



Methodology for Optimizing Water Use in Shared Management Schemes Under Conflict Conditions

Maria Camila Alves Ramos¹ · Fernando Falco Pruski² · Tarcila Neves Generoso¹ · Eber José de Andrade Pinto³

Received: 21 December 2020 / Accepted: 3 June 2021 / Published online: 19 July 2021
© The Author(s), under exclusive licence to Springer Nature B.V. 2021

Abstract

The granting of permits for the use of water resources has been legislated to ensure adequate access to water for all user sectors. However, this management instrument may not effectively perform quantitative control over the granting process, and permits for flows greater than the water availability may be granted and thus are not always representative of the actual abstractions. Therefore, the present study aimed to develop a methodology to optimize the use of water in shared management schemes under conflict conditions. The proposal is based on the initial evaluation of water availability conditions within a legal plan, in which the flows that consider all uses are associated with the annual run-of-river water availability, and, subsequently, for the segments where the demands are higher than the availability, on the analysis of water availability condition in an operational plan. At the operational level, the demands are characterized by the permitted flows that consider all uses except those corresponding to irrigation activities, which are estimated based on the flows required by the equivalent hectares. In this plan, the availability is considered on a monthly run-of-river basis and with the presence of flow-regulation reservoirs. For the application of the proposed methodology, the Rio Branco basin in western Bahia State is considered. The results indicated that management bodies require extensive knowledge of the actual abstractions corresponding to the permits granted, the potentialities of considering the minimum monthly run-of-river water availability and potential water availability of the basin under regulated-flow conditions, changes in cropping calendars and the use of deficit irrigation under conditions with conflicts over water use.

Keywords Irrigated agriculture · Water availability · Planning and management of water resources · Water scarcity

1 Introduction

Water is an essential element for the maintenance of human life; however, improper exploitation of this resource has necessitated laws and norms for regulating its use to ensure the sustainability of the resource while meeting the demand.

✉ Maria Camila Alves Ramos
mcamilaaramos@gmail.com

Extended author information available on the last page of the article

In Brazil, one great evolution of the institutional model for water resources management was in 1997 with the enactment of the Water Resources Management Law (Elabras Veiga e Magrini 2013), which established the National Water Resources Policy. This policy has as one of its management instruments the granting of the right to use water resources. According to this legislation, the granting of permits is performed to ensure quantitative and qualitative control of the uses of water resources and the effective exercise of access rights to water resources (Brasil 1997).

Despite being enforced for more than twenty years, the process of granting of permits needs to be improved. For example, limiting the maximum permissible flow for a permit to an annual criterion restricts water use in months of greater availability (Oliveira et al. 2013; Silva et al. 2015); and granted flows frequently do not represent the actual abstractions and thus may be underutilized or exploited beyond the amount granted (Piau 2016). The combination of these factors makes it difficult to implement an effective water management plan in river basins, especially in areas with water use conflicts.

In situations in which there is conflict over the use of water, one of the practices adopted is to consider a single permit for all users, who then decide on how the water resources will be shared (Minas Gerais 2019).

Until mid-2018, approximately 67% of total flow of permits estimated for abstractions in Brazil was destined for irrigation (ANA 2019a). The use of water by agriculture is often applied to adjust the total demand according to the existing water availability (HLPE 2015) since irrigation activities have considerable potential to save water by the adoption of rational methods of use (Castro 2012).

The global water demand for all uses will increase by 20% to 33% by 2050 (Burek et al. 2016). The climate change indicating that certain regions will experience changes in weather patterns and the increased frequency of extreme precipitation or dry spells (WBCDF 2014), with progressive decrease in the average annual runoff and changes in the seasonal and interannual variability of watercourses (Garrote 2017). In view of these and other issues, water management for agriculture represents a challenge (Pereira 2017) and the search for planning and management alternatives that have potential in the face of conflict situations is very important. Thus, this study aimed to develop a methodology to optimize the use of water in a shared management scheme under conflict conditions.

2 Material and Methods

The methodology for water use optimization is based on characterizing the water supply and demand conditions within legal and operational frameworks to provide a better representation of the hydrographic conditions, with the goal of attenuating or even resolving existing incompatibilities.

2.1 Legal Plan

A legal plan is defined as the one in which the demand is estimated by the sum of granted flows that consider all the user sectors and the supply is estimated by the annual water availability under run-of-river conditions.

2.1.1 Annual Run-of-river Water Availability

The annual run-of-river water availability represents the maximum flow that can be granted in a watercourse without the presence of reservoirs and corresponds to the minimum reference flow in the segment, subtracted from the percentage of the remaining flow that must be preserved in the hydrographic region.

According to Smakhtin (2001), the minimum flows are defined as a seasonal phenomenon that naturally constitutes the flow regime and are derived from groundwater discharge and surface storage sources.

In Brazil, generally, the variables used to characterize the minimum flow are $Q_{7,10}$ (average minimum flow of seven consecutive days and return period of 10 years) and Q_{90} and Q_{95} (flows with permanence in time of 90% and 95%, respectively).

2.1.2 Granted Flows

The granting of permits is one of the instruments adopted by the National Water Resources Policy to support the management of water resources and consists of the administrative act by which the granting public power (union, state or federal district) gives the grantee (applicant) the right to use water resources for a fixed period under the terms and conditions expressed in the respective act (Brasil 1997). The values of granted flows are public domain information.

2.1.3 Analysis of Legal Conditions for Water Availability

The analysis of the legal conditions of water availability is carried out using the following equation:

$$\Delta WA = \left(\frac{Q_{\text{avail_annual_ror}} - Q_{\text{granted}}}{Q_{\text{avail_annual_ror}}} \right) 100 \quad (1)$$

where: ΔWA = legal condition of water availability, %; $Q_{\text{avail_annual_ror}}$ = run-of-river water availability in the segment, $\text{m}^3 \text{s}^{-1}$; and Q_{granted} = accumulated granted flow considering all user sectors upstream of the confluence with the next segment in the flow direction, $\text{m}^3 \text{s}^{-1}$.

