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QUALITATIVE AND QUANTITATIVE EVALUATION OF STORMWATER INFILTRATION STRUCTURES IN AN URBAN BASIN. CASE STUDY: DISTRICT OF CAMPECHE, FLORIANÓPOLIS-SC.

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ABSTRACT: The use of compensatory infiltration-based techniques for control of urban drainage should include a careful evaluation of the quality of infiltrated water in order to prevent the pollution of soil and groundwater. Pollution in stormwater can reach significant levels, and it cannot be ignored when it comes down to the quality of the receiving medium. The main objective of this paper was to develop a selection methodology to quali-quantitatively characterize rainwater infiltration structures used in an urban basin for future monitoring and instrumentation. The study was conducted in three stages. First, the most relevant infiltration structures were selected using the Geographic Information Systems (GIS) as a tool, together with hydrological models. Next, stormwater was qualitatively diagnosed and, finally, an infiltration ditch and an infiltration pit were characterized. This research study was conducted in the city of Florianópolis, Santa Catarina, Brazil. The methodological procedures consisted of a literature review, the physical characterization of the structures and the infiltration basin, and modeling of the basin based on physical and land use characteristics, by means of map databases provided by the municipality and the satellite images made available from the Corporate GIS project. The Quantungis 8.0 software was used for selection of stormwater infiltration structures. Qualitative analyses were performed at the Integrated Environment Laboratory (LIMA), Sanitary and Environmental Engineering Department at the Federal University of Santa Catarina. The main contribution of this study is the methodology which included field work, computational modeling and qualitative characterization of stormwater runoff and infiltration structures, thus helping decision makers employ stormwater infiltration structures based on scientific and technical criteria.

Key Words: Quality of stormwater runoff, infiltration structures, monitoring

1. INTRODUCTION

The management of the urban drainage system is an important element in the control of urban flooding. In Brazil, there is currently a major national effort to universalize sanitation services including urban drainage. However, monitoring, which is the basis for managing the systems, has been neglected. The expansion of the systems has not been accompanied by records and neither by components that allow their evaluation and operation in most Brazilian cities. The result is a large mismatch between the deployment of the systems and the organization of their management systems. This paper introduces a methodology for the characterization and implementation of monitoring as an alternative control structure of urban drainage. The development of this study has revealed several elements of urban drainage management in a medium-sized city that proved important. These elements are reported in this article along with the results for the characterization of two stormwater infiltration systems.

Alternative urban drainage systems have been used in Brazil since the 1940s, but only in the 1990s experimental research started being conducted on these structures. The instrumentation and monitoring of alternative measures of urban drainage help the government and decision makers in developing standards for sizing, monitoring and maintenance of structures, thus facilitating the design, operation and maintenance of this equipment. When alternative drainage systems for retention and infiltration are poorly built and serviced, they can become sources of contamination of surface and groundwater, causing environmental, economic and public health problems for society. Research on infiltration structures in Brazil is relatively recent and it mostly encompasses quantitative analysis of the structure compared with flow control and flood attenuation.

In the municipality of Florianópolis, Santa Catarina, Brazil, there are no studies that monitor the qualitative and quantitative efficiency of drainage work in flow control and reduction of diffuse pollution from stormwater runoff. In this context, a cooperation agreement was signed with the City Council of Florianópolis for implementing a full-scale field lab in the District of Campeche, which will deepen the knowledge about the interface between hydrology and urban hydrogeology, and assist the City Council in improving the understanding of the operation of stormwater infiltration system adopted. Just like in several other Brazilian cities, urban drainage is almost always treated as a complementary service of the municipal secretariat for public works, and it is limited to networks and stormwater conduits; to date, it lacks the necessary coordination with urban dynamics of land use and occupancy. Thus, this partnership formed with the City Council not only fosters the analysis of the structural measures adopted, but also motivates the implementation of non-structural measures and the creation of the Urban Drainage Plan for the municipality.

Structural measures adopted in Florianópolis include drain sinks (infiltration pits), infiltration trenches, channels and galleries, and only the urban master plan is a nonstructural measure. For this study, only those structures that cause infiltration were selected, because they contain the phenomena of surface runoff, infiltration, percolation and aquifer recharge. Analyses were performed in two stages: first, the most relevant structures were selected, considering the physical characteristics of the district of Campeche (use and land occupancy, drainage network and road network) in addition to the morphological features of the water basin, hypsometry and hydrography. In the second phase, the structures were analyzed qualitatively and quantitatively, for further implementation and monitoring.

The main contribution was the development of the methodology which included fieldwork with the computer modeling activities and the use of geospatial techniques for diagnostics, instrumentation and monitoring of stormwater drainage works. This analysis will help evaluate the measures adopted by the City Council, providing decision-makers with scientific and technical support to improve stormwater management. Another expected outcome is the technical support for the design of an integrated system to monitor the qualitative and quantitative behavior of stormwater in an urban water basin.

