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COMPENSATORY DRAINAGE SYSTEMS A LOCAL AND REGIONAL DRAINAGE SOLUTION WITH A SUSTAINABLE BIAS – CASE STUDY ON THE UFSCAR CAMPUS, SP

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ABSTRACT

The intense urbanization generated from the twentieth century and the emergence of large urban centers caused a considerable change in the use and occupation of the soil, which began to waterproof extensive areas, resulting in a significant increase in surface runoff. Among the problems arising from the growth of this runoff, we can mention floods, climate change, interference in the hydrological cycle and water balance. The objective of this work was to survey and organize several studies carried out and their methodologies in a watershed where eight compensatory drainage systems were installed over time. Among these systems are listed a retention basin, four infiltration wells, a grassy channel and two infiltration planes, and the landscape design and guidelines of these systems, all receiving water from building roofs. The study surveyed the characterization of the systems, the constructive design and the results obtained by the researchers and as a result it was estimated that at least about 20% of the volume of surface runoff generated in the basin did not reach the conventional drainage network. Another important aspect was to conclude that, in addition to the control of drainage in the basin, these structures can significantly reduce the costs of acquisition and implementation of shackles and galleries of the urban rainwater network.

Keywords: Compensatory drainage, Construction design, Infiltration wells, Lawn channel, Infiltration plans.

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INTRODUCTION

Stormwater management planning is a sustainable water resources management strategy that identifies and develops solutions to problems that can be managed more effectively than orthodox drainage projects, both on a local scale and on a regional basis. The product of this planning process, such as a sustainable regional stormwater management plan, covers the boundaries of individual properties, neighborhoods, municipalities and even intermunicipal borders (Peruci *et al.*, 2024). A sustainability plan in rainwater management can present several engineering and water security solutions, as well as attenuating the emission of rainwater in large quantities in rainwater galleries, proving to be an effective solution in the occurrences of localized flooding; in water quality solutions from surface runoff generated in watersheds with excess pollutant load; in the solutions of the volumes and quality of water that can be generated by the development and future urbanization of cities.

It should be borne in mind that rainwater management, with a bias in regional planning, should start from the combination of regulations and actions tailored to the specific needs of a given drainage area without, however, reducing the protection of the environment and the quality of life in cities. Instead, regulations, legal frameworks, organic laws, etc., should be allowed to give more flexibility to combine urban, environmental, social and economic conditions, characteristics of regions that are interconnected by a common drainage area (Assis *et al.*, 2024).

Directly participating, one among many other agents, the Government must aim to maximize the efficiency of the services, equipment and urban infrastructures that are applicable to it, seeking to provide the best service at the lowest price and with maximum efficiency. The objective of urban planning is, without a doubt, to contribute to the improvement and social transformation of the urban environment. The role of cities as a means of social reproduction and the use of urban management as an instrument of social engineering are intimately linked to the notions of the right to the city and refers to urban inclusion as a form of social inclusion (Lefebvre, 1972). From this perspective, urban planning must be understood in all its interrelations and must seek conditions to improve the quality of urban and social life. Part of this social demand, in addition to the others, is the control of floods and rainwater, which are currently listed in the master plans of the cities. These master plans gained strength with Federal Law No. 10,257 of 2001, called the

Statute of Cities[4]. This law is based, in the environmental sphere, on the definition of special areas and on an impact assessment system, which is still undefined (TUCCI, 2001). Above all, the institutional structure is the basis of the management of urban water resources and its control policy. The institutional definition depends on the spaces of attribution of the organization of the country, its interrelationship both legal and management in relation to water, land use and the environment (Tucci, 2001: 454p).

In the State of São Paulo – SP, Law No. 12,526[5], of January 2, 2007, establishes rules for flood containment and rainwater disposal, which regulates the mandatory implementation of systems for the capture and retention of rainwater, collected by roofs, roofs, terraces and uncovered pavements, in lots, built or not, that have a waterproofed area greater than 500 m², with the following objectives, among others, *(i)* to reduce the speed of rainwater runoff to the watersheds in urban areas with a high soil waterproofing coefficient and difficult drainage; *(ii)* control the occurrence of floods, cushion and minimize the problems of flood flows and, consequently, the extent of damage; *(iii)* contribute to the reduction of consumption and adequate use of treated drinking water and also provides guidance on how to control the outflow of water after precipitation events, such as infiltrating the soil, preferably, or being dumped into the public drainage network, after one hour of rain, with the possibility of this water being used for non-potable purposes, if the buildings have a reservoir for this purpose.

In São Carlos, although incipient and only applicable to new urban subdivisions, Municipal Law No. 13,246[6] of November 27, 2003, provides for the implementation of a program for the construction of water retention or detention reservoirs in housing complexes, commercial and industrial areas, subdivisions or subdivisions in urban areas and was approved for potential control of recurrent floods and floods in the city. Basically, the law relates the total area to the volume of water that the lot or enterprise must retain in units of volume of meteorological precipitation, as well as presents some instruments for controlling peak flow at the source and on the characteristics of the retention equipment, such as the use of roofs and roofs for retention, or the possibility of building organic and landscape forms with these structures.

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[4] http://www.planalto.gov.br/ccivil_03/leis/LEIS_2001/L10257.htm
[5] www.al.sp.gov.br/norma/?id=6947
[6] https://leismunicipais.com.br/sp/sao.carlos/lei-13246-2003-sao-carlos-sp.pdf

In Brazil, however, there is little experience with the use of low-impact development drainage solutions, particularly in the case of infiltrating systems, especially in the context of research work (Souza and Goldenfum, 2004; Tavanti and Barbassa, 2012). According to Canholi (2005), the Metropolitan Region of São Paulo (MRSP) has become an international reference in recent years, through actions of the city hall, due to the use of innovative urban drainage techniques and the implementation of about 33 detention basins, until 2003. The first retention reservoirs, still functional today, were implemented in the mid-50s, in Belo Horizonte at the Santa Lúcia dam and Lagoa da Pampulha (Baptista et al., 2011). However, some Federal Universities throughout Brazil have come together to produce, disseminate and share experiences in research focused on this new vision of drainage and have significantly boosted scientific productions on the theme of sustainable drainage in recent years. Among these universities, the Federal University of São Carlos – UFSCar, is one of them and that, ambitiously, used the new expansion area of the Campus to install several of these sustainable drainage structures as a way to objectively research: the constructive optimizations and hydrodynamic processes of each structure and their combinations; landscape conceptions, ecologically and hygienically balanced (vector proliferation studies), comfortable and visually organic; its hydraulic and hydrological effects such as studies of flood waves, formation of discharge peaks, phreatic recharge, water storage in the soil, etc.; and, environmental effects such as the removal of pollutants and suspended solids.

Thus, this work is a form of representation and dissemination of a medium and long-term project idealized by the Hydrological Studies Group (G-Hidro) in the expansion area of UFSCar, with special attention to those who created, maintain and develop ways and conditions for the entire team to investigate the idealization of innovative engineering and, as science indicates, futuristic and undeniable the good municipal and regional management of urban drainage, with respect to the hydrographic basin management unit. To this end, the low-impact drainage structures that are inexorable constructions of good practices of sustainable rainwater management in operation on the Campus were documented in detail in the area in the process of urban consolidation of UFSCar; its main processes and its project conceptions; the methods used in the studies and research carried out in each of the structures and their objectives; and, finally, the results of each of these surveys carried out by the G-Hidro team.

PURPOSE OF ALTERNATIVE TECHNIQUES IN URBAN DRAINAGE

Urban flooding, which results from direct surface runoff (ESD) of excess rainfall, is a recurring problem in several Brazilian municipalities. The hygienist concept of rapid evacuation of effluents generated in cities was the main precursor of these problems and predominated worldwide until the twentieth century, but with territorial expansion without legislation and supervision that would guarantee adequate discipline of land use and occupation, the problems of flooding and flooding intensified and were distributed throughout urban centers (Righetto *et al*., 2009).

