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Fragments of green infrastructure: the case of the Tijuco Preto stream in São Carlos, São Paulo, Brazil

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ABSTRACT

The growing and accelerated Brazilian urbanization has caused several adverse effects, among them the channelization of streams and rivers, often seen as a sign of progress. This urbanization and the worsening of climate change increases the magnitude of the threats to urban areas. The planning of green infrastructure seeks to integrate nature with the city, favoring the mitigation of environmental impacts and allowing greater adaptation and resilience in facing the problems caused by climate change. In this context, this study sought to analyze the renaturalization of a section of the Tijuco Preto stream, in the city of São Carlos, São Paulo state, Brazil, as a green infrastructure strategy and to contrast this section with the others, composed of gray infrastructure. The stream was divided into three study sections: (i) section 1 – renaturalized; (ii) section 2 – buried; and (iii) section 3 – channelized. Section 1, despite presenting the best environmental conditions of the whole stream, is configured as a fragment of green infrastructure that, alone, cannot mitigate all the impacts of adverse events downstream, such as floods. Thus, it is necessary to integrate this space with other equipment and green spaces, as well as expand the renaturalization initiative to the other sections.

KEYWORDS: Climate change. Green infrastructure. Stream renaturalization.

1. INTRODUCTION

In the late 2000s, the world reached a population milestone where, for the first time in human history, half of the world's population lived in urban areas. The pace of urbanization in the world today is unprecedented, with a nearly fivefold increase in urban population between 1950 and 2011 (UNITED NATIONS, 2011). In Brazil, the spatial and population configuration changed dramatically between the 1940s and 1980s. While in 1940, about 26.35% of the Brazilian population lived in cities, in 1980 this rate was 68.86%. It is also noted that in the 1970s, the population becomes more than half urban (SANTOS, 2018). Currently, about 84.72% of the Brazilian population lives in cities (IBGE, 2021c).

The effects of urbanization, climate change, and global warming are converging in dangerous ways, with unprecedented negative impacts on quality of life and economic and social stability, as well as increasing the magnitude of threats to urban areas (UNITED NATIONS, 2011). Changes in land uses from natural covers to agricultural and urban uses have adverse effects on water quantity and quality, for example, in increased runoff volume and rates, decreased runoff lag time and decreased groundwater recharge (BERLAND et al., 2017; LIU et al., 2017).

Infrastructures should be understood and designed as means to contribute and improve sustainability in urban landscapes (AHERN, 2007). The intense Brazilian territorial reorganization process has caused several adverse effects, among them the channelization of streams and rivers, often seen as a sign of progress. Channeled water bodies make up the so-called gray infrastructures, which usually have a single function within cities (for example, drainage systems aim to get rid of water as quickly as possible, without additional or complementary functions, such as landscaping or leisure). This type of infrastructure blocks natural dynamics and suppresses natural wetland/floodplain and forested areas that provide irreplaceable ecological services in urban areas. Thus, improvements to gray infrastructure systems can only partially address the problems associated with excessive storm-water runoff and represent significant investments (BERLAND et al., 2017; HERZOG; ROSA 2010).

On the other hand, green infrastructure can be understood as a connected and multifunctional infrastructure of green spaces, present in and around the urban space, that provides a set of benefits in the ecological, economic, and social levels (FRANCO, 2010; TZOULAS et al., 2007). In highly altered landscapes, especially in urban environments, connectivity is greatly reduced, resulting in fragmentation of landscape elements with significant impacts on ecological processes. In the urban context, traffic routes represent the greatest barrier to connectivity and are the main contributor to fragmentation (AHERN, 2007).

The planning of green infrastructure provides the integration of nature with the city, favoring the mitigation of environmental impacts and allowing greater adaptation and resilience when facing problems caused by climate change (HERZOG; ROSA 2010). Among the main benefits that can be achieved through this type of infrastructure, there are the containment of erosion processes and silting of water bodies, reduction of flooding impacts, reduction of water and soil pollution, carbon capture from the atmosphere, improvement of air quality, reduction of heat islands formation, besides the promotion of landscape as a determining factor of urban aesthetics and creation of sports, contemplative and leisure spaces (FRANCO, 2010; HERZOG; ROSA 2010; SPAHR et al., 2021).

