Embracing the ambiguity: Tracing climate response diversity in urban water management

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Abstract

Climate change is a management and governance challenge requiring diverse potential responses. This article highlights the critical role public managers play in navigating the response diversity of such governance systems. Response diversity is the rule-based set of options available for responding to unexpected service disruptions and is distinguished from ambiguity, which holds a negative valence within public administration. We first develop theoretical propositions about how institutions influence response diversity, drawing on public administration, resilience, and cognitive science research. Then, we use the Institutional Grammar and Institutional Network Analysis tools to empirically trace the rate-making processes in two U.S. urban water utilities. We conclude that institutional designs do distinctively influence response diversity and are therefore key for evaluating the climate adaptability of heavily engineered infrastructure systems. Specifically, we identify important differences in the diversity of information, participation, and heuristics used for selecting investment strategies.

1 INTRODUCTION

Many of the physical systems public managers oversee, from transportation and energy systems to drinking water and stormwater infrastructures, are facing significant challenges from climate change. Urban water systems globally are witnessing unevenly distributed increases in wet and dry conditions that can lead to different types, frequencies, and severities of extreme events, such as acute droughts and flood-producing heavy rain events, as well as more gradual changes to regional hydroclimate (e.g., aridification) (Holsman & Lucatello, 2022). These challenges highlight the need for governance and management approaches that integrate multiple types of knowledge and develop a diverse portfolio of risk-mitigation options (Anderies et al., 2019b; Walker et al., 2023).

Adequate approaches for managing most complex challenges depend, to some degree, upon the prevailing rules or norms in place that shape the timing, quality, and effectiveness of collective planning and action (Chaffin et al., 2014; Ostrom, 1990; Siders, 2019). For example, aging or outdated urban water infrastructure in the United States has been engineered to achieve specific levels of robustness to high-frequency stressors like seasonal flooding (Anderies et al., 2020; Garcia et al., 2019); however, these systems can be politically and technically problematic to maintain or update and can undergo destabilizing perturbations when pushed beyond historically typical hydroclimatic conditions (Lopez-Cantu & Samaras, 2018). Institutions—defined as the rules and norms which govern collective action—are important for supporting adaptive responses to such challenges. Much like biological evolution relies on natural selection of genetic traits suited to their habitats, societies can flourish or vanish depending on how successfully their rules or norms of behavior support diverse, adaptive, and collective responses to changing environments (Anderies & Janssen, 2013; Ostrom, 2009).

This article highlights the critical role public managers play in supporting such *response diversity* (Folke et al., 2005; Walker et al., 2023). As climate threats have intensified across a range of human-designed systems, a growing number of interdisciplinary scholars have emphasized the need to pay greater attention to the capacity or development of response diversity, defined as the preparation of a broad set of options to avoid or respond to unanticipated climate-related service disruptions (Anderies et al., 2019a, 2019b; Levin et al., 2021; Walker et al., 2023). From a management perspective, organizational systems, much like living ecosystems, depend on processes (e.g., budgeting, strategic or long-range planning, capital investment) that permit them to function and require multiple ways for proactively preparing and responding to external changes or shocks (Deslatte, 2022; Walker et al., 2023). These processes can be thought of as the coping mechanisms or latent capacities which organizational managers or policymakers have at their disposal to maintain system performance.

We posit a core component of response diversity lies within the institutional configurations (laws, regulatory systems, operating rules) which bind or empower political and administrative actors to develop or mobilize information, collaborate, and make timely decisions (Deslatte, 2022; Swann, 2017; Terman, 2023). Institutions serve to routinize patterns of human interaction and endeavor (Ostrom, 1990). They enable groups to filter and process information, take collective action, and evaluate outcomes. In the face of novel or ambiguous threats, however, institutions may either provide unclear guidance or constrain entrepreneurship and innovation. In public administration, ambiguity is often considered something to be avoided or mitigated by selecting lower-risk courses of action (Bullock et al., 2019), as uncertain linkages between actions and results can lead to arbitrariness or opportunism. Conversely, rigidly prescriptive criteria for minimizing risk can also limit participation or creativity in diagnosing threats and may hinder responses to chaotic or evolving problems. Consequently, existing institutions may be maladaptive for emerging, multifaceted social dilemmas—a sentiment echoed in the voluminous literature on the legal, political, and organizational characteristics of environmental governance in social-environmental systems (Anderies, 2015; DeCaro et al., 2018; Hering et al., 2013). The concept of response diversity leverages the benefits of both sides of the misleading ambiguity-rigidity trade-off by emphasizing that adaptive flexibility is not found in the absence of guidance but in a well-structured institutional environment that consciously facilitates an array of options.

To examine such institutional designs, we draw from public administration, resilience, and cognitive science research to develop theoretical propositions about how institutions may enable or constrain response diversity (Cairney et al., 2016; Clark, 2013; Gigerenzer et al., 2022). Then, we use the Institutional Grammar (IG) and Institutional Network Analysis (INA) tools to empirically trace the rate-making processes in two U.S. urban water utilities (Crawford & Ostrom, 1995; Mesdaghi et al., 2022). Rate-making is one important standard process through which policymakers and administrators can implement a variety of infrastructure investment and equity-aimed policies (e.g., changes to rate structures), which can influence both the supply and demand response options' utilities have to confront climate-related stressors. Because rate-setting is conducted through a detailed regulatory review process and subjected to varying degrees of public scrutiny, the process of developing rates requires that public managers provide detailed analysis and justifications for how and where they recommend deploying financial capacity (i.e., system maintenance, expansion, performance). Thus, we argue it is a useful keyhole for observing the role that institutions play in these manager-led strategic processes (Deslatte, 2022).

We conclude that institutional designs do distinctively influence response diversity and are therefore key for evaluating the climate-adaptability of heavily engineered infrastructure systems. Specifically, we identify important differences in the diversity of information, participation, and heuristics used for selecting investment strategies. Thus, we argue that research on climate resilience and sustainability in sub-national governments should focus more broadly on institutional designs that enable more diverse and responsive risk management on the front lines of the climate crisis (Ostrom, 2011).

1.1 Climate risk, service robustness, and response diversity

Complexity science has shown that many systems, such as climate, are inherently chaotic, meaning probable future states are often impossible to confidently forecast (Ladyman et al., 2013). The complex combination of climate hazards, the exposure of people and built infrastructures to those hazards, and the social vulnerabilities that may amplify their impacts make managing climate risks to sustain or improve services a fundamental challenge for public administrators.

We define climate risk, in line with the Intergovernmental Panel on Climate Change, as the "potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems". This definition implies that managing climate risks inherently involves developing stronger causal identification of threats, resolving contested welfare goals implicated by those threats, and predicting future scenarios based on available response options. Managing such risks imposes a sizable cognitive information-processing load, introduces considerable uncertainty, and may motivate managers to try and reduce risks by downplaying them or relying on "out of the box" generic policy or management tools (Bullock et al., 2019). For these reasons, resilience scholars have called for devoting more attention to identifying different sources of response diversity and assessing their suitability for current and future climate-related risks (Walker et al., 2023).

Managers of heavily engineered physical infrastructure such as water supply systems tend to focus on ensuring the reliability or *robustness* of services despite variation in inputs over some planning horizon (Anderies et al., 2019a, 2019b). Service robustness is defined as the preservation of a system's desired performance within acceptable bounds to a specific set of input disturbances (Anderies et al., 2019a). A central challenge to robustness for groups and governments is that climate change creates considerable ambiguity. Ambiguity is characterized in cognitive science as uncertain mapping between "hidden states" or potential outcomes and observed ones (Friston et al., 2017). For good reason, ambiguity tends to evoke feelings of animosity, anxiety, or ambivalence in public administrators (Bullock et al., 2019). Management reforms tend to emphasize responding to problems easier to understand, like increasing efficiencies, rooting out redundancies, and enhancing a sense of agency, control, or autonomy (DiMaggio & Powell, 1983; March & Olsen, 2010; Moynihan, 2006). For decades, public managers were professionally indoctrinated to think they could rationally techno-manage organizational problems, and doctrines such as "New Public Management" were premised on optimization routines supported by performance information, science, technologies, and business practices (Noordegraaf & Abma, 2003; Pandey & Wright, 2006; Vakkuri, 2010). The inconclusive results from such reforms were often blamed on the inherent ambiguity, conflicting or unclear goals, and uncertainty surrounding public sector services (Cohen et al., 1976; Pandey & Wright, 2006; Vakkuri, 2010).

