Revista Brasileira de Recursos Hídricos
Brazilian Journal of Water Resources
Versão On-line ISSN 2318-0331
RBRH, Porto Alegre, v. 27, e12, 2022
Scientific/Technical Article

https://doi.org/10.1590/2318-0331.272220220019

Protected springs water resilience in watershed of south of Brazil

Resiliência hídrica de nascentes protegidas em bacias hidrográficas do sul do Brasil

Raul Todeschini[1], Alexandre Swarowsky[2], André Gonçalves Panziera[2], Guilherme Lemes Erthal[2], João Francisco Carlexo Horn[2] & Jussara Cabral Cruz[2]

[1]Faculdade Horizontina, Horizontina, RS, Brasil
[2]Universidade Federal de Santa Maria, Santa Maria, RS, Brasil

E-mails: todeschini.raul@gmail.com (RT), aleswar@gmail.com (AS), andregpanziera@gmail.com (AGP), gerthal09@gmail.com (GLE), jfchorn@gmail.com (JFCH), jussaracruz@gmail.com (JCC)

Received: March 10, 2022 - Revised: May 11, 2022 - Accepted: May 24, 2022

ABSTRACT

Springs of the Vacacaí-Mirim river basin, in the Atlantic Forest biome, are protected by law because they provide an environmental service through water supply. No study provided identification, estimates and information about the seasonality of water resilience and environmental conditions of these springs, which supply the central region of the state of Rio Grande do Sul, Brazil. This study monitored headwater flow volume and interpreted the results through seasonality and use of the flow duration curve, characterizing the springs and showing the water production capacity. As a result, the springs presented higher flow duration curve contrasts. Considering consistent monitoring time, differences in flow characteristics occurred in the analyzed springs allowed to qualify based on their persistence, temporary or ephemeral flow, showing which springs are more resilient. The shape of the flow permanence curve was different for each spring in the basin. The study was able to determine the flow duration curve and confirm the resilience and reality of a headwater of the Vacacaí-Mirim river basin, being more accurate and necessary than estimates of flow from springs.

Keywords: Base flow; Water supply; Hydrology.

RESUMO

Nascentes da bacia hidrográfica do rio Vacacaí-Mirim, no bioma Mata Atlântica, são protegidas por lei porque prestam um serviço ambiental por meio da provisão de água. Nenhum estudo proveu identificação, avaliações e informações sobre a sazonalidade da resiliência de água e condições ambientais dessas nascentes, que abastecem a região central do estado do Rio Grande do Sul, Brasil. Este estudo monitorou o volume de vazão de cabeceira e interpretou os resultados através da sazonalidade e uso da curva de permanência da vazão, caracterizando as nascentes e mostrando a capacidade de produção de água. Como resultados, as nascentes apresentaram contrastes de curvas de duração de vazão maiores. Considerando tempo de monitoramento consistente, diferenças de características de vazão ocorridas das nascentes analisadas permitiram qualificar com base em sua persistência, vazão temporária ou efêmera, mostrando quais nascentes são mais resilientes. A forma da curva de permanência da vazão foi diferente para cada nascente na bacia. O estudo foi capaz de determinar a curva de duração de fluxo e confirmar a resiliência e a realidade de uma cabeceira da bacia do rio Vacacaí-Mirim, sendo mais preciso e necessário do que estimativas de fluxo de nascentes.

Palavras-chave: Fluxo de base; Abastecimento de água; Hidrologia.

INTRODUCTION

Permanent Preservation Areas (PPAs), in the watersheds of the Atlantic Forest biome, are recognized for their effective protection of water resources and environmental service. Across the vast portion of these regions, it is common for the water table to rise naturally to the soil surface as a result of rainfall infiltration and subsequent emergence as springs (Leal et al., 2017; Lopes et al., 2019). Different types of springs occur in the region, among them perennial (continuous flow), temporary (flow only in the rainy season) or ephemeral (emerging during rains and remaining only for a few days or hours). The type of spring is related to the nature of the groundwater flowpath, with perennial spring having deeper/longer flowpaths and ephemeral springs, dominated by shallower/shorter soil interflow.

Located in the Atlantic Forest biome, springs within the hydrographic basin of the Vacacaí-Mirim River are important because provides a environmental service. Such areas require special technical attention, because these springs are invaluable to the water resources of the region, a potable water source for more than 250,000 inhabitants in the growing central region of the state of Rio Grande do Sul, southern Brazil. Between 33 to 60% of the region's supply depends on the water resilience of these headwaters, located in PPA's (Guerra, 2016; Konrad, 2005). Instead, these headwaters contain unknown hydrologic information human/animal water supply and resilience, which was not identified, assess and inform based on field monitoring in different seasonality, neither by boundary environmental conditions, such as land use caractheristcs in watershed scale. Resilience have been increasingly used in relation to water systems and water governance more broadly from drought and flood management, to climate change adaptation in the water services sector, and watershed and catchment-scale water resource management (e.g., Baird et al., 2016a, 2016b; Rijke et al., 2013; Rodina, 2018; Rockström et al., 2014; Shin et al., 2018; White et al., 2016; Xu & Kajikawa, 2017). But for that, representative and reliable historical flow series, frequently non-existent or reduced, are required, with costs in the implementation, operation and maintenance of the hydrological monitoring network (Silva et al., 2019b). Thus, the scarcity of observed data flows, in these natural watercourses, makes it impossible to carry out evaluations for the region.

In response to current water protection laws in Brazil, spring water sources must be monitored if they comprise part of a PPA, located in watersheds considered environmental management units (Torres et al., 2016; Santos & Melo, 2017). Providing information for land-use modification on springs and surface water outlets, field-monitoring programs at the small watershed scale inform decision support for resolving multiple water use scenarios, as water pollution source/fate/transport and conflict management among watershed stakeholders. By improving the understanding between cause and effect, watershed management practices can be more effectively discovered and mitigated, with consequent improved long-term availability of water supply. So, starting from the monitoring of flows over time, it is possible to obtain primary data and transform them into new hydrological information about the region, hitherto unknown. With the environmental characterization of the surroundings of the springs, it is also possible to verify if there is an effect of land use on the flow of the springs and between them, through the use of statistics.

A methodology which is widely used and powerful tool in the hydrological sciences is the flow duration curves (FDC). FDC are the probability of average daily flow of a watercourse be exceeded or equaled, obtained through the relationship between flows and percentages of time (Vogel & Fennessey, 1995). It results in a graphical that condense valuable hydrological information, that can be easily accessed (Zhang et al., 2015; Zhang, 2017; Ridolfi et al., 2020; Leong & Yokoo, 2021). The FDC was used in studies of water supply and quality (Sinha et al., 2019), water concession (Detzel et al., 2018), irrigation (Silva & Manzione, 2020), hydroelectricity (Castellarin et al., 2007; Ceola et al., 2018), environmental flows (Blanco et al., 2013), climate change and extreme hydrological events (Pumo et al., 2016). Thus, FDC is a fundamental guiding instrument in managing use of water, which its usage persists in modern hydrology.

Therefore, for identify, assess and inform water resource supply and resilience in a watersehd of Atlantic Forest biome, this study monitored headwater discharge volume and interpreted the results through the seasonality and use of FDC, characterizing the springs and observing their capacity of water production. Six springs and the watershed outlet for the Vacacaí-Mirim River (southern Brazil) were monitored for a one-year period and the water production trend were related to source area land use, land cover characteristics and hydrogeology.

MATERIAL AND METHODS

Study site characterization

The study area (78.2 ha) comprised an upstream catchment of the Vacacaí-Mirim river basin, located in the state of Rio Grande do Sul (southern Brazil) (Figure 1). Water from this basin supplies a portion of the municipal water to regions in the cities of Itaara and Santa Maria (population ~290000). In the study area, there are six springs that converge to contribute surface water outflow (CO) into the Vacacaí-Mirim reservoir, providing between 33 to 60% of the water supply for the region.

Land use in the region is predominantly agriculture (e.g., soybean) and unconfined animal husbandry (e.g., pasture areas dominated by beef cattle with some dairy cattle and sheep). The basin includes areas of native forest and permanent preservation areas (PPAs; legally preserved environmentally significant areas). The PPAs have representative Atlantic Forest biome species, including several sub-deciduous forest species dominated by *Ficus insipida*, *Lonchocarpus muehlbergianus*, *Paraptadenia rigida*, *Crysophyllum gonocarpum*, *Ocotea cf. acutifolia*, *Colubrina glandulosa*, *Helietta apiculata* and *Syagrus romanzoffiana* (Leite & Klein, 1990; Ferreira & Pereira Filho, 2009). The PPAs in the Vacacaí-Mirim watershed were developed to protect many of the important springs in this region. Human occupation and development in the study area are minimal (less than 2.8 people ha^{-1}), with unpaved access roads being the primary infrastructure (Figure 2).

