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Chapter 13

Water allocation in Brazil: main strategies, learning and challenges

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ABSTRACT

Brazil is characterized by highly diverse biomes, hydrologic regimes and water uses. The relevance of irrigated agriculture in the county's economy, combined with the significant contribution of hydropower to the electricity matrix and the presence of large metropolitan areas translate to a strong water-food-energy nexus. Water management under this context requires control and allocation in an extensive network of long rivers, operated with seasonal and multi-year carryover capacity. The future development and overall water security in Brazil will bring increasingly competing demands and growing challenges to water allocation, demanding more robust regulations and institutions. This chapter reviews the nature of Brazilian water rights and the current legal and policy framework determining water allocation, followed by the presentation of several innovative initiatives to control water access, based on locally defined allocation rules and local needs, challenges and opportunities. From this rich experience, we draw recommendations on how to move forward in improving water allocation strategy at the national level and adapting water management practices to cope with the challenges ahead.

Keywords: Stakeholder's engagement, water allocation, water resources management, water rights

13.1 THE BRAZILIAN CONTEXT ON AGRICULTURAL WATER USE: SUPPLIES AND COMPETING DEMANDS

Agricultural production in Brazil has supported an active agribusiness sector, contributing to 10% of the Brazilian GDP, 137 USD billion (10^9) in annual revenues and 15% of the industry jobs (FGV, 2016). This is due to several factors, including mechanization, crop and soil research, access to credit and irrigated agriculture.

The irrigated area has increased over 4% annually since the 90s, reaching 8.2 million hectares in 2019 (ANA, 2021a), which represents 12.36% of the total 66.32 million ha crop-planted area (EMBRAPA, 2022). It currently represents 46.2% of the total withdrawals in Brazil estimated at 2098 m^3/s, and 67.2% of the total consumption (1109 m^3/s). Urban supplies and industries are next, with 23.3% and 9.2% of the withdrawals and 8.8% and 9.5% of the consumption, respectively (ANA, 2017b). Ecosystem water demands are still largely unknown and mostly marginally met with minimum flow requirements. Recent studies (Marques & Tilmant, 2018; Dalcin *et al.*, 2022) indicate that restoring key components of flow regimes will require better knowledge of the trade-offs to other sectors, to support negotiation and water allocation solutions.

Despite its relatively small participation in the total crop area, irrigated agriculture plays a key role in terms of food security. Among all crops, the grains that constitute the staple food in Brazil (rice, beans and wheat), when irrigated presented productivity from 1.9 to 3.7 times the productivity of the non-irrigated areas (ANA, 2021a).

Recent estimates point to an *effective irrigation expansion potential* of 13.1 million ha, of which 4.2 million ha is expected by 2040 (ANA, 2021a). This is likely to reinforce tensions with competing uses (e.g. urban) and increase pressure on aquatic ecosystems, which are already suffering from insufficient minimum flows. An increasingly higher number of municipalities across the country is expected to either boost withdrawals from existing supply sources or find entirely new ones.

Rainfall, flow patterns and water availability vary greatly across the country. Around 80% of the available surface water flows in the Amazon basin, where the population is the smallest (ANA, 2017a). In terms of groundwater, 90% of the Brazilian rivers are fed by base flow from aquifers, which maintain surface waters during the dry seasons (ANA, 2017a). While the total groundwater annual average availability is estimated at 13,205 m^3/s, the aquifer systems in sedimentary basins provide the highest storage potential, covering 48% of the Brazilian territory. This resource is increasingly exploited: from 145 thousand registered groundwater supply sources in 2008 (most are groundwater wells) to approximately 2.6 million wells in 2021, extracting 1083.3 m^3/s (ANA, 2021b). Figure 13.1 presents the major Brazilian watersheds and hydrolithology groups.

Water management in this context requires water control and allocation in an extensive network of long rivers, operated with seasonal and multi-year carryover capacity. The future development of irrigated agriculture, power supply, environmental protection and overall water security will bring increasingly competing demands and growing challenges to water allocation, demanding more robust regulations and institutions. Most of those challenges are associated with four main elements.

