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Sustainable Urban Drainage Systems

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1. Introduction

Water is a natural resource renewed through the physical processes of the hydrologic or water cycle. Through the action of solar energy, water is evaporated from the surfaces of oceans, lakes, and rivers and from land surfaces, returning to the atmosphere in the form of water vapor. Water is also returned through plants, which use it to satisfy their physiological needs and send it back in the form of transpiration. The whole process of transfer of water vapor from the Earth's surface to the atmosphere is called evapotranspiration. Once present in the atmosphere, it may precipitate in the form of rain, snow, dew, or frost. When it reaches a surface, it may run off the surface or infiltrate soil layers. Due to topographical conditions, surface runoff converges to valley regions, giving rise to rivers and lakes, which drain to ever larger bodies of water until reaching the ocean. The infiltrated water may flow to deeper soil layers, emerging in the form of springs, or percolate to even deeper layers, reaching underground aquifers. When an aquifer is in direct contact with the surface, it is said to be non-confined, and the water is stored in what is called the water table, which is acted on by atmospheric pressure. When there is a geological formation which separates the water storage zone from the soil surface, the aquifer is said to be confined and it is subject to a pressure greater than atmospheric pressure. The water stored in either of these aquifers may emerge in the form of base flow, due to the topographic gradient, feeding rivers, lakes, and other bodies of water. Indeed, this base flow is responsible for regularization of river flow during dry periods.

The process described above does not cease, it is continually activated by solar energy, and for that reason it is called the hydrologic cycle. Nevertheless, for this cycle to continue in its natural course, there may not be alteration in the water volumes that remain in one or another phase of the process, that is, in the atmosphere, on the surface, and in the soil.

Actually, there are a large number of human and non-human activities that can destabilize the hydrologic cycle. Among human activities that have the greatest impact on the natural hydrologic cycle is the urbanization process.

Urbanization leads to impermeabilization of the soil by means of paving, and soil compaction from the passage of vehicles and from buildings, among other things, which impedes rainwater infiltration (Silveira, 2002). This water that was formerly able to infiltrate soil now flows off surfaces, creating a greater volume of runoff, which ends up converging to regions of a lower topographic level, thus generating areas of flooding. The increase of surface runoff may also lead to overflow of streams, gullies, ditches, and rivers, creating problems of riverside flooding.

Flooding results in risks to people's health and quality of life, in addition to social and economic losses. This is a recurrent event, practically every year, in large Brazilian urban centers. Specialists affirm that the trend is for the number of critical events to increase because, currently, at least some point of flooding may be detected in almost all medium-sized cities in Brazil.

In the face of this situation, up to the 1990s, the solution to flooding problems had been dealt with according to a health services approach (Silveira, 2002). Up to this period, flooding problems were solved through construction of a rainwater drainage system which had the purpose of increasing water flow efficiency, sending rainwater to another downstream body of water.

However, this solution did not effectively solve flooding problems because whenever a city grew and soil impermeability increased, new points of flooding were observed and the use of ever larger means of channeling of water became necessary. In other words, the natural hydrologic cycle was totally altered, and the process of increasing the water flow efficiency of this channeling was continued, at ever increasing costs.

In addition to this aspect, rainwater in urban areas may be contaminated while still in the atmosphere if the atmosphere is polluted or may become polluted upon coming into contact with urban surfaces, due to the washing of oil, greases, and fecal material, among other pollutants. As a consequence, soil becomes contaminated and bodies of water degraded, compromising availability of surface water.

In the face of this unsustainable situation, in the midst of the 1990s, various countries, following the example of the United States, France, and Australia, proposed a set of new strategies for qualitative and quantitative treatment of rainwater in the urban milieu. The main idea contained in the proposals presented for rainwater management in the urban milieu is maintenance of natural water flow mechanisms, or the use of structures that seek to "imitate" some process of the natural hydrologic cycle that was altered.

Thus, the main techniques used contemplate the use of structures that seek to reproduce water infiltration capacity in the soil lost due to impermeabilization. As a result, a smaller volume of surface runoff is created, and there is a reduction in flooding problems. Furthermore, this promotes recharging of underground aquifers and improvements in water quality.

Although the natural hydrologic cycle is not totally restored through the aid of these techniques, there is significant improvement of the urban environment. Currently, the set of best practices for water management in the urban environment is considered to be the Sustainable Urban Drainage System (SUDS).

