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Proposal of Blue and Green Infrastructure for the Jaguaré Stream Watershed, São Paulo, Brazil

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***Abstract*—**The blue-green infrastructure in recent years has been pointed out as a possibility to increase the environmental quality of watersheds. The regulation ecosystem services brought by these areas are many, such as the improvement of the air quality of the air, water, soil, microclimate, besides helping to control the peak flows and to promote the quality of life of the population. This study proposes a blue-green infrastructure scenario for the Jaguaré watershed, located in the western zone of the São Paulo city in Brazil. Based on the proposed scenario, it was verified the impact of the adoption of the blue and green infrastructure in the control of the peak flow of the basin, the benefits for the avifauna that are also reflected in the flora and finally, the quantification of the regulation ecosystem services brought by the adoption of the scenario proposed. A survey of existing green areas and potential areas for expansion and connection of these areas to form a network in the watershed was carried out. Based on this proposed new network of green areas, the peak flow for the proposed scenario was calculated with the help of software, ABC6. Finally, a survey of the ecosystem services contemplated in the proposed scenario was made. It was possible to conclude that the blue and green infrastructure would provide several regulation ecosystem services for the watershed, such as the control of the peak flow, the connection frame between the forest fragments that promoted the environmental enrichment of these fragments, improvement of the microclimate and the provision of leisure areas for the population.

***Keywords*—**Blue and green infrastructure, sustainable drainage, urban waters, ecosystem services.

I. Introduction

IT is possible to classify the use of the vegetal elements forming a multifunctional web within the cities in order to assist in the control of the quality of air, water and soil, as techniques of the green infrastructure. The green infrastructure consists in the requalification and enrichment of urban green areas in order to reestablish the natural processes that provide important services to the city, ecosystem services, basing itself on the concepts of landscape ecology that emerged in the mid-90's [1].

Ecosystem services are basically the benefits that ecosystems bring to humanity, that is, the exploitation of the natural functions of ecosystems in favor of human development. There are two types of ecosystem services, provisioning services that provide inputs to the development of man, such as food, water, wood, etc., and regulation services that regulate some processes that are fundamental to human life, such as climate regulation. These ecosystem functions exist independently of man's use, as they form part of the homeostasis of the system; however, man can suppress the living elements of his day-to-day life, as in urban areas, and can lose the benefits that these ecosystem services would provide [2].

The establishment of green infrastructure in urban areas makes possible to take advantage of the regulation ecosystem services, which are often ignored because they are difficult to measure, such as improving air, water and soil quality and the promotion of leisure areas, benefits that directly result in improving the quality of life of the population and its health. Besides that, bearing in mind the context of climate change, the benefits of green infrastructure are of great importance in mitigating the negative effects of these changes on cities.

One of the first initiatives to create a network of green areas for the use of ecosystem services within cities was the Emerald Necklace in Boston, designed by Frederick Law Olmsted in the late 19th century. The project included the recovery and interconnection of floodplain areas in order to restore water dynamics, combining flood control with water, air and soil quality, biodiversity protection, climate control and population integration [6].

The focus of landscape ecology is to study the spatial relationships between ecosystems and landscape elements; studying energy, nutrient and mineral flows; and to study the ecological dynamics of landscape mosaics [5]. The green infrastructure uses the basic principles of landscape ecology to assist in the development of more resilient cities and the changing perception of man's relationship with nature in urban areas.

It consists, therefore, in a network of natural open areas that are fundamental for the ecological functioning of the territory. The concept goes beyond the original concept of landscaping for the beautification of the city. The green infrastructure, in addition to incorporating the interconnected network of green areas, also combines natural elements that are not restricted to vegetation, such as watercourses and the atmosphere, and is, therefore, an important agent in the regulation of water and air quality, resulting in a wide variety of benefits to the population [4]. The incorporation of the blue elements of the landscape, the waters in their different forms, made this group of techniques to be called by some authors as blue and infrastructure, a term used in this study.

