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Restoring, Revitalizing and Recovering Brazilian Rivers: Application of the Concept to Small Basins in the City of São Paulo, Brazil

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***Abstract*—**Watercourses in Brazilian urban areas are constantly being degraded due to the unplanned use of the urban space; however, due to the different contexts of land use and occupation in the river watersheds, different intervention strategies are required to requalify them. When it comes to requalifying watercourses, we can list three main techniques to fulfill this purpose: restoration, revitalization and recovery; each one being indicated for specific contexts of land use and occupation in the basin. In this study, it was demonstrated that the application of these three techniques to three small basins in São Paulo city, listing the aspects involved in each of the contexts and techniques of requalification. For a protected watercourse within a forest park, renaturalization was proposed, where the watercourse is preserved in a state closer to the natural one. For a watercourse in an urban context that still preserves open spaces for its maintenance as a landscape element, an intervention was proposed following the principles of revitalization, integrating the watercourse with the landscape and the population. In the case of a watercourse in a harder context, only recovery was proposed, since the watercourse is found under the road system, which makes it difficult to integrate it into the landscape.

***Keywords*—**Sustainable drainage, river restoration, river revitalization, river recovery.

I. Introduction

IN Brazil, the structure of the road system was based on the occupation of the floodplains, constituting the well-known sanitary avenues. Nowadays, the galleries carried out are already saturated, due to the changes in the soil occupation across the watershed. From the environmental point of view, these systems show many fragilities, since they are concrete structures without any life. The degradation of the urban watercourses has been emphasizing the importance of the requalification of these systems and the preservation of the remaining natural systems [2].

In the last decades, a more comprehensive approach has been adopted in many projects that involve interventions in watercourses. The social and environmental issues of floodplain areas in conflict with urbanization was included. However, although the concept has evolved, what is often observed in practice is a series of incomplete interventions, such as the implementation of linear parks in polluted areas [5].

The city of Fountain Hills, Arizona, USA, provides a good example of the sustainable drainage system. During the city development, three important planning measures were taken to assist the hydrological and geomorphological processes. First, the rainfall was identified to promote storm control and flood prevention. Second, the floodplains were prevented from being occupied through heavy taxation, and specific occupation criteria were also created to avoid the dense occupation. Third, streets were designed to function as drainage channels, conveying rainwater to permeable areas and reducing the impact on the canal [4].

The principles for the ecological design of floodplains can be divided into three areas [3]:

1) General principles, where ecological goals and economic development are predicted, protection and restoration of the natural characteristics of rivers, promotion of measures that attract the population to near the watercourse, as devices to outdoor leisure activity.
2) Principles of planning, predict the promotion of a strong relationship between the community and the river. Disseminate knowledge of the river ecosystem and the dynamism of the rivers, to minimize the human development in the floodplains. Provide public access and recreation in floodplains, promoting events to celebrate the history of the river, helping to create a relationship between the community and the river. Besides that, the involvement of the community in the planning process of these areas.
3) Principles of design, where protection of the river's natural function is foreseen, creation of protection zones for sensitive areas, restoration of riparian vegetation, use of non-structural alternatives for water resources management, reduction of impermeable construction, and prioritization of non-structural approaches.

Due to the concern with the issue of floods in urban areas, it is possible to list possible uses for floodplain areas for different return periods that integrate social, economic and environmental interests. A floodplain of a half year return period is destined for natural reserves, playgrounds and gardens; for a one year of return period, it is reserved for temporary parking lots, low circulation roads and intermittent use buildings resistant to water; for a 25 year of return period, it is possible to use roads of greater circulation, car parks and buildings with a ground floor but of intermittent use; and for a 100 year return period, it ultimately allows large urban areas, with the exception of hospitals and other essential services [3].

The water management techniques can be divided into three

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different areas [3]: Restoration or naturalization: Restore the relationships between the watercourse and the landscape in order to return to a natural condition, or as close to the natural condition as possible. Rehabilitation or recovery: Aims to reestablish the physical, chemical and biological conditions of the watercourse, in order to reestablish the sanitary conditions. Revitalization: Restore the relationships between the watercourse and the landscape in a functional way, that is, reintroduce the canal giving it life again, without depriving other uses. These classifications, renaturalization, revitalization and recovery, will be used in this work to treat the areas described below.

