

## **Sustainable Stormwater Management: use of multifunctional landscapes in urban drainage for flood control**

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### **ABSTRACT**

Urbanization process has been continuously increasing proportion of residents in urban areas worldwide, exceeding 80% of Brazilian population in 2000. As cities grow, the impacts of urbanization on the natural environment increase, highlighting the necessity of new development forms that seek to mitigate or eliminate those impacts. Water systems are very sensitive to changes imposed by watersheds urbanization, suffering negative impacts on hydrological cycle that may be felt on increasing severity and frequency of urban flooding and water bodies degradation. Several alternatives for urban projects have been studied to reduce these impacts on hydrological cycle, such as compensatory techniques and unconventional measures in urban drainage. These solutions are more effective when provided within a Sustainable Stormwater Management System. This paper presents a case study of flood control project using a stormwater retention pond, designed to allow multiple use of an urban space, under the concept of *multifunctional landscapes*. The operation of the system is evaluated by a *Cell Model*, developed in the Computational Hydraulic Laboratory (LHC in portuguese) of *Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa of Universidade Federal do Rio de Janeiro (COPPE/UFRJ)*, known as MODCEL (MIGUEZ, 2001).

### **KEYWORDS**

Cell modeling; compensatory techniques; multifunctional landscapes; urban drainage

### **INTRODUCTION**

Advances in the field of urban hydrology and flood control have highlighted the use of compensatory measures in urban drainage projects as a necessity for achieving a sustainable development of cities, always looking for a way to mitigate and reduce the urbanization impacts on hydrologic cycle. However, in Brazil it is still prioritized the use of local solutions and flow acceleration measures, without considering the increasing of ground surfaces sealing caused by a lack of control over land use and occupation. Several alternatives for urban projects have been studied to reduce urbanization impacts on hydrological cycle, such as compensatory techniques in urban drainage (BAPTISTA *et al.*, 2005) and unconventional measures in urban drainage (CANHOLI, 2005), but these alternatives are more effective when provided within a Sustainable Stormwater Management System.

Detention or retention ponds are widely used devices in such systems, in order to control the volumes and peak flood runoff, considering in some cases both aspects of quantity and quality. Development of such interventions in urban environment becomes important when associated with other uses like landscaping and recreational area, being inserted in the city as *multifunctional landscapes* and thereby further enhancing urban space and its surrounding area, through a harmonious design of built and natural environment.

Miguez *et al* (2007) state that the basic idea of the use of *multifunctional landscapes* is that an urban area can meet different objectives and functions with ecological, economic, cultural, historical, social and aesthetic concerns. This technique has a good feasibility of application in peripheral countries, but it is important to emphasize that particular aspect of communities and stakeholders should be considered, in order to increase the acceptability of these interventions. Hall & Potterfield (2001) suggest that retention and detention basins, used for flood control, may be designed to create healthy and functional environments, supporting the conservation of plants and animals species as well as adding aesthetic aspects that help to raise land values.

The interest area for implementation of the retention basin proposed in this paper is located in the city of Mesquita, metropolitan region of Rio de Janeiro. The urban occupation of the city is very dense, with few open spaces. This characteristic claims for a solution that is concerned about social urban space use, valorizing degraded areas and giving it different possibilities of use.

## **METHODS**

To achieve the proposed objectives in this work, it was adopted a methodological procedure based on the following steps:

- (1) Review of the main points about urban flood control issue in order to exhibit a theoretical basis for the work;
- (2) Area definition of Case Study: Governador Celso Peçanha urban watershed, in the municipality of Mesquita, Rio de Janeiro;
- (3) Definition of modeling tools: HIDROFLU System for hydrological simulations and MODCEL for hydrodynamics simulations;
- (4) Elaboration of an alternative of intervention for stormwater runoff control and definition of simulation scenarios for the diagnosis and project evaluation;
- (5) Simulation of the proposed scenarios and presentation of results;
- (6) Discussion of the results considering th alternatives and their potential benefits.

In this paper it is not presented the extended review. The complete work may be seen at Rezende (2010).

### **Hydrological and Hydrodynamics Modeling System**

For hydrological modeling it was used the HIDROFLU System (Magalhães *et al.*, 2005), a computer program developed at COPPE/UFRJ with multiple applications that can be exclusively used as a concentrated rainfall-runoff-type model. Such system divides the hydrograph calculus into four main steps: 1- *watershed characterization*; 2- *design rainfall intensity pattern*; 3- *runoff separation*; 4- *design hydrograph*.