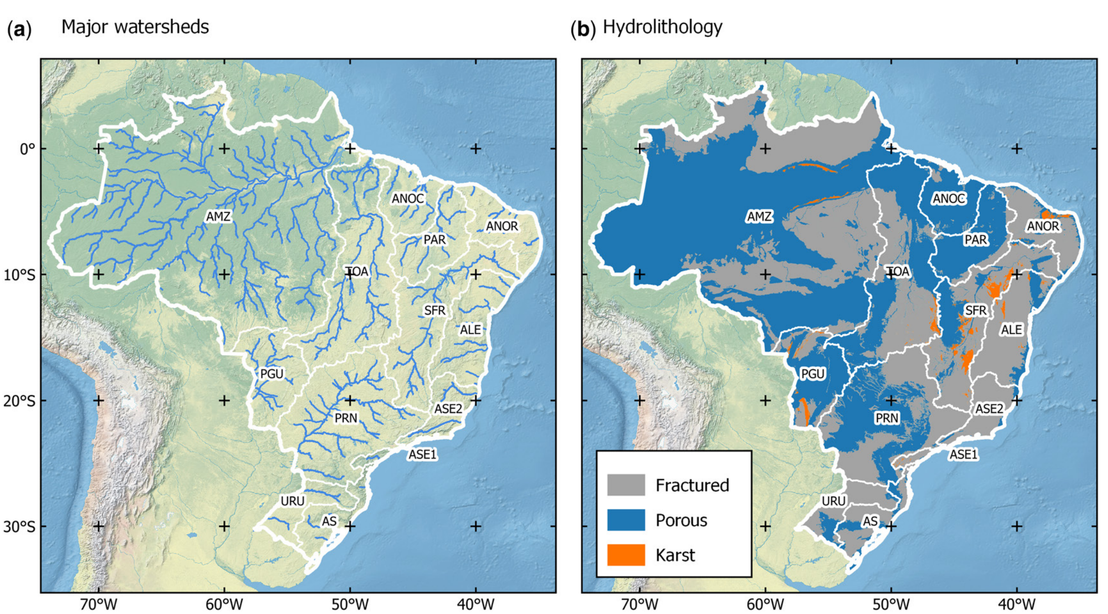

Figure 13.1 Major Brazilian watersheds and hydrolithology groups (source data: Brazilian Geologic Service – CPRM).

The first is the lack of a widespread long-term strategic approach to water allocation mechanisms. Implementation of water allocation policies, with more elaborate criteria for inter- and intra-sectoral water allocation, is the exception rather than the rule (OECD, 2015), as the proper institutional arrangement for this negotiation is insufficient, and the knowledge about the allocation trade-offs is lacking. This is aggravated by the large gap between water management in the state and federal rivers. If water is not properly regulated at the state level, it becomes difficult to account for its availability in the federal rivers. While recent procedures for formal water regulatory agreements (*marcos regulatórios*) and water allocation agreements (*Termos de Alocação de Água*) have improved this aspect, these have been mostly deployed as problem responses.

Second, the negotiation regarding water quantity and quality expected to flow from state to federal rivers is beyond the capability of most current watershed committees, which often have limited implementation capacity due to lacking technical support for such a complex engagement. The determination of boundary 'delivery' agreements (*condições de entrega*) is a fundamental water allocation decision which has yet to be addressed by the Brazilian water resources management framework, except in specific cases responding to local problems.

Third, water allocation must be brought up to sectoral policymaking at nationwide scale, to coordinate large-scale investments (e.g., irrigation, energy and infrastructure).

And fourth, climate change impacts will differ, depending on each region's characteristics and infrastructure. Different coping and adaptation strategies to mitigate the climate impacts in one water use may adversely reflect on others.

This chapter reviews the nature of Brazilian water rights and the current legal and policy framework determining water allocation, followed by the presentation of several initiatives to control water access, based on locally defined allocation rules and accounting for local needs, challenges and opportunities. From this rich experience, we draw recommendations on how to move forward in improving water allocation strategy at the national level and adapting water management practices to cope with the challenges ahead.

13.2 THE NATURE OF BRAZILIAN WATER RIGHTS: PAST AND PRESENT

While past water allocation initiatives in Brazil differ greatly, including informal water markets in the Northeast dating back to 1855 (Campos *et al.*, 2002) and water ditches societies (*associações de vala*) organized by rice farmers dating back to 1927 (Liberato Jr., 2004), the State interfered very little in water allocation until 1934.

