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Dimension of Permanent Preservation Areas (PPAs): considerations on the Itaquarinchim River

Dimensão das Áreas de Preservação Permanente (APPs): considerações sobre o rio Itaquarinchim

Tamaño de las Áreas de Preservación Permanente (APP): consideraciones sobre el río Itaquarinchim

Luis Guilherme Aita Pippi, PhD in Philosophy – Design Area of Landscape Architecture from NCSU, NC, USA, Professor in the Department of Architecture and Urban Planning at the Federal University of Santa Maria, Rio Grande do Sul, Brazil.
E-mail: luis.g.pippi@ufsm.br http://orcid.org/0000-0002-4714-4138

Karine Perius Chartanovicz, Architect and Urban Planner from the Integrated Regional University of Alto Uruguai and Missoes, Santo Ângelo; Master's student in the Postgraduate Program in Architecture, Urban Planning, and Landscaping, Federal University of Santa Maria, Rio Grande do Sul, Brazil.
E-mail: karine.chartanovicz@gmail.com http://orcid.org/0000-0002-2738-8725

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Abstract

Throughout history, occupying areas adjacent to rivers transformed spaces of great ecological and landscape value in locations with environmental and social problems. In this context, Permanent Preservation Areas (PPAs) (Áreas de Proteção Permanente;

APPs) are one crucial tool that seeks to protect water resources. The legislation defines which APP range (buffers) are suitable according to the width of the water resource. However, there is debate about whether these dimensions are adequate. With the Itaquarinchim River, in the municipality of Santo Ângelo/RS, as a case study, we seek to understand its relationship with the surrounding landscape, both in the rural and urban context. For the scope of this research, we consider a buffer of 500 meters from each side of the riverbed. Based on the spatialization of the study area via geoprocessing, the analysis will revolve around how the use and land occupation, just as the relation of the river with its surroundings, took place. In addition, we will analyze if the river has an APP following current legislation (30m) along its course, the state of this APP, and, ultimately, if there is the potential to expand this APP range from 30m to greater width and if it could support multifunctional activities in this context.

Keywords: Rivers; Permanent Preservation Areas; PPAs; Buffer.

Resumo

Ao longo da história as áreas adjacentes aos rios foram ocupadas, transformando espaços de grande valor ecológico e paisagístico em locais com problemas de ordem ambiental e social. Neste contexto, as Áreas de Preservação Permanente (APPs) são uma importante ferramenta que busca a proteção dos recursos hídricos. A legislação define quais faixas de APPs são apropriadas de acordo com a largura do recurso hídrico, porém há discussões se essas dimensões seriam adequadas. Tendo como estudo de caso do rio Itaquarinchim no município de Santo Ângelo-RS, busca-se compreender sua relação com a paisagem do entorno, tanto no contexto rural quanto urbano. Como recorte dessa pequisa foi considerado um corredor ripário (*buffer)* de 500 metros para cada lado do leito do rio. A partir da espacialização da área de estudo em geoprocessamento será analisado como se deu o uso e ocupação do solo e a relação do rio com seu entorno. Além disso, se o rio possui APP de acordo com a legislação em vigor (30m) ao longo do seu percurso e a sua condição. Por fim, se possui potencial para expandir essa faixa de APP de 30m para uma largura maior e se poderia comportar atividades multifuncionais nesse contexto.

Palavras-chave: Rios; Áreas de Preservação Permanente; APPs; *Buffer*.

Resumen

A lo largo de la historia se han ocupado zonas aledañas a los ríos, espacios exteriores de gran valor ecológico y paisajístico en lugares con problemática ambiental y social. En este contexto, las Áreas de Preservación Permanente (APP) son una importante herramienta que busca proteger los recursos hídricos. La legislación define qué rangos de APPs (buffers) son adecuados según el ancho del recurso hídrico, pero hay discusiones sobre si estas dimensiones serían adecuadas. Tomando como estudio de caso el río Itaquarinchim en el municipio de Santo Ângelo-RS, buscamos comprender su relación con el paisaje circundante, tanto en contextos rurales como urbanos. Como corte de este levantamiento se consideró una zona de amortiguamiento de 500 metros

para cada lado del cauce del río. A partir de la espacialización del área de estudio en geoprocesamiento, se analizará cómo se dio el uso y ocupación del suelo y la relación del río con su entorno. Asimismo, si el río tiene un APP de acuerdo con la legislación vigente (30m) a lo largo de su recorrido y su estado. Finalmente, si tiene el potencial para expandir este rango de APP de 30m a un ancho mayor y si podría soportar actividades multifuncionales en este contexto.

Palabras clave: Ríos; Áreas de Preservación Permanente; APPs; *Buffer*.

Introduction

Water has always exerted a strong power to attract people, a factor of great importance for developing human settlements. It represents a source of food, the possibility of navigation, energy generation, leisure, circulation of people and products, and territory control, among other factors (Gorski, 2010; Costa, 2006). With the growth of cities, rivers were transformed and shaped according to the population's current needs, generating various environmental and social problems (Gorski, 2010). Given this scenario, Costa (2006) argues that there is an urgent need to seek interdisciplinary solutions to alleviate these problems, articulating environmental, social, and urban dimensions.

Many cities were directly influenced by the presence of watercourses, turning to them and having their layout and way of life shaped by them (Guimarães, 2011). Under the physical aspect and urban form, rivers are vital landscape elements. They structure the adjacent urban fabric, often becoming axes for the development of the city's design, delimiting the urban configuration. However, there are many cases in which the rivers conflict with the surrounding towns, presenting a scenario of environmental degradation and social and infrastructure problems that fail to value and even perceive these bodies of water.