SUDS are designed to allow water to either infiltrate into the ground or be retained in devices in order to mimic the natural disposal of surface water (Charlesworth et al. 2003; Charlesworth 2010). Among the goals of SUDS, are:

- Quantitative control of surface runoff;
- Improvement in the quality of water from surface runoff;

- Conservation of natural characteristics of bodies of water;
- Balance of hydrological variables in watersheds.

These four goals of SUDS contribute to flood control in urban watersheds, principally when they are still in the urbanization phase and the application of SUDS in new undertakings is possible.

This system is designed to manage the environmental risks resulting from urban runoff and to contribute wherever possible to environmental enhancement. SUDS objectives are, therefore, to minimize the impacts from the development on the quantity and quality of the runoff, and maximize amenity and biodiversity opportunities (Woods et al., 2007).

Uncertainty about long-term maintenance and other operational factors have retarded the widespread adoption of SUDS but environmental regulators and many local authorities and developers are keen to implement this approach in addition to traditional urban drainage systems (Andoh & Iwugo, 2002).

2. History of SUDS

To understand the concepts, proposals, and need for implementation of Sustainable Systems, it is necessary to contextualize, in a historical manner, how the urban drainage systems being used in our cities were developed.

Through time, and up to the Modern Age, drainage works, as a rule, were not considered as necessary infrastructures providing conditions for the development and ordering of urban centers (Matos, 2003). Nevertheless, rainwater drainage systems have been found in much more ancient cities or city ruins.

In the period prior to the Christian Era, systems implemented by the Persians and Greeks are worthy of note. Drainage networks constructed by the Romans (8th Century B.C. ~ 3rd Century A.D.) may be observed yet today, with small sections still in operation. The same holds true for ruins of cities built by Pre-Columbian peoples in various countries of Latin America (TIM, 2008).

Before giving an account of the important transformation which occurred in the 19th Century related to sanitary waste systems and rainwater drainage, it is worthwhile to go back some years in history when, according to Silveira (2002), a period of elimination of flooded areas began, the burying of septic tanks and then their replacement by underground channeling systems. This process for removal of waste and rainwater began in Italy as a result of observing a correlation between mortality rates of people and animals and the sanitation system; after that, it was adopted in innumerable European cities as a public health measure.

Thus emerged the concept of sanitary and hygiene related drainage systems, with the principle of expelling waters from cities, whether rainwater or waste water, giving the false impression of a "problem solved". To understand why this solution did not completely solve the problem, one need only look at the resulting physical aspects and observe the immense erosion caused at the end of these drainage systems, as well as all the morphological changes imposed on receiving bodies of water.

Interestingly enough, rainwater drainage as a public measure did not evolve as a result of modernization of engineering practices in search of comfort, but rather as a recommendation of medical prophylaxis. Evidently, the task of making it concrete in public works and integrating it with the urban landscape belonged to engineers and urban planners, but, unfortunately, this only received greater impulse with the occurrence of cholera epidemics in large cities around the world in the 19th Century. Epidemics which occurred in Europe in the years 1832 and 1849 are of special note.

Between 1850 and the end of the 19th Century, many important cities of the world, principally European capitals, were provided with large single underground networks for waste materials (rainwater drainage and sewage conducted by the same conduits) (Silveira, 2002). According to Jones & MacDonald (2007), in terms of urban drainage, one of the most famous examples of this period was the reconstruction of Paris in the Second Empire of Haussmann and Napoleon III, who used a system designed to rapidly remove waters from the city.

The sanitary hygiene concept, as already mentioned, foresees rapid expulsion of waters from the city for the purpose of preserving the health of the population and eliminating any type of discomfort the water could cause. Nevertheless, what was not foreseen in this effort for channeling is the impact caused downstream, since the sanitary hygiene concept acts only in a local manner in the sense of transferring the problem to other regions. Thus, this concept, associated with rapid growth of the urban population, and by the latter, understanding all the characteristics brought about by urbanization such as impermeabilization of the soil and removal of plant cover, is responsible for constant flooding, landslides, and problems created in relation to recharging of aquifers.

Such a concept was adopted worldwide up to the 1960s of the past century (20th Century). In this period, developed countries began to perceive the conflict generated between the existing rainwater drainage system and the environment. Thus began a new drainage concept, an evolution of the former; concerned not only with public health, but also with the environmental question.

In recent decades, new focus approaching sustainability have been studied, with various names: Low Impact Development (LID), in the USA and Canada; Sustainable Urban Drainage Systems (SUDS), in the United Kingdom; Water Sensitive Urban Design (WSUD), in Australia; and Low Impact Urban Design and Development (LIUDD), in New Zealand. Regardless of the name, the ideas and concepts of the sustainable systems presented are very similar and all make reference to balance among the variables of the hydrologic cycle and their effects on watersheds.