State-driven hydropower projects in the 1930s called for formal water regulation to secure reliable supply to the hydropower reservoirs, leading to the 1934 Water Code. This legal milestone formalized the first water allocation system with the public sector controlling an authorization process to grant the right to use water to specific users (Brasil, 1934; Carvalho, 2015). The 1934 Water Code distinguished public waters of common use, which could be property of the Union, the states or municipalities, and private waters, which belonged to the owners of the land on which they were located. It also warrantied access and free use to common waters for basic human needs. Groundwater could be appropriated by the owner on whose land the source was located, provided its use did not interfere with other public and private waters (Brasil, 1934). While the Water Code established fairly advanced concepts for its time, alluding to common water benefits and recognizing the impacts of private uses on others, it was a top-down, sectoral approach, detached from other public policies and focused on preserving the economic potential of the water resources, with environmental considerations mostly absent.

As the Brazilian industry expanded, hydropower systems became interconnected in the 70s and 80s, highlighting the temporal aspects of water allocation (Lopes & Freitas, 2007), and demanding water use and reservoir operation optimization integrated with flood protection. The result was the establishment of minimum flow requirements downstream of federal and state reservoirs and water quality standards with improved regulation of environmental laws in the 80s, which indirectly established environmental water allocation. Given that water scarcity and conflicts were not significant at this time, this was largely uncontested by other users.

The Brazilian Federal Constitution of 1988 provided another milestone, defining water as a common good belonging to the people, to serve public interests (Brasil, 1998). It established the water permits as key instruments to water allocation and management, as well as extinguishing the concept of private waters and the municipal water domains from the 1934 Water Code. After this change, water could be either federal or state domain, and previous private users (e.g., farmers, industries, etc.) had to apply for a permit to maintain access. While significant from a legal standpoint, this change did not bring major contestation from the users. Large water uses (e.g., hydropower) already had formal concessions and maintained access to water. Smaller users applied for permits, which were granted in most cases given the competition for water was not as intense as it is today. However, there were cases where users resorted to legal action to seek compensation.

However, water allocation remained essentially centralized, in a top-down approach controlled by state and federal water authorities. Later, the Brazilian National Water Resources Policy (Federal Law 9433/97) initiated a transition towards more decentralized water management, relying on new organizations, including a National Water Council, State Water Resources Councils, River Basin Committees, State Water Resources Authorities and Water Agencies, drawing inspiration from the French experience and example (Laigneau, 2011). The Federal Law 9433/97 further defined water as a public good. The water permits, along with water charges, watershed plans, water quality standards and water information systems were formally described in the law as water management instruments. An important component in this organizational framework was the formalization of River Basin Committees, with key roles in exercising participative and shared negotiation for water management and conflict resolution (Veiga & Magrini, 2013).

The responsibility for water allocation and management is defined through two different domains: the state and the Union. Public Water Resources Authorities (both at the state and federal levels) are responsible for controlling and registering the water uses permits. Rivers and lakes entirely located within a single state belong to the domain of the corresponding state. Rivers and lakes crossing more than one state, or which form the boundary with another state or country, belong to the domain of the Union. All groundwater is state domain. Waters stored in instream reservoirs built by the federal government are considered federal waters, regardless of the river (state or federal). This shared jurisdiction of state and federal waters is a challenge, as it requires high levels of institutional coordination and decision-making between users and public agencies, often lacking in Brazil (OECD, 2015).

13.3 LEGAL AND POLICY FRAMEWORK TO CONTROL ACCESS TO WATER (GROUND RULES)

13.3.1 Permits and concessions

The formal water allocation process defines water permits and concessions ('*outorgas*' in Portuguese) established by Federal Law 9.433/97. Permits are issued to private users and renewed every 5–10 years (depending on the state). Concessions are issued for public water use (i.e. public utilities and urban water supply systems) and are renewed every 10–12 years. Other concessions, such as for hydropower use, may last up to 30 years. Users submit a withdrawal request to the corresponding Water Resources Authority (state or federal). The request specifies the flowrate and the number of withdrawal hours for each month, followed by the total requested volume each month. Criteria for monthly volumetric caps are based on reference flowrates, which vary across state and federal rivers. The request is usually processed by filling order. Once approved, the permit is capped by the total monthly volume described in the request.

The Water Resources Authority is responsible for maintaining an information system with user and water availability databases to determine if new requests can be accommodated, following general criteria of water availability and request filling order (first come, first served). Water uses considered 'insignificant' (often less than 1 L/s for domestic and animal supply) are exempt from approval, but still require the user to register the use in the database.