According to based on a Geographic Information System (GIS), digital elevation model and land use/land cover (LU/LC) (Table 1) were used to define boundary conditions for each spring

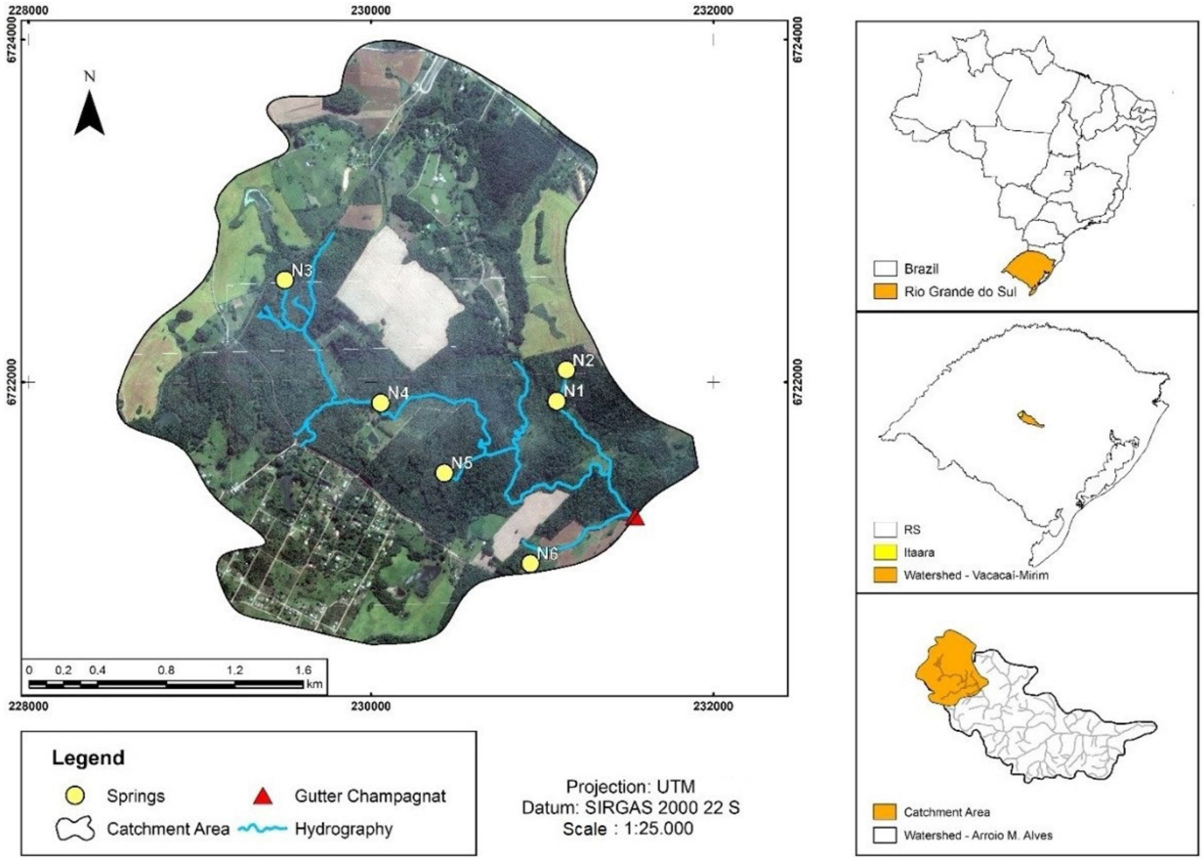

Figure 1. Study area location.

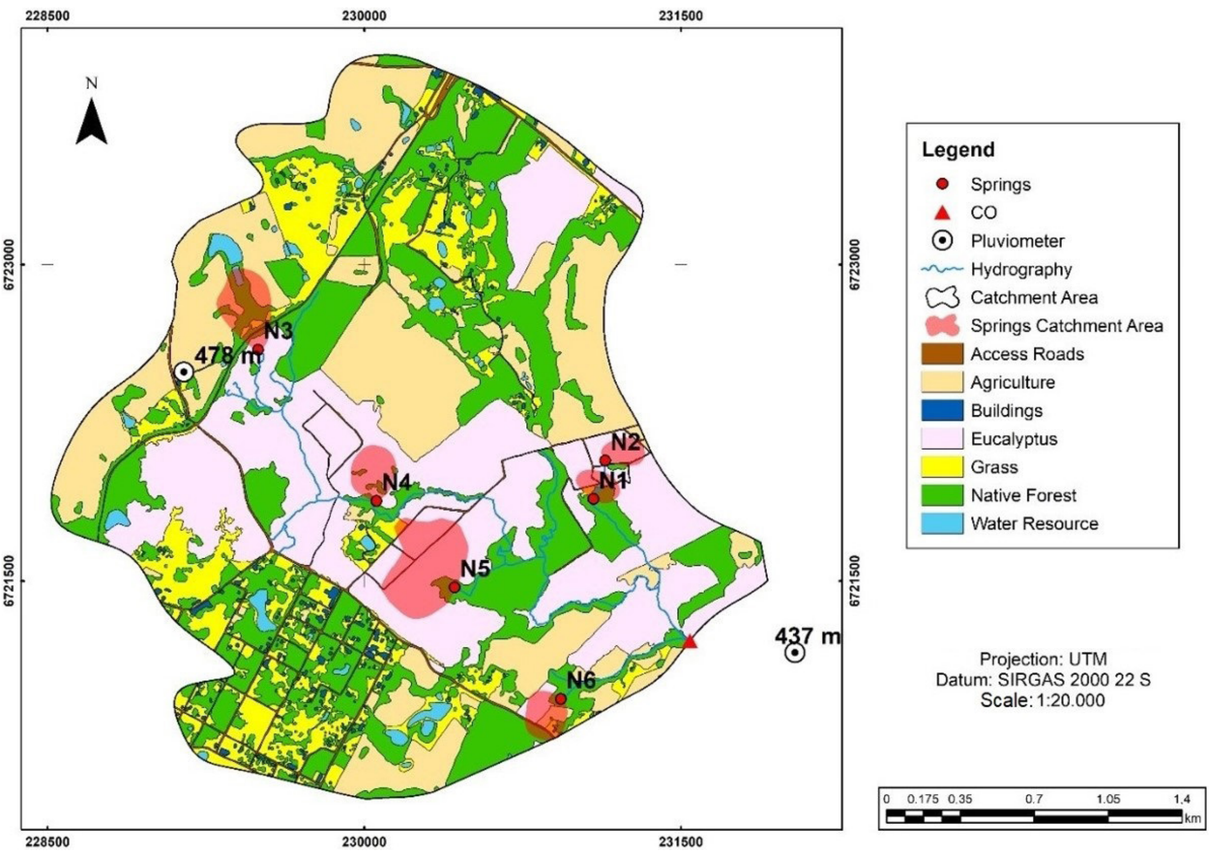

Figure 2. Land use-land cover of the study area.

Table 1. Land use and cover in the investigated catchment areas.

Class		Agricultural lands	Building area	Eucalyptus forest	Grass lands	Native forest	Water resource	Access roads	Total Catchment Area
N1	ha	<0.01	<0.01	1.12	0.17	0.72	<0.01	0.14	2.15
	%	0	0	52	8	34	0	6	100
N2	ha	<0.01	<0.01	1.87	<0.01	0.02	<0.01	0.06	1.95
	%	0	0	96	0	1	0	3	100
N3	ha	2.38	<0.01	0.43	0.37	3.21	0.27	0.08	6.75
	%	35	0	6	6	48	4	1	100
N4	ha	<0.01	<0.01	3.54	<0.01	0.54	<0.01	<0.01	4.08
	%	0	0	87	0	13	0	0	100
N5	ha	<0.01	<0.01	12.21	0.22	0.80	<0.01	0.30	13.52
	%	0	0	90	2	6	0	2	100
N6	ha	0.81	0.04	1.26	0.25	1.03	<0.01	0.13	3.53
	%	23	1	36	7	29	0	4	100
CO	ha	179.9	7.4	210.9	98.75	216.3	10.9	16.2	732.4
	%	24	1	28	13	30	2	2	100

investigated in this study (Figure 2). The boundary conditions in this study were defined by the LU/CL, which was also characterized in table in supplemental information section. Contrasting LU/LC classifications served as an important criterion for assessing differences in water quality among the investigated springs. Thus, this information was important to enable discussions about the catchment shape, as the environmental conditions of the contour of these are reported.

Overview of geological, soil, spring and watershed characteristics

Geologically, the central region of Rio Grande do Sul is divided into three components: Upper Serra Geral in the northern half and a mixture of Lower Serra Geral and Formação Botucatu in the southern half. The Upper Serra Geral formation consists of basic volcanic rocks (basalts, SiO_2 content between 45-52%), while the lower Serra Geral Formation is characterized by acidic volcanic rocks (rhyolite, rhyodacite, granofels with SiO_2 content between 52-55%). The Botucatu Formation is dominated by quartz sandstones, with minor components of altered feldspar cemented by silica or iron oxide (Leinz & Amaral, 1989; Maciel Filho, 1990; Ferreira et al., 2009).

Soils within the study area are dominated by strongly weathered Ultisols and Oxisols (Soil Taxonomy) (Rizzardi et al., 2014). The dominant soil is Claysoil alic red and dystrophic (Typic Hapludox) with the following physical characteristics: i) mean particle size = 42% sand, 22% silt and 27% clay (0-20 cm); ii) penetration resistance between 4252-7252 kPa (0-40 cm); iii) saturated hydraulic conductivity = 0.53 $cm.h^{-1}$; iv) mean soil bulk density and particle density = 1.53 and 2.76 g cm^{-3}, respectively; and v) mean macropores and micropores volumetric fraction = 5.4 and 39.4%, respectively (Rizzardi et al., 2014; Kemerich et al., 2018). The elevation of the study area ranged from 408 to 499 m with a mean slope value of 6-18% (Silva et al., 2015, 2019a). The climate, according to the Köppen classification system, is considered subtropical (Cfa), characterized by well-defined seasons and an average annual precipitation of 1600 mm. Mean annual temperature is 19.3 °C, with occasional winter (July-Sept) freezing (below 0 °C) and hot/dry summers (Jan-March) with temperatures exceeding 30 °C (Toniolo et al., 2013).

