

## ASSESSING GROUNDWATER POTENTIAL USE FOR EXPANDING IRRIGATION IN THE BURITI VERMELHO WATERSHED

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### 1 ABSTRACT

In Brazil, the increasing middle class has raised food demand substantially. The Brazilian Savannah (Cerrados) is one of the rare places where agriculture can expand and address this new demand without jeopardizing the environment. Cerrados has a strictly divided dry and wet season. The dry season lasts from May to September. This long period contributes to various problems such as water shortages, conflicts and insecure food production. Without irrigation, only two crops can be grown per year in this region. Production suffers with a recurrent drought. Because agricultural production is uncertain, irrigation has an important role in this context, but its expansion is limited by water availability. Water conflicts have already occurred in some watersheds, which may jeopardize agriculture and decrease the livelihood of rural communities. In general, water for irrigation is limited to surface water. Therefore, it is important to investigate alternative sources of water, like groundwater. The purpose of this study is to assess the groundwater potential for expanding the irrigated area in a small-scale catchment (Buriti Vermelho, DF, Brazil). The current water demand was investigated and simulated by an Irrigation Strategies Simulation Model (MSEI). A daily water balance was computed, which quantified catchment storage over time. In addition, groundwater behavior and availability were investigated by recession curve analysis. The irrigated area was changed using two scenarios that showed different effects in both catchment surface water balance and groundwater levels. A decline in groundwater levels is seen in all scenarios one year after the beginning of extra extraction. With time, water levels may decline beyond the natural recovery capacity, which will certainly penalize poorer farmers and result in areas being taken out of agricultural production.

**Keywords:** Base flow Recession, Catchment Hydrology, Hydrogeology, Crop Water Productivity

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## 2 RESUMO

A demanda por alimentos no Brasil cresceu substancialmente devido, entre outras coisas, ao aumento da classe média. O Cerrado brasileiro é um dos poucos lugares no país onde a agricultura ainda pode expandir e atender a essa nova demanda, sem comprometer o meio ambiente. A região do Cerrado possui duas estações climáticas bem definidas, uma seca e outra chuvosa. O longo período da estação seca, que vai de maio a setembro, contribui para o surgimento de vários problemas, entre eles restrições hídricas, conflitos e insegurança na produção de alimentos. Sem irrigação, apenas dois plantios podem ser feitos por ano. Os cultivos sofrem com os veranicos e a produção é incerta. A irrigação é de fundamental importância nesse contexto, mas sua expansão é limitada pela disponibilidade de água. Em algumas bacias hidrográficas já se observam a ocorrência de conflitos, que podem comprometer a agricultura irrigada e a qualidade de vida das comunidades rurais. De maneira geral, a água para irrigação é de superfície. Desta forma, é importante investigar fontes alternativas de água, com vista ao crescimento da irrigação, tais como a água subterrânea. O Objetivo deste trabalho é avaliar a viabilidade de se utilizar água subterrânea para expandir a agricultura irrigada na bacia hidrográfica do Buriti Vermelho, DF, Brasil. A demanda atual de água foi estimada por meio de um modelo de simulação de estratégias de irrigação (MSEI). Um balanço diário da água no solo foi realizado. O comportamento e a disponibilidade de água subterrânea foram avaliados por meio de uma análise da curva de recessão. Para fins da análise, foram utilizados três cenários de área irrigada, que indicaram diferentes efeitos tanto no perfil do balanço de água no solo quanto no nível do lençol freático. Nos três cenários avaliados, em apenas um ano após a expansão da área irrigada, verificou-se um rebaixamento do lençol freático, que pode atingir níveis abaixo da sua capacidade natural de recuperação. Esse rebaixamento penalizará principalmente os agricultores menores. Em alguns casos haverá necessidade de interromper a produção em algumas áreas.

