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Participatory approach and Nature-based Solutions (NbS) as resilience and revitalization strategies in watersheds

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ABSTRACT
In the face of climate change, adopting participatory, integrative, and systemic management approaches capable of regulating hydrological, ecosystemic, and social interactions and redefining urban and rural planning, transitioning from the municipal scale to a micro and sub-basin approach, is crucial to ensure water security and resilience to extreme weather events. The revitalization of watersheds through adaptive management of natural resources, is fundamental because it allows for environmental recovery and conservation, the provision of ecosystem services and water resources for multiple uses. This work aimed to present proposals for the watershed of the Jaú River, São Paulo/BR. In 2022, the city of Jaú was hit by an unprecedented flood, which made it clear the mistakes made in urbanization, especially those related to the occupation of the floodplain by roads and buildings. Through a participatory methodology, with the support of the Tietê-Jacaré Watershed Committee and the involvement of municipalities, the productive sector, and civil society organizations, guidelines were defined to mitigate impacts and prevent new occurrences. Considering that the Jaú River is an important source of public water supply, providing water for more than 57 thousand people, the proposed actions are based on principles of nature-based solutions aiming to maintain the natural properties of riverbeds, maximize permeability, recover riparian forests along watercourses, and ensure appropriate land use and conservation practices..

KEYWORDS: Soil conservation. Permanent Preservation Areas. Ecohydrology.

1 INTRODUCTION

Water security is a fundamental concept in the field of water resources management and refers to the ability to guarantee accessible water to everyone for a healthy and productive life, communities protected against extreme events (floods and droughts) and water-related diseases, in addition to provide water for the maintenance of natural ecosystems (WEF, 2011; ANA, 2023).

Cities play a fundamental role in ensuring water security, since, in the Brazilian legal context, municipal responsibilities are clearly delineated, especially in the context of basic sanitation (BRASIL, 2007; DE SOUZA & FLANERY, 2013) and territorial planning. However, it is necessary to reframe urban planning and water security from a municipal scale to a micro and sub-basin scale approach. The watershed approach emerges as a more comprehensive and efficient management unit (MASCARENHAS et al., 2009).

Understanding and properly managing the watershed means promoting conservation actions that mitigate the risks associated with water scarcity and susceptibility to extreme events and provide multiple uses of water. In the urban environment, the incorporation of such conservation practices into city planning can provide an occupation that guarantees soil permeability and allows the adoption of rainwater capture and reuse strategies (BROWDER et al., 2019). Additionally, the integration of innovative technologies, such as monitoring systems and hydrological modeling, are also part of the watershed revitalization.

Implementing appropriate land use techniques, promoting reforestation, preserving water sources and springs and adopting conservationist agricultural practices are among the main strategies used to improve water security. (TUCCI & CHAGAS, 2017; SAAD et al.; 2018 SANTOS et al., 2020). There are several examples of watershed restoration that have contributed significantly to improving water quantity and quality (OBRACZKA et al., 2019; CASTRO & PEREIRA, 2019; SANTOS & SCHWINGEL, 2021).

The interconnection between urban and rural areas in watershed requires an integrated approach to dealing with water-related challenges, such as extreme flooding events. In this context, the planning of public policies and the implementation of practical actions must transcend municipal borders (STRIFLING, 2018). The coordinated action of public authorities,

civil society, environmental agencies and other interested parties is imperative to promote the effectiveness of the adaptive actions to extreme events.

Given these premises, this work presents the initial results of the proposals presented during the "I *Jauense* Waters Forum", which had as its theme "Solutions for the Jaú River Watershed". The forum, held by the Municipality of Jahu, with the support of the Tietê-Jacaré Hydrographic Watershed Committee (CBH TJ), the College of Technology of Jahu (Fatec Jahu), the Municipal Environmental Council (Comdema Jahu) and the Jaú City Hall, took place on March 22, 2022.

The forum was motivated by the extreme meteorological event that hit the municipality on the weekend of January 29th and 30th, 2022. On these two days, rainfall of around 320 mm was recorded upstream of the urban area. This precipitation caused the largest flood ever observed in the city. The Jaú River left its enclosed main channel, and occupied, in addition to the seasonal hydrologic floodplain, its exceptional flood channel, causing two deaths and directly affecting, according to the Civil Defense of Jaú, 864 residences and 139 commercial establishments, bringing disruption to daily life for approximately 5,000 people and compromising mobility in the city, affecting practically all residents.

