0.042
TI (technocratic insulation)	**0.467**	**0.12**	**0.001**	**0.232**	**0.586**
TN (technical networks)	−0.282	0.213	0.208	−0.7	−0.069
U (understanding)	**0.654**	**0.164**	**0.001**	**0.333**	**0.818**
AA (access)	0.109	0.145	0.463	−0.174	0.254
AP (access to participation)	−0.082	0.206	0.697	−0.487	0.124
OA (outreach activities)	−0.171	0.301	0.579	−0.76	0.13
Regression R^2 value					**0.665**
F test *P* value					**0.00027**
		(D2) Climate Forecasts			
AI (actor influence)	−0.013	0.133	0.923	−0.274	0.12
CR (conflict resolution)	−0.692	0.349	0.067	−1.376	−0.343
D (level of democratization)	0.024	0.399	0.954	−0.758	0.422
E (education)	−0.007	0.17	0.966	−0.341	0.163
ET (entropy)	**−4.173**	**1.252**	**0.005**	**−6.628**	**−2.921**
F (flexibility)	−0.219	0.304	0.484	−0.815	0.085
I (income)	−0.231	0.425	0.595	−1.065	0.194
LP (level of participation)	−0.267	0.258	0.318	−0.772	−0.009
P (performance)	−0.085	0.343	0.808	−0.757	0.258
PI (perception of information value)	0.323	0.549	0.566	−0.754	0.872
TR (trust)	0.158	0.287	0.59	−0.405	0.446
PW (power)	−0.072	0.202	0.727	−0.469	0.13
S (stake)	**0.658**	**0.147**	**0**	**0.371**	**0.805**
TE (technical experience)	0.019	0.313	0.953	−0.595	0.332
TI (technocratic insulation)	0.234	0.139	0.115	−0.039	0.374
TN (technical networks)	−0.213	0.206	0.319	−0.615	−0.007
U (understanding)	−0.066	0.232	0.782	−0.521	0.167
AA (access)	0.026	0.17	0.881	−0.307	0.196
AP (access to participation)	0.064	0.181	0.73	−0.291	0.245
OA (outreach activities)	−0.12	0.31	0.703	−0.727	0.189
Regression R^2 value					**0.63**
F test *P* value					**0.00058**
		(D3) EIS, Water Quality Information, and Management Planning Studies			
AI (actor influence)	−0.404	0.412	0.343	−1.212	0.009
CR (conflict resolution)	1.408	0.788	0.094	−0.137	2.196
D (level of democratization)	1.1	0.779	0.178	−0.426	1.879
E (education)	0.574	0.656	0.395	−0.712	1.231
ET (entropy)	−2.617	3.61	0.48	−9.693	0.994
F (flexibility)	1.513	0.863	0.1	−0.179	2.377
I (income)	1.435	1.377	0.314	−1.265	2.812
LP (level of participation)	−0.932	0.699	0.202	−2.301	−0.233
P (performance)	1.549	0.879	0.098	−0.174	2.428
PI (perception of information value)	**5.375**	**1.445**	**0.002**	**2.542**	**6.82**
TR (trust)	−1.045	0.615	0.11	−2.25	−0.431
PW (power)	0.8	0.514	0.14	−0.207	1.314
S (stake)	0.437	0.407	0.3	−0.361	0.844
TE (technical experience)	1.682	0.95	0.097	−0.179	2.632
TI (technocratic insulation)	−0.201	0.409	0.63	−1.003	0.208
TN (technical networks)	0.68	0.654	0.314	−0.601	1.334
U (understanding)	0.691	0.468	0.16	−0.226	1.159
AA (access)	0.366	0.415	0.392	−0.447	0.78
AP (access to participation)	0.718	0.533	0.198	−0.327	1.251
OA (outreach activities)	−1.727	0.847	0.06	−3.387	−0.879
Regression R^2 value					**0.464**
F test *P* value					**0.00187**

Table 3. (continued)