Figure 3 shows the elevation map of the study basin. The catchments with the studied springs had slopes between 6 and 18%, a dendritic drainage pattern and no impermeable areas (Ferreira, et al., 2009; Souza & Gastaldini, 2014; Silva et al., 2017). The depth to the local water table varied between 4.6-30.5 m, with semi-confined and unconfined groundwater aquifers. The maximum amount of water in the soil zone available for evapotranspiration ranges between 150 and 300 mm (Kemerich et al., 2013; Silva et al., 2016). Soil/vadose zone stratigraphy is predominantly sandy (average: fine sand = 52.8%, medium sand = 27.1%, coarse sand = 11.6%; silt = 2.3%, clay = 4.7%) with soil/vadose zone depths ranging from less than 5 m and up to 20 m (data obtained from water monitoring well logs). The average groundwater recharge is ~1.6 mm d-1 with annual recharge ranging between 50 to 100 mm yr-1 (Farias, 2011). The water flow path supporting the springs originates primarily from interflow through the sandy soil profile/vadose zone. This information is important to support interpretations of the hydrological data of the study area and the activities of springs, when relevant in the results and discussions.

Instrumentation of catchment area

Flow data for springs were obtained using 2.5 cm (N1, N2, N3, N4 and N6) or 5 cm (N5) Parshall Gutters installed below each source with automatic sensors for hourly water level measurement (Levelogger and Barologger; Solinst). The level sensors were calibrated before the measurements, and only after that they were programmed. As well as the springs, the CO also received monitoring from a level sensor. From the installation of level sensors in the hydraulic structures, they were programmed to determine the hydraulic quotas in hourly frequencies. After determining the water depths, the values were applied to the key curve equation, which is specified according to the brand and type of Parshall Gutter. The result obtained from this equation corresponds to the flow of water that is passing through the gutter

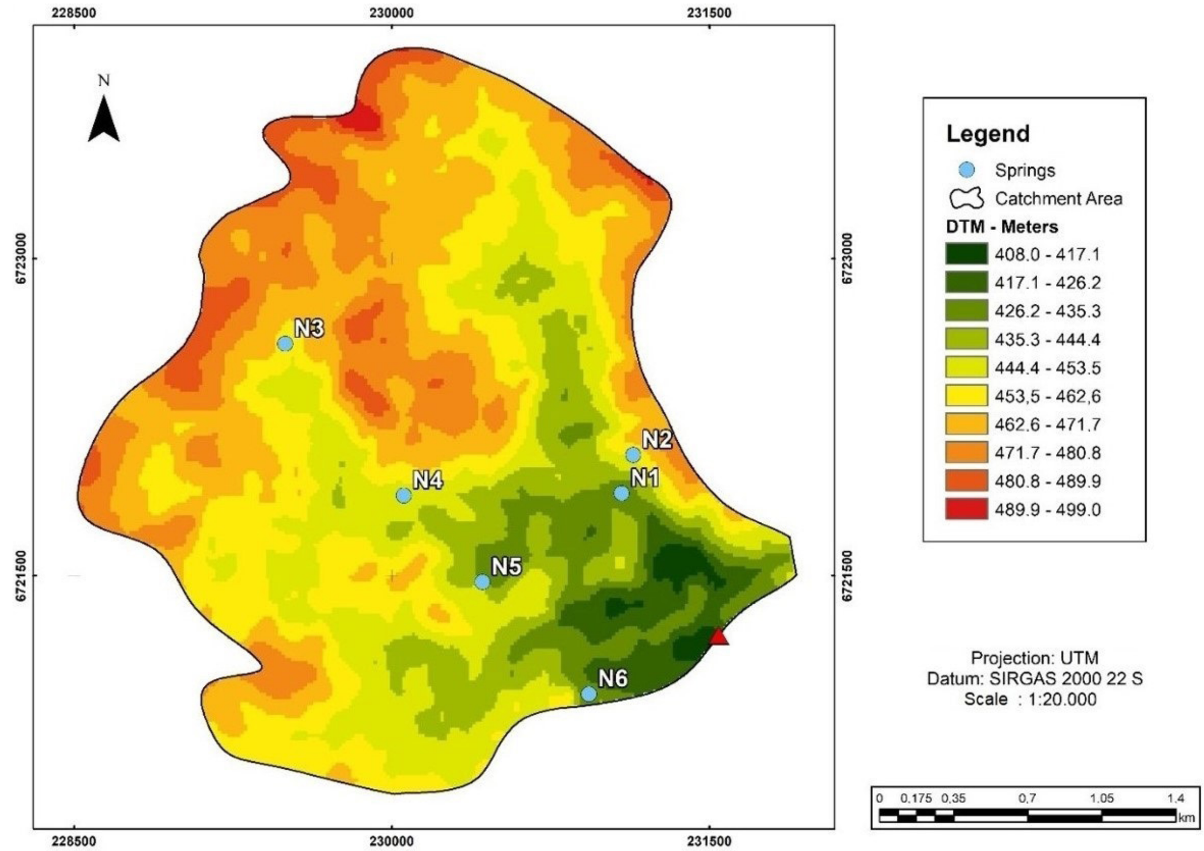

Figure 3. Digital elevation model of the catchment outflow.

at the time of reading (flow in L s-1), equivalent to the height of the water depth.

Precipitation was measured at two watershed locations with ONSET rain gauges (RG3-M) integrated with HOBO® dataloggers. A 17-year rainfall record (1991-2007) was available from nearby Itaara (454 m elevation; located 9.1 km from CO) to provide context for our study.

Data collection e processing

The duration of flow and rain monitoring was 12 months. The flow data collection campaign was conducted for a one-year period commencing January 8, 2015 and ending January 22, 2016, because it was the defined time of funding of data collections during the design of the study. Flow data were obtained by coupling stage-height measurements from the automatic level sensors, installed at each sampling location, together with discharge relationships for each flume. No flow values were recorded that exceeded the measurement limits of the corresponding equipment: 5.67 L s-1 for 2.5-cm flume, 14.17 L s-1 for 5-cm flume, and 255.5 L s-1 for catchment outlet. To fill nine gaps in the capture of peak flow data for catchment outlet, the synthetic unit hydrograph (HUS) by Soil Conservation Service method was used according to data from Toniolo et al. (2013). Because they are simple and practical methods, HUS are widely used in hydrological studies (Silveira, 2016).

Quantitative-qualitative data processing

Flows between springs were statistically analyzed. Analysis of variance was performed for the springs using the Scott-Knott procedure at a significance level of $p \leq 0.05$. This statistical method uses the likelihood ratio test to group a known number of treatments into a known number of groups (Scott & Knott, 1974). The objective was to verify if there are significant differences between the flows of the springs. Since the flows are statistically different, it is possible to provide inferences and explanations of these differences related to systemic factors, such as land use around the spring areas, protected or not.

Water discharge data were also used to construct FDC. The permanence of flow represents the probability of occurrence of an average daily flow greater than or equal to a certain value during an observation period, assigning to each flow (q) an associated probability of exceedance (p) (Quimpo et al., 1983; Vogel & Fennessey, 1994), according to Equation 1.

$$p = 1 - F_q(q) \quad (1)$$

where "p" is the exceedance frequency, "q" is the flow rate and FQ (q) is the cumulative probability density function of the flows. Flow percentile was estimated from flow sample with an empirical cumulative probability function from the choice of a plotting position to be applied to the sample.

The flow in percentile (Qp%) is often called an empirical function and can be estimated from an empirical accumulated probabilities function by choosing a plot position. One of the most used to determine the FDC is the Weibull equation, in which, where (i) is the order number of the ordered flow rate q(i), and in the number of ordered data, the probability of exceedance (pi) of flow rate is given by Equation 2.

$$p_i = 1 - F_q\left[q(i)\right] \quad (2)$$

The corresponding Weibull plot position is given by Equation 3. In hydrological processes, using Weibull calculation positions is appropriate to provide unbiased estimates for all distributions. More, this produces a slightly smoother and more representative curve than other techniques.

$$p_i = \frac{i}{n+i} \quad (3)$$

RESULTS AND DISCUSSION

Hydrological data

The average monthly rainfall totals in the Vacacaí-Mirim river basin showed a season with highest precipitation in the Spring-early Summer (Oct-Jan) and lower precipitation during the Summer-Fall (Feb-Aug) period during our study period. The months of lower rainfall distribution (February and August) were 47.3% below the recent historical 17-year average, whereas the months with higher precipitation (September to December) were 83.8% above the recent historical average (Figure 4). Notably, the Oct and Dec precipitation values were the highest monthly values for these months during the 17-year historical record. The resulting precipitation distribution resulted in the perception of drier and more humid periods. This seems to be a trend in these basin headwaters, but it is not possible to identify seasonal patterns, which requires studies with much longer time series. That is an important factor to assess, along with antecedent precipitation timing, in the interpretation of water dynamics.

Individual spring flows displayed similar monthly variations over the monitoring period (Figure 5). Sharp declines in flows occurred in February-March and August corresponding to the low precipitation during these months. Conversely, the high rainfall period from September into October generated the highest flows for most springs. Thus, it corroborate the close association between precipitation and runoff dynamics occurring through relatively shallow (soil/vadose zone) hydrologic flowpaths. The CO flows were typically intermediate with respect to spring flows inferring an integration of various spring water inflows from the basin regulating the overall catchment runoff.