1.1 Quali-quantitative monitoring of stormwater

Qualitative and quantitative monitoring of stormwater has been done in a disorganized manner. Planning and control over the use of water require the simultaneous knowledge of two sets of information in the same space and time interval to support management actions whose aim is to meet the demands sustainably. Through monitoring, problems can be diagnosed and the best solutions can be proposed on a technical and scientific basis.

The assessment performed as pre-monitoring identifies deficiencies in the natural drainage system based on hydrological studies, and identifies the micro and macro drainage system of the region, as well as its interface with the morphological characteristics of the water basin, road network, infrastructure and land use and occupancy. Thus, it is possible to implement the best forms of design and instrumentation of structures in order to qualitative and quantitatively monitor the efficiency of operation in flow control and flood attenuation and their behavior compared with groundwater, if they work as an aquifer recharge system or as a contaminant discharge system.

The integrated monitoring of urban waters should encompass the physical-chemical characterization of surface runoff, percolated water, and groundwater, as well as the physical and physico-chemical characterization of the soil, to check whether it acts as a filter to pollution, preventing pollution from going into the deeper layers of soil and reaching groundwater (MOURA, 2010). Diagnosis allows to ascertain the relevant contaminants to be monitored, to characterize the water basin for hydraulic and hydrologic analysis of structures, to define the actual contribution area of the basin and the area resulting from human intervention with stormwater drainage systems.

2. MATERIALS AND METHODS

2.1 Characterization of study area

The study was conducted in Florianópolis, Santa Catarina, located between the geographical coordinates 27°10' and 27°50' south latitude and between 48°25' and 48°35' west longitude. The district of Campeche is located on the island of Florianópolis, comprising the southern part of the island (Figure 1). The region of Campeche belongs to the sedimentary coastal plain; it is called "Planície Entremares" or "Planície do Campeche", comprising the whole Tavares River Basin, which is bounded on the north by Campeche Hill, to the south by "Morro das Pedras" hill, "Morro dos Padres" hill and Peri Lagoon, on the west by Highway SC 405 and on the east by the Atlantic Ocean (ARAÚJO, 1993 apud MILLON, 2004). The study area is predominantly flat, and it is becoming increasingly urbanized, which threatens the local lagoons, swamps, marshes and wetlands, and makes it difficult to precisely locate watersheds and thalwegs.