2 MATERIALS AND METHODS

2.1 Study Area

The Jaú River Watershed has approximately 420 m of altitude range, with a maximum altitude of 861 m near its headwaters in Serra do Tabuleiro, in the municipality of Torrinha and 440 m at its estuary in the Tietê River on the border of the municipalities of Jaú, Itapuí and Bariri. In 90% of the watershed, the slopes are less than 12%, and in more than 55% of the area has the slopes less than 6%.

The Jaú River is a 5th order watercourse, has 22 main tributaries and 2 forming streams (Ribeirões do Bugio and Peixe). Its watershed is located in the Tietê - Jacaré Water Resources Management Unit (UGRHI TJ), has a total area of 752.25 km² and a drainage network of 745.8 km. Its territory covers part of the municipalities of Bariri, Bocaina, Dois Córregos, Itapuí, Jaú, Mineiros do Tietê and Torrinha, between the parallels 22°09' and 22°28' S and the meridians 48°13' and 48°42' W There are three urban areas within the basin: Jaú (partially), Dois Córregos and Mineiros do Tietê (Figure 1).

The climate of the Jaú River Watershed according to the Koopeen classification is defined as "Aw", tropical rainy with dry winter. Annual precipitation in normal years varies between 1200 and 1400 mm. The rainy period occurs from October to March, with the rainiest quarter being December to February. The dry period runs from April to September, with the driest quarter between June and August.

The average rainfall for the month of January between 1936 and 2022 is 238.2 mm, according to the Department of Water and Electric Energy – DAEE. Until 2022, the wettest January had occurred in 1997. At the time, the precipitation rate recorded was 486.8 mm in the month. In January 2022, the rainfall recorded was 502.4 mm, of which 332 mm in less than 48 hours, between the 28th, 29th and 30th of January.

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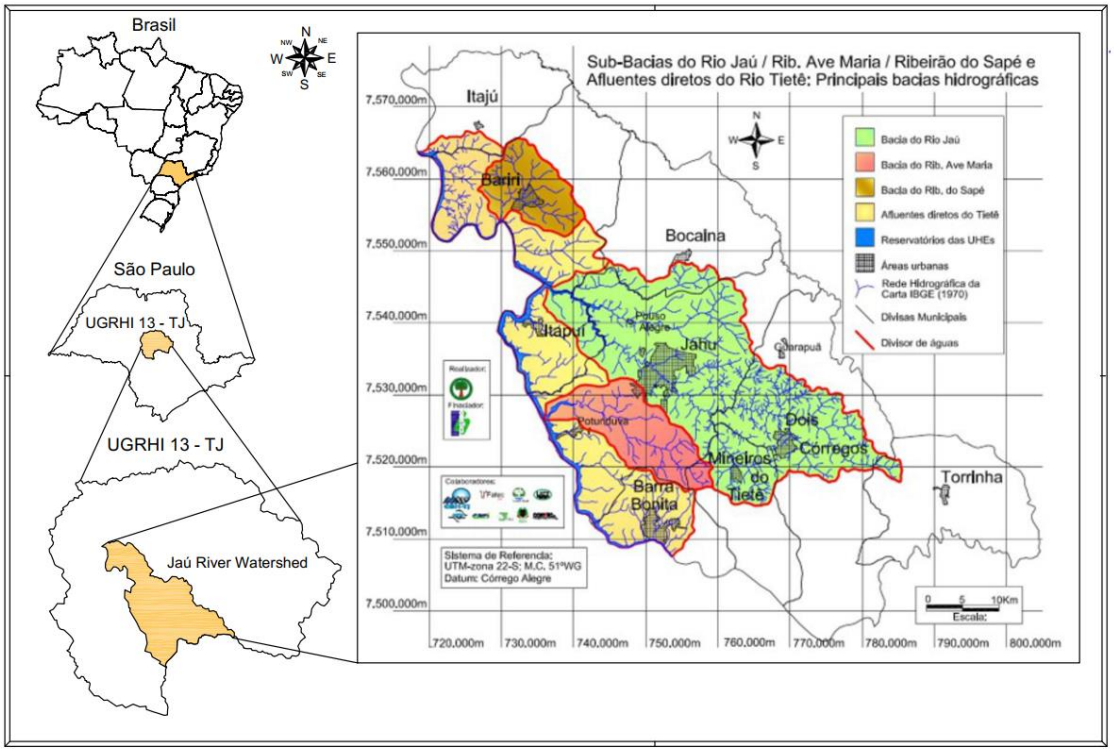
Figure 1 – Location of the Jaú River Watershed