**Palavras-chave:** Curva de recessão, hidrologia, hidrogeologia, produtividade do uso da água

## 3 INTRODUCTION

The demographic distribution in Brazil is changing rapidly due to economic growth of the middle class. This change results in a change of diet on national level. Brazil's agriculture faces a challenge in meeting the increasing food demand. From 1996 to 2008, a growing trend (12%) is seen in the domestic product of agriculture (Valdes et al., 2009). Currently food production needs to be expanded, although the possible areas for agriculture expansion are limited in a wide range. The Brazilian Savannas (Cerrados), which represents 24% of Brazil's territory, has great potential for increasing agriculture.

However, water availability is becoming a limiting factor. Approximately 90% of the precipitation falls during the monsoon. The long dry season lasts from May to September. Water availability is limited during the grow season that increases the likelihood of successful irrigation in the dry season (Van Vliet 2012). Only two crops can be grown in rain fed conditions. Hence, the potential to increase food production with irrigation is large. Water supply is crucial to overcome recurrent droughts. Water should be used efficiently to avoid a shortage of water that might occur due to an expanded irrigated area. Extensive water use for agriculture may jeopardize water supply for communities. In fact, conflicts have already been

reported in some regions, despite the strict regulations for water use by the Brazilian law (Maneta et al., 2009b; Balazs, 2006).

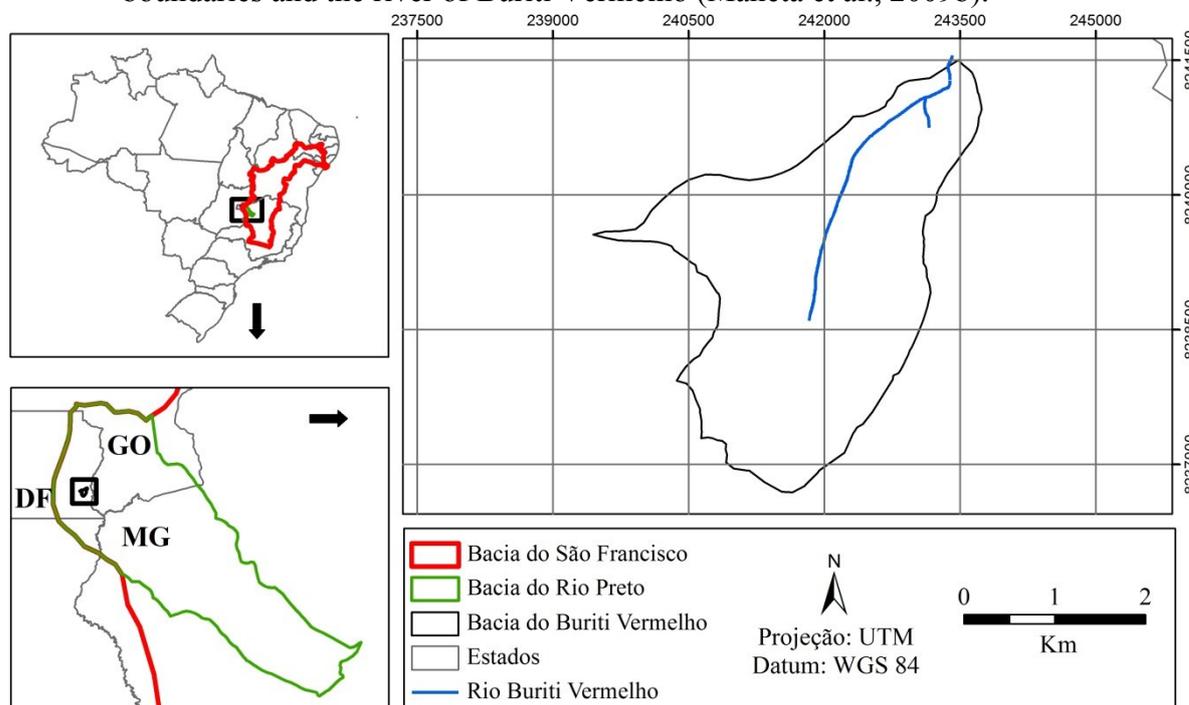
With the need to increase food production, irrigation areas are expected to increase, and therefore more water will be required. Innovation and advanced irrigation systems will help to save water, but water supply is still limited to surface water. Possibilities for agricultural expansion using surface water were investigated by Maneta, et al. (2009) and Van Vliet (2012). However, the potential for groundwater is still uncertain. Analyses indicated that Buriti Vermelho is a groundwater fed river and the substantial rainfall surplus indicates a significant groundwater recharge in the monsoon (Van Vliet, 2012). The aquifer(s) in this catchment seem to be shallow and accessible. If these aquifers characteristics are estimated correctly, there will be a large potential for groundwater extraction by wells. This alternative source would boost local agriculture to address the increasing food demand.