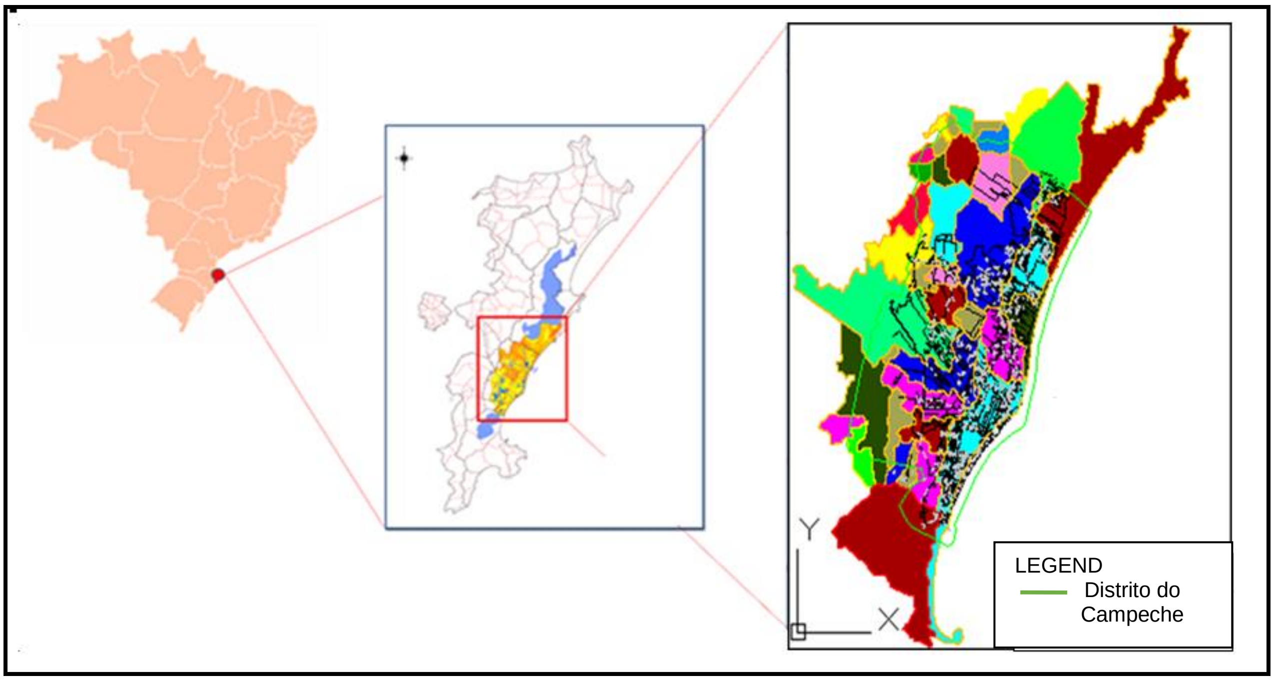

Figure 1-Location of study area

According to Pacheco (2012), the hydrography of the district of Campeche is basically formed by the lagoons Pequena and Chica and by rivers Tavares, Moca (little river of Campeche) and Rafael, and small streams that rise on the Atlantic Rainforest of the Costeira do Pirajubaé Massif (PPA) and culminate near a stone mining area (pebbles) in the plain of Campeche and by the Campeche Aquifer. The Campeche aquifer is predominantly free, composed of fine to medium sands with discontinuous intercalation of sandy clay levels. It is mainly recharged by direct stormwater infiltration and artificially recharged by local systems of domestic sewage disposal (septic systems) and losses of the supply system, although relevant, play a minor role.

The geological formation of the Costeira plain is represented by lacustrine, marine, eolian, colluvial and fluvial environments thay may or may not coexist. Lacustrine and marine environments comprise marine terraces, stretches of sandbanks and sandbank plains formed by the movement of waves. The colluvial and fluvial environments are basically made of relief ruptures of the plains, and they are found along the slopes of the Ribeirão da Ilha hill and Morro das Pedras hill (HERRMANN e ROSA, 1991 apud BORGES, 1996).

The average annual rainfall in the region is 1627 mm. The rainfall data were provided by the Aeronautics Climatology Department (Institute of Airspace Control - ICEA) and are relative to the weather station located in the Air Force Base Florianópolis. Surface runoff from the Rio Tavares basin and Morro das Pedras basin is characterized by low steepness added to sandy and very permeable soils. There are swamps and marshes throughout the basin. Runoff is, therefore, slow toward the lower areas (mangroves and beaches). These basins are the Water Resource Planning Units in Florianópolis where the Campeche district is located.

2.2 Methodology for implementing the monitoring system

Among the alternative control structures of urban drainage in Florianópolis, two types of infiltration structures were selected for monitoring: a linear structure (infiltration trench) and a control structure at source (infiltration pit). These types were chosen because they are the most frequently used in the drainage system of the city. The availability of resources, time and personnel limited the study to one structure of each type. The monitoring will work as a pilot study that will provide the necessary data for an evaluation of the implementation in the remaining structures of the system in Florianópolis. The choice of which pit and trench should be monitored was based on their representativeness in terms of the drainage area, type of land use and environmental attributes of the tributary basin.

Infiltration structures to be monitored were selected through spatial assessment of the contribution area considering the following elements:

- Contribution area;

- Land use and occupancy, particularly the uses that pose a higher risk of contamination of drainage water;

- Roads with high traffic flow;

- Strcutural aspects of the drainage structure depending on the risk of pollution (gravel pit) and ease of sampling.

To integrate the information from maps on hydrography, road network, contribution basin, hypsometry and microdrainage, the GIS system was used by means of software programs QuantumGIS 2.1 and Autocad 2011. The table of attributes of each information plan (map) was cross-checked within GIS, which enabled the choice of the most relevant structures.

To delimit the contribution area of each structure, rainfall was considered for the urbanized basin shaped by human action, not only by the water basin bounded by the topography. Therefore, it was necessary to compile all the information on the drainage network in the region. As drainage is performed as a complementary service to road paving, all documentation was available on paper or as Autocad drawings whose only identification was the name of paved roads. The extensive work began with a) a preliminary delimitation of micro-basins, which brought information on the natural circulation of surface waters, b) identification of pathways within the water basins, c) compilation of drainage projects of each pathway in the Department of Public Works in Florianópolis, d) integration into GIS, and finally e) defining runoff direction in drainage projects to allow f) the identification of the drainage network contributing to each structure. After the contribution basin was bounded, a study was carried out on land use and occupancy and a survey was made on the respective uses and their areas. For this purpose, software QuantunGis 2.1 was used, as well as files of map databases in shapefile format, provided by the City Council. The shapes used were: hydrography, public places, buildings, hypsometry, slope, urban roads and delimitation of water basins. The theme classes of surface ground cover, determined according to density and type of use and occupancy of the soil were: buildings, lots, and hydrography (lakes, rivers, ponds and swamps) because this classification was meant to find the most impermeable area.