MODCEL (Miguez, 2001; Mascarenhas and Miguez, 2002; Mascarenhas *et al.*, 2005) was used for hydrological and hydrodynamics modeling. This is a computational program also developed at COPPE/UFRJ, able to simulate different hydrologic and hydraulic scenarios. MODCEL is applied to hydrodynamic modeling of watersheds subject to flooding events. This model assumes that the basin can be represented by compartments interconnected, forming a bidimensional net. These compartments are called flow cells, and therefore the basin is subdivided into different cells, which are interconnected, and the flow between cells is calculated by one-dimensional hydraulic equations, defined according to the topographical and

urbanization pattern of the region, through hydraulic relations, *id est*, weir, orifice, Saint-Venant equations and others.

Nature representation can be done through isolated cells or a group of cells, to represent the possible pathways of water complexity in a flood event. Miguez (2001) lists the following hypotheses for cell model application in urban watersheds:

- (1) Nature can be represented by homogeneous interconnected compartments;
- (2) The water line profile in each cell is considered horizontal and interconnections between cells define the water profile;
- (3) Each cell communicates with neighboring cells, which are arranged in a topological scheme, consisting of formal groups, where a cell of a given group can only communicate with cells of the same group or groups immediately anterior or posterior;
- (4) Flow between cells can be calculated using known hydraulics equations;
- (5) Flow between two adjacent cells is a function of water levels within these cells;
- (6) Cross sections of flow are taken as the equivalent rectangular sections;
- (7) Flow may occur simultaneously in two layers, surface and underground, through galleries, and there may be communication between surface and gallery cells.

### **CASE STUDY: RETENTION BASIN CELSO PEÇANHA, MESQUITA, RJ**

The interest area for implementation of the retention basin proposed in this paper is located in the city of Mesquita, metropolitan region of Rio de Janeiro. Figure 1 displays a satellite image of the region. The city has an area of 3,477 ha, with a very intense urban occupation and few free areas.

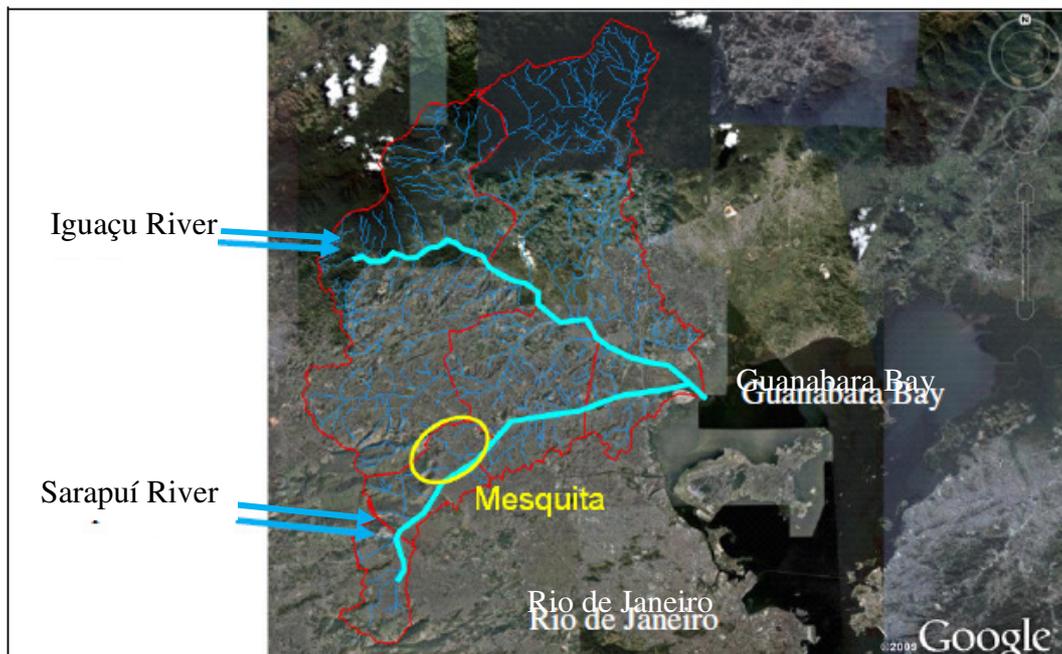


Figure 1. Location of the city of Mesquita in the River Iguaçú-Sarapuá watershed.