Modified from CBH TJ (2013)

2.2 Methodology

The holding of the "I Jauense Water Forum" was proposed at a meeting that brought together the President of CBH TJ, the President of the Jaú City Council, the Municipality's Secretaries of Environment and Agriculture and the President of the Comdema of Jaú. The agenda was to evaluate strategies and actions for adaptation and resilience to extreme meteorological phenomena. The meeting defined the date, theme, format and guests.

The approach within the watershed and nature-based solutions were deliberated as guidelines to direct the discussions and the main actors were invited to participate in the forum, including the mayors and secretaries of environment and agriculture of the 7 municipalities in the area and representatives of Civil Defense, DAEE, Agricultural Defense (CATI-SAA), CBH TJ, Municipal Environmental Councils - COMDEMA, sugar and alcohol plants, associations of rural producers, residents of affected neighborhoods, non-governmental organizations - NGOs and technical and trade associations .

The program was defined as follows: in the morning lectures on the topic with teachers and researchers from Fatec Jahu and EESC/USP, technicians from DAEE and Civil Defense. In the afternoon, a debate was held moderated by the president of CBH TJ, in which everyone present had the right to speak. The forum was attended in person by more than 100 people and was broadcast live on TV Câmara.

The suggestions presented were discussed and the approved proposals were described in a document entitled "Proposals presented at the "I Jauense Water Forum - Solutions for the Jaú River Watershed" sent to the Municipal Mayor of Jahu. The final document was accompanied by a legal document proposing the creation of a "Municipal Commission" to deal

with matters relating to the Jaú River, its tributaries and its watershed, with the function of planning and monitoring short, medium and long-term actions.

3 RESULTS AND DISCUSSION

The incorporation of diverse actors in the decision-making process in the handling and management of natural resources not only expands the knowledge base, but also promotes greater representativeness, legitimacy and acceptance of the implemented measures.

Thus, given the rainfall event that took place in January 2022, on August 10, 2022, through Municipal Decree no. 8,364, the "Municipal Commission for Affairs of the Jaú River, its tributaries and its Hydrographic Watershed – COMARJ" was created, formed by representatives from various municipal departments, representatives of the affected residents and professor of Fatec Jahu. The actions proposed at the forum were classified according to their execution time and the actors responsible for their implementation (Chart 1). Since then, the commission, chaired by the Municipal Secretary of the Environment, has met regularly to discuss, plan and monitor the strategies and actions.

Chart 1 - Actions proposed at the 1st Jauense Water Forum to revitalize the Jaú River Watershed and to prevent, control and combat floods and flooding in the urban area

Actions	Expected results	Deadline*	Actors
1. Create a Municipal Commission (city hall, civil defense, research institutions and civil society) to monitor actions to prevent, control and combat floods.	Optimized planning, decision-making and monitoring of actions	**Emergency**	Jahu City Hall
2. Install real-time monitoring and alarm system (flow/rain).	Minimizing risks and losses		
3. Carry out interventions in the river channel in the urban area (cleaning and desilting).	Elimination of critical points		
4. Assess the stability of the river's embankments throughout the urban area, plan the necessary actions and carry out interventions.	Reduction in the vulnerability of the river bed and slopes	**Short**	
5. Prepare risk zoning and elaborate a plan to combat floods and flooding in the municipality.	Risk areas identified and classified for each scenario		
6. Improve soil and water conservation systems in rural areas and local roads.	Reduction of erosive processes and reduction of silting	**Medium**	CBH and CATI-SAA City Halls and Municipal Chambers, Sanitation Concessionaires Plants and Rural Producers
7. Create the Intermunicipal Consortium of the Jaú River Watershed.	Regional actions and fundraising for the watershed		
8. Develop executive engineering projects (overflow channel and dam for flood control) and raise funds for execution.	Safeguarding residents and buildings built in the riverbed		
9. Restore the riparian forests in the Permanent Preservation Areas of springs and watercourses in the watershed.	Protected and resilient rivers, maximized ecosystem services	**Long**	CBH and CATI/SAA Plants, Producers and NGOs, City Halls
10. Institute municipal public policies (Sustainable drainage, blue green infrastructure, Revitalization of urban rivers, riverside linear parks, green taxes, Rainwater harvesting).	Legislation proposed, discussed, approved and regulated		CBH, City Halls and Municipal Sectors