	B	SE	*P* Value	Lower Limit	Upper Limit
			(D4) Models, Forecasts, and Disaster Alert Systems		
AI (actor influence)	−0.454	1.003	0.658	−2.42	0.55
CR (conflict resolution)	2.631	1.702	0.143	−0.705	4.333
D (level of democratization)	3.258	1.627	0.064	0.068	4.885
E (education)	0.923	1.187	0.449	−1.404	2.11
ET (entropy)	−14.972	8.97	0.116	−32.554	−6.002
F (flexibility)	1.153	1.959	0.565	−2.687	3.112
I (income)	−0.336	2.939	0.911	−6.097	2.604
LP (level of participation)	−2.269	1.661	0.192	−5.524	−0.609
P (performance)	2.86	1.543	0.084	−0.165	4.403
PI (perception of information value)	1.36	3.894	0.732	−6.273	5.255
TR (trust)	−2.427	1.419	0.108	−5.207	−1.008
PW (power)	1.986	1.232	0.128	−0.428	3.218
S (stake)	1.581	0.872	0.09	−0.127	2.453
TE (technical experience)	−0.198	2.325	0.933	−4.755	2.127
TI (technocratic insulation)	**2.482**	**0.807**	**0.007**	**0.899**	**3.289**
TN (technical networks)	−0.024	1.426	0.987	−2.818	1.402
U (understanding)	1.997	1.022	0.07	−0.006	3.019
AA (access)	0.854	0.776	0.288	−0.666	1.629
AP (access to participation)	0.193	1.362	0.889	−2.475	1.555
OA (outreach activities)	−1.707	2.003	0.408	−5.634	0.296
Regression R^2 value					**0.371**
F test *P* value					**0.00727**
			(D5) All Knowledge Types		
AI (actor influence)	−1.118	0.805	0.187	−2.695	−0.313
CR (conflict resolution)	−1.217	3.044	0.695	−7.182	1.827
D (level of democratization)	−0.767	2.478	0.762	−5.623	1.711
E (education)	0.451	1.304	0.735	−2.104	1.755
ET (entropy)	−12.474	8	0.141	−28.153	−4.474
F (flexibility)	2.599	1.919	0.197	−1.162	4.518
I (income)	0.098	2.85	0.973	−5.488	2.947
LP (level of participation)	−0.979	1.894	0.613	−4.691	0.915
P (performance)	**7.608**	**1.54**	**0**	**4.59**	**9.148**
PI (perception of information value)	2.919	4.316	0.51	−5.541	7.236
TR (trust)	0.331	1.759	0.853	−3.116	2.09
PW (power)	**4.664**	**1.184**	**0.001**	**2.343**	**5.848**
S (stake)	0.708	1.046	0.51	−1.343	1.754
TE (technical experience)	1.707	2.022	0.413	−2.257	3.729
TI (technocratic insulation)	1.291	0.808	0.133	−0.293	2.099
TN (technical networks)	0.036	1.427	0.98	−2.761	1.463
U (understanding)	0.086	1.441	0.953	−2.74	1.527
AA (access)	0.681	1.085	0.54	−1.444	1.766
AP (access to participation)	1.19	1.153	0.32	−1.071	2.343
OA (outreach activities)	−0.12	2.307	0.959	−4.643	2.187
Regression R^2 value					**0.694**
F test *P* value					**0.00014**

[a]Values in bold (except in last two rows) are included in the regression.

the relevance of their decisions to water management and society or that their enhanced sense of effectiveness encourages them to seek technical knowledge to support their decisions.

[27] Third, and not surprisingly, use of knowledge is positively correlated with the level of understanding of the information, that is, whether science-generated knowledge is *accessible* to members (the *U* term in *D*1). Our survey questionnaire differentiates between information availability (whether knowledge was on hand or obtainable) and information accessibility (whether potential users were able to understand technical knowledge). According to our model, the more members understand the science, the more they report using it. Conversely, if they believe technical knowledge, even if available, is not understandable, they report low use. This suggests that knowledge, even when available to all, may introduce an element of inequity since those who understand it may have an unfair advantage in relation to those who do not. In this case, for knowledge to be usable and equitable, it needs to be not just available but also accessible.

