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The economic value of water in crop productions and policy implications in southern Brazil

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Promoting economically efficient solutions to meet competing demands for water under uncertain and variable supplies requires knowledge about the economic value of water and costs for its scarcity. In this work, an agricultural production optimisation model was used to evaluate the marginal value of water (MVW) in an agricultural region of rice and soybean growing in southern Brazil. The results indicate a MVW of 0.02–0.09 R$/m^3 (1 R$ = £0.14), which is higher than common values considered for water charges for agricultural uses in Brazilian watersheds. The total scarcity costs of two recent drought periods were also investigated – these were approximately R$138 million (£19 million) and accounted for up to 15.5% of irrigated rice and soybean agriculture net return in some of the studied regions. Finally, the potential for cropping mix changes for some regions was explored through short-term water reallocation programmes to mitigate drought impacts. The results of this work should be useful in the design of water policies in terms of improved economic water management instruments, key infrastructure investments to be prioritised by watershed plans, strategies to integrate with other sectoral policies to secure funding for new water infrastructure and strategies to reinforce local adaptation through crop mix changes and short-term water reallocation.

1. Introduction

Imbalances in water availability along with growing demands and limitations on water management have been responsible for economic and environmental losses in several regions of the world (EEA, 2009). For example, in Brazil, the northeast region has scarcity problems due to limited water availability; in the southeast region, urban areas such as São Paulo, Rio de Janeiro and Belo Horizonte have water quality issues and difficulties meeting urban demands; in southern Brazil, even with its well distributed and relatively abundant rainfall pattern, water scarcity occurs due to significant demands for agricultural irrigation (ANA, 2010). Addressing such competitive and uncertain contexts to ensure future economic development requires effective water management, including (*a*) strategy, planning and policymaking, (*b*) engagement with stakeholders and (*c*) the development, allocation and management of water resources (Rees *et al*., 2008). A well-functioning governance and management system incorporating these elements is ultimately responsible for delivering water to users in the quantity, quality and reliability required.

In a water governance study in Brazil, the Organisation for Economic Cooperation and Development (OECD) noted that water is often not allocated towards benefit maximisation, is not easily adjusted to changing conditions and that financial sustainability is still a severe bottleneck to effective water management (OECD, 2015). In a study on economic instruments, the OECD indicated that, in Brazil, water charges have been largely ineffective at inducing rational water use, mostly due to the very low prices charged (water prices are proposed by watershed committees and approved by water resources councils) (OECD, 2017).

Previous works have highlighted that the economic value of water is necessary to drive water management towards economic efficiency. When discussing the benefits and costs of the Ebro water transfer project in Spain, Albiac *et al*. (2006) noted that the correct benefit measure of the incremental water supply in the receiving areas of the project was the marginal value of water (MVW); with this value, Albiac *et al*. were able to calculate the avoided profit loss resulting from importing transferred water into the basin. Pulido-Velazquez *et al*. (2013) also noted that the MVW can be used to determine the economic benefits of water projects, identify temporary water reallocation opportunities and design improved economic water management instruments.

In the work reported in this paper, the economic value of water was determined, the associated scarcity costs during droughts were assessed and potential responses from users in terms of changes in irrigated cropping patterns in a region of soybean and rice agriculture in southern Brazil were evaluated. The results were then framed into policy implications that explore how water management instruments can be improved and implemented. This paper contributes to the body of knowledge by (*a*) communicating the importance of economic water scarcity, (*b*) identifying opportunities for water management and policy responses to changing conditions, (*c*) evaluating the economic benefits of water management actions and programmes and (*d*) providing a reference value for economic water management instruments. Combined, these results not only provide a reference to the economic benefits of improving water resources management in the region, which are often unknown in Brazil and elsewhere, but also help to identify opportunities to deliver the results to users and water managers, focusing on economic efficiency.

The economic values obtained in this study are a lower bound on the real economic value of water because there are several other intangible non-economic benefits associated with effective water management, including social wellbeing, cultural and aesthetic benefits, food security, the economic stability of small-scale household agriculture and the maintenance of ecosystem services, among several others. These benefits were beyond the scope of the current work, but should be addressed in the future.

2. Methods

Determining the economic value of water is necessary for better water resources management decisions (Pulido-Velazquez *et al.*, 2014). It can be defined as the maximum amount users would be willing to pay (Briscoe, 1996). The relationship between water availability and its value can be described by marginal benefit curves – these curves relate users' willingness to pay (for water in this case) to its availability, which means that the more scarce the resource, the greater its value to users (Griffin, 2006; Mankiw, 2014). Marginal benefit curves can be employed to support decision making in water resources management, policy analysis, efficient water allocation and so on (Howitt *et al.*, 2012; Tilmant *et al.*, 2008).

In this work, an economic optimisation model was used to estimate marginal benefit curves for water use in agricultural operations (Howitt *et al.*, 2001, 2012). The study area was the Santa Maria River basin (SMRB), in southern Brazil.

2.1 Study area: SMRB

The state of Rio Grande do Sul in southern Brazil accounts for approximately 50% of rice and 16% of soybean national production (Conab, 2016). In the western region of the state, despite the relatively abundant water availability, significant water demands for irrigated agriculture have sparked conflicts between users and led to reduced reliability of the water supply (ANA, 2010). According to the Brazilian national water agency (ANA), this region has the second worst imbalance between water supply and demand in the country (ANA, 2014).

The SMRB, in the western region of Rio Grande do Sul, comprises an area of approximately 15 790 km^2 (IBGE, 2015). The two main crops in the SMRB are soybean and rice, which account for 11% and 6% of the basin area, respectively (DRH/Sema, 2016). Soybean is an annual crop that is irrigated with centre-pivot systems, while rice is cultivated in areas with flood irrigation. Some rice farmers pump water from local rivers to feed small storage dams on their properties, from which water is fed to the crop area (DRH/Sema, 2016). At other properties, local dams are filled by small streams.

The SBRB comprises six municipalities, which were defined as model regions M1 to M6. Two gauging stations of the Brazilian national water agency (ANA, 2017) were used for hydrologic analysis: Dom Pedrito (gauging station 76251000 and rain station 03054002) and Rosário do Sul (gauging station 76310000 and rain station 03054007). Figure 1 shows the SMRB, the location of regions M1 to M6, hydrography (ANA, 2017) and crop distribution (IBGE, 2015). The average annual production (in terms of areas covered) of rice and soybean in each economic region are listed in Table 1.