Such is the case of the city of Santo Angelo/RS, whose origin is directly linked to the presence of rivers, where the surrounding city conflicts with the Itaquarinchim River. This river cuts through the municipality and urban perimeter of Santo Ângelo and is hugely degraded. It rises in the rural area and is 26.7 km long, and the width of the riverbed does not exceed 10 meters. It covers a large area in the countryside and the urban perimeter. Its final route and mouth are within the urban perimeter but in an area characterized as "*rururbanba*"[1] or, as we will refer to in this article, *ruruban* (rural and urban).

Bartalini (2006) states that most rivers are in critical environmental situations. Despite the legislation contemplating the protection of riverbanks and springs, it faces problems of a social nature – such as the frequent occupation of riverbanks,

1 "Urban perimeter region comprised by the characterization and composition of elements linked to rurality, agricultural production and by the relations between city and countryside" (Pinto, 2014, translated by the authors).

or economic hindrance, such as the high costs of intervention in urbanized areas. A critical issue that needs consideration when protecting rivers is the definition of adequate widths for Permanent Preservation Areas (PPAs). However, the PPAs generate many debates, mainly in the urban context. The parameters and limits of the protection strips (buffers) stand out, imprecise legislation allowing different interpretations and its restrictive character regarding usage.

As for the definition of the width of APP buffers, there is much questioning whether the legislation would recommend an adequate size, considering the preservation of water resources, fauna, and flora. Bentrup (2008) suggests a minimum buffer (or riparian corridor) width of approximately 90m. For this kind of APP, the width must be sufficient to adequately control and manage water flows and nutrients and facilitate the mobility of wild fauna (Forman & Godron, 1986).

In addition to questions about the width of the protection buffers, restrictions on using these protection buffers are in discussion. Mello (2008) says cities need free spaces and spaces for leisure. However, environmental legislation prevents formal occupation on the banks of watercourses in Brazilian territory, aiming at environmental protection. Thus, idle urban fluvial spaces arise, which, given the socioeconomic inequality present in Brazil and the lack of inspection, become targets of irregular occupations. In this sense, the management of water resources must go beyond the static vision of preservation (Mello, 2008).

It is possible to observe that new models of environmental urban management are on the agenda, considering the multifunctional character of the landscape of urban rivers. While we see the need to increase APP ranges, we understand the importance of including various activities within these areas, which include fauna, flora, and human activity. Therefore, this study seeks to understand how the Itaquarinchim River relates to its surroundings in Santo Ângelo. For this analysis, we considered a 500m buffer from each side of the Itaquarinchim riverbed. The research seeks to determine whether the river is integrated with the surrounding landscape and respects the APP range of 30m recommended by current legislation and its current environmental situation. In addition, we question whether there is potential for expanding the APP range from 30m to a bigger width and if it could support multifunctional activities in this context.

Considerations on the Legislation of Permanent Preservation Areas (PPAs)

To strengthen preservation policies, several laws were created to establish measures to protect the rivers. At the federal level, the Forestry Code (Law nº 12.651/2012) defines the so-called Permanent Preservation Areas (PPAs, Áreas de Preservação Permanente), which establish the protection of springs, slopes with a high degree of inclination, restingas, mangroves, plateaus, as well as margins of natural watercourses. APP is defined as follows:

> A protected area covered or not by native vegetation, with the environmental function of preserving water resources, the landscape, geological stability, and biodiversity, facilitating the gene flow of fauna and flora, protecting the soil, and ensuring the well-being of human populations. (Brasil, 2012, Art. 3, item II).[2]

Thus, according to the Forestry Code, the establishment of PPAs aims to maintain the local socio-environmental balance by preserving natural areas that can promote local well-being. The Forestry Code also defines the width delimitation of PPAs in the case of rural and urban watercourses. The planned buffers around water courses vary from 30 meters for rivers less than ten meters wide – the case of Itaquarinchim River – up to 500 meters for rivers surpassing 600 meters. Table 1 shows the minimum dimension for APP buffers according to the rivers' width and the APP size recommended for springs.

Width of water resource	Width of Permanent Preservation Area (APP)
Springs and water sources	At least 50m
Rivers up 10m	At least 30m
Rivers from 10 to 50m	At least 50m
Rivers from 50 to 200m	At least 100m
Rivers from 200 to 600m	At least 200m
Rivers with a width above 600m	At least 500m

Table 1: Widths recommended by the Forestry Code (Law no. 12.651/2012) for Permanent Preservation Areas (PPAs). Source: Adapted by the authors based on the Forestry Code (Law no. 12.651/2012).

According to Araújo and Ganem (2016), the first version of the Brazilian Forestry Code (Law No. 23,793/1934) already indicated the need to preserve riparian forests to protect hydric and urban resources. The Brazilian Forestry Code of 1934 also addressed rural areas, foreseeing the preservation of a quarter of the forest inside the rural property, which, years later, originated the legal instrument called "Legal Reserves." However, only in the second version of the Code (Law No. 4771/1965) did these norms get clearer, giving rise to Permanent Preservation Areas (PPAs). According to Mello (2008), this was when a five-meter protection buffer for rivers with less than ten meters in width was settled, making it possible for urban settlements to take place in the proximities of the riverbeds.

Afterward, with the institution of the Urban Land Subdivision Law (Law No. 6.766/1979, Lei de Parcelamento do Solo Urbano), a non-buildable range of fifteen meters along the bodies of water (rivers, streams, lakes, lagoons, etc.)

2 In Brazilian Portuguese: "Área protegida, coberta ou não por vegetação nativa, com a função ambiental de preservar os recursos hídricos, a paisagem, a estabilidade geológica e a biodiversidade, facilitar o fluxo gênico de fauna e flora, proteger o solo e assegurar o bem-estar das populações humanas" (Brasil, 2012, Art. 3º, inciso II).

was considered (Mello, 2008; Araújo; Ganem, 2016). In addition, the institution of the 1980s Law No. 7511/1986 modified the limits of the PPAs above in the 1965 Forestry Code. In this context, the minimum APP buffer size goes from five to thirty meters in courses with a width of less than ten meters, a parameter sustained to this day.