At the same time, public administration scholars have shown an enduring interest in how administrative rigidity and discretion can shape the organizational processes which, in turn, influence outcomes (Bullock, 2019; Carpenter, 2020; Chang & Brewer, 2023; Christensen et al., 2020; Miller & Whitford, 2016). Processes such as strategic planning and performance management are designed to carve out spaces where managers can be forward-looking, anticipatory, and proactive in confronting complex or emerging challenges (Deslatte, 2022). Yet, efforts to study the institutional linkages between such processes and the administrative discretion they afford remain uneven and underdeveloped (Schlager et al., 2021; Siddiki & Frantz, 2021).

The concept of response diversity, originating from ecology, has come to represent an understanding that policymakers and managers need the ability to develop a broad set of options to avoid and respond to anticipated and unexpected disruptions in services (Anderies et al., 2019b). While national governments have been criticized for failing to respond to climate change, resilience scholars note it is possible that existing legal, regulatory, and management processes could help public managers confront climate risks (Garmestani et al., 2019). In the context of water management, response diversity represents the latent capacity of varied demand- and supply-based policy, financial, and management tools for responding to a range of potential climate impacts (e.g., building new water storage reservoirs or promoting water efficiency technology). Response diversity can allow managers and policymakers to pivot or adjust responses when given new information because alternatives *have been designed* or are available to them. Thus, response diversity depends upon the rule-based processes of interaction which permit or restrict the proactive preparation and response to service disruptions.

Institutional designs, under specific conditions, can provide guard rails (via stability or the pragmatic decision rules it provides) but also increase thoughtfulness and the consideration of broader views of a problem (via flexibility or the epistemic exploration of alternatives) (Koebele, 2020; Ostrom, 1990). They do so by enabling or constraining the types of information, participation, and collective strategies available to groups. To foster response diversity, institutions must facilitate the gathering and use of diverse information about the risks of both environmental changes and the effects of available response options. They must also support diverse participation in decision-making, which enables decision-makers to consider multiple rationales and converge on more accurate mental models of climate challenges. Finally, institutions must support the availability of diverse organizational heuristics so that actors can more frugally make decisions based on plausible future risks. We elaborate on these conditions below through three propositions which connect institutional designs to response diversity and use the empirical context of water utility rate-setting to examine them.

1.1.1 Diverse information

Managing climate risks requires the generation and mobilization of multiple types of information. Scholars note that complex systems often rely on "knowledge infrastructures"—scientific research, the media, universities, think tanks, community groups—to process multiple types of information about the history and experience of a system (Anderies et al., 2019b). These information streams may include efforts to model historical resource flows and the dynamics of social and environmental interactions. They can also be used to improve monitoring of resource use or to generate a more probabilistic understanding of future risks from extreme events as well as gradual shifts in mean conditions (Anderies et al., 2019b; Chaffin et al., 2016; Moser & Ekstrom, 2010).

Limitations to developing such diverse information flows can arise from the difficulty modeling local climate impacts and the cognitive difficulties humans have updating their beliefs. In the context of urban water management, service robustness depends on understanding the current state of the system, the dynamics between social, economic, and environmental factors, and the limits or thresholds in a current system state (Anderies & Janssen, 2013). For instance, the 2021 Phoenix Water Resource Plan (WRP) takes into account patterns of climatic variability known as the El Niño/Southern Oscillation cycle when modeling various future water supply-and-demand scenarios. Moreover, the plan also incorporates demand-side management actions, such as water conservation and efficiency measures, that have been implemented to increase water supply reliability. However, the plan does not account for climate change-related variability in demand, meaning it may not be representative of the system dynamics or nonlinear changes underway.

Climate change also creates difficulty in ascertaining how a system will respond to changes in the frequency of extreme events like flooding and drought. Given the typical, 75-year lifespan of urban water infrastructure, incorporating climate research into design and operating standards is a non-trivial task. Standards based on observed trends or history run the risk of being vulnerable to the increased frequency of extreme events, given the non-stationarity of hydroclimate (Underwood et al., 2020). Generalized climate models that predict likely impact scenarios at the regional level are often produced at spatial scales too coarse (~100 km or larger) for anticipating utility-specific impacts (Underwood et al., 2020). In this sense, more information may not always be advantageous for maintaining some types of robustness, because more information aimed at quantifying the uncertainty of future risks tends to introduce more variance or noise into complex choice situations (Gigerenzer & Brighton, 2009).

These modeling challenges are further complicated by the ways in which humans process complex environmental information. Cognitive science research suggests that humans make choices and process feedback through an "active inference" process of exploiting or exploring information when prediction error occurs (Clark, 2013; Kaplan et al., 2016). When it comes to highly ambiguous threats, humans and groups often minimize errors by actively exploiting their information environment to seek data or predictions that conform with their prior beliefs (Druckman and McGrath, 2019; Kunda, 1990). Individuals can resist disconfirming information on climate impacts when presented with conflicting cultural, political, or social beliefs or identities (Bayes & Druckman, 2021). This can lead them to ignore or rationalize away (and hence, fail to account for) new and rapidly accumulating information about dynamic stressors.

Conversely, under the right conditions, they may explore the environment to discover new information and accurately update predictions (James and Van Ryzin, 2017; Johnson et al., 2015). Building response diversity in this context may require developing the ability to facilitate such exploration to create more options over longer time spans (Walker et al., 2023, p. 3). Practically, if managers are unable to ascertain their proximity to a threshold or limit, they may be less robust than they realize to system-wide disturbances. Hence, diversity in when and how frequently managers can respond to error signals is crucial and depends on the ability to detect diverse drivers of error.

In summary, institutions can be designed to increase the potential that individuals will be more aware of thresholds by incorporating new types of information, including feedback from prior choices, into their decision-making (North et al., 1990). Although information processing imposes a cognitive cost, especially when large quantities of highly complex information are available, we expect that institutional arrangements will be more likely to foster response diversity when they facilitate the use of more diverse forms of information.

Proposition 1.*Institutions support response diversity when they facilitate the use of diverse types of information or feedback*.

1.1.2 Diverse participation

Adequately responding to climate risks requires not just greater awareness of the past and future plausible scenarios, but also the specific exposures and vulnerabilities of populations, places, and environmental assets. Diverse participation in climate risk management can help to provide this broader perspective in two ways: by aggregating diverse evaluative performance criteria (e.g., equity versus efficiency) which may be used across groups with contested goals and by raising awareness of differing spatial scales of historical, current and potential future problems.

Climate change produces many uneven impacts across groups and thus invokes competing evaluative criteria. For instance, focusing primarily on providing highly reliable water services can produce tradeoffs that impact conservation, environmental protection, economic growth, and equity (Scott et al., 2018; Teodoro, 2010). Such prioritization therefore evokes value conflicts between users over fairness and the adequacy of responses to needs (Meerow & Newell, 2021). Processes for setting water rates, for example, can invoke contested goals, because utility rate increases disproportionately impact lower-income households (Teodoro, 2005). Acknowledging this, utilities may create low-income water assistance programs or develop alternative rate structures which shift some financial burden to higher cost-of-service or larger-scale water users (Teodoro, 2010). However, these efforts are often opposed by resource-users who would shoulder larger financial burdens. Nevertheless, diverse participation increases the chances that differing evaluative criteria will be brought into decision contexts, especially when institutions are intentionally designed to support equity amidst power asymmetries (Koebele et al., 2023).