Landscaping, environmental, and economic gains reinforce the advantages presented by this conception of urban drainage treatment, controlling not only the peak flows, but also the volume, the frequency, the duration, and the quality of runoff and drainage (Souza, 2005).

In contrast, developing countries are relatively behind the times, since quantitative control of urban drainage is still limited and quality control of the water drained is still far from accomplished. This reinforces the need for researching means for encouraging the use of techniques, like charging for water use, with the goal of control at the source and maintenance of characteristics of the pre-development hydrologic cycle.

3. Hydrologic concepts used in SUDS

The Hydrologic Cycle represents the passage of water through its three physical states: solid, liquid, and gas. All the factors described above have a large influence on the behavior of this cycle, principally when we think on a global scale.

However, on a local scale, the quantity of water and the speed at which it circulates through the different phases of the hydrologic cycle are directly influenced by factors such as plant cover, altitude, topography, temperature, type and use of the soil, and geology.

As we can say that the hydrologic cycle basically consists of a continuous process of transport of water masses from the ocean to the atmosphere, and from it once more to the ocean through precipitation and runoff/flow (surface and underground), it may also be inferred that alterations in the variables involved in this system can modify its characteristics locally.

Within the context of sustainable watersheds, the main variables (evaporation, evapotranspiration, precipitation, surface runoff and underground flow) need to be maintained or compensated for by direct actions on one or more of these variables.

Descriptively speaking, the hydrologic cycle functions because water from the Earth's surface receives energy from the Sun to undergo heating and rise to the atmosphere in evaporation. Gravity causes condensate water to fall, and there is precipitation. Upon arriving at the surface, water circulates through waterways (surface runoff) that gather into rivers until reaching the oceans, or it infiltrates in soils and rocks through their pores, fissures, and cracks, creating underground water flow.

But not all water from precipitation will advance in this flow because part of it will be retained in constructions, trees, bushes, and plants; therefore, it never reaches the soil (evaporates), and is thus known as loss through interception.

So, it may be said that waters that arrives at the soil may take various routes; some of them will evaporate and return to the atmosphere and others will infiltrate the ground. But if the intensity of rain goes beyond the infiltration and evaporation portion, small accumulations of water called depression storage is formed.

When these depressions fill and overflow, water begins to move along the surface, which is designated as surplus rainfall. Upon forming a layer of water that covers the trajectory of movement, we say that surface runoff has begun. If this runoff is stored during its trajectory, this phase comes to be called detention storage.

Even so, it must be remembered that the process is complex and the other phases continue occurring simultaneously; therefore, part of the flow may infiltrate the soil or it may evaporate, returning to the atmosphere before reaching a body of water. The water that infiltrates the soil enters first in the soil zone containing plant roots. This upper part of the soil may retain a limited quantity of water, and this quantity is known as field capacity.

Another route for the water that infiltrates the soil is direct evaporation to the atmosphere, which, through transpiration of the plant that took it up, returns it to the atmosphere. This process is called evapotranspiration and occurs at the top of the non-saturated zone, that is, in the zone where spaces between the soil particles contain both air and water.

Therefore, processes may be distinguished as:

- Evaporation: this is the physical process in which a liquid or solid passes to the gaseous state due to solar radiation and to the processes of molecular and turbulent diffusion;
- Transpiration: this is the release of water vapor by plants by means of stomata and organelles located on leaves;
- Evapotranspiration: this is the sum of the evaporation and transpiration processes, given the difficulty of separating the two phenomena. Evapotranspiration is expressed in terms of water depth, in mm.

The main factors that interfere in the processes of Evaporation and Evapotranspiration are:

- Air temperature: the greater the temperature, the greater the capacity of the air for containing water vapor;
- Water temperature: the hotter the water, the greater the evaporation;
- (Relative) atmospheric humidity: the lower the relative air humidity, the greater the evaporative capacity of the air;
- Wind: the displacement of air masses constantly renews the mass of water vapor over the evaporating surface;
- Salinity: the presence of salts reduces evaporation (2% to 3%).

When the water that passed through the previous phases continues to infiltrate, it reaches the saturated zone, enters in underground circulation, and contributes to increase stored water, therefore recharging the aquifers. In the saturated zone or aquifer, the soil pores or fractures in rock formations are completely filled by water, and are therefore saturated. The top of the saturated zones corresponds to the level of the water table and for that reason they are also most susceptible to contamination.