The term segment refers to each segment of the hydrographic region existing between two consecutive confluences or to the segment that extends from the source of the river to the confluence immediately downstream. The length of each segment depends on the scale of the hydrographic region considered in the study.

The values of ΔWA can be negative or positive. When the annual run-of-river water availability is not exceeded by the granted flow, the value is positive, indicating a balance between supply and demand, whereas the opposite conditions lead to a negative value and indicate the occurrence of conflict and the need to adjust the demands according to the supply of water.

2.2 Operational Plan

The operational plan is defined as the one in which the demand is obtained by the sum of the granted flows that consider all uses except irrigation, for which a specific methodology

is considered in the estimation. In this plan, the supply is given by the monthly water availability under the run-of-river conditions and annual water availability under regulated-flow conditions. Although there is a legal criterion referring to the regulation, it was included in the operational plan because it is not the reference base for the granted permits considered in the present study.

2.2.1 Monthly Run-of-river Water Availability

A variety of hydrological regimes are observed in Brazil, with some of the regions presenting a seasonality of natural flows, in which the flows are lower at certain times of the year and higher during rainy months (Pessoa Filho 2013).

Although estimates of minimum flows traditionally involve the use of all available data, data collected over shorter time intervals, such as months or groups of months, may be adopted (WMO 2008).

A study analysed the use of different criteria for granting the right to use water resources based on six segments of the Paracatu basin hydrographic region and showed that the change from an annual basis to a monthly basis and considering the criterion of 30% of $Q_{7,10}$ would lead to an increase in the permissible permitted volume between 91.0% and 168.6% (Bof et al. 2012). Thus, considering a monthly criterion can be an excellent option to improve water use to reduce conflicts among users (Pruski et al. 2014).

2.2.2 Potential Water Availability

In situations where the run-of-river water availability is not sufficient to meet the demand, then the alternative is to exploit the potential water availability of the basin, which can be achieved through flow-regulation techniques.

Regulated flow is defined as the amount of water that a reservoir can provide with a certain safety based on a period of data of the historical series of tributary flows (ANA 2005). From a theoretical perspective, the highest flow that can be regulated is the average flow (Almeida et al. 2014).

In a study of the Paracatu Basin, Ribeiro, Ramos and Pruski (2018) obtained variations from 3.7 to 10.0 for the relationship between Q_{mlt} and $Q_{7,10}$ according to availability increments of 531% to 1,795%.

According to Nunes (2013), the increase in water availability through the implementation of flow-regulation structures can increase the efficiency of meeting water use demands.

2.2.3 Flow Required By Irrigation

The flow required by irrigation is estimated from the equation described below and considers the unit flow required by the equivalent hectare:

$$Q_i = \sum \left(\frac{q_{ueh} F_p}{1000} A \right) \quad (2)$$

where: Q_i = flow required by irrigation accumulated upstream of the confluence with the next segment in the flow direction, $m^3 s^{-1}$; q_{ueh} = unit flow required by the equivalent hectare, $L s^{-1} ha^{-1}$; A = irrigated area in the drainage area of each segment of the hydrographic region, ha; and F_p = pumping factor.

$$F_p = \frac{24}{\text{NHoff}} \quad (3)$$

where: NHoff = number of pumping hours during off-peak time. The base value considered is described in the ordinance of the permits.

The equivalent hectare was proposed by Ramos (2020) and is based on a weighted average that considers the occupied areas and the unit flows of the main irrigated crops, which contain information on cropping calendars and local climate.

2.2.4 Analysis of Water Availability Operational Condition

The analysis of the operational condition of water availability is performed especially in situations where the sum of flows granted considering all user sectors exceeds the annual water availability under run-of-river conditions. Its application requires a joint analysis of the demands of all users involved; thus, it is based on a shared use of all water availability upstream of the segment of interest.

The shared use is based on the granting of a single permit for the users involved in conflict situations and maintaining flows destined for the priority uses recommended by the legislation and an agreement among the other users.

2.3 Case study: Branco River basin

2.3.1 Study Area Characterization

The Branco River basin is located in western Bahia state between the geographic coordinates 11° 21' 28.54" and 12° 8' 1.50" S latitude and 44° 54' 55.53" and 46° 21' 13.34" W longitude (Fig. 1). The region has a tropical climate, type Aw, according to Köppen's classification, with dry winters and rainy summers (Gaspar, 2006).

The western region of Bahia State has stood out as one of the main agricultural frontiers of the country. The favourable topography associated with the adoption of agricultural production practices based on the intensive use of inputs and implementation of irrigation projects allowed for the expansion of large plantations in the region (Passos et al. 2010).

According to Gaspar (2006), an increasing number of permits have been granted in the western region of Bahia in recent years. The author showed that from 2003 to 2006, surface water and groundwater permits increased by 76% and 125%, respectively.

2.3.2 Water Availability

The annual run-of-river water availability in the Branco River basin was characterized by 80% of the minimum flow associated with a permanence of 90% in time (Q_{90}), and it was considered the reference flow used to grant permits under these conditions by the legislation of Bahia State, where the basin is located. Potential water availability was characterized by 80% of the mean long-term flow (Q_{mlt}).

Q_{90} and Q_{mlt} were obtained by the regionalization equations available in SIHBA-Oeste software (Sousa, 2018) and presented in Table 1.

The monthly run-of-river water availability was estimated by the product of the annual water availability considered by the seasonality ratio obtained by Ribeiro (2020) (Table 2). This ratio corresponds to the lower confidence interval (confidence level of 95%) of the