The contribution area for the trench was determined based on a planialtimetric survey in an area of approximately 800 meters, where drainage elements were registered, e.g. culverts, sewer grates, pipes, channels, and the distinction of pervious and impervious areas. Topographic data were processed on AutoCAD and topoGRAPH software programs. The contribution area for the infiltration pit was determined by the program of the Municipality of Florianópolis called Corporate Geoprocessing, which is a GIS tool developed for Florianópolis and made available on the internet.

2.3 Characterization of the infiltration trench

The design of the infiltration trench is shown in Figure 2. The inlet of the trench is a pipe 60 cm in diameter, and the outlet is a 50 cm pipe for non infiltrated excess stormwater, with bottom and sides being made of natural soil with vegetation. Surface runoff that reaches the trench was previously evaluated on a precipitation event and the parameters analyzed were pH, COD, Phosphorus, Nitrate, Suspended Solids and TOC.

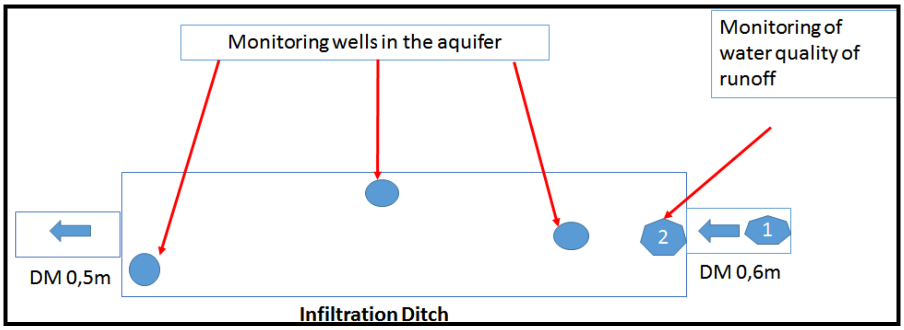

Figure 2-Schematic representation of the infiltration trench with sampling points.

2.4 Challenges to the implementation of monitoring in the drainage structure

After monitoring was implemented in this drainage structure, data were collected on all the elements required for conducting the study and facing the challenges of the process. These elements were associated with the management system of urban drainage and began to compose a matrix of the relationship between management and monitoring associated with current practices in the management of urban drainage in the city.

3. RESULTS AND DISCUSSION

3.1 Choices of monitoring structures

Hydrographic hypsometric maps were obtained from the cartographic databases provided by the City Council and processed on Autocad, so as to obtain the result shown in Figure 3. The resulting map of all the work of compiling drainage projects of the case study area is shown in Figure 4. This map, which took 6 months' work by 3 people, would have been an unnecessary step if network registration had been previously implemented as a policy in the drainage management system. It is noteworthy that the area of Campeche, which is the subject of this case study, accounts for 8% of the urban area of the city of Florianópolis. The collection and compilation of information from the existing drainage network would have taken much longer if had been extended to the whole urban area. It is also relevant to consider that the work done was relative to compiling the project; the entire check and actual data collection for the network built was not yet performed. This check was made only for the network which leads to the structures selected for monitoring.