Underground circulation continues and water may come to the surface through springs and feed bodies of water or discharge directly into the ocean.

The problem begins when human activities begin to interfere in the aforementioned processes, and these alterations produced by man on the ecosystem may alter part of the hydrologic cycle.

Thinking globally, human activities that release elevated concentration of gases to the atmosphere increase the greenhouse effect and consequently change the conditions of thermal radiation emissions and cause imbalance in the system.

Locally, engineering works in general cause changes in variables such as infiltration, evaporation, and runoff. Among these works are water engineering works which act on rivers, lakes, and oceans, modifying their natural routes.

In addition, practically all activities that carry out deforestation for utilization of wood, or even for cleaning the area for new construction work, act negatively on behavior of the watershed. Among the main effects of deforestation are increased runoff and reduction of evapotranspiration for the same amount of precipitation (varying in terms of the different types of soil use).

But of all human activities, urbanization is that which produces the greatest local changes in the processes of the Earth's hydrologic cycle. The most rapidly changed factor is the Runoff

Coefficient, which is the ratio between the volume of surface water runoff and the volume of rainwater.

Various problems are caused by change in the Runoff Coefficient. These problems go beyond erosion of the drainage area; they cause imbalances in the rainwater channel (erosion and silting) and the ever so frequent urban flooding.

4. The effect of urbanization

Alteration of natural drainage basin, either by the impact of forestry, agriculture, or urbanization, can impose dramatic changes in the movement and storage of water (Booth, 1991).

Along with urbanization, new engineering works arise such as buildings, paving of streets, sidewalks, and consequent removal of original plant cover from the environment, which causes a change in the natural permeability of these areas. Due to this impermeabilization, there is a reduction in rainwater infiltration, leading to a strong increase of rainwater runoff.

Currently, in Brazil, all large cities have some point of flooding and medium-sized cities have at least some inundated points during high water periods. This problem has worsened year after year in Brazilian cities, which seem lost in trying to control these events.

This occurs principally because urbanization tends to remove existing vegetation in watersheds and it is replaced by impermeable areas (sidewalks, paved streets, roofs, parking lots, etc.). These changes end up leading to changes in the local hydrograph, causing concentration times to be reduced and peak flows to be expanded. In the same degree of precipitation, the runoff volume is expanded and thus the lower or flat areas of the watershed will tend to flood.

Some engineering solutions bet on transfer of the problem by improving or increasing the rainwater drainage system, but in general, they end up transferring problems further downstream. In addition, upon transferring a greater volume of runoff to the final point of the drainage system, serious erosion problems are generated.

In addition, the presence of peak flows has resulted in increases of the frequency and seriousness of flooding and in intensification of erosion processes with increase of production, transport, and deposit of sediments. Impacts like these directly affect the quality of bodies of water in these watersheds.

Changes in the local hydrologic cycle and its consequences due to the urbanization process, as previously mentioned, directly affect the environmental balance and, thus, the quality of life of the resident population. Problems arise both due to the inflows to the system, which in future will be less certain, and increasing downstream hydraulic and regulatory constraints on outflows (Ashley et al., 2007).

In this context, it may be observed that the conventional rainwater drainage system with the principle of rapid flow downstream is not able to eliminate any disturbance that these waters may bring about.

5. Types of sustainable systems

Among the sustainable systems that are being developed and implemented, the following devices or techniques may be highlighted:

- Permeable pavement;
- Semipermeable pavement;
- Detention and retention reservoirs;
- Infiltration trenches;
- Infiltration gullies;
- Infiltration wells;
- Microreservoirs;
- Rooftop reservoirs;
- Green roofing;
- Underground reservoirs; and,
- Grassed strips.

These devices adopted in sustainable systems seek to mitigate the effects of urbanization through reduction of runoff and provide for significant increases in infiltration rates. To obtain these results, permeable areas and rainwater retention areas must be created as part of a larger complex, which is water resource management.

Such systems may be used jointly or separately according to the proposed project or the local needs and/or possibilities, providing a good cost/benefit ratio, in addition to social, economic, and environmental gains. Even so, in general, systems only produce a good (significant) result when applied jointly and in various parts of the watershed to compose a greater project.

Currently there are a large number of sustainable drainage systems being tested or even already consolidated in innumerable countries. In following, we will present the principal systems that may be adopted in management of urban watersheds as a way for improving or supplementing conventional drainage systems.