In 2021, Law No. 14,285 brought flexibilization in the definition of APP ranges in consolidated urban areas. According to the new Law, after considering advice from states, municipalities, and districts regarding environmental issues, municipalities can settle on buffers that differ from the current legislation (30 to 500m). However, hazardous areas cannot be occupied, and the guidelines of the urban masterplans must be respected, just as basin, drainage, and basic sanitation plans – in case they exist in the municipality. In addition, it is essential to observe cases where changes involve public usefulness, social interest, and low environmental impact.

Law No. 14,285/2021 amended Law No. 12,651/2012 – Forestry Code, including the definition of *consolidated urban areas* and the possibility of municipalities to define the width of the APP buffers in urban areas. Besides, the 2021 Law also amended Law nº 6.766/1979 – Urban Land Installment Law, stating that non-buildable buffers along rivers must follow the Forestry Code, making it possible for municipalities to change the PPAs. Lastly, it also amended Law 11.952/2009 – Landholding Law Regularization (Regularização da Lei Fundiária), which defines municipal laws that will determine the boundaries of river PPAs in urban areas after deliberation with environmental councils. Table 2 summarizes the changes in APP-related legislation.

Law year	Amendments
1934	Law nº 23.793/1934 – 1º Brazilian Forestry Code Presents the need to preserve riparian forests to protect hydric resources.
1965	Law nº 4771/1965 – 2º Brazilian Forestry Code Establishes APPs as a 5m protection buffer for rivers of < 10m of width.
1979	Law nº 6.766/1979 – Urban Land Subdivision Law Establishes a 15m non-building buffer along bodies of water.
1986	Law nº 7.511/1986 Altered APP parameters by establishing a 30m protection buffer for rivers of < 10m of width.
2012	Law nº 12.651/2012 – New Forestry Code Maintains a 30m protection buffer for rivers of <10m of width.
2021	Law nº 14.285/2021 In consolidated urban areas, through the elaboration of municipal laws for this purpose, buffers of Permanent Preservation Areas can be defined with a width different from that suggested by the 2012 Forestry Code, with some reservations.

Table 2: Historical evolution of Brazilian environmental legislation concerning river PPAs. Source: Elaborated by the authors (2022).

Interventions in PPAs are allowed when they are of public utility or social interest. The problem arises as public interest activities permitted by Federal Law are aggressive to regions of environmental interest, such as the road system necessary for the subdivision of urban land, work on energy and telecommunications, and mining activities (Croce, 2020). Federal Law 6.766/1979, which provides for the Subdivision of Urban Land, reinforces the Master Plan as a fundamental instrument for controlling urban land. With Law No. 14285/2021, municipalities can set PPAs smaller than 30m (minimum 15m) within consolidated urban areas and increase this range. Thus, the responsibility for managing urban river spaces is in the hands of municipalities.

Given the above, there is frequent questioning of the parameters adopted to determine the dimensions of PPAs. For Mello (2008), this criterion is generalist since it does not consider the specificities of the biomes and the hydromorphological characteristics of each hydrographic basin. The parameter must adequately meet the premise of protecting water resources and other environmental functions associated with PPAs. In addition, several scholars have warned about the lack of integration between urban and environmental legislation's distinct spheres, whether federal, state, or municipal (Croce, 2020).

Considerations on the width of riparian corridors (buffers) in the configuration of PPAs

River corridors are by far the most dynamic natural landscapes in many contexts. The anthropic uses imply rapid changes; however, the forces of nature remain almost always in control. Floods, droughts, erosion, sedimentation, nutrient flows, and vegetation succession, among other factors, are dominant (FORMAN, 1995). In this sense, Permanent Preservation Areas are essential to preserve river corridors and riparian vegetation. Riparian corridors follow hydrological networks and their margins of influence. These areas contain large amounts of biodiversity and act as buffer zones. They filter sediments, help control erosion, regulate temperature, maintain water quality, protect habitat from external disturbances, and contribute to the flow of materials, organisms, and nutrients (Forman, Godron, 1986).

Buffer is defined as a parallel and linear distance, configuring a range of a given area to be protected against anthropic effects. It is commonly used in PPAs, where a strip accompanies and protects the water resource along its length. In this buffer range, anthropic actions are restricted and obey specific legislation to increase the area's protection value (Jongman & Pungetti, 2004). Buffers can only be effective if designed with an understanding of landscape processes. Corridor effectiveness varies according to length, habitat quality, and many other environmental factors (Bentrup, 2008).

According to the studies carried out by Bentrup (2008), the graph shown in Figure 1 shows the investigation of the movement of species through the corridors. The green bar suggests the minimum width, while the gray bar indicates the upper end of the recommended width.