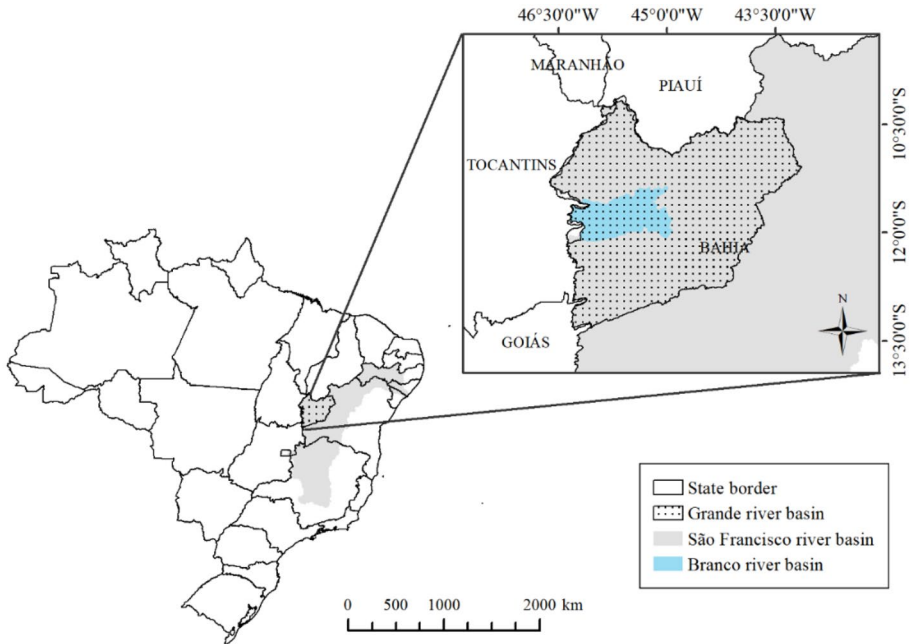


Fig. 1 Geographical location of the Branco River basin

values of the ratio between the minimum monthly and annual flows of the stream gauge stations of the hydrologically homogeneous region in the Rio Grande basin considered for the study of flow regionalization on an annual basis.

2.3.3 Survey of Granted Flows

The studied river area is a state domain; thus, the permits were surveyed based on information provided by the State Institute of Environment and Water Resources (Inema) and the State Register (SR). All valid and recently expired permits were considered, and they were counted until August 2018. The spatial distribution of the permits was determined according to the geographic coordinates and datum provided, and for those that did not have this last piece of information, the official geodesic reference system of the country, SIRGAS 2000, was considered. In the absence of units for the flow value, the pattern of the others was adopted, which corresponded to $m^3 \text{ day}^{-1}$. Permits granted under regulated-flow conditions were not considered, and there was no differentiated

Table 1 Equations used for the regionalization of Q_{90} and Q_{mlt} in the study area

	Equation
Q_{90}	$Q_{90} = 0.4674Peq_{750}^{0.9284}$
Q_{mlt}	$Q_{mlt} = 0.6759Peq_{750}^{0.9288}$

Peq_{750} is the flow equivalent to the precipitated volume less the precipitation abstraction factor of 750 mm used to form the flows. Source: Adapted from Sousa (2018)

Table 2 Seasonality ratio

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.2	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.9	1.0	1.2

Source: Adapted from Ribeiro (2020)

treatment with respect to the source of abstraction. According to ANA (2005), the abstraction of groundwater at a certain point implies a lower contribution of the aquifer to the river and, consequently, a reduction of available water in the latter.

The association of permits with hydrographic segments was performed considering the sum of all permits in the drainage areas corresponding to each segment of the hydrographic region.

2.3.4 Flow Required By Irrigation

The unit flow required by irrigation in the equivalent hectares was obtained from Ramos (2020) and multiplied by the irrigated area estimated from ANA (2019b). The association of the irrigated area to a given drainage area is based on the location of the centroid of each centre pivot. This criterion is adopted as an alternative to the process of identifying the effective abstraction point of each irrigated area because of the complexity of executing such an identification on the hydrographic basin scale. Furthermore, the differentiation of irrigated area in relation to abstraction source is not considered; therefore, the total is counted as coming from the surface water availability.

3 Results and Discussion

3.1 Analysis of the Legal Condition of Water Availability

Figure 2 presents the legal condition of water availability, which is estimated based on the sum of flows granted considering all user sectors and the annual water availability under run-of-river conditions. Because the variations in flow granted over months are not significant in the region and most of permits report a fixed demand, the results were only presented for the month of May, which is the most critical in terms of demands. In the figure, continuous and dashed lines differentiate the parts of the hydrographic region where ΔWA is positive and negative, respectively, and the numbers along the hydrographic region represent identifying codes for each segment.

Approximately 77.6% of the hydrographic segments of the Branco River basin have positive values for ΔWA , that is, considering all user sectors, the sum of granted flows is lower than the annual water availability under run-of-river conditions. Moreover, 100% availability is estimated in half of the positive segments and over 90% availability is estimated in approximately 73% of these segments.

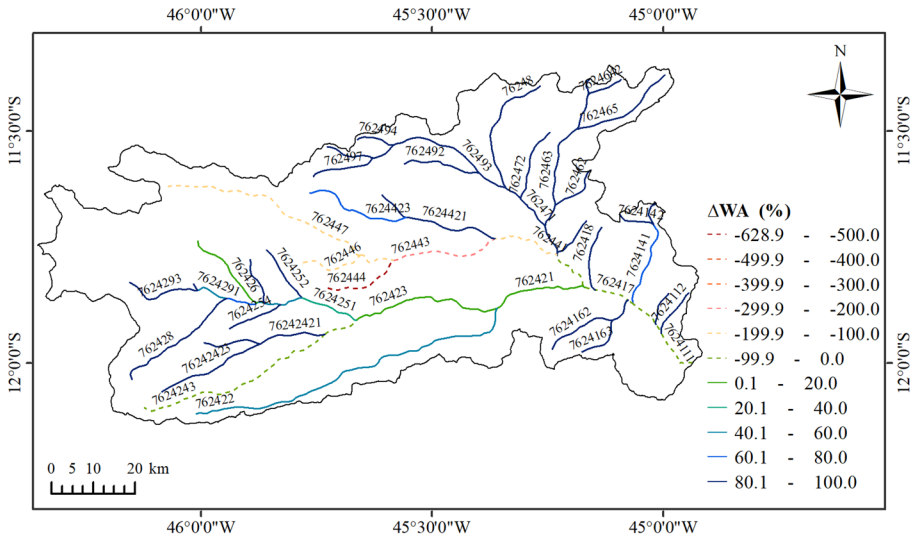


Fig. 2 Representation of the legal condition of water availability in the Branco River basin

Although the individual segment evaluations indicate a significant potential for increased water use in the basin, a global analysis demonstrates that certain segments at downstream positions, where many areas do not have permits, exceed the potential for water use based on annual water availability under run-of-river conditions, which implies that up to the mouth of the Branco River basin, a balance between supply and demand has not been achieved. This fact highlights the real need for granting water use based not only on the reference flow that can be granted in the segment of interest but also on the permits already granted at the upstream and downstream positions.