The runoff-to-precipitation (R:P) ratios (mm runoff: mm precipitation) for the springs were: 0.44 for N1; 0.40 for N2; 0.13 for N3; 0.29 for N4; 0.48 for N5; 0.17 for N6; 0.27 for CO. The R:P ratio was distinctly lower for N3/N6 (0.13-0.17) compared to N1/N2/N5 (0.40-0.48). Similarly, the monthly variability of stream runoff (standard deviation) was lower in N3/N6 (16-18 mm) versus N1/N2/N5 (56-73 mm). The distinction in the catchments associated with these two groups of springs was LC/LC. The N3 and N6 catchments had 35% and 26% agricultural land

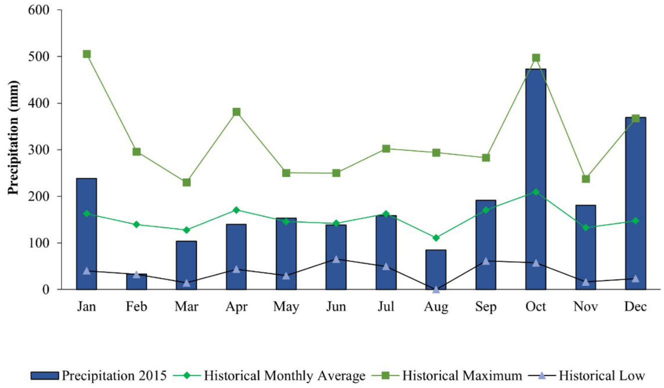

Figure 4. Precipitation distribution for the 2015 study year compared to the recent 17-year record (1991-2017).

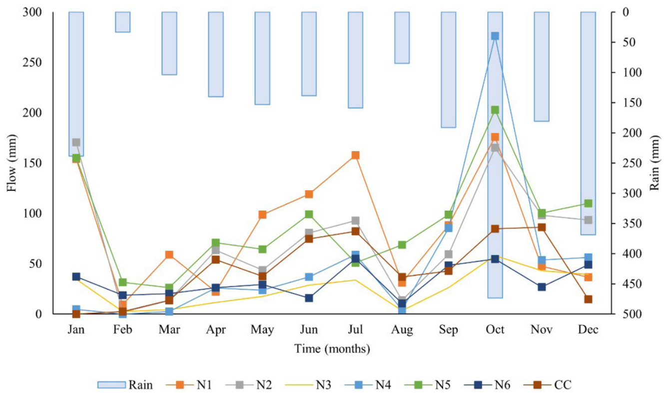

Figure 5. Annual rainfall and flow totals of each spring.

use, whereas N1/N2/N5 contained no agricultural component (Table 2). No consistent trends were noted for other watershed characteristics (e.g., area, form factor, slope) between these two grouping of springs. Thus, the relief and physiography effect in N3/N6 basins does not seem to incur mostly, despite what would commonly be considered in the flow. These components are not governing the surface water movement to the springs. The low R:P ratio in the two basins of these springs is 0.23 in relation to the others, which implies potential differences in water quality, in terms of concentration. This also conduct favorable and isolated interpretations for changes due to land use, especially between agriculture and forests.

Activity of the springs

Peak rainfall and spring flow rates in N1 were mostly coincident with rainfall onset. N1 had a form factor of 1.20 (catchment area/ catchment length) and the highest average slope (15%) among spring sources. The catchment shape was rather circular providing a similar water flow path length from the entire catchment area. Thus, N1 flow rates were highly responsive to the onset and cession of precipitation during major rainfall event. Furthermore, these watershed characteristics result in the highest runoff:precipitation ratio among springs. Nevertheless, the high forest vegetation

Table 2. Physiographic elements and characterization of the use and cover of the investigated areas.

Spring	Latitude/ Longitude	Altitude (m)	Slope (m/m)	Form Factor	Mean flow (L s^{-1})	Description of Use and Cover Soil
N1	53°46'34"O 29°36'08"S	429	0.15	0.20	0.37	Surrounded spring in the middle of native forest, with on-site maintenance of tree; downstream from grasses, a small dirt road, and eucalyptus forest. Contains no agricultural components.
N2	53°46'36"O 29°36'14"S	427	0.09	0.55	0.34	Surrounded spring in the middle of native and eucalyptus forest. Contains no agricultural components.
N3	53°46'42"O 29°36'44"S	457	0.07	0.43	0.25	Spring considered degraded due to loss of original forest cover and no forest restoration treatment. Located in the middle of eucalyptus forest, accessible to animals, especially cattle. Downstream from has native forest, agricultural area, grasses, a dirt road, and a small reservoir.
N4	53°47'01"O 29°36'27"S	447	0.08	0.60	0.48	Enclosed spring in the middle of native forest, with a high density of araucaria trees. Management is of regeneration by isolation. Located downstream from eucalyptus forest and fragments of native forest
N5	53°47'34"O 29°35'49"S	429	0.08	0.8	3.75	Spring that has its native characteristics preserved, i.e. no forest restoration treatments. Established in the middle of eucalyptus and native forest, freely accessible to animals, mainly cattle. Downstream from eucalyptus cultivation as well as small roads and grassy areas. Contains no agricultural components. It should be noted that the collection point is located approximately 100 m downstream of the actual spring, due to the irregular topography and difficulty in installing instruments.
N6	53°47'14"O 29°36'13"S	428	0.13	1.30	0.37	Spring surrounded by dense vegetation in an advanced successional stage, with an 8-year regeneration treatment. Downstream from residences, grasses, agricultural areas, a dirt road, and eucalyptus and fragments of native forest.
CO	53°46'21"O 29°36'35"S	410	0.08	0.62	136.16	Outlet of the basin under study, collecting water from the above springs as well as from other water courses.

cover buffers peak flows and extends the descending limb of the hydrograph into the baseflow period (Figure 6).

Spring N2 drained the smallest watershed area and experienced intermittent flows during summer periods, in spite of no drought periods exceeding 15 days (Figure 7). Yet, N2 had the third highest runoff:precipitation among the springs. In addition to the small source area, a low form factor (0.55) contributes to what appears to be a relatively shallow flowpath that leads to a

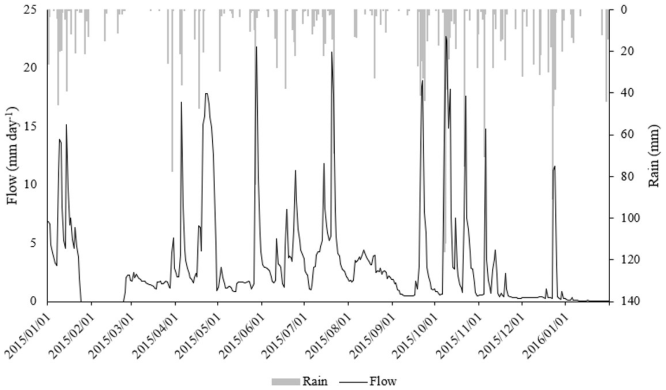

Figure 6. Ratio of rain, flow and dates for spring N1.

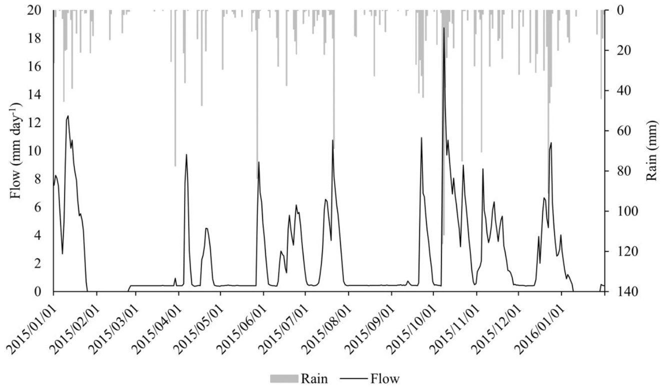

Figure 7. Ratio of rain, flow and dates for spring N2.

flashy hydrograph response to precipitation events. N2 has nearly complete vegetative coverage (96%) with a eucalyptus forest which contributes to an extended falling hydrograph limb.

The surrounding conditions of N3, which, like the other springs, is considered PPA by legislation, clearly show aspects of degradation. The catchment area has lost part of its native forest, keeping 35% of its area for agriculture. Despite being located in the middle of a small eucalyptus forest (0.43 ha), N3 is freely accessible to large animals. Additionally, N3 contains little vegetation cover and is precariously managed. All these surface features should promote greater water flow leads to more surface runoff in rainy periods. This is accentuated by a form factor of 0.45.

Two parallel flow sections were observed, very close to zero. Such occurrences are not commonly seen in flow series, indicating continuity of flow at the source (base flow). However, physiographic characteristics favor infiltration, not runoff (small average slope of 0.07 m/m). In N3, higher peak flows were observed relative to rainfall, which was not intense enough to generate similar flows in the other springs. It was observed that the flow peaks are followed by sudden drops and a small base flow. It seems that water from the groundwater (Serra Geral aquifer) does not re-emerge surface through this spring. Since there is a large amount of rain in the region, the peaks followed by sudden falls provide an intermittent character of this spring, constituting an oscillation of the water table for the water surge. Thus, it is possible to infer that there is dependence on recurrent rainy periods in the spring. The low rainfall frequency in N3 can cause variation in the water table surface elevation. This is important, because the transition from base flow to surface runoff provided by the spring feature is an important hydrological process, especially in the time of concentration in the watershed (Figure 8).

As in N2, the intermittent flow of spring N4 was verified. Observing Figure 9, it can be seen that there were periods in the second half of February, April and August when N4 did not present water flow. This is strong evidence of the relationship between water scarcity and the observed low precipitation volumes. In the periods preceding these collections, rainfall amounts were all less than 25 mm. The opposite effect of rainfall on flow occurred in part of September through October, when all rainfall precipitation generated flows higher than the measurement capacity of the flume, as can be seen by the lateralization of the flow curve on the graph.

In N5, many peak flows exceeded the measurement capacity of the gutter. This occurred at least 6 times during the monitoring period. This can be seen by the lateralization of the flow line on the graph during and slightly after the rainfall events (Figure 10). Unlike the other sites, the location where the Parshall gutter was installed to monitor flow from N5 was located approximately 100 meters from the source of the spring. It was not possible to transport and install the flow measurement instruments close to the source of N5 due to the very irregular topography. In addition, the rain catchment area of N5 is the largest of all sources investigated (13.52 ha), with a Kf of 0.8. This indicates a shape factor close to a circle, where rainwater from all sides of the large catchment area tends to flow almost simultaneously into its principal water course. Thus, with the measuring instruments approximately 100 meters away from the source of N5, it can be inferred that increments of flows occurred from the sides of the watercourse, clearly observed during rainfall events above 60 mm (Figure 10). This was also reflected in the minimum flows during the monitoring period, which were higher than the other springs.