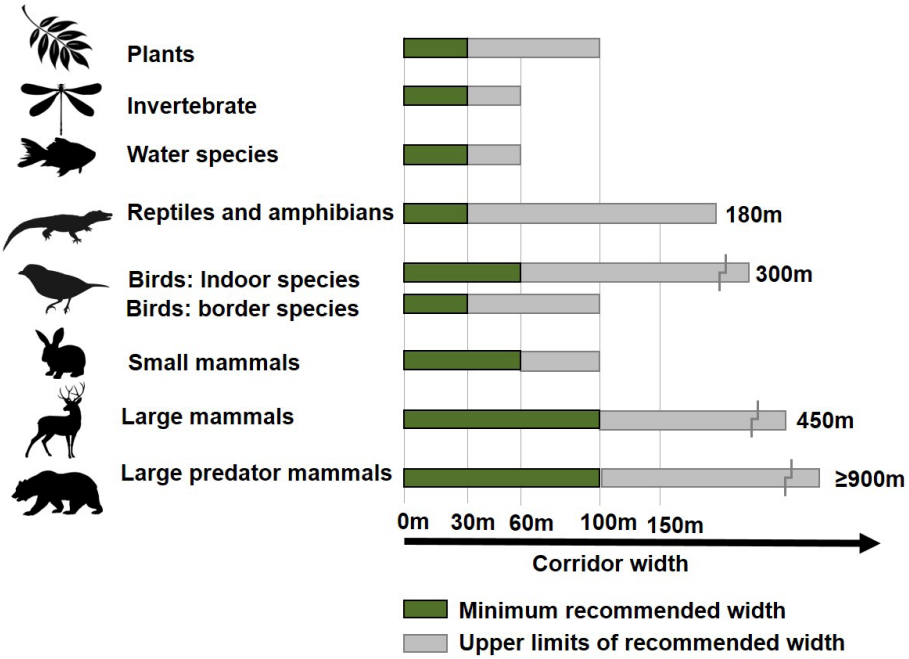

Figure 1: Recommended riparian corridors. Source: Adapted by the authors based on Bentrup (2008).

Along the same lines, Hawes and Smith (2005) also question the widths indicated for the protection of water resources, as shown in Table 3, where they make recommendations for buffer zones. The authors suggest the most appropriate dimensions, considering factors such as water quality, stabilization of banks, ecological corridors, flood mitigation, and the entry of debris.

Function	Description	Recommended width
Protection of water quality	Buffers, predominantly dense grassy or herbaceous buffers on graded slopes, intercept surface runoff, retain sediment, remove pollutants, and promote groundwater recharge. Most filtering occurs within the first 10 meters for low to moderate slopes. However, steeper slopes need larger widths, with buffers composed mainly of shrubs and trees, and where soil has a low rate of permeability.	5-30m
Stabilization of river banks	Riparian vegetation moderates soil moisture conditions on stream banks and roots to improve stability. Reasonable erosion control may only require the bank width to be protected unless active bank erosion requires a broader buffer. Excessive margin erosion may require additional bioengineering techniques.	10-20m
Ecological corridor and habitat	Dampers, remarkably diverse groups of shrubs and trees, provide food and shelter for a wide variety of aquatic, riverine wildlife. They also connect forest fragments in the landscape, facilitating plant and animal gene flow.	30-500m
Flood mitigation	Riparian buffers act as barriers, intercept surface water flow, and increase absorption time, resulting in reduced flood peaks.	20-150m
Debris deposit	Leaves, twigs, and branches that fall from the tops of riparian forests into the creeks are a vital source of nutrients and habitat.	3-10m

Table 3: General recommended buffer zone widths. Source: Adapted by the authors based on Hawes and Smith (2005).

Bentrup (2008) defends a minimum recommended width of 100 meters so all species of fauna and flora can develop. As a recommended maximum width for the development of large predatory mammals, the suggestion is a width greater than or equal to 900 meters. For Hawes and Smith (2005), the recommended width is a minimum of 30m and a maximum of 500 meters to create an ecological corridor for fauna and flora. Given the above, it is essential to question which dimensions would be the most appropriate for buffers of water resources, considering the maintenance of fauna, flora, and social activities. In addition, it is also necessary to consider the dimensions suggested by the legislation and question if they meet the existing demand for maintaining river quality in urban or rural contexts.

The Itaquarinchim River in the Santo Ângelo (RS) municipality

The Itaquarinchim River is located in the Northwest mesoregion of Rio Grande do Sul, in the municipality of Santo Ângelo, also known as the Missões region. The territorial extension of the municipality is 680.498km², and the estimated population is 77,544 inhabitants (IBGE, 2021). The primary access is via the BR 392, RS 344, and RS 218 roads. The Itaquarinchim River is one of the principal watercourses present in the urban perimeter of the municipality, but it rises in the rural area and then cuts through the city (Figure 2). With 27.8 km, it is a third-order river and the main tributary of the microhydrographic basin of the Itaquarinchim River, with approximately 60 km² (Castro, 2016). The river is part of the Ijuí River

hydrographic sub-basin and the Uruguay River hydrographic basin. However, this river, which had great strategic importance in the development of Santo Ângelo throughout its history, is currently degraded and polluted.