As a way to reduce the effects generated by runoff excesses, some diffuse detention and retention techniques can be employed in the watershed. Such compensatory techniques, also known as alternative drainage systems, can be applied throughout a region, as well as at the level of the lot itself or allotments. This alternative system aims to reduce the amount of water in galleries and rivers during the peak of rainfall by infiltrating water into the soil, decreasing the speed of runoff and increasing the evapotranspiration rate, enabling the protection of water quality and the implementation of environmentally pleasant landscapes. These technologies are also considered alternatives because they consider the impacts of urbanization in a global way, taking the watershed as a reference. In other words, compensation occurs by controlling excess precipitation, in order to avoid its rapid transfer to downstream areas (Baptista et al., 2011).

In this context, around the 70s, the concept of alternative urban drainage technologies was born to replace the hygienist concept, seeking to establish alternatives to the concept of rapid evacuation, recognizing rainwater as also a sanitation problem and a growing pressure developed for it to be collected and even treated, for this, it was necessary to retain and dampen runoffs, such as permeable pavements, surfaces, pits, planes, trenches and infiltration ditches, reservoirs and detention lakes. This new conception had greater momentum from the 80s to the present day (SILVEIRA, 2002). According to Righetto *et al*. (2009), the concept of sustainable development has been used as a basis in the environmental policies of some developed countries and the demand for this concept has had a relevant impact on the design of drainage systems in recent years.

Alternative solutions to deal with urban water management are beginning to be proposed, seeking to promote the delay of runoffs, increasing the concentration time and, consequently, reducing the peak of floods, in order to avoid the disturbances caused by floods. These solutions provide for the reduction of surface runoff volumes by containing them at the precipitation site using methods that are based on increasing infiltration areas or temporary storage in reservoirs (Canholi, 2005). Another concern that arose concomitantly is related to the quality of this surplus runoff, which, in general, according to Tucci (2005), the amount of material suspended in the rainwater drainage is much higher than that found in the raw sewage. According to Tomaz (2009) it is very difficult to estimate the value of total suspended solids present in rainwater, as it can vary from 114 mg/L to approximately 4000 mg/L depending on the local situation.

According to Urbonas and Stahre (1993), many studies show that the concentration of pollutants is higher at the beginning of the runoff process, depending on the intensity and duration of the rainfall, and diffuse pollution of rainwater origin begins with the dragging of air pollutants by rain and ends through surface runoff, which is directly responsible for the transport of pollutants placed on the surface of urban areas until they are released into the receiving body. Therefore, the direct relationship between diffuse pollution and the hydrological cycle is clearly noticed. For Schueler (1987), the first 25 mm of surface runoff carries most of the pollutant load of rainwater origin.

According to Tucci (2012), it is the first fifteen minutes of rain that represent the greatest source of pollution, while Tomaz (2011) considers that it is the first 10 minutes of rain. Luca and Vasquez (2000) *apud* by Reis et al., (2008) analyzed the physicochemical patterns of rainwater in the metropolitan region of Porto Alegre and found high levels of ammonia, phosphate, chromium and mercury. When analyzing samples of rainwater precipitated on the roof of a block of the Polytechnic School of the University of São Paulo, May (2004) found total coliforms in 89% of the samples and fecal coliforms in 50% of the samples, indicating a high degree of bacteriological contamination. The quality of rainwater depends on several factors such as the frequency of urban cleaning, the intensity of precipitation and its spatial and temporal distribution, and the use and occupation of the urban area (Tucci, 2001). The identification of polluting agents, their origin and impacts, as well as their removal are essential to avoid harmful effects on water quality, such as, for example, the contamination of the water table and the eutrophication of water bodies.

According to Moruzzi *et al*. (2016), these new alternative techniques in urban drainage, also known as compensatory drainage measures, maintain the concept of neutralizing the effects of the urbanization process on hydrological processes using techniques that treat rainwater runoff at the place where it is generated, calling it control at the source of rainwater drainage, in which it aims at reduction through storage processes, detention, retention and infiltration of rainwater runoff.

Around the 90s, a new approach to sustainable drainage management emerged, known as Low Impact Development (LID), in which it seeks to make the *layout* of structures compatible , meeting the landscape and satisfying aesthetic requirements as a characteristic of urban waters. For this to occur, it is necessary to maintain the effectiveness in the treatment of rainwater and the non-compromise of the hydrodynamic behavior of the system (Persson *et al*., 1999). For this reason, urban water management must be associated with city planning and its dynamism. It is necessary to adopt multidisciplinary solutions, in which all aspects related to infrastructure and urban planning works are analyzed in an integrated manner (Canholi, 2005). The design of the urban fabric and its expansion, the zoning of activities, the road and transport network, landscape aspects, among others, must be considered in order to obtain economic, aesthetic and ecological benefits (Pompêo, 2000).

AREA OF STUDIES AND COMPENSATORY DRAINAGE SYSTEMS

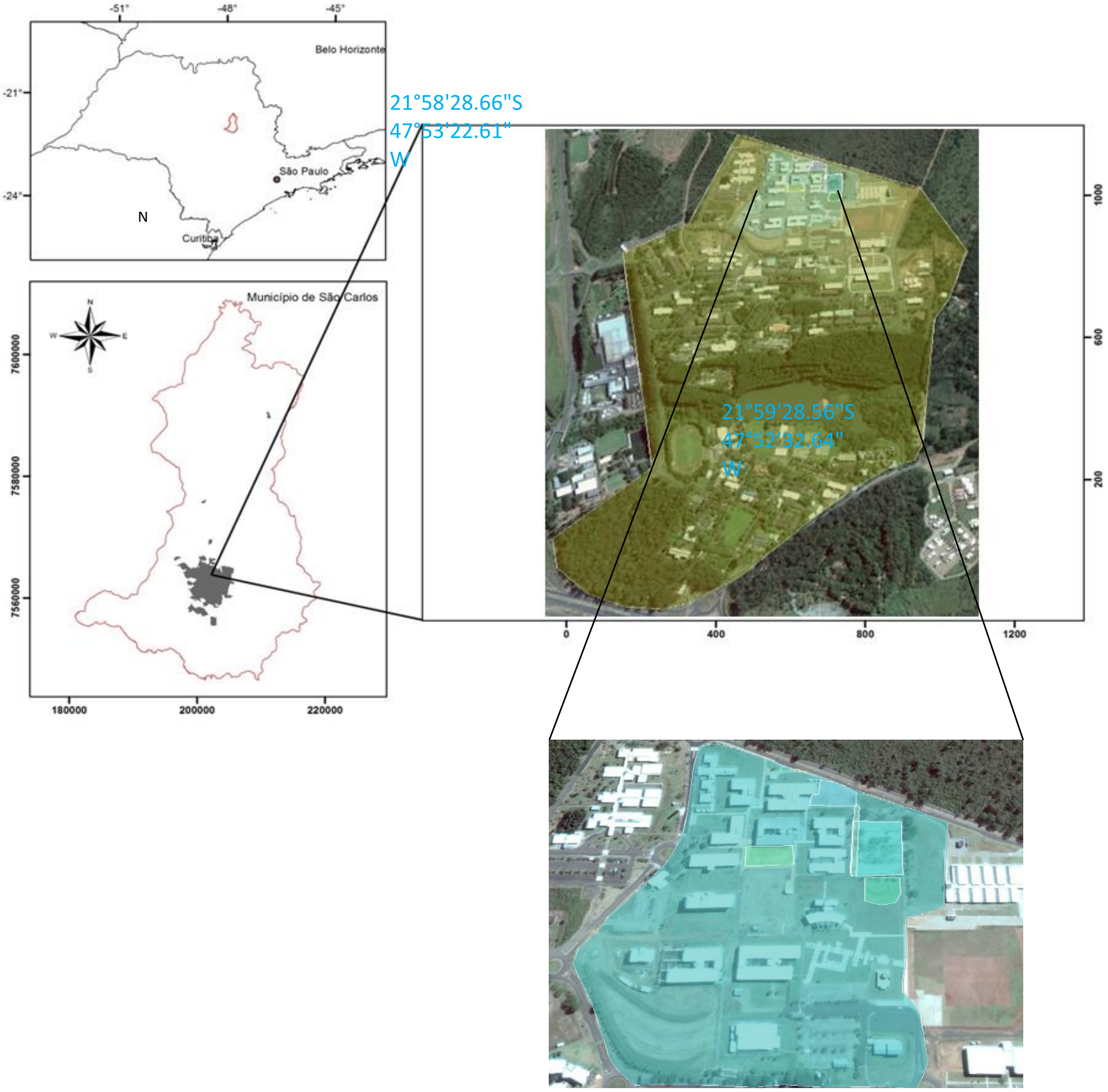
The investigated systems were built on a real scale on the campus of the Federal University of São Carlos, in the city of São Carlos (UFSCar) – SP, which is in the expansion area of UFSCar and all within the same hydrographic basin. The first system implemented was the combined system called Filter-Ditch-Trench (FVT), built in 2010, which collects precipitated water on the roof of the Medicine Building I on the Campus, which is formed by a retention basin, a grassy filter and an infiltration trench. This system works to this day and has a robust engineering characteristic since it was the first system to be implemented and researched. In it, several surveys of rainwater quality were carried out, and are still being carried out, which determined the hydrodynamic characteristics and the constructive design by Lucas (2011a), the removal of pollutants and particulates by Gutierrez (2011), the volume of surface runoff and the volume capable of recharging the water table by Sirio (2014) and the retention of water in the soil of the area below the FVT system by Sirio et al., (2020).