II. Methodology

In this study, it was proposed the requalification of three small watersheds following three strategies: Restoration, revitalization, and recovery. The adoption of each technique in the three different areas was based on the type of the existing soil use and occupation, in order to use the most appropriate approach.

A. Restoration

In order to make feasible the restoration process, the following service points were proposed in this study:

1) Control of pollutant loads in the watershed (point and diffuse);
2) Removal of irregular housing in floodplains;
3) Flora requalification: Exotic species control and native species replanting;
4) Requalification of the channel physical structure: Meanders reconstruction or installation of structures that recreate their functions, demolition of artificial coverings and protections of banks and bottoms that are not suitable for colonization of the biota, and control of erosive processes in the floodplain;
5) In case of the watercourses located inside parks, creation of sacrifice zones with contemplation structures and leisure to the population to access the watercourses;
6) Monitoring the evolution of water quality through the use of physical-chemical and biological indicators;
7) Implementation of an environmental education program in the watershed;
8) Implementation of a program for payment for environmental services (PES) in the watershed.

B. Revitalization

In order to make feasible the revitalization process, the following service points were proposed in this study:

1) Control of pollutant loads in the watershed (point and diffuse);
2) Removal of irregular housing in floodplains;
3) Flora requalification: Planting of species that aid in hydrological regulation and that act in the pollutants control;
4) Requalification of the physical structure of the canal: Use of coating and protections of margins and bottom that manage vegetal growth.
5) Implantation of leisure structures along the watercourse such as observation decks, hiking trails, cycle paths, banks, sports equipment, etc.;
6) Implementation of service areas such as restaurants, kiosks, etc.;
7) Monitoring the evolution of water quality through the use of physical-chemical and biological indicators;
8) Implantation of leisure structures along the watercourse such as observation decks, hiking trails, cycle paths, banks, sports equipment, etc.;
9) Implementation of environmental education program in the watershed;
10) Implementation of a program for payment for environmental services (PES) in the watershed.

C. Recovery

In order to make feasible the recovery process, the following service points were proposed in this study:

1) Control of pollutant loads in the watershed (point and diffuse);
2) Monitoring the evolution of water quality through the use of physical-chemical indicators;
3) Implementation of environmental education program in the watershed;
4) Implementation of a program for payment for environmental services (PES) in the watershed.

D. Study Area

The areas considered in this study make up part of the Jaguaré watershed: the renaturalization of the watershed of the Itaim stream (A) in the area that corresponds to the Tizo Park; the revitalization of the watershed of the Evandro Valério square (B); and the recovery of the watershed at Avenida Corifeu de Azevedo Marques (C). The location of the areas is shown in Fig. 1 below.

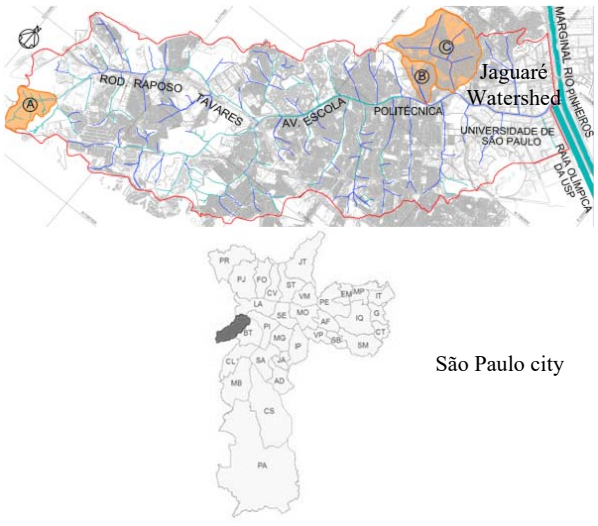


Fig. 1 Location of the study areas for restoration, revitalization and recovery proposals in the Jaguaré watershed. Source: Prepared by the author