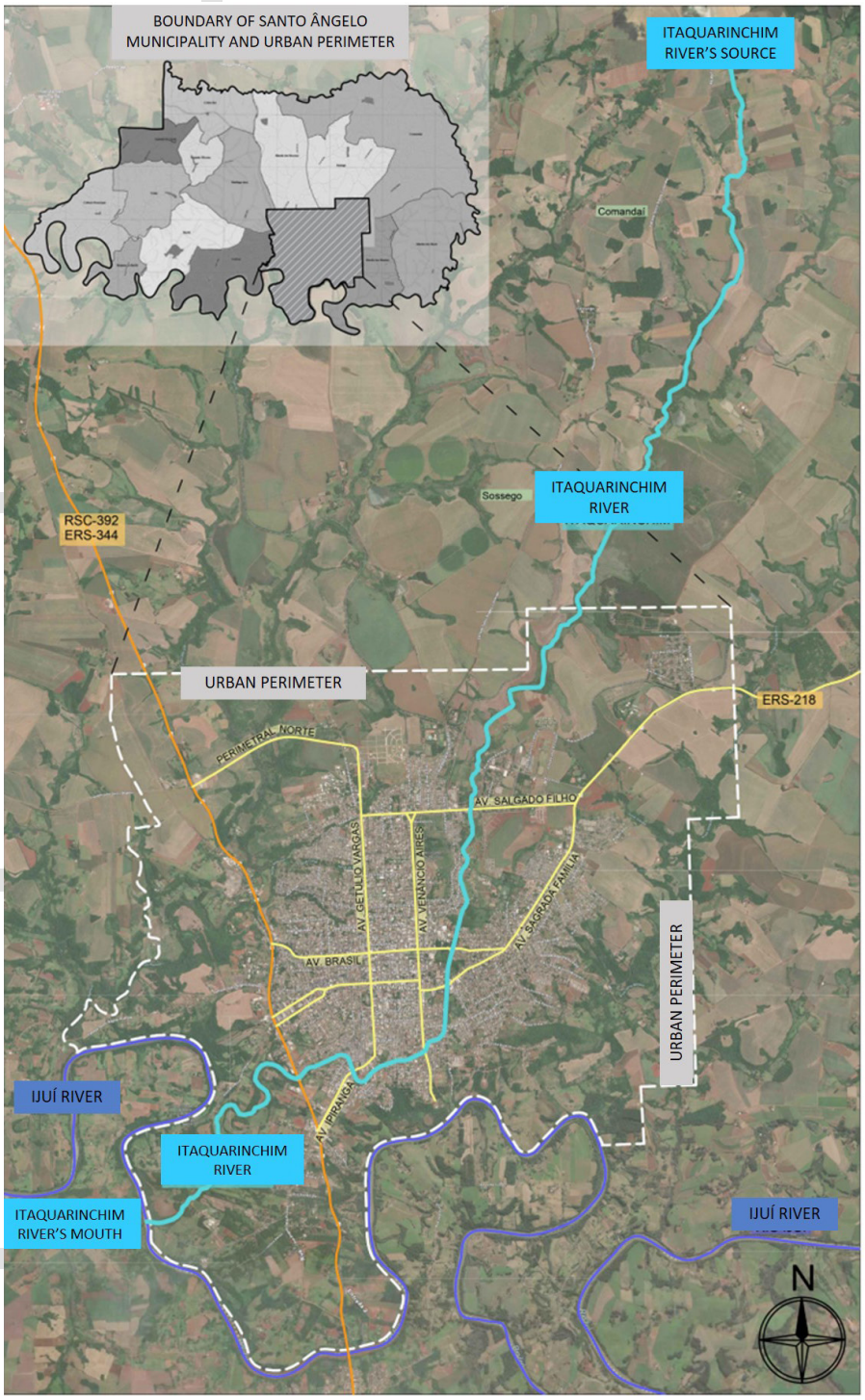

Figure 2: Urban perimeter of Santo Ângelo, main accesses, roads, and Itaquarinchim River. Source: Adapted by the authors based on Google Maps (2022).

Itaquarinchim River had strategic importance in the development of Santo Ângelo throughout the city's history. It is possible to say that the city's location, in the surroundings of Praça Pinheiro Machado, is due to the river's existence. Among the criteria considered by the Jesuits before defining their settlements were good land, luminosity, altitude of the place, abundance, and proximity of water to supply the village (Marchi, 2010). Since its formation, the Itaquarinchim River has played a fundamental role in the daily lives of nearby residents. This body of water was used to capture water for homes, churches, workshops, and animal water fountains, and it served as a geographic reference. With the increase in population, people started to use it as a source of leisure, for bathing, fishing, and picnics (Marchi, 2010).

According to Peringer and Silva (2001), the Itaquarinchim River went through three phases, the last two responsible for its current state. The first phase brings back good memories; it's a time that many city residents would like to bring back – the phase of natural balance lasted until the beginning of the 1940s. Between 1940 and 1990, the city's growth started the period of industrialization and exploitation of the soil, which caused the riverbed to be taken over by the agriculture fertile soils and industrial waste. After that, until today, the phase of indiscriminate settlements resulted in an environmental impact on the riverside populations, the leading cause of river pollution at the beginning of the 21st century. The city turned its back on the Itaquarinchim River, which is currently seen as a problem. With many challenges ahead to preserve and restore it, it's evident that the current attitude of the population towards it worsens the tendency of the situation to get worse. Even with pollution and human intervention, beautiful landscapes are still to be appreciated and preserved (Figure 3).

Figure 3: Itaquarinchim River landscapes. Source: Elaborated by the authors (2022).

Table 4 presents some essential characteristics of the Itaquarinchim River and its relationship with the municipality of Santo Ângelo. The facts that stand out are

that the river is the source of water for the northern part of the city; the lack of infrastructure present along its length to provide leisure and recreation activities for the population; the lack of integration with the landscape; the pollution of the resource; and the lack of preservation of the surrounding green areas.

Data about Itaquarinchim River, Santo Ãngelo/RS	Description
River length	27,8 km
Micro-basin area	60 km²
Source	Located in rural zoning
River mouth	Located in urban zoning
Santo Ângelo population	77,544 hab.
Walkways or bicycle lanes	Absent nearby the river.
Recreation and playground areas	A few soccer fields were identified in the proximities of the study area. A public square with good infrastructure and another open space with a few equipment in a precarious situation were registered as well.
Riparian forest	Presence of a strip of riparian forest, fragmented or inexistent in some areas. The big areas that are still interesting are being pressed by nearby activities.
Green areas	Presence of green areas of great importance and potential. Rural and *rururban* areas have more green areas and sections connected with each other if compared with the urban zone.
Riverbed and APP buffer length according to legislation	Riverbed length is less than 10 meters. According to the Forestry Code (2012) the recommendation of the APP should be of at least 30 meters.
Channeling ratification	There is a section located within the urban perimeter that has been canalized and ratified.
Streets and Avenues	There are streets and avenues parallel to the river course and outside the 30m APP strip.
Usages	The river has predominant residential occupations in its margins. There are commercial, industrial and institutional occupations as well.
Proximity with the central area	A section of the river is dose to the municipality's central area.
Pollution	The river is polluted; there's presence of waste on the riverbed and margins, as well as siltation and irregular settlements along its margins.
Flooding and riverbank erosion	There is history of flooding which has affected some residences. Stretches of the river present erosion on the margins, a consequence of the absence of riparian forest.
Supply	The river is a source of water for the north of Santo Ângelo municipality.