The second drainage equipment installed was the Infiltration Well I, implemented in 2010. In this system, rainwater was collected from half of the roof of the Campus Teacher Training Building. This well was studied by Sobrinha (2012) using the PULS method to evaluate the hydrodynamic behavior in the well. The third drainage equipment installed was the Infiltration Plan I, which collects water from the roof and an extensive area around the Campus Physiotherapy Building. This system was studied by Tecedor (2013) in the evaluation of the cost of implementation and also of the hydrodynamic context. This infiltration plan has as its outlet the fourth system installed, which was the Gramado Canal, implemented in the experimental microbasin, located in the north zone of the university, with the purpose of managing rainwater from the buildings of the Department of Medicine II and Gerontology and was researched by Shinzato (2015) and Felipe (2014) and takes part of the volume of water generated by these buildings to the Infiltration Plan II, which was the fifth system installed. In the grassy channel, the removal of particulates from a rainfall simulator with a known concentration of suspended solids was investigated.

In the fifth system, the second infiltration plane, which is the outlet of the grassy channel, landscaping work was carried out together with the landscaping of the second system (infiltration well) researched and by researcher Pereira (2016). The objective of this work was to create harmony between the systems and architectural designs of the buildings, thus generating an area that is pleasant to look at, functional from the hydrological, environmental and organic point of view of the buildings, giving greater environmental, social and visual comfort to those passers-by and people who use the space. The sixth system installed in the area were the Infiltration Wells II and III built near the Campus Biopolymer Laboratory, and have the purpose of receiving the water from this building. These two wells were studied and designed by Ferreira (2016) who researched their hydrodynamics in relation to the constructive differences of each of them.

The seventh and last compensatory drainage equipment installed was another infiltration well in the Teacher Training Building (Infiltration Well IV), whose objective is to collect the volume of rainwater generated in the other half of the building's roof. Figure 1 shows the urban area of the campus in yellow and the watershed of the expansion area of the UFSCar campus, São Carlos – SP, in blue.

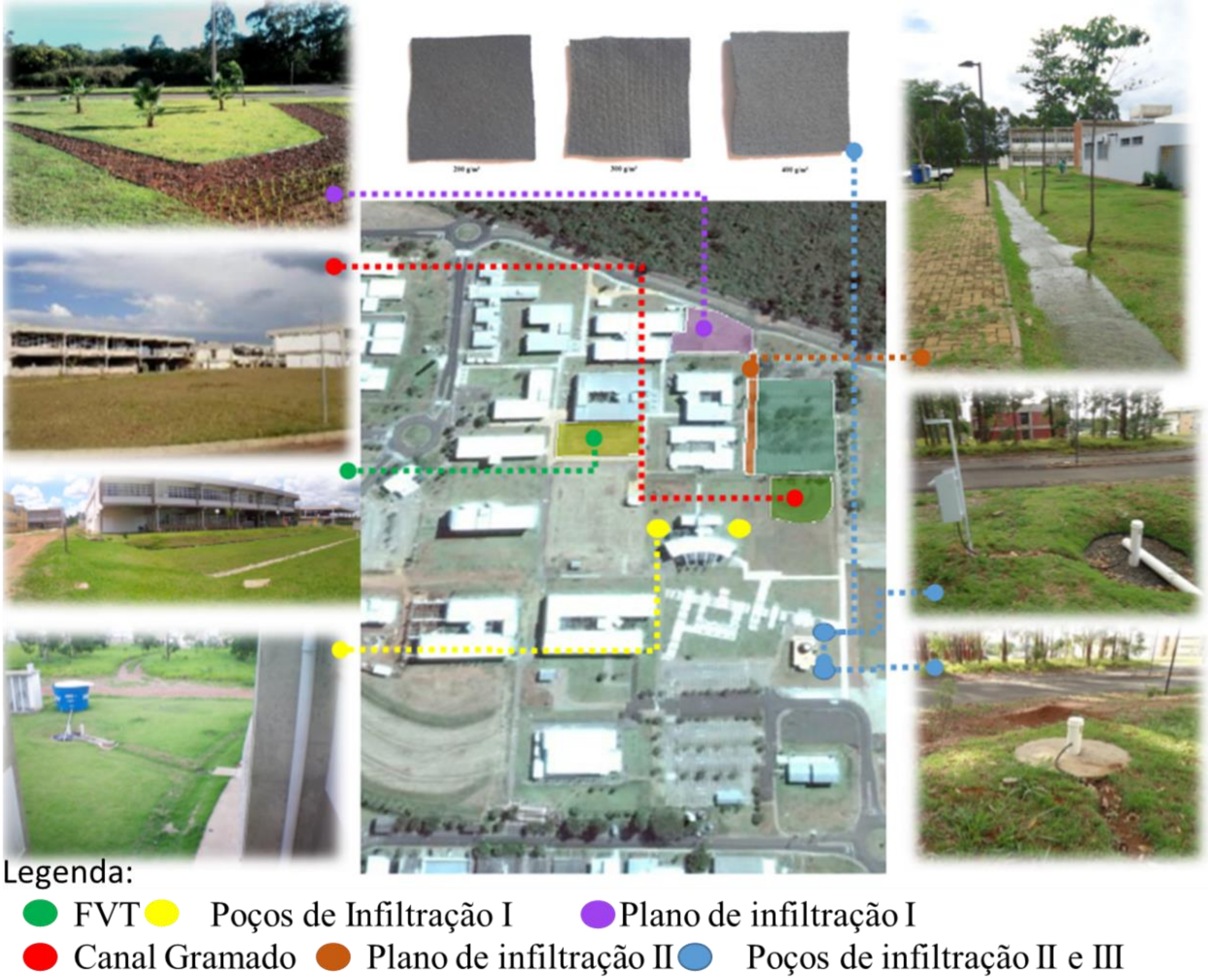
Figure 1 - Location of the UFSCar Campus in São Carlos, in the hydrographic basin where 8 compensatory drainage works are implemented



Fonte: Google Earth

Figure 2 shows the compensatory drainage systems, the buildings and their respective names.

Figure 2 – Compensatory drainage systems, the buildings and their respective names.



