Integrated proactive drought management in hydrosystems and cities: building a nine-step participatory planning methodology

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Abstract
Drought is a natural hazard with complex socioeconomic impacts and influences on human experiences. Preparedness is the only way a society can mitigate drought impacts but integrating participatory decision-making with hydrological modeling into a more comprehensive planning process is still a challenge. Here, we present a step-by-step methodology to guide the implementation of a participatory drought preparedness plan (DPP), specially designed for hydrosystems and cities scales. We highlight strategies to engage local stakeholders in constructing such plans and build trust in the process. We propose two types of drought preparedness plans: (1) Socio-technical—built only from the tacit knowledge of the system operators, which needs only two days to be ready; and (2) Socio-technical with modeling-intensive simulation—a more robust methodology that adds hydrologic and hydraulic modeling to the existing tacit knowledge. The participatory DPP methodology was developed and applied to hydrosystems and cities in a drought-prone area of Brazil. Our findings suggest that modeling was important, but not essential to assessing vulnerability scenarios and strategies. However, the simplified version can achieve satisfactory results even when data and resources are limited. We present the methodology as a nine-step participatory planning methodology developing a meaningful and convincing narrative that speaks to theory and practice.

Keywords Drought · Drought preparedness · Participatory planning · Proactive drought plan · Socio-technical planning
1 Introduction

Increasing extreme droughts resulting from climate change have raised interest among researchers and water managers in better understanding and preparing for droughts in the future (FGV and ANA 2018; Hervás-Gámez and Delgado-Ramos 2019; Marengo et al. 2017). This current information regarding droughts can be compiled into a drought preparedness plan (DPP), a new planning instrument specializing in drought management. In DPP, multiple scales of drought occurrence with impact systems are considered. DPP relies on crisis and risk management (Raikes et al. 2019; Sivakumar et al. 2014; Wilhite et al. 2000). Crisis management is associated with reactive plans, while risk management is associated with proactive plans.

The crisis management approach defines the response and recovery actions performed by various social agents during a drought. The risk management approach’s plan foresees actions prior to and during the event, including measures for mitigation, preparation, monitoring, early warning, response, and recovery. The consideration of the following question is what distinguishes the two approaches: (Wilhite 2012).

In a proactive approach, lessons learned from previous drought periods are retained when the drought subsides. These lessons influence institutions, policies, infrastructure, water storage, and allocation. Despite climatological and socioeconomic contexts, a deep understanding of drought vulnerabilities is critical for enhancing drought resilience (de Azevedo Reis et al. 2020). Pre-drought activities are designed to increase readiness levels or improve operational and institutional capabilities to respond to drought events (Ahmad Yousefi et al. 2020; Van Loon et al. 2016; Wilhite 2000). Social actors express their positions on allocation rules, rationing levels, and other strategies to reduce potential impacts prior to the drought (Lund et al. 2018) and under the “veil of ignorance” (Rawls 1971). Arbitrating conflict during a crisis without predefined rules can be problematic.

The constraint on drought preparedness has been the lack of methodologies to guide technicians while conducting participatory planning. A ten steps methodology has provided a set of guidelines or a checklist of the critical elements of drought (Wilhite 1991; Wilhite et al. 2000). Consequently, the importance of proactive planning for future droughts is well established. However, engaging local stakeholders in constructing such plans remains challenging, and a participatory-building methodology for such drought preparedness planning is absent in the current literature.

“Knowing what to do is not enough when seeking to achieve goals” (Pfeffer and Sutton 1999). Scientists have valuable knowledge relevant for decision makers; however, there is often ineffective communication between scientists and society. Scientists often understand communication with the public as a one-way information flow. However, scientists should act as facilitators for an ongoing social learning process among many stakeholders who have valid and essential knowledge (Shackleton et al. 2009).

Advocates of participatory approaches (Kainer et al. 2009) claim that partnerships with local stakeholders can enhance knowledge exchange, identify problems and solutions, trust among parties, credibility in scientific findings, and benefit the incorporation of scientific knowledge for planning. Consequently, such participatory approaches have improved public’s perception of drought preparedness plans. State and society are a continuum are comprised of entities enabling social interactions, such as councils, committees, forums, networks. These entities facilitate interaction between civil society and representatives of public authority. This connection does not imply the replacement of the state but does not recognize the importance of “expert knowledge,” as theorized by Giddens (1991).
A method of managing public goods is to recognize tacit knowledge. Participation becomes essential for the effectiveness of public policy, interaction with the political system, conflict resolution, and a method to democratize decisions. However, it would be an error to believe that the political planning model lacks a robust and rich scientific basis. The quality of a decision in the current complex society is related to the available information and knowledge base. Without a solid technical foundation to guide the process, a consensus can only achieve satisfactory results by happenstance.

Poorly coordinated and poorly timed responses to drought result in a typical crisis management approach (Aitkenhead et al. 2021; Neisi et al. 2020; Wilhite et al. 2014). In Brazil, recent drought episodes in both the southeast and northeast regions have demonstrated the ineffectiveness of such a crisis management approach in assessing and responding to severe drought events, thus emphasizing the need to shift from a reactive to a proactive drought approach (Gutiérrez et al. 2014; Martins et al. 2016).