Decision-making situations that feature diverse participation can also raise awareness of spatially isolated or concentrated vulnerabilities. For instance, low-lying or blighted areas of a community may be more flood-prone, and suffer from greater legacy pollution impacts, neglected infrastructure, and a lack of resources to bounce back after extreme events or system failures. Trust in government may also be low in these areas. Referring to the knowledge infrastructures from our first proposition, diverse participation increases the likelihood that groups with diverse experiences will be heard, and Indigenous or institutional knowledge of resource management is incorporated alongside other types of quantitative or technical knowledge (Borthakur & Singh, 2020). Diverse participation can also prompt heterogeneous participants to forge some compromise on goals. Repeated-game experiments have shown that institutional designs may facilitate this by fostering norms of trust, reciprocity, and cooperation where decision-makers continue to work together on an issue over time (Ostrom, 2011). Research also generally suggests that cooperation can create intrinsic rewards in the brain, and it follows that institutional arrangements which foster cooperation are more likely to converge on shared valuations that participants find rewarding (Clark, 2013; DeCaro et al., 2021; Janssen et al., 2022). Institutions may also be intentionally designed to incentivize collaboration and consensus-building toward common goals among diverse participants (Koebele et al., 2023).

Together, these streams of literature suggest that managing complex risks often requires resolving contested welfare goals about where and what elements of performance to focus on, and where actions to shore up robustness of the system may produce new fragilities. We expect that institutions will foster response diversity when they include more diverse participants—and by extension, differing goals and experiences—in decision-making venues that can help them develop common understandings. Administrative contexts that contain a diverse array of views, experiences, and beliefs are more likely to bring broader perspectives and valuations into deliberative processes; simultaneously, institutions can be designed to encourage cooperation and the development of shared norms.

Proposition 2.*Institutions support response diversity when they enable more diverse stake holders with different experiences and evaluative criteria to participate in decisions*.

1.1.3 Diverse heuristics

Finally, institutional designs can influence the way that decision-makers and administrators use heuristics (i.e., rules of thumb that support decisions) to actively select long-term strategies under conditions of uncertainty. Biases in decision-making have received attention in psychology, political science, and public administration for decades, based on Herbert Simon's foundational model of bounded rationality (Jones, 2003; Simon, 1957). Today, scholars have identified dozens of mental shortcuts that impact decision-making, including anchoring, loss aversion, negativity bias, representativeness, and many others (Blumenthal-Barby & Krieger, 2015). Pertaining to public organizations, relevant biases include the tendency to over-weight past performance (outcome bias, sunk-cost bias, or path dependency) and more readily adopt new policies or actions diffusing through a population (bandwagon effect).

While heuristics are often depicted as a limitation on decision-making, psychology researchers have also posited that they can sometimes allow organizations and individuals to make better decisions over the long run when confronting uncertainty (Lo, 2017; Ostrom, 2009; Rieskamp & Hoffrage, 2002). In fact, heuristics—known as "less-is-more" inference strategies—can outperform more complex predictive models (Gigerenzer & Brighton, 2009), under specific conditions of "ecological rationality" where they provide cues for determining when to shift from exploring information to exploiting existing knowledge or understanding of a problem (Gigerenzer et al., 2022).

Under conditions of more diverse information and group participation, heuristics are critical for timely, pragmatic decision-making. For instance, water managers or policymakers confronting potential water shortages may utilize several heuristics: they may choose a recognized policy alternative rather than gambling on an unfamiliar approach (the *recognition* heuristic); they may favor an approach they recognize more quickly than others (*fluency*); they could select based on the highest value of a single variable, like affordability (*take-the-best*); or, they could choose the first alternative that exceeds normative aspirations (*satisficing*).

Psychology researchers have applied heuristics to organizations and posited that a "toolbox" of heuristics can theoretically aid in choosing and shifting strategies as outcomes emerge over time (Gigerenzer et al., 2022). A prominent example is the *imitation* social heuristic, in which organizations copy the strategies of others when they are deemed to be an improvement over their current course (Gigerenzer et al., 2022). In local government climate mitigation and adaptation, imitation of peer communities is commonplace and allows public managers to minimize risks associated with more innovative or proactive strategies (Deslatte, 2022). Because the concept of response diversity requires facilitating multiple options with differing coerciveness (e.g., voluntary versus mandatory water restrictions) and risks of adverse impacts, we propose that institutional designs which allow more diverse information and participation will also need to incorporate a broader array of heuristic-based selection strategies in order for organizations to reconcile different forms of information and contested goals. Because simple heuristics are both a "black box" and default mode of administrative decision-making, the empirical manifestation of such a design would allow for alteration in strategies as participants "muddle through" options and employ different comparative or reflective approaches to assess outcomes (Cohen et al., 1976; Lindblom, 2018; Pandey & Wright, 2006), thereby supporting response diversity.

Proposition 3.*Institutions support response diversity when they allow a variety of heuristics for improving decision-making under uncertainty*.

The gist of our argument is that existing institutional designs can enable or restrict differing methods of information search, engagement, and selection strategies and thereby support or constrain more diverse climate response options. To explore these propositions empirically, our methodology focuses on identifying institutionally guided processes in which information, participation, and inference strategies can vary.

2 METHODOLOGY

Our empirical analysis focuses on identifying diversity in the information, participation and decision criteria used by utilities as they adjust water rates and infrastructure investments. Rate-setting is one primary means by which urban water utilities can expand or reinvest in infrastructure intended to ensure sufficient water quantity and quality. Given its expansive geography, varying urbanization patterns, and federalist system, the U.S. features urban water systems facing distinct challenges from aging infrastructure, intensifying droughts, and vulnerability of built environments to flooding and stormwater-related pollution (Garcia et al., 2019). Therefore, the response options-utilities may need to develop can be highly determined by the complexity of the challenges they face, but also the inferential effort they make to identify these challenges and prepare proactive alternatives for responding. These challenges were a primary impetus for the 2021 Infrastructure Investment and Jobs Act passed by the U.S. Congress, which devoted more than $41 billion to water infrastructure upkeep and replacement, along with other flooding, drought, and conservation needs. However, rate-setting, as a means of generating revenue sufficient for short- and long-term infrastructure needs, is largely ubiquitous across urban systems, meaning it is a way to standardize cross-case comparisons.

Our methodology focuses on comparing two cases and consists of four steps. First, we identified cases based on variation in both hydroclimatic conditions and variation in a six-category taxonomy of governance rules determining who is responsible for setting water rates and how they enter and exit their positions (Deslatte et al., 2022). This method allows us more broadly to consider cases from varying climates and more or less politically responsive governance and management decision-making processes (see Deslatte et al., 2022, for a detailed description of the case selection methodology). From an initial list of 40 candidate cases, we then reduced the sample to 16 cases for analysis based on convenience and to achieve a geographically diverse set of cases across the country. For this analysis, we compare two cases—Indianapolis and Phoenix—which varied along both taxonomy criteria (alternative water rights states; high and low autonomy in our taxonomy) to maximize the potential for the variety of responses developed over the study period (2015–2022). Both developed response options primarily through long-range planning and water-rate setting—which, as illustrated in our analysis, may be institutionally interdependent processes that influenced broader short- and long-range investment strategies. Thus, both systems represent "most different" cases in terms of infrastructure, hydroclimate, and institutional designs.

Second, we use the Institutional Grammar Tool (IGT), developed by Crawford and Ostrom (1995) to identify institutional statements from state statutes and local ordinances and decompose them into syntactic components for analysis of the actors, allowable actions, and constraints placed on water utilities. Third, we adapt a novel INA approach (Mesdaghi et al., 2022), which facilitates plotting relationships between the institutional statements (see Siddiki et al., 2022). This allows us to create diagrams or "flow charts" for the formal institutional processes of rate-setting and long-range planning, and to compare these processes across cases. Finally, we use the IGT-informed network diagrams to facilitate process tracing of rate-setting over the study period, relying primarily on public documents, meeting transcripts, interviews, participant observation, and media accounts to assess the content validity of our institutional analysis and the evidence for our propositions.