2.2 Agricultural production model

The statewide agricultural production model (SWAP) was used to determine the economic value of water in the SMRB. Swap is an optimisation model that maximises the sum of producer surplus (regional profits) and derives the economic benefit to farmers from cropping operations (Draper *et al.*, 2003; Howitt *et al.*, 2001; Howitt *et al.*, 2012). Swap has been used in several studies, including an assessment of climate change impacts on agricultural water demands in California (Medellin-Azuara *et al.*, 2011), the economic evaluation of conjunctive use and water reservation in southern California (Pulido-Velazquez *et al.*, 2004), an evaluation of the willingness to pay for water resources in a semi-arid region in Brazil (Silva *et al.*, 2015), economic simulation of a water system in California (Marques *et al.*, 2006) and integrated modelling of conjunctive water use in a canal–well irrigation system (Liu *et al.*, 2013).

Swap employs positive mathematical programming (PMP), which is a deductive approach to modelling agricultural production and water use, initially presented by Howitt (1995). The main advantages of PMP are nearly exact auto-calibration to a base dataset, minimum data requirements to set up a working model and the possibility of analysing water management policy decisions (Howitt *et al.*, 2010). As Swap self-calibrates to a base dataset, inputs must be correctly defined, otherwise this could lead to misinterpretation of the results. Swap is defined over relatively homogenous agricultural regions and it selects crops, water supplies and other inputs subjected to constraints on water, land and capital, while also considering economic conditions such as prices, yields and costs to optimise production and economic benefit (Howitt *et al.*, 2012).

The self-calibration process comprises the following three stages.

(*a*) Linear programming for profit maximisation, in which the constraints of the calibration are relative to land use, the set of crops and their base values.

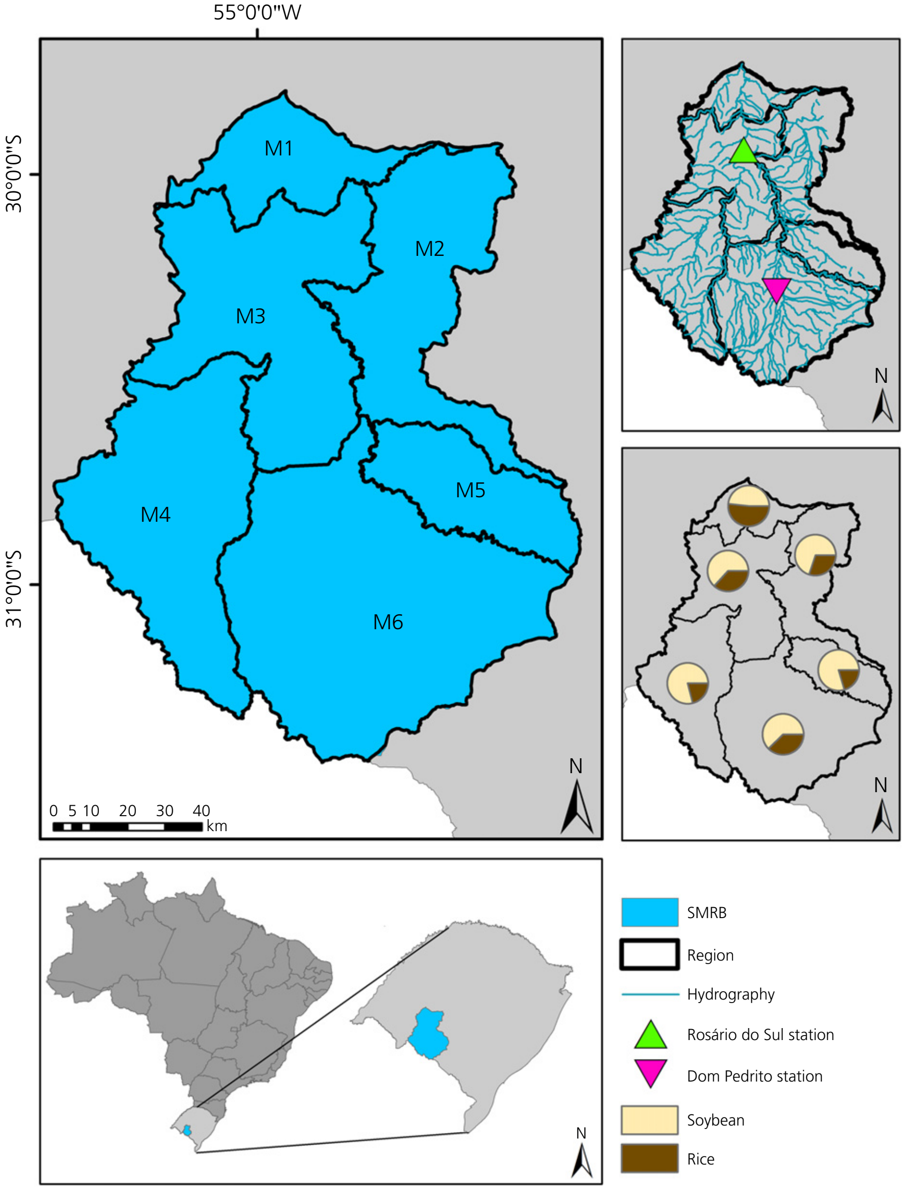

Figure 1. Location of the SMRB and regions

(*b*) Derivation of the parameters of a cost function based on Lagrange multipliers obtained from the calibration constraints of the first step and the first-order conditions of the objective function.

(*c*) Incorporation of functions that were previously calibrated into a non-linear profit maximisation programme, subject to constraints of the production factors (water, land, labour and supplies) used in the first step and a new restriction on annual water consumption.

The model is run in multiple loops; at each loop the water availability constraint is changed towards reducing the available water and the respective Lagrange multiplier is recorded. At each water availability loop, the Lagrange multiplier represents the marginal economic value of one additional unit of water. By combining the set of the marginal economic values with their respective water availability values from each loop, a marginal water benefit function is constructed (Booker *et al.*, 2012; Howitt *et al.*, 2012). In this work, a marginal water benefit function for each one of the six regions of the SMRB was generated. The general algebraic modelling system (Brooke *et al.*, 1998) was used to assemble the model. Equations and a model description are provided in the online supplementary material.