COMPENSATORY DRAINAGE SYSTEMS INSTALLED AT UFSCAR

THE INFILTRATION TRENCHES

Infiltration structures aim to minimize the effects of urbanization, soil sealing, increased direct surface runoff (ESD) and flooding, acting at the origin of ESD production. Infiltration trenches are linear devices that aim to capture, store and infiltrate a portion of the surface runoff generated in a given area, reducing the volume of rainwater that reaches the galleries and delaying the peaks of the flood hydrograph. This structure can function as a flood buffer reservoir, providing a reduction in volumes and maximum flows and reestablishing part of the infiltration that is lost with the urbanization of the hydrographic basin (SOUZA, 2002; GRACIOSA et al., 2008b; LUCAS, 2011; SIRIO, 2014). Trenches can be used in association with other systems, such as the filter-trench-trench (FVT) system studied and modeled by Lucas (2011) in relation to the implementation costs and the dimensioning of the construction project, by Gutierrez (2011) who studied the removal of pollutants in the system's lawn filter and by Sírio (2014) who evaluated the groundwater recharge of the aquifer by the rainwater collected.

The objective of Lucas' (2001) work was to monitor and model the FVT system, built on the UFSCar campus in full scale to retain the ESD produced by impermeable areas. In addition, the construction design of the FVT system showed that the system was built in soil characterized as medium clayey sand, with infiltration capacity between 2.30x10-5m$^{/s \text{ and}}$ 6.05x10-6m/s, obtained in field test with double ring and inverted well, respectively. The FVT system was monitored through measurements of precipitation, influent flow to the system, water level stored in the trench and infiltration ditch, and verification of the system's operation during the rains.

60 rain events with up to 48 years of return period were monitored, with no record of system overflow. Differences were observed between the design and operation of the system, such as catchment area, infiltration area and losses in the distribution diaphragm channel. The fines content of the filling gravel and filter sand and the permeability of the geotextile of the infiltration trench were compared, sampled after construction and after the one-year operation of the system. After the period of operation, the filling gravel and the filter sand showed an average reduction in the fines content of 29% and 58%, respectively. The geotextile showed partial clogging and reduction of its permeability on average by 45%. The infiltration system was modeled using PULS and the SWMM model. The modeling by the PULS method made it possible to represent the stages of operation of the FVT system and storage level in a satisfactory way. Graphically, the storage level curves are similar, with mean values of the Nash-Sutcliffe coefficient (NS) of 0.43, the maximum absolute error of 29% and the absolute error of the emptying times of 36%, obtained in the validation of the model.

The modeling using SWMM made it possible to simulate the watershed composed of the Department of Medicine Building and the FVT system in an unsatisfactory way and with limitations. The validation of the model resulted in mean absolute errors of peak influent flows to the system of 58%, influent volume of 35%, maximum storage level 72%, emptying time of 79%, mean NS of influent flows of 0.02 and mean NS storage levels of -0.79. Modeling using SWMM resulted in lower storage levels and shorter emptying times than those using PULS. The maintenance of the FVT system consisted of land cleaning services, removal of sediment from the measuring channel and gardening services. The cost of maintaining the system in its first year of operation was R$85.00/month or R$0.67

per unit of drained impermeable area, considered high in relation to the maintenance costs of conventional drainage systems.

Gutierrez (2011) researched the monitoring of the FVT system from the evaluation of the water quality of the direct building surface runoff before and after passing through the proposed infiltration system, parallel to the monitoring of rainwater quality, through analysis of physical-chemical and microbiological parameters established in legislation and in national and international experiences, compared to the conditions of the study area, and exploratory analysis of the data by two chemometric techniques: Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA). According to the author's analysis, the variation of the results obtained, especially the quality of atmospheric water and the quality of water from direct surface runoff, resulted in significantly lower concentrations of the parameters Turbidity, Color, ST, STD, Nitrate, Nitrite, Ammonium Nitrogen, Sulfate, Chloride, Cadmium, Copper, Lead and Zinc analyzed in the water samples directly from rainfall, compared with previous studies in the literature and current water resources standards and legislation. The filter-trench-trench infiltration system removed the following parameters analyzed, comparing them with the water from the direct building surface runoff in the channel: Zinc (90.89%), Copper (88.31%), Electrical Conductivity (31.40%), Ammonia Nitrogen (24.32%) and Chloride (5.88%). Regarding the PCA analyses, the characteristics between the samples were evidenced according to the sampling conditions (day, month, place and time) and variables analyzed, dividing them into groups of samples and contributing to the extraction and interpretation of information that would hardly be directly visualized in the data matrix. HCA analyses complemented PCA analyses.

In the work of Sírio (2014), the objective was to model and estimate the volume of water infiltrated in the FVT soil that is capable of contributing to groundwater recharge. The modeling was carried out through the method of storage and variation of storage in the soil using a tensiometer and digitally using the Hydrus 2D/3D software. The drainage system monitored and the digitally diagrammed consisted of a water retention basin, a ditch, or grassy filter and an infiltration trench.

In an attempt to estimate the water recharge, soil analyses, geophysical investigations, flow measurements, rainfall data collection, in addition to continuous monitoring of the system for 454 days through the installation of tensiometers on site, rain graphs, in addition to the construction of bimodal water retention curves in the soils through the filter paper method. From the identification of the matric potentials of the soil, the hydraulic conductivity under saturated conditions for the monitored depths and the obtaining of the characteristic curves of the soil, it was possible to calculate the moisture content at different depths, identify the zero flow plane and calculate the volumes in motion in the soil matrix. The results obtained by the verification of the Soil Water Retention Curves (CRAs) and field moisture were not very expressive from 80 cm depth, however, the estimated recharge obtained by the tensiometer method and the Hydrus digital model was around an average value of 45% of the total precipitated volume. Advanced studies that are still in progress demonstrate that the system's capacity to recharge the aquifer is enormous and represents a great solution for the reuse of the volume of rainwater collected by the buildings and surroundings of the FVT system.

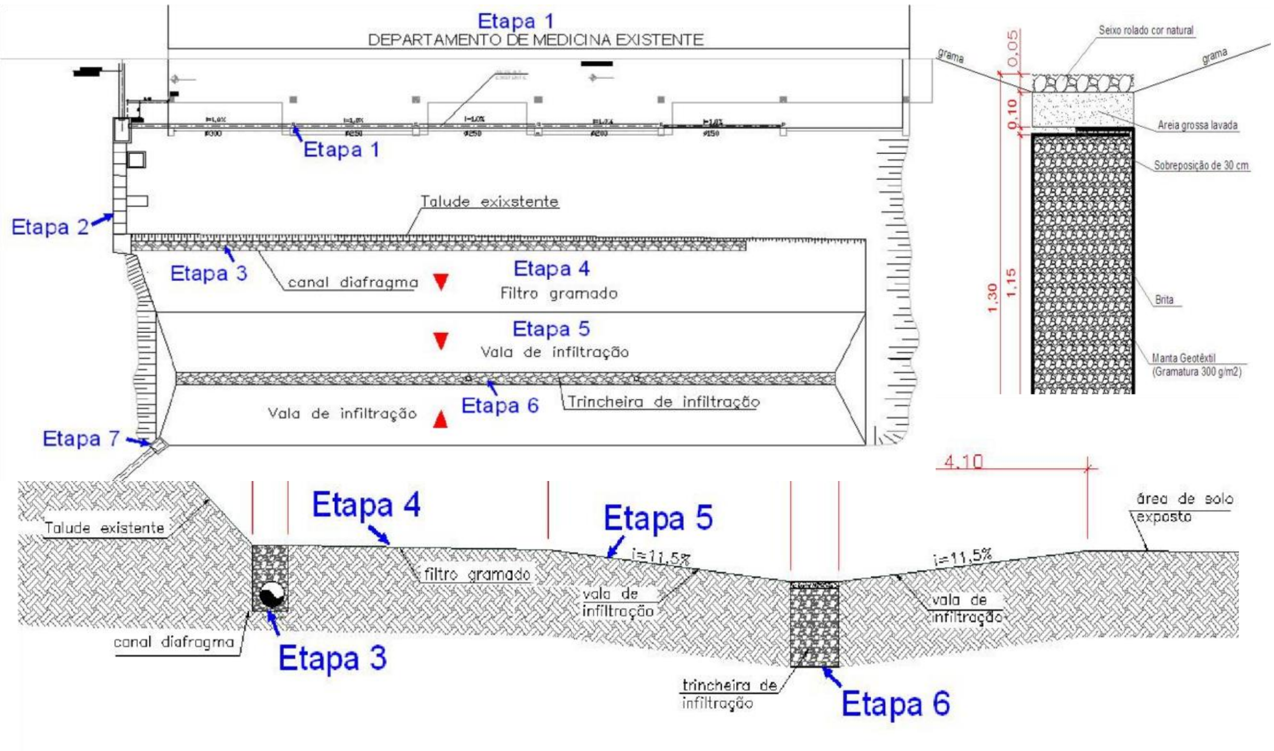
The construction project of the FVT system on the UFSCar Campus

The FVT system was designed to capture the runoff water generated by the roof and surroundings of the building, whose contribution areas correspond to 1701.3m² of building coverage and 2200m² of grassed area (GUTIERREZ, 2011). According to Gutierrez (2011), in the operation of the system, the water captured by the building roof can be detailed in 7 stages. In the first stage, the water from the precipitation is collected by the roof of the Department of Medicine building and directed to the building connections that take the volume captured to a 0.60m wide channel.