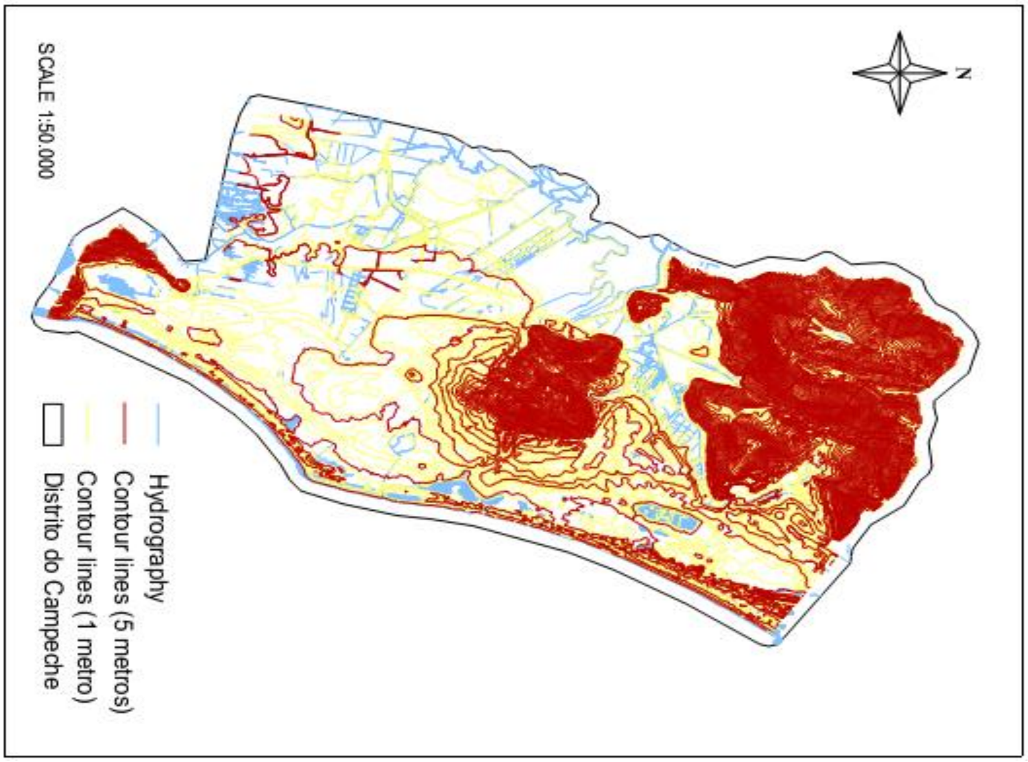

Figure 3- Hydrographic and Hypsometric Map

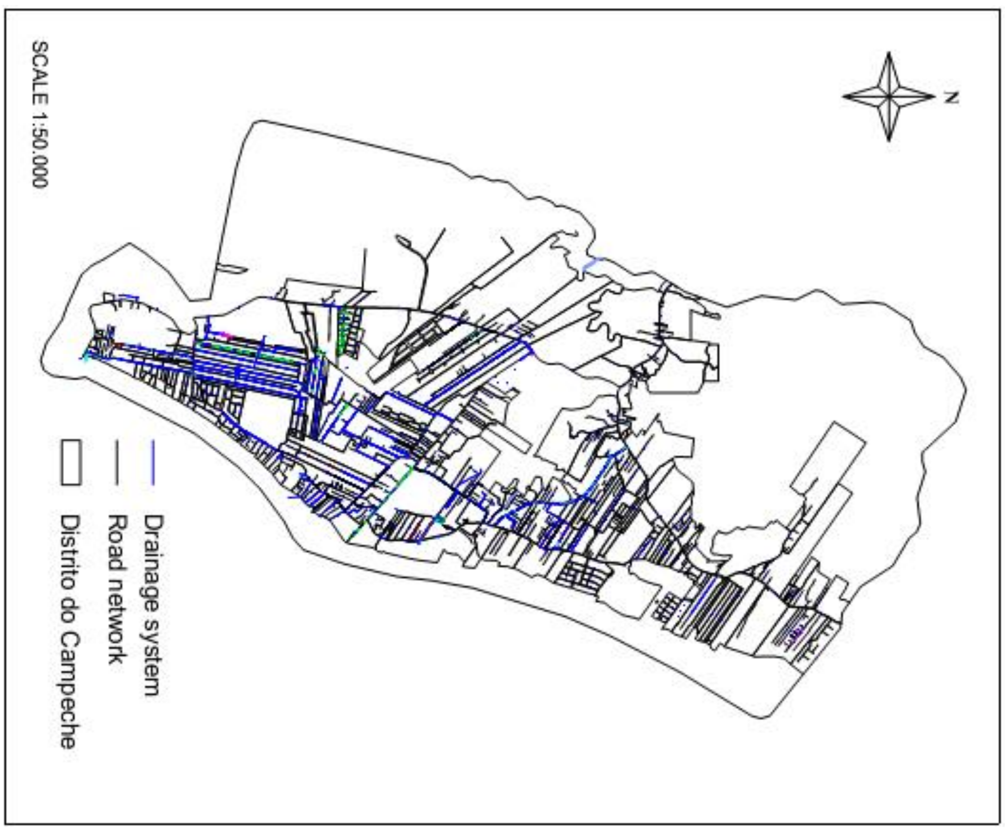

Figure 4-Drainage System and Road Network

Figure 5 shows the map for land use and occupancy. Based on this map, it was possible to identify that the contribution area for each of the selected structures is mainly composed of commercial and residential areas. The trench is located on avenue “Avenida Pequeno Príncipe”, which is the route of greater traffic flow and greater concentration of trade with restaurants, stores, markets and gas stations. The contribution area for the infiltration pit is a street parallel to “Avenida Pequeno Príncipe”, where residential areas are prevalent. On the map of land use and occupancy, the regions of flooding, wetlands and lagoons were taken into account, because such regions are more often subject to occupancy. These regions are part of the natural drainage of the basin, and they are affected by increased urbanization in the region, which ultimately waterproofs the basin and interferes in the urban water cycle, as well as overloads the microdrainage the region.