Model inputs included irrigated land, applied water per unit area (based on crop requirements for irrigated crops), labour

Table 1. Average annual areas for rice and soybean agriculture in the SMRB for base year 2015 (IBGE, 2015)

		Agricultural area: ha	
	Region	Rice	Soybean
M1	Cacequi	7656	7178
M2	São Gabriel	13 410	31 130
M3	Rosário do Sul	14 138	24 376
M4	Santana do Livramento	4 053	15 225
M5	Lavras do Sul	1475	5710
M6	Dom Pedrito	42 985	71 563

Table 2. Summary of SMRB model input data

Input data	Rice	Soybean
Water use: 1000 m^3/ha	11.50	5.23
Average yield: t/ha	7.15	2.25
Selling price: 1000 R$/t	0.74	1.20
Labour: h/ha	12.80	8.16

expenses per unit area, agricultural supplies and crop yields and prices (Table 2). The input data were obtained from the Brazilian Institute of Geography and Statistics (IBGE, 2015), the Brazilian Agricultural Research Corporation (Embrapa, 2005) and Rio Grande do Sul Institute of Rice (IRGA, 2015). Data were also collected from a field visit to the study area and from members of the Association of the Water Users of the Santa Maria River Basin (AUSM).

3. Results

The results are now presented in four subsections – analysis of water marginal benefit curves and raw water charges (Section 3.1), cropping patterns (Section 3.2), scarcity cost of drought periods (Section 3.3) and policy implications (Section 3.4).

3.1 Water marginal benefit curves

The marginal benefit curves of water presented in Figure 2 show the economic value of water (in R$/$m^3$ (1 R$ = £0.14)) associated with the respective water availability (hm^2) for each region. Crops with a higher economic return will have water allocated before crops with a lower return, as can be observed when comparing the curves for M1 and M4: although M1 has a larger planted area for rice (7656 ha for M1 and 4053 ha for M4), M4 has a higher yield (6 t/ha for M1 and 7 t/ha for M4). This means that the same amount of water would be more valuable to users in M4 than users in M1. Therefore, the economic impact of water scarcity is likely to be higher in M4.

The marginal benefit values of water provided by the Lagrange multipliers are an important reference for a discussion of raw water charges as they represent a proxy for users' willingness to pay for an additional unit of water (Pulido-Velazquez *et al.*, 2004). As shown in Figure 2, the MVW ranged from 0.02 R$/$m^3$ to 0.09 R$/$m^3$ considering water availability fixed at 99% of full demand; these values indicate the economic benefit from water use for rice and soybean production in each region. Water charge schemes in large watersheds in Brazil vary from 0.01 R$/$m^3$ to 0.02 R$/$m^3$ (Finkler *et al.*, 2015), which is close to the lower bound of the obtained MVW (0.02 R$/$m^3$).

The SMRB does not yet have a water charging scheme but there are some strategies under study by the River Basin Committee and the state's Department of Water Resources. A study by the AUSM resulted in two values for water use on irrigated rice: 0.007 R$/$m^3$ and 0.015 R$/$m^3$ (AUSM, 2017). In another investigation (FATEC/UFSM/FINEP, 2009) the raw water charge was proposed to be 0.008–0.012 R$/$m^3$. According to Forgiarini *et al.* (2007), the River Basin Committee members are in favour of establishing a raw water charging scheme and believe it should prioritise the efficiency and transparency of the use of water resources.

If the raw water charge is close to the MVW for 99% water availability (i.e. where users are being delivered almost full demand), one should not expect a meaningful behaviour change in terms of inducing rational water use as this charge is approximately what water is worth to crop producers in normal water supply conditions. At this point, users would rather not adjust their production systems to use less water, since this would likely be more expensive than using the same amount of water and paying the water charge. The upper bound of the MVW in the SMRB was calculated to be 0.09 R$/$m^3$ in this study. This indicates that water charges around 0.01 or 0.02 R$/$m^3$, which are values often seen in water schemes in Brazil, may not result in significant water use changes in certain regions. However, the MVW alone should not be used to determine water charges given that there are other factors that influence the value of water.

3.2 Cropping patterns

Figure 3 shows the percentage change in cropped areas of rice and soybean in each region as response to variations from 99% to 50% of full water availability, where full water availability is the observed water consumption that indicates a normal hydrological year. As water availability changes, farmers make production adjustments such as reducing the crop area, switching inputs, changing the crop type or any combination of those to maximise profits and Swap tries to capture this behaviour. Howitt *et al.* (2015) evaluated drought impacts in California using Swap and found that water transfers and shifts in the crop mix had a significant effect on the drought impact; they also observed a shift towards higher value perennial crops. In the California case, crops holding a lower value per unit of water had the largest proportional cuts in irrigated acreage.

In the SMRB, as expected, crop areas became smaller as water availability was reduced. When looking at the changes in the