2.1 Cases

Phoenix, Arizona, situated in an arid climate, supports a population of over five million people in the southwestern U.S. and has experienced rapid growth in recent years. The Phoenix Water Services Department (WSD) serves 1.7 million customers using a combination of surface and groundwater sources, as well as reclaimed water mostly for industrial uses. Notably, many of Phoenix's water sources, such as their allocation of the Colorado River, increasingly face threats from prolonged drought and regional aridification as a result of climate change. While per capita water use in Phoenix has declined 30 percent since 2000, the city has continued to face water supply sustainability challenges. Arizona water law is based on the prior appropriation doctrine, which is used in various western states in the U.S. to allocate scarce water resources. This legal framework allows water claims and use of "senior" appropriators—those who were first-in—to trump the water rights of "junior" users.

Indianapolis, Indiana, supports a growing metropolitan area population of 2.1 million people in the midwestern U.S. As an older water system, the utility manages both drinking and wastewater systems, the latter of which is combined with stormwater infrastructure. After a century of private ownership, the City of Indianapolis purchased the water utility in 2002 and handed it over to another private contract operator, which aggressively sought to reduce operating costs and finance capital improvements via debt rather than rate-increases. The City is under a federal consent decree to reduce pollution caused by this combined sewer system which, during heavy rains, produces combined sewer overflows into waterways. Over the years, the financial costs for environmental cleanup and compliance with the federal decree—passed on through wastewater rates—have impacted the political willingness to increase drinking water rates to maintain infrastructure and spurred heavier reliance on debt. In 2011, the City transferred its water and wastewater utilities to Citizens Energy Group (CEG), a public trust, which inherited significant debt from the water utility. Indiana is also expected to witness increased precipitation and flooding events in future decades due to climate change, which exacerbate its stormwater pollution issues. Like most states east of the Mississippi River, Indiana water law falls under a version of the riparian doctrine, which provides that all landowners adjacent to a water body have equal access to it.

2.2 IG tool

For each city, researchers identified institutional statements by searching city charters and/or ordinances, state statutes, and administrative codes using the search terms "water" and "water utility," and relevant statements were selected based on iteratively developed inclusion and exclusion criteria (available from the authors upon request). All text was downloaded from official state legislative sites, the Phoenix City Charter online, and the company formerly known as Municipal Code Corporation (Municode). This effort produced a large corpus of statements, most of which were not germane to this specific analysis. For Indianapolis, statements were drawn from the Indianapolis Revised Code of the Consolidated City and County ($N = 40$), Indiana State Code ($N = 667$), and Indiana Administrative Code ($N = 280$); for Phoenix, we drew statements from the City Charter ($N = 126$) and from the City Code ($N = 171$). The statements were coded by two coders (inter-coder reliability >0.8) and a subset of statements pertaining specifically to water utility rate-making and long-term planning were used for this study.

We employ an extended version of the IGT (Frantz & Siddiki, 2022), which involves coding the following syntactic components of statements: [A] the attributes or individual/corporate actors within a statement carrying out an action; [DO/IO] the direct and indirect objects which receive the action; [D] the deontics or prescriptive operators noting whether an action is compelled, prohibited or discretionary; [I] the aIms or action of a statement assigned to the attribute; [C] the context, distinguished as either activation conditions [AC] specifying a preceding condition or action which must be present for a statement to be active, or execution constraints [EC] which set spatial or temporal limitations on an action; and finally, [OR] the optional "or else" sanctioning component which applies to the aIm of the statement. Recent advances in the use of the IGT in public administration research have been detailed by Frantz and Siddiki (2021, 2022). This gives us a standardized way to compare the formal "rules, norms, and shared strategies" of collective choice and operational situations (Crawford & Ostrom, 1995). For instance, we could distinguish between when a utility operator "must" or "may" engage in long-range planning, and what temporal or spatial constraints are placed on such processes. Or, it can allow us to compare what actors must "recommend" water rate structures compared to who must "approve" them.

2.3 Institutional network diagrams

Administrative contexts like urban water management consist of multiple interconnected action situations where, for instance, outputs from one activity impact another (McGinnis, 2011). In order to ascertain such junctures, we use the IG coding to construct INA diagrams which allow us to identify (1) conditional *dependencies* between statements, and (2) institutional *voids*, where specific guidance, directives, or incentives are absent (Biesbroek et al., 2009; Deslatte et al., 2023; Gao et al., 2017; Mesdaghi et al., 2022).

Dependencies arise when institutionally defined situations present conditions or constraints on the sequencing of potential choices, so that actions may or must be delayed until antecedent activation conditions are met (Mesdaghi et al., 2022). Institutional voids have been defined as an absence of any coercive mechanisms compelling administrators to develop specific guidance, such as climate-change mitigation or adaptation plans or vulnerability assessments, or to "mainstream" such efforts into climate-impacted domains (Biesbroek et al., 2009; Fussel, 2007). This literature tends to assume voids fail to provide significant prescriptive guidance for climate action, although the resilience literature suggests they may also be sources of latent capacity for adaptive governance (Chaffin et al., 2014). Such junctures, for instance, may prohibit collective action until sufficient public engagement or feedback has been received.

The results of this step are network diagrams (displayed for our cases as Figures 2 and 3 below) in which some IGT components (A, C, DO/IO) are depicted as network nodes, while others (D, I) are network edges. These diagrams link water rate-setting and investment statements in which the objects of one statement are connected to the conditions of another (dependencies) or when two statements may create ambiguity in the range of actions available to the same actor through varying objects or aims (voids) (see Deslatte et al., 2023, for a fuller description of this methodology).

2.4 Process-tracing

Our final step involves using process tracing to assess the validity of the IGT/INA outputs in order to ultimately evaluate the evidence for our propositions. Process tracing is a systematic way to examine evidence for multiple steps or activities within a "causal process" which has theoretically led to a deterministic outcome (Beach & Pedersen, 2019). Here the outcomes (rate increases supportive of response diversity) are observed and considered deterministic in each case (Beach & Pedersen, 2019), while the theoretical process under investigation is detailed via our propositions and hypothetical activities where they are featured. Essentially, process tracing is a method with high internal validity, making it ideal for determining whether the formal institutional roles and prescribed actions which make up the design played out in the real world.

Following recent work combining the IGT and process tracing (Deslatte et al., 2023), the analysis focuses on three administratively guided activities which align with our propositions: *sensing* information signals from the environment; *updating* prior beliefs or predictions about future threats; and *selecting* response options via one or more heuristic-based strategies. We organize these activities within an institutionally guided process by using the Coupled-Infrastructure Systems framework (a descendant of the Institutional Analysis and Development or IAD, framework developed by Elinor Ostrom and colleagues). The Coupled-Infrastructure Systems framework allows us to situate the process we are tracing within a construct called "the robust controller" depicted in Figure 1 and detailed more extensively in Deslatte et al. (2022, 2023). Derived from robust control theory (Anderies et al., 2019a; Anderies & Janssen, 2013), the controller is an amalgamation of the policies or processes for managing heavily engineered infrastructure systems, which features public infrastructure providers (which are the utilities in this study) the built or physical public infrastructure along with the policies for maintaining robustness of services and the resource users (RUs). In robust control theory, the controller is used to develop dynamical systems models for identifying the sensitivity of outputs, like the ability to meet current and future water demand, to the variability of specific system inputs such as precipitation (Anderies et al., 2019a, 2019b; Deslatte et al., 2023). Each of the three activities that together make up the controller's processing of information (Figure 1) are places where institutional design, as suggested by our three propositions, may facilitate response diversity in this conceptual system controller.