In the second stage, the level of influent water is measured inside the channel to calculate the flow and volumes captured. In the next step, the volume captured passes through a spillway and enters a junction box that directs the water to a water distributor of the lawn filter. This distributor consists of a 250mm perforated PVC pipe, covered by gravel and wrapped in plastic canvas. In the fourth stage, the runoff is directed and evenly distributed by a grassy filter. This filter has a 2% slope and considerably decreases the speed of the runoff, promoting greater water infiltration into the soil and also storage in the depressions of the soil. In the fifth stage, after the volume of water distributed passes through the filter, it will then be directed to the infiltration ditch, which has a slope close to 11.5%.

In the next stage, the water is directed and retained in the infiltration trench. In the last stage, in case of overflow and a volume of water exceeding the capacity of the system, the excess volume will be directed to a box built in the basin, at 1.75m high in relation to the bottom of the trench, to direct the overflow volume to the conventional rainwater drainage network (GUTIERREZ, 2011; LUCAS, 2011; SÍRIO, 2014). According to Lucas (2011) and Gutierrez (2011), the water table was not identified during the construction and implementation of the FVT system and flow measurement and sample collection equipment and they state that the level is deeper than 2.00m. In this area, permeability tests were carried out in the field (double ring and Guelph permeameter) and in the laboratory, in addition to compaction tests, joint granulometry, physical indices and mass of solids. Figure 3 is the basic conception of the FVT system project in floor plan, profile and detail of the trench construction.

Figure 3 – FVT construction project



INFILTRATION WELLS

Infiltration wells are point systems that reserve a certain volume at peak times and then infiltrate the accumulated water into the soil, acting to recharge the water table. These structures aim to reestablish or maintain the natural water balance of the pre-development period, through the infiltration of rainwater into the soil until it reduces its absorption capacity. A study conducted in 2005 analyzed the impact of groundwater recharge performed by 3,763 infiltration wells installed in the city of Chandler, Arizona, USA.

It was found that in the pre-development situation the recharge was 2x105 m³ of water per year. The recharge in the post-development situation through the infiltration wells was estimated to be approximately ten times higher, with an average of 3x106 m³ of water per year, considering the rainy and dry seasons (Graf, 2015). There are also infiltration wells built with recycled materials, making their use more viable and sustainable, since it reuses civil construction waste, tires, among others (Carvalho and Lelis, 2010).

Reis *et al.* (2008) point out that one of the advantages of infiltration wells is that they can be installed where the surface layer is poorly permeable but has adequate infiltration in the deeper layers and that these infiltration wells are integrated into urban solutions since they occupy little space and may go unnoticed if this is a choice of the designer (Suderhsa, 2002; Silveira 2002; Souza 2002). Infiltration wells are appropriate devices for a distributed control of rainfall excesses, allowing significant savings in the construction of conventional rainwater networks. A possible disadvantage is the relatively small volume of storage of the wells, but this can be overcome by associating them with other compensatory measures (Silveira, 2002).

The work of Sobrinha (2012) carried out an experimental study of an infiltration well built on a full scale at the Campus of the Federal University of São Carlos – SP with the objective of evaluating its performance as a compensatory structure for urban drainage in the control of surface runoff and in the removal of suspended material. The soil was characterized as Medium Clayey Sand – SC, with infiltration capacity between 93.38 mm/h and 19.24 mm/h, values obtained in field tests by the inverted well and double-ring methods, respectively. The Envelope Curve method was used in the design and the safety recommendations for the project were intentionally not followed. With the help of electronic equipment and precipitation measurements, 22 real rainfall events and simulated rainfall were monitored during 11 months of operation of the well. In this period there was no record of overflow from the well, representing an efficiency of 100% in reducing the volume flowed. After eight months of its operation, tests were carried out on the permeability of the geotextile, the content of powdery materials of the aggregates to the well, that is, the gravel and sand that make up the filter of the cover, and the qualitative parameters: apparent color and turbidity. The geotextile showed an average permeability reduction of 50.7%, 7.7% and 21.2% in the samples of the bottom, walls and well cap, respectively. The sand from the lid filter retained 34.8% of fines, while the gravel retained 0.13% of fines in the same period. Regarding the removal of the apparent color and turbidity, it was found that the well is not characterized as a treatment unit for these parameters, this fact is probably due to the quality of the water on the roof, which represents the entry of water into the structure. For the modeling by the Puls method, the permeability of the saturated soil defined as non-optimized K (Kno) was calculated for each monitored event. The Kno was adjusted through nonlinear regression (optimized K - Ko), restricting the parameters based on the values obtained in the field tests, so that for each monitored event two modeling was obtained for the constant K values (Kno and Ko). The representativeness of the model was evaluated by means of the explanation coefficients that ranged from 0.68 to 0.98 for the events modeled with the Ko values, and from 0.02 to 0.76 for the Kno, with the Ko being more representative for the Puls modeling.

Ferreira *et al*. (2013) designed a well associated with an infiltration plan for rainwater drainage of a building at the Federal University of São Carlos, located in the municipality of São Carlos-SP. The results obtained were satisfactory in terms of disconnection of the rainwater network of conventional drainage, ensuring the hydrological and urban function of the project. Like any compensatory infiltration measure, wells do not allow large loads of sediments and pollutants (Silveira, 2002). If the flows from the impermeable areas are considered to be of high risk by the designer, the flows must be diverted or previously treated in special structures, such as decanters or filters, before being sent to the infiltration wells (Carvalho and Lelis, 2010; Silveira, 2002).

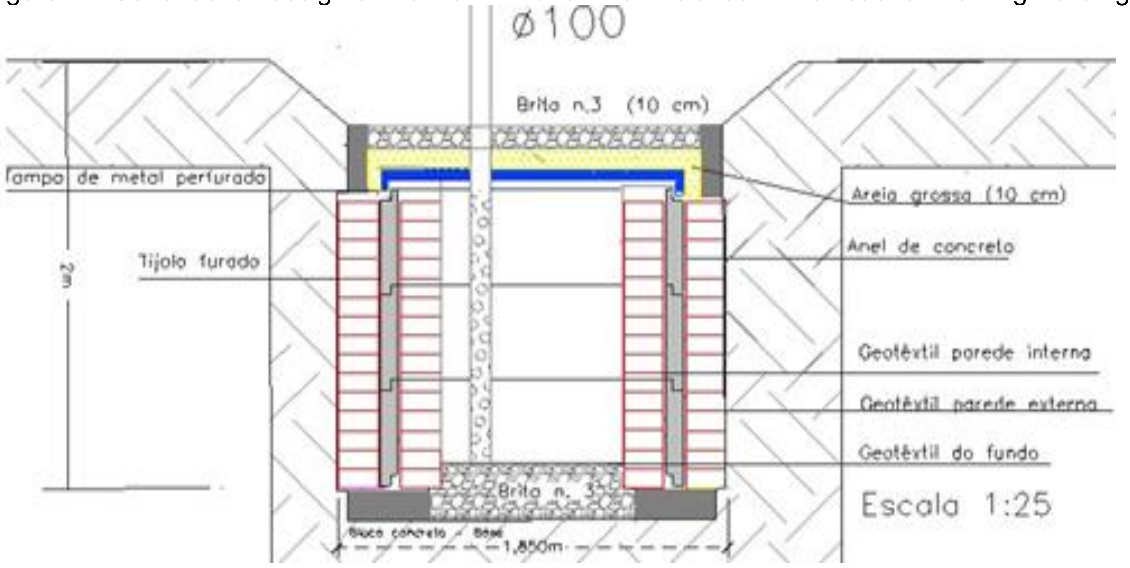
The construction design of the infiltration wells on the UFSCar Campus