Table 4: Itaquarinchim River and its surroundings' characteristics. Source: Elaborated by the authors (2022).

Considerations about riparian corridor (buffer) widths in the APP configuration in the Itaquarinchim River

Aiming to understand the relationship between the Itaquarinchim River and its surroundings, we explored the study area's spatialization using geoprocessing tools. For that, we used the ArcGIS ArcMap 10.8® software and acquired the database to create the maps on the Santo Ângelo-RS City Hall website. Starting from the spatialization of the study area in geoprocessing, we analyzed how the use and occupation of the soil and the river's relationship with its surroundings took place. A buffer of 500m was set for each side of the Itaquarinchim riverbed to carry out the analysis. We investigated whether the river has an APP per the legislation in force (30m) or greater widths. The potential to expand this APP range of 30m was examined, as well as if it could support multifunctional activities in this context. Afterwards, a table presenting the characteristics and relationships observed in the study area was elaborated.

The 500-meter buffer set on each side of the Itaquarinchim riverbank is based on an average from recommendations by Bentrup (2008) and Hawes and Smith (2005). For large mammals to be able to develop, the recommended width for buffers is 100 to 450 meters. There is a range recommendation of 100 to 900 meters for large predatory mammals to develop. However, since there is no history of species of large predatory mammals in the region and considering the existing anthropization, the 900-meter width was not included. Hawes and Smith (2005) suggest that a strip of 30 to 500 meters can work as an ecological corridor and habitat for several animal and plant species. By defining and analyzing the study area, it was also possible to observe and delimit compartments for the analyzed landscape within the 500-meter buffers. The identified landscape compartments were CP-01 – Rural; CP-02 – Urban; and CP-03 – Rururban (Figure 4).

Furthermore, for each identified Landscape Compartment – Rural, Urban, and Rururban – it was possible to locate Land Uses and occupations within the clipping. This identification came about from observing the study area, interpretation, and classification according to the perceived use and occupation. In this way, it is possible to see how the expansion of agriculture and urban infrastructure around the Itaquarinchim River took place and to examine the still-existing green areas (Figure 5).

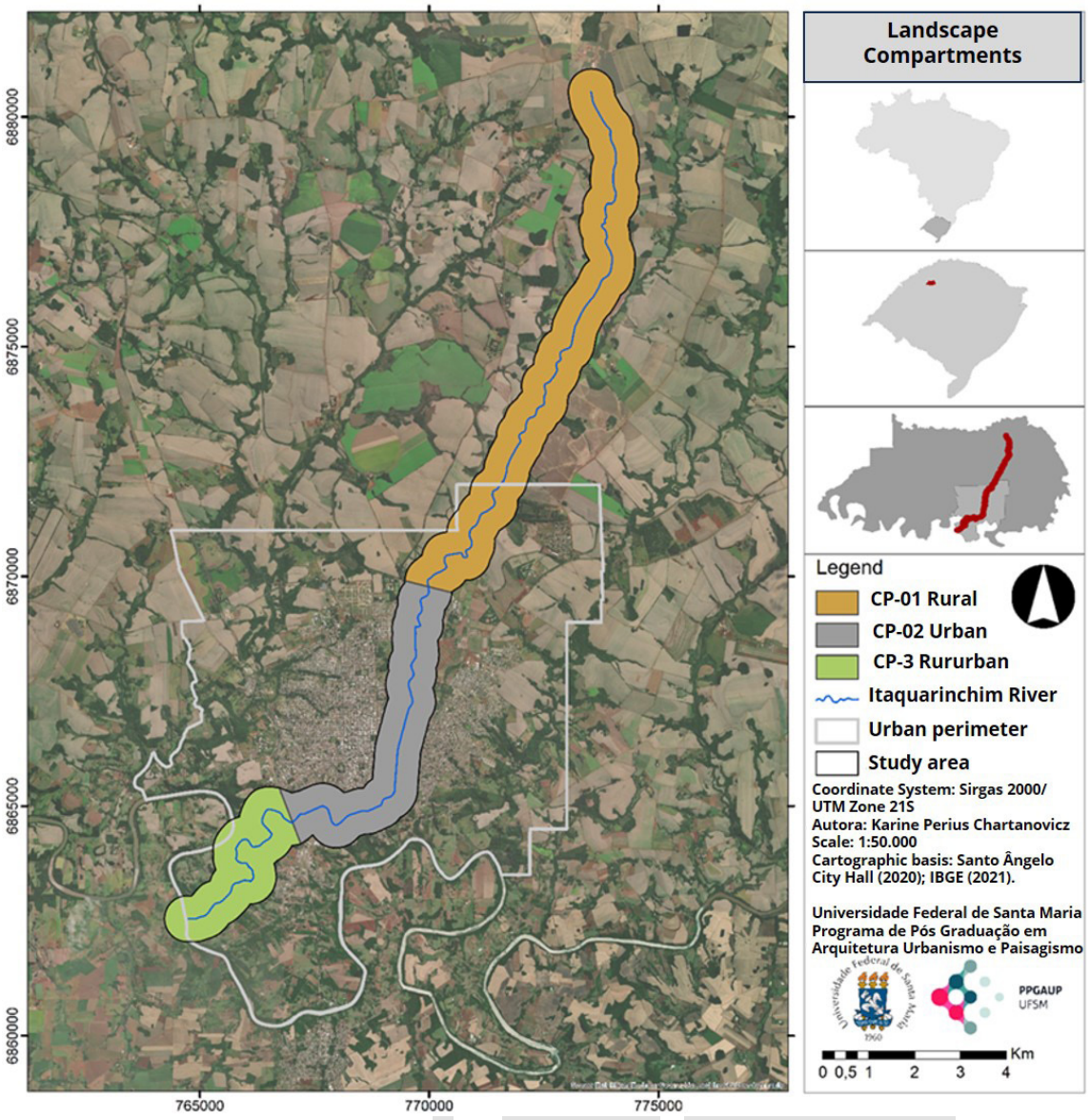

Figure 4: Study Area and Landscape Compartments: Rural, Urban, and Rururban. Source: Elaborated by the authors (2022).