Moreira et al. (2012) state that management bodies often do not comply with the permissible limits for granting a grant, which occurs due to the lack of adequate tools management of the issued grants.

Of the approximately 22.4% of the segments in which ΔWA is negative, the annual water availability under run-of-river conditions exceeded 271.6% in 6.7% and was lower than 18.8% in 46.7%. Almeida et al. (2014) evidenced that there are segments with granted flows above 80% of Q_{90} and Q_{mlt} in the Branco river, which are a concern for the maintenance of water resources in the basin.

The permit data indicate that the segments showing abstractions for irrigation correspond to more than 92% of the flow granted, with variations from 65.9% to 100%, which indicates a significant participation of the sector in local demands.

3.2 Analysis of the Operational Condition of Water Availability

In this study, two conflicting segments of the Branco River basin were analysed: 762447 and 7624111, which represent different levels of incompatibility between supply and demand. The lines connecting the markers in all graphs presented below were only used to facilitate the visualization of flow variations over time and do not indicate continuity of the values.

Figure 3 present the annual distribution of the flows in the hydrographic region (minimum annual flow, mean long-term flow, annual run-of-river water availability, annual water availability under regulated-flow conditions, and monthly run-of-river water availability) and demand (flows required for irrigation and granted flows accumulated up to the confluence with the next segment in the flow direction) for each segment under conflict conditions. Although no distinction was made regarding the source of abstractions of the permits (surface water or ground water), these are presented separately. In addition, a distinction between water uses is also presented to allow a better comparison of the flows required by irrigation and permits granted for this purpose. Permits with incomplete information regarding the type of use and/or source of abstraction were allocated separately.

Figure 3a shows segment 7624111, which is located at the mouth of the Branco River basin. According to the Δ WA results, for the legal plan, an 8.2% exceedance of the annual run-of-river water availability occurs at this position. In May, the approximation is fairly accurate between the flow required by irrigation and the sum of the flows granted for the same use, which is only 3.1% higher. In the other months of the year, however, the representativeness of the flows granted relative to the actual abstractions decreases significantly, with the granted flows approximately 931.1% higher than the actual abstractions. The demand for irrigation has great seasonal variability due to the various growth stages of different crops (Wada et al. 2016) or variations in climatic conditions (Rodriguez et al. 2006), which together demonstrate the importance of requesting seasonal permits because a large amount of water resources could be allocated to other users.

In the month of maximum demand, the flows granted approximate those required by irrigation; however, the analysis of the unit flows granted in the basin indicates that the permitted flows exceed the required unit flows estimated for all rotations. This fact was not reflected in the sum of the flows granted because the irrigated areas reported in the permits corresponded to approximately 79.8% of those considered for estimating the required flows.

Requesting permits for flows up to the value of the maximum potential demand is justifiable because the authorization is valid for several crop seasons and irrigators must retain some flexibility for possible changes in crops. According to Piau (2016), estimating water availability by considering the permits granted may differ considerably from the actual water availability because certain users may not use any water resources and others may abstract more than what is authorized. In addition, this author highlights the need for the management body to have control not only over the permits but also over the actual abstractions.

The application of the operational plan associated with shared use is in line with this idea because it favours a better use of water through more active participation of users in the planning of available flow allocation.

Considering the minimum monthly flows in May, which has higher water demand, it is possible to meet the demand corresponding to the sum of the flows required by irrigation and those granted for other uses upstream of the segment. This fact corroborates the results found by Silva (2014) for the Entre Ribeiros River basin, in which the higher demand by irrigation does not necessarily coincide with the period of lower availability.

As the dry period approaches, water availability is reduced in the hydrographic region and a small exceedance of the flows required by irrigation occurs in September. Nevertheless, a global analysis indicated that sufficient water resources were available to meet the existing demands in the Branco River basin. Despite the restrictions for the months of May, August and especially September, an increase in new demand is possible. However, it is important to point out that changes at any position of the basin have a direct impact on

the mouth; therefore, the restrictions for the current agricultural plan regarding the months mentioned above are valid for all segments upstream.

Although the criterion of monthly water availability characterizes the worsening of the conflict in relation to the demands in some months, the consideration of a characteristic flow of the dry period for the whole year does not represent the actual condition of the hydrographic region since it is restrictive to use in certain months and does not favour the use of water and is too permissible in others months, thus creating a false expectation of supply and risks of shortage. This condition, according to Ramos et al. (2017) and Ribeiro et al. (2019), guarantees a better plan for water use.

Figure 3b shows the condition of segment 762447, which is located at a headwater position in the northwest portion of the Branco River basin. According to the result presented for Δ WA, which was estimated based on the legal criterion, at this position, the annual run-of-river water availability is exceeded by 167.5%.

A comparison of the flows granted and those required by irrigation in this segment showed that the former is at least 1.9 times greater, which characterizes a severe incompatibility of demand in relation to the annual run-of-river water availability. The flows granted at this position exceed even the mean long-term annual flow.

Although considering the monthly run-of-river water availability also allows for the expansion of water use for the months of highest water availability, this situation is more serious than that shown for the previous segment due to the greater incompatibility in September and the emergence of other incompatibilities associated with the months of May, June, July and August.

In the face of a situation of conflict over water use, reducing the irrigated area is an option when the intention is to reduce the flows required; however, its adoption implies a reduction in the production corresponding to that area, which may cause negative socio-economic impacts. In this context, some measures can be evaluated by irrigators seeking an adequate supply for crops according to the demand, such as the rescheduling of cropping calendars, the adoption of deficit irrigation, and increments in water availability, such as flow regulation.

Figure 4 shows the unit flows required by irrigating the crop rotations and the equivalent hectare obtained by Ramos (2020) for segment 762447. The figure also shows the cultivation calendars considered for each of the four rotations and the percentage of area occupied by each rotation in relation to the total irrigated area in the region.