2. OBJECTIVES

The aim of this study is to analyze the renaturalization of a section of the Tijuco Preto stream, located in the city of São Carlos, São Paulo State, Brazil, as a green infrastructure strategy and to contrast such section with the others, composed of gray infrastructure.

3. METHODOLOGY

The methodology of this work is composed of three stages: (i) survey and characterization of the physical conditions of the Tijuco Preto stream; (ii) division of the stream into study sections according to different infrastructure typology profiles (green or gray); and (iii) survey of the environmental conservation conditions and urban insertion of each of the sections.

In the first stage, a survey of the location of the micro-basin of the Tijuco Preto stream and its occupation history was carried out. In step 2, the stream was divided into study sections, according to the characterization of different types of infrastructure (green or gray), besides the conditions of urban insertion. In this stage, the sections and the intervention projects already carried out in the stream were detailed, in addition to the adverse events to which each section is susceptible. In the third and last stage, a survey of environmental conditions was conducted at strategic points of each of the sections.

4. RESULTS

4.1 Occupation history of the Tijuco Preto stream micro-basin

The stream is located in the municipality of São Carlos, which, in turn, is located in the central region of the State of São Paulo, Brazil, about 230 km from the state capital, and has an

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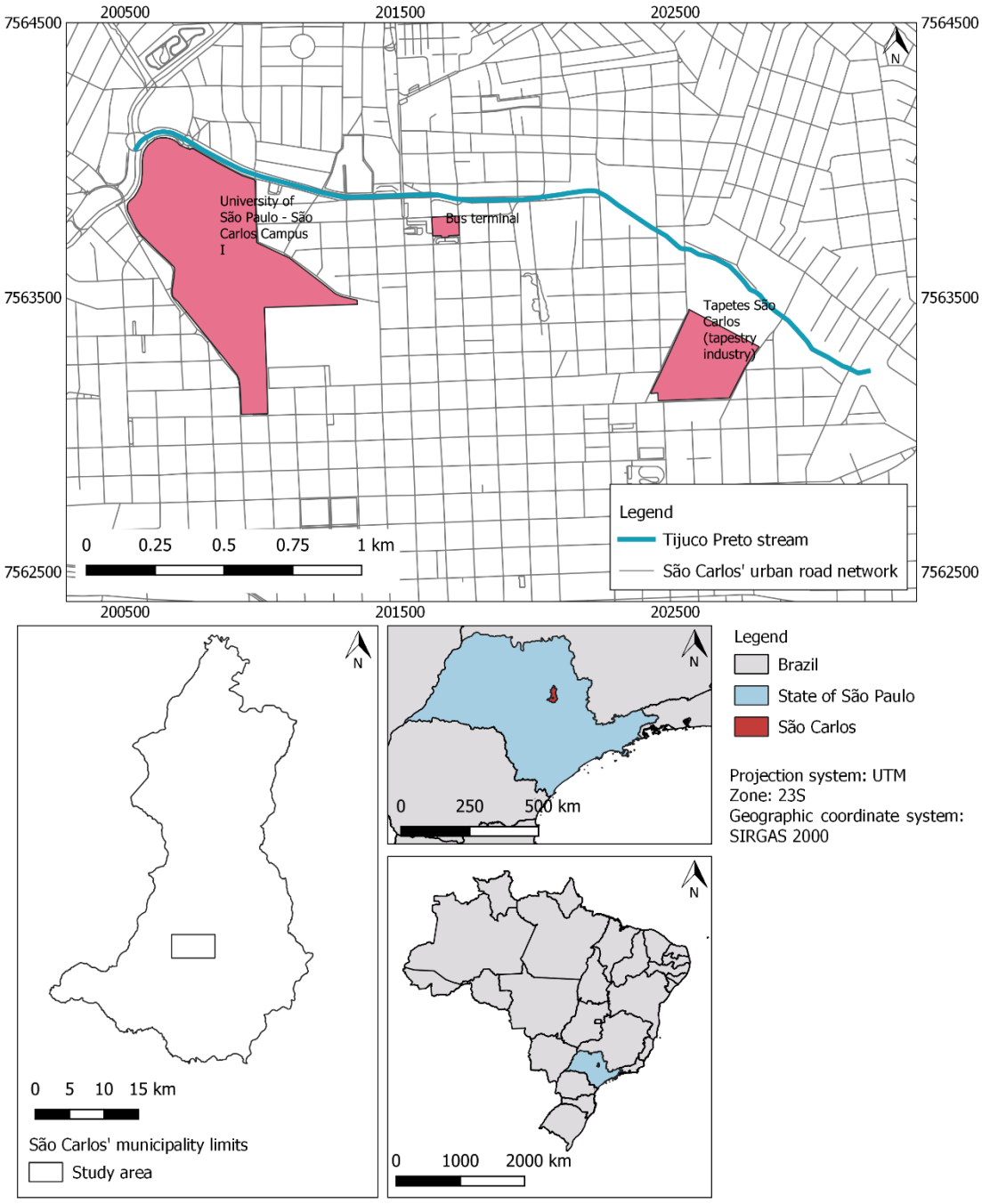
estimated population of 256,915 inhabitants (IBGE, 2021b), being considered a medium-sized city. The municipality lies on the watershed of two Water Resources Management Units (Unidades de Gerenciamento de Recursos Hídricos - UGRHI), to the north the Mogi-Guaçu basin (UGRHI 9) and to the south the Tietê-Jacaré basin (UGRHI 13). Figure 1 shows the location of the stream, where it is also possible to see three points of interest nearby, being a tapestry industry, a bus station and integration terminal of public transport of São Carlos and the campus 1 of the University of São Paulo (USP).