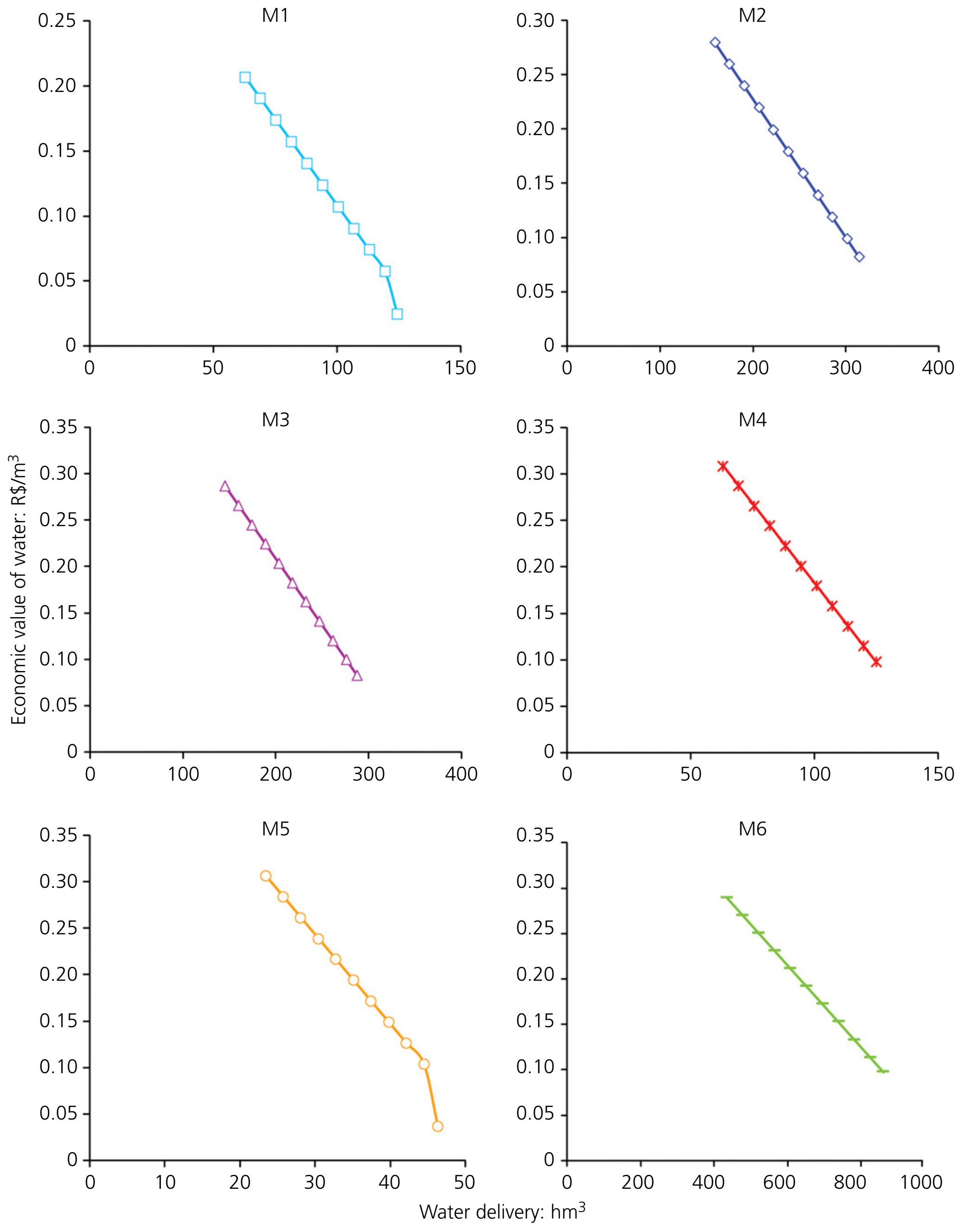

Figure 2. Water Marginal benefit curves for the six regions

crop mix, regions M2, M3 and M6 did not present significant variations on the percentage of each crop, indicating that the ratio between soybean and rice is already optimised. However, in regions M1, M4 and M5, an increase in water scarcity led to an increase in soybean area and a decrease in rice area, indicating a potential response in the crop mix to the conditions water availability. Since producers seek to maximise economic benefits and water use, this result suggests that, with limitations on water availability, producers will gain more economic benefit if they shifted the crop mix.

Rather than a prescriptive solution, the shifts in cropping patterns are indicative of opportunities to adjust to changing conditions, such as higher competition for scarce water, droughts or even long-term changes in water availability due to climate change and land use, which is in alignment with OECD recommendations (OECD, 2015). This result supports the design of economic instruments that signal water scarcity and opportunity costs to users, along with short-term water reallocation responses. During a drought in the Brazilian northeast in 2001, a temporary water reallocation programme was deployed and water deliveries were shifted from water-intensive rice production to higher value perennial crops, with some economic compensation to rice farmers (ANA, 2018). With more detailed information about water value and scarcity costs, such as that provided in this paper, future temporary (and even permanent) reallocation responses could be more effective. In this work, only the shift in cropping patterns between soybean and rice was evaluated, but the opportunity cost for land use must be considered because there could be other crops or uses that would bring greater economic benefits for producers and the SMRB.

3.3 Scarcity cost in drought periods

Reduced water availability is often caused by droughts and is aggravated by limited or non-existent water management responses. When studying farmers' responses to limited water availability, an important concept is water scarcity – which can be defined as the difference between water used and the amount of water users would take if it were freely available with zero marginal cost (Jenkins *et al.*, 2004). Water scarcity has a cost, which is given by the economic benefit users do not have because they lack access to the amount of water they need. Water scarcity cost is a lower bound on the value of