## Characteristics of Study Area

The chosen area for deployment of the stormwater damping device is located at the left margin of Sarapuí River, receiving the draining water of an urban watershed with 628,136 m<sup>2</sup>. The basin is relatively plain, with an average slope of 0.0054 m/m and a maximum elevation of 34.5 meters. Figure 2 shows the level and density of occupation of the study area.

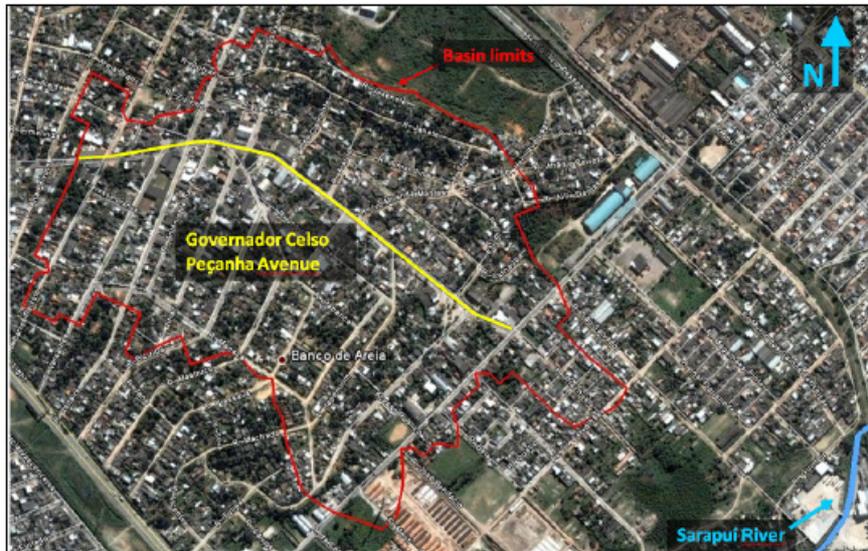


Figure 2. Urban basin of Governador Celso Peçanha Avenue. Source: *Google Earth*.

## Hydrological Studies

The hydrological studies were performed in order to build design rainfalls for different project scenarios defined in this work. Previous studies conducted for this region were used as references. These studies were part of the "Water Resources Master Plan of the Iguaçu/Sarapuí River Basin" conducted by the Laboratory of Hydrology and Environmental Studies at COPPE/UFRJ (LABHID, 1996). Project precipitations were calculated using the following premises:

- recurrence times of 5, 10, 20 and 50 years for the rainfall precipitated over the watershed;
- duration of precipitation equal to 76.38 minutes, which was the calculated concentration time;
- there were considered different values of runoff coefficient for each cell, according to the analysis of satellite images for land use evaluation.

Table 1 presents values of design rainfall calculated for different Recurrence Times (RT) and peak flow hydrograph that resulted from each rainfall event, used in the simulation of the proposed retention basin operation.

**Table 1. Design rain and peak flow used in modeling.**

Recurrence Time (years)	RT5	RT10	RT20	RT50
Total Height Rainfall (mm)	62.57	70.73	77.63	89.20
Peak Flow (m <sup>3</sup> /s)	1.71	2.03	2.32	2.81

### Diagnosis of Present Situation

None natural water body is responsible for draining the water precipitated over the study watershed. The drainage of this area is conducted superficially through the streets and improvised galleries for sewage collection, often built by the residents themselves. The storm water runoff mixed with contaminated water is directed to Sarapuí River through Governador Celso Peçanha Avenue, which is called Riachuelo Street after the intersection with Coelho da Rocha Avenue, acting as a basin trunk collector. A gallery runs until the end of the street Riachuelo simply releasing water into the natural terrain, forming a kind of highly unhealthy swamp, by receiving all contribution of sewage from this basin. On the left bank of Sarapuí River, downstream the flooded area, there is still an occupation of a 140 meters strip by irregular housing. These characteristics can be viewed at Figure 3.