Figure 1 - Location of the Tijuco Preto stream



Source: adapted from IBGE, 2021a and Open Street Maps, 2021.

The Tijuco Preto micro-basin is located in the northeast region of the city and composes the set of 14 major urban basins in the municipality. The stream corresponds to one tributary that makes up the Monjolinho River basin, which is part of the Jacaré-Guaçú River basin, the latter being a tributary of the Tietê River. Thus, it is inserted in UGRHI 13 and composes the Integrated System of Water Resources Management of the State of São Paulo, through the Tietê-Jacaré Hydrographic Basin Committee (OHNUMA; MENDIONDO, 2014).

The urbanization process of the surrounding area began in the 1940s. In the 1960s, the area still had dense native vegetation in the main spring and along the stream, and other springs with riparian vegetation. There was a high urban occupation that expanded from the city center (south of the stream), while the area to the north presented low occupation. Still, there was a low presence of crossings in the stream, and there were neither high impermeability roads nor heavy traffic. In the 2000s, several negative impacts to the river basin were noticed because of the approval of urban allotments in Environmental Protection Areas, the presence of high impermeability roads and heavy traffic. Among the main effects of the disordered urban occupation can be cited the suppression of riparian vegetation, the disposal of sewage in the water body, siltation processes, channelization of secondary springs and the stream itself in some sections (PERES; MENDIONDO, 2004). Currently, the region has an urbanization of about 70%, being one of the main occupation areas of the city (OHNUMA; MENDIONDO, 2014).

4.2 Characterization of the sections

At this stage, the stream was divided into three sections, given the different conditions presented: (i) section 1 corresponds to the upstream area of the basin and was the object of the Pro-Tijuco project implementation, being the section with the green infrastructure; (ii) section 2 is currently buried and represents a model of gray infrastructure; and (iii) in section 3, the stream is unburied, but is channeled, also a model of gray infrastructure.