Rotations II and III account for the highest percentages in relation to the total irrigated area, and these same rotations are characterized by high unit flows required in the months in which the demand exceeds the availability. Rotation I, despite being characterized by a lower percentage of occupied area than II and III, has the highest unit flows for May.

Based on these data, we sought to evaluate the impact of two changes in sowing dates to reduce the demands in the months of conflict. For this evaluation, factors associated with phytosanitary measures were not considered.

Modification 1: one-month advance in the sowing of all crops related to rotations II and III.

Modification 2: one-month delay in the sowing of cotton in rotation I.

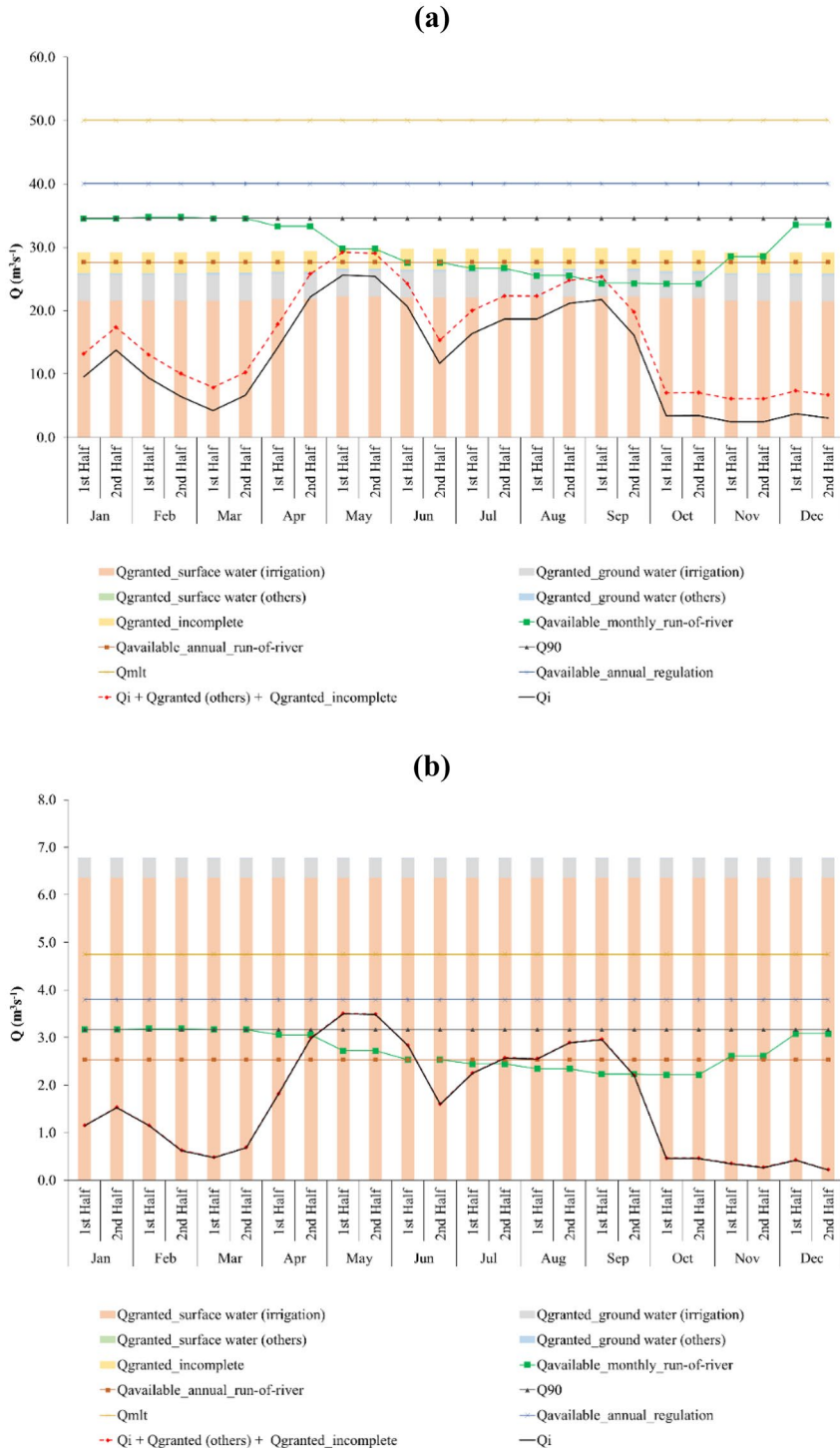


Fig. 3 Representation of the distribution of water availabilities and demands throughout the year in segments 7624111 **(a)** 762447 **(b)**