[28] Fourth, there is a correlation between when and where decisions are made and the perceived use of technical knowledge. Specifically, the more members believe decisions are made during plenary meetings (in the questionnaire a total of 67% of the respondents reported so), the more they report technical knowledge use (the TI terms in *D*1 and *D*4). While the plenary is the official arena for collective decision making, in the context of river basin councils' negotiations, it is not uncommon for members to meet outside of and prior to plenary meetings. Such meetings can be motivated either by the need to understand technical matters that better inform plenary voting or as a maneuver from members or sectors to build and solidify

their position vis-à-vis other participants. In the first case, members may tap technical chamber and-or executive board members' expertise to synthesize, elucidate, or interpret knowledge informing councils' decisions. The second case is usually perceived negatively as skewing power within the council. Thus, the more respondents think decision-making processes are inclusive of all members (made during plenary sections), the more they report using knowledge; in contrast the more they perceive the process as intermediated by small groups (decisions made by technical chambers and the executive board even before the plenary meetings), the less they report use of technical knowledge.

[29] Fifth, knowledge use is influenced by group composition. Councils with a higher number of members who are nongovernment employees (irrespective of whom they are representing in the council) tend to report higher levels of technical knowledge use (the *S* term in *D*2). This reflects the influence of civil society in broadening the agenda and discussion within the council. Whereas before the reform, issues of water quantity and quality dominated the official water resources management agenda, in the river basin councils, a much broader range of issues has been introduced (e.g., environmental education, conservation, equitable distribution of water). Councils also cover a much broader range of relationships and processes, including the interaction between water, ecosystems, and socioeconomic systems. Thus, the inclusion of civil society in the councils may have pushed new items and broader use of technical knowledge in the council deliberations, especially when compared with the less inclusionary prereform agenda.

[30] Sixth, there is a negative correlation between a measurement of entropy within the council, that is, the level of agreement or cohesiveness between members and reported knowledge use (the ET term in *D*2). The more members agree with each other (lower entropy) across a number of different issues (e.g., council role, effectiveness, level of democracy, and ability to resolve conflict), the higher the level of technical knowledge use reported. One explanation is that in councils where the level of conflict is low, members may be less likely to dispute technical knowledge presented to them. Another is that the use of technical knowledge may contribute to diffusing dissent and building consensus among members (not tested in our model).

[31] Finally, reported use of technical knowledge correlated negatively with the distribution of power within the committee; that is, in councils where members perceived that power was unequally distributed, higher levels of knowledge use were reported (the PW term in *D*5). This makes sense in the context of many committees in which knowledge is dominated by *técnicos*, that is, stakeholders with a technical background (as committee members, hired consultants, or members of technical chambers). It is likely that in committees where *técnicos* play a prominent role, the use of knowledge will be higher (since they are responsible for either producing or brokering much of the knowledge available) and power will be skewed toward those who produce and understand knowledge and away from those who do not. In the questionnaire, council members attributed to technical knowledge the largest source of inequality within councils. This is also consistent with findings from qualitative research focusing on river basin committees, which suggest, that even in the context of expanding participation and inclusion of the Brazilian water reform, técnicos can hold disproportionate levels of power in councils' decision-making processes [*Abers et al.*, 2009; *Lemos*, 2008]. While this finding may appear at first glance to be in contradiction with a positive correlation between low entropy and knowledge use, it is important to distinguish entropy (the level of agreement between members) and their perception of the distribution of power between members. The fact that members agree and think alike regarding many issues within the council does not mean that they think power is equally or even equitably distributed between members. Our observations of council meetings suggest a complex relationship between water users and *técnicos*. Although members sometimes resent *técnicos* for their tight control of meeting agendas, for the most part they seek and appreciate expert support. Indeed, even if members believe *técnicos* carry the heavier "weight" regarding decision making, they are also appreciated and well regarded as working to improve decision making. The councils' strong reliance on technical chambers and outside experts (as consultants) to support their decisions indicates some level of trust in producers of technical knowledge [*Formiga-Johnsson et al.*, 2007].