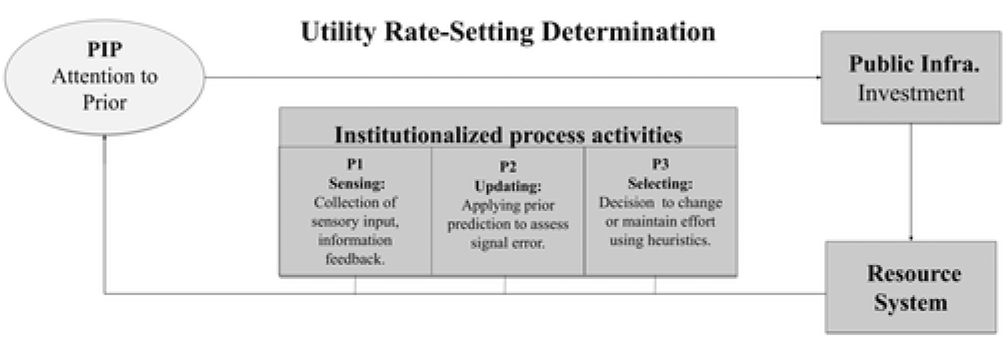

FIGURE 1

The robust controller process where investment determination occurs via hypothesized steps of processing new sensory inputs, updating predictions about current or future conditions, and selecting new strategies. PIP, public infrastructure provider.

Process tracing is then conducted through within-case triangulation of qualitative and quantitative data acquired through document analysis, participant observation, and semi-structured interviews. The triangulation involved examining a variety of sources such as public hearings and interviews with water utility personnel (account evidence), rate-filing proceedings (sequence evidence), planning documents and analyses of water demand trends (pattern evidence), and media accounts (trace evidence) stemming from utility rate-making processes (Beach & Pedersen, 2019).

We use the previously identified IGT components and INA diagrams to guide the search for empirical materials which could shed light on the rate-setting processes both utilities engaged in during the study period. Interviews were conducted with water utility administrators via Zoom and lasted between 1 and 2 h; documents were obtained from utility websites, regulatory agency repositories, and ProQuest media searches. Where possible, public meetings of rate-hearings were transcribed. As illustrated in Table 1, each piece of empirical material ($N = 95$) was reviewed and assigned to a specific type if it was determined to hold evidentiary value (although some documents, such as WRPs, may contain multiple types of evidence, and many were determined to be of no theoretical value). These sources ($N = 38$) were reviewed in the fall of 2022 and coded based on whether they contained evidence of the three theoretical activities we have posited to guide the process of water rate-setting. They were then evaluated based on their theoretical certainty (whether they must be present; a necessary condition) and theoretical uniqueness (whether it is unlikely to explain another phenomenon; a sufficient condition). For instance, analyses of past and future water demand may be evidence of "sensing" with high theoretical certainty (utilities must attempt to predict the future to develop diverse response options) but be less theoretically unique (the analysis could be perfunctory, "routine" outputs which do not guide long-term risk assessments). The hypothetical attributes and aims, examples of empirical fingerprints, and theoretical expectations are reported in Table 2.

TABLE 1. Evidence types and collected empirical materials.

	Account	**Pattern**	**Sequence**	**Trace**
Indianapolis	Interviews (4 utility managers in leadership roles); public testimony related to rate-setting cases	CEG Annual, Financial Reports (2010–2021); CEG Sustainability Reports (2013, 2015, 2017, 2021); CEG Integrated WRP (2020)	Indiana Utility Regulatory Commission CEG rate filing documents (e.g., petitions, exhibits, final orders)	News media coverage of CEG rate-setting, ProQuest ($N = 23$)
Phoenix	Interviews (3 utility managers in leadership roles); public comments, testimony related	Comprehensive Annual Financial Reports (2010–2021); Phoenix Climate Action Plan (2021); WRP (2011, 2021); Water Equity	Phoenix City Council meeting minutes, videos (2018–2021); Citizens Water Rate Advisory Committee	News media coverage of WSD rate-setting, ProQuest ($N = 15$)

Account	Pattern	Sequence	Trace
to rate-setting cases	Study (2020); Water Financial Plan (2021)	meeting minutes (2020)	

- Abbreviations: CEG, Citizens Energy Group; WRP, Water Resource Plan; WSD, Water Services Department.

TABLE 2. Process trace of water rate-setting.

	P1: Sensing	P2: Updating	P3: Selecting
Attribute [A]	PIP; RU; RS	PIP; RU	PIP
aIms [I]	Information search	Revising expectations	Decision criteria
Empirical fingerprint	Supply/demand forecasts; climate modeling; socio-environmental interactions	Statements indicating changing beliefs about future climate threats; revisions to planning documents encoding changing predictions	Formal aggregation rules for collective choice; official records or media accounts of actions taken
Evidence type	Trace, pattern	Account, sequence	Account, trace
Theoretical certainty	High	High	High
Theoretical uniqueness	Low	High	High

- Abbreviations: PIP, public infrastructure provider; RU, resource user.

3 RESULTS AND DISCUSSION

We find important distinctions in the diversity of information and participation across the cases which can support flexibility in responses, while we find less evidence supporting a diversity of decision-making heuristics. We present these results through a brief description of the institutional diagrams for Phoenix and Indianapolis and evidence from the rate-setting process tracing. The diagrams in Figures 2 and 3 capture linked institutional statements demonstrating dependencies, when the objects of one statement are connected to the conditions of another. Institutional voids are depicted by a “star” when two statements are identical except for their objects or their aims. Evidence descriptions from the process tracing are then reported in Tables 3 and 4.

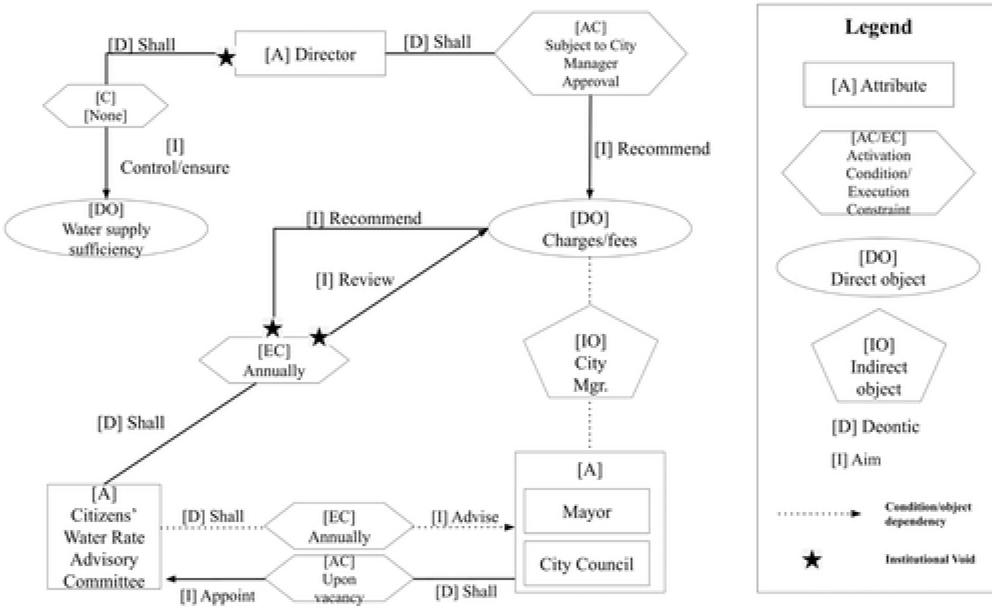

FIGURE 2
Institutional diagram of city of phoenix investment determination.