III. Results

A. Itaim Stream Restoration

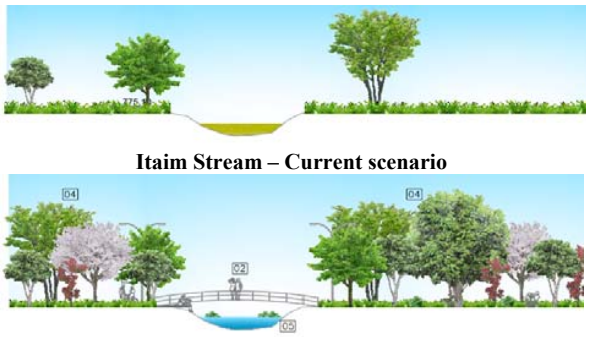
For the application of these steps and elaboration of a restoration proposal, the area of Itaim stream was chosen, a greater tributary of the Jaguaré stream that is inside Tizo Park. Although the springs have been protected since the creation of the park, they are influenced by the pollutant loads coming from the external areas and diffuse loads coming from Esperança Village, which borders the park. Fig. 2 shows the location of the Tizo park area in green and the Itaim stream within the park.

Fig. 2 Location of the Itaim stream in Tizo Park. Source: Prepared by the author from Google Earth Pro

In addition to the threats due to the release of pollutant loads, the channels within the park are not in totally natural conditions, and not integrated with the park goers. The section near the entrance to the park has its banks taken by tall exotic vegetation, which prevents access and even the view of the channel, as shown in Photo A of Fig. 3. Photo B of the same figure shows a second stretch of the canal where access is possible, but that presents the banks that are eroded and without vegetation.

Itaim stream has enormous potential for restoration since it is inserted in a context of vegetal remnant under protection; in this way, a series of measures were proposed for restoration, in order to attend the set of detailed techniques, as presented in the section of Figs. 4 and 5.

Fig. 3 Itaim stream in Tizo Park. Source: Photos of the author

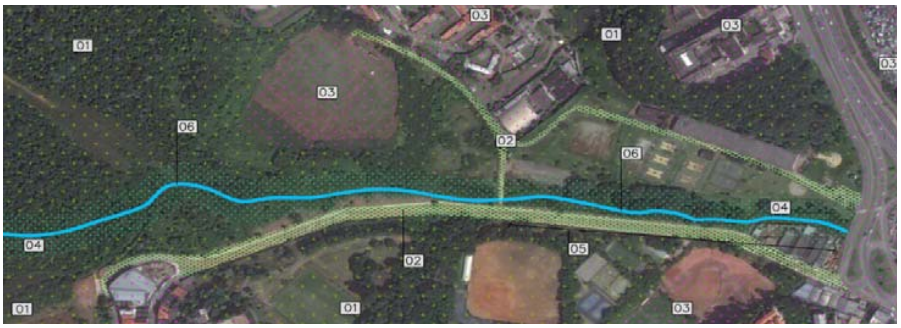


Itaim Stream – Current scenario

Itaim Spring - Proposed scenario

Legend: (01) Integration of the population of the park with the waters; (02) Crossing bridge for pedestrians; (03) Use of phytoremediation species for water treatment; (04) Planting of suitable species in the floodplains; (05) Regularization of margins and bottom with sustainable techniques.

Fig. 4 Cut of the existing and proposed scenario for the Itaim stream in the Tizo Park. Source: Prepared by the author



Legend: (01) Area that demands environmental enrichment; (02) Road that requires green infrastructure; (03) Buildings and facilities; (04) Requalification of the floodplain area; (05) Zone next to the visitation area: demands water observation equipment; (06) Requalification of the channel.

Fig. 5 Proposal for restoration of Itaim stream in Tizo Park. Source: Prepared by the author

The payment system for environmental services rendered by the population of the basin in the case of restoration watershed should be based mainly on actions aimed at the preservation of green areas and water quality:

- Tax incentives for the maintenance of green areas in private properties;
- Tax incentives for users who proceed with the registration of new sewage connections with the concessionaire;
- Reward system for denunciations of irregular launches of pollutant loads in the drainage system and watercourses;

- Fiscal incentives for the adoption of green infrastructure techniques on the lot scale to control pollutant loads and peak flow.

The water quality monitoring system in this case must be rigorous in order to assess whether the quality of the water presented by the watercourse meets the demands of the aquatic ecosystem and should be carried out at least monthly and using biological, physical and chemical indicators.