5.1 Permeable pavement

The need for draining surface waters to outside the location where they are being generated may be reduced or eliminated. This may be accomplished by leading it to flow through porous pavements built with materials like concrete blocks, crushed rock, or porous asphalt. Depending on soil conditions (permeability, infiltration rates, etc.), the water may infiltrate directly into the subsoil or be stored in an underground reservoir as, for example, in a layer of crushed rock or in a reservoir, respectively. If infiltration is not possible or appropriate (as, for example, due to soil contamination), an impermeable membrane may be used as a barrier to keep the pavement free of water under all conditions. Even in these cases, removal of most pollutants occurs both on the surface or sub-base of the material itself, or through the filtering action of the reservoir or in the subsoil.

Thus, it may be said that permeable pavement is an alternative infiltration device where surface runoff is diverted through a permeable surface into a rock reservoir located under the same surface (Urbonas & Stahre, 1993). According to the same authors, permeable pavement may be classified into three types:

- Porous asphalt pavement: has its upper layer constructed in a similar way to conventional pavements with a difference in the fraction of fine sand, which is removed from the mixture of the aggregates used in construction of the pavement;

- Porous concrete pavement: just as in porous asphalt pavement, it only has a difference in the sand fraction as compared to conventional pavements;
- Semipermeable pavement (described below).

For Silveira (2002), permeable pavements are pavements that normally act in control of the peak and volume of runoff, in control of diffuse pollution, and, when they infiltrate water in the soil, they promote recharging of underground waters. Porous pavements are appropriate for use on light traffic roadways, parking areas, pedestrian streets, squares, and sports courts.

Schlüter et al. (2002) studies have demonstrated that porous pavement can get good results, such as:

- average percentage outflow of just under 50%;
- lag times of 45 minutes for medium and 145 minutes for small events;
- initial rainfall capacity in the order of 2.27 mm.

Abbott & Comino-Mateos (2003) have also shown the peaks of storm events were significantly reduced as they flowed out of the pavement system. For example, the peak outflow corresponding to a rainfall intensity of 12 mm/h was 0.37 mm/h. This is a major benefit of these systems because:

a. it reduces the capacity of sewerage systems; and,
b. enables urban developments to comply more easily with discharge consents.

Even so, as mentioned above, this system only leads to temporary water storage and therefore needs to be joined with another system for retention and/or infiltration of the water absorbed, since this system does not have that function.

5.2 Semi-permeable pavement

For Urbonas & Stahre (1993), semi-permeable pavements are constructed of hollowed concrete blocks filled with granular material like sand or undergrowth, like grass, placed over a granular base layer and this layer is covered by geotextile filters to avoid migration of the granular base.

According to studies of Araújo *et al.* (2000), semipermeable pavements may be industrial concrete blocks, as well as paving blocks, among other items. According to Cruz *et al.* (1999), they have the function of providing for reduction in runoff volumes and in the time for recharging the watershed.

Moreover, according to Araújo *et al.* (2000), in their studies performed on different types of semipermeable pavements (concrete, concrete blocks, compacted soil, paving blocks, and hollowed blocks), after simulations of similar precipitation levels, the following runoffs were obtained, respectively: 17.45 mm, 15.00 mm, 12.32 mm, 10.99 mm, and 0.5 mm. These studies were able to prove the efficiency of different types of pavements in reduction of runoff through increase of infiltration rates.

Furthermore, according to Araújo *et al.* (2000), the use of permeable pavements eliminates the need for collection boxes and water conduits because the device practically does not generate runoff. In addition to implementation costs of permeable pavements, there are maintenance costs, which consist of cleaning the pores of porous pavements (porous concrete) with water jets and machines for vacuuming of dirt and sediment. These costs were not estimated due to the non-existence of companies specialized in maintenance of this type of device in the country. Nevertheless, to have an idea, average expense on maintenance in the United States is in the order of 1% to 2% of the implementation cost of the device.

5.3 Retention and detention reservoirs

The great advantage of retention reservoirs is that they may be installed in public areas, such as squares, parks, and courts that have another use after precipitations. Detention reservoirs, for their part, are maintained with a water layer and have controlled water quality. They may be applied in grassy marshes or urban reservoirs. Closed detention reservoirs have a cost seven times greater than open reservoirs. There are the further alternatives of off-line systems in which a part of the discharge floods in a lateral manner and then returns to the main waterway (Parkinson *et al.*, 2003).