While this flow-based allocation procedure is the same throughout the country, specific criteria applied to evaluate the requests are defined by the corresponding River Basin Committee and Water Resources Authority. The River Basin Committee defines the priority water uses, the water quality standards and the insignificant water uses, along with other uses exempt from formal permitting. Priority water uses are defined between sectors only, and often only establish that domestic (human consumption) and small-scale animal consumption come first.

A water permit can be indefinitely suspended, totally or partially and without liability to the public authority, in cases of:

(i) Non-compliance from the user on the water permit terms.
(ii) Water not being used for three consecutive years.
(iii) Water being needed to meet other priorities or under calamities caused by adverse weather conditions.
(iv) Water being needed to prevent or revert severe environmental impact.
(v) Water being needed to maintain navigation conditions.

13.3.2 Issuance of permits for surface water

Withdrawals taking place in a flowing water body are based on a reference flow (flow with a chosen exceedance probability, e.g. Q_{90}), established by the Water Resources Authority, which will be used to calculate the maximum permissible flow rate that can be allocated. The reference flow varies according to the state. Very often, only a fraction of the reference flow is available for allocation so that minimum instream flows can be met.

Finally, other criteria may include an evaluation of the degree of commitment of the waters in the river and the impact of the requested flow relative to the availability (e.g., indicators of the ratio between the user-requested flow and the maximum permissible flow rate or the ratio between all current uses and maximum permissible flow rate). Basins with a very high commitment may go into a 'closure' state, where permits are no longer issued, prompting action for conformity from users.

The Water Resources Authority receives the request and calculates the water budget based on the allocable fraction of the reference flow, subtracting existing permits upstream of the request and checking on existing permits downstream, resulting in the maximum permissible flow rate. The criteria for water permitting are then applied to decide if the permit is approved or denied. For example, a River Basin Committee may determine, in the watershed plan, that new water permits should be restricted if the degree of commitment reaches a critical status. However, very often the water budget is the sole criterion and if the maximum permissible flow rate is larger than the flow requested, the permit is approved. Permits due for renewal take priority over new requests.

If the withdrawal takes place in a surface reservoir with carryover storage, the maximum permissible flow rate is the regulated flow (ANA, 2011), provided the reservoir releases are also able to meet the minimum instream flow to downstream in case of perennial rivers. If the river is intermittent, the allocation can also be volumetric.

13.3.3 Issuance of permits for groundwater

Allocation of groundwater is conducted by the state Water Resources Authority, which defines the criteria to issue pumping and withdrawal permits. User engagement in this process has been essentially reactive and conflict-driven, often taking place in severe cases of interference of pumping in local surface water sources or in other wells. Afonso and Junior (2006) present one example of conflict between irrigators in the state of Minas Gerais in 1991, where small-scale, river-fed, downstream irrigation was affected by intense groundwater pumping upstream. Such cases are managed by the

State with either suspension of some of the water permits or change in the regime of use (e.g., reducing the number of hours of pumping and increasing the interval between pumping operations). Such cases are often started when impacted users formally complain to the State (or the police), which prompts the state Water Resources Authority response. In some cases, a solution is found and users comply, while others end up in court.

To withdraw water from a groundwater source, the user fills out a request with information about the source conditions, including flow measurement during the dry season (performed by the user), hydrogeological characteristics of the well and pumping tests (in the case of wells equipped with pumps), among others. Caps on allowable pumping rates vary depending on the state. Other criteria include analysis of interference in nearby wells, aquifer vulnerability, proximity to other water bodies (e.g., rivers and streams) and environmental protection areas. However, there is no water balance analysis to allocate groundwater, mostly due to lack of information on recharge rates, regional groundwater use, storage capacity, fluxes and surface water interaction, which increases the risk of overallocation. Recent large-scale groundwater study projects are under way to support regulation of allocating ground and surface water between different states.