The first infiltration well installed in the area was installed in the Teacher Training Building of the Campus and receives water from part of the roof of the Teacher Training Center. The well was built with perforated concrete rings and covered with geotextile blanket. The perforated PVC pipe serves as a support for the installation of the level meter that was placed inside the structure, and for the collection of water samples. The internal and external sides of the well were covered with perforated bricks and a geotextile blanket. Its base was secured with a concrete block, and at the bottom of the well a 20cm layer of gravel No. 3 was placed. The well inlet device contains: a metal cap, geotextile blanket, a 10cm layer of coarse sand and a surface layer of crushed stone No. 3. The concrete ring has an external diameter of 1.45 m, an internal diameter of 1.35 m and contains eight holes in the side wall of 50mm in diameter each.

The concrete rings were fitted together and placed in the pit mechanically in concrete blocks of dimensions 19x14x30 cm and serve to give stability to the ring since the soil was not compacted. Bricks were placed on the inner and outer walls of the concrete rings in order to ensure that the earth does not return into the well, and to better distribute the water, benefiting the infiltration through the walls of the well. One of the reasons that explain the need for internal and external brick layers is the need to increase the infiltration area of the well walls, as only the areas of the concrete ring holes could not benefit the infiltration of water through the walls. The selected brick is the perforated brick with dimensions of 19x9x19 cm and with eight holes of 3.3 cm in diameter.

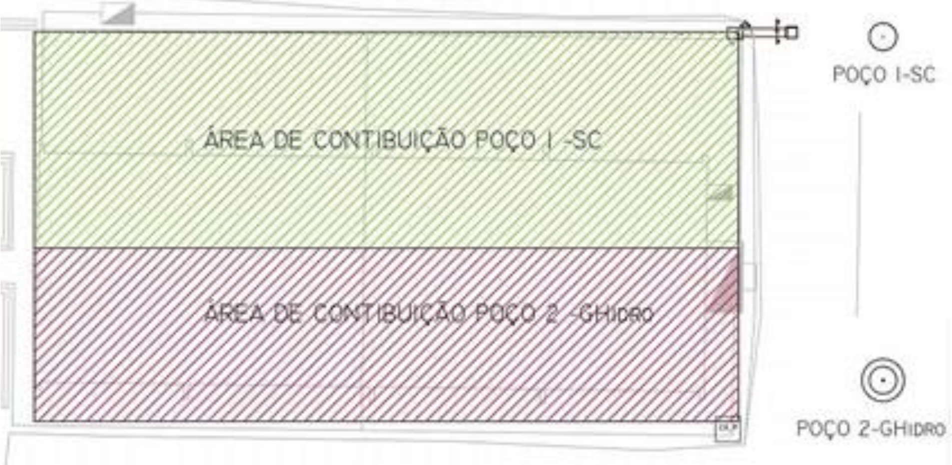
Figure 4 shows the construction project of the first infiltration well installed in the teacher training building.

Figure 4 – Construction design of the first infiltration well installed in the Teacher Training Building



In Infiltration Wells II and III built near the Campus Biopolymer Laboratory, whose order, seventh drainage structure installed on the Campus designed by Ferreira (2016), evaluated six physical parameters, which were topography, the existence of a permanent outlet, the saturated permeability of the soil, the level of groundwater, the permanent supply of water and the stability of the subsoil; three infrastructure and urban planning which are the availability of space, the existing networks and the slope and shape of the roof; and, three environmental parameters, namely the risk of pollution, the risk of fine waters and the sanitary risk. The sizing of the wells was done according to the Code of Works and Buildings of the municipality of São Carlos. The total contribution area of the building is 468.35 m². Infiltration Wells II receives a flow of 287.80 m² referring to the yard and half of the roof, and Infiltration Wells III receives the flow referring to the 180.55 m² of the remaining roof (Figure 5).

Figure 5 – Construction design of the first infiltration well installed in the Teacher Training Building



The dimensioning of the Infiltration Wells II in accordance with Municipal Law No. 15,958[7] of 2011 required a storage volume of 1.44 m³. As the wells were built with precast concrete rings, 4 rings were used. For comparison, the two wells were built with the same number of rings. The useful storage volume of Infiltration Wells III, however, is greater due to the space with gravel on the sides between the soil and the concrete rings and on the cover. Article 79 of this legislation states that the volume of the detention or retention reservoir must be calculated at the rate of 5 liters for each square meter of the land waterproofed.

INFILTRATION PLAN

An infiltration plan is commonly defined as lowered areas covered with side lawns that receive rainwater from impermeable surfaces (Tecedor, 2015). These plans reduce pollutants, necessitating the construction of sustainable urban drainage structures downstream of these plans (Moura, 2005). Baptista et al. (2011) define planes when their longitudinal dimensions are not much larger than the transverse ones and with reduced depth. This type of structure should be used on terrain with low slope, since in rough terrain the water gains speed and remains in contact with the ground for a short time, not allowing its adequate infiltration, the main characteristic of this device (Holz and Tassi, 2007).

Kobayashi et al. (2008) mention as positive points of this type of structure, the fact that it allows the infiltration of part of the water into the subsoil, delays direct surface runoff and is aesthetically pleasing. As negative aspects, the author mentions that planes with a

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[7] http://www.saocarlos.sp.gov.br/images/stories/legislacao_urbanistica_municipal/lei15958%20-%20Codigo%20de%20Obras.pdf

slope greater than 0.1% should not be used, because the transport of solid material to the infiltration area can reduce its infiltration capacity; the accumulation of water on the plane during the rainy season prevents traffic over the area; Grassy areas should be pruned periodically, including maintenance costs. There are few studies in the literature that refer to the infiltration planes, showing that these structures still need to be experimented with.

Tecedor (2014) aimed to design, build, monitor and model an infiltration plan, built on a full scale, for rainwater management of the building with an area of 3,001.3 m². The resources came from the MCT/FINEP Project/Transversal Action Environmental Sanitation and Housing 07/2009 – MAPLU2 – Urban Rainwater Management 2. To this end, the author carried out the characterization of the soil considering the physical indexes, granulometry, permeability, degree of compaction and soil profile. The survey of water infiltration in the soil was carried out with double ring tests. One of the objectives of the study was to verify whether the compensatory technique infiltration plan met six physical aspects, three urban and infrastructure aspects, two sanitary and environmental aspects and two socioeconomic aspects.

The method adopted for the design was the envelope curve, using a return period of 10 years. Through level measurement sensors and precipitation measurements, 32 real rainfall events were monitored. During this period, there was no overflow from the infiltration plan, representing, in these events, an efficiency of 100% in reducing the volume flowed. For the modeling of the ESD in the infiltration plane, the PULS method was used, however, the model was considered difficult to be applied due to the enormous amount of uncertainties in relation to the infiltration areas, perhaps due to the high capacity of initial infiltration of the soil and the fact that the water flows in preferential areas in the infiltration plane. Future research in the planning phase will be carried out to evaluate the soil water dynamics conditions of the infiltration plan and a possible refined hydrodynamic modeling of the hydrological processes at the site.