B. Revitalization of the Stream of the Squares Evandro Valério and Father Campos

The Squares Evandro Valério and Padre Campos, despite having favorable conditions for the maintenance of a watercourse, shelter a stream canalized in an underground gallery. According to the residents of the squares, the stream was canalized in response to requests from the population itself, since it was polluted generating a series of inconveniences, such as the presence of urban pests (insects and rats) and the exhalation of odors from sewage deposited improperly. Fig. 6 shows the contributor basin (Orange), the area of the squares (Green), the location of the watershed, and the location of the photographic memorial. The basin also has an area subject to flooding that can be solved with the implementation of sustainable drainage.

Fig. 6 Location of the Evandro Valério and Padre Campos squares in the Jaguaré watershed. Source: Prepared by the author from Google Earth Pro

Fig. 7 shows emblematic points of the squares. Point A shows a football field installed by the population; photo B, photo C1 and photo E illustrate the density of vegetation at different points; photo C2 shows the lack of maintenance in one of the stretches, where vegetation invades the sidewalk, which ends up encouraging the inadequate deposit of waste by the population; and photo D shows an excerpt that has public equipment for sports practices.

The square also houses a spring that has a contribution from the underground aquifer, since it remains in the landscape with significant flow even in the dry season (Volumetric flow on 08/10/2015 = 0.33L/s), which is used intensively by the population for water abstraction for non-potable uses. In a 30-minute observation period from the source on a Saturday, eight users were registered visiting the source for water collection (gallons) and car wash. The spring (photo G) was treated by the municipality service through the construction of a gravel trench, according to a resident, who directed the water to a catchment point where the population captures the waters (photo H2).

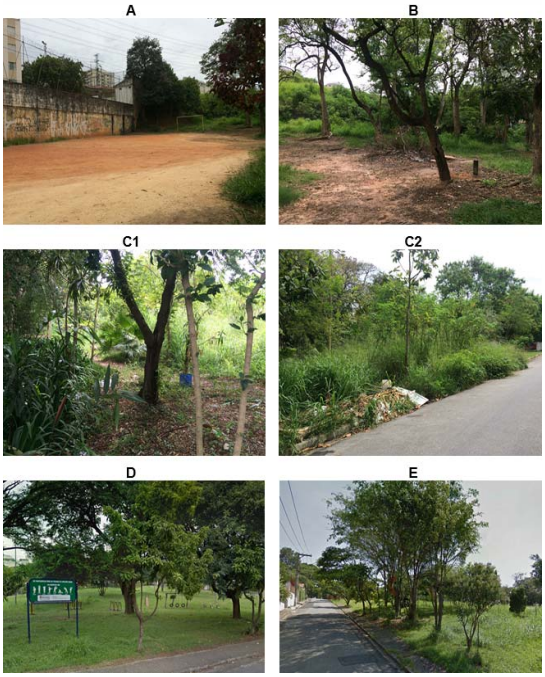


Fig. 7 Evandro Valério Square in the Jaguaré watershed. Source: Photos of the author

The square receives the sewage of some houses, which is collected by a concrete box built by the local population (photo H1), it unduly directs the collected sewage to a drainage gallery near the spring. A sewage network exists a few meters from this box, and therefore it would be necessary to promote the correct connection, to eliminate this pollution source (photo H3). The site demands interventions to consolidate the sewage system in order to guarantee the preservation of the spring waters, since the demand for its waters by the population is high and the lack of proper management can pose a serious health risk. Fig. 8 below shows the area situation.

The stream within the squares, known as “Spring stream”, receives part of the runoff from the São Francisco Village condominium, a complex of high-rise residential and commercial buildings. The condominium was built before municipal law No. 13,276 of 2002 that makes it mandatory to install rainwater holding reservoirs in projects with a built area greater than 500 m², so it has no measures to assist in the control of peak flow. If built today, the enterprise which has an area of about 260,000 m² would demand a volume of 1404 m³ (considering 60% of built area). Of the total area of the condominium, the parcel of 75,000 m² contributes to the spring stream, computing a required holding volume of 405

m³. The retention of this volume would relieve the drainage system during periods of heavy rainfall, reducing the risk of flooding in the region. Thus, this study proposes the creation of areas for retention of this volume in Evandro Valério and Padre Campos squares, as shown in Fig. 9.