13.3.4 Regulatory agreements

In regions with very limited water availability and potential water conflicts, the government established regulatory agreements, which define specific water use ruling and are implemented after a negotiation process involving the Water Management Authority and stakeholders. Such ruling may define specific priorities for water permits, minimum efficiency levels for each user sector, adjustment on irrigation schedules, water use restriction based on specific water levels on rivers and reservoirs, maximum allowable flowrates for each user sector in different watershed regions, limits on water storage for new infrastructure, water quality targets and other criteria for water permits (e.g., renewal criteria) (ANA, 2016). The process to reach a regulatory agreement can be initiated by either the users or the Water Management Authority, often in response to water conflicts and crises. It starts with the identification of the water problem (e.g., a conflict), its hydrologic conditions, the users involved, the probable causes (e.g., limited water availability, low efficiency, water quality constraints), the problem time frame (e.g., permanent, cyclical or based on a critical event) and delimitation of the affected water system (ANA, 2017b). Alternatives to solve the conflict are discussed and selected, also considering the watershed plan. A legal document formalizes the multilateral agreement to implement the solution. Finally, monitoring and overseeing of system status are implemented, to re-evaluate the regulatory agreement and make adjustments as conditions change. Examples of alternatives include different scenarios to redistribute the water, capping withdrawals and constraining cropping areas. A recent regulatory agreement in the Brazilian Midwest capped the irrigated acreage in two different states sharing a river and established a minimum flow from one state to the other (ANA, 2010).

13.3.5 Strength and weaknesses of the current permitting regime

Overall, the flow-based allocation system based on water permits provided better control of the water and reduced the possibility of overallocation, which contributed to increasing reliability to existing users compared to the past where regulation was mostly focused on larger scale economic uses (i.e., hydropower).

However, it still suffers from several weaknesses (Spolidorio, 2017):

- No flexibility to accommodate local seasonal hydrology variations.
- Groundwater allocation is not addressed.
- Inadequate during droughts, when water availability may be less than the reference flows.
- More water than needed requested by users.
- Users fail to request cancellation of the water permit when the water use ceases.
- Permits are rarely reviewed or updated, unless under critical events.

By allocating only a flow with high exceedance probability, the chances of a conflict between users with water permits is reduced, at the expense of the flexibility to accommodate new users. Considering the reference flows commonly adopted in Brazil, at least 90% of the time there are flows in the water bodies that are not allocated, which has been long criticized by users.

Finally, water permits and allocations disregard the impact of present decisions on future water demands and availability, having little connection with other development policies and even water management instruments, such as the water resources plans (Dalcin & Marques, 2020). The large number of users, many using water without permits, combined with limited oversight and monitoring by the Water Management Authorities, leads to error in determining available water for new permits, reducing reliability and trust. For Lopes and Freitas (2007), the public authorities still take a lead in managing the water allocation mechanisms. While this increases the guarantees to existing users, it also hinders the development of local control and user participation, increasing the costs of oversight.

13.4 DEFINING WATER ALLOCATION MECHANISMS: MAJOR CATEGORIES AND EXAMPLES

As water problems evolve, the limitations of the simple criteria adopted in the ground rules become more evident, prompting user engagement to propose other mechanisms. These complementary allocation mechanisms, however, do not necessarily replace the ground rules, but rather present solutions to allocate water under more specific conditions or problems (e.g., temporary droughts, permanent scarcity and intermittent water availability, conflict areas). The emerging institutional arrangements vary depending on the region's social capital, local history and challenges. This section presents the complementary allocation mechanisms, illustrated by examples selected based on their innovative approach. The mechanisms are organized as different types, based on the temporal characteristics of their context in Brazil.

13.4.1 Collective water permits

The effective implementation of the ground rules requires a very organized water management framework to register, track and engage users, detect non-compliance and to elaborate and update hydrological studies in the watershed. Not all Brazilian states have a fully functional system, and the most common gaps are incomplete water user databases. As a result, having users operating without permits is not uncommon in some watersheds. To enforce compliance over a river reach, collective water permits are established. Within this mechanism, the permit request lists all users, irrigated area, pumping coordinates and flow rate pumped.

In the example of Rio Grande do Sul state, collective irrigation water permits are requested through the River Basin Committee to the state Water Resources Authority, as in the recent example of a collective permit for rice growers in the Sinos River Basin (DRHS, 2021). The Water Resources Authority verifies the request against the maximum permissible flow rate and, if there is not enough water to fulfill the request, it is returned to the River Basin Committee for user negotiation and adjustment. Once an agreement is made, a new request is submitted and approved.