Drought management is particularly important for the Brazilian political and institutional agenda. Brazil is developing a national drought policy and defining specific drought management tools for a new, proactive, and risk-based management model. The Brazilian Drought Monitor, implemented in 2013 by the national government in partnership with the Brazilian National Water and Sanitation Agency (ANA) and the Ceará Foundation for Meteorology and Water Resources (Funceme), in addition to other institutions, is an excellent example of this novel approach (Martins et al. 2015). The new objective is the definition of drought preparedness plans at five levels of planning, which would function as a cascade system. The levels include the national, state, hydrographic regions/basins, hydrosystems, and water users (water supply to urban areas, irrigation districts, dispersed rural populations, or rainfed agriculture).

This paper is a “guide” regarding the development of a DPP that local society can trust and effectively implement. It is tailored to agents interested in guiding the implementation of participatory proactive drought plans, particularly those designed for hydrosystems and city scales. We present strategies for engaging local stakeholders in constructing such plans by building trust. We describe the implementation of the methodology for a drought-prone area located in Brazilian Semi-arid region, to illustrate and develop a meaningful and convincing narrative that relates to theory and practice.

The proposed methodology provides a replicable framework to construct DPPs in hydrosystems and urban areas, which can be readily applied to any region that experiences recurrent droughts worldwide. The participatory planning approach was used to identify vulnerabilities of past droughts according to users’ memories and to build adaptive strategies that comply with local conditions. In this process, we acknowledge the existence of social capital (i.e., local social networks with shared norms, values, and understanding), which provides the context for the solution design.

2 Methodology

We propose two types of drought preparedness plans depending on the regional financial and time constraints.

- Socio-technical DPP—A simplified methodology built exclusively from the tacit knowledge of system operators. It requires two days of preparation.
• Socio-technical with modeling-intensive simulation DPP—A more robust methodology that incorporates hydrologic and hydraulic modeling to existing tacit knowledge.

Both the proposed methodologies are built on three pillars (Wilhite et al. 2005): (i) monitoring and early warning, (ii) evaluation of vulnerability and impacts, and (iii) mitigation and planning of responses and measures. The step-by-step approach to elaborate the socio-technical aspects of the model-intensive simulation version is explained in nine steps (Fig. 1). The socio-technical version only includes the first four steps. The plan was constructed in a participatory mode through workshops involving those in charge of water resource system management.

The DPP steps are detailed below. We also present a list of actions and the information required to replicate the methodology.

2.1 Step 1: Characterization of the study area

The starting point in DPP preparation is to characterize the regional conditions based on the current literature. If available, the team should address the local physical characteristics (topology, water supply, water demands, leading problems, and viable solutions) and previous environmental and water resource plans. The task force (defined in Step 2) must be aware of the regional characteristics and their main problems before the workshop with local stakeholders (Step 3) to (i) build trust with local participants and (ii) explain the interactions between previous studies/plans and the proposed drought plan.

2.2 Step 2: Task force creation and initial contact with key actors attending the workshop

A task force should be created to facilitate discussions regarding the problems and solutions in participatory workshops. The task force should comprise a multidisciplinary group
of scientists and water authorities. A multidisciplinary group of scientists includes civil/environmental engineers, social scientists, hydrologists, geologists, and other natural scientists. Water resource managers should also be included in the task force, and they should be objective regarding existing conflicts. In addition, they should be viewed as an authority by the participants.

The primary purpose of the task force was to lead the workshop and guide participants through the definition of problems and solutions. Task force members must meet before the workshop to discuss the results from the first step and method the workshop should be conducted. The task force should then list and invite key actors to participate in the development of the drought plan. If key actors do not feel included in the planning phase, it can be challenging to implement the plan. However, if participants genuinely feel like co-authoring the plan, its implementation will be much smoother. Residents are often best to act on local issues by complementing, extending, refining, or initiating conventional science (Baldwin et al. 2012).

The key actor’s list may include

- Hydrosystems: hydrosystem operators, regional water managers, water user associations, irrigators, municipal authorities, army, universities, and non-governmental organizations associated with water issues.
- For the city scale: hydrosystem operators, water supply operators, regional water managers, municipal authorities, residents’ associations, departments of health and social care, civil defense, army, universities, and non-governmental organizations associated with water issues.

The hydrosystem and water supply operators, for example, are engineers and technicians engaged with operational tasks such as regulating the flow, stopping leaks, and reducing the water supply and distribution system pressure. These professionals have the most in-depth knowledge regarding the system; consequently, their knowledge is vital when managing drought conditions.

The list of participants on the city scale was intended to address users’ needs and interests. The smaller the planning scale, the more discernable actions of specific local actors; consequently, the problem diagnosis and solution proposal can be more accurate in such circumstances. In summary, one must ensure that the appropriate shareholders are included, clearly understand the process, and are cognizant of the drought plan goals while formulating the drought plan (Wilhite et al. 2005).

The invitation to participate in the drought planning workshop should come directly from the task force and include a brief explanation of workshop’s events. In addition, an explanation of the differences regarding the workshop and basin committee meetings should be included. This explanation is essential to align the participants’ expectations with the meeting’s objectives and to prevent the inclusion of unfinished discussions from previous events.

In this step, the task force must define the categories of drought-related problems that might occur in the region and the categories of viable solutions. Additionally, the group should select few examples of problems and solutions to be presented later in the workshop.

2.3 Step 3: Workshop1

This article presents a methodology for developing a drought preparedness plan that encourages social participation for integrating state and the community participation for
the implementation of public policy. This methodology requires the participation of different social actors and is adopted in the workshops. It is inspired by some methodological procedures with a participatory approach. Specifically, some principles of the Goal-Oriented Project Planning Method (GOPP-ZOPP) include working in subgroups, mediation, and visualization of ideas validated by the participants. Among the techniques adopted by this method, we used the METAPLAN technique. This technique was developed by the German consultancy Metaplan GMBH. The technique consists of two procedures: a mobile visualization technique and moderation.