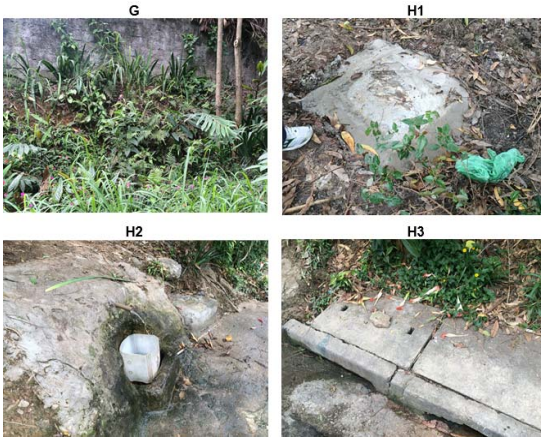


Fig. 8 Spring in Evandro Valério Square in the Jaguaré watershed. Source: Photos of the author

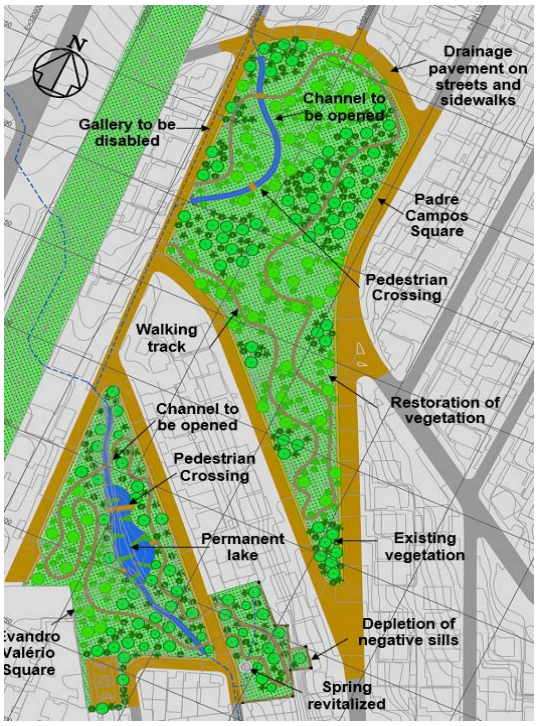


Fig. 9 Proposal of revitalization of the area - Plant of implantation. Source: Prepared by the author

In spite of the presence of vegetation in the squares, there are stretches that require management, so the proposal includes the recomposition of vegetation in certain stretches (represented in Fig. 8 by the lighter green vegetation). For this, suitable species should be selected, such as those that promote erosion control and preserve water quality. The SVMA urban afforestation manual [1] identifies 253 native species from the municipality of São Paulo, extracted from Administrative 61/ SVMA/2011, which can be used in vegetation restoration programs in urban areas and are suitable species for urban management because they present anatomical and physiological characteristics that allow harmonious coexistence with the urban elements.

The sanitary sewage system is consolidated in the basin, that is, there are collector networks in all the streets and all of them are received by the existing trunk collector at Av. Escola Politécnica. To consolidate the system, it is necessary to check if all the households in the basin are connected to the public grid and that there are no cross-links between the sewer system and the drainage system.

C. Recovery of the Stream at Corifeu de Azevedo Marques Avenue

The stream under Av. Corifeu de Azevedo Marques is tributary of the Jaguaré stream, also runs under this avenue and surrounding streets; therefore, it has low potential for revitalization that would include the opening of the underground galleries since the avenue has heavy traffic. The channel opening in Corifeu de Azevedo Marques Avenue would require the complete deconstruction of the avenue, which is an important axis of circulation that connects Butantan village, Osasco city and Mario Covas highway. Today, the avenue has two lanes of road, one lane of buses and a track for cycling in each of the directions. In addition, the tributaries of the watercourse are under the narrow streets, so its opening would make it impossible for vehicles and traffic to travel these routes. The location of the watercourses and the situation of the roads are shown in Fig. 10 and Fig. 11, respectively.