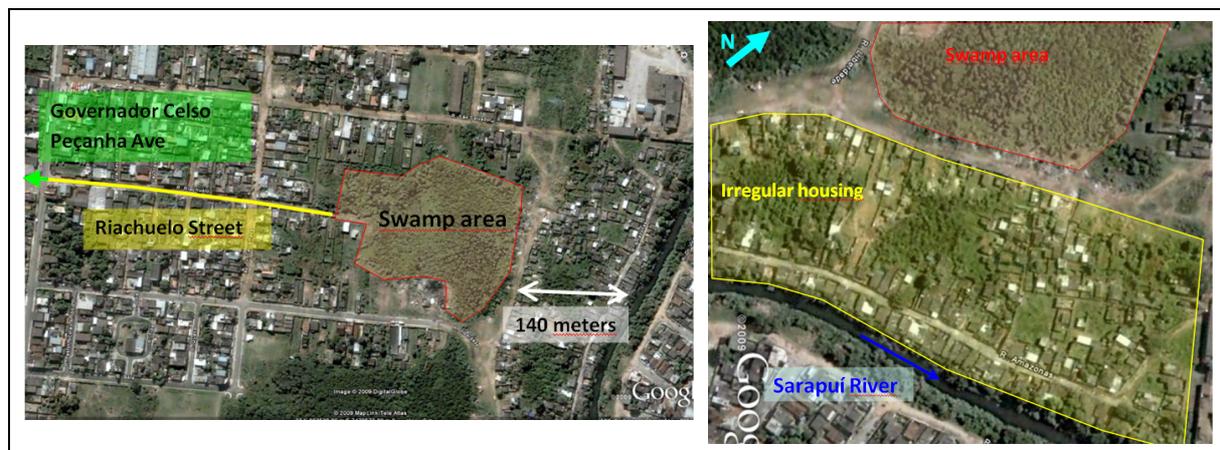


Figure 3. Images of project area, highlighting the swamp and the irregular housing areas. (Google Earth)

The diagnosis study considered only the hydrologic event of 20 years of recurrence time (RT). The simulation of this event resulted in the inundation of an area with something around 15 ha and an average water depth of 60 cm. Simplifications considered for model construction and the lack of an updated database may lead to small variations in these results, which must be analyzed carefully. Taking into account the tendency of region occupation, possible sites considerate as free areas might have been changed and occupied, so flooded area may be smaller than the expected in the mathematical simulation, but with increased depths.

### Proposed intervention

The proposed solution for runoff control considers the sanitation of the urban area and implementation of a retention basin with permanent water surface, downstream of the catchment. The initial conception of this retention basin design regards on multiple uses opportunities of urban space coupled with flood control purpose, providing the region with a recreational area, dedicated to sports, landscaping and urban and environmental improvement. This conception is known by *multifunctional landscaping*.

In order to allow different uses in the inner area of retention basin, ground levels were provided in different land elevations that will suffer flooding, depending on the recurrence time of rainfall precipitated on the contributing urban watershed. With this division into levels, the partial use of area can be prioritized in accordance with flood frequency of each level. There were also provided two areas with lower elevations in order to maintain a

permanent water surface, which can add urban and environmental value to region, and may also help to improve the quality of water that is drained by urban watershed, before it reaches the final water body. This improvement in water quality will be given by sedimentation of suspended solids present in stormwater after washing the urban surface. This impact on quality has not been quantitatively evaluated in this paper. The designed retention basin implementation requires a range of interventions like *ground excavation to shape the different levels, construction of a semi-circular canal to carry water between the two lakes and implementation of a circular gallery with a one-way gate (type Flap Gate) to link designed channel with Sarapuí River*. The schematic drawing is displayed at Figure 4.

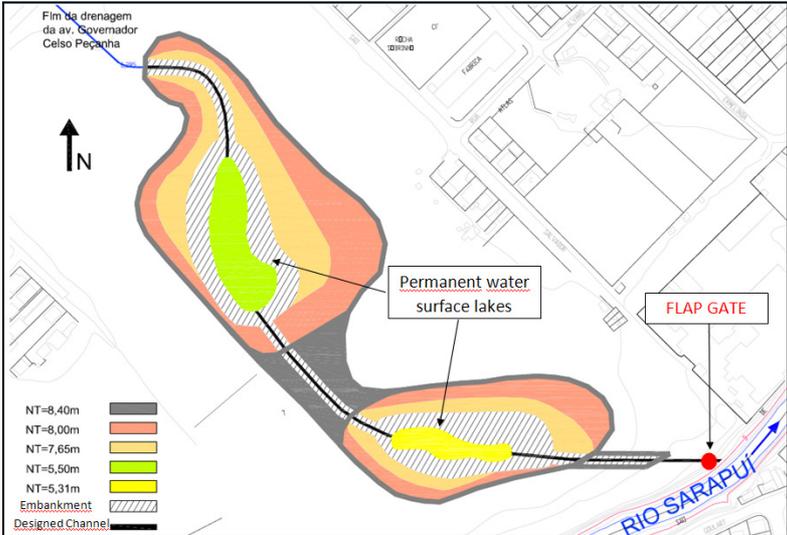


Figure 4. Ground levels (NT) inside Celso Peçanha retention basin.