This step may be described as the participatory process of the drought plan (Fig. 2). First, the task force summarizes the information collected during the diagnosis phase using an infographic to be presented to the participants. The participants validated the data and indicating details absent from the diagnosis. In addition, changes regarding the water system may have occurred and should be updated. After presenting the infographics and updating the information, the task force grouped the participants according to the number of categories of problems defined in the previous step. Participants can be divided according to their ability to contribute different work groups of the participant’s choice. Each group is designated a task force member to facilitate discussions and encourage participants to contribute to the debate.

Survey of the “Problems”—vulnerabilities and impacts of drought: In this activity, the workshop participants identify the potential impacts of drought in the region. Pre-selected potential drought problems, which did not necessarily occur before in the region, are presented to each group to start the discussion. Participants could use this list to identify problems in the region due to previous droughts. After the initial brainstorming session, a task force member presents the selected problems to the plenary. Participants can then decide the relevance of the issues or introduce novel issues. For instance, a list of problem categories is presented, but stakeholders can add new categories:

1. Environmental issues
2. Economic issues
3. Social issues and conflicts
4. Water supply and distribution issues

For each problem, participants were invited to formulate a historical impact assessment, detailed questions such as historical and current impacts, rank impacts concerning other
participants, describe the historical strategies used to mitigate such impacts, reflect on the historical effectiveness of such strategies, analyze potential future impacts, and recommended strategies. E-mails were sent after workshop I, summarizing all problems and asking for additional contributions.

Survey of the “Solutions”—preparation, mitigation, and response strategies: Later in the same day, the task force initiates the second activity by presenting a synthesis of the problem identification session. The previously defined groups are reunited to formulate drought preparation, mitigation, and response strategies according to their defined problems.

The focus regarding identifying eligible actions is to be implemented in each drought state. These strategies have the purpose of reducing the system vulnerability to drought and the severity of its impact. The solutions are divided into five categories.

1. General and structural measures (these should occur prior to a drought event, with the objective of proactive preparation)
2. Supply management measures (e.g., increasing the flexibility of water distribution control)
3. Demand management measures (economic incentives that consider willingness to pay, tariffs, or desire to receive, e.g., tariff bonuses and other behavior modification strategies)
4. Legal-institutional measures (framework for conflict management during drought)
5. Water safety and health measures

A detailed measure spreadsheet must be defined after Workshop I for each proposed action. The spreadsheet has a 4W1H matrix format and contains the answers for simple questions such as “What to do” (actions), “When” (drought state), “How” (description), “Where” (place), and by “Whom” (responsible). Increasing clarity can facilitate implemented measures when needed. Detailed measures spreadsheets were sent to the participants via e-mail for later approval.

Drought states trigger the activation of previously established measures as the crisis progresses. Different monitoring and early warning systems can be used to trigger drought states. In small-scale systems such as hydrosystems and cities, triggers can be defined according to the reservoir levels because they are related to the corresponding demands. Drought states were described as follows: no drought (ND), low drought (LD), moderate drought (MD), and severe drought (SD). These measures should be designed according to the drought state defined by the reservoir levels (Fig. 3).

The number of drought states and their names can be changed according to the regional needs. This participatory process is critical for drought plan implementation.

2.4 Step 4: Elaboration of a socio–technical drought plan

The planning phase involves decisions regarding the strategies and actions to be implemented to avoid or reduce the adverse drought effects through measures. After Workshop 1, the task force can consolidate the problems and solutions indicated by the participants into a socio-technical drought plan and discuss the planning process and its challenges (Fig. 4). The diagnostic section of the document is provided below.

1. Present a hydrosystem description.
2. Describe the current information and early warning system.
3. Assess the impacts (of drought) and vulnerabilities (of the region).

The task force seeks to identify the legal, institutional, technical, economic, and social conditioning factors as well as the historical development and current situation of the water system. The vulnerabilities and potential impacts associated with operational drought were evaluated at this step in the process.

The planning section consists of defining:

1. Preparedness, mitigation, and response strategies according to workshop discussions
2. Drought states and triggers

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**Fig. 3** Reservoir zones according to the drought states

**Fig. 4** Methodological steps for the elaboration of an Urban Drought Preparedness Plan
3. A mitigation and response action plan, which should provide a fast response to upcoming events.

Finally, the plan was implemented and reviewed/updated after each drought event. In this phase, the drought status should be monitored to identify opportunities to implement the strategies and actions proposed during the planning phase.

The DPP obtained at this step is constructed on “participatory socio-technical-based information,” that is, the plan is based on the tacit knowledge of workshop participants and does not include hydraulic or hydrological modeling. Drought states, triggers, and measures were defined ad hoc. Hence, if there are no data or monetary funds for the next steps, a DPP may still be prepared.

2.5 Step 5: Conducting technical visits for data collection

After the workshop, task force members conduct one or more technical visits to the area to obtain additional data necessary to perform hydrological and hydraulic modeling.

For hydrosystem modeling, the required information includes (i) reservoir information (capacity, minimal operational level, area–volume–elevation curve) (ii) historical inflow time series, (iii) water demand, and (iv) evaporation rates.

For hydraulic modeling, specifically for the cities’ scale drought plan, the relevant information consists of (i) water supply system networks, (ii) pressure in the nodes of the network, and (iii) location of the pumping stations and water tanks.