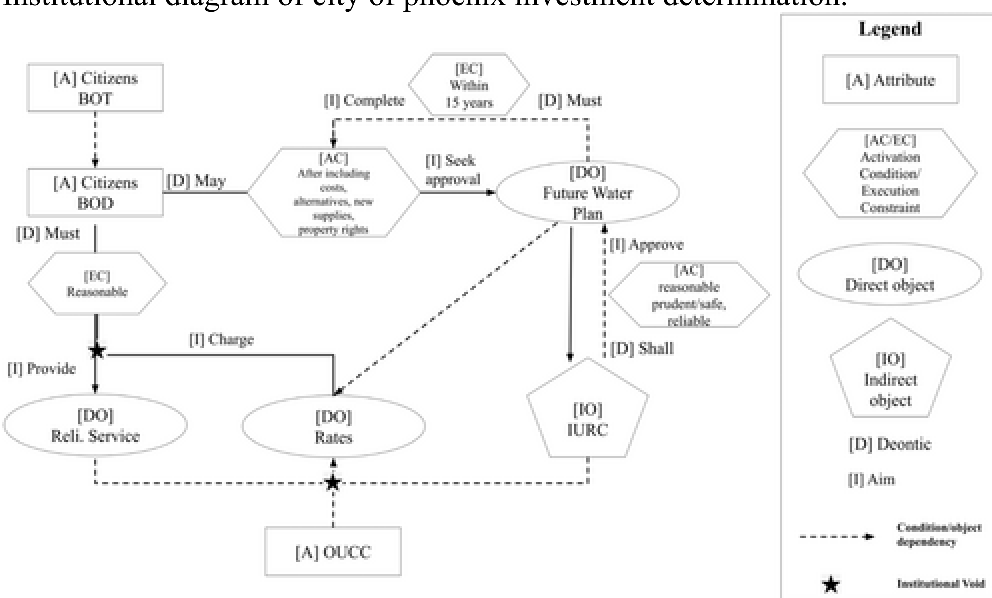

FIGURE 3
Institutional diagram of citizens energy (Indianapolis) investment determination.

TABLE 3. Phoenix process of water rate-setting.

	P1: Sensing	P2: Updating	P3: Selecting
Attribute [A]	PCC; DWS; CAC	PCC; CAC	PCC
aIms [I]	Data analysis	Evaluation	Choice
Empirical fingerprint	WRP; climate modeling; rate study	"Sustainability" based criteria emphasizing multiple dimensions of	"Equity" heuristics which equally weight a

	P1: Sensing	P2: Updating	P3: Selecting
		resource provision and its equity/economic implications	variety of decision criteria
Evidence type	Pattern	Account, sequence	Account, trace

- Abbreviation: CAC, Citizens' Water Rate Advisory Committee.

TABLE 4. Indianapolis process of water rate-setting.

	P1: Sensing	P2: Updating	P3: Selecting
Attribute [A]	CEG; IURC; OUCC	CEG; OUCC; cities	CEG; IURC
aIms [I]	Financial forecasts	Rate-filing; intervention	Bargaining; litigation
Empirical fingerprint	IWRP; demand plan; rate-filing	Stated financial needs for system maintenance that meet reasonable/reliable threshold	One-reason heuristics based on legal requirement and case precedent
Evidence type	Pattern	Account, sequence	Trace

- Abbreviations: CEG, Citizens Energy Group; IURC, Indiana Utility Regulatory Commission; IWRP, Integrated Water Resource Plan; OUCC, Office of Utility Consumer Counselor.

Both cases feature distinct processes for setting rates and thus investment strategies. Rate-setting institutions shape the choice sets of managers, who even though they cannot directly set rates, must strategically set investment priorities and make rate recommendations. The formal design of the Phoenix rate-making process depicted in Figure 2 illustrates multiple formal institutional dependencies and voids where different forms of information, participation, and inference strategies (heuristics) could guide rate-making decisions. Dependencies appear through the requirement that the City of Phoenix's WSD and its volunteer Citizens' Water Rate Advisory Committee (CAC) both make rate recommendations through the City Manager to the full City Council for consideration. The City Council is composed of the mayor and eight council members elected every 4 years, and it must make the final decisions on rates. The Council appoints the volunteer members of the CAC, which must annually advise the Council on the adequacy of rates. These formal, parallel processes have the potential to both increase the types of information and diversity of participation but also the cognitive costs of searching and curating information, introducing and resolving contested goals and making collective decisions.

These interdependent processes also produce two formal institutional voids because they lack rigid guidance on how rates and investments are determined and could introduce varied forms of information. The first void is the WSD's charge to ensure “water supply sufficiency” without formalized evaluative criteria to facilitate planning time horizons or defining “sufficiency.” The second void is the charge to annually review and recommend rate-making adjustments.

In contrast, Indianapolis displays a more hierarchical institutional configuration that ties rate-making more closely to long-term investment planning but allows more RUs to challenge water rate adjustments through a state-level regulatory commission. Water utilities in Indiana are regulated by the Indiana Utility Regulatory Commission (IURC), which oversees water rate schedules, utility expansions and acquisitions. Figure 3 depicts dependencies which require CEG utility managers to seek approval for both “future water plans” and linked water and sewer rate structures and fees through the IURC. For instance, the Indiana Office of Utility Consumer Counselor (OUCC) solicits public comment for any water- or sewer-rate proposal and has the authority to intervene and propose alternative rate structures to the IURC. This regulatory process potentially introduces financial and water-demand information into deliberations. One important distinction is the unique structure of the utility—with a volunteer Board of Trustees who fill their own board vacancies (no political appointment) and also appoint the utility's Board of Directors. This design affords the utility more autonomy from the Indianapolis mayor and City-County Council. However, the need to seek state approval from the IURC and the ability of water users to intervene lengthens the deliberation process and can result in litigation over rate increases.

Figure 3 also depicts two voids in Indianapolis. Plans must be supported by “reasonable” rates which provide “reliable” water services, and rate proposals—and thus, the linked plans—may be challenged in a quasi-judicial rate-review process by the OUCC. As with Phoenix, no specific evaluative criteria are present.

This analysis suggests that administrators and policymakers have varying points of reflexivity within existing laws, rules, or regulations to introduce diverse information, participation, and decision-making heuristics. We further validate this claim below through process tracing of rate-setting efforts in both cases.

3.1 Sensing via diverse information

Both cases featured varying efforts to search for and mobilize diverse types of information to support long-term infrastructure investments. However, the Phoenix system introduced climate science-based modeling expressly into its planning process—a process which existed outside of its formal rate-setting—and there is no evidence that Indianapolis did so in either its rate-setting or long-term planning. For multiple reasons, the evidence suggests that Phoenix appears capable of facilitating a wider variety of information flows through the flexibility afforded to WSD managers and its citizen committee. This is demonstrated as follows.

The Phoenix City Council approved a series of water-rate increases between 2015 and 2018 in response to both a multi-decadal drought and its aging infrastructure. In 2021, the City approved another 6.5 percent water rate-increase, projected to raise 1.7 billion dollars, to mitigate additional supply shortfalls and make improvements to its distribution infrastructure based on uncertainty about future water supplies.

The WSD is required to maintain short-run supply and demand data that feed into the city's 5-year financial and capital improvement planning, which formed the basis for rate increases prior to the study period. Knowledge of historic resource flows is commonly used to forecast future needs, although exclusive reliance on this type of information is problematic given the non-stationary nature of hydroclimatic changes. However, account evidence from interviews and pattern evidence from planning documents indicates WSD widened its range of data sources after this time to incorporate more detailed modeling of social-environmental system dynamics and future scenarios during the rate-change processes in 2018 and 2021.

For example, the Phoenix Water Department developed a new WRP, which expressly identifies climate change as a threat to the water system's resilience. More recent long-range scenario planning integrated research and forecasts from federal agencies, the University of Arizona, and the SRP, in order to prepare four supply-and-demand scenarios through 2070 that account for climate change. Utility staff relied on hydrologic scenarios from scientists and predictions from federal agencies such as the U.S. Bureau of Reclamation, which forecast a 14 percent chance that historic “Tier 3” water shortage restrictions could be put in place in the Colorado River basin within 5 years.