The constructive design of the infiltration plans on the UFSCar Campus

The device was designed to receive water from the galvanized sheet roof of the Physiotherapy department building, with an area of 1,747.54 m² and an expansion area between the building and the device, with 1,253.76 m², adding up to an area of 3,001.30 m². The rainfall method was used for the design of the compensatory technique (Baptista et al. 2011) with a return period of 10 years. To calculate the intensities of precipitation, in turn, the rainfall equation of the city of São Carlos, constructed by Barbassa (1991), was used. In addition, a double ring permeability test was carried out in which a hydraulic conductivity for saturated medium equal to 3.75x10-5m/s was adopted. In the implementation of the infiltration plane, tapes and piles were used to demarcate the points and the shape of the infiltration plane and its location; earthworks were made to remove with a 0.30 backhoem of soil to obtain the desired quotas in the project; then the soil was subsoiled to a depth of 0.50 m to try to recover the permeability of the soil; the project dimensions were met, after subsoiling, a measurement was made with a level device to verify that the project dimensions were still correct; and, finally, the vegetation cover with grass and the installation of a bottom exit were carried out. With the system allocated, new permeability field tests were then carried out that corresponded to the project, the instrumentation for monitoring was carried out, which included a channel with distributor and damping of the current lines, installation of the 120° spillway and level sensors (Tecedor, 2016).

Three rainfall simulation tests were also carried out at the site and also the monitoring of 32 rain events in which only seven of them were able to form hydraulic load in the infiltration plane. It was noticed that some parameters of the project conception were hindering the modeling both in the delay between the formation of the blade by the filling of the distributor infiltrating channel, and by the high rate of the initial infiltration capacity of the soil, which is dependent on soil moisture.

However, the research showed that the costs for the construction of the infiltration plan were R$8,500.29, resulting in R$76.34/m³. However, of this total amount, R$3,596.85 went to planting grass. Baptista *et. al*. (2011) evaluated the infiltration wells at an average implementation cost of R$256.26/m³. Regarding the trenches, the average cost of implementation is R$150.22/m³. Sobrinha (2012) evaluated the total cost of implementing an infiltration well in the city of São Carlos at a cost of R$4,157.93, and it can be inferred that the implementation of infiltration plans are much less costly than the techniques of infiltration wells and infiltration trenches also implemented on the Campus (Tecedor, 2016).

GRASSY CANALS

In this work, we sought to evaluate and mathematically model, by means of a phenomenological model, the removal of particulate matter in a grassy channel built on a real scale. To this end, different initial concentrations (Co) of particulate matter were investigated: 65; 131; 196; 262 and 327 mg/L, which were discharged by means of simulated rainfall in a channel of 100 m in length and slope of 2%. Particulate matter measurements were made by turbidity and total suspended solids (TSS) analysis at 26 positions along the length of the channel. The experimental data were adjusted to the model by means of nonlinear regression of the parameters (k) and (C*), which correspond to the kinetic decay constant and the minimum asymptotic value of the removal curve, respectively.

The removed fractions and the mathematical adjustment were evaluated and performed for each isolated event and also for the set of results. In average terms, the relative error modulus varied between 0.83% and 5.11%, with the highest average value obtained for the lowest concentration of particulate matter investigated (65 mg. L-1). Regarding the values obtained for the decay constants (kd), which represent the frequency of removal of particulate matter, it is verified that it tends to a minimum value for the highest initial concentrations of particulate matter (Co). This fact indicates that the higher the initial concentration of particulate matter (Co), the greater the length of the path required for its removal, with a maximum limit observed around 80 m, for concentrations above 196 mg. L-1.

The study developed by Shinzato (2015) analyzed the sediment removal behavior for a grassy channel built on a full scale, 100 m long, slope of 2% and base width of 0.7 m, located at the Federal University of São Carlos, São Carlos - SP. For this analysis, surface flows were simulated for three volumes of discharges: 5; 7; 10 m³, each represented with its respective hydrograph and blade height by the passage of the flood wave. These flows were mixed with the particulate matter produced from the local soil of the campus region, sieved to dimensions smaller than 75 μm, which was used to vary the initial concentration for the tests carried out.

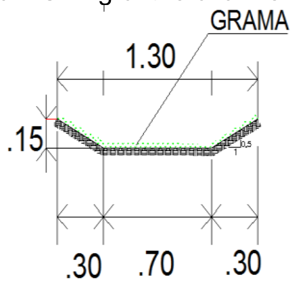
The experimental data were adjusted to a first-order decay model, in pistonated ideal flow by means of nonlinear regression, using the kinetic parameters of decay (kd) and equilibrium concentration (C*). The removed fractions and the mathematical adjustment were evaluated and performed for each isolated event, along the length of the grassy channel and monitored in 26 positions. The peak of the investigated hydrographs was of the order of 11±2L/s, and the base time (tB) determined at the point of discharge in the channel ranged from 15, 25 and 35 minutes. The transit time in the channel (tT) was around 10.5±2.5 minutes, corresponding to a speed of 0.14±0.02 m/s. The maximum efficiency of particulate matter removal along the length of the grassy channel ranged from 47 to 81% in positions of 20 to 90 m.

Considering all the concentrations investigated, it was found that for 15-minute tB, the average maximum efficiencies were around 64±3% for the 31±26 m position. For 25-minute tB, the average maximum was 73±3% for 59±24m positions. Finally, for 35-minute tB, the average maximum efficiencies obtained were 65±3% in the 73±15 m positions. tB/tT showed a correlation of 0.98 with the position of maximum efficiency. The maximum removal positions are related to the decay constant (kd). It was found that 70% of the values of the decay constant (kd) are between 0.005 and 0.015 $^{s-1}$, and when disregarding the hydrograph represented by 15-minute tB, 90% of the data are contained in the interval 0.005 ≤ kd ≤ 0.015 $^{s-1}$ and 85% in the interval 0.007 ≤ kd ≤ 0.012 $^{s-1}$. A direct and proportional relationship between equilibrium concentration (C*) and initial concentrations (Co) was identified.

The construction project of the grassy channel on the UFSCar Campus

The studied device is 100 m long and has a 2% slope. Rainwater from the roof of the Medicine II department building is drained by the rainwater installations and then conducted to the grassy canal. On the other hand, the precipitated water in the building of the Gerontology department is conducted through a secondary grassy channel, flowing into the main grassy channel, the object of the study. The values used for the design are shown in Table 1 and the cross-section of the channel is shown in Figure 6.

Figure 6 – Sizing of the channel in grass



SOURCE: G-HIDRO (2013)

Rational Method		Manning's formula	
Runoff coefficient (C)	0,80	Roughness coefficient	0,033
Rainfall intensity (I)	46 mm/h	Inclination	2%
Catchment Area (A)	1,501.48m^2		
Calculated flow rate = 0.68 m3/s			

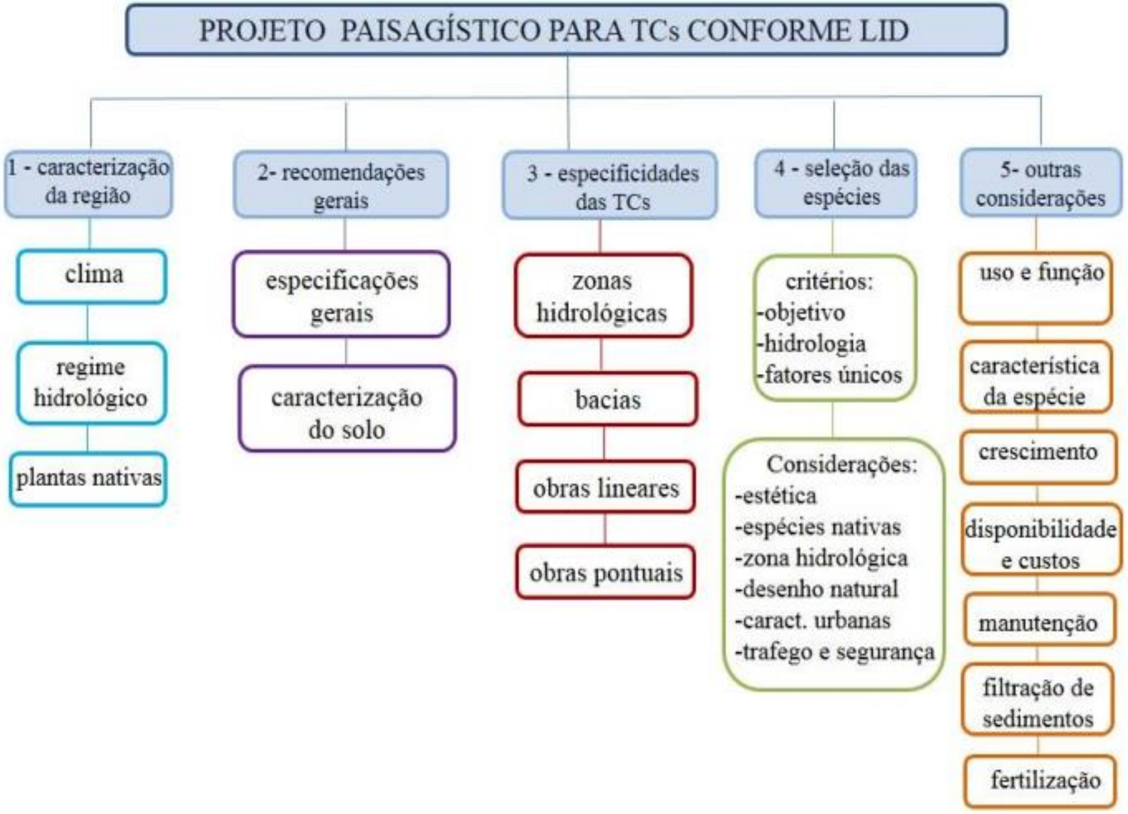
LANDSCAPE DESIGN OF INFILTRATION PLANS I AND II