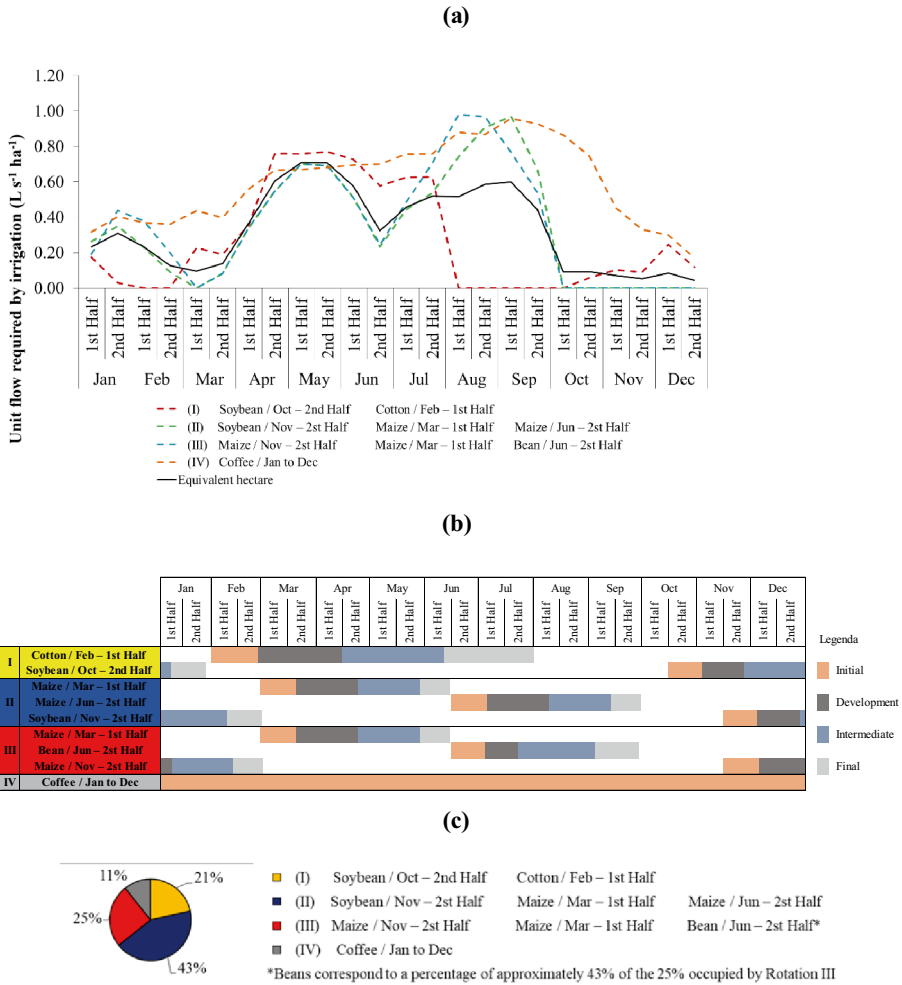


Fig. 4 Representation of the distribution of unit flows required to irrigate the rotations in the equivalent hectares throughout the year in segment 762447 (a), the characterization of the cultivation calendars associated with the growth phase of each crop of interest in the region (b) and the percentage of each rotation in relation to the total irrigated area in the region (c)

The analysis of the modifications reveals that the original calendar is the most efficient in terms of water use since the changes in sowing dates promote not only the displacement of demand peaks but also their elevation in conflicting months. In modification 1, this displacement occurs because the demands associated with maize and beans in the intermediate growth stage of the maximum crop coefficient in the cycle are transferred from August to July. Although the latter does not have a higher evapotranspiration rate than the following months, the presence of cotton in the irrigated area causes the unit flow of the equivalent hectares to be higher than that of September. In modification 2, the demand of cotton at the final growth stage is transferred from July to August, which has the highest evapotranspiration rate.

Another alternative technique under conditions of restriction in water supply is the application of deficit irrigation, which consists of the application of an amount of water lower than that of evapotranspiration (Feres and Soriano 2007). According Pereira (2017), the advances in estimating crop water and irrigation requirements are among the basic conditions for achieving food and nutritional security.

In the analysis of the percentage deficit of the flow required by irrigation in relation to the minimum monthly flow in Sect. 762447, variations of approximately 5% to 25% are observed for the months of lesser and greater conflict, respectively. These values indicate the order of magnitude of the reductions in water demand necessary for the compatibility of demands on monthly water availability in run-of-river conditions.

In the first half of the year, the need to apply deficit irrigation for the study area would be associated with reductions in water depths during the intermediate growth stages of cotton and maize, and in the second half of the year, it would be associated with the development and intermediate stages of maize and intermediate and final stages of beans. In both periods, it is also necessary to reduce the water depth for coffee crops.

It is important to highlight that the application of deficit irrigation to reduce water consumption should be performed based on plant physiology, which define different responses to reduce the irrigation depths based on each crop, which has a direct impact on production. In addition, soil salinity also needs to be considered for deficit application (Du et al. 2015).

Several studies in the literature prove the advantages associated with the application of deficit irrigation. English (1990) and Feres and Soriano (2007) described the generic behaviour of crop yield as a function of the amount of water applied, which has an initially linear and then curvilinear relationship, thus demonstrating that water use becomes less efficient as the value approaches the total irrigation depth. Capurro et al. (2017) studied the application of deficit irrigation in soybean in Uruguay and concluded that it was possible to reduce the water volume by 22% compared to the total water demand during the crop cycle without reducing the final yield. Chuanjie et al. (2015) evaluated the application of deficits in cotton crops in an arid region in northwestern China and found losses below 10% for reductions of evapotranspiration of 15% and 30%, which was considered acceptable given the benefit of water savings in the region. Seid and Narayanan (2015) conducted an experiment in Ethiopia and observed that the application of 100% and 85% crop evapotranspiration caused no significant difference in maize yield.

According to Silva (2014), certain situations exist in which even the consideration of variations in the monthly run-of-river water availability is not sufficient to meet the demand; thus, water must be stored in reservoirs. The variation in availability and demand throughout the year allows for the accumulation of a considerable surplus in periods of low consumption, and this supply can be utilized in short periods of deficit. Water abstraction in reservoirs is one of the main alternatives for addressing the variability in water supply and demand (Deng et al. 2020).

In a study conducted for the Entre Rios River basin, Oliveira (2011) observed that even when using the criterion of 50% of the monthly $Q_{7,10}$ to meet the granted flows, it would be necessary to build flow-regulation structures in several segments of the hydrographic region.

Thus, a third alternative to adjusting the demands in segment 762447 would be water storage, and Fig. 3 shows that the volume corresponding to the excess flow of a few months preceding the deficit would be sufficient.

According to Hamada (2017), half of the large reservoirs in the world were built exclusively or mainly for irrigation, and approximately 30 to 40% of the 268 million hectares of irrigated land worldwide depend on dams.

4 Conclusions

The proposed methodology allowed for a more realistic characterization of the demand conditions and water availability of the basin and could promote a joint assessment of potential measures for implementation during conflict conditions. Considering different possibilities of water use conflict mitigation represents an important step because water supply tends to be reduced under increases in demand and with climate change.

The application of the legal and operational plans showed the need to evaluate the conditions under which the management system operates and the conditions that characterize the river basins. The operational plan allows for the joint analysis of the various scenarios of water use and has the potential to avoid situations in which the granted flow is many times greater because it is based on a much more judicious knowledge of both the availability and demand.