2.6 Step 6: Hydrological/hydraulic modeling

After collecting the data, the task force uses modeling to assess system vulnerabilities, scenarios, and management strategies. Hydrological modeling is required to analyze hydrosystems, whereas hydraulic modeling is recommended for urban areas. Workshops and technical visits should provide existing operating rules and water allocation priorities. Modeling should enable the task force for determining if the operating rules are optimum and propose new rules if necessary. However, local operators are free to determine whether they should adopt new optimized rules or remain with pre-existing rules.

Moody and Brown presented a measure for hydrosystem performance for which the stakeholder defines the risk of the system over a wide range of climatic conditions (Moody and Brown 2012). Vulnerability to drought is assessed by reservoir levels and should be discussed during workshops. An indicator based on reservoir levels defined by stakeholders can assist water resource managers and decision-makers evaluate vulnerability to drought in a meaningful manner (Borgomeo et al. 2015).

Hydraulic modeling of a water distribution network is necessary to effectively manage network losses. Leaks in the distribution networks are relevant because of the significant volume of water that does not reach the end user. Pressure control is one of the most efficient alternatives to reduce water loss. Water utilities commonly use pressure-reducing valves to minimize leakage. This device reduces the piezometric pressure of the distribution network when consumption is reduced, usually during the dawn period, so that the absence of excess pressure does not increase water losses due to leaks. To evaluate the impact of loss reduction, the modeler should create pressure reduction scenarios. Pressure reduction is achieved by inserting pressure-reducing valves at specific network points. The
adjusted pressures were evaluated under several drought scenarios in the region. Finally, the task force estimated the volume of saved water.

2.7 Step 7: Model implementation

The task force applies hydrologic and/or hydraulic modeling to assess vulnerabilities, scenarios, and strategies for hydrosystems and/or urban areas. Local actors are not expected to possess modeling knowledge, but modeling results and discussions can be further improved if local actors are familiar with modeling.

2.8 Step 8: Conduct workshop 2 with key actors to present the results from modeling, guarantees, and risks

After the task force produces the socio-technical information with a modeling-intensive simulation informed DPP, another workshop should be scheduled. In this meeting, the task force presents the modeling findings to the workshop participants, which should be identical to that of workshop 1. Then, participants can decide whether to maintain previous operational rules or use the new optimized rules obtained with computational modeling.

2.9 Step 9: Final DPP–socio–technical with modeling-intensive simulation

Drought preparedness planning is a process that is not discrete. Workshop 2 participants must approve the DPP’s final version prior to publication. Its implementation should be monitored, and the proposed measures should be reviewed according to technological, legal, institutional, policy, and management changes and acknowledge the evolving needs of the hydrosystem/urban area.

3 Results

This paper proposes a methodology to build two DPP categories: (i) socio-technical DPP (steps one to four) and (ii) socio-technical with model-intensive simulation DPP (steps one to nine). The socio-technical DPP is principally derived from the participatory process, where workshop participants indicate problems related to drought and possible solutions. The socio-technical with model-intensive simulation DPP can be prepared if there is sufficient information to apply computational models to determine optimal operating rules (for either the hydrosystem or the water distribution system).

3.1 Participatory outcomes: the socio-technical DPP

The proposed methodology was used to build four drought preparedness plans: two for the hydrosystem scale and two for the city scale. The application area had recurrent droughts. When the task force arrived at the study area, one of the most prolonged and severe droughts in recorded history (2012–2018) had recently ceased (Pontes Filho et al. 2020). Therefore, there was some hostility between the participants due to recent conflicts and pre-established pacts.
In hydrosystems, power relations among actors are evident. In urban areas, new actors who do not participate in committee meetings were present. These new participants disrupt the pre-existing social networks as the new groups formed new balances. Still, the task force had to intervene when workshop attendees mention unresolved discussions from the past. Actors linked to the decision-making process had credibility. Details regarding the participatory process are described in the following sections.

3.2 Step 1: Diagnosis of the study area

The diagnostic phase of the process sought to identify the legal, institutional, technical, economic, and social conditioning factors regarding hydrosystems and water supply systems. In addition, the task force assessed the system’s historical evolution and current situation. The goal was to assess operational drought vulnerabilities and their potential impacts.

The study area is at the Piranhas–Açu river basin, in the semi-arid region of Brazil, which is a densely populated region in northeast Brazil. The total annual precipitation ranges from 400 to 800 mm. The region has substantial seasonal and interannual variability. The yearly rainfall is concentrated over three to four months. In addition, recurrent droughts occur that may last up to a decade. To mitigate drought issues, pluriannual dams have been constructed. However, during the drought of 2012–2018, a significant fraction of this infrastructure failed due to the event’s extreme duration and severity (Pontes Filho et al. 2020). For example, the Coremas-Mãe D’água hydrosystem, which has a capacity of 1,159 hm³, retained only 3% of its reserves during the worst period. The drought exposed the fragilities in water management and created an opportunity to consolidate all the knowledge acquired during the crises and use the result to improve resilience to future drought events.

The Piranhas–Açu federal basin has a transboundary river that crosses the borders of two states: Paraíba and Rio Grande do Norte (Fig. 5). During the 2012–2018 drought, ANA was highly active in the region, dealing with emerging conflicts and constructing new planning instruments. The Piranhas–Açu Water Resources Plan was approved in 2016 (ANA 2018). One of the actions proposed in the basin’s water resources plan was to construct another instrument to mitigate drought impacts. As a result, the basin’s DPP was built in 2016 (World Bank, 2015).