For Cruz *et al.* (1998), the main problem of detention reservoirs is maintenance, as they create heavy obligations on their owner. The reason for this is that with rains, surface runoff carries all types of solid residues and sediments available in the watershed. Therefore, the need for seeking devices for periodic cleaning of the reservoirs must be taken into account, thus avoiding loss in their efficiency.

Consideration of maintenance costs has the greatest influence in the case of the open device since it has a lower cost of implementation, but needs more periodic maintenance due to public health problems; that way, this type of structure presents annual maintenance costs estimated at US$ 130.00, which may bring it up to the cost of the other systems in 4 or 5 years (Cruz *et al.*, 1998).

5.4 Wetlands

Wetlands are land areas whose soil remains saturated with water, whether this is permanent or seasonal moisture. They may be natural or constructed, and these areas may also be partially or totally covered by a certain depth of water. This wetlands system includes swamps, marshes, and lowlands, among others. In addition, the water in wetlands may be salt water, fresh water, or brackish water.

Although they may be designed as wet or dry lagoons, they are more visually pleasing and promote biodiversity where permanent water is included. In addition, when dealing with a flooded system, they may be designed to accommodate considerable variations in water levels during precipitations, reinforcing storage capacity against flooding.

Another important characteristic is that the level of solids removal may be significant when there is adequate detention time. Algae and plants of wetlands provide a particularly good level of filtering and removal of nutrients. Thus, lagoons and wetlands may be fed by drainage gullies or piping systems, small areas of urban sewage, as well as serving as a type of sediment "trap", aiding in sedimentation management problems.

According to Costa *et al.* (2003), for minimizing risks of residual waters, also reducing microbiological contamination, constructed wetlands are currently considered as a treatment method that uses simple technology which is easily operated and of low cost. In them, there is principally good cycling of nutrients, removal of organic material, and reduction of pathogenic microorganisms present in residual waters. Among the numerous mechanisms that cause this removal, the principal ones are settling (sieving effect caused by microbial biofilm adhering to the roots and substrate), predation and competition among microorganisms and possible toxic substances produced by plants and released through their roots (Brix, 1994). For Zheng et al. (2006), combined wetlands and infiltration ponds are cost-effective 'end of pipe' drainage solutions that can be applied for local source control as part of urban development and regeneration.

In summary, it may be said that these systems have important functions, among which the following stand out:

- Their capacity for regularization of water flows, moderating peaks of flooding (according to their designed capacity);
- Capacity for modifying and controlling water quality (in the event of limits to be established);
- Their importance in the function of reproduction and feeding of aquatic fauna;
- A form of protection of local biodiversity as a refuge area for land fauna;
- A silting control system for rivers due to their capacity in retaining sediments.

Even with these benefits, this system may be adopted only after adequacy studies in regard to characteristics of the location, as well as studies for avoiding problems with proliferation of insects that may cause health risks to those living near the area.

5.5 Infiltration trench

Infiltration trenches are reservoirs full of rock to which rainwater is directed for initial storage and from which water gradually infiltrates the soil. Its longevity may be increased through incorporation of a filter, or deposit, which removes excessive entry of solids and thus avoids colmatation of the system.

According to Silva (2007) infiltration trenches (percolation and/or draining) are linear structures in which length is preponderantly greater than width and depth. Their geometry depends on the infiltrability of the soil and the area available for infiltration to occur. Depending on local conditions and the volume to infiltrate, the design may give priority to infiltration, storage, or both. Generally trenches are planned for large volumes of water to be infiltrated, are closed, and allow landscaping use in harmony with other structures.

According to Silveira (2008), the main function of infiltration trenches is to reduce runoff and promote recharging of aquifers, but another important function is to promote water treatment by means of soil infiltration.

Waste filters (also known as French drains) are widely used by authorities along highways. They are similar to infiltration trenches, but use a perforated pipe, which carries the flow along the gulley. This allows storage, filtration, and infiltration of water that passes from the collection area to the final point. Pollutants are removed by absorption, filtering and microbial decomposition in the surrounding soil. That way, these systems may be successfully designed so as to incorporate infiltration as well as to serve as efficient filtration systems.

Thus, according to Nascimento (1996), the advantages in the use of this type of structure are:

- Reduction or even elimination of the local microdrainage network;
- It avoids reconstruction of the downstream network in the case of saturation;
- Reduction of risks of flooding;
- Reduction in pollution of surface waters;
- Recharging of underground waters;
- Good integration with the urban area.