In this work the objective was to develop and apply guidelines for the elaboration and execution of landscape design in compensatory techniques aiming at its integration into the urban landscape. The guidelines were based on Low Impact Urban Development (LID), the traditional method of landscaping design and international recommendations related to techniques and were synthesized in seven sequential design stages.

The guidelines presented in the work were executed with coherence and guarantee of functionality of the compensatory techniques, will allow the professionals involved with the issues of sustainable rainwater management (architects, landscapers, hydrologists, agronomists, among others) guidelines that aim to be applied in each region in order to develop landscape projects that respect the characteristics of these drainage techniques and each location. In the microbasin studied, the intended use for the areas where the infiltration plans were implemented were green and free areas, but not qualified from the aesthetic and functional point of view. They were simple grassy areas, *non aedificandi*, guaranteeing insolation and ventilation to the buildings.

The elaboration of landscape projects in general is found in Abud (2010), Hardt (2010), and in LID manuals, such as Prince George County (1999), New Jersey (2004), given that the compensatory techniques require greater care, which correspond to restrictions related to their functionality, configuring a differentiated methodology given by the LID manuals (Figure 7) in relation to the elaboration of the traditional landscape project. For the application of the Pereira (2016) guidelines, followed The author followed the general criteria for landscape design in compensatory techniques according to LID manuals according to New Jersey (2004) and Batista *et al*. (2005).

Figure 7 - General criteria for landscape design in compensatory techniques (TCs), according to LID manuals



Source: Pereira (2016)

Landscape integration, costs and application of the guidelines

The landscape integration allowed a freer design for compensatory techniques, going beyond the orthogonal and classical layout predominant in hydrological projects and brought organicity to the forms. The space of the drainage device and the green area are not restricted to the hydrological functionality of storage and infiltration of the ESD, but also to the aesthetic enhancement of the ESD. In this way, these areas became multifunctional, meeting the hydrological control, landscaping and the access and interaction of users with the installation of informative signs of the structure that characterized the techniques and used and their objectives.

The Infiltration Plan I has a total area of approximately 500m² and receives direct surface runoff water from the roof of the building that houses the Physiotherapy Department of the campus, with an area of 1,747.54 m², added to an expansion area of 1,253.76 m², between the building and the infiltration plan, totaling 3,001.3 m². The Infiltration Plan II has a total area of approximately 655 m² and receives direct surface runoff water from the roof of the Department of Medicine II with an area of 1,426.7 m², added to the adjacent parking area with 5,732.5 m2 and part of the roof of the Department of Gerontology with 188 m².

The hydraulic dimensioning of the Infiltration Plan II meets a payback period of 10 years and emptying time of less than 24 hours, as well as the Infiltration Plan I. The landscaping and application of the guidelines occurred in the Infiltration Plans I and II and the costs involved in the landscape application were around R$ 16.77 and R$ 18.73 for the Infiltration Plans I and II, respectively.

In the landscaping of the infiltration planes , a more organic form was chosen, however it would facilitate the sizing and implantation of the species and the results of the application of the guidelines in the two infiltration planes demonstrated that the guidelines provided a freer design for the compensatory techniques, created an identity for the recognition of the community and multifunctionality in order to integrate free and green areas to the hydrological function (PEREIRA, 2016).

The elaboration and implementation of the full-scale landscape projects on campus were carried out based on the guidelines defined in the work, and the experiments confirmed the need to carry out the steps defined for the elaboration of the project. Landscape integration, on the other hand, allowed a freer design for compensatory techniques, going beyond the orthogonal and classical layout predominant in hydrological projects and brought organicity to the forms. The space of the drainage device and the green area are not restricted to the hydrological functionality of ESD storage and infiltration, but also to the aesthetic enhancement of CT (with the composition of shapes and colors), in addition to remaining as a green and free area, becoming multifunctional areas, meeting the hydrological control, landscaping and user access and interaction (Pereira, 2016).

The maintenance after the execution of the landscaping in the infiltration plans presented the need for monthly periodicity for monitoring, such as frequent irrigation, ant control and weed removal. However, these actions correspond to common gardening techniques, without large investments in human or financial resources, attesting to the feasibility of maintenance (PEREIRA, 2016).

FINAL CONSIDERATIONS

It should be taken into account that the G-Hidro project is pioneering and had many difficulties in its trajectory, however, it is visible that the research carried out so far is of extreme scientific, environmental, social and economic importance, since all the theoretical foundation with the greatest possible scientific rigor was used in the construction, methods, validations of the results of the research and, above all, in the strategic arrangement of drainage structures. It is also worth mentioning that there were some technical difficulties in the beginning in relation to the Campus City Hall for the implementation of these systems, since they are innovative structures and still little studied. Table 1 shows the calculations of the area of influence of the systems in relation to the total area of the hydrographic basin and corroborates the statement that about 20% of the volume is no longer part of the runoff that reaches the conventional rainwater drainage network.

Table 1 – Relationship of areas of influence of drainage systems in relation to the total area of the watershed

Compensatory drainage system	**Area (m²)**		**% of total river basin area**
FVT's area of influence	3.694		3,2%
Area of influence of the Infiltration Plan I	6.852		5,9%
Area of influence of the infiltration wells	536		0,5%
Area of influence of the grassy channel	10.358		8,9%
Area of influence of the Infiltration Plan II	1.494		1,3%
Area of influence of infiltration wells II	468		0,4%
Total area of the river basin	**116.325**	**Total (%)**	**20,1%**

However, when we analyze it in general, the hydrographic basin had as a consequence of these projects a considerable reduction in the direct surface runoff generated in the area. In terms of volume, it is inferred that about 20% of the volume of rainwater generated in the basin is now no longer directed to the public drainage network. This is due to the fact that all compensatory drainage systems have the soil as an outlet, contributing to the recharge of the aquifer and relieving the rainwater network in terms of volume and flow.

It should be borne in mind that not all rainwater runoffs generated in the entire watershed studied, especially those generated on the roofs of buildings, have a compensatory drainage structure as a control measure. Thus, we can infer that the volumes reduced by these structures, if applied to all buildings in the basin, would be even smaller than those calculated here. It should also be noted that in addition to these advantages of flood control, there is another of extreme importance, which is the cost of the shackles and their implementation, which in a way, would reduce their nominal diameters and would be less burdensome for conventional drainage works. Therefore, it is necessary to talk about costs, since in the implementation of these structures a substantially onerous cost was not identified in relation to conventional drainage. It is concluded that, in addition to positive results in relation to the control of drainage in watersheds by the implementation of these systems, the costs and aesthetic benefits are also appropriate and can, without any doubt, be implemented throughout the city (at least in new expansion areas) and also regionally.

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