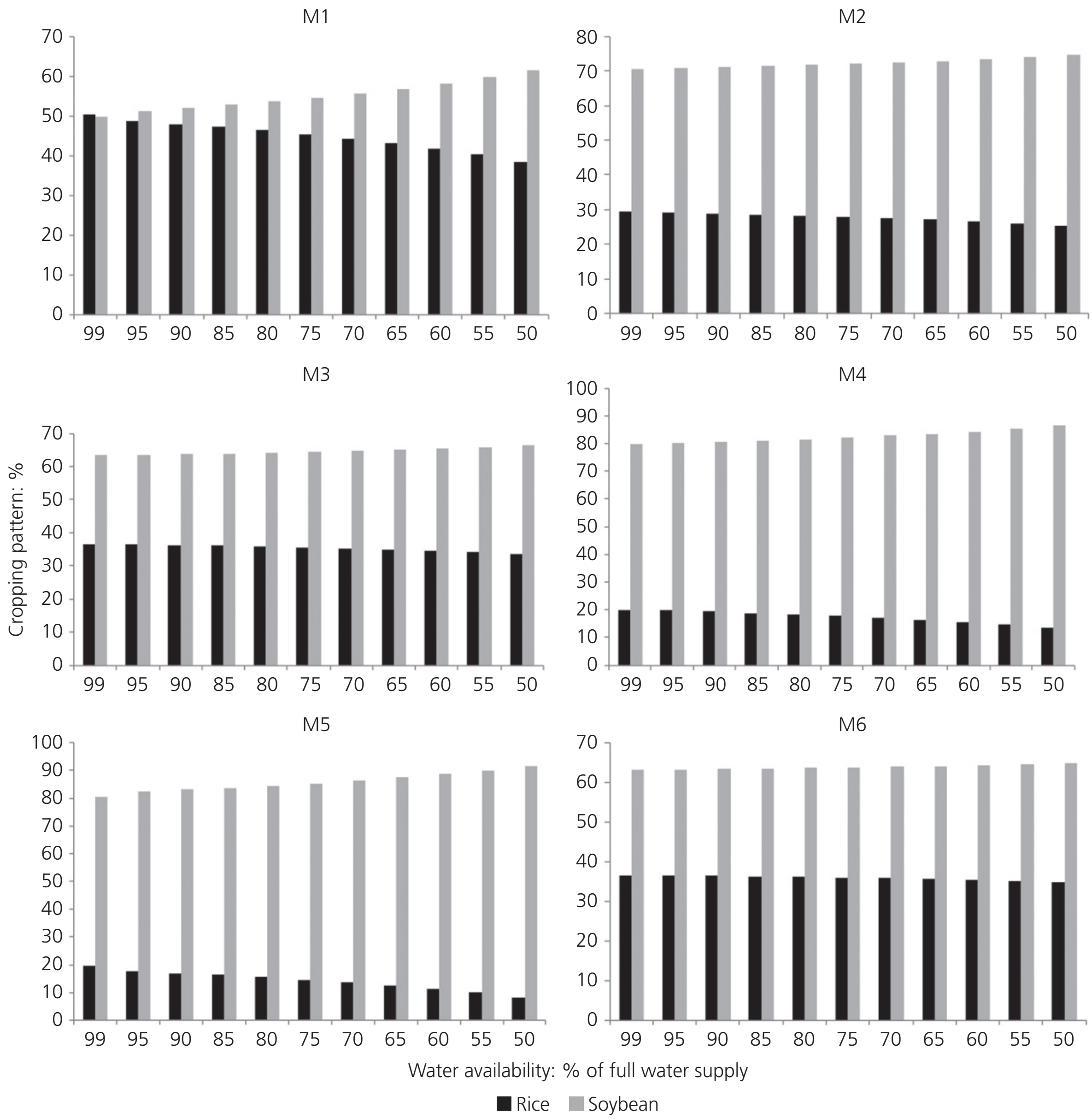

Figure 3. Change in cropping patterns in the six regions according water scarcity

effective water management to users and it provides an economic basis for a volumetric definition of shortage.

Figure 4 shows scarcity cost curves for the six studied regions. These curves were calculated by integrating the marginal water benefit curves between a given water supply and full demand (i.e. the point where scarcity is zero). These indicate the lost economic benefits to irrigated agriculture in a given year under limited water availability.

During a visit to the SMRB, several farmers reported two droughts that had a negative impact on agricultural production – the crop years 2006/07 and 2011/12. Cropped areas for rice and soybean for each municipality of the SMRB are shown in Figure 5 (IBGE, 2015). The figure shows that, during the droughts, the rice area was reduced by up to 37% while soybean crop areas were reduced by up to 45%. This section presents further detail on the droughts and evaluates the impact in terms of water scarcity and scarcity costs.

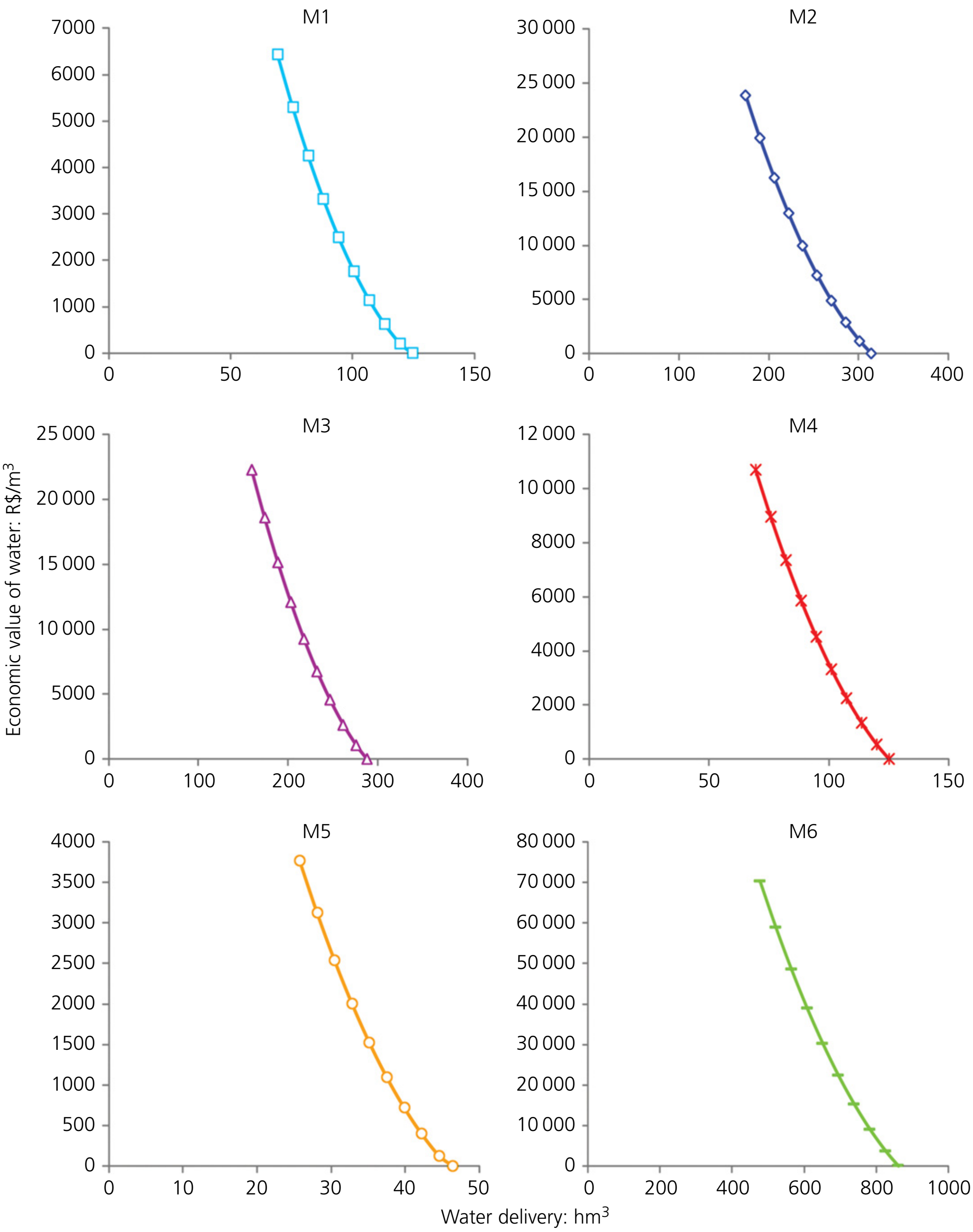

Figure 4. Water scarcity cost curves for the six regions of the SMRB

The annual average streamflow in the Santa Maria River and accumulated annual precipitation in regions M6 (Dom Pedrito) and M3 (Rosário do Sul) are shown in Figure 6 (ANA, 2017). In region M3, rain data for years 2009 and 2010 were completed with satellite-observed precipitation (Rozante *et al*., 2010). The dry periods of 2006/07 and 2011/12 are characterised by a reduction in streamflow and low annual precipitation in years 2006 and 2011. The average precipitation for the SMRB is 1444 mm/year (ANA, 2006).