The identified areas in the study were: Forested Areas – green areas with significant vegetation; Shrub cover – areas with small vegetation; Pastures/lawns – areas of permanent pasture for cattle raising; Agriculture – where the production of soy, corn, wheat, and pastures in the region stands out, with crop rotation; Built-up area – area with consolidated urban infrastructure; New Subdivisions – spaces that have undergone a recent change in urban design, shifting from rural or preservation areas into places of urban infrastructure; Military Area – restricted area for military use, which does not allow use or access by general population. The map also delimits a buffer of 30m for each side of the riverbed, which will be used to examine whether the legislation is being complied with in the case of the Itaquarinchim River (Figure 5).

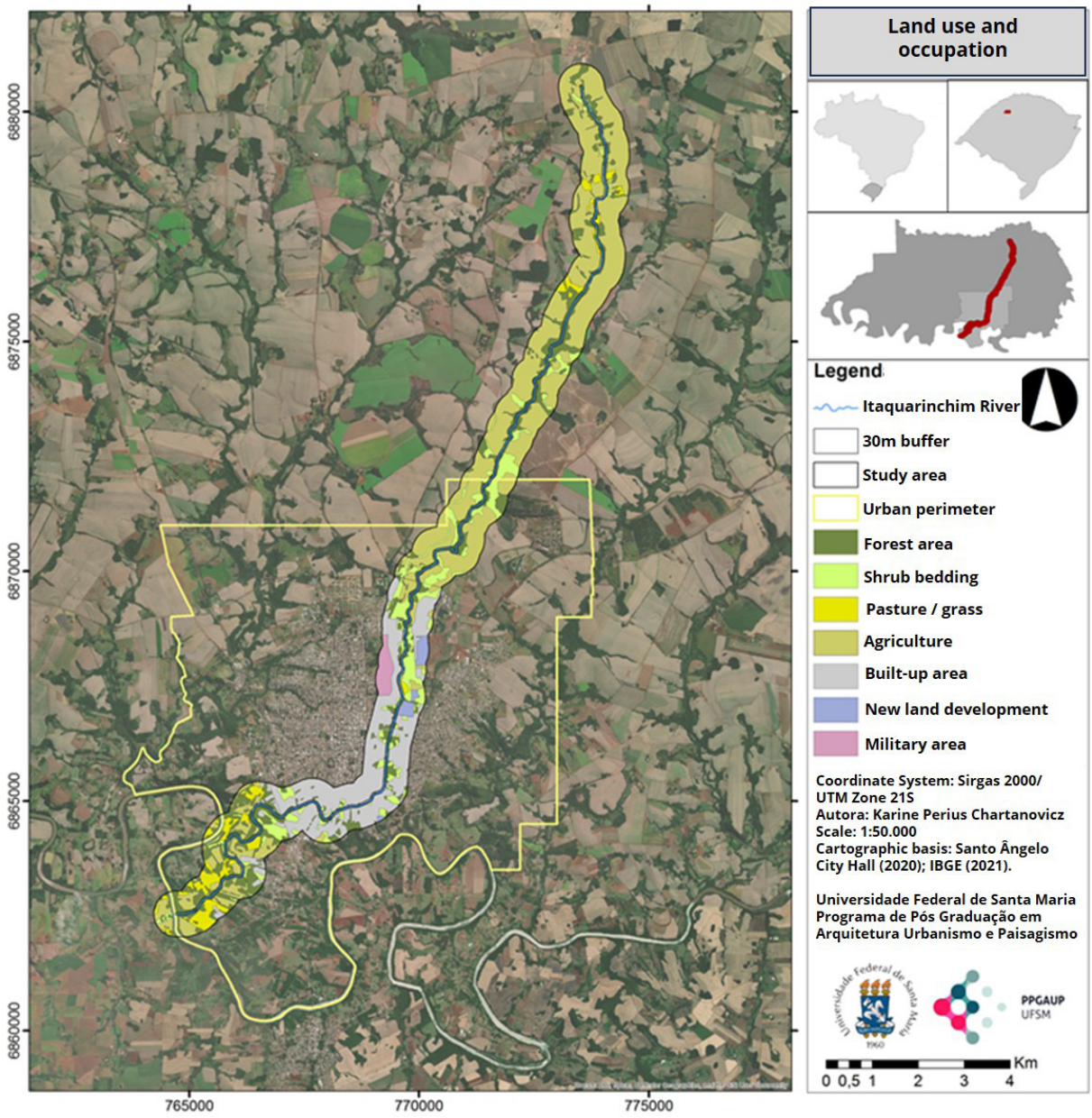

Figure 5: Land Use and Occupation in Itaquarinchim River surroundings (500m buffer for each side of the river bed). Source: The authors (2022).

The study clipping area consists of 29,42 km² in total, while the identified landscape compartments have the following dimensions: CP-01 – Rural: 13,19 km²; CP-02 – Urban: 7,44 km²; and CP-03 – Rururban: 4,66 km². In addition, Table 5 presents the areas corresponding to each type of Land Use and Occupation identified in the map shown in Figure 5, in square kilometers (km²), hectares (ha), and percentages of the total area of each compartment.