Much has been learned from the 2012–2018 drought. The lessons included acknowledgment of infrastructure imperfections and limitations. System storage capacities were updated, and the process to mitigate with institutional challenges was created. Finally, emergency actions were implemented.

Close experience with the crisis has ingrained these factors in the memory of the basin’s water users. It is common knowledge regarding what to do in specific situations, but these measures are at risk of being forgotten as people retire, move, and die. The only method to prepare for future droughts is to engage those who know the system best in the planning process and document their experience.

Once the intention of building a DPP specific for urban areas and hydrosystems of the Piranhas–Açu Basin was acknowledged, the first step was to acquire and analyze drought-related information in the region. As the basin’s DPP had been in existence only a few years when the task force was forming, it was imperative to construct a participative process that could evolve, instead of building plans from scratch. Some issues were missing from the basin’s DPP, as the macroscale does not encompass sufficient detail to resolve
Fig. 5 The Piranhas–Açu river basin. Location of the hydrosystems and cities where the proposed methodology was implemented.
smaller areas. Therefore, a DPP for a coarser scale (such as a hydrographic basin) can be useful. However, it is not mandatory to create DPPs for cities and hydrosystems.

3.3 Step 2: Task force creation and initial contact with the selected key actors who will attend the workshop I

The task force was comprised of a multidisciplinary group of scientists from the Federal University of Ceará and ANA representatives. As the study area is in a transboundary basin, the river domain is federal, which necessitates the contribution from the ANA. The group elaborated regarding strategies to engage stakeholders in the respective study areas and the themes to be addressed in future workshops.

At this time, a second meeting involving local state water resource managers occurred and was indispensable for engaging the participants in the process and identifying the actors who should attend the workshops. During the event, the task force explained the importance of documenting the memory of drought conditions directly from those managing current crises. Many lessons were learned during the meeting, such as the importance of providing legal instruments that enable joint actions between states during critical situations.

Together with the local water managers, the task force identified the key actors that would be invited for workshops on each city and hydrosystem. For cities, the protagonists participating in the workshops included water supply operators. For hydrosystems, participants included river basin committee members. The group also defined categories to classify the problems and solutions that would be discussed during the workshop, as suggested in the Methods section.

During these first two meetings, it became evident to the task force that the area’s previous studies and plans had to be acknowledged and respected, as key actors were involved with most of the previous plans. Therefore, a misunderstanding regarding the difference between previous plans and the proposed one could be an issue for the development of future steps.

3.4 Step 3: Conducting the workshop I

Workshop I involved the task force and key actors as defined in the previous step. The event had the duration of one day, and the activities were divided into the following categories:

1. Presentation of the members of the task force and the objectives and context of the DPP.
2. Validation and update of the information resulting from the diagnosis.
3. A discussion regarding problems related to drought and viable solutions.

Information regarding the system (hydrosystem and urban water supply system) obtained in the first step was summarized in infographics, which were printed and presented in the workshop. The participants were then invited to analyze the infographics to validate and/or suggest modifications because of lessons learned from the last drought event. Updates were made by hand during workshop I on the infographics (Fig. 6).

After the infographic update, surveys regarding problems and solutions were discussed as dictated by material in the methodology section. One day was sufficient to discuss problems and solutions with residents. The information collected at the workshop could not be obtained in any other manner. The workshop was valuable for the
elaboration of the DPP. The workshop also showed participants that the facilitators knew of the system’s structure and the principal problems. A general impression shared by the task force was that the participants enjoyed updating the information. This was especially true for infrastructure built in response to the last drought event. In addition, the participant’s division into groups to discuss problems/solutions was imperative to provide enough opportunities for every member to participate in the discussion.

To facilitate the ongoing social learning process at the workshop, the task force was conducted in the presence of ANA technicians, as the federal agency has legitimacy and is well recognized in the region. Without their presence, the task force would have to create these favorable conditions prior to planning, which would have inhibited the process.

For the problem/solutions surveys, the groups received cards containing examples of problems to foster discussion among group members. Participants could decide on the relevance of such issues or introduce a new problem to the region that has not been identified. Following this brainstorming, a group member presents the plenary selected issues, focusing on its validation, as illustrated in Fig. 7. The participants also defined the actions to be implemented in each drought state. A detailed measure spreadsheet was proposed for each action, and an example is presented in Table 1.

Despite the preparation for the participants’ invitation, the task force must adapt to the presentation and workshop dynamics according to the participants’ profiles. For instance, in a city with an unsolved water conflict, the invited participants brought acquaintances to the meeting. A vast audience, including several city council members, surprised the task force. The city radio erroneously announced that the workshop was a meeting with the river basin committee. Many water users were unhappy with a previous decision from the
committee and went to the meeting; however, when the task force informed the audience of workshop’s objective, many audience members left.

3.5 Step 4: Elaboration of the socio-technical drought plan

The first DPP version (the Socio-technical Drought Plan) includes the diagnostic and planning phases. This consolidates the information obtained during the workshop and the diagnosis. The focus regards identifying the impacts and system vulnerabilities (problems) with developing strategies and actions to reduce the vulnerabilities present in the hydrosystems and city (solutions). To shift from crisis management to a risk management approach, mitigation actions related to drought planning have been proposed for different scales.

The operational measures for both cities and hydrosystems were linked to actions that could be taken under different degrees of drought severity; a threshold triggers measures to be taken in each state of drought. Each measure is assigned to one (or more) of the system. According to the reservoir levels, previous agreements between users and water managers have established drought thresholds. Therefore, the task force suggested maintaining these thresholds, and workshop participants concurred.