“When you're relying upon surface water supply, specifically, the impacts of climate change have been significant,” said one interviewee [PH02 Interview]. “And they haven't always been easy to project. I think we're just now really starting, and I'm not even sure I would say that today we have a very reliable way of projecting impacts to supplies.”

While supplies from the SRP are expected to be more resilient to climate impacts throughout the city's 2070 planning horizon, the WSD's 2021 WRP notes that Colorado River supplies are far more difficult to forecast and will likely continue to be negatively impacted by climate change. The WRP supply scenarios incorporate roughly 110 years of measured and modeled flow data records and historical modeled flow based on tree ring records for some 900 years. Demand scenarios based on population changes were developed by the State of Arizona and Maricopa (County) Association of Governments. While relying largely on external modeling, “[WSD] developed our own projections of what was happening on the Colorado River, as well” [PH05 Interview].

As a result, portions of the Phoenix service area are expected to witness “significant supply deficits” under future scenarios of long-term dry conditions and reduced snowpack runoff caused by climate change (WRP, 2021, p. 92). Given the increased risk of diminished CAP supplies and increased reliance of surrounding, developing suburbs on groundwater supplies, the Phoenix WSD noted the need to implement a diverse range of deficit mitigation strategies in coming years, including infrastructure system improvements and regional collaboration, increased demand management, and water supply augmentation (WRP, 2021, p. 96).

Indianapolis, by contrast, relied more extensively on shorter-term financial, water quality and cost-of-service information (knowledge of the past and of resource use or appropriation). Throughout its rate-setting process, CEG's filings and justifications relied on information about its backlogs in capital costs for aging infrastructure. Prior to 2011, the water utility had experienced decades of population growth, degraded water quality, and under-investment in infrastructure maintenance through private ownership and then for-profit contract management.

“Unfortunately, that is what contract operations is all about…how do you reduce your operational risk, and how do you reduce your operational costs?” said one interviewee [IN04 Interview]. “And so it's more short-range focused. And it's more focused on protecting the contract operator versus protecting the utility.”

When the Indianapolis mayor and City-County Council transferred ownership to CEG, the trust assumed significant debt and an obligation to comply with an Environmental Protection Agency consent decree to reduce combined sewer overflows. While sewer rates have tripled since 2012 to meet the 2025 goal, the utility has encountered more resistance than Phoenix's WSD in convincing rate regulators to approve water-rate increases.

In 2015, Indianapolis' CEG sought approval of a 22-percent water rate increase, which was intended to shift the financing of capital infrastructure expansions and replacement to water revenues rather than debt. The rate-filing was supported with financial cost-of-service information for each user class (residential, agricultural, etc.) and estimated capacities for these classes (resource appropriation information). The rate request was challenged by the OUCC and neighboring cities on multiple grounds, including its imposition of greater cost burden on current users and over whether major reservoir additions should be counted as “expansion and replacement” costs under Indiana law. Ultimately, the request was reduced to 16 percent by the IURC. In the rate filings, CEG officials noted that the decision left the utility with insufficient revenues to maintain infrastructure over its planning horizon. In 2022, the utility submitted another request for a nearly three-dollar distribution system improvement user-charge to make up some of the gap in its infrastructure needs, but the request was reduced to an 87-cent charge.

The Indianapolis utility also engages in long-range planning, focused on ensuring the robustness of services to historical patterns of drought and population growth. CEG develops an Integrated WRP (IWRP) and a Demand Planning report, which are both updated annually. Trace and account evidence indicate the utility's Operations Department water modeling relies predominantly on historical precipitation patterns and expected demographic shifts.

“We look back at the current year and compare it to previous years,” said one interviewee [IN04 Interview]. “And [we] look at where growth is occurring throughout the system, and what the needs are to ensure that we can meet the anticipated growth going forward.”

While the IWRP is intended to forecast needs 50 years into the future, the yearly demand forecast looks 5–30 years forward. Neither the IWRP nor demand planning uses climate modeling or otherwise attempts to probabilistically account for future climate-related risks.

In summary, the two cases relied on some similar types of information—historical trends and RU forecasts based on assumptions of stationarity in climate—to process future threats. However, Phoenix also expressly incorporates feedback on climate-related uncertainty and linked this uncertainty to the need for increasing the diversity of considered information in Phoenix climate forecasting, leading to more diverse response options. Conversely, Indianapolis focused on known environmental (pollution) and physical (aging infrastructure) system conditions and thresholds. While the need for climate adaptation is evident across all urban water systems, forecasting future scenarios and making contingencies for them remains difficult. Phoenix and

Indianapolis, like many urban water utilities, both appear intent on maintaining the robustness of water services they provide. But, as the Phoenix case indicates, identifying thresholds in the future will depend on finding new ways to forecast climate trends.

3.2 Updating via diverse participation

Both Phoenix and Indianapolis encountered stressors during the study period which required updating prior beliefs about future conditions. Evidence suggests the Phoenix system incorporated a more diverse group of stakeholders to do so, using its citizen-based committee (CAC) over a series of multiple rate increases from 2015 to 2021. This proved beneficial primarily for considering different narrative frames and evaluative criteria associated with climate risks and the distributional nature of the impacts of rate increases.

"I would say the primary stressor for me from a policy standpoint has been…how you frame it," said one interviewee [PH02 Interview]. "Is it a long-standing drought? Is it a mega drought? Is it climate change? I tend to think it's the latter, and so trying to deal with what I would now call the 'full-scale adaptation to climate change' has been a significant stressor."

While the formal institutions depicted in Figure 2 do not specify how the WSD and CAC reach consensus on recommendations, evidence indicates that this occurred over a year-long series of deliberations in 2018 which settled upon an issue frame of affordability. Guided by WSD staff, the committee formed an "affordability" subcommittee and developed a definition and metrics for affordability "reasonable for our community." These metrics depicted Phoenix rates as more affordable compared to peer communities. In this sense, the committee functioned as a forum where a shared normative evaluation of the rate hike was developed, focused on equity considerations. Subsequent WSD public messaging highlighted the relatively low recent rate increases and how the proposed rates favorably compared to other large U.S. cities.

The affordability framing introduced new performance information that was considered in the subsequent 2020–2021 rate-increase deliberations. "We're in charge of trying to make sure that…the lifestyle of the people who live in our community is, you know, is equitable, is livable," said one interviewee [PH02 Interview].

By contrast, the Indianapolis utility largely restricted participation in the decision-making processes to institutional water users and the OUCC via rate-review processes, depicted in Figure 3. Account and trace evidence indicate these processes focused on information about the utility's debt burden and limited response options to those that would maintain a statutorily defined evaluative standard of "safe and reliable" service [DSIC final order, 2022].

This "safe and reliable" criterion was highlighted in the aftermath of Indiana's 2012 drought, which interviewees termed a "wake-up call." Prior to CEG's utility takeover, the Indianapolis City-County Council had imposed a 5-year moratorium on water rate hikes, leading the previous utility operator to delay repairs and become highly debt-leveraged. During the drought, water use doubled, the utility came close to depleting one of its two primary reservoirs, and managers had to impose mandatory water-use restrictions. In the aftermath, CEG embarked on a long-range plan to expand storage capacity and catch up on infrastructure upkeep by raising rates.

Interviewees noted the utility's unique public trust status afforded it more flexibility than a traditional municipal utility in making rate and investment determinations based on longer-term needs. “We're not a political body, so we don't have to worry about the next election,” said one interviewee [IN03 Interview]. However, CEG also functions much like a corporation with limited transparency or opportunities for public input. While the company has three advisory groups for stakeholders and technical assistance, it is unclear whether they played any substantive role in the rate-setting process.