In section 1, corresponding to the High Tijuco Preto, following a Conduct Adjustment Agreement with the Public Ministry, the City of São Carlos implemented the Pro-Tijuco project (MINISTÉRIO PÚBLICO, proc. No. 332/95). The approximate length of the section is 1.35 km. In the past, this section of the stream was buried and channeled with concrete pipes. The Pro-Tijuco project consisted of the section's unburying, renaturalization and progressive environmental recovery of the stream, besides offering a new public space to the population by creating a linear park between the streets Monteiro Lobato and Totó Leite. The technical aspects of the environmental recovery consisted in lateral containment by enveloped soil and eucalyptus logs, with biodegradable blanket slopes and hydroseeding as margin coverings. The method ensures soil support and the life in the stream bed (OHNUMA; MENDIONDO, 2014; PERES; MENDIONDO, 2004; SÃO CARLOS, 2005a; 2005b). The linear park plan included the implementation of bike lanes, pedestrian walkways and crossings, landscaping and lighting project (PERES; MENDIONDO, 2004; SÃO CARLOS, 2005c). The Pro-Tijuco Project is, therefore, a project for the transformation of gray infrastructure into green infrastructure, whose construction began in 2005, being concluded in 2007. This study, consequently, analyzed the environmental conditions about 15 years after the project.

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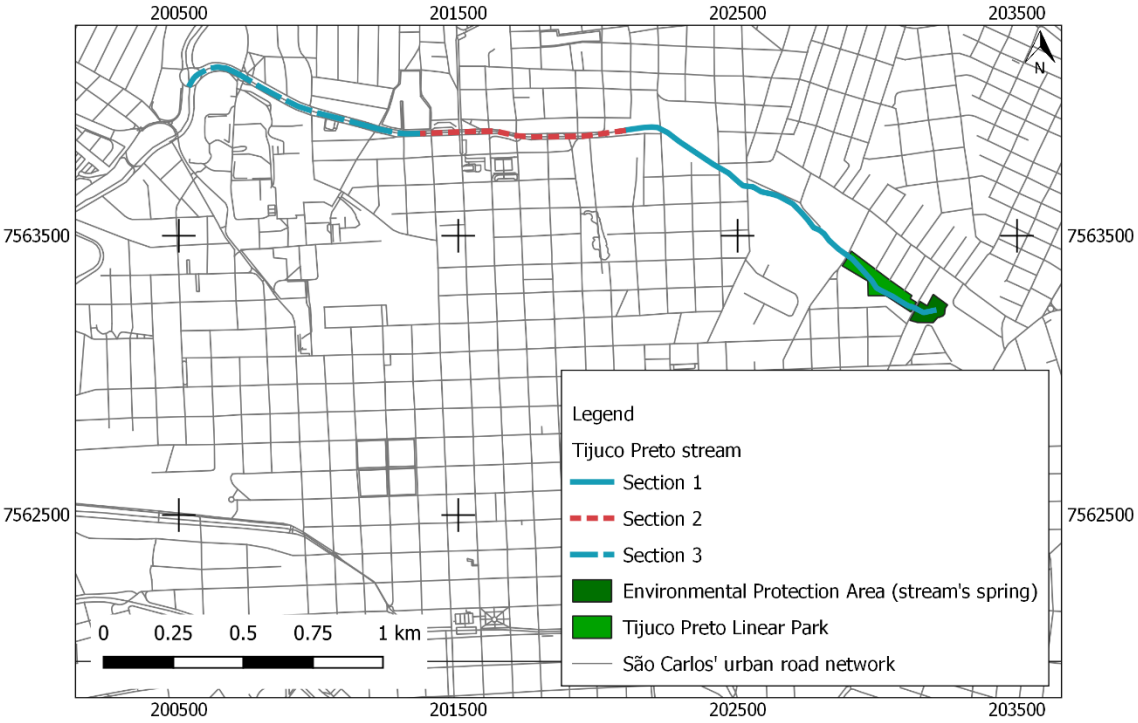
The other sections have models of gray infrastructure. Section 2, with an approximate length of 0.72 km, is fully buried and marks the beginning of the duplication of the Trabalhador Sancarlense Avenue (completed in 2018). The avenue is divided by a median strip under which the stream passes unnoticed. Finally, section 3 has an approximate length of 0.90km, in which the stream is unburied, but channelized.