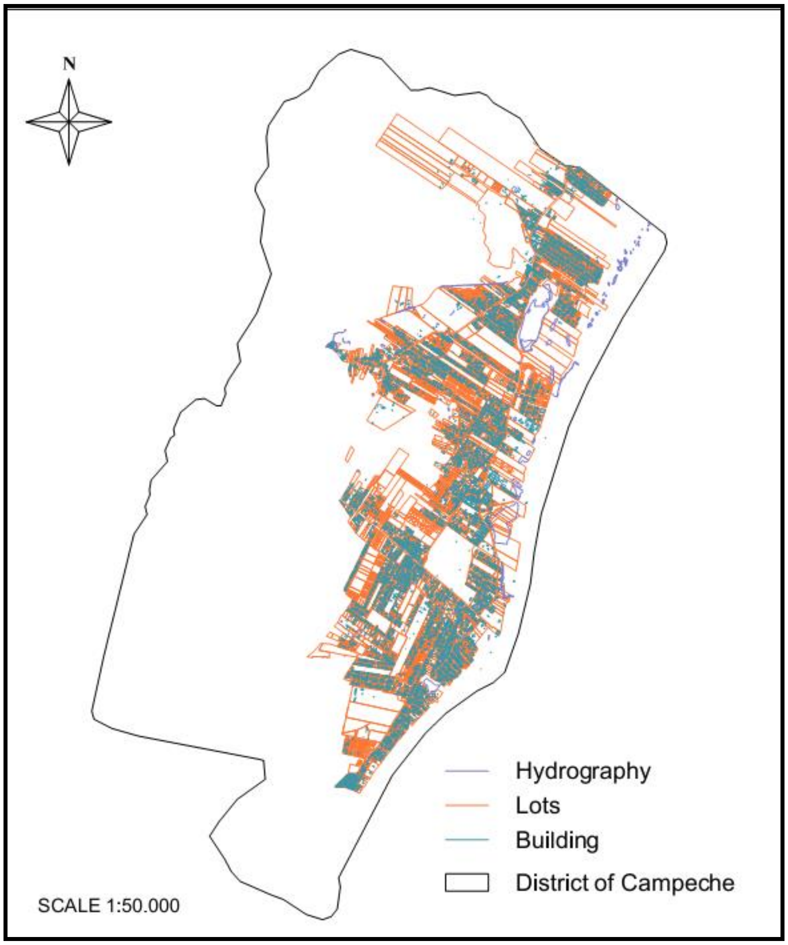

Figura 5-Map and land use and occupancy

Figure 6 shows the delimitation of the contribution area of the selected structures. Contribution areas total 8,390.00 m² of contribution to the infiltration trench and 16669.14 m² for the infiltration pit.

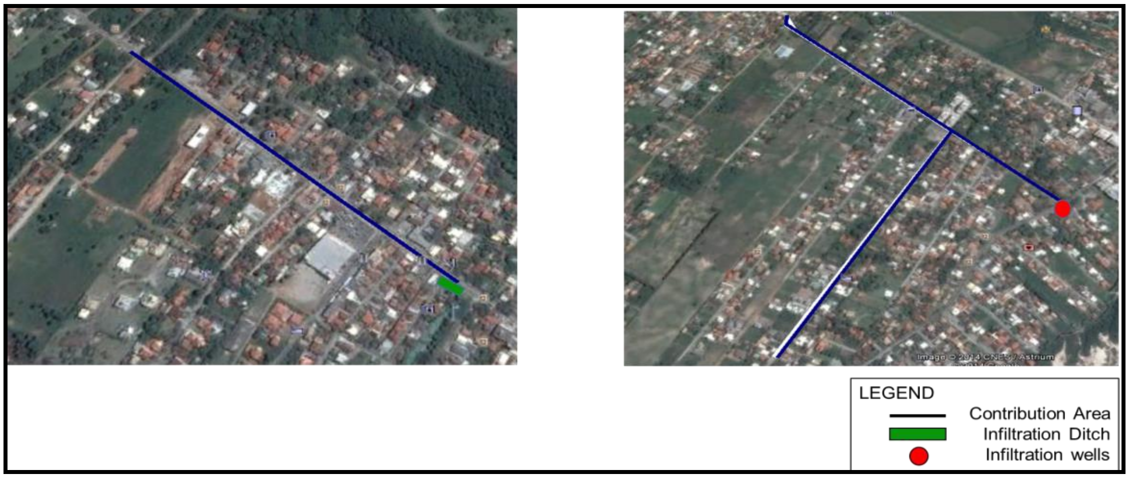

Figure 6-Contribution Area

3.2 Characterization of structures

While selecting the structures, the greatest difficulty was found in the design of the network because the projects undertaken by the City Council were not articulated and had not been scanned. In addition, human action has dramatically altered the courses of the rivers with plumbing and coverings that hindered the morphological characterization of the basin by the analysis of satellite images and maps provided by the City Council. Several stretches had to be confirmed in the field. For example, when selecting the trench, the third most relevant trench was chosen, because fieldwork showed that the first two selected trenches had been channeled and covered without the awareness of the government.