The flow duration curves for the Santa Maria River for the years 2006 and 2011 and the complete series for region M6 (2000–2016) and region M3 (1967–2016) are shown in Figure 7. The curves for both 2006 and 2011 are below the complete series curves, indicating that water availability in those years was lower than the long-term average. These results reinforce the information obtained from farmers and the crop area data.

To estimate the scarcity cost for the drought years 2006/07 and 2011/12, it was assumed that if there was no change in water availability farmers would have cropped similar areas as in the previous and following years. Therefore, the average cropped area from years 2005/06 and 2007/08 minus the cropped area from year 2006/07 for each region was the uncropped area due to water shortage. The same calculation was done for the year 2011/12. Determining the uncropped area allowed estimation of the amount of water needed in the drought periods, which was used along with the scarcity curves presented in Figure 4 to obtain the scarcity cost. Other exogenous variables such as crop prices and yields were assumed to be unchanged.

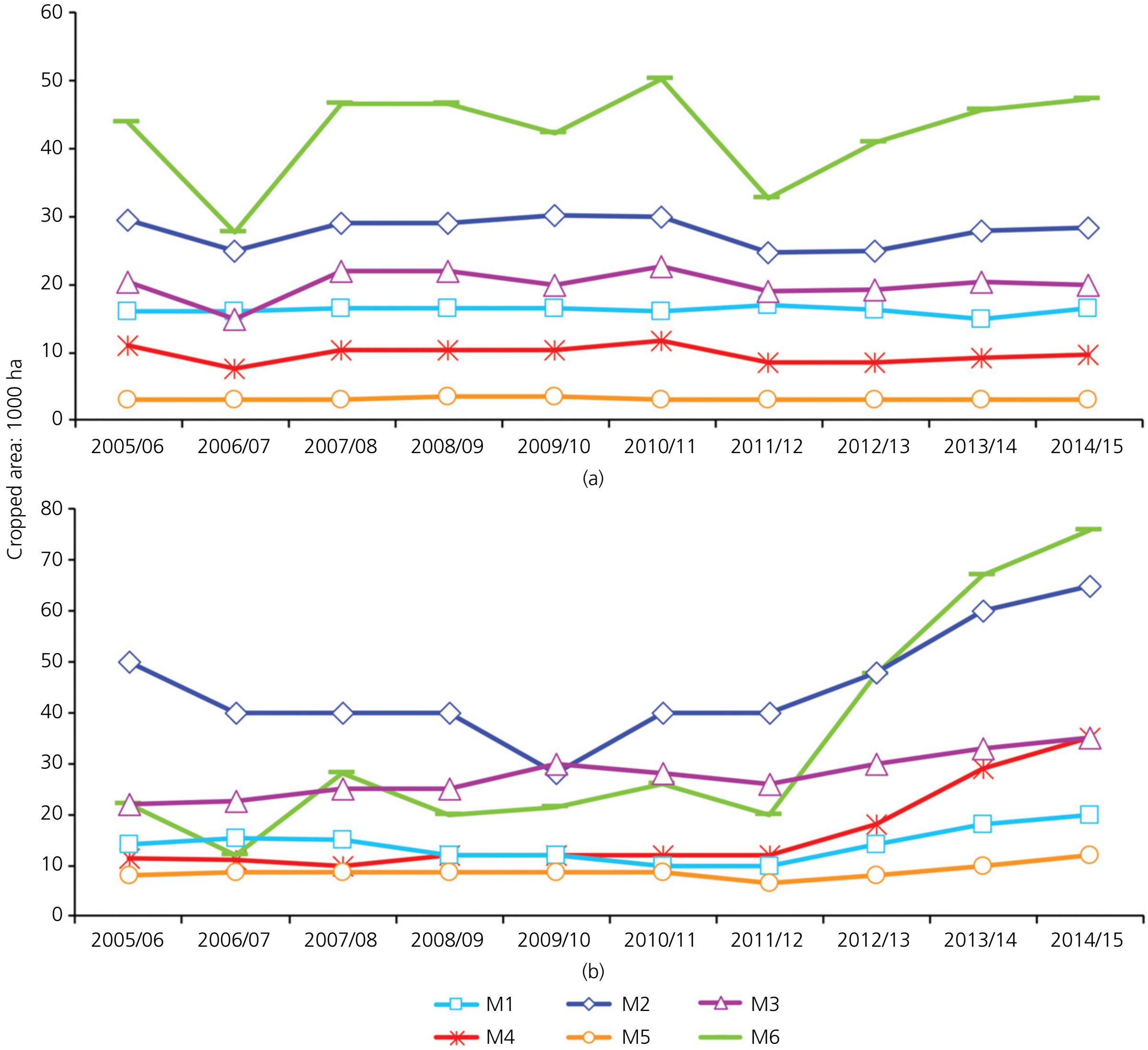

Figure 5. (a) Rice and (b) soybean planted areas (2005–2014). A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com)

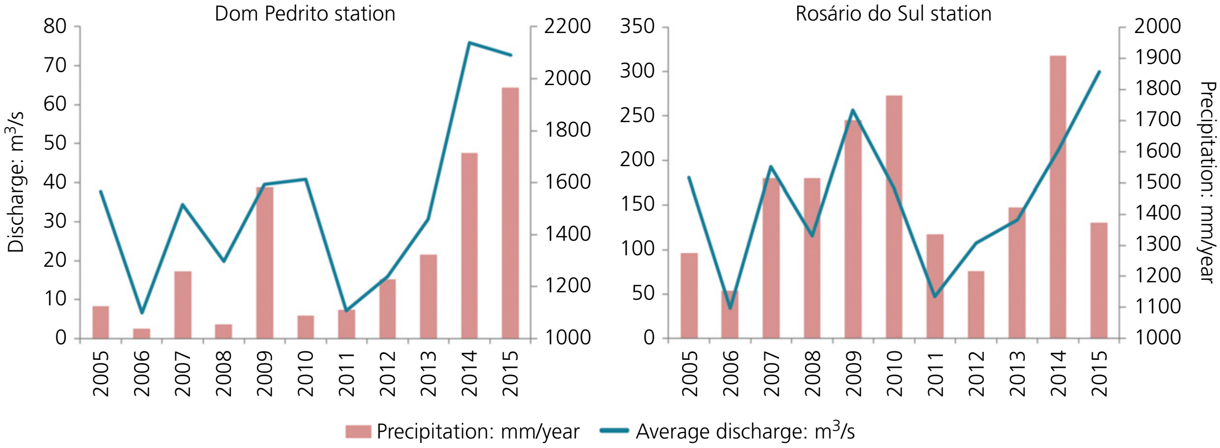

Figure 6. Annual average stream flow and accumulated annual precipitation of the Santa Maria River