At N6, the highest peak flows occurred only in response to rainfall greater than 70 mm, even though the average slope was 0.13 m/m. Unlike N5, and similar to the other springs, the baseflows of N6 quickly returned after a rainfall event, to values below 0.5 L s^{-1}. But, several small fluctuations in the base flow were observed, outside of the pluvial events. This can be explained by the natural provision by the exfiltration of water from sequential refills, but also from the storage in the porous space of the soil, added by the root tension of eucalyptus reforestation. The eucalyptus reforestation is a particular aspect of this spring, which is the phase of vegetative regeneration in its catchment area, which is already 8 years old. Eucalyptus is one of the trees used for regeneration, representing 36% of the N6 area, while 29% is native forest. In a study on post-planting water erosion in eucalyptus forests in the Paraná River basin in eastern Mato Grosso do Sul, it was concluded that areas with eucalyptus had lower soil and water loss values, being the closest to native vegetation (Cândido et al., 2014). Analyzing the water holding capacity of the vegetative canopy between Atlantic Forest and eucalyptus forest, it was found that the Atlantic Forest basin intercepts 30% of total incident rainfall, twice as much as Eucalyptus urophylla and Eucalyptus grandis cover (Groppo et al., 2019). Such results indicate a synergistic interaction of these two types of plant cover,

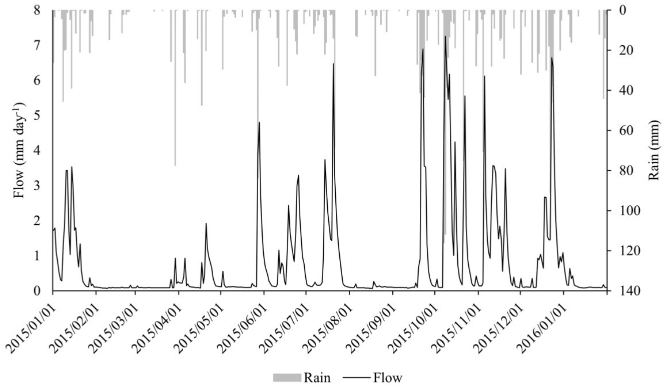

Figure 8. Ratio of rain, flow and dates for spring N3.

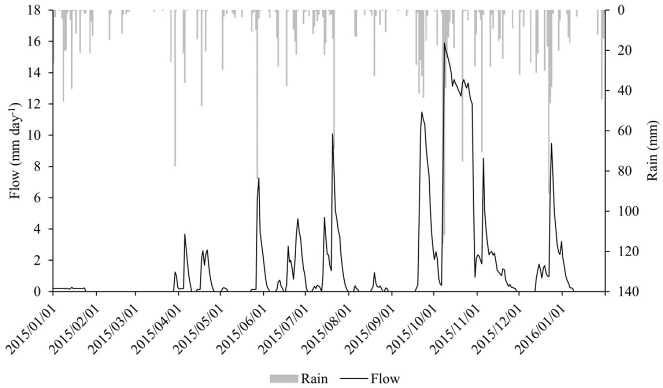

Figure 9. Ratio of rain, flow and dates for spring N4.

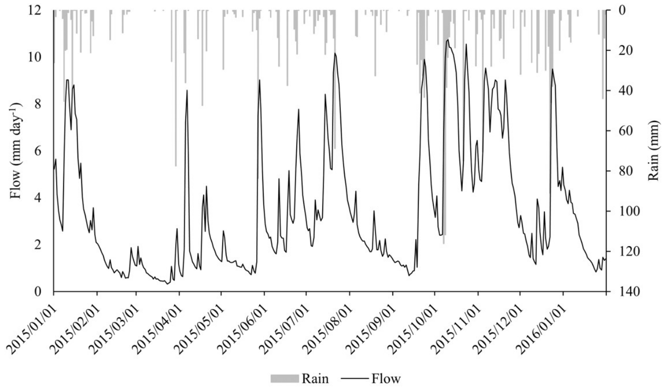

Figure 10. Ratio of rain, flow and dates for spring N5.

i.e. Atlantic Forest and Eucalyptus. This mixed Atlantic forest-eucalyptus cover is also present in N6, and, together with Serra Geral aquifer, improves infiltration capacity as well as replenishing water tables (Figure 11).

During most of the observation period, the observed flow at CO was higher than 255.5 L s^{-1} (Figure 12). Throughout almost all of September and October, the channel's measurement potential was exceeded, evidently influenced by the accumulation of rainfall in this period. However, it can be seen that this situation is also partially a result of the contribution of all the streams present in the basin, including some that were not investigated in this study.

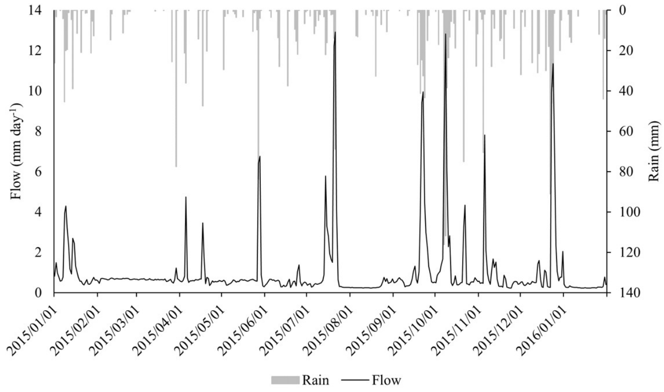

Figure 11. Ratio of rain, flow and dates for spring N6.

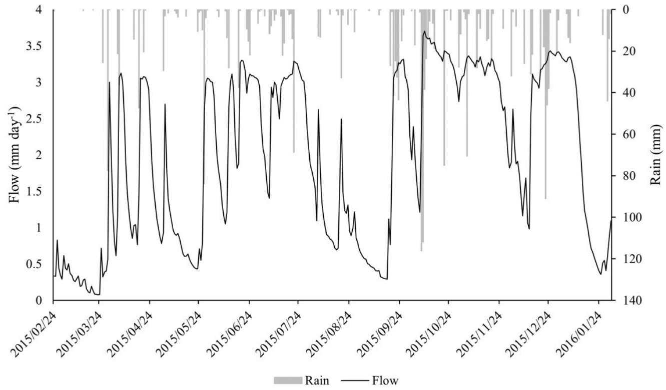

Figure 12. Ratio of rain, flow and dates for catchment outlet.

In addition, CO has a catchment area of 781 ha, diversified land use upstream of the measurement system, as well as a rocky bed. Therefore, even with a low average slope in relation to the study site and biome, as well as a not very circular form factor, the minimum flow observed at CO at the end of the rainy periods was higher than the set of flows coming from the six springs.

Water production resilience and flow duration curves

Springs N1, N2 and N4 had peak flow rates well above their median, being at least four times greater than their data distribution center. These discrepancy situations were considered atypical in the experiment, corresponding more to the high-water dissipation activity of intense rainy events in the catchment (≥ 45 mm day^{-1}) than the base flow (Figure 13). The greatest asymmetries in terms of peak were observed in N1 (mean of 4.95 mm day^{-1}) and N2 (mean of 6.25 mm day^{-1}), being statistically equal to each other in terms of water production. Despite this, these are two springs that concentrate the data more (50%) in higher water production than the others, even if their interquartile ranges are wider.

Flows in N3 and N6 had statistically less intense responses compared to other springs, but more consistent. Observing their interquartile ranges, the flows were smaller compared to other springs (N3: 0.4-1.9 / N6: 0.6-1.4 mm day^{-1}). This indicated low flow maintenance in the monitored time. Due to statistical differences, together the activity of these springs described in the

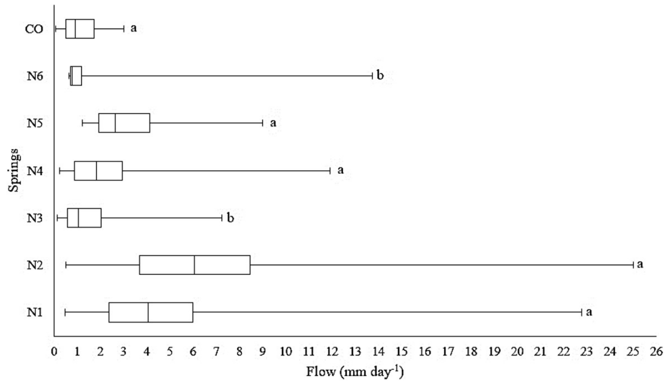

Figure 13. Boxplot of flows monitored by springs and catchment outflow, with statistical analyses. Different lower-case letters in a given column indicate a significant difference (5% probability) between springs.

previous item, they qualified as resilient in water production. This is systemically the opposite of what happens in N4. The latter did not have constant water production over the months, showing itself to be very dependent on the seasonality of rainfall, especially.

The FDC shape is unique to a catchment; it is determined by the hydrologic heterogeneity in the catchments, and the resulting shape exhibits distinct information of these interacting processes (Leong & Yokoo, 2021). Thus, in the analysis headwater, the springs had very large FDC contrasts. Comparison of FDC from observed data indicated chances of problems in water resources management, especially regarding multiple uses in the summer period, especially in terms of the region's reference flow (Q_{95} and Q_{90}). The Q_{95} and Q_{90} in the study region, correspond to the flows that are present in the water course for at least 95% or 90% of the time. Thus, the high slope up to 10% of the observed time, in the FDC curves, indicates that the baseflow, which is the persistent water flow, is low in all springs, especially in N1 (Figure 14). This behavior configures inefficiency in soil infiltration, as well as high runoff potential. The average of 4.95 mm day^{-1} prevailed in less than 50% of the monitored time, demonstrating the low continuity of water production. For Q_{90} and Q_{95}, flows were 1.5 and 1.8 mm day^{-1}, respectively.