The selected infiltration trench is parallel to the main avenue of the district of Campeche (Figure 7). It is currently deteriorating, and the accumulation of solid waste and organic matter in the bed, directly on the soil, may be intensifying the discharge of contaminants into the Campeche aquifer. In the region where the trench was implemented, the unsaturated zone is less than 1 m thick, posing a great risk to the use of this type of structure for control of the urban drainage.

Figure 7 - Infiltration trench

The selection of drain sinks was more difficult because a large number of sinks contained in the projects registered in the City Council had failed to comply with the standards. In certain locations, while the project had drain sinks in the field, pass-through boxes were built instead. The drain sink adopted by the city is similar to an infiltration pit. The system consists of three different configurations, all of which were made of bricks and mortar, the only difference being the infiltration system, which was built with a gravel pit and geotextile blanket, or PVC pipes and geotextile blanket. The structure to be analyzed will be selected for sampling and analyses in accordance with the availability of the City Council and access to the bottom of the structure. The first drain sink was basically formed by concrete pipes whose diameters were specified in the project. They were ungrouted, and were wrapped in geotextile blanket with gravel placed at the bottom of the structure, as shown in Figure 8. In the second configuration, the bottom of the structure was made of concrete but there was an infiltration system with PVC tubes which promote infiltration. In the third configuration, there are systems that promote infiltration and storage of stormwater.

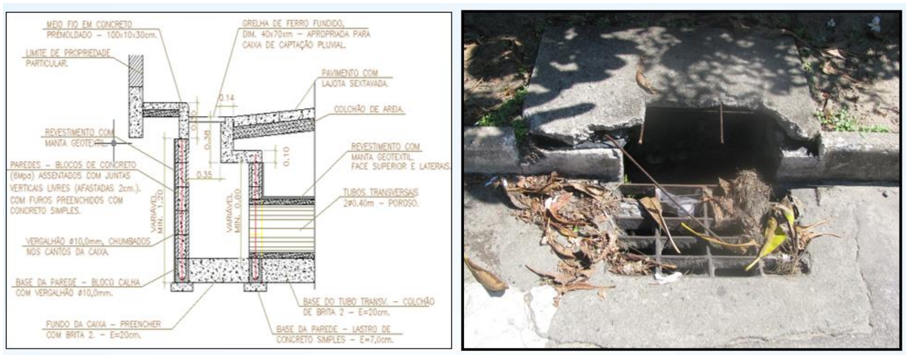

Figure 8 - Infiltration Wells

3.3 Qualitative characterization of surface runoff

Diffuse pollution is diversified and depends on factors such as land use and occupancy, population density, seasons of the year, topography, geology and the intensity and frequency of rainfall. Soil contamination by metals stems mainly from the disposal of household and industrial waste, atmospheric deposition from emissions of automobiles and industries, and also agricultural practices, e.g. the increasingly intensive use of fertilizers, liming and pesticides (NASCENTE 2006).

Urban runoff contains a variety of particles of different sizes, textures, and compositions. These solids can be considered as carriers of important nutrients, metals and toxic elements into the urban environment. Table 1 shows the results of the surface runoff evaluation made by the inlet of the infiltration trench.This table also shows the relationship of the contaminants with the likely source and an association with the grain size of the sediments.

Table 1 - Qualitative characterization of surface runoff

Parameters	*Results*	*Source**	*Particle size***
pH	7.45	-	
COD (mg/l)	63	Animal waste, solid waste and wastewater	>500 µm
TOC (mg/l)	13		
Phosporous (mg/l)	3.8	Domestic and industrial waste, detergents, animal droppings, fertilizers and pesticides	>500 µm
Nitrate(mg/l)	0.35		63-250 um.
TSS (mg/l)	1487.5	Soil erosion, construction.	

*Source: * (MENEZES,2004), **(GASTALDINI,2011)

TOC and COD analyses were made for organic matter because inorganic substances and their interactions may affect the results of COD. According to Dechenes (2002), the average concentration of COD in surface runoff for different commercial areas was 61.53 mg/L; in the downstream pipe, the infiltration trench had a concentration of 63 mg/l. TOC values greater than 10 mg/l may be indicative of contamination by domestic sewage (PROSAB, 2009). TOC concentration was 13 mg/l and pH was 7.45; associated with the presence of nutrients and organic matter; they are indicative of underground sewage connections in the drainage network.