The techniques of green infrastructure have been widely discussed as an alternative for the quantitative and qualitative control of surface runoff. This is of extreme relevance to cities, especially in tropical and subtropical areas, which suffer from heavy rains that quickly saturate their traditional

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drainage systems, resulting in great harm to the population. Heavy rains tend to be even more frequent due to climate change, which makes the adoption of blue and green infrastructure even more timely in future projects.

In Brazil, the concept of blue-green infrastructure has been adopted through the implementation of linear parks. The linear parks come from the concept of Green Ways that aims to create green areas along the watercourses, which meet both the demand for services to the population and also makes it possible to coexist with the periodic floods of watercourses. In Brazil, linear parks are areas close to the watercourses associated with pedestrian traffic, which has the primary function of recovering the surrounding ecosystems, controlling floods and promoting areas for leisure [4].

Although there are already some initiatives for the implementation of linear parks in Brazil, it is still necessary to propagate the concept of blue and green infrastructure so that these areas can be connected and in fact constitute a blue-green infrastructure, as proposed in this study.

II. Methodology

Following the concepts of blue and green infrastructure, it was proposed for the Jaguaré watershed to interconnect its green areas in order to propagate wetlands, creating an urban ecological corridor that is a diffuser of fauna and flora species, promoting environmental enrichment, landscape requalification and the well-being of the population.

In this study, the mapping of existing green areas in the basin, public and private and the potential areas for expansion of these green areas, the creation of corridors connecting them, based on the records of the Municipality of São Paulo, were carried out. The floodplains of the waterways were used to create the corridors, and therefore, these ecological corridors are called blue and green corridors.

Based on the new configuration of green areas in the Jaguaré watershed, the hydrological modeling of the existing scenario and the proposed scenario was carried out in order to verify the impact of the adoption of the blue and green infrastructure on the peak flow of the basin. In addition, mapping of existing studies on avifauna in the two large forest fragments that the basin connects was conducted to assess the potential benefit of its connection.

Finally, a survey of the ecosystem services brought by the proposed green infrastructure in the Jaguaré watershed is presented.

III. Case Study

The Jaguaré watershed, shown in Fig. 1, is located in the western zone of São Paulo city. The Jaguaré stream is a tributary of the Pinheiros River, one of the most important watercourses of the municipality; therefore, it is of great importance for the region.

The Jaguaré watershed has a drainage area of approximately 28 km², with its main accesses being Marginal Avenue and the Raposo Tavares Highway. The land use and occupation is predominantly residential, but there are commercial and industrial uses too, due to the proximity to the Raposo Tavares Highway, which is an important connection between the city, the countryside and the southern coast of the state, as well as the south of the country.

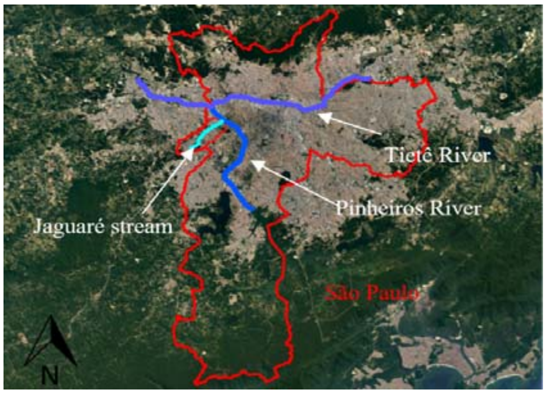

Fig. 1 Jaguaré watershed in São Paulo city. Source: By the authors from Google Earth

The Jaguaré watershed, contrary to many other watersheds in urban areas, still has a significant amount of forest remnants in different stages of conservation. Currently, 26.85% of the basin is made up of urban green spaces. It consists of areas under greater human intervention, such as the case of beds and squares, to relatively preserved areas that have high ecological interest, such as forest fragments remaining or in the stage of recovery of Atlantic forest in Tizo Park and Vila São Francisco Park.