The basin division resulted in a topology with 10 flow cells, 9 cells representing the retention basin operation and one cell responsible for simulating the behavior of Sarapuí River in front of the Flap Gate. Figure 5 shows the division scheme of cells in the retention basin.

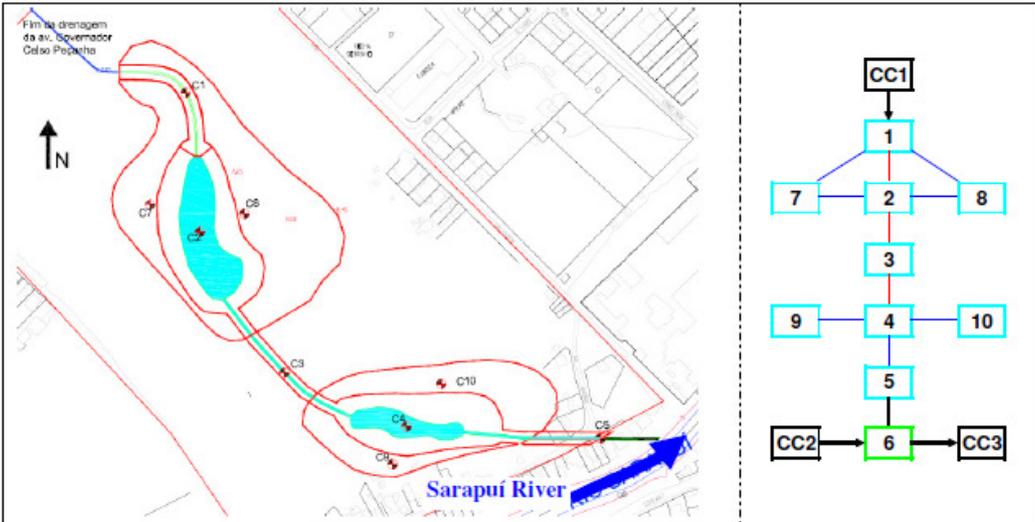
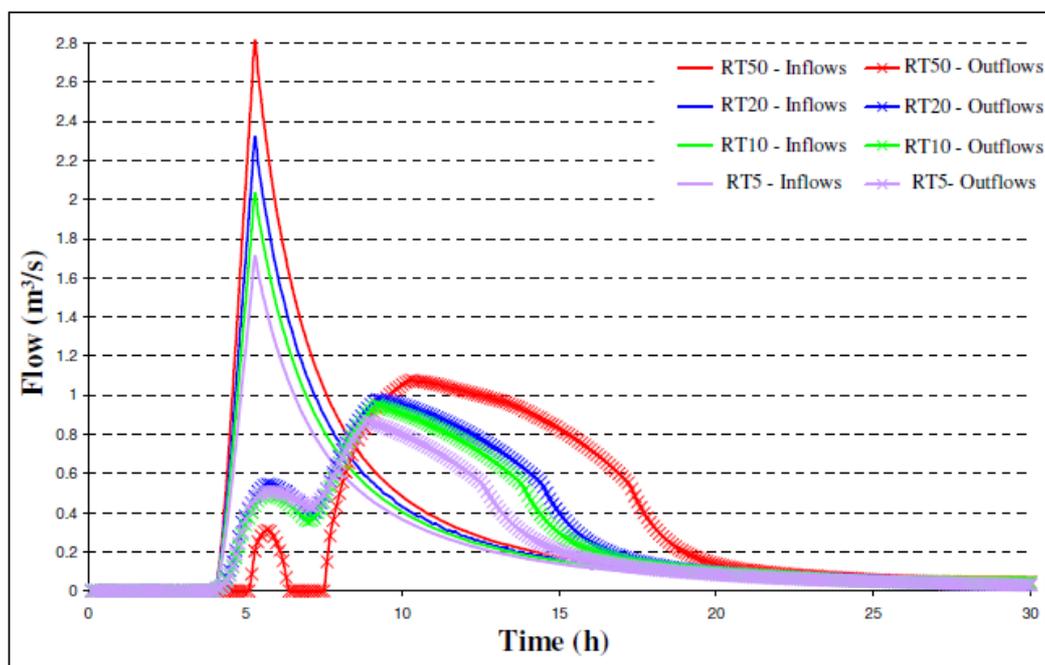


Figure 5. Retention basin division in cells (left) and topological modeling scheme (right). Cell 6 represents Sarapuí River.