* EMERGENCY (up to 1 year); SHORT (from 1 to 4 years); MEDIUM (from 4 to 8 years); LONG (from 8 to 12 years)

In addition to the creation of COMARJ, interventions were carried out in the river channel in the urban area (cleaning and desilting), which have not yet been fully completed. The commission proposed the acquisition of a telemetric system, measuring precipitation at 5 points in the watershed area and the level rise and flow increase of the Jaú River at another 5 points. The flow and rain monitoring system and real-time alarm are in the bidding phase. The system must be powered by solar panels and have autonomy to guarantee transmission even after a sequence of several days without sun. City hall engineers carried out the initial assessment of river embankments throughout the urban area. The models to be adopted to guarantee stability and the techniques to be used to carry out the necessary interventions are under discussion.

Aiming to improve soil and water conservation systems in rural areas and local roads, meetings were held with representatives of the group that controls the sugar and alcohol plants in the region. Furthermore, the Tietê-Jacaré Watershed Committee approved, at its 81st Plenary Meeting held on March 10, 2023, a motion to repudiate the soil conservation system adopted by sugar and alcohol plants in the Jacaré-Pepira and Jaú river watershed.

The motion of censure, sent to various departments of the government of the state of São Paulo, among other recipients, questions the adoption of the production system. It has been noted that the mechanized harvesting of raw sugarcane were changed to adapt to the machines, prioritizing operational performance to the detriment of soil conservation. The use of this techniques such as the adoption of greater spacing between terraces, smaller terraces, the expansion of plot sizes, straight furrowing without terraces with long shoots, straight furrowing in through terraces and no scarification by subsoilers tends to favor erosion processes.

Inadequate planning of soil mobilization in rural areas, leaving soil exposed, without cover, during the months of December, January and February, in which rainfall is very intense in the region, was confirmed based on surveys carried out in February 2022 and satellite images from the week before the extreme precipitation event.

It was possible to identify contiguous plots of land, with areas ranging from 500 to 800 hectares without any cultivation, with soil preparation carried out using a plow harrow or with recent planting. The motion suggests the adoption of alternative practices such as minimum cultivation, crop rotation, strip cultivation, deep level furrowing, subsoiling, runoff catchment basins, energy dissipaters and drainage channels to minimize impacts and adequate planning.

In addition to issues related to mitigating flood impacts, it is important to highlight that the Jaú River is a source of water that supplies more than 57 thousand inhabitants (1/3 of the population of the municipality of Jahu). In 2022, 5,768,180 m^3 (658 m^3/h) were captured. The Jaú River, therefore, is an essential provider of ecosystem services and the management of its waters and its basin must be carried out from a holistic view, in an integrated and systemic manner, considering the interaction between the social and natural system (ZALEWSKI, 2010; ARAÚJO, 2012).

The purpose of the actions discussed and presented must be to mimic natural processes, adopting as basic principles the maintenance of the natural characteristics of river beds (sinuosities), the maximum permeability of rainwater on the surfaces, both in rural and urban areas. Additionally, banks along the watercourses occupied by riparian forests, and the adequacy of soil uses and conservation to the environmental support capacity of each of the hydrogeodynamic zones (recharge, erosion and sedimentation-floodplains). These strategies, based on the principles of ecohydrology, are called Nature-Based Solutions – NbS. (TAMBOSI et al. 2015; COHEN-SHACHAM et al., 2016; UNESCO, 2018).

The adoption of NbS, through an interdisciplinary, integrative and systemic approach, can enable the regulation of hydrological and ecosystem interactions with the demands of society, allowing the balance, functions and resilience of river ecosystems while protecting people and goods against floods (LEZY-BRUNO; OLIVEIRA, 2007; ZALEWSKI, 2010).