Fig. 2 Types of forest fragments in the Jaguaré watershed. Source: Author's photos

Fig. 2 shows different examples of green areas in the Jaguaré watershed, such as Evandro Valério Square, which has recreational equipment improvised by the population; the site of the Escola Politécnica Avenue at its intersection with the Raposo Tavares Highway, which was recently planted by the Green and Environmental Secretariat of the São Paulo

Municipality (SVMA); Tizo park, with significant vegetation remnants of Atlantic forest in the regeneration stage; and Vila São Francisco Park, a legal reserve of the Vila São Francisco condominium that has been transformed into a public park, with leisure facilities for use by the local population.

The SVMA has been active in the basin for such areas to be preserved and for connections to be made through the creation of linear parks across the basin. The department has been working specifically in 17 areas, public and private, either through the implementation of conservation and recovery measures or through the adoption of participatory community management plans to make actions more effective. Fig. 3 shows the 17 SVMA performance areas. These areas, besides being important from the point of view of biota maintenance, are also important from a hydrological point of view, since they function as underground recharge zones, attenuating the peak flow in the basin, since they allow precipitated water on these to have high rates of infiltration, contrary to what occurs in densely urbanized areas, where water flows quickly to the drainage channels. The loss of these permeable plots in the basin would potentially result in an increase in the significant peak flow that would increase the occurrence of floods in the current channel of the Jaguaré stream. In addition, the headwaters of the Jaguaré watershed have significant forest fragments that house important representatives of the Mata Atlântica, in its flora, such as that registered for [3], and its fauna; in this way, the proposed blue and green corridors will function as diffusers of these species to the other green areas of the basin, reaching to Villa Lobos park.

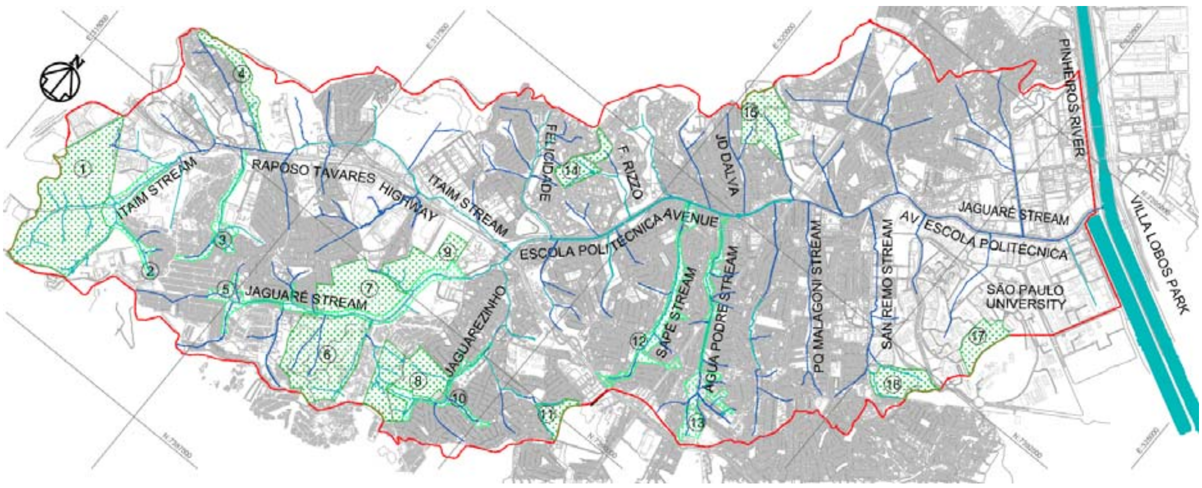

Fig. 3 Remnant forest in the Jaguaré watershed focus of SVMA. Source: Prepared by the author based on information from the SVMA. (1) Tizo Park; (2) Itaim Linear Park; (3) Passagem Grande Linear Park; (4) Juliana Park; (5) Jaguaré Springs Linear Park; (6) Educandário Park; (7) Cemetery Israelita; (8) Private Area; (9) Private Area; (10) Jacarezinho Linear Park; (11) Raposo Tavares Park; (12) Sapé Linear Park; (13) Água Podre Linear Park; (14) Príncipes Park; (15) São Francisco Park; (16) USP; (17) USP

IV. Results

A. Blue and Green Infrastructure Proposal

From the SVMA map of the remnant forest, a study to identify the potential areas for the interconnection of existing fragments was carried out. The floodplains, flowerbeds and squares were used to propagate these areas. The map of Fig. 4 shows the result obtained for the proposed blue and green infrastructure network in the Jaguaré watershed. With the proposal, there was an increase of green areas in the basin from 26.85% to 38.3%.