6. Conclusions

[32] Although the importance of technical knowledge in informing decision making in water resources management has been widely recognized by both scholars and practitioners, the factors influencing its use have been examined empirically relatively little. This study explores knowledge use across 18 Brazilian river basin councils based on data collected among 626 council members by the Watermark survey. Because of the small sample, our main findings refer primarily to the basins studied. We find that several factors and processes affect knowledge use across these councils. First, use of knowledge aligns well with members' perception of accessibility; that is, the more accessible knowledge is, the higher is the level of use reported. In this study, access goes beyond availability to include also understanding. Thus, knowledge should be not only available but also intelligible to be effective in informing decision making. Second, the higher the perception of effectiveness and influence among committee members, that is, whether the members believe the council to be influential and effective vis-à-vis other sectors of society, the higher the level of technical knowledge use reported. This positive relationship suggests that knowledge use is related to a belief among council members that their decisions matter for the governance of water across the council's jurisdiction. Third, the more that council members perceive most decisions as being made during plenary meetings, the higher their report of technical knowledge use. Here again, the perception that knowledge is used directly by members to make decisions at the plenary meeting rather than being filtered by experts is positively associated with higher knowledge use. Fourth, knowledge use is influenced by group composition; that is, councils with higher number of members who are not public officials report higher levels of technical knowledge use. This suggests that the inclusion of private and civil actors in the policymaking process broadens the governance agenda and the use of technical knowledge. Fifth, the level of agreement between members shapes reported knowledge

use; that is, the more members that agree with each other (lower entropy) across a number of different issues (e.g., council role, effectiveness, level of democracy, and ability to resolve conflict), the more they say they use technical knowledge. Finally, councils whose members perceive power as unequally distributed report high levels of technical knowledge use.

[33] Taken together, these findings indirectly support two statements we made earlier in this article: (1) technical knowledge might contribute to make decisions easier and possibly better (at least in the eyes of council members) while (2) introducing elements of inequality to the processes of making those decisions. In the case of river basin councils in Brazil, knowledge use positively aligns with access, a more diverse and broader agenda, and higher sense of effectiveness. Yet technical knowledge use is also associated with skewed levels of power within the councils. This suggests that action to increase knowledge availability, but more especially accessibility, may be critical to increase technical knowledge usefulness in supporting improved decisions and democracy within integrative and adaptive approaches to water resources management. This research shows that technical knowledge use in water management in Brazil has changed with institutional reform. It has become more open and diverse and may have contributed to the sense of effectiveness of new actors introduced into the management process. But it has also preserved some of its more traditional role of enabling technocratic insulation (by skewing power toward technical actors) in the water sector. The picture painted here is that technical knowledge use is seldom clear-cut, and understanding its many implications is far from straightforward. Further research combining quantitative approaches with in-depth understanding of knowledge use "at the ground" is necessary to inform better institutional designs to address emerging water-related problems.

Appendix A

[34] In our algorithm, each of the 20 variable categories is considered a gene or trait; each variable within the category is an allele of this trait. A particular set of variable inputs to the stepwise regression can be thought of as a genetic sequence, and the fitness associated with this sequence is simply the resulting function F above. The genetic algorithm works in a manner analogous to natural selection:

[35] 1. Create a population of m individuals, each characterized by a randomly selected genetic sequence of 20 variables.

[36] 2. For time steps 1 to t,

a. Evaluate the fitness F for each individual.

b. Let the fittest fraction, f_{fit}, of the population mate in pairs, producing children whose genetic sequence includes a random half of the traits from each parent.

c. Let these children replace the least-fit fraction $f_{un\mathrm{fit}}$ of the population.

[37] 3. Let traits among the population randomly mutate to other traits at a rate z.

[38] Because the fitness function F varies relatively smoothly across the variable space, this algorithm will quickly (within 10 or 20 generations) find locally optimal F values. By performing different random initial configurations, and varying the population size m, fittest fraction f_{fit}, and mutation rate z, the entire parameter space can be explored relatively quickly. The optimal genetic sequence is the one that consistently emerges as having the highest F across all populations. For our study, we used populations between 60 and 80 individuals, fittest fractions between 0.2 and 0.5, and mutation rates between 0.001 and 0.02. This setup consistently found the same optimal solution within 20 generations, significantly cutting the computational requirement for finding a simple manual search.

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References

Abers, R. N. (2007), Organizing for governance: Building collaboration in Brazilian river basins, *World Dev.*, *35*(8), 1450–1463, doi:10.1016-j.worlddev.2007.04.008.