This new approach, ecohydrological, seeks to simulate and recover natural processes of the hydrological and ecological cycles, adopting as principles the maximum permeability of rainwater along the watercourse and also on other surfaces, the maintenance of the natural properties of the river channels (sinuosities) and the banks with the presence of vegetation (SANCHES, 2007). Ecohydrology deals with holistic approaches that seek the sustainability of ecosystems and human populations, providing a solid scientific basis for adopting the watershed as a planning territorial unit (ZALEWSKI, 2010).

In order to find long-term solutions that integrate social components with ecosystem sustainability to improve the efficiency of water use and the integrated management of water resources, hydrological and ecological processes are studied in a connected way from molecular to macro scales. This is called the multifunctional objective of the five elements responsible for strengthening the capacity of altered ecosystems: water, biodiversity, ecosystem services, resilience and culture or social dimension (WBSRC) (UNESCO, 2018).

In relation to urban areas, the revitalization of rivers and streams plays an important role in the search for sustainability and water security in cities. The revitalization process must be based on the use of vegetation, soil and natural urban and peri-urban water systems as components of the drainage system with the potential to mitigate the adverse effects of urbanization (ROLO; GALLARDO; RIBEIRO, 2017).

This model implies the adoption of adaptive procedures for natural resources, recognizing the changes and dynamics of the natural resources to be managed, and requiring continuous adjustments as the situation changes, always considering learning and interaction between the social and natural system (ARAÚJO, 2012).

This urban water management and adaptive strategy is based on the use of natural ecosystems as infrastructure and has the following guidelines (USEPA, 2012):

- Preservation and recovery of vegetation and maintenance of natural drainage paths and native soil characteristics, minimizing impermeable areas and interventions in the relief;
- Unique and specific projects, respecting local and natural peculiarities throughout the watershed, to the detriment of standardized models;
- Increased infiltration and recharge of base flow and aquifers;
- Maintenance of wetlands and streams;
- Controlled direction of flow towards vegetated areas;
- Water management as close as possible to the source of generation of excess runoff in an integrated manner, starting with the residence and block (small-scale distributed control);
- Planning and implementation of drainage systems that mimic natural hydrological processes with predictive and preventive conservation of drainage systems aiming to increase their efficiency and longevity;
- Systemic action in pollution prevention and environmental education;
- Attractiveness and belonging with appropriate landscaping and routine cleaning and maintenance.

In relation to watercourses in rural areas, appropriate soil conservation strategies and the ecological restoration of riparian forests in permanent preservation areas and recharge zones are fundamental. In this sense, the remaining vegetation index in the watershed and, in particular, the percentage of riparian forests in relation to the total water permanent preservation areas, are good indicators for evaluating the situation of vulnerability or ecological and hydrological integrity of a watershed.

In the Forest Restoration Master Plan of the Tietê-Jacaré Water Resources Management Unit, sub-basin 3, which encompasses the Jaú River Watershed, the area was divided into 41 micro-hydrographic basins (Table 1 and Figure 2), of which 12 are upstream of the urban area of Jaú totaling 39,143 ha (CBH TJ, 2013).

In these microbasins, the remaining vegetation mapped was 2,008 ha, that is, just over 5% of the total area and the drainage network was estimated at 356.15 km (CBH TJ, 2013). The Permanent Preservation Areas of these 12 microbasins total almost 1,784 ha, of which a little more than 70% (1,254.01 ha) is degraded, that is, without riparian forest (Table 2).

Table 1. Microbasins and hydrographic microregions upstream of the urban area of Jaú/SP: area, remaining vegetation and drainage network.