More recently, an online water permit (http://www.siout.rs.gov.br) system has been implemented in Rio Grande do Sul, integrating a mapping system with hydrology and water users' databases, where each user can individually fill out a request and immediately check his demanded flow against the maximum permissible flow rate at the withdrawal's location (the system performs the water balance considering existing registered permits upstream and downstream). The Water Resources Authority in the state of Rio Grande do Sul is phasing out the collective water permits and transitioning to individual ones through the online system

13.4.2 Long-term, cyclical allocations for reservoir operations

In the challenging climate and hydrological conditions faced in the Brazilian Northeast (NE), water supply depends largely on how the reservoirs are operated, as there are no additional inflows during the dry season (which lasts 9 months). To avoid conflicts and maximize water supply, several institutions are involved in water management and allocation, including a State Secretariat of Water Resources, a State Water Resources Policy (Brasil, 1992) and a state Water Resources Authority (COGERH). This institutional arrangement formalized water allocation procedures that are cyclical, with great attention on how to operate the system and share the released waters every dry season.

Users' participation occurs within the River Basin Committee, responsible for deliberating on criteria for water permits, reservoir releases, execution of new water infrastructure, water charges and how the available resources should be invested in the watersheds. In addition, Reservoir Operation Committees are involved for final validation of reservoir releases, and a users' overseeing committee monitors the implementation of the agreement throughout the dry season.

The general procedure for water allocation is based on evaluation of current storage after the wet season, followed by a series of Reservoir Operations Planning seminars. In the latter, users are presented with simulations of reservoir depletion scenarios and discuss release solutions, negotiating water allocation. Once agreement is reached, reservoir releases are determined for the coming dry season and a formal document is signed by users. During the dry season, reservoir depletion is monitored. If drought conditions are worse than expected, the user committee discusses further changes and water is allocated proportionally to their original shares, with urban/human demands taking priority (Silva *et al*., 2006; Pinheiro *et al*., 2011).

This allocation process has been under constant improvement and reservoir releases have been reduced throughout the years (1998–2005), despite growth in population and irrigated areas. According to Silva *et al*. (2006), this reflects increased rational use and public awareness. With smaller releases, there is a higher safety margin and reduced risk in managing the available water stock. Despite this favorable result, there is a need for constant oversight, especially during droughts, when some users may avoid the negotiation process and resort to illegal damming of upstream waters (Pinheiro *et al*., 2011). In those cases, COGERH has a role to help ensure compliance, and enforcement is carried out by the State.

13.4.3 Short-term, event-based, water allocation mechanisms

Events such as droughts and conflicts trigger adjustments to permit conditions, which can be initiated by users or the Water Resources Authority. In any event, water allocation is negotiated among users and a solution is presented to the Water Resources Authority. The adjustment is temporary, lasting from a few weeks to 18 months. Permit conditions prevail afterwards. In this section we present several examples taking place in different Brazilian states involving allocations to agricultural irrigation.

13.4.3.1 Collective flow rate caps

In the state of Minas Gerais, watersheds with combined demands surpassing the maximum permissible flow rate are declared conflict areas by the state Water Resources Authority. This condition may be detected during the analysis of a water permit, and it may be caused by excess unregistered (illegal) uses. Once a basin is declared a conflict area, the River Basin Committee facilitates user negotiation around the distribution of the available water, so that the maximum allowable flow rate is met. A Local Management Committee is created, with representatives from the affected river reaches. This is a smaller user group drawing inspiration from the French *Commission locale de l'eau* (CLE) to negotiate the withdrawal adjustments. Private consulting is hired by the group to provide technical assistance, and users have equal contribution to the discussion regardless of size or economic power and a full agreement must be reached.

The agreed solution is formalized into a collective water permit request submitted by the River Basin Committee to the Water Resources Authority, which oversees implementation. The state Water Resources Authority is empowered to determine a solution if users cannot reach an agreement. The objective of the negotiated allocation process is to meet economic, social and environmental needs and mitigate occurring conflicts. The proposal must include (SISEMA, 2015):

(i) A technical study of water availability in the area, organized by the Local Management Committee.
(ii) Criteria to define priority withdrawals during severe scarcity.
(iii) Criteria to implement rational water use, considering available technology.
(iv) A schedule to alternate withdrawal pumping.