Similarly, N1, N2 provides high outlet starting from the analyzed headwater, for the intense hydrological events observed. But, in N2, the percentage of time of flow decline after a rainy event is smaller. The average of 6.25 mm day-1 remained only 60% of the monitored time. But for Q_{90} and Q_{95}, the flows were 1.8 and 1.4 mm day^{-1}, respectively. N2 demonstrates a high dependence on rainfall to maintain the base flow close to the median, especially due to the congruence of the observed data.

In N3, the FDC had a less pronounced decline in flow dissipation due to intense rain events (≥ 45 mm day^{-1}) in the catchment. The average water production was 1.45 mm day^{-1}, more than twice below the average flow rates than N1 and N2. This average remained only 30% of the monitored time. for Q_{90} and Q_{95}, the flows were 0.25 and 0.4 mm day^{-1}, respectively. As reference flows, these flows are low, but being close to each other in the interquartile range, as well as to the data distribution center, there is a strong indication of the perpetuity in the production of water in N3.

In N4 and N5, FDC did not have a sharp decline in flows after periods of heavy rain. N4 had an average flow of 2.40 mm day^{-1}, prevailing 35% of the monitored time. The lower limit deviates a little from the first quartile and median (data distribution center), and the upper limit (peak flow) exceeds, for example, N3. Linked to this, there were periods of time in which no activities were observed in the spring. The opposite of this is N5, where the average flow was 2.42 mm day^{-1}, and permanence of 45% of the time, being the largest producer of water of all the springs. Its flow activity was not low like the others, even in smaller periods of rainfall.

At N6, the FDC had consistent water production at more than Q95, being also very close to the average of 1.01 mm day-1. There was a low distribution of data in relation to the median. Such observations consolidate water production consistent with N6, denoting a clear perennial characteristic, different from N1, N2 and N4. It was also evidenced the rapid recession to the observed intense rainy events, in which such outflows prevailed less than 2.5% of the monitoring time.

In CO, the flow contributions from the six springs corresponded to an average of 1.13 mm day-1. As it was used in the unit of analysis of an area of the basin of 732.4 ha, the interpretation in this way seems to indicate little water outflow from the basin. But, disregarding the area, in terms of volume and time, the average in catchment outlet was 136.1 L s^{-1}. The variation of the lower and upper limits was very small in relation to the springs. The first and third quartiles are only 0.5 and 0.6 mm day^{-1}, respectively, from the data distribution center, as well as only 1.1 mm day^{-1} between them. This represents important information in monitoring, revealing the quantitative constancy of water production in the investigated headwater, which before was unknown.

Hydrograph information assessed from the storm-event scale, activity of spring and FDC, provides valuable information concerning the nature of the hydrologic flowpath, supplying the individual springs (Table 3). For consistent monitoring time, the springs were qualitatively assessed based on their persistence (perennial-continuous flow); temporary-flow (only in the rainy season); ephemeral (emerging during rain events and remaining only for a few days or hours after rainfall cessation) and responsiveness to a given rainfall event in term of time to peak and return to baseflow (spiking-days; intermediate-weeks; lagging-month).

Spring N5 was unique among the springs displaying perennial/lagging hydrograph dynamics. We interpret this signature as a deeper groundwater flowpath that buffers stream discharge between individual rain events. Spring N6 also displays a low perennial flow, but has a spiking response to individual storm events that is contributed by a shallower soil interflow pathway. Spring N1 has an temporary persistence sensitive to seasonal rainfall trend and an intermediate responsiveness reflecting a mixture of deeper flowpaths (groundwater/vadose zone) with soil interflow delivering rapidly in response to a storm event. Springs N2, N4 and N3 have ephemeral persistence trend suggesting a limited input from deeper groundwater sources. The responsiveness of N3 was spiking compared to an intermediate response in N2 and

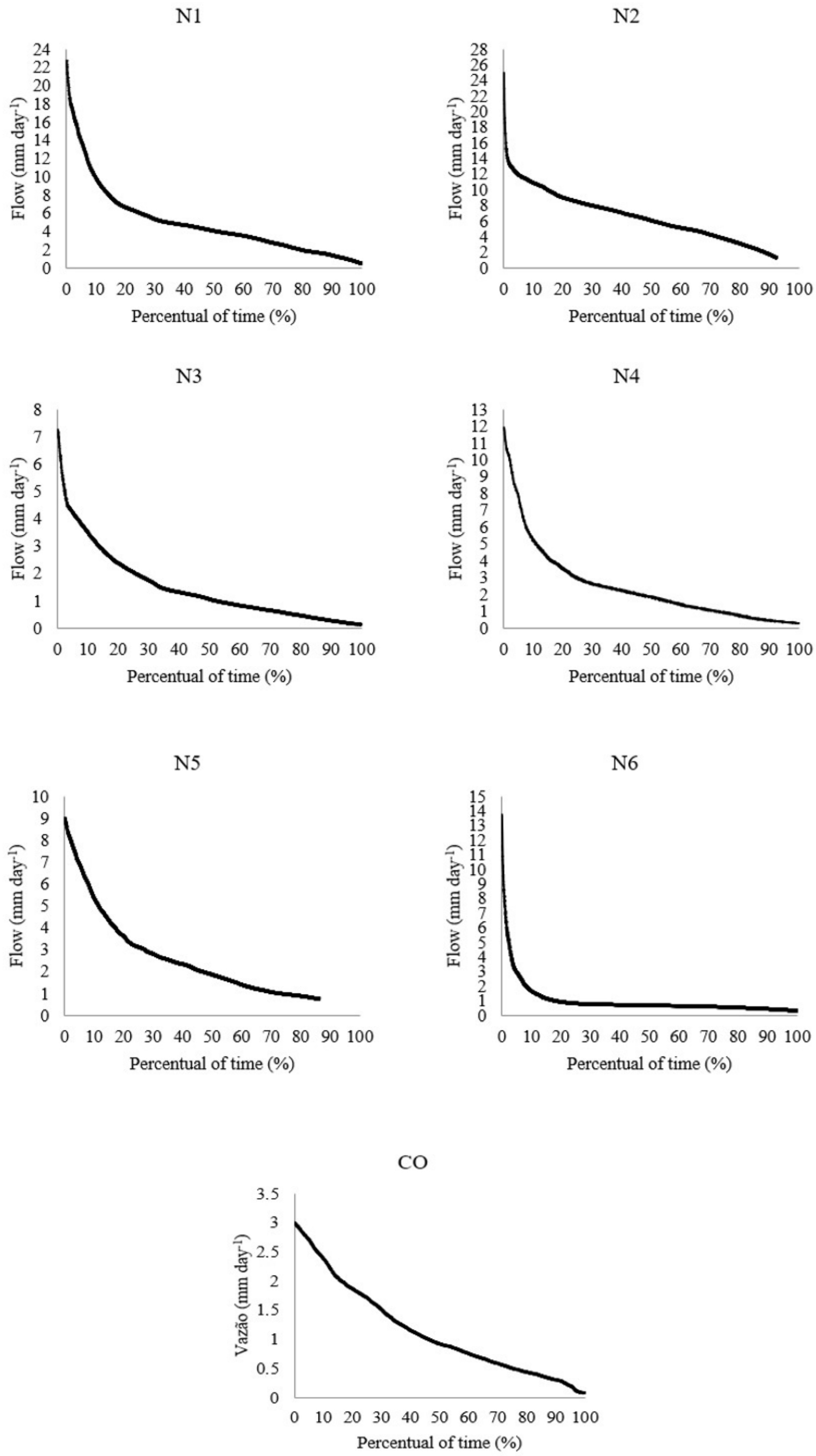

Figure 14. Flow duration curve in springs and catchment outlet.

Table 3. Difference of flow characteristics of the analyzed springs.

WATERSHED	PERSISTENCE	RESPONSIVENESS
N1	Temporary	Intermediate
N2	Ephemeral	Intermediate
N3	Ephemeral	Spiking
N4	Ephemeral	Intermediate
N5	Perennial	Lagging
N6	Perennial	Spiking

N4. This suggests that the N4 flowpath is dominated by rapid subsurface lateral flow through soil layers, whereas N2 and N4 retain and release some water from deeper soil zones.

As with their sharply lower R:P ratios, N3 and N6 were distinctive in displaying spiking responsiveness to individual storm events. The dominantly forested (>90%) were less responsive to storm events owing to canopy interception and enhanced infiltration/storage in the surficial litter layer. N3 and N6 has its total basin areas with 53 and 64% composed of native forest and eucalyptus, respectively, against more than 85% in the others. But, N3 has only 0.07 m/m of slope and N6 has its source (and therefore measurement site), densely surrounded by eucalyptus trees. Eucalyptus forests can have wastewater storage of 14 mm (0-20 cm), 35 mm (20-60 cm) and 53 mm (60-120 cm), available water capacity (AWC) in just 64% of the time, according to studies (Targa et al., 2017, 2020). Variations in water storage from 20 to 60 cm in eucalyptus forest may occur as a function of the root system composed of fine roots (< 2 mm) concentrating up to 50 cm in depth, as well as due to the 0 to 20 cm layer, where the ground-air interface is formed (Paula et al., 2013; Witschoreck et al., 2003). Thus, the root activity of the eucalyptus forest creates preferential sub-surface water paths in the soil, which add to the impact of ETP (Figure 15). This creates a delay or even elimination in the surface water contribution to the stream. Thus, there is a clear water contention in the intercourse between the use of land in the basin and the stream. The smaller flow effect during storm is modulated by the rough components of the boundary conditions of the spring, provided by the litter and eucalyptus roots.