Groundwater irrigation gets increasingly more attention. Irrigation water would be readily available at any moment and accessible at any irregular land surface (Maneta et al., 2009a). Despite of the potentials, groundwater irrigation is rarely applied in the Cerrados. The objective of this study is therefore to investigate groundwater possibilities for expanding irrigated areas in the Buriti Vermelho watershed.

#### **4 MATERIAL AND METHODS**

The study area, Buriti Vermelho (BV), is located in the East of District Federal in Brazil (Figure 1). BV is part of the larger São Francisco river basin (approx. 630,000 km<sup>2</sup>), which borders are marked in the upper left map of Figure 1 (Maneta et al., 2009b). This research focused on a sub-basin of São Francisco in which BV site covers a small area in Rio Preto. A detailed map is shown at the right hand side of Figure 1.

**Figure 1.** Location of Buriti Vermelho in Brazil. The left figures indicate the São Francisco river basin in red and the sub-basin Rio Preto in green. The right hand side shows the boundaries and the river of Buriti Vermelho (Maneta et al., 2009b).



BV is a first order basin of 941 ha. The catchment is located on a small plateau with an average altitude of 1,100 m. The plateau is drained by two small streams, of which one is Rio Buriti Vermelho. BV's drainage area is defined by the surface water divide (no-flow boundaries). The climate of BV is characterized by the plateau (tropical highland), resulting in an average temperature of 21 °C. Annual precipitation varies from 1,200 mm up to 1,700 mm. The majority falls in the wet season (October until March). The rest of the year is defined as dry season, in which evapotranspiration exceeds often the precipitation (Castro et al., 2009).

In BV, a thick layer of Ferralsol (Oxisol) is dominantly present. Smaller areas of Cambisol and Gleysol are found in respectively the SW and NE of the catchment (Castro et al., 2009). The Ferralsol is often highly physical and chemical weathered. Due to the weathering, high concentrations of iron and aluminium oxides are present in the soil. Despite the high clay percentage, physical properties resemble pseudo-silt or pseudo-sand. Therefore, the defined soil texture is sandy clay. Strong micro-aggregates form a loose structure in which water can move and infiltrate easily.

The land use is dominated by rain fed agriculture and irrigation. The rain fed crop cycle is determined by the growth of soybean, maize, and sorghum. The irrigated crop rotation is defined by the growth of maize, beans, and wheat (Maneta et al., 2009a). These three crops are sometimes alternated with soybean (Cenci, 2013). The total irrigated area is defined by three pivots (229 ha) in BV. Another source of water use in the area is determined by small-scale farmers that irrigate vegetables, orchards, and limes (Maneta et al., 2009a). A minority of the land is covered with pasture, riparian area and some original Cerrados vegetation. Recent observations indicate that agricultural areas have already expanded in BV. The typical Cerrados vegetation was cultivated with rainfed crops in June 2013. The conversion to agriculture land affects the water use in the catchment. These changes may jeopardize the water availability for the community.