The proposed blue and green network creates a connection between the remaining green areas, creating corridors so that the avifauna can transit through the watershed, promoting the dispersal of species and increasing the environmental quality. In addition, the green areas around watercourses work like buffer zones for extreme hydrological events by increasing flood basin safety.

The proposed blue and green corridors also function as leisure areas for the population, with recreation areas for children and areas for sports, besides hiking trails, cycle paths, etc. The existence of these areas in the basin results in an important increase in the quality of life of the population. In addition, these areas function as climatic regulation zones, promoting increased air humidity, control of suspended particulate matter, carbon sequestration by vegetation and decrease of thermal amplitude, thus having a direct effect on the health of the population.

Currently, the Jaguaré watershed has a population of 268 thousand habitants, considering the minimum recommended by the World Health Organization (WHO) of green area per habitant of 12 m²/habitant, the basin should have about 3 km² of green areas; today, the basin has 7.6 km², which represents 28 m²/habitant. While that is an excellent index, it does not represent the reality of most Brazilian urban areas, or even that of other districts of the city of São Paulo. The adoption of the proposed scenario would increase the availability of the green area, reaching the rate of 40 m²/habitant. This would raise the basin to above the ideal condition of green area availability per habitant, which WHO recommends to be 36 m²/habitant.

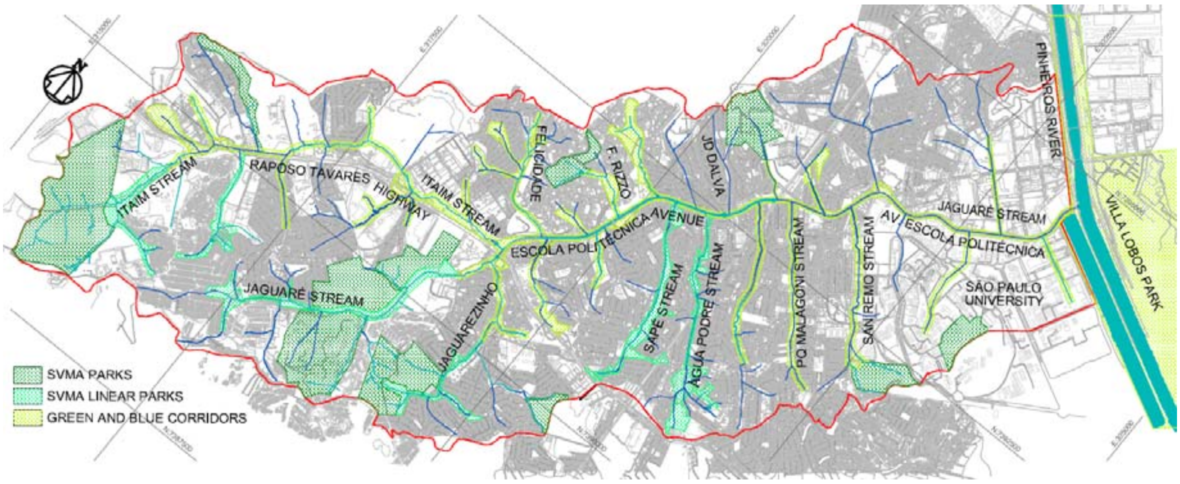

Fig. 4 Blue and green infrastructure proposal. Source: Prepared by the author

Fig. 5 Typical cut for the proposed blue and green corridors. Source: Prepared by the authors. (1) Multiple use buildings with green roof; (2) Living Ground Floor with commercial units; (3) Crossing bridge for pedestrians; (4) Planting of suitable species; (5) Public transportation; (6) Bike trail; (7) Limitation of the use of individual transport; (8) Roof terrace; (9) Sustainable drainage; (10) Use of phytoremediation species in the watercourse; (11) Sustainable drainage; (12) Health infrastructure; (13) Regularization of the canal bed with sustainable techniques; (14) Adequate lighting to promote nighttime use of structures

Fig. 5 shows a typical cut that could be applied to a blue and green corridor with leisure areas, transportation infrastructure, vegetation requalification, sanitary infrastructure to control water quality, elements of connection between population and area, control of use and occupation to promote the circulation of the population in the area.