In terms of adverse events, section 1 is considered of a low potentiality for the occurrence of urban floods, as this section is one of those responsible for storing rainwater that drains into the main basin of the municipality (Gregório Stream) (OHNUMA; MENDIONDO, 2014). The preeminent adverse events (floods and inundations) occur downstream of section 1, that is, in sections 2 and 3, which as mentioned, are more urbanized and share the valley bottom with the Trabalhador Sancarlense Avenue (DE LIMA; SCHENK, 2018; EIRAS, 2017). Figure 2 shows the division into sections used in this study.

Figure 2 - Study sections of the stream Tijuco Preto



Source: adapted from Open Street Maps, 2021.

4.3 Current Situation

The survey points are presented in Figure 3. There are six points located in section 1, for being the largest and presenting the most contrasting conditions along the extension. Point 7 represents the transition between sections 1 and 2, as well as point 11 is in the transition between sections 2 and 3, both with three more survey points.

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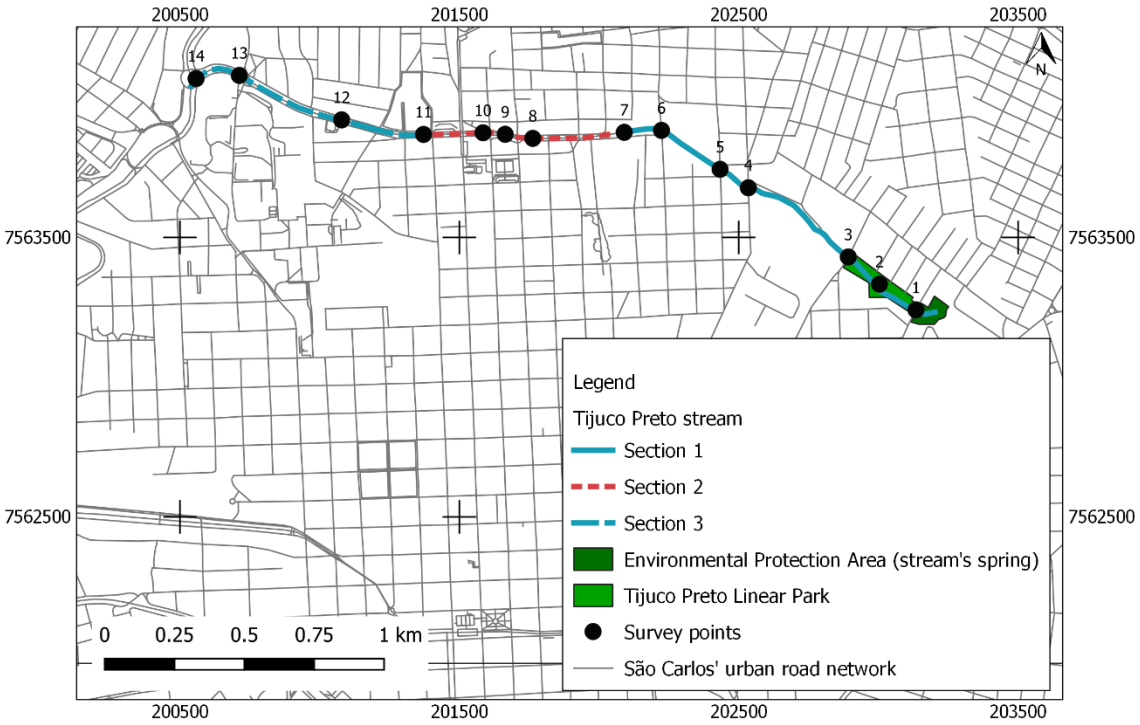
Figure 3 - Survey points in the Tijuco Preto stream



Source: adapted from Open Street Maps, 2021.