Identification	Microbasin or Hydrographic microregion	Area (ha)	Remaining Vegetation (ha)	Vegetation in the watershed (%)	Drainage Network (km)
3025	Santo Antônio Stream	2.324,16	129,63	5,58%	18,50
3026	Matão and Floresta Stream	2.510,74	101,54	4,04%	24,85
3027	João da Velha Stream, Jaú River, dos Nunes Stream, São João Stream	5.688,69	310,34	5,46%	43,01
3028	Garra and Palmeiras Stream	2.581,51	309,54	11,99%	40,58
3029	Saltinho and Veadinho Stream, Jaú River	3.694,75	173,14	4,69%	36,30
3039	Gavião Stream	2.035,60	49,84	2,45%	19,34
3040	São João, Faz. Santa Estefânia and Boa Vista Stream	2.416,28	38,41	1,59%	17,56
3041	Pascoal, São João, Borralho Stream	5.416,39	257,56	4,76%	49,03
3042	Lajeado and Fura-Olho Stream	3.881,50	138,96	3,58%	32,47
3043	Bugio and Queixada Stream	2.749,42	162,97	5,93%	27,71
3044	Prata Stream	1.794,30	92,69	5,17%	15,85
3045	Bugio Stream	4.049,66	243,61	6,02%	30,95
TOTAL		**39.143,00**	**2.008,23**	**5,13%**	**356,15**

Modified from CBH TJ (2013)

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Figure 2 – Jaú River Watershed and subdivisions into microbasins
Modified from CBH TJ (2013)

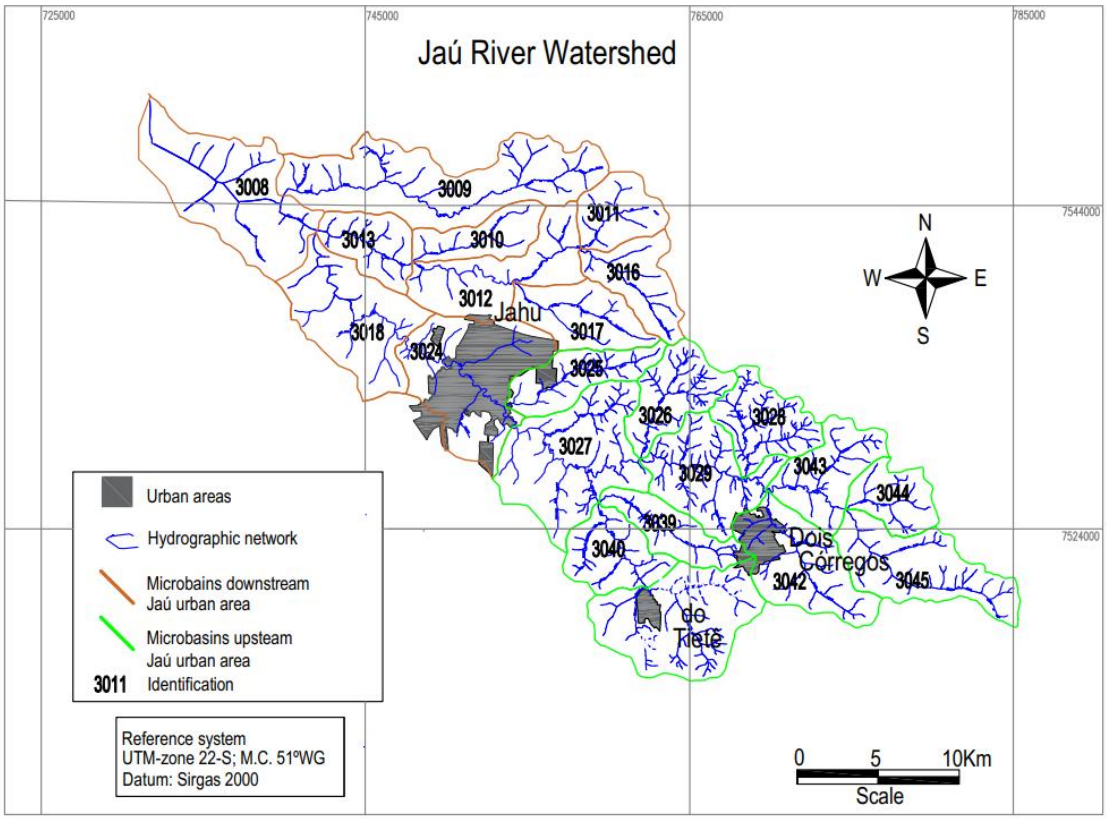

Table 2 - Water Permanent Preservation Areas (PPA) of Microbasins and hydrographic microregions upstream of the urban area of Jaú/SP and riparian forests (Adapted from CBH-TJ, 2013).