The collected data consisted of climate observations that were obtained by a meteorological station in BV, at which daily and hourly measurements were recorded from 2008-2012. The following variables were measured: air temperature ( $^{\circ}\text{C}$ ), humidity (%), wind speed ( $\text{m s}^{-1}$ ), solar radiation ( $\text{W m}^{-2}$ ) and precipitation (mm). Two other meteorological stations placed outside the catchment (PADF and CPAC) recorded daily observations (for 13 and 31 year) that were used as a reference. Gaps in the hourly database were replaced and a few unrealistic observations (e.g. negative humidity) were linearly interpolated. Moreover, discharge rates were measured every 5 minutes at the outlet of the catchment. Missing observations or errors could not be replaced. However, their influence was marginal. For some days, sudden decreases/increases were interpolated.

Data quality was examined using a correlation analysis and a double mass curve. These methods examined if the data are representative on a longer time scale. The correlation analysis compared the long-term mean of BV with the 13 year-average of CPAC and PADF. The double mass curve was performed to verify possible inconsistencies. Two cumulative precipitation series were used to examine their proportional relationship (Mirás-Avalos et al., 2009). In case of systematic errors, rainfall was corrected by Thiessen polygons to adjust for non-uniformly distributed observations. Similarly, discharge observations were examined. Regarding the continuity of discharge records, irregularities were found using a probability distribution. Moreover, this distribution could be used to correct the measurements (Razzorenov, 1980).

In BV, the long-term catchment water balance would be zero, if groundwater is not considered a source/sink. Using this principle, the balance was used to identify the groundwater supply in BV according to Equation 1. The balance is driven by two incoming components; precipitation and irrigation. Water leaves the catchment via evapotranspiration and discharge. It should be mentioned that irrigation would be only included, when water is imported in the catchment. Irrigation from the reservoir was assessed as a recirculation of water and therefore it was excluded from the balance.

$$\Delta S = P + I - ET_a - Q \quad (1)$$

Where: P = precipitation (mm); I = irrigation (mm);  $ET_a$  = actual evapotranspiration (mm); Q = discharge (mm)

Theoretically, P is considered to be total precipitation, assuming that surface runoff would be counted in discharge (Q) in the catchment water balance. The overland flow can be differentiated in Hortonian (Horton, 1993) and Dunian (Dunne and Leopold, 1978). Several methods are known to analyze the Hortonian overland flow. One method is published by Allen et al., (2008), which is more simplified and generalized. They recommend a fixed 80% of infiltrated rainfall below events of  $100 \text{ mm h}^{-1}$ . One major disadvantage is that regardless the intensity, a part is assumed to be runoff.

In this study an exponential curve was made based on (hourly) events measured in BV catchment, supplemented by literature examples. Infiltration during the events was determined by the complement of the runoff coefficient (ROC), which is determined by the relationship between volume of runoff and precipitation. Hereby is assumed that all precipitation will either infiltrate or flow over the surface during the event. Evaporation is not considered during the rainfall event. Single precipitation events ( $>10 \text{ mm h}^{-1}$ ) were selected from the database, other events were considered non-erosive (Da Silva, 2009). The volume of runoff was computed by a constant-discharge base flow separation (Gonzales, 2009). In addition to the observations, literature examples were selected on similar runoff characteristics as observed at the field

location (Da Silva, 2005; Mirás-Avalos et al., 2009). Therefore similar soil type, vegetation cover, and slope were used for the selection criteria. Finally, 15 values were selected to plot an exponential curve.

Actual evapotranspiration ( $ET_a$ ) was calculated in several steps. First, grass reference evapotranspiration ( $ET_0$ ) using ASCE Penman-Monteith equations (FAO, 1998), was calculated. The reference evapotranspiration is converted into potential using a crop factor and  $ET_a$  using a water stress coefficient based on the available soil moisture. Therefore, a simulation of crop growth and demand was made by an Irrigation Strategies Simulation Model (MSEI by Rodrigues (2013)). Both evaporation results and irrigation simulations were used in the surface water balance.

MSEI is designed to estimate the water demand for cultivated crops in the Cerrados. This model is based on the irrigation model by George et al. (2000). The irrigation rotation is determined by a soil moisture balance and crop growth monitoring. Irrigation frequency relates soil moisture to the maximum allowable depletion (MAD) of the soil. These soil characteristics (field capacity, wilting point, bulk density) were determined by 25 measurements that were averaged for the simulations.