Section 1, whose survey points are shown in Figure 4, is located in an Environmental Protection Area and, despite the relatively precarious conditions of several points, is the section with the highest environmental preservation. Within section 1, the spring area (point 1) presents the best environmental conditions, being the only one with an area of riparian vegetation of considerable width (about 30 meters on one side and 45 meters on the other). The linear park of Tijuco Preto (point 2) has some urban equipment, such as walking tracks and a playground, but the density of vegetation is lower than in the spring area. The urban insertion of the park is deficient, since it is located at the back of the neighboring houses and the access to the park does not have much connectivity with other urban equipments, nor does it have surrounding roads with adequate infrastructure for pedestrians and cyclists. The park ends up being isolated, frequented by local residents, but with little influence on the city dynamics. At the end of the park, just on the other side of Totó Leite Street, it is possible to observe points of irregular waste disposal near the stream (point 3). As one advances along the path of the body of water, from upstream to downstream, the degree of urbanization and the proximity of built urban elements to the banks of the stream increases. It is also in this sense that the environmental quality of the stream deteriorates. There are pollution foci from sewage discharge into the stream (points 4 and 6), as well as hillside slidings (points 4 and 5).

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Figure 4 - Survey points of section 1

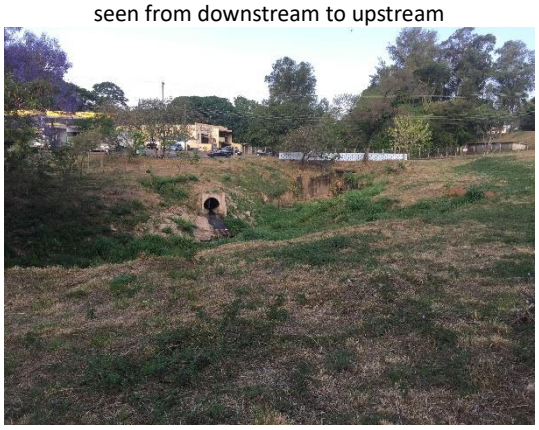
Point 1 - Stream spring seen from downstream to upstream

Point 2a - Linear Park of Tijuco Preto seen from downstream to upstream

Point 2b - Stream bed inside the linear park of Tijuco Preto

Point 3 - Irregular waste disposal in the vicinity of the stream seen from upstream to downstream

Point 4 - Landslide and pollution focus on the stream seen from downstream to upstream



Point 5 - Landslide in the stream seen from downstream to upstream

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Point 6 - Pollution focus on the stream seen from downstream to upstream

Source: the authors, 2021.

The transition between sections 1 and 2 is quite abrupt, in which the green space, even if precarious, is replaced by the view of an avenue. The stream disappears from the landscape, as if it were a mere obstacle that concrete can bypass. Section 2 is, therefore, the most critical, precisely because it is buried (Figure 5).

Figure 5 - Survey points of section 2

Point 7a - Transition between sections 1 and 2 of the stream seen from upstream to downstream

Point 7b - Beginning of buried stream section seen from upstream to downstream

Point 8a - Drainage structure in the buried stream section seen from upstream to downstream

Point 8b – Bike lane implemented over the buried stream seen from downstream to upstream

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Point 9 - Trabalhador Sancarlense Avenue over the buried stream seen from downstream to upstream

Point 10 - Trabalhador Sancarlense Avenue over the buried stream seen from upstream to downstream

Source: the authors, 2021.

In general, there is a low to non-existent vegetation incidence. The configuration of Trabalhador Sancarlense Avenue varies along the buried section, and at point 8 there is a wide median strip with a bicycle lane implemented along two city blocks. Points 9 and 10 represent important points in the city, especially in terms of urban mobility. Next to these points are located the city's bus station and the integration terminal of urban and intercity buses, besides the São Carlos Avenue viaduct (main north-south axis of the city). There is a clear trade-off between mobility and sustainability. The burying of the stream assumes that mobility would be impaired if the stream was unburied, and this type of mobility prioritizes the circulation of individual vehicles.

Finally, in section 3 the stream is channelized, as can be seen in Figure 6. On the banks of the stream contained by concrete walls, there is a presence of grass and some trees, with a density of vegetation higher than in section 2, but lower than in section 1. In this section of the Trabalhador Sancarlense Avenue there is no infrastructure for cyclists, who end up circulating alongside vehicles. The infrastructure for pedestrians is precarious, with few crossing points (there are only two crossings, one of them shown in point 12).