Identification	Microbasin or Hydrographic microregion	Permanent Preservation Areas (PPA) (ha)	Remaining Vegetation in PPA (ha)	PPA with Riparian Forests (%)	Riparian Forest Liabilities (ha)
3025	Santo Antônio Stream	96,32	10,59	10,99%	85,73
3026	Matão and Floresta Stream	123,19	27,79	22,56%	95,40
3027	João da Velha Stream, Jaú River, dos Nunes Stream, São João Stream	227,33	47,04	20,69%	180,29
3028	Garra and Palmeiras Stream	200,24	96,11	48,00%	104,13
3029	Saltinho and Veadinho Stream, Jaú River	180,01	57,01	31,67%	123,00
3039	Gavião Stream	94,06	11,44	12,16%	82,62
3040	São João, Faz. Santa Estefânia and Boa Vista Stream	87,64	11,00	12,55%	76,64
3041	Pascoal, São João, Borralho Stream	243,23	79,13	32,53%	164,10
3042	Lajeado and Fura-Olho Stream	160,67	49,17	30,60%	111,50
3043	Bugio and Queixada Stream	136,33	38,80	28,46%	97,53
3044	Prata Stream	77,49	30,25	39,04%	47,24
3045	Bugio Stream	157,27	71,44	45,42%	85,83
TOTAL		**1.783,78**	**529,77**	**29,70%**	**1.254,01**

Modified from CBH TJ (2013)

The reduction and fragmentation of areas of natural vegetation in watershed and along water courses are directly related to changes in the amplitude, intensity, frequency and recurrence of minimum and maximum flows in water courses. In addition to compromising water quality. Riparian vegetation, among other functions, acts as a natural protection strip for water courses. Its absence causes an increase in the input of particulate matter into rivers and streams, intensifying the silting process and altering the hydraulic patterns of watercourses. This process deteriorates aquatic habitats and increases the risk of flooding and water treatment costs (MARCOMIN, 2002; BARRELA et al., 2001).

Continuous riparian forests along watercourses, in addition to the protection and increased resilience conferred to the river channel and the aquatic ecosystem, contribute to the balance of the water in the watershed, through the recharge of aquifers, especially in areas around the springs. They also act as ecological corridors when connected to nearby forest fragments, allowing the biological flow of flora and fauna, as they guarantee the movement of animals and facilitate the dispersal of seeds (KUNTSCHIK; EDUARTE; UEHARA, 2014).

4 CONCLUSIONS

The adoption of solutions generated from the understanding of the principles and processes of nature and the active and collective engagement and participation of all segments of the communities involved are fundamental to providing water security and promoting resilience to extreme flood and drought events prolonged. The territorial approach within the scope of watersheds, the definition of guidelines based on the precepts of ecohydrology and the choice of strategies that consider the balance of the water balance, maximizing water infiltration into the soil and that seek to maintain as much as possible the natural characteristics of the slopes and of water courses are essential in this sense. Only the planning and execution of actions in accordance with nature-based solutions can allow the continued provision of ecosystem services and the consequent social and economic benefits arising from this choice.

In relation to the case study presented, which involves the Jaú River Watershed and its tributaries, it is clear that revitalization depends on the implementation and continuity of regional public policies, in addition to the investments necessary to finance works and services. Furthermore, most of the proposed solutions must be carried out jointly and proactively by all segments of society that inhabit the cities and rural areas of the municipalities in the watershed.

City halls have the role of conducting and coordinating work in their territories, the sugar and alcohol sector, since sugar cane cultivation is the matrix of the regional landscape, extensionists and rural producers can contribute to soil conservation management and water and with the recovery of riparian vegetation liabilities, organized civil society and the media have the role of promoting the dissemination of information and providing support for the engagement of the entire society and higher education and research institutions to indicate technically appropriate alternatives to the issues.

In this sense, the Tietê-Jacaré Hydrographic Watershed Committee, a regional entity responsible for promoting the integrated management of water resources in thirty-four municipalities in the region, including municipalities located in the Jaú River Watershed, has an important role, as it can elect the revitalization of the Jaú river as one of its priorities and guide the necessary actions for the formation of an intermunicipal consortium, aiming at cooperation

between municipalities to carry out activities and projects together, optimizing and allowing the capture of resources to face the common challenges.

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