The methodology is especially aimed at rural basins, where water is primarily used for irrigation; however, urban basins can also benefit from conflict mitigation by considering the seasonality of flows and water storage in regularization structures.

This study highlights the need for managing water resources segment by segment in a hydrographic region to prevent problems that may generate risks of shortages in the future, which is not advantageous for the environment, water managers and water users in general.

Authors' Contributions Maria Camila Alves Ramos: Conceptualization, Methodology, Writing—Original Draft, Writing—Review & Editing; Fernando Falco Pruski: Conceptualization, Methodology, Writing—Original Draft, Writing—Review & Editing; Tarcila Neves Generoso: Methodology, Writing—Review & Editing; Eber José de Andrade Pinto: Writing—Review & Editing, Visualization.

Funding This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001 and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Data Availability All data and materials support the published claims and comply with field standards.

Code Availability This work did not produce any software application or custom code to be made available.

Declarations

Consent to Participate The authors declare that they participated in the preparation of the manuscript.

Consent to Publish The authors declare that they agree with the publication of the manuscript.

Conflicts of Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Almeida WA, Moreira MC, Silva DD (2014) Applying Water Vulnerability Indexes for River Segments. *Water Resour Manage*. <https://doi.org/10.1007/s11269-014-0745-5>
- Agência Nacional De Águas – ANA (2005) Caderno de recursos hídricos: diagnóstico da outorga de direito de uso de recursos hídricos no país – Diretrizes e prioridades. <https://arquivos.ana.gov.br/institucional/sge/CEDOC/Catalogo/2012/OutorgaDeDireitoDeUsoDeRecursosHidricos.pdf> Accessed 02 June 2021
- Agência Nacional De Águas – ANA (2019a) Conjuntura dos recursos hídricos no Brasil 2019: informe anual. http://www.snirh.gov.br/portalsnirh/centrais-de-conteudos/conjuntura-dos-recursos-hidricos/conjuntura_informe_anual_2019-versao_web-0212-1.pdf Accessed 02 June 2021
- Agência Nacional De Águas – ANA (2019b) Levantamento da agricultura irrigada por pivôs centrais no Brasil / Agência Nacional de Águas, Embrapa Milho e Sorgo. <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1121226/levantamento-da-agricultura-irrigada-por-pivos-centrais-no-brasil> Accessed 02 June 2021
- Bof LHN, Pruski FF, Silva LMC, Justino F (2012) Analysis of appropriate timescales for water diversion permits in Brazil. *Environmental management*. <https://doi.org/10.1007/s00267-012-9982-7>
- Brasil (1997) Lei nº 9.433, de 8 de janeiro de 1997. http://www.planalto.gov.br/ccivil_03/leis/19433.htm. Accessed 02 June 2021
- Burek P, Satoh Y, Fischer G, Kahil MT, Scherzer A, Tramberend S, Nava LF, Wada Y, Eisner S, Flörke M, Hanasaki N, Magnuszewski P, Cosgrove B, Wiberg D (2016) Water futures and solution: fast track initiative (final report). <http://pure.iiasa.ac.at/id/eprint/13008/1/WP-16-006.pdf> Accessed 02 June 2021
- Capurro MC, Beretta A, García C, Sawchik J, Puppo L (2017) Rendimiento de la soja en respuesta a distintas dosis y momentos de riego. *Agrociencia Uruguay* 21(2):65–76. http://www.scielo.edu.uy/scielo.php?script=sci_arttext&pid=S2301-15482017000200065 Accessed 02 June 2021
- Castro CN (2012) TD 1744 - Gestão das águas: experiências internacional e brasileira. https://www.ipea.gov.br/portals/index.php?option=com_content&view=article&id=15034 Accessed 29 June 2021
- Chuanjie YANG, Yi LUO, Lin SUN, Na WU (2015) Effect of deficit irrigation on the growth, water use characteristics and yield of cotton in arid Northwest China. *Pedosphere*. [https://doi.org/10.1016/S1002-0160\(15\)30071-0](https://doi.org/10.1016/S1002-0160(15)30071-0)
- Deng X, Song C, Liu K, Ke L, Zhang W, Ma R, Zhu J, Wu Q (2020) Remote sensing estimation of catchment-scale reservoir water impoundment in the upper Yellow River and implications for river discharge alteration. *J Hydrol*. <https://doi.org/10.1016/j.jhydrol.2020.124791>
- Du T, Kang S, Zhang J, Davies WJ (2015) Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security. *J Exp Botany* <https://doi.org/10.1093/jxb/erv034>
- Elabras Veiga LB, Magrini A (2013) The Brazilian Water Resources Management Policy: Fifteen Years of Success and Challenges. *Water Resour Manage*. <https://doi.org/10.1007/s11269-013-0288-1>
- English M (1990) Deficit irrigation. I: analytical framework. *J Irrigation and Drainage Eng* 116(3):399–412
- Fereres E, Soriano MA (2007) Deficit irrigation for reducing agricultural water use. *J Exp Botany* 58(2):147–159. <https://doi.org/10.1093/jxb/erl165>
- Garrote L (2017) Managing water resources to adapt to climate change: facing uncertainty and scarcity in a changing context. *Water Resour Manag* 31:2951–2963. <https://doi.org/10.1007/s11269-017-1714-6>
- Gaspar MTP (2006) Sistema Aquífero Uruçuaia: caracterização regional e propostas de gestão. Universidade de Brasília, Tese
- Hamada YM (2017) The Grand Ethiopian Renaissance Dam, its impact on Egyptian agriculture and the potential for alleviating water scarcity. Springer, 187. <https://doi.org/10.1007/978-3-319-54439-7>
- HLPE (2015) Water for food security and nutrition. Rome (A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security). <http://www.fao.org/3/av045e/av045e.pdf> Accessed 02 June 2021
- Minas Gerais (2019). Decreto nº 47.705, de 4 de setembro de 2019. <http://www.siam.mg.gov.br/sla/download.pdf?idNorma=49498> Accessed 02 June 2021
- Moreira MC, SILVA DD, Pruski FF, LARA MDS (2012) Índices para identificação de conflitos pelo uso da água: proposição metodológica e estudo de caso. *Revista Brasileira de Recursos Hídricos*. <https://doi.org/10.21168/rbrh.v17n3.p7-15>
- Nunes AA (2013) Reservatórios de acumulação de água: novas propostas para o dimensionamento e representação dos seus efeitos. Universidade Federal de Viçosa, Dissertação
- Oliveira JRS (2011) Otimização do aproveitamento da disponibilidade de águas superficiais na bacia do ribeirão Entre Ribeiros. Universidade Federal de Viçosa, Dissertação