A second example of this mechanism includes several watersheds in the Federal District (DF) region. The first initiatives took place in the Extrema watershed, when the Water Resources Authority (ADASA) detected violations of minimum instream flows during the 2016 drought. Meanwhile, large-scale irrigators discussed how to minimize and distribute economic losses through water sharing. Users realized that without a mutually agreed solution, they would be unable to secure enough water to irrigate the crops and comply with minimum flows.

ADASA organized users into three groups, based on irrigated area, which would alternate pumping and irrigation schedules in order to maintain the original water permit flows. Users would determine how the schedules would be organized, without ADASA's intervention, resorting to mobile phone message groups to rapidly communicate and adjust pumping schedules. The negotiation and allocation processes were legally formalized in ADASA (2017) with a regulation decree, followed by specific water allocation agreements (*Termo de Alocação de Água)*. By 2017, as hydrological conditions worsened, it became necessary to also reduce the water permit flows and the cropping area. The reduction in irrigated area was based on individual planted areas and determined by users. According to Maniçoba (2021, personal communication), despite some initial resistance from the farmers, a relationship of trust was built along the process, which was key to its effectiveness.

Other initiatives took place in Alto Rio Jardim and Pipiripau watersheds and started back in 2006. The Pipiripau watershed has 71% of its area irrigated, mostly with small-scale agriculture that is more vulnerable to drought, also being responsible for urban water supply downstream. With significant growth of both agricultural and urban areas, water demands surpassed local availability during drought events, resulting in water shortages to urban areas downstream.

Increasing water scarcity led to the issuance of Water Regulations (ADASA, 2006; ANA, 2006; ADASA, 2017) that formalized water allocation regime during droughts. The Water Regulations defined control points in specific river reaches, minimum flows at each control point and water uses exempt from permits. Water Allocation Follow-up Commissions were created for each river basin, with representatives from users, national, state and municipality public power and a state technical agricultural support institution. Each Commission meets monthly, discussing current water availability, proposing actions, and proposing strategies to optimize allocations. Allocation decisions are made by consensus or simple majority, and the results formalized into water allocation agreements (ADASA, 2021). This document informs the current hydrologic state and the flow cap (for each control station), along with the pumping schedule for each user. If users cannot reach an agreement, the state Water Resources Authority intervenes (ADASA, 2020).

As a general rule, agreements require that users adjust withdrawals proportionally to the irrigated area whenever flows reach the minimum limit at the control points. During the 2017 and 2019 dry seasons, users implemented water pumping schedules to avoid concentrated pumping, but also curtailed irrigation withdrawals and reduced the crop area. This maintained the required downstream flows to meet urban demands while minimizing the impact to production. The local water public utility also implemented a water rationing schedule for urban users.

A major improvement over the recent experience by the Extrema watershed was a new real-time supervisory system to monitor individual irrigation systems, built and maintained by the farmers. Full access to the system was given to ADASA and the other users in the watershed. Any off-schedule pumping was detected and adjustment requested. Despite this, very few schedule violations were verified and ADASA's intervention to enforce the schedule was not necessary. For Maniçoba (2019), the acceptance between farmers was very good, and communication was also improved.

The experience in Pipiripau and Alto Rio Jardim further refined the allocation mechanism (ADASA, 2017, 2019), separating the user groups based on crop types (perennial or annual), crop water consumption, management and number of harvests per year. Water balance was improved at the watershed level, which benefited from the new real-time supervisory system.

13.4.3.2 Individual, compensated caps

A severe drought in 2001 in the Ceará State (Brazilian NE) triggered the design of a temporary water allocation mechanism which included a form of economic compensation to reduce water demand. The region's 19 000 hectares of irrigated land includes high water demand annual crops (taking up to 55% of the irrigated area and 71% of the total water demand) and perennial crops (taking up 16% of the irrigated area and 12% of the total water demand). According to Oliveira (2008), 70% of the irrigation uses furrow methods, with efficiencies ranging from 60% to 70%, which contributes to a high water demand given that the region is semi-arid.

As the drought event lowered local storage, releases were prioritized to meet human and livestock demands. Only 50% of the total irrigation demand was met. The severe conditions led the National Water Agency (ANA), along with the state government, to propose an emergency irrigation water use plan, the '*Aguas do Vale*'. The main objectives were to (a) improve the water management through higher irrigation water use efficiency, (b) induce more efficient irrigation practices and shift to crop mixes with lower water demand and higher value and (c) bring the water balance to an equilibrium (Oliveira, 2008).