Finally, four years were simulated for irrigated and rain fed crops. Cropping dates of Van Vliet (2012) were used.  $ET_a$  between cultivations was computed for evaporation only (fallow) (Rodrigues et al., 2005). The water loss is then determined by a soil parameter ( $\alpha$ ), described by an exponential function, Equation 2. Other land uses than agriculture (i.e. riparian area and pasture) were assumed to act similar as rain fed cultivation.

$$E = \alpha * t^{-\frac{1}{2}} \quad (2)$$

Where:  $t$  = time, days;  $\alpha$  = soil evaporation rate,  $\text{mm d}^{-1/2}$ ;  $E$  = evaporation,  $\text{mm d}^{-1}$

Groundwater characteristics and availability in BV were analyzed by the discharge observations. Autocorrelation and cross-correlation diagrams were used to compute the catchment's memory time. In addition, base flow recessions indicated general storage capacities and aquifer characteristics (Tallaksen, 1994). Recession curve analyses are based on discharge measurements: 'the gradual depletion of discharge during periods with little or no precipitation constitutes the drainage or recession rate' (Tallaksen, 1994). Long recessions ( $P < 1\text{mm}$ ) were selected. Multiple recessions could be compared, since BV is a single linear catchment (Tallaksen, 1994). The curves formed a linear relationship as a function of time at a semi-logarithmic scale, Equation 3 (Shevenell, 1996). This slope was used to formulate the relation between discharge and storage (Rahunath, 2006). The daily depletion factor ( $e^\alpha$ ) indicates the amount of days before the lowest storage is reached (Rahunath, 2006). The total groundwater storage is the integral of this recession curve.

$$Q_t = Q_0 e^{-\alpha t} \quad (3)$$

Where:  $Q_t$  = actual recession discharge,  $\text{m}^3 \text{d}^{-1}$ ;  $Q_0$  = initial discharge,  $\text{m}^3 \text{d}^{-1}$ ;  $\alpha$  = Recession coefficient,  $\text{d}^{-1}$ ;  $t$  = days.

Annual variations within the selected recessions were overcome by the master depletion curve (MDC) that formulated one general storage equation, Equation 4 (Berhail et al., 2012). These characteristics resulted in the recession constant for the recession curve. The specific

time interval and time lag were chosen according to the length of the recession (Nathan and McMahon 1990).

$$K = 10^{-\alpha} = \left( \frac{Q_t}{Q_0} \right)^{1/t} \quad (4)$$

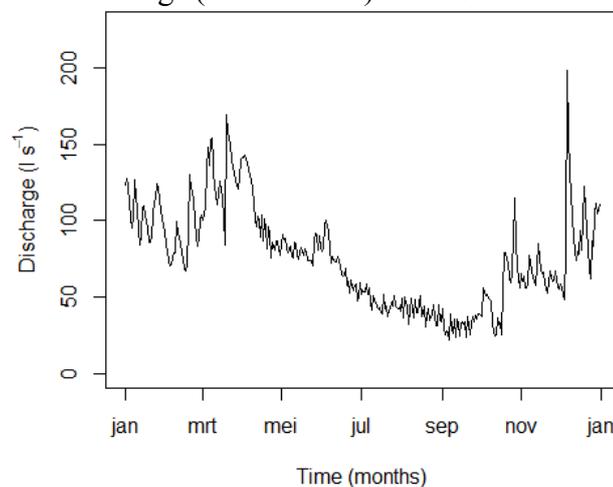
Groundwater behavior was analyzed by hydrographs of the groundwater levels. Three piezometers in BV showed annual variation that was used to characterize storage of the aquifers with a similar method to the surface water recession curves. The coefficients of the groundwater recession limbs indicated the specific yield, which is the amount of water that was drained or stored relative to the de/increase of the water table (Shevenell, 1996).