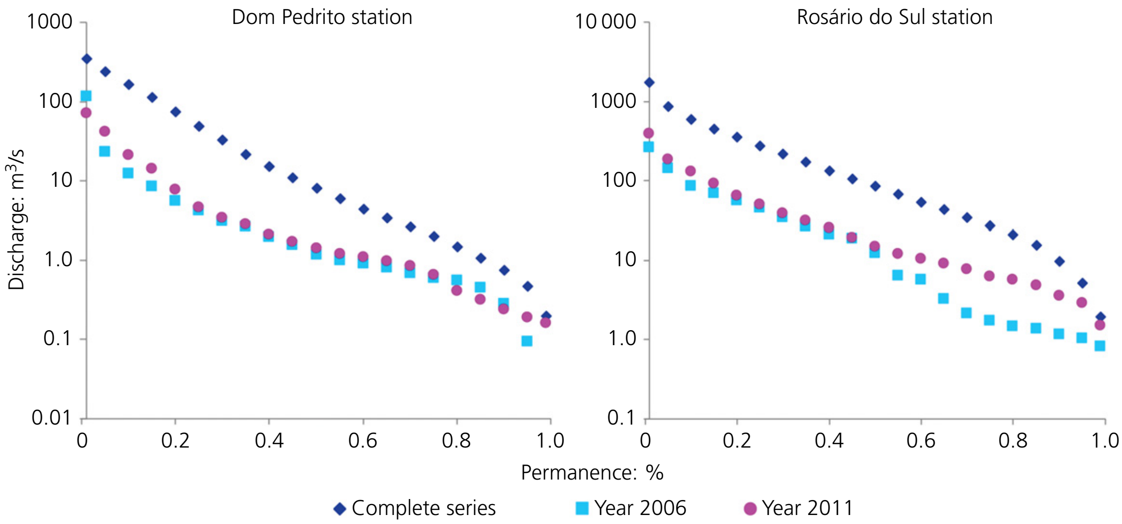

Figure 7. Flow duration curves for Santa Maria River for years 2006 and 2011 and the complete series for Dom Pedrito (M6) (2000–2016) and Rosário do Sul (M3) (1967–2016)

The calculated scarcity costs during the investigated drought years are presented in Table 3. The total planted areas of rice and soybean (Figure 5) were weighted by the area of the county within the limits of the SMRB (IBGE, 2015). The amount of water was derived from the consumption of water by the crops (hm^3/ha) (Embrapa, 2005; IRGA, 2015). As shown in Table 3, the scarcity cost was found to be in the range R$61 000–57 206 000. The total scarcity cost for all six regions was calculated to be approximately R$71 million in 2006/07 and R$66 million in 2011/12. These values represent the lost economic benefits to farmers, which could be mitigated by improving water management in order to provide drought responses.

Using different sources to increase water availability can improve water system resilience and generate benefits for agricultural regions (Pulido-Velazquez *et al.*, 2004). The scarcity costs were compared with the net returns of producers in the studied regions, and the results are shown in Table 4. The net return was calculated by the production gross return minus production costs using the same information as the input for the SMRB agricultural production model described earlier. The results show that the scarcity cost ranged from 1% of the total net returns in region M1 (2011/12) up to 15.5% in region M6 (2006/07). This range is due to the large variations in cropped areas among the different regions.

The results in Tables 3 and 4 highlight the importance of effective water management and governance systems for the economy and society. The SMRB management plan (DRH/Sema, 2016) is a 20-year programme that sets out several

Table 3. Scarcity cost of the years 2006/07 and 2011/12 for the six regions

	Rice (1000 ha)		Soybean (1000 ha)		Water scarcity: hm^3		Scarcity cost: 1000 R$	
Region	2006/07	2011/12	2006/07	2011/12	2006/07	2011/12	2006/07	2011/12
M1	0.1	—	—	1.0	1.4	11.0	61	457
M2	2.0	2.4	1.3	1.9	51.0	36.9	5612	3930
M3	4.4	0.7	1.3	2.1	58.1	39.3	6994	4483
M4	1.3	—	0.7	1.3	14.6	23.2	1803	3011
M5	—	—	—	0.8	—	4.4	—	305
M6	16.6	12.2	12.1	15.8	332.3	320.5	57 206	54 370

Table 4. Scarcity cost percentage of net return for the six regions

		Scarcity cost: 1000 R$		Scarcity cost percentage of net return: %	
Region	Net return: 1000 R$	2006/07	2011/12	2006/07	2011/12
M1	47 818	61	457	0.1	1.0
M2	137 278	5612	3930	4.1	2.9
M3	133 519	6994	4483	5.2	3.4
M4	58 092	1803	3011	3.1	5.2
M5	23 295	—	305	—	1.3
M6	369 587	57 206	54 370	15.5	14.7

actions towards improving water management; the total cost of this programme was calculated to be R$1.3 billion. One specific action is dedicated to increasing water storage and distribution, and this accounts for 84.5% of the total cost (approximately R$1 billion). The scarcity costs calculated in this work demonstrate that two recent droughts in the SMRB have cost over R$138 million in foregone agricultural economic benefits – this figure represents about 14% of the development programme budget on water storage and distribution.

A study by the Department of Economics and Statistics of Rio Grande do Sul calculated the economic impact of droughts on the state's municipalities (Colombo and Pessoa, 2013). The main findings were that, between 2003 and 2013, gross domestic product (GDP) growth in municipalities that experienced droughts was smaller than that in the municipalities without droughts, with a difference between the GDPs of up to −9.8%. The study observed that drought events were especially recurrent in the northeast, west and south regions of the state and have been causing losses in the municipalities' GDPs and increasing regional disparities. It was suggested that actions towards making the economy less vulnerable to climatic oscillations were a priority for the development of the state.