Fig. 10 Location of the canalized stream under Corifeu de Azevedo Marques Av. Source: Prepared by the author from Google Earth Pro

Streams in this situation demand, at least in the short term, more conservative solutions, as is the case of recovery. For the recovery of the channel, it is necessary to control the existing pollutant loads that flow into it. In addition, there are sewage discharge in the drainage system that needs to be solved, as

shown in Fig. 12.

Fig. 11 Stream channeled under Corifeu de Azevedo Marques Avenue in the Jaguaré watershed. Source: Author's Photos

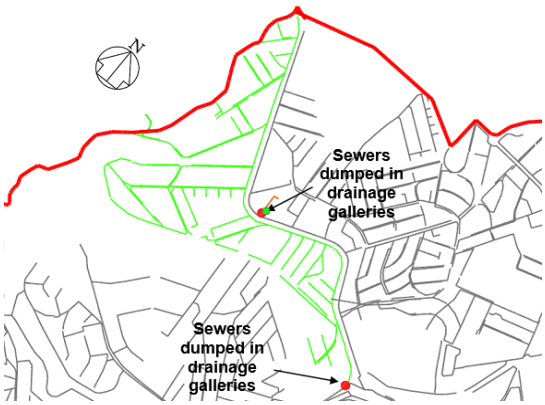


Fig. 12 Catchment system of the stream basin under Av. Corifel de Azevedo Marques. Source: Prepared by the author from the SABESP registry

The resolution for these two launch points is simple, since both have topographic conditions to be received by the already deployed networks, rather than just the construction of two stretches of network that make such connections. However, for complete consolidation of the sewage system, additional measures are required to ensure complete isolation between the sanitary sewer system and the urban drainage system. Following the techniques used in the "Córrego Limpo" program (SABESP and prefecture of São Paulo), sewage networks must go through the following steps:

- Complete scanning of nets with the aid of remotely guided equipment to identify ruptured pipes and subsequent execution of repairs;
- Application of dye in nets in the cross-section to trace cross-links and later deactivation;
- In the presence of areas with irregular occupation that do not have sanitary infrastructure, proceed with the regularization and implementation of the necessary infrastructure or expropriation.

The payment system for environmental services rendered by the population of the basin in the case of basins in recovery should be based mainly on pollution control actions such as the following:

- Tax incentives for users who proceed with the registration of new sewage connections with the concessionaire;
- Reward system for denunciations of irregular launches of pollutant loads in the drainage system and watercourses;
- Fiscal incentives for the adoption of green infrastructure techniques on the lot scale to control pollutant loads and peak flow.

The water quality monitoring system in this case can be more simplified, focusing only on key variables such as BOD, COD, OD, turbidity, conductivity and pH. In addition, monitoring frequency may be less often, such as monthly monitoring.

The environmental education program in the basin should be based mainly on the control of pollutant loads and the importance of registering new household connections with the concessionaire that operates the sanitary sewage system in the basin.

IV. Conclusions

This work aimed to gather the main techniques for re-qualification of basins in the scope of renaturation, revitalization and recovery, and working the appropriate adaptations for the Brazilian environmental, social and economic reality, in order to help in the elaboration of studies in this area.

Despite that the context of watercourses in developed countries are most often different from that which Brazilian watercourses are exposed, it is important to observe the historical process of requalification projects in these areas to achieve greater efficiency in local projects. The basic interactions existing in the watercourse are the same throughout the world, such as the intimate relationship between watercourse and watershed. In addition, the human factor is the main one responsible for a project to succeed, and therefore, trying to understand how the population was reconciled with the waters in these successful projects is of great importance.

Through the case study presented in this work, it was possible to verify the main aspects and challenges involved in the requalification process of rivers, which goes far beyond water depollution, and includes the social, political and economic structure of the watershed. The question of water in Brazilian urban areas is closely linked to the housing deficit and unequal income distribution. This process results in the occupation of the free - in the sense of not built - areas of the city that are in most cases areas of great environmental importance, such as for example, floodplain areas, slopes and protected areas of springs. The creation of a new culture of sustainable management of urban waters goes before the resolution of existing social, political and economic conflicts among cities.

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