For example, in the city of Caicó, the “supply management measures” group defined households or institutions with elevated water consumption that required monitoring. Some actions may be adjusted as drought severity evolves. Supply side measures may be implemented in the following order: installing quick coupling reducers (normal state), drilling deep wells, and reusing water (severe drought). Water safety and health measures consider

Fig. 7 Group discussion and presentation of Caicó’s problems
Table 1  Example of a detailed measures spreadsheet proposed to the action: “Define a monitoring system for the city”. States of drought for triggering actions include: No Drought (ND); Low Drought (LD); Moderate Drought (MD); and Severe Drought (SD)

| What                      | When          | How                                           | Were                           | Whom                        |
|---------------------------|---------------|-----------------------------------------------|-------------------------------|-----------------------------|
| Reservoir monitoring      | ND, LD, MD, SD| Daily monitoring                              | Reservoir that supplies the city | Water Agency                |
| Reduce water loss         | LD, MD, SD    | Intensify campaign to reduce water loss by checking water distribution system | Water distribution system    | Water supply operators      |
| Check well’s state        | MD            | Check the state of existing wells and their capability to supply the city if the drought persists | City’s wells                  | Water supply operators      |
actions to implement and monitor the legal instruments regulating water resources, sanitation, water quality, solid waste, and preservation and protection of vegetation. Participants mentioned the need to train water users’ representatives to monitor government actions and collaborate with water resource management, especially in the implementation phase.

At the city of Souza workshop, water supply operators presented no data regarding the water distribution network. Thus, the city’s socio-technical drought plan was the only option available. This example shows the importance of a methodology that allows water managers to recover memory from previous droughts and plan for future events without necessarily using advanced modeling techniques. In the city of Caicó and two hydrosystems, the task force continued to collect data for hydraulic and hydrological modeling to parameterize the socio-technical model with model-intensive simulation DPP.

4 Modeling outcomes: The socio-technical with modeling-intensive simulation DPP

4.1 Step 5: Conducting technical visits for data collection

After the workshops, the task force revisited the study areas to obtain hydrological and hydraulic modeling data. Information for hydrologic modeling (reservoir morphometry, withdrawals, and discharges) was obtained during the first meeting of the task force. Distribution network modeling is a step exclusive to the city scale; therefore, the task force visited the city of Caicó to collect data regarding the hydraulic conditions of the water distribution network. The initial objective was to verify network parameters such that the task force could simulate the water distribution system operation under different drought conditions.

The representatives of Caicó’s water utility explained, at the meeting, all the specifics regarding the water collection and distribution system: (i) The city has a rotating supply system: The network is divided into four zones, each of which is supplied for three consecutive days per week (this measure reduces water losses from 50 to 23%); (ii) Three water towers were built after the 2012–2018 drought, increasing the city’s water storage capacity, and providing pressure control for the water network.

4.2 Steps 6 and 7: Hydrological/hydraulic modeling

Hydrologic Modeling Due to the intensification of conflicts between users during the 2012–2018 drought, both hydrosystems already have been the subject of recent ANA studies. Specific regulatory milestones for each hydrosystem resulted, which defined the maximum demand and water use requirements.

Because the hydrological states were previously defined, simulations were performed to verify when each hydrosystem should be used to mitigate water supply failures. Flow network algorithms can be used to simulate the operation of reservoirs, considering their priorities for usage. Task force engineers set priorities according to the current operational state obtained from workshop attendees. For example, in the Caicó analysis, five different hydrosystems were used to supply the city. Supply priorities (Table 2) were defined in the following order: Itans Reservoir, Coremas-Mãe D’água, and Engenheiro Armando Ribeiro Gonçalves Reservoir, as water supply operators indicated at the workshop (Fig. 8).
Table 2  Priorities used for flow network modeling

| Reservoirs                                      | Priority |
|------------------------------------------------|----------|
| Coremas                                         | 88       |
| Coremas—Mãe D’água                             | 90       |
| Engenheiro Armando Ribeiro Gonçalves            | 84       |
| Itans                                           | 93       |
| Mãe D’água                                      | 88       |

Fig. 8  Scheme used to simulate the supply system for the city of Caicó

Table 3 presents the simulation results. One may observe that the Engenheiro Armando Ribeiro Gonçalves reservoir faces the most significant hydric stress and is for 56.07% of the analysis period, unable to satisfy use demands. The city of Caicó presented the lowest percentage water systems being unable to meet required demand (1.98%); however, when a failure occurred, the supplied flow was only 13.6% of the demand. In this case, diversifying water sources lowered the risk of water shortages. However, as hydrosystems are highly correlated (rainfall influences all water sources), each may collapse during the same water crises. Persistent drought events in the region cover vast areas and affect all hydrosystems used in Caicó’s water supply. When a collapse occurs, very few demands are met.