Rather, the rate hearings featured challenges from neighboring utilities which bought wholesale water from CEG, along with the OUCC on the grounds that it was “inequitable” to finance infrastructure expansion and maintenance through revenues alone rather than debt, which spread costs between current and future water users. Moreover, IURC regulators refused to approve a reduced rate structure for low-income households proposed by CEG, arguing it was “discriminatory” under state law because it “would require increases to the rates of other customer classes to meet Citizens Water's authorized revenue requirement” [2016 Final Order, p. 23].

Since the 2012 drought, CEG has made numerous storage improvements, system optimizations, and policy changes as part of its long-range planning effort to improve service robustness. However, the evaluative criteria of “reasonable” rates and “reliable” service have limited its options, prompting a focus on maintaining the current system state and preference for “lower-cost alternatives…while maintaining higher-cost alternatives as options for future long-term supply needs,” [2021 CEG Sustainability Report].

In summary, both cases feature policymakers and managers updating their beliefs about future needs. However, the Phoenix case appeared to engage more diverse participation in the process of developing response options (specifically, the level and timing of rate increases) as well as how they could be justified based on their affordability. Indianapolis' more litigious and hierarchical regulatory process for infrastructure investment limited the diversity of participation to primarily institutional water users and thus curtailed the potential for alternative normative valuations. While cost efficiency is a universal concern for water utilities, the IURC's rejection of equity-based considerations in CEG's proposed rate structure may render the water system less capable of responding to the varying spatial scales or distribution of social vulnerabilities. While relatively more robust to known stressors, Indianapolis may be less responsive to contested welfare goals likely to be exacerbated by climate change in the future.

3.3 Selecting via diverse heuristics

Given the cognitive limits of individuals and groups, we argued that organizational heuristics (inference strategies) which support timely decision-making are theoretically important under conditions of increased information and participation. However, heuristics studies often require experimental designs; it is difficult to assess whether research subjects in the field converged on the same heuristics for selecting strategies, whether multiple heuristics were engaged across decision-making contexts, or if one type of heuristic dominated. Rather, we observe that the selection process appeared to conform to one of two “classes” of heuristics identified by the psychology literature: equity decision-making or o*ne-reason decision-making* (Gigerenzer et al., 2022; Katsikopoulos, 2011).

In the Phoenix case, this appears to occur via equity decision-making, in which there are multiple cues for making decisions which have similar informational value. In our IG analysis, we observed how decision-making is guided by the deontics and objects of formal institutional statements, such as requirements that Phoenix WSD "shall…ensure" water supply sufficiency and the CAC "shall…review" rates. Both, in turn, "shall…recommend" rates to the PCC, which induces multiple institutional voids in which participants had to forge consensus-based informally on heuristic-based decision rules. For instance, WSD and the PCC appear to have relied on the scientific uncertainty surrounding the length of the drought (2018) and service disruption from water line breaks (2021) to make rate recommendations ([Omitted], 2023). Meanwhile, the CAC appears to have relied upon comparison to peer communities through an "affordability ratio" developed by converting water and sewer costs in Phoenix to the equivalent hours of working at the minimum wage.

Conversely, Indianapolis displayed evidence of one-reason decision-making, in which decisions are based on a single dominating reason or consideration. The IG statements declare the utility "must" provide "reasonable" rate structure and "reliable" service. We labeled this statutory stipulation an institutional void, but case precedent (i.e., debt to revenue ratios from previously approved rate increases) is used to define "reasonable" and the overriding motivation of reducing short-term costs dominated the selection of a strategy.

Moreover, the multilevel characteristics of the Indianapolis rate-review process—in which investment determinations were dependent on the interpretation of a higher-level monitor (OUCC) and the approval of an authority (IURC)—limit the ability of local cultural norms to determine the heuristics used. Interviewees suggested that CEG's internal review allowed for considerations such as "affordability" [IN04 Interview] and that "partisan politics doesn't become part of the operations of the company" [IN03 Interview]. Nevertheless, the institutional design appears to hinder incorporating other heuristics beyond a financial "take-the-best" rule, which optimizes on short-term cost. Alternative rules could give equal weight to cues that may be more appropriate for developing options to respond to social vulnerability, ecosystem restoration, or resilience more generally.

In summary, both Phoenix's and Indianapolis' water utilities witnessed resilience challenges over the past two decades and face ongoing uncertainties, which have been articulated in rate-making cases. Both have acted to make increased investments in hard infrastructure; however, Phoenix displayed the propensity for a greater variety of selection heuristics, which may enable greater response diversity that supports climate resilience. Indianapolis appeared to rely exclusively on a one-reason class of heuristics which may be only "ecologically rational" when a single dominant cue like short-term financial costs is sufficient for enhancing the resilience or robustness of system services.

4 CONCLUSION

Climate change is a management and governance challenge requiring diverse potential responses. This article builds from an expansive resilience and adaptive environmental governance literature to posit that public managers play a critical role in fostering climate response diversity through the institutional designs of governance processes.

The analysis identifies differences in the quality of these processes through which rate-setting occurs, meaning response diversity is parameterized through the information, participation, and selection criteria the utilities used. This led to differing degrees of flexibility within water-rate investment determinations. Comparing our two cases, we find Phoenix WSD, as an organization, benefited more from the integration of more comprehensive types of information, broader participation in decision-making, and equitable weighting of alternative evaluative criteria. During the study period, Phoenix engaged in multiple rate increases which supported both expanding infrastructure—so Salt River Water could be used on Colorado River-serviced areas—and in maintenance to existing infrastructure, which was being stressed by age and climate change. Meanwhile, Indianapolis was denied its full rate-increase request and had to tap other resources and defer some maintenance. Indianapolis was also not allowed to design rates which provided discounts for lower-income users.

Our study has several limitations. First, our three propositions likely work in tandem and require broader empirical validation before becoming prescriptive design guidance. Increasing the flow of information alone, for example, can have adverse consequences for human and organizational decision-making, requiring more varied human resources, technical know-how, and decision rules for cutting off deliberation and acting. Given the political polarization surrounding climate change, it is unsurprising that discourses on climate science, the anthropogenic nature of the problem, and inter-generational equity are virtually absent from formal institutional instructions and the deliberations they require. Institutions do not reason or squabble. They provide the "scaffolding" for humans to do so (Clark, 2013). We find that institutional designs do distinctively influence response diversity and are therefore key for evaluating the climate-adaptability of heavily engineered infrastructure systems, such as urban water systems. Research on climate resilience and sustainability in sub-national governments should focus more broadly on rule designs that enable more diverse and responsive risk management on the front lines of the climate crisis (Ostrom, 2011). Logical next steps should involve comparing cases which share similar climatic conditions and legal frameworks (i.e., in western or eastern states), as well as to simulate how institutional designs with these decision-making parameters perform under varying levels of stress.

Second, formal institutional designs should be treated as "candidate" rules (i.e., "rules-in-use" vs. "rules-in-form") and viewed as merely a starting point for analysis. While the formal institutions we analyzed here clearly instruct the pertinent action situations, the process tracing elucidated informal and evolving rules important for structuring information, assigning normative value to alternatives, and selecting among them. Future research should expand applications of the IGT to interviews (Watkins & Westphal, 2016) and case study documents (e.g., qualitative IG) to help identify informal institutions or those not well-defined in formal institutional documents, as well as to understand individual actors' interpretations of formal institutions.

Lastly, we cannot determine whether changes happening in the present across water utilities are truly adaptive to future changes. For example, hardening existing physical infrastructure like water treatment plants may ultimately increase the risks of destabilizing climate impacts as the frequency of flooding-related disasters increases. More rapid changes in rate schedules, conservation ordinances, and capital- and water-resource plans all reflect some degree of response diversity which may prove valuable in coming decades. But even for social evolution, these time spans are trivial, and additional public administration research is necessary to understand the institutional role in these robustness-fragility tradeoffs.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest related to this research.

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