The cost of implementation of an infiltration trench, according to Souza & Goldenfum (1999), basically depends on the cost of earthwork and the cost of materials (crushed rock and geotextile). A trench that drains an area of around 300 m^2 costs around US$ 239.00 (experimental module). That gives us an estimated cost of US$ 0.79/m^2.

Infiltration systems may also be very effective in industrial zones. But the use of solutions based on infiltration for these locations requires careful reflection, principally because there is the risk of environmental damages caused by soil contamination. In this case, the focus will be on not mobilizing the contaminants.

5.6 Infiltration ditch and gulley

Ditches and gullies are compensatory techniques consisting of simple depressions dug into the ground for the purpose of collecting rainwater, making temporary storage and favoring infiltration (Silva, 2007).

The depressions are linear and on permeable land, where generally there is a grassy covering. In addition, the infiltration gulley may incorporate small deceleration dams that favor infiltration and protect against erosion. Nevertheless, according to Silveira (2002), this system may cause colmatation and allow the passage of pollutants and it has a propensity to retain stagnant water. Therefore it needs frequent maintenance.

Ditches are characteristically works of large width and low slope in the longitudinal direction dug into the earth. Gullies, for their part, are ditches that are not very deep (Brito, 2006). In both cases, they may also be used as one of the management resources within gardened areas of the urbanized watershed, or may even be incorporated in leisure areas.

These systems provide temporary storage for rainwater, reducing peak flows of waters and also aid in filtering of pollutants (deposited in the impermeable areas). They are often installed as part of a drainage network, where they help to connect it to a lagoon or wetland before final discharge into a natural waterway. Even so, they have often been installed along avenues, streets, and roadways to substitute conventional drainage systems.

5.7 Microreservoir

For Loganathan *et al*. (1985), microreservoirs are storage devices for precipitated water which act in the sense of retarding concentration time, mitigating the peaks of flow hydrographs.

Agra (2001) defines it as simple structures in the form of boxes similar to those used for supply water. They may be made of diverse types of materials as, for example, concrete, masonry, PVC, or another material, having a discharge structure like an orifice. They are normally buried, but they may be open to view provided that there is a height limitation due to the drainage network.

According to Cruz *et al.* (1998), the general cost of implementation of an underground microreservoir for control in urban lots is, on average, from US$ 400.00 to US$ 500.00, with the need for additional spending on its maintenance.

5.8 Infiltration well

For Reis *et al.* (2008), infiltration wells are isolated devices that allow infiltration of runoff into the soil. They may be structured through filling with crushed rock (porous medium), as well as being lined by perforated concrete piping or bricks laid in a staggered manner surrounded by a geotextile sheet making the soil/piping interface. They have the advantages of low cost of execution and attempt at balance of the urban hydrologic cycle by intermediation of recharging the water table.

Nevertheless, for Silveira (2002), the well also has its drawbacks for not having the capacity for supporting large loads of sediments and offering risks in regard to infiltration of pollutants.

According to Reis (2005), the cost of execution of an infiltration well for an area of 500 m^2, determined in December 2004, was US$ 1,312.50.

5.9 Rooftop reservoir

According to Silva (2004), this is a device that seeks to compensate the effect of impermeabilization by means of the impact structure itself, which in this case is the roof. According to Azzout *et al.* (1994), the rooftop reservoir functions as provisional storage of rainwater, releasing it gradually to the rainwater network by means of a specific regulating device. For Silva (2004), both roofing tiles as well as concrete roofing structures that can store rainwater may also be used for the purpose of collecting water.

Nevertheless, Azzout *et al.* (1994) present considerations in regard to the rooftop reservoir, expressing the need to take care with more highly sloped rooftops by the fact that its installation is restricted to rooftops with a slope limit of 2%, also emphasizing the difficulty of installing the reservoir on already existing rooftops and possibly the high cost of the device.

With respect to its pollutants, roof runoff is generally considered as non-polluted, or at least not significantly polluted, compared to waste waters and highway runoff, since it consists of rainwater flowing over various, in general less abrasive materials, such as tiles, bitumen, less corrosive metals and concrete. In general, it may be stated that the quality of runoff may be ameliorated or become worse compared to the composition of atmospheric deposition depending on the kind of materials used for roof cover and drainage systems and their interaction with the atmospheric deposition. For building materials displaying open air corrosion data or data of leaching experiments, runoff loads can even be assessed (Zobrist et al., 2000).

5.10 Green roofing

Other techniques that reduce the flow of rainwater and improve water quality include green roofing and its reuse. Green roofing may reduce local peak flows and the total volume discharged into the conventional drainage system. In addition, they may improve thermal and acoustic insulation and increase the useful life of the roofing.