The task force simulated the Itans, Engenheiro Armando Ribeiro Gonçalves, Coremas, Mãe D’água, and Coremas-Mãe D’água systems from 1961 to 2019. The Itans Reservoir had a percentage of failures similar to that of the previous simulation (8.47%). Failures over six months occurred from 1992 to 1993, 1998 to the beginning of 2002, and during 2017.
Table 3  Results for hydrosystems simulations showing the water demand and water supplied for the city of Caicó

| Demand                     | Frequency below required demand (%) | Average required demand (m³/s) | Average flow rate supplied (m³/s) | Average flow rate supplied when failures occur (m³/s) |
|----------------------------|------------------------------------|-------------------------------|-----------------------------------|-----------------------------------------------------|
| Caicó City                 | 1.98                               | 0.205                         | 0.202                             | 0.028                                               |
| Coremas Reservoir          | 3.53                               | 4.360                         | 4.246                             | 1.131                                               |
| Eng. Armando Ribeiro Reservoir | 56.07                             | 10.317                        | 4.998                             | 0.832                                               |
| Itans Reservoir            | 6.21                               | 0.101                         | 0.095                             | 0.005                                               |
| Mãe D’água Reservoir       | 3.39                               | 1.800                         | 1.753                             | 0.411                                               |
Figure 9 shows an example of the operating rules developed for Caicó. The Itans reservoir and the Coremas-Mãe D’água system were the water source for 86% and 14% of the analysis duration, respectively. The optimization software did not present flow values for the link between Engenheiro Armando Ribeiro Gonçalves and Caicó’s demand. This indicates that capturing water from this reservoir is not an optimum solution. Hence, the other two sources would be sufficient to meet Caicó’s demands.

**Hydraulic modeling** The distribution network of Caicó was modeled using software that can perform hydraulic sizing for water supply networks, pipelines, and sewage networks (Fig. 9).

Considering hypothetical drought scenarios, a new simulation was performed in the city’s four zones: (i) for the no-drought state, the minimum pressure permitted was 10 m water column, and (ii) in the moderate-drought state, the minimum pressure permitted was 5 m water column. For this purpose, a pressure-reducing valve was inserted into the model next to the tank outlet pipe of each zone. (Fig. 10).

![Fig. 9](image1.png)

**Fig. 9** Decision tree for defining the withdrawal from the Itans reservoir

![Fig. 10](image2.png)

**Fig. 10** The Caicó water network used in the hydraulic modeling
As an example of the results found in Zone 2 of Caicó, the insertion of the pressure-reducing valve for the scenarios with no drought, moderate drought, and severe drought resulted in savings of 0.7, 2.26, and 3.36%, respectively. These results help the water supply concessionaire perform a simple measure of pressure-reducing valve installation, reducing water losses, and the pipeline’s rupture rotation operation between the zones.

4.3 Step 8: Conducting workshop 2 with key actors to present the results from modeling, guarantees, and risks

After the plan was developed, the task force presented the DPP to the actors who participated in the first workshop so that they were aware of the modeling results. This is a critical step of science translation and must consider the willingness of the actors to adopt the modeling results or not. The results were presented simply by considering the water stocks, drought states, and actions to be taken. Methodological details were presented only if needed, to avoid confusion in technical terms. After presenting the results, participants choose to either use the new proposed drought states or remain with the previously developed states.

Hydrological and hydraulic modeling results to deal with droughts may not be immediately incorporated into institutional and social practices. It is an innovation that promotes changes in information systems, especially in the knowledge and modus operandi generated by applying this methodology. The changes need to be relevant for those who make the decision, legitimate for those who participate in the process, and credible for managers, technicians, and other social agents. This will result from the maturation and recognition that the methodology provides risk reduction by promoting adaptive management guided by the logic of proactivity when drought occurs.

In addition, the detailed measure spreadsheet is discussed again to avoid any misunderstanding of what, where, when, how, and by whom the measures should be taken when the drought states are triggered. This spreadsheet, in conjunction with reservoir monitoring and drought states, consists of a decision support system that helps system operators to mitigate drought effects during future events. With clear rules on what to do and when, it is easier to act and reduce drought impacts.

4.4 Step 9: Final socio-technical DPP with modeling-intensive simulation

After the plan was approved in the second workshop, the DPP was considered complete. DPP must be publicized, so all actors can have access to it and demand its implementation. It is water management agencies responsibility to store, publicize and implement the plan when it is needed. DPP acts as a tool that changes the initial balance of decisions when drought occurs. There is now a concrete parameter of decisions that must be taken and their non-compliance can be enforced through formal channels.

The broadening of participation is related to the creation of plural public spaces and the recognition of local social capital. The meetings sought to provide an opportunity to deepen the discussions regarding vulnerabilities previously identified through the creation of ideas, face-to-face interaction among participants, and the collective construction of proposals for actions whose meaning, and importance are shared and validated by the public involved in the activity. This is the construction of a collective agreement that incorporates the participants’ tacit knowledge. It also combines it with technical knowledge to build a participative drought plan, whose planned actions are adherent to reality while recognizing
the particularities of the places and people who live or work in these hydrosystems and cities.

5 Discussion

The purpose of DPPs is to reduce drought impacts by identifying activities, groups, or regions most at risk and presenting mitigating actions and programs to ease these vulnerabilities. This tool is expected to reduce vulnerability as more coordinated and effective measures can be taken. There is a brief window of opportunity between the end of an event, when all the knowledge regarding the drought impacts is available and the actors are still active, and the “apathy stage,” when the water reserve returns to normal (Wilhite 2000). During this window, engaging with local stakeholders to preserve the memory of drought conditions is essential to better manage future events.

Participation is a relational concept with several adjectives that represent methods of integrating individuals into society. The use of expressions such as social participation, political participation, citizen participation, community participation, and participatory democracy, among other adjectives, refers to the concept of social action performed by agent intentionality (WEBER, 1999). These agents are mobilized by actions in the field of public policies or by engaging in social movements to participate in specific processes to fight for recognition, guarantee rights, and assume joint responsibility with the state when establishing and approving rules regarding the use of certain common goods.