Figure 6 - Survey points of section 3

Point 11 - Transition between sections 2 and 3 seen from upstream to downstream

Point 12 - Pedestrian crossing over channelized stream seen from upstream to downstream

Point 13 – Trabalhador Sancarlense Avenue seen from downstream to upstream

Point 14 - Meeting of the Tijuco Preto stream with the Monjolinho River seen from downstream to upstream

Source: the authors, 2021.

It can be noticed, in general, that section 1 has more points for waste disposal and sewage dumping in the stream, although it is the section with the greatest contribution in terms of environmental benefits. Sections 2 and 3 have a more hygienistic profile, focused on mobility and circulation of individual vehicles, where the stream has minimal importance in the landscape's composition.

5. CONCLUSION

This paper sought to analyze the renaturalization of a section of the Tijuco Preto stream as a green infrastructure strategy, contrasting it with two others composed of gray infrastructure. For this, a historical survey of the occupation of the micro-basin was done. Subsequently, the stream was divided into three sections, with one green infrastructure model that underwent a renaturalization process and other two with gray infrastructure models, one buried and the other channelized.

Among the results found, it was noticed that during the urbanization process, Environmental Protection Areas within the micro-basin were irregularly occupied, and currently the urbanization rate of the area is about 70% and represents one of the main occupation areas of the city. There is also the presence of roads with high impermeability and heavy traffic on the banks of the stream, especially in sections 2 and 3. In terms of adverse events such as floods, section 1 is considered of low occurrence potential, being responsible for storing rainwater that drains into the main city basin (Gregório Stream). The main adverse events (floods and inundations) occur downstream of section 1, in sections 2 and 3.

Section 1 is configured as a fragment of green infrastructure that, alone, cannot mitigate all the impacts of adverse events downstream, such as floods. It is necessary to integrate this space with other equipment and green spaces, as well as expand the renaturalization initiative to the other sections. It is a change that can affect not only the improvement of environmental issues, but can also significantly alter urban mobility, with a transition to active modes of transportation. The Pro-Tijuco project and the renaturalization observed in section 1 can also serve as a model for other Brazilian cities, which should seek to

replace gray infrastructure models with green infrastructure to achieve greater urban sustainability and resilience.

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REFERENCES

AHERN, J. Green infrastructure for cities: the spatial dimension. In. In: **Cities of the future: towards integrated sustainable water and landscape management. IWA Publishing**. 2007.

BERLAND, A.; SHIFLETT, S. A.; SHUSTER, W. D.; GARMESTANI, A. S.; GODDARD, H. C.; HERRMANN, D. L.; HOPTON, M. E. The role of trees in urban stormwater management. **Landscape and urban planning**, v. 162, p. 167-177, 2017.

DE LIMA, M. C. P. B.; SCHENK, L. B. M. Estudo de infraestrutura verde na bacia hidrográfica do córrego Monjolinho, São Carlos, SP. **Revista LABVERDE**, v. 9, n. 1, p. 50-72, 2018.

EIRAS, C. G. S. **Mapeamento da suscetibilidade a eventos perigosos de natureza geológica e hidrológica em São Carlos-SP**. 2017. Tese de Doutorado. Universidade de São Paulo.

FRANCO, M. A. R. Infraestrutura verde em São Paulo: O caso do corredor verde Ibirapuera-Villa Lobos. **Revista Labverde**, n. 1, p. 135-154, 2010.

HERZOG, C. P.; ROSA, L. Z. Infraestrutura verde: sustentabilidade e resiliência para a paisagem urbana. **Revista Labverde**, n. 1, p. 92-115, 2010.

IBGE - Instituto Brasileiro de Geografia e Estatística. Malhas municipais. 2021a. Rio de Janeiro: IBGE. Disponível em: https://downloads.ibge.gov.br/downloads_geociencias.htm. Acesso em: 26 set. 2021.