The effect of expanding irrigation using groundwater was verified by different scenarios. These scenarios investigated the effect of changing land use on the water balance. The current water balance was used as the basis for the possible increase of agricultural areas. The land use changed evapotranspiration and irrigation components in the water balance and this change is related to the annual groundwater storage using the aquifer characteristics.

## 5 RESULTS AND DISCUSSION

The correlation analysis indicates that BV's weather station records systematically and significantly less rain (approximately 400 mm) over the last 5 years (single tailed t-test,  $\alpha=0.05$ :  $P<0.05$ ). The double mass curve shows little fluctuations and the measurements series are consistent compared to CPAC and PADF ( $R^2>0.95$ ) (Mirás-Avalos et al., 2009). However, the systematic lower observations required a correction for the areal precipitation using Thiessen polygons. Double mass curves cannot correct for a systematic overestimation (Dahamsheh and Aksoy, 2007; Searcy and Hardison, 1960). Based on the spatial influence weight factors are determined (BV 58%, CPAC 8%, PADF 34%), which correct the precipitation with 167 mm annually. Including the correction, the precipitation is consistent and in agreement with CPAC and PADF. Discharge observations show a large annual variation with a consistent base flow of 30-40  $l\ s^{-1}$ , as shown in Figure 2. This variation is consistent with the used probability distribution. Hence, data correction is not necessary.

**Figure 2.** Measured annual discharge (data of 2010) at the outlet in Buriti Vermelho catchment.



Annual storage is defined by the water balance components. The balance is based both on measured (precipitation and discharge) and modeled variables (irrigation and actual evapotranspiration). A small portion runoff is identified in the hydrograph. The highest precipitation intensity reaches up to 23 mm h<sup>-1</sup> that causes approx. 1% of runoff. Literature examples indicate 2% runoff with events over 30 mm h<sup>-1</sup>. The small difference indicates that runoff is negligible even for larger precipitation intensities. Hence, precipitation is not corrected for a small runoff proportion. Evapotranspiration was computed by the growth cycle and the cropping dates (Table 1). The actual evapotranspiration is modeled by MSEI and by the cultivated area converted to volumes. MSEI provided both evapotranspiration and irrigation. Only one of the center pivots uses water from a small surface reservoir in BV. As this reservoir is filled with rainfall from within the catchment, it is not accounted as source term. The other two pivots use extracted water from outside the catchment. Hence, this share of the irrigation water is seen as a positive component in the water balance.

**Table 1.** Irrigated and rain fed crop rotation dates, total evapotranspiration (ET<sub>a</sub>) and the total irrigation in BV.

	<b>Crops</b>	<b>Planting date</b>	<b>Harvest date</b>	<b>Growth period (days)</b>	<b>Total ET<sub>a</sub> (mm)</b>	<b>Total irrigation</b>
Rain fed Crops	<b>Maize</b>	18-Feb	16-Jun	130	231	-
	<b>Soybean</b>	01-Oct	08-Feb	118	347	-
	<b>Fallow</b>	-	-	105	61	-
Irrigated	<b>Beans</b>	08-Mar	20-Jun	105	338	229
	<b>Wheat</b>	02-Jul	20-Oct	120	472	397
	<b>Maize</b>	01-Nov	26-Feb	118	365	110
	<b>Fallow</b>	-	-	32	34	-

The annual storage is computed by the combination of all components of the surface catchment water balance (Table 2). The results for 2008-2011 are averaged to give a general view of the catchment in- and outflows. A consistent shortage is found that hints a non-surface water source to sustain a natural equilibrium. The storage shortage is estimated on 55 mm y<sup>-1</sup> (16.4 l s<sup>-1</sup>). Note that storage is determined as a rest term in the water balance. Therefore the absolute number should be considered as a general indication for the storage in BV.