Aguas do Vale also aimed to motivate a crop mix change through economic compensation mechanisms. While annual crops (e.g. rice) consumed 16 670 m^3/ha with an average return (All dollar figures are 2001 values adjusted for inflation to 2020.) of \$0.051/m^3, permanent crops (e.g., melons) demanded 5000 m^3/ha with an average return of \$2.19/m^3 (SRH & SEAGRI, 2001). The plan would target rice planters to reduce demand, allowing the flow to be allocated to higher value/lower water demand perennial crops.

Joining the program was voluntary, and the execution did not involve a direct negotiation between users to determine the flow allocation and compensation value. A rice planter willing to join would fill out a request for a water permit to irrigate his land to full demand, followed by a secondary request to forgo part of the water and fallowing 50% of the planned rice area in exchange for compensation. A requirement was to join a training program on efficient water use and irrigation management. Compensations ranged from \$292.4 to \$438.6/ha to the rice planters, depending on farm size (smaller areas, up to 2 ha, received \$438.6/ha while larger ones, above 100 ha, only received \$292.4/ha). Variables including historical rice prices, yields and average revenues were used to calculate the compensation values. The Federal Government and the Ceará state treasury provided the funds for the compensation mechanisms, which included water charges paid by the water users (OLIVEIRA, 2008). Resources from the water charges in the Jaguaribe River Basin also supported the Plan. After the drought, the program ended, and users returned to their original permit conditions.

The outcome was successful in the short term: the rice planted area was reduced from an original 8370 ha to 637.6 ha in 2001 and 1936 ha in 2002. This significantly reduced the water demand in the period, allowing reservoir releases to be minimized and allocated exclusively to human and livestock uses, while available groundwater was shifted to irrigate higher value perennial crops.

13.5 CONCLUDING REMARKS

The different examples presented in this chapter have common traits and challenges, which are useful to guide water allocation in other contexts. The key instruments to the success of allocation include strong user involvement and ownership, in a 'co-management' approach to organize and discuss the problems before formal involvement of the Water Resources Authority. Formal but flexible rules must also be present to guide the user's behavior, as well as developed and easily accessible monitoring and

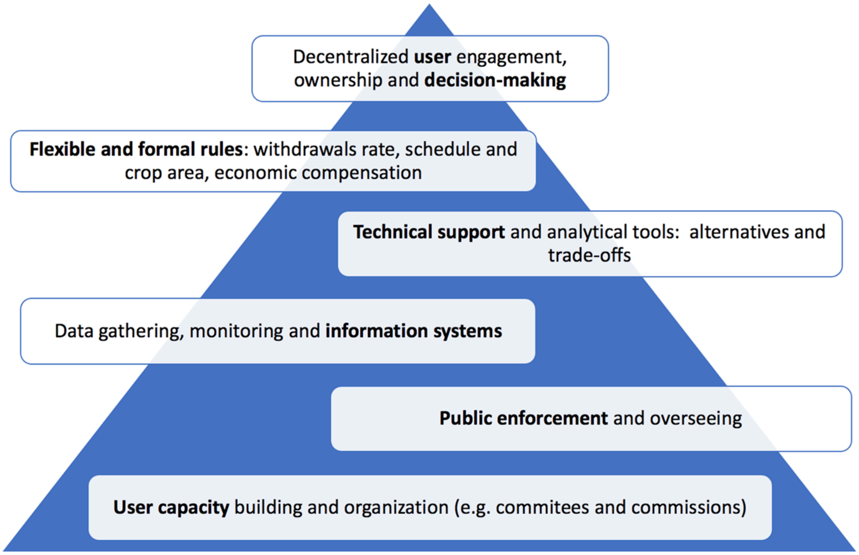

Figure 13.2 Hierarchy of instruments to effective water allocation.

information systems to track conditions and update users frequently, ranging from daily/hourly for short-term drought allocation in small systems, to monthly/yearly for larger ones.

User negotiation and decision-making needs to be supported with analytical (e.g. simulation) tools, to investigate alternative operations and withdrawal schedules, as well as to identify trade-offs between alternatives, including social dimensions. Finally, instruments must be applied in a context of dialogue and transparency among involved parties, as well as proper rule enforcement to build trust. This context requires users' capacity building, so they can understand the actions being implemented and are able to collaborate in the water management process. Those aspects are organized in Figure 13.2.

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