The values identified in this first sampling only were used to make a qualitative diagnosis of surface runoff and to analyze their degree of contamination. Or this purpose, the results were compared with the standards for effluent discharge determined by resolution CONAMA 357/2005, considering class 1 water bodies. The values found are within the standards for effluent discharge for COD (maximum concentration of 180 mg/l). The maximum value for nitrate is 10mg/l, and for phosphorus, 0.025 mg/l for intermediate environments, which is similar to the behavior of runoff in a pipe located in an area of low slope. The very high value of phosphorus was probably due to the fact that phosphorus is associated with sediments accumulated at the bottom of the pipe where the collection was made.

Conventional draining systems are usually not capable of controlling the solids contained in urban runoff. Coarse particles can be trapped in pipes and gutter, but most solids of stormwater are directly transported to water bodies or wastewater treatment plants. Bäckström (2001) examined the transportation and retention of contaminants in drainage trenches, and they showed that grassy trenches have the potential to capture a considerable amount of suspended solids. 79-98% of TSS removal was observed. It was found that sedimentation processes, rathern than filtration, regulate overall efficiency by trapping the particles. Particle capture efficiency was influenced by the state of vegetation, infiltration rate and length of the trench.

Thus, continued qualitative monitoring of surface runoff requires the trench to be cleaned, because the amount of organic matter due to sweeping and pruning, may have influenced the results mainly for the pH for the water from the runoff. Moreover, dredging the pipe downstream of the trench must be carried out so that the qualitative data can reflect the actual state of the runoff water without interference from materials and sediments accumulated over time.

3.4 Challenges in implementing monitoring of the drainage structure

Table 3 shows the array of challenges associated with monitoring and management of urban drainage for the city of Florianópolis.

Table 2 – Challenges to implementation of monitoring and their association with urban drainage management in Florianopolis.

Challenge	***Component of urban drainage monitoring***	***Component of urban drainage management***
Survey of microdrainage system	Basis for identifying contribution areas of drainage structures	Registration of nonexistent microdrainage systems Disarticulation of the data in the Secretariat of Public Works: Basic Design, Executive Project, budget and execution of the works.
Field recognition of structures	Executive project different from project executed in the field	Works performed by residents without supervision; Inconsistencies found in the projects registered at the Secretariat of Public Works resulting from lack of systematic return of the project "as built".

Urban Master plan	Zoning and land use and their association with the quality of drainage water	No standards for design and installation of structures. Implementation of drainage works without hydraulic design and regardless of hydrological data.
Plan for Urban Drainage	Should include the monitoring system of urban drainage	A plan was developed in 2002, but due to the amount of expropriations, it has not been implemented. In the Sanitation Plan in Florianópolis (PMISB, 2011) urban drainage has not been adequately considered; it was just addressed at the level of diagnosis macrodrainage.
Instrumentaton and monitoring of structures	Purchase and delivery of equipment. High costs. Time for supply of equipment.	

4. CONCLUSIONS

The main challenge faced for installation of a monitoring network for the region was the map database and the lack of articulation of the projects in the City Council, which would require the work of at least 10 people to register and collect information on all the drainage system for the area. Furthermore, there was a lack of supervision of works in the field, whose changes are not updated in the executive projects. No records "as built" are required; as a consequence, the datebase of drainage projects of the City Council is outdated.

The diagnostics identified the deficiencies in the natural drainage system, and in infiltration trench used, because one of the prerequisites of this system is a minimal distance of 1.2 m from the water table and, because the soil has silty-clayey sand, it is permeable and light, has low water holding capacity and low organic matter content, i.e. discharge of contaminants into the aquifer takes place rather than recharge. The infiltration pits are overloaded, as the contribution area is greater than the threshold supported by this kind of structure. In addition, the aquifer shallow; thus, flooding occurs in the lower parts of the region.

For the qualitative analysis, there are not resolutions and rules that define standards for discharge of stormwater effluents. Another important issue of the study was the high value of TOC, COD and phosphorus, which may be indicative of possible contamination of surface runoff as a result of illegal connections in wastewater pipes for stormwater drainage, because the main sources of organic matter and nutrients are animal waste, solid waste and wastewater. Furthermore, this lack of cleaning and maintenance of the network directly influences the accumulation of contaminants, which will be carried to the trench and infiltration pit, which may turn the trench into an system of injection of contaminants into the aquifer.

The implementation of monitoring in the infiltration trench and infiltration pit will allow to use of better methods for design and instrumentation of trenches as control structures of urban drainage. It will also show how they truly work, check their effectiveness in flow control and flood attenuation, and show how they behave as regards the risk of groundwater contamination. The communication established between the City Council and the Research Group is enabling the diagnostics of a number of problems that occur in the daily management of the municipal drain management, which were reported in this paper. The main one is the lack of municipal records for drainage, which makes it very difficult to manage the system. It can be certainty stated that this is a frequent situation in most municipalities in Brazil.

5. ACKNOWLEDGMENTS

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