B. Impact of the Proposed Scenario on Jaguaré Watershed Peak Flow

In order to verify the impact of the adoption of the proposed blue and green infrastructure scenario for the Jaguaré watershed in the peak flow control, the peak flow modeling was performed for two scenarios: 1) The current scenario, which has 26.85 % of urban green areas, and 2) The proposed blue and green infrastructure scenario, which extends through green corridors, green areas in the basin to 38.3% of the total area, and also allows these areas to function as detention areas, water advance in the canal. With this, it was obtained through the hydrological modeling in ABC6 software that in the proposed scenario there would be the reduction of the peak flow from 99.24 m³/s to 79.51 m³/s. In addition, there would be the delay of the peak of the flow, as it is possible observe in the hydrograph obtained in the graph of Fig. 6. In this way, it is noticed that the techniques of blue-green infrastructure in the proposed scenario are of great importance for the hydrological control of the basin.

Considering also the scenario of climate change, the adoption of more resilient techniques in the control of the peak flow are of great importance to face the extreme events that tend to be more common.

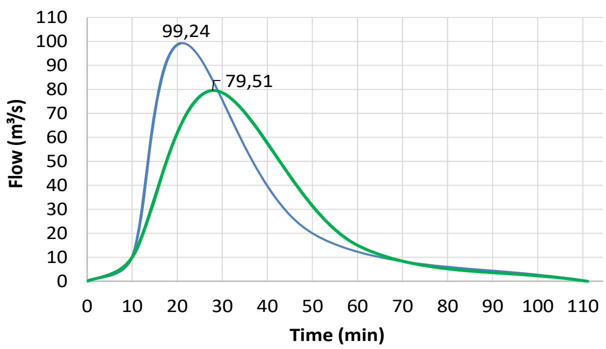

Fig. 6 Hydrogram obtained for the current scenario and for the proposed scenario. Source: Prepared by the authors

C. Potential Impact on Birdlife

Birdlife has great ecological importance in green areas, since they perform a valuable ecosystem service in the form of seed dispersal. In Tizo Park, the following bird species can be easily found: Bem-te-vi or Great kiskadee (Pitangus sulphuratus), Green-billed toucan (Ramphastos dicolorus), Caracara (Caracara plancus), Campo flicker or field woodpecker (Colaptes campestris), White-faced whistling duck (Dendrocygna viduata), Rufous-bellied thrush (Turdus rufiventris), and the Common moorhen, also known as a swamp chicken (Gallinula chloropus) [8]. Fig. 7 shows the bird sighting points in Tizo Park, according to a survey conducted by SVMA [8]. In the Villa Lobos park, according to [7], 51 species of birds were found, as presented in Table I.

Fig. 7 Birding sites at Tizo Park [8]

TABLE I
BIRDLIFE SIGHTED IN THE VILLA LOBOS PARK [7]