Landscape Compartment	Compartiment 01	Compartiment 02	Compartiment 03
Landscape type	Rural	Urban	Rururban
Area km²	13,19 km² / 52.15%	7,44 km² / 29.42%	4,66 km² / 18.43%
Description	It goes from the river's source until the beginning of the urban perimeter. Predominance of agriculture, sowing area for crops such as soybeans, corn wheat, and pasture. Shrub bedding and forest areas are still present.	Situated inside the municipality's urban perimeter, the river is surrounded by urban infrastructure. Built-up areas prevail, but there are still a few wooded and shrub bedding areas that persist. There is also a new land development area and a big military domain area.	Located inside the urban perimeter of the municipality, it includes the river's final stretch and its mouth. In this compartment, agriculture and pasture areas prevail. The urban infrastructure advances in a few axes and has been "making pressure" on the area. There's also the presence of significant forest and shrub bedding areas.
Forest area	2,365 km² / 236,551 ha / 17.9%	0,986 km² / 98,645 ha / 13.3%	1,855 km² / 185,554 ha / 40.8%
Shrub bedding	1,224 km² / 122,484 ha / 9.2%	1,153 km² / 115,374 ha / 15.5%	0,305 km² / 30,566 ha / 7.5%
Agriculture	9,358 km² / 935,909 ha / 70.8%	0,282 km² / 28,237 ha / 3.8%	1,248 km² / 124,849 ha / 27.6%
Pasture/grass	0,283 km² / 28,331 ha / 2.14%	0,041 km² / 4,117 ha / 0.5%	0,854 km² / / 85,423 ha / 18.3%
Built-up area	–	4,333 km² / 433,335 ha / 58.2%	0,278 km² / 27,823 ha / 5.9%
New land development	–	0,304 km² / 30,450 ha / 4.1%	–
Military area	–	0,347 km² / 34,789 ha / 4.6%	–

Table 5: Characteristics identified in the landscape compartments and Land Use and Occupation areas. Source: Elaborated by the authors (2022).

In this sense, it is worth noting that the forest area is predominant in CP-03 – Rururban, occupying 40.8% of the compartment. In CP-01 – Rural and CP-2 – Urban, forest areas occupy 17.9% and 13.3%, respectively, revealing a worrying percentage in CP-02. Shrub bedding areas appear more in CP-2 – Urban, occupying 15.5%, surpassing the rate of forest areas. The CP-1 – Rural is predominantly agricultural, 70.8% of the compartment. We can also see that agriculture occupies 3.8% of the CP-2 – Urban and 27.6% of the CP-3 – Rururban compartments. Pasture/grass occupies 18.3% of CP-3 – Rururban, while it represents a smaller percentage in other compartments. The built-up area represents 58.2% of CP-2 – Urban and advances to CP-3 – Rururban, with 5.9%. On the other hand, the infrastructure

of new land development and military areas can be seen only in CP-2 – Urban, representing 4.1% and 4.6% of the compartments, respectively.

Conclusions

Considering that the Itaquarinchim River is 10 meters wide, the Law nº 12.651/2012 recommends a minimum 30-meter width for the APP. The analysis of the area shows excellent fragmentation in the existing green spaces in the closest stretch to the river's source. The riparian forest is fragmented and, in some parts, does not comply with the 30-meter width. From the middle of CP-01 – Rural until the beginning of CP-02 – Urban, green areas close to the river are more consolidated, with width complying with the legislation, even exceeding the recommended 30m in some stretches. However, when approaching and entering the CP-2 – Urban, the fragmentation of green areas can be observed again. In the CP-2 – Urban area, the green spaces are the most fragmented among all the study areas, and there are many places where the river does not have the necessary protection. In some stretches, the built-up areas advance within the 30m range, mainly in the southernmost portion of CP-02. Finally, on CP-3 – Rururban, there is a considerable presence of green areas and riparian forests in compliance with most of the river route legislation. However, some stretches are fragmented, and the pressure caused by agriculture and urban occupations in these areas is noticeable. We also emphasize that some margins exceed the width of the riparian forest recommended by law.

In this way, it is clear that some areas need more attention and do not offer a 30m protection strip for each side of the Itaquarinchim River along most of its extension. Those areas are the CP-2 – Urban, for most of its size, and the area surrounding the river source, which belongs to CP-1 – Rural. The areas that best play their role in protecting water resources are from the middle of CP-01 – Rural to the beginning of CP-02 – Urban, with the presence of connected and more consolidated green areas, and we highlight here the APP green areas that exceed the 30 meters. Finally, the CP-3 – Ruruban also has a significant presence of green space, and we emphasize that there are stretches that exceed the width provided for in the legislation in this area.

Given the above, it is noticeable how green areas are being suppressed by the advance of agriculture and urban expansion. Although some stretches comply with the 30m APP range recommended by law, areas that do not meet this width are cause for concern. The presence of strips exceeding 30 meters in width is commendable, but to ensure that these areas are not suppressed, it is essential to think about and consider even larger buffers. None of the river stretches have a 500-meter strip buffer. Still, there are buffers around 100m wide, which are extremely important, as they allow the development of various animal and plant species, allowing the development of an ecological flow.

Considering the possibility of occupation of these APP areas with multifunctional activities, it is strongly recommended that the urbanized area makes use of these strategies, offering integration between environmental and social actions. The urban zone has few green spaces left, and to prevent them from getting suppressed by the expansion of the built-up area, it is essential to use them for the environmental preservation of Santo Ângelo's municipality and the well-being of its citizens. In addition, few spaces provide leisure and recreation in Santo Ângelo, so attending to this demand is essential. In this sense, we can mention some alternatives considered for multifunctional landscapes. Among them is the creation of linear parks for leisure, recreation, and contemplation. To promote conservation in urban areas, green and blue infrastructures are important alternatives, integrating environmental, hydraulic, landscape, and social functions. And yet, to encourage the connection between landscapes, green corridors are a solution that fulfills ecological, recreational, cultural, aesthetic, and sustainable purposes.

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