A more recent study by the same department showed similar findings about the drought of 2012 (Zanin, 2012). Predicted production for 2012 was compared with actual production and it was found that losses in the gross value of the total production in Rio Grande do Sul were up to R$2.9 billion, with soybean and rice responsible for 89% of the total loss. However, it should be noted that this study was conducted before the end of the drought and therefore the actual values may be different. Zanin (2012) noted that, although the calculation used was simple, it highlighted the importance of having strategies to face recurrent droughts more efficiently and even suggested some solutions such as the construction of wells and dams and the financing of irrigation systems.

It is difficult to compare the values obtained in the present study with the results of other assessments because the methods used evaluate the impacts of water availability differently. Nevertheless, the calculations presented here indicate the importance of the design and implementation of public policies towards diminishing the negative effects of recurrent droughts.

3.4 Policy implications

Guiding principles highlighting the economic value of water are present in the Dublin statement on water and the environment (WMO, 1992), in the European water framework directive ('getting the prices right') (EC, 2000), in the Brazilian national water resources policy ('water is a limited resource and has economic value') (Brasil, 1997: p. 1) and in several other water policy regulations around the world. Yet few systems have managed to identify the economic value of water properly and implement it in management policies. This is easy to understand when the economic instruments for water management fail to communicate scarcity to users and there is a lack of financial resources necessary to ensure a well-functioning governance and management systems. While water management and governance have a cost, the absence of the same is likely to have more costs to water users and society in the long run. The findings in the present study suggest the following five major policy implications.

(*a*) *Improving development programmes.* This is especially the case for investment in storage, new water supply sources and improved efficiency to increase water security for users.
(*b*) *Integration with other sectoral policies to improve funding security.* There is limited integration between water policies and agricultural development policies in Brazil, and information about scarcity costs could be used to establish a common ground to negotiate funding and investment opportunities towards solutions that reduce farmers' vulnerability to droughts. These investments could be planned from a watershed and water management perspective rather than an exclusive agriculture benefit standpoint.
(*c*) *Integration with environmental policies.* By improving water reliability for irrigated agriculture, which is the most significant water use in the region, the competition for water would be reduced and the flexibility and adaptation capacity of the whole water system could be improved. In this case, environmental water uses – which are often the first to be compromised during droughts – could also benefit. If environmental policies determine how much water is needed and the temporal flow regime, both development programmes and infrastructure operation could be adapted to meet both agricultural and environmental demands. If trade-offs arise, which is likely, the MVW and scarcity cost could be used to evaluate the opportunity costs of meeting environmental demands, which is the starting point for negotiating a fair cost distribution with users.
(*d*) *Economic water management instruments.* Water charging schemes currently under discussion for the studied region are close to the lower bound of the MVW, which implies that very limited – if any – change in water use should be expected if water charges close to 0.01 or 0.02 R$/m^3 are implemented. However, direct application of the MVW as the water charge should not be expected: it is first necessary to identify which water uses (and where) present opportunities to improve rational use with design charges varying according to these opportunities. In Brazil, urban water demands take priority of water deliveries under conditions of scarcity and this often results in irrigation systems being requested to stop withdrawals during certain periods. Given that not all urban demands are for human consumption (there are system losses and other non-potable uses), the opportunity cost of water during a drought could be used to establish temporary water charges to urban demands with the purpose of signalling scarcity during critical periods and curbing consumption for lower value non-potable uses, thus creating an economic compensation reserve to fund drought insurance in the region.
(*e*) *Local adaptation*. Integrated agricultural and water management policies can contribute to improving the resilience of irrigated agriculture to drought. Farmers' adjustments of inputs and production as a response to changing water availability conditions are likely to be reflected in the crop mix (local adaptation). However, to evaluate if those changes are indeed feasible, other aspects should be analysed, including farmers' risk aversion, income distribution, access to credit and water infrastructure, local and regional markets, opportunity costs and so on.

As already mentioned, the economic values presented in this study are a lower bound of the real economic value of water management. In order to design and implement effective water management policies, other aspects need to be considered, such as the maintenance of ecosystem services, cultural and aesthetic benefits, social wellbeing, opportunity costs and so on.

4. Conclusions

The economic value of water and the associated scarcity costs during drought events were determined for a region of soybean and rice agriculture in southern Brazil. These results were framed into policy implications that explore how water management instruments could be improved and implemented.

The major findings from this study are as follows.

(*a*) *Reference value for economic water management instruments.* The marginal value of water (MVW) was found to be 0.02–0.09 R$/m^3, which is higher than the water charges often adopted in Brazil and those proposed for the SMRB in recent studies.
(*b*) *Opportunities for water management under changing conditions.* Shifting the crop mix could be a local adaptation strategy to maintain economic benefits and/or reduce losses under changing water availability. While crop mix change was not significant (matching the reality that not all rice areas are suitable for soybean production), it does provide opportunities for water demand management decisions. Knowledge of how cropping patterns are geared towards value can give direction to economically efficient water allocation in a watershed. Temporary water reallocation schemes to different crops have been used in Brazil in the past – detailed information about water value and scarcity costs could contribute to a better understanding and design of such programmes in the future.
(*c*) *Economic impacts of scarcity cost*. Scarcity cost due to low water availability was found to account for 1–15.5% of net return of irrigated agriculture of rice and soybean in the SMRB. The total scarcity cost for two drought

periods (2006/07 and 2011/12) in all six regions of the SMRB was estimated to be approximately R$138 million.

(*d*) *Economic benefits of water management actions and programmes.* Water management to improve resilience against drought can be costly. The SMRB management plan has actions dedicated exclusively to increasing water storage and distribution over 20 years, costing approximately R$1 billion. The scarcity costs calculated in this work indicate that two recent droughts in the basin represented approximately 14% of the development programme budget on water storage and distribution.

It is important to recognise that, although scarce water has economic value, it is not always clear how to incorporate this monetary value into effective water management because the values and scarcity costs are unknown or because there are no clear policies to signal that value to users. The policy implications provided in this paper highlight some opportunities, with special focus on policy integration to improve funding solutions and design more effective economic instruments. While users rely on water resources management to improve water supply reliability and reduce vulnerability, guaranteeing financial security to management projects can be improved by bringing together other sectoral policies and funding.

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