This entire afforestation process under N3/N6 boundary conditions creates a reduction in the surface and hypodermic water flow path towards the springs. Since water is partially retained by the roots, other forces act in disciplining water storage, such as gravity and retention energy and hydraulic conductivity by porous spaces. Considering the monthly flow of springs (Figure 16), the

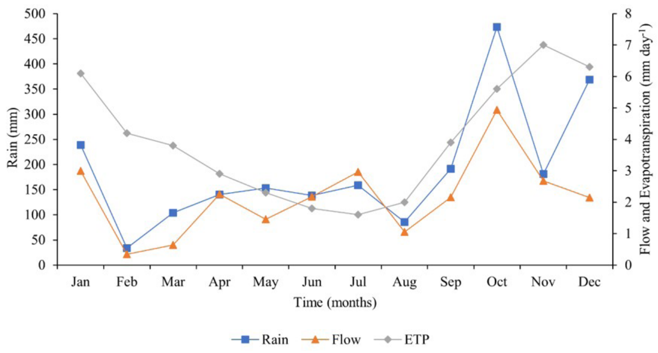

Figure 15. Relationship between monthly average rainfall, daily average spring flow and daily average evapotranspiration in the study area.

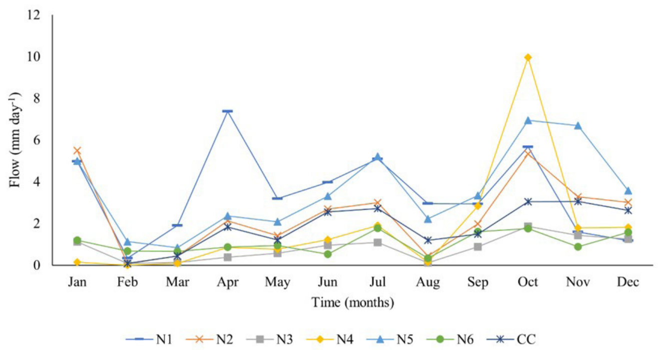

Figure 16. Daily average monthly of flows by springs and catchment outflow.

fraction of precipitation that infiltrates and percolates through the the soil aeration zone will become a saturated zone, where water will occupy all the pores of the soil, constituting a uniform watery body over a geological structure, that will make the function of a reservoir and a means of circulation (aquifer). Thus, all these processes promote deeper overall infiltration which enhance the importance of deeper and slower hydrologic flowpaths.

CONCLUSIONS

The results obtained by the flow duration curves helped to reveal new precise information about water resilience by springs in the hydrographic basin of the Vacacaí-Mirim river. The activity of the springs is varied and some have a tendency to be intermittent, having more dependence on rain to generate flow and demand more environmental protection. The springs that generated more flow are more resilient to changes in land use. The study was able to determine FDC and confirm the resilience and reality of an important headwater of the Vacacaí-Mirim river basin, which is more accurate than spring flow estimates. Streamflow results could be useful for calibrating models in other parts of Vacacaí-Mirim watershed. Furthermore, the investigation of the hydrological activity of the springs by the aforementioned method will be also essential for decision making by the Vacacaí and Vacacaí-Mirim Rivers Hydrographic Basin Management Committee, and public entities, mainly against problems of multiple uses of water, supply impacts on local water security and preservation. Therefore, once it was identified, evaluated and reported how the activity of the basin's headwaters is and how the conditions of land use interact with them, the study filled a knowledge gap in the management of water resources in the region.

ACKNOWLEDGEMENTS

The authors would like to thank CAPES, MO'Ã Foundation, PETROBRÁS, and the GERHI/UFSM Research Group for supporting this research.

REFERENCES

Baird, J., Dzyundzyak, A., Plummer, R., Bullock, R., Dupont, D., Jollineau, M., Kubik, W., Pickering, G., & Vasseur, L. (2016a). Ecosystem perceptions in flood prone areas: a typology and its relationship to preferences for governance. *Water*, *8*(5), 191. http://dx.doi.org/10.3390/w8050191.

Baird, J., Plummer, R., Moore, M.-L., & Brandes, O. (2016b). Introducing resilience practice to watershed groups: what are the learning effects? *Society & Natural Resources*, *29*(10), 1214. http://dx.doi.org/10.1080/08941920.2015.1107788.

Blanco, C. J. C., Santos, S. S. M., Quintas, M. C., Vinagre, M. V. A., & Mesquita, A. L. A. (2013). Contribution to hydrological modelling of small Amazonian catchments: application of rainfall-runoff models to simulate flow duration curves. *Hydrological Sciences Journal*, *58*(7), 1423-1433. http://dx.doi.org/10.1080/02626667.2013.830727.

Cândido, B. M., Silva, M. L. N., Curi, N., & Batista, P. V. G. (2014). Post-planting water erosion in eucalyptus forests in the Paraná River basin, in eastern Mato Grosso do Sul. *Revista Brasileira de Ciência do Solo*, *38*(5), 1565-1575. http://dx.doi.org/10.1590/S0100-06832014000500022.

Castellarin, A., Camorani, G., & Brath, A. (2007). Predicting annual and long-term flow duration curves in ungauged basins. *Advances in Water Resources*, *30*(4), 937-953. http://dx.doi.org/10.1016/j.advwatres.2006.08.006.

Ceola, S., Pugliese, A., Ventura, M., Galeati, G., Montanari, A., & Castellarin, A. (2018). Hydro-power production and fish habitat suitability: assessing impact and effectiveness of ecological flows at regional scale. *Advances in Water Resources*, *116*(9), 29-39. http://dx.doi.org/10.1016/j.advwatres.2018.04.002.

Detzel, D. H. M., Fernandes, C. V. S., & Mine, M. R. M. (2018). Non-stationarity in the construction of permanence curves with a view to the granting of water resources. *Revista Brasileira de Recursos Hídricos*, *21*(1), 80-87. http://dx.doi.org/10.21168/rbrh.v21n1.p80-87.

Farias, P. D. (2011). *Growthwater levels fluctuation in Vacacaí-Mirim river small watershed* (Dissertação de mestrado). Universidade Federal de Santa Maria, Santa Maria.

Ferreira, A. B., Silvestre, K. B., Leite, E. F., Rosa, R., & Pereira Filho, W. (2009). Analysis of the physical environment of watershed Vacacaí-Mirim-RS/Brazil. *Revista Geografia Acadêmica*, *3*(2), 28-34.

Ferreira, A. B., & Pereira Filho, W. (2009). Analysis of use and land cover of three sub-basin – Rio Grande do Sul / Brazil. *Revista Brasileira de Geografia Física*, *2*(13), 20-36.

Guerra, C. P. (2016). *Environmental perceptions in the microbasin of the Vacacaí Mirim river around the D.N.O.S Santa Maria, RS* (Monography). Universidade Federal de Santa Maria, Santa Maria.

Groppo, J. D., Salemi, L. F., Moraes, J. M., Trevisan, R., Seghesi, G. B., & Martinelli, L. A. (2019). Vegetative canopy water retention capacity: comparison between Atlantic Forest and eucalyptus forest plantation. *Ciência Florestal*, *29*(1), 96-104. http://dx.doi.org/10.5902/1980509816862.

Kemerich, P. D. C., Sergio, R. M., Kobiyama, M., Silva, V. R., Descovi Filho, L., Rizzardi, A., & Willian, F. B. (2013). Natural vulnerability to contamination of the underground water in the Vacacaí-Mirim river's basin: use of the god methodology. *Engenharia Ambiental*, *10*, 189-207.

Kemerich, P. D. C., Martins, S. R., Kobiyama, M., Silva, V. R., Koppe, E., Borba, W. F., Flores, C. E. B., Fernandes, G. D., & Gomes, C. H. (2018). Evaluation of soil physical indices under different uses in Vacacaí-Mirim River Basin. *Anuário do Instituto de Geociências*, *41*(2), 66-73. http://dx.doi.org/10.11137/2018_2_66_73.

Konrad, C. G. (2005). *Environmental zoning of the DNOS reservoir watershed in Santa Maria - RS* (Dissertação de mestrado). Universidade Federal de Santa Maria, Santa Maria.

Leal, M. S., Tonello, K. C., Dias, H. C. T., & Mingoti, R. (2017). Hydroenvironmental characterization of springs. *Revista Ambiente & Água*, *12*(1), 146-155. http://dx.doi.org/10.4136/ambi-agua.1909.

Leinz, V., & Amaral, S. E. (1989). *General geology* (543 p.). São Paulo: Editora Nacional.

Leite, P. F., & Klein, R. M. (1990). Vegetation. In Instituto Brasileiro de Geografia e Estatística, *Geografia do Brasil: Região Sul* (Vol. 2, pp. 113-150). Rio de Janeiro: IBGE.

Leong, C., & Yokoo, Y. (2021). A step toward global-scale applicability and transferability of flow duration curve studies: a flow duration curve review (2000-2020). *Journal of Hydrology*, *603*, 126984. http://dx.doi.org/10.1016/j.jhydrol.2021.126984.

Lopes, M. G., Sanches, N. A. O., Gorni, G. R., Corbi, V. C., & Corbi, V. C. (2019). Qualidade da água em nascentes do município de Araraquara-SP: uma abordagem utilizando bioindicadores ambientais. *Revista Brasileira Multidisciplinar*, *22*(1), 109-120. http://dx.doi.org/10.25061/2527-2675/ReBraM/2019.v22i1.511.