- Oliveira JR, Pruski FF, Nunes ADA (2013) Otimização do aproveitamento da disponibilidade de águas superficiais na bacia do Ribeirão entre Ribeiros. *Revista Brasileira de Recursos Hídricos*. <https://doi.org/10.21168/rbrh.v18n4.p157-172>
- Passos AL, Rocha SS, Hadlich GM (2010) Evolução do uso do solo e agronegócio na região oeste do Estado da Bahia. *Cadernos de Geociências* <https://repositorio.ufba.br/ri/bitstream/ri/1507/1/2997.pdf> Accessed 02 June 2021
- Pereira LS (2017) Water, agriculture and food: challenges and issues. *Water Resources Manag.* <https://doi.org/10.1007/s11269-017-1664-z>
- Pessoa Filho LMN (2013) Estudo da variabilidade e previsibilidade das chuvas e vazões sazonais na bacia do Rio Iguaçu. Universidade Federal do Paraná, Dissertação
- Piau LPA (2016) Controle de vazões outorgadas: estudo de caso da bacia do São Francisco. Universidade de Brasília, Dissertação
- Pruski FF, Bof LHN, Silva LMC, Silva JMA, Rego FS, Justino FB (2014) Impact of the substitution of reference annual streamflow by monthly streamflow on the potential use of water resources. *Engenharia Agrícola* 34(3):496–509. <https://doi.org/10.1590/S0100-69162014000300013>
- Ramos DD, Pereira SB, Arai FK, Santos FAD, Carnevali TDO (2017) Water seasonality in granting permits and impact of irrigation in the Dourados River basin, MS, Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental*. <https://doi.org/10.1590/1807-614>
- Ramos MCA (2020) Métodos para otimização do uso dos recursos hídricos pela agricultura irrigada. Universidade Federal de Viçosa, Tese
- Ribeiro RBR (2020) Otimização do processo de estimativa da disponibilidade hídrica. Universidade Federal de Viçosa, Tese
- Ribeiro RB, Pruski FF, Ramos MCA (2018) Disponibilidade hídrica em condições de regularização de vazão. *Sustentare*. <https://doi.org/10.5892/st.v2i2.5117>
- Ribeiro RB, Serrano LO, Oliveira JRS, Generoso TN, Ramos MCA, Pruski FF (2019) Variabilidade sazonal das vazões mínimas em três bacias hidrográficas. In: *Simpósio Brasileiro De Recursos Hídricos*, 23, Foz do Iguaçu PR
- Rodriguez RDG, Pruski FF, Novaes LD, Silva DD, Ramos MM, Teixeira AF (2006) Vazões consumidas pela irrigação e pelos abastecimentos animal e humano (urbano e rural) na bacia do Paracatu no período de 1970 a 1996. *Revista Brasileira de Recursos Hídricos* <https://doi.org/10.21168/rbrh.v11n3.p223-233>
- Seid MM, Narayanan K (2015) Effect of deficit irrigation on maize under conventional, fixed and alternate furrow irrigation systems at Melkassa, Ethiopia. *International Journal of Engineering Research & Technology*. <https://doi.org/10.17577/IJERTV4IS110178>
- Silva BMB, Silva DD, Moreira MC (2015) Influência da sazonalidade das vazões nos critérios de outorga de uso da água: estudo de caso da bacia do rio Paraopeba. *Revista Ambiente & Água*. <https://doi.org/10.4136/ambi-agua.1587>
- Silva MV (2014) Adequação da disponibilidade hídrica com a demanda de água na agricultura. Universidade Federal de Viçosa, Tese
- Smakhtin VU (2001) Low flow hydrology: a review. *J Hydrol.* [https://doi.org/10.1016/S0022-1694\(00\)00340-1](https://doi.org/10.1016/S0022-1694(00)00340-1)
- Sousa JRC (2018) Sistema de Informações Hidrológicas para o Oeste da Bahia (SIHBA-Oeste) <http://aiba.org.br/modulo-de-visualizacao/> Accessed 02 June 2021
- Wada Y, Flörke M, Hanasaki N, Eisner S, Fischer G, Tramberend S, Wiberg D (2016) Modeling global water use for the 21st century: Water Futures and Solutions (WFaS) initiative and its approaches. *Geoscientific Model Development*. <https://doi.org/10.5194/gmd-9-175-2016> Accessed 02 June 2021
- World Business Council for Sustainable Development - WBCSD (2014) Water, food and energy nexus challenges http://docs.wbcsd.org/2014/05/WBCSD_Nexus_Challenges.pdf Accessed 02 June 2021
- World Meteorological Organization – WMO (2008) Manual on low flow estimation and prediction. Koblenz, Germany. (Operational Hydrology Report No. 50/WMO Publication No. 1029)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Maria Camila Alves Ramos¹  · **Fernando Falco Pruski²** · **Tarcila Neves Generoso¹** · **Eber José de Andrade Pinto³**

Fernando Falco Pruski
ffpruski@gmail.com

Tarcila Neves Generoso
tarcilangeneroso@gmail.com

Eber José de Andrade Pinto
eber.andrade@cprm.gov.br

¹ Agricultural Engineering Department, Federal University of Viçosa, PH Rolfs, Viçosa, Minas Gerais 36570000, Brazil

² Fellowship 1A of CNPq, Agricultural Engineering Department, Federal University of Viçosa PH Rolfs, Minas Gerais 36570000 Viçosa, Brazil

³ Engineering School, Federal University of Minas Gerais, Av. Antônio Carlos, 6627, 31270901/Geological Survey of Brazil, Avenida Brasil, 1731, 30140002 Belo Horizonte, Brazil