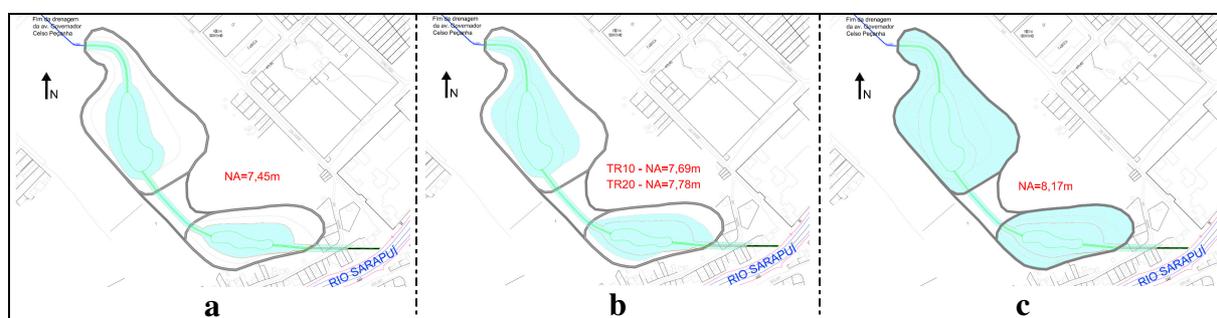
The designed device showed efficiency to control runoff in the region, achieving a maximum damping value of 61.7% when considering the event with 50 years recurrence time. The results can be seen in Table 2, through the values of flood peak damping, maximum water level and flooded area for each simulated event, and Figure 6 shows the In and Out projects hydrographs. Figure 7 shows schematic plants with flooded area for each event.

**Table 2. Flood damping, water level (WL) and flooded area (FA) of retention basin project.**

RT (years)	Peak flow (m <sup>3</sup> /s)		Damping (%)	WL (m)	FA (m <sup>2</sup> )
	Inflow	Outflow			
5	1.71	0.87	49.29	7.45	4,832
10	2.03	0.95	53.37	7.69	9,391
20	2.32	0.98	57.83	7.78	9,391
50	2.81	1.08	61.69	8.17	16,081



**Figure 6. Inflow and outflow design hydrographs of proposed retention basin.**



**Figure 7. Inner basin flooded area for different recurrence time events (a- 5; b- 10 & 20; c- 50 years).**

## CONCLUSIONS AND RECOMMENDATIONS

The project for flood control and stormwater runoff redistribution through the use of a retention basin associated with the recreational use of urban land demonstrated to be satisfactory for this case study. Celso Peçanha Retention Basin is able to store volumes of generated stormwater for all recurrence time events studied in this work (RT's of 5, 10, 20 and 50 years), significantly damping the flood peak flow, reaching more than 60% of reduction in the case of a hydrological event with 50 years of recurrence time.

Drainage solutions integrated with urban areas revitalization programs can be an important option for flood control solution, due to the possibility of designing actions distributed over the urbanized watershed, and the optimization of public resources, once they are targeted to multi-purpose activities, enhancing the concept of *multifunctional landscapes*. This solution also adds a higher urban, social and environmental value for the surrounding region, and takes all potential of integrating an engineering project with an urbanistic design, considering the social function use of urban space based on degraded environment revitalization needs.

Several aspects related to the topic have not been fully discussed, leaving some gaps to be filled by further studies. An important issue not considered in the proposed project is related to the urban stormwater quality. Even perfect operating state sanitation systems would present complications due to possible water contamination by diffuse pollution. Sedimentation and further maintenance are also points to be discussed.

It is also recommended a detailed economic study to evaluate different alternatives of project. Flood control projects using *multifunctional landscapes* design have benefits that can present difficult quantification and often these benefits are not tangible, which would require a more refined economic analysis. Other benefits are easily perceptible, as impacts on urban mesh and its surrounding areas value, which increases the opportunities for construction funding.

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