In Brazil, the channels for dialog with society to enable participation in certain arenas that debate the implementation of public policies were strengthened at the end of the 1980s, with the promulgation of the 1988 Federal Constitution and the National Water Resources Law. This law is based on an articulated tripod: integration, participation, and decentralization. Therefore, collective construction of water resource plans as part of a social pact is relatively new in Brazil. Considerable progress has been made in this regard. The transformations that have occurred in Brazil in recent decades have also changed the modes of water resource management.

The selection of actors involved in the DPP must recognize the existing institutional framework and value basin committees. Since the formulation of the current water law in Brazil (9.433/97), the principal challenge has been the creation of mechanisms to coordinate actions and bring civil society and the private sector into the decision-making process (Abers 2007). The river basin committee was created to stimulate discussions and participatory decisions. These committees are composed of federal, state, and municipal government representatives; civil society entities; and water users. The river basin committees are well-structured, and actors continue to participate in meetings nearly 25 years after implementation. This commitment is especially true in regions where water conflicts frequently emerge, such as the study region. This long history of the river basin committees created a complex social network with the intra-relations between segments and the inter-relations between the basin committees and other entities of the water management system (Ribeiro et al. 2012).

Despite advances in water governance, power inequalities remain, and some major decisions may be completed outside these deliberative bodies (van den Brandeler et al. 2014). A lack of understanding of the water management system and limited technical knowledge by committee members weaken the exchange of ideas and the fair balance of members’ participation (Matos et al. 2022). Thus, social actors who directly experienced the systems’
operation should be invited. In hydrosystems, the list of participants can be similar to those used for river basin committee meetings, by bringing government representatives, civil society, and local water users together. Additional consideration must be given to the water supply systems in cities, where system operators can be critical water management components.

The success of implementing the DPP in the next drought event is related to local people’s appropriation of the measures and actions proposed. The implementation and monitoring process considers the collective construction of the plan in a participatory manner, recognizing their social capital, and validating and evaluating its operational model. When a new drought event occurs, a local task force should be formed, preferably including the actors participating in the development plan. Actions should be executed based on the triggers and measures established in the plan. The local task force must base the frequency of their meetings on the drought severity and intensity of the different users’ conflicts. In addition, a meeting should be held if monitoring changes in the drought state. In these meetings, actors must verify the measures to be taken and those responsible for them. It is important to remember that the residents are the owners of the DPP. They have planned actions that adhere to their conditions, recognizing the particularities of their sites and the residents.

After each drought episode, new experiences were incorporated in the plan. The goal was to preserve the memory of drought conditions. What is desirable is a continuous planning process, rather than just an immutable document. The preservation of the memory of drought conditions and efficient organizations and strategies must constitute the drought management cycle. A workshop should be conducted to update the measures and actions defined in the plan. This workshop should occur via meetings using an expository dialog, which will favor the continuous evaluation process. In addition, it will facilitate the verification of the efficiency and effectiveness of the plan and enable institutional learning and strengthening.

6 Conclusions and lessons learned

To cope better with drought, it is important to improve risk management strategies. A method to manage the negative drought effects is to eliminate the reactive paradigm, with its poorly coordinated and untimely measures, and increase efficiency and effectiveness by transitioning toward a proactive approach. Appropriate drought management should be based on reactive, preventive, and adaptive measures. A proactive drought management plan is a tool that may reduce drought impacts and is supported by an early warning system. The challenge for creating such a plan is to engage local actors in retrieving their knowledge regarding past management of previous events and their experience of what functioned satisfactorily compared to what did not.

Here, we propose a framework for involving local actors who are familiar with the water systems and encourage them to take ownership of the planning phase. As noted during the DPP construction using the proposed methodology, there is initial skepticism regarding the importance of such a plan, especially in a region where other planning instruments have been utilized recently. Clear boundaries and relationships between the current plan under construction and other existing plans, such as the water resources basin plan or a drought plan of larger scales, should be initially established.
In addition, the task force charged with formulating the plan must understand that there are knowledge gaps affecting task force members and local actors. Social learning processes must be used to obtain essential and valid knowledge from these actors. Even more important than incorporating this information is empowering the actors take ownership of the plan’s construction. When a new drought occurs, the actors must realize that implementing what has been planned is practical and effective.

The selected key actors who participated in the plan’s construction will have the DPP as a guide to be implemented during future events. The capacity to anticipate actions is fundamental to avoiding system collapse and can be the most significant advantage of such a plan. The explicit role of each institution expedites decision-making and avoids the necessity of finding new consent during crises. Drought knowledge, which was first only in people’s minds, is now documented at the DPP and can be accessed by anyone. Therefore, the memory of drought conditions is preserved, and the region has a new level of preparedness for future drought events.

The task force had the impression that the workshop participants gained significant ownership of the DPP. The success of the DPP implementation depends on local stakeholders, and the best method to ensure this ownership is to engage actors at all planning stages to enable them to understand that they are co-authors of the plan and not just sources of information. After the occurrence of a new drought, each region should analyze its own experience and share it with other areas to systematically mitigate the effects of future droughts.

The proposed methodology was applied to a basin that recently faced severe drought. The basin’s users have learned many of the system’s fragilities. The users know what actions to take specific situations. These measures were at risk of being lost over time as people retire, move, and die. Future drought events will occur in the region at an unknown time. Now that the DPP has been formulated, the region is well prepared for future drought events.

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Declarations

Conflicts of interest The authors declare no conflict of interest.

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