IBGE - Instituto Brasileiro de Geografia e Estatística. Panorama sobre o município de São Carlos – SP. 2021b. Rio de Janeiro: IBGE. Disponível em: https://cidades.ibge.gov.br/brasil/sp/araraquara/panorama. Acesso em: 29 set. 2021.

IBGE - Instituto Brasileiro de Geografia e Estatística. População rural e urbana. 2021c. Rio de Janeiro: IBGE. Disponível em: https://educa.ibge.gov.br/jovens%20/conheca-o-brasil/populacao/18313-populacao-rural-e-urbana.html. Acesso em: 01 out. 2021.

LIU, Y.; ENGEL, B. A.; FLANAGAN, D. C.; GITAU, M. W.; MCMILLAN, S. K.; CHAUBEY, I. A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. **Science of the Total Environment**, v. 601, p. 580-593, 2017.

MINISTÉRIO PÚBLICO. TAC. **Ministério Público do Estado de São Paulo, Termo de Ajustamento de Conduta entre Prefeitura Municipal de São Carlos e a Associação para Proteção Ambiental de São Carlos – APASC, com a interveniência do Ministério Público.** Processo No 332/95. 11p.

OHNUMA JR, A. A.; MENDIONDO, E. M. Análise de cenários com proposição de medidas de recuperação ambiental para a micro-bacia do Tijuco Preto, São Carlos-SP. **Brazilian Journal of Environmental Sciences (Online)**, n. 32, p. 42-51, 2014.

OPEN STREET MAPS. Mapa da cidade de São Carlos – SP. Disponível em: https://www.openstreetmap.org/#map=12/-22.0046/-47.8977. Acesso em: 26 set. 2021.

PERES, R. B.; MENDIONDO, E. M. Desenvolvimento de Cenários de Recuperação como Instrumento ao Planejamento Ambiental e Urbano - Bases conceituais e Experiências Práticas In. SEMINÁRIO NEUR/CEAM, 2004, Brasília, DF A questão Ambiental e Urbana: Experiências e Perspectivas, Brasília NEUR/CEAM, UnB, 2004.

SANTOS, M. **A urbanização brasileira**. 5ª ed., 4ª reimpr. São Paulo: Editora da Universidade de São Paulo, 2018.

SÃO CARLOS. PREFEITURA MUNICIPAL. Prefeitura recupera córrego do Tijuco Preto. 2005a. Disponível em: http://www.saocarlos.sp.gov.br/index.php/noticias/2005/146896-prefeitura-recupera-corrego-do-tijuco-preto.html. Acesso em: 28 set. 2021.

SÃO CARLOS. PREFEITURA MUNICIPAL. Coletor de esgoto é instalado no projeto Pró-Tijuco. 2005b. Disponível em: http://www.saocarlos.sp.gov.br/index.php/noticias-2005/147151-coletor-de-esgoto-e-instalado-no-projeto-pro-tijuco.html. Acesso em: 28 set. 2021.

SÃO CARLOS. PREFEITURA MUNICIPAL. Parque do Tijuco Preto ganha calçada e ciclovia. 2005c. Disponível em: http://www.saocarlos.sp.gov.br/index.php/noticias-2005/147671-parque-do-tijuco-preto-ganha-calcada-e-ciclovia.html. Acesso em: 28 set. 2021.

SPAHR, K.; SMITH, J. M.; MCCRAY, J. E.; HOGUE, T. S. Reading the Green Landscape: Public Attitudes toward Green Stormwater Infrastructure and the Perceived Nonmonetary Value of Its Co-Benefits in Three US Cities. **Journal of Sustainable Water in the Built Environment**, v. 7, n. 4, p. 04021017, 2021.

TZOULAS, K.; KORPELA, K.; VENN, S.; YLI-PELKONEN, V.; KAŹMIERCZAK, A.; NIEMELA, J.; JAMES, P. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. **Landscape and urban planning**, v. 81, n. 3, p. 167-178, 2007.

UNITED NATIONS. Global Report on Human Settlements 2011: Cities and Climate Change. 2011. Disponível em: https://unhabitat.org/global-report-on-human-settlements-2011-cities-and-climate-change. Acesso em: 01 out. 2021.