Abers, R. N., R. M. Formiga-Johnsson, B. Frank, M. E. Keck, and M. C. Lemos (2009), Inclusão, deliberação e controle: Três dimensões de democracia nos comitês e consórcios de bacia hidrográfica no Brasil, *Rev. Ambiente Soc.*, *12*(1), 115–132.

Arvai, J., et al. (2003), Adaptive management of the global climate problem: Bridging the gap between climate research and climate policy, paper presented at Conference on Adaptive Research and Governance in Climate Change, Columbus, Ohio.

Berkes, F., et al. (2000), Rediscovery of traditional ecological knowledge as adaptive management, *Ecol. Appl.*, *10*, 1251–1262, doi:10.1890-1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Blok, A. (2007), Experts on public trial: On democratizing expertise through a Danish consensus conference, *Public Underst. Sci.*, *16*(2), 16.

Blomquist, W., et al. (2005), Comparison of institutional arrangements for river basin management in eight basins, Policy Res. Working Pap. *3636*, 46 pp., World Bank, Washington, D. C.

Brannstrom, C., et al. (2004), Civil society participation in the decentralization of Brazil's water resources: Assessing participation in three states, *Singap. J. Trop. Geogr.*, *25*(3), 304–332, doi:10.1111-j.0129-7619.2004.00188.x.

Brooks, N., et al. (2005), The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation, *Global Environ. Change*, *15*, 151–163, doi:10.1016-j.gloenvcha.2004.12.006.

Dietz, T., et al. (2003), The struggle to govern the commons, *Science*, *302*(12), 1907–1912.

DuPuis, E. M., and B. J. Gareau (2006), Neoliberal knowledge: The decline of technocracy and the weakening of the Montreal Protocol, paper presented at Annual Meeting of the Society for Social Studies of Science (4S), Vancouver, B. C., Canada.

Elliott, M. L. P. (1999), The role of facilitators, mediators, and other consensus building practitioners, in *The Consensus Building Handbook: A Comprehensive Guide to Reaching Agreement*, edited by L. Susskind et al., pp.199–240, Sage, Thousand Oaks, Calif.

Etzioni-Havely, E. (1983), *Bureaucracy and Democracy: A Political Dilemma*, Routledge and Kegan Paul, Melbourne, Australia.

Ezrahi, Y. (1990), *The Descent of Icarus: Science and the Transformation of Contemporary Democray*, Harvard Univ. Press, Cambrdge, Mass.

Folke, C., et al. (2005), Adaptive governance of social-ecological systems, *Annu. Rev. Environ. Resour.*, *30*(1), 441–473, doi:10.1146-annurev.energy.30.050504.144511.

Formiga-Johnsson, R. M. (2001), La nouvelle politique de l'eau au Brésil: Forces et enjeux d'une transformation vers une gestion intégrée, *Rev. Tiers Monde*, *166*, 403–425, doi:10.3406-tiers.2001.1512.

Formiga-Johnsson, R. M., et al. (2007), The politics of bulk water pricing in Brazil: Lessons from the Paraiba do Sul River Basin, *Water Policy*, *9*(1), 87–104, doi:10.2166-wp.2006.001.

Healy, R. G., and W. Ascher (1995), Knowledge in the policy process: Incorporating new environmental information in natural resources policymaking, *Policy Sci.*, *28*(1), 1–19, doi:10.1007-BF01000818.

Jamieson, D. (2000), Prediction in society, in *Prediction: Science, Decision Making and the Future of Nature*, edited by D. Sarewitz et al., pp. 315–326, Island Press, Washington, D. C.

Jasanoff, S. (1990), *The Fifth Branch: Science Advisers as Policymakers*, Harvard Univ. Press, Cambridge, Mass.

Kemper, K. E., et al. (2007), *Integrated River Basin Management through Decentralization*, Springer, New York.

Kingdon, J. W. (1985), *Agendas, Alternatives and Public Policies*, Little, Brown, Boston, Mass.

Leach, W. D., et al. (2002), Stakeholder partnership as collaborative policymaking: Evaluation criteria applied to watershed management in California and Washington, *J. Policy Anal. Manage.*, *21*(4), 645–670, doi:10.1002-pam.10079.