**Table 2.** Averaged surface water balance for BV (averaged over 4 years of data).

	<b>Water balance components (mm y<sup>-1</sup>)</b>	<b>Area (km<sup>2</sup>)</b>	<b>Water balance components (Mm<sup>3</sup> y<sup>-1</sup>)</b>
<b>Precipitation (P)</b>	+1008	9.4	+9.47
<b>Total Evapotranspiration Rain fed (EVR)</b>	-790	7.1	-5.60
Soybean	503	7.1	
Maize	226	7.1	
Fallow	61	7.1	
<b>Total Evapotranspiration Irrigated (EVI)</b>	-1317	2.3	-3.05
Beans	333	2.3	
Maize	415	2.3	
Wheat	535	2.3	
Fallow	34	2.3	
<b>Irrigation (I)</b>	+829	1.8	+1.51
Beans	214	1.8	
Maize	187	1.8	
Wheat	429	1.8	
<b>Discharge (Q)</b>	-304	9.4	-2.86
<b>ΔS=P+I-EVR-EVI-Q</b>	<b>-55</b>	<b>9.4</b>	<b>-0.52</b>

\*The signs indicate the positive and negative values for the balance.

The phreatic aquifer is dominated by the weathered ferralsol layer (0-30 m). The unsaturated zone varies during the year and reaches up to 10 m in the dry season. In a comparable catchment, phreatic wells deliver up to 3.3 l s<sup>-1</sup> (Lousada, 2005). In BV, groundwater time series indicate a memory of 105 days. Cross-correlation diagrams show that discharge is independent of precipitation after this period (tested for all years). Two different aquifers are visible in the groundwater recession curves. An inflection point indicates different aquifers are supplying water in the recession period. Results differ slightly, as the transition of these two aquifers deviates for the three piezometers (Table 3). The first period (105 days) shows a fast responding component. The second trend line indicates a slower responding component. Considering the characteristics of the first order catchment and cross-correlation diagram, the 'fast' component represents probably base flow and the relatively slower responding component may be fracture flow. In terms of quantity, fracture flow would contribute 11 l s<sup>-1</sup> in 2011 (integral of recession curve). The shortage that year is determined on 19 l s<sup>-1</sup> using the catchment water balance. The fracture flow covers thus the majority of this shortage, even though a small part remains unknown. Compared to the main drivers of the water balance, this amount is relatively small (<2%). Table 3 shows an overview of the three groundwater levels (GWL) for the two years of data. For 2011, two aquifers are identified, whereas the recession of 2012 indicates only one. This single recession in 2012 has similar characteristics for its scale and timing as the slow corresponding aquifer B. In the last row general characteristics of the aquifer and its behavior are given. These summarized values for specific yield and storage are used in the scenarios.

The catchment water balance gives the base for the groundwater extraction scenarios. The first scenario is self-sufficient irrigation, in which the center pivots use water available in the catchment (Table 4). This shows the effect of imported water in BV. It should be mentioned

that the balance shows the effect one year after the current situation only and therefore the effects and implications for the change in discharge and seepage are unknown for longer time scales. The second scenario is made to simulate the increase of irrigated agriculture (Table 4). In this scenario all agricultural land is sprinkler irrigated. The non-agricultural land (riparian, pasture and village) remains constant. For this reason, a rain fed evapotranspiration component is still visible.

**Table 3.** Groundwater levels (GWL) for three wells (Aquifer A and B) using two years of data (2011 and 2012).

Year	Aquifer A				Aquifer B			
	GWL	Recession constant (m day <sup>-1</sup> )	R <sup>2</sup>	Specific yield (%)	GWL	Recession coefficient (m day <sup>-1</sup> )	R <sup>2</sup>	Specific yield (%)
2011	1	0.04	0.97	0.17	1	0.008	0.96	0.04
	2	0.03	0.83	0.17	2	0.005	0.98	0.08
	3	0.04	0.92	0.12	3	0.007	0.94	0.10
2012					1	0.01	0.95	0.11
					2	0.03	0.96	0.12
					3	0.01	0.98	0.10
Average		0.03	0.9	0.15		0.01	0.96	0.09