Species	**Brazilian popular name**	*Dryocopus lineatus*	pica-pau-de-banda-branca
Accipiter striatus	gavião-miúdo	*Aratinga leucophthalma*	periquitão-maracanã
Streptoprocne zonaris	taperuçu-de-coleira-branca	*Brotogeris tirica*	periquito-rico
Syrigma sibilatrix	maria-faceira	*Diopsittaca nobilis*	maracanã-pequena
Coragyps atratus	urubu-de-cabeça-preta	*Forpus xanthopterygius*	tuim
Vanellus chilensis	quero-quero	*Athene cunicularia*	coruja-buraqueira
Coereba flaveola	cambacica	*Rhinoptynx clamator*	coruja-orelhuda
Columba livia	pombo-doméstico	*Conirostrum speciosum*	figuinha-de-rabo-castanho
Patagioenas picazuro	pombão	*Thlypopsis sordida*	saí-canário
Zenaida auriculata	pomba-de-bando	*Thraupis sayaca*	sanhaçu-cinzento
Pyroderus scutatus	pavó	*Trichothraupis melanops*	tiê-de-topete
Piaya cayana	alma-de-gato	*Theristicus caudatus*	curicaca
Paroaria dominicana	cardeal-do-nordeste	*Amazilia lactea*	beija-flor-de-peito-azul
Sicalis flaveola	canário-da-terra-verdadeiro	*Eupetomena macroura*	beija-flor-tesoura
Zonotrichia capensis	tico-tico	*Troglodytes musculus*	corruíra
Estrilda astrild	bico-de-lacre	*Turdus flavipes*	sabiá-una
Falco femoralis	falcão-de-coleira	*Turdus leucomelas*	sabiá-barranco
Carduelis magellanica	pintassilgo	*Turdus rufiventris*	sabiá-laranjeira
Furnarius rufus	joão-de-barro	*Fluvicola nengeta*	lavadeira-mascarada
Molothrus bonariensis	vira-bosta	*Machetornis rixosa*	suiriri-cavaleiro
Basileuterus culicivorus	pula-pula	*Myiodynastes maculatus*	bem-te-vi-rajado
Passer domesticus	pardal	*Pitangus sulphuratus*	bem-te-vi
Phalacrocorax brasilianus	biguá	*Pyrocephalus rubinus*	príncipe
Celeus flavescens	pica-pau-de-cabeça-amarela	*Serpophaga subcristata*	alegrinho
Colaptes campestris	pica-pau-do-campo	*Xolmis cinereus*	primavera
Colaptes melanochloros	pica-pau-verde-barrado	*Cyclarhis gujanensis*	pitiguari

The discontinuity between the green areas causes the isolation of populations decreasing the diversity of birds. The connection of these environments through ecological corridors makes possible the occurrence of less generalist species in more degraded areas, since it enlarges the area of action of the individuals who begin to move further through the fragments.

The proposed blue and green corridors, besides expanding the possibilities of shelter and food for birds, has great importance in the balance of the populations since it provides the genetic exchange among the populations present in the forest fragments.

D. Summary of the Ecosystem Regulatory Services Provided in the Proposed Scenario

The following ecosystem services of regulation would be promoted in the proposed scenario of adoption of the blue-green infrastructure in the Jaguaré watershed:

1) Control of peak flows through the expansion of the retention and detention zones proposed by the green infrastructure;
2) Control of diffuse load through retention in vegetated floodplains;
3) Control of the microclimate, reducing the thermal amplitude and increasing the humidity of the air;
4) Promotion of the quality of life of the population through access to leisure areas and contact with natural elements;
5) Promoting improved population health through access to better quality air and areas for exposure to sunlight;
6) Integration of water into the urban landscape;
7) Control of soil quality;
8) Air quality control (carbon sequestration and control of particulate matter);
9) Promoting the environmental enrichment of forest fragments, increasing the diversity of fauna and flora not only in dense forest fragments, but in less dense vegetated areas.

IV. Conclusions

Through the proposed scenario, it was possible to verify the advantages in the adoption of blue and green infrastructure in watersheds. The hydrological modeling of the existing scenario and the proposed scenario revealed that the adoption of the blue and green infrastructure in the Jaguaré watershed would result in a reduction and a delay in the peak flow of the basin, which would result in a great gain for hydrological safety in the area. In addition, a large number of bird species were found in the forest fragments of the basin that would benefit from the creation of the proposed blue and green corridors, since they would have extended their possibilities of shelter and food along the basin, which would also bring a return to the dispersion of plant species by the same, resulting in a greater environmental gain for flora and fauna.

Finally, the quantification of the ecosystem services of regulation brought with the adoption of the proposed scenario revealed the great opportunity for an increase in the environmental quality and the quality of life of the population, which is formed by the adoption of blue-green infrastructure techniques in urbanized river basins.

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