Lemos, M. C. (2003), A tale of two policies: The politics of seasonal climate forecast use in Ceará, Brazil, *Policy Sci.*, *32*(2), 101–123, doi:10.1023-A:1024893532329.

Lemos, M. C. (2008), Whose water is it anyway? Water management, knowledge, and equity in NE Brazil, in *Water, Place and Equity*, edited by J. Whiteley et al., pp. 249–270, MIT Press, Cambridge, Mass.

Lemos, M. C., and A. Agrawal (2006), Environmental governance, *Annu. Rev. Environ. Resour.*, *31*, 297–325, doi:10.1146-annurev.energy.31.042605.135621.

Lemos, M. C., and J. L. F. Oliveira (2004), Can water reform survive politics? Institutional change and river basin management in Ceará, Northeast Brazil, *World Dev.*, *32*(12), 2121–2137, doi:10.1016-j.worlddev.2004.08.002.

Lindblom, C. E. (1959), The science of "muddling through", *Public Admin. Rev.*, *19*, 79–88, doi:10.2307-973677.

Lubell, M., et al. (2002), Watershed partnerships and the emergence of collective action institutions, *Am. J. Polit. Sci.*, *46*(1), 148–163, doi:10.2307-3088419.

Maxwell, S. E. (2000), Sample size and multiple regression analysis, *Psychol. Methods*, *5*(4), 434–458, doi:10.1037-1082-989X.5.4.434.

Medema, W., et al. (2008), From premise to practice: A critical assessment of integrated water resources management and adaptive management approaches in the water sector, *Ecol. Soc.*, *13*(2), 29, http://www.ecologyandsociety.org/vol13/iss2/art29/.

Menard, S. W. (2002), *Applied Logistic Regression Analysis*, 2nd ed., 111 pp., Sage, Thousand Oaks, Calif.

Nunes, E. d. O., and B. Geddes (1987), Dilemmas of state-led modernization in Brazil, in *State and Society in Brazil: Continuity and Change*, edited by J. D. Wirth et al., pp. 103–145, Westview Press, Boulder, Colo.

Olsson, J. A., and K. Berg (2005), Local stakeholders' acceptance of model generated data used as a communication tool in water management: The Ronnea study, *Ambio*, *34*(7), 507–512.

Olsson, P., et al. (2004), Adaptive comanagement for building resilience in social-ecological systems, *Environ. Manage. N. Y.*, *34*(1), 75–90, doi:10.1007-s00267-003-0101-7.

Pahl-Wostl, C. (2007), Requirements for adaptive water management, in *Adaptive and Integrated Water Management: Coping With Complexity and Uncertainty*, edited by C. Pahl-Wostl et al., Springer-Verlag, Berlin.

Pahl-Wostl, C., and M. Hare (2004), Processes of social learning in integrated resources management, *J. Community Appl. Soc. Psychol.*, *14*, 193–206, doi:10.1002-casp.774.

Ribot, J. C. (2002), *Democratic Decentralization of Natural Resources: Institutionalizing Popular Participation*, World Resour. Inst., Washington, D. C.

Smit, B., et al. (2000), An anatomy of adaptation to climate change and variability, *Clim. Change*, *45*(1), 223–251, doi:10.1023-A:1005661622966.

SRH (2006), Plano Nacional de Recursos Hídricos—Síntese executiva Secretaria de Recursos Hídricos, Ministerio do Meio Ambiente, Brasilia, Brazil.

Steel, B. S., et al. (1993), Are civil servants really public servants? A study of bureaucratic attitudes in the U.S., Brazil, and Korea, *Int. J. Public Admin.*, *16*(3), 409–442, doi:10.1080-01900699308524807.

Stone, D. A. (1988), *Policy Paradox and Political Reason*, Scott, Foresman, Glenview, Ill.

Wampold, B. E., and R. D. Freund (1987), Use of multiple-regression in counseling psychology research—A flexible data-analytic strategy, *J. Couns. Psychol.*, *34*(4), 372–382, doi:10.1037-0022-0167.34.4.372.

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