**Table 4.** Water balance scenarios for the Buriti Vermelho watershed.

Water balance components	Base Scenario (Mm <sup>3</sup> y <sup>-1</sup> )	Scenario 1 Self-sufficient irrigation			Scenario 2 Expanded irrigation		
		irrigation (mm y <sup>-1</sup> )	Area (km <sup>2</sup> )	(Mm <sup>3</sup> y <sup>-1</sup> )	irrigation (mm y <sup>-1</sup> )	Area (km <sup>2</sup> )	(Mm <sup>3</sup> y <sup>-1</sup> )
<b>Prec. (P)</b>	+9.47	+1008	9.4	+9.47	+1008	9.4	+9.47
<b>Total EV Rain fed (EVR)</b>	-5.60	-790	9.4	-5.60	-790	2.1	-1.65
Soybean	3.57	503	7.1	3.57			
Maize	1.60	226	7.1	1.60			
Fallow	0.43	61	7.1	0.43			
<b>Total EV Irrigated (EVI)</b>	-3.05	-1317	2.3	-3.05	-1317	7.3	-9.63
Beans	0.77	333	2.3	0.77	333	7.3	2.43
Maize	0.95	415	2.3	0.95	415	7.3	3.04
Wheat	1.23	535	2.3	1.23	535	7.3	3.91
Fallow	0.07	34	2.3	0.07	34	7.3	0.25
<b>Irrigation (I)</b>	+1.51	-			-		
Beans	0.39						
Maize	0.34						
Wheat	0.77						
<b>Discharge (Q)</b>	-2.86	-304	9.4	-2.86	-304	9.4	-2.86
<b>Seepage (S)</b>	+0.52	+55	9.4	+0.52	+55	9.4	+0.52
<b><math>\Delta S = P + I + S - EVR - EVI - Q</math></b>	<b>0</b>	<b>-161</b>		<b>-1.51</b>	<b>-441</b>		<b>-4.14</b>

Unsurprisingly, the two water balances show a larger storage shortage. It emphasizes the necessity of the imported water. In reality, negative storage is compensated by either a reduction in discharge or an increased groundwater contribution. In the following results the assumption is made that these components share the shortage equally. Using the specific yield, the shortage is translated to the groundwater table. A clear decline in groundwater levels is seen in Table 5.

To calculate the decline in groundwater table we assumed that the seepage would increase as much as the discharge was reduced. For the first scenario, it implies a compensation of 81 mm per year (24 l s<sup>-1</sup>). According to the found discharges in the fractured aquifer in Lousada (2005), groundwater flows of 26.5 l s<sup>-1</sup> are possible to restore the equilibrium. However, compared to the current groundwater inflow, this increase might cause conflicts with the water use on regional scale.

Regarding to the magnitude of this groundwater decline, the phreatic aquifer might depleted on a larger scale than only BV. Moreover, it should be mentioned that this is simulated one year after the current situation. The second year of an expanded irrigation system might result in an even lower water table and so forth until equilibrium is reached. This situation continues until a new balance is found. Regional groundwater flows are mainly determined by

the plateau at which BV is located. These flows form the recharge for the Estreito basin. If the recharge of BV decreases, regional flows may be negatively affected as BV seems to supply the majority to the Estreito River.

**Table 5.** Water balance components and groundwater levels for two scenarios.

	<b>Scenario 1</b> <b>mm y<sup>-1</sup></b>	<b>Scenario 2</b> <b>mm y<sup>-1</sup></b>
<b>Groundwater contribution</b>	-81.0	-220
<b>Change in discharge</b>	-81.0	-220
<b>Reduced storage in phreatic aquifer</b>	14.9	40.8
<b>Change in groundwater table</b>	99.4	272.2

## 6 CONCLUSION

Aquifers in Buriti Vermelho seem not able to supply the current irrigation area, independent of a possible increase in the irrigated area. The existing external water source appears to be irreplaceable by groundwater. Even if irrigation system can be expanded using aquifers' storage, a large shortage in the catchment water balance would be a likely result. All simulations show a decline in groundwater level one year after the extractions. This decline of groundwater levels will directly affect the users, as small-scale farmers are using small wells to irrigate their crops.

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