Maciel Filho, C. L. (1990). *Carta geotécnica de Santa Maria* (1. ed., Vol. 1. 21 p.). Santa Maria: Universidade Federal de Santa Maria.

Paula, G. R., Batista, G. T., Targa, M. D. S., Souza, C. F., Dias, N. W., & Peres, J. G. (2013). Avaliação do comportamento da umidade do solo em áreas de eucalipto e de floresta nativa. *Revista Ambiente & Água*, *8*(4), 237-252. http://dx.doi.org/10.4136/ambi-agua.1419.

Pumo, D., Caracciolo, D., Viola, F., & Noto, L. V. (2016). Climate change effects on the hydrological regime of small non-perennial river basins. *The Science of the Total Environment*, *542*(Pt A), 76-92. PMid:26519569. http://dx.doi.org/10.1016/j.scitotenv.2015.10.109.

Quimpo, R. G., Alejandrino, A. A., & McNally, T. A. (1983). Regionalized flow duration for Philippines. *Journal of Water Resources Planning and Management*, *109*(4), 320-330. http://dx.doi.org/10.1061/(ASCE)0733-9496(1983)109:4(320).

Ridolfi, E., Kumar, H., & Bárdossy, A. (2020). A methodology to estimate flow duration curves at partially ungauged basins. *Hydrology and Earth System Sciences*, *24*(4), 2043-2060. http://dx.doi.org/10.5194/hess-24-2043-2020.

Rijke, J., Farrelly, M., Brown, R. R., & Zevenbergen, C. (2013). Configuring transformative governance to enhance resilient urban water systems. *Environmental Science & Policy*, *25*, 62-72. http://dx.doi.org/10.1016/j.envsci.2012.09.012.

Rizzardi, A. S., Righes, A. A., Kemerich, P. D. C., Silva, R. F., Santos, S. A., & Borba, W. F. (2014). Atributos físicos e fluxo de água em solos da bacia hidrográfica do rio Vacacaí-Mirim – RS.

Revista do Centro do Ciências Naturais e Exatas, *13*(4), 3690-3701. http://dx.doi.org/10.5902/2236130814260.

Rockström, J., Falkenmark, M., Allan, T., Folke, C., Gordon, L., Jägerskog, A., Kummu, M., Lannerstad, M., Meybeck, M., Molden, D., Postel, S., Savenije, H. H. G., Svedin, U., Turton, A., & Varis, O. (2014). The unfolding water drama in the Anthropocene: towards a resilience based perspective on water for global sustainability. *Ecohydrology*, *7*(5), 1249-1261. http://dx.doi.org/10.1002/eco.1562.

Rodina, L. (2018). Defining "water resilience": debates, concepts, approaches, and gaps. *WIREs. Water*, *6*(2), 1-18. http://dx.doi.org/10.1002/wat2.1334.

Santos, M. O., & Melo, S. M. (2017). A influência do uso e ocupação do solo na qualidade da água de nascentes: análise de macroinvertebrados Bentônicos como bioindicadores. *Journal of Environmental Analysis and Progress*, *2*(1), 36-43. http://dx.doi.org/10.24221/jeap.2.1.2017.1029.36-43.

Shin, S., Lee, S., Judi, D., Parvania, M., Goharian, E., McPherson, T., & Burian, S. (2018). A systematic review of quantitative resilience measures for water infrastructure systems. *Water*, *10*(2), 1-25, 164. http://dx.doi.org/10.3390/w10020164.

Silva, C. O. F., & Manzione, R. L. (2020). Revisitando a regionalização de vazões na região do Médio Paranapanema no Estado de São Paulo: utilização de curvas de permanência em microbacias hidrográficas. *Revista do Instituto Geológico.*, *41*(2), 1-13. http://dx.doi.org/10.33958/revig.v41i2.678.

Silva, R. L. L., Edgar, L., Buriol, G. A., & Estefanel, V. (2017). Space variation of monthly and annual average temperatures in the area of the Vacacaí-Mirim river hydrographic bowl, RS, Brazil. *Disciplinarum Scientia*, *18*(2), 287-303.

Silva, R. L. L., Hentges, S. C., Domingues, A. L., Maciel Filho, C. L., & Buriol, G. A. (2015). Natural vulnerability of groundwater resources in the Vacacaí-Mirim River Basin – RS. *Disciplinarum Scientia*, *16*(3), 333-355.

Silva, R. L. L., Richter, L. A., Iensen, R. E., Kemerich, P. D. C., & Buriol, G. A. (2019a). Geographic variation of rainfall in the Vacacaí-Mirim Hydrographic basin. *Disciplinarum Scientia*, *20*(1), 41-51.

Silva, R. S., Blanco, C. J. C., & Pessoa, F. C. L. (2019b). Alternative for the regionalization of flow duration curves. *Journal of Applied Water Engineering and Research*, *7*(3), 198-206. http://dx.doi.org/10.1080/23249676.2019.1611493.

Silveira, A. L. (2016). Fator de pico para hidrogramas unitários sintéticos triangulares. *Revista Brasileira de Recursos Hídricos, Porto Alegre*, *21*(1), 46-52. http://dx.doi.org/10.21168/rbrh.v21n1.p46-52.

Sinha, R., Gupta, A., Mishra, K., Tripathi, S., Nepal, S., Wahid, S., & Swarnkar, S. (2019). Basin-scale hydrology and sediment dynamics of the Kosi river in the Himalayan foreland. *Journal of Hydrology*, *570*, 156-166. http://dx.doi.org/10.1016/j.jhydrol.2018.12.051.

Souza, M. M., & Gastaldini, M. C. C. (2014). Water quality assessment in watersheds with different anthropogenic impacts. *Engenharia Sanitaria e Ambiental*, *19*(3), 263-274. http://dx.doi.org/10.1590/S1413-41522014019000001097.

Scott, A. J., & Knott, M. A. (1974). Cluster analysis method for grouping means in the analysis of variance. *Biometrics*, *30*(3), 507-512. http://dx.doi.org/10.2307/2529204.

Targa, M. S., Batista, G. T., Almeida, A. A. S., Pohl, E., & Paula, G. R. (2017). Evaluation of soil water storage in native forest and eucalyptus áreas. *Revista Ambiente & Água*, *12*(6), 973-983. http://dx.doi.org/10.4136/ambi-agua.2195.

Targa, M. S., Almeida, A. A. S., Pohl, E., Silva, L. G., & Silva, M. C. (2020). Balanço de água em floresta tropical e eucalipto na bacia hidrográfica do rio Una, Vale do rio Paraíba do Sul. *Revista Técnica Ciências Ambientais*, *1*(1), 1-11.

Toniolo, G. R., Lacruz, M. S. P., & Sausen, T. M. (2013). Análise do escoamento superficial na bacia hidrográfica do rio Vacacaí-Vacacaí Mirim. *Revista Brasileira de Cartografia*, *65*(3), 605-615.

Torres, C. J. F., Medeiros, Y. D. P., & Freitas, I. M. D. P. (2016). Training watershed committee members to aid on the decision-making process for the execution program of the framework of water bodies. *Revista Brasileira de Recursos Hídricos*, *21*(2), 314-327. http://dx.doi.org/10.21168/rbrh.v21n2.p314-327.

Vogel, R. M., & Fennessey, N. M. (1994). Flow-duration curves. I: new interpretation and confidence intervals. *Journal of Water Resources Planning and Management*, *120*(4), 485-504. http://dx.doi.org/10.1061/(ASCE)0733-9496(1994)120:4(485).

Vogel, R. M., & Fennessey, N. M. (1995). Flow duration curves. II: a review of applications in water resources planning. *Water Resources Bulletin*, *31*(6), 1029-1039. http://dx.doi.org/10.1111/j.1752-1688.1995.tb03419.x.

Xu, L., & Kajikawa, Y. (2017). An integrated framework for resilience research: a systematic review based on citation network analysis. *Sustainability Science*, *13*, 235-254. http://dx.doi.org/10.1007/s11625-017-0487-4.

White, I., Connelly, A., Garvin, S., Lawson, N., & O'Hare, P. (2016). Flood resilience technology in Europe: identifying barriers and co-producing best practice. *Flood Risk Management*, *11*, S468-S478. http://dx.doi.org/10.1111/jfr3.12239.

Witschoreck, R., Schumacher, M. V., & Caldeira, M. V. W. (2003). Estimativa da biomassa e do comprimento de raízes finas em *Eucalyptus urophylla* S.T. Blake no município de Santa Maria-RS. *Revista Árvore*, *27*(2), 177-183. http://dx.doi.org/10.1590/S0100-67622003000200008.

Zhang, Y., Vaze, J., Chiew, F. H. S., & Li, M. (2015). Comparing flow duration curve and rainfall-runoff modelling for predicting daily runoff in ungauged catchments. *Journal of Hydrology*, *525*, 72-86. http://dx.doi.org/10.1016/j.jhydrol.2015.03.043.

Zhang, Z. (2017). The index gage method to develop a flow duration curve from short-term streamflow records. *Journal of Hydrology*, *553*, 119-129. http://dx.doi.org/10.1016/j.jhydrol.2017.07.045.

Authors contributions

Raul Todeschini: Paper's lead author, partial requirement to obtain Master's degree in Civil Engineering at Universidade Federal de Santa Maria.

Alexandre Swarowsky: Data interpretation, statistical analysis, reviewer of the article and member of the main author's board of examiners.

André Gonçalves Panziera: Responsible for textual adjustments, statistical interpretations and standardization.

Guilherme Lemes Erthal: Responsible for textual adjustments and standardization.

João Francisco Carlexo Horn: Reviewer of the article.

Jussara Cabral Cruz: Lead author's advisor.

Editor-in-Chief: Adilson Pinheiro

Associated Editor: Michael Mannich