Reuse of rainwater involves collecting it at the location (residential, commercial or industrial) and its use as a substitute for treated water (with high treatment and distribution costs), for example in watering the garden, washing sidewalks, or even for flushing of toilets. Reuse of rainwater will be dealt with in the following item.

According to Heneine (2008), green roofing is currently most widespread in German speaking countries of Central Europe and is spreading to the north and northwest of Europe and North America. Such devices consist of a green covering composed of plants and soil, emphasizing that the plant cover has average growth and is planted on an impermeable base. However, additional layers, as for example, a barrier of roots, and a drainage and irrigation system may and should be included.

Heneine (2008) affirms that green roofing provides for reduction of the effects of torrents of rain, carry benefits for fauna, and mitigate heat in buildings. In relation to planting style, there are two distinct focuses, one being "intensive" (which needs more soil, more depth, and accommodates larger plants that may be as large as trees and bushes) and the other "extensive" (which needs little soil and contains vines and grasses).

This technology arose as a new proposal for retaining precipitated water through the natural holding power existing in the vegetation and also generating delay in runoff from the system. That way, compared with unprotected roofing that has no type of water containment, the volume generated from a roof with the green roofing technology is less and with a greater concentration time in relation to urban drainage systems.

Studies undertaken by Oliveira (2009) show that in addition to its precipitation retaining characteristics and its delaying of runoff, green roofing presents thermal comfort characteristics. It is very efficient in reducing the temperature of the internal and external environment of buildings, even modifying the surrounding microclimate and mesoclimate because this roofing reduces heat emission.

Confirming the thesis that green roofing relieves heat in buildings, this system can lead to a reduction of around 25% in cooling needs, and with a substrate layer of 12 cm, it can reduce outside noise by around 40 decibels, and a substrate layer of 20 cm can reduce it from 46 to 50 decibels.

In general, green roofing makes use of three systems:

- The Alveolar System which permits the use of a greater variety of plants, including native species (ecological system); in this case a roof of grasses may be used because the alveoli retain a greater quantity of water;
- The Planar System characterized by the use of a layer of water over a raised base made of support modules, increases the benefits of retaining precipitated water, and also the thermal comfort of the area below it;

- The Modular System which is composed of prefabricated modules (already planted) where these modules are placed one beside another over an anti-rooting membrane and a membrane for retaining of nutrients (support systems of the modules).

5.11 Reuse of rainwater

For Fendrich (2003), it is worth emphasizing that all captured rainwater will reduce the waters that may cause flooding. Thus, this application is highly important for controlling water balance and it may play an important social role in areas subject to drought.

When there is the occurrence of rainfall and there is no system for capturing this water, it will end up in storm drains. Until this water arrives at the storm drain, it traces a route where it comes in contact with innumerable type of residues, contaminating it and making it inappropriate for consumption. Nevertheless, this water may potentially be used in many day-to-day situations. According to Pereira (2008), through Brazilian legislation, all water derived from rains is treated as sewage, creating the need for this water to be treated before its use, even without having been used.

5.12 Underground reservoir

According to Silveira (2002), an underground or buried reservoir is a type of impervious tank built below the ground (with impermeable concrete walls) allowing utilization of the surface for another purpose. In general, an underground reservoir operates as an impermeable open air detaining reservoir. Therefore, it weakens the runoff introduced in it through the controlled effect of water release through the orifice and valve at the bottom. Nevertheless it should have a mechanism to avoid the accumulation of pollutants and sediment, it requires frequent maintenance, and it is restricted to areas with more frequent rainfall.

5.13 Grassed strips

According to Silveira (2002), grassed or tree-lined strips are conceived to decelerate and partially infiltrate laminar flow coming from impermeable urban surfaces (parking areas and other surfaces), but may have its application associated with other situations. In macrodrainage, they assume the role of escape zones for flooding. Therefore, the main benefit of grassed strips is that in addition to significantly reducing the speed of surface runoff, they significantly help in reduction of peak flows in urban areas (when applied in large stretches).

Another focus could be given regarding the use of grassed strips. The concentration of sediment decreased exponentially with distance along the grass strip, reaching sometimes a constant value. Particles less than 5.8 μm had a very low trapping efficiency (sometimes negligible), while a substantial proportion of particles above 57 μm were trapped. Knowing that fine particles are the main source of pollution, this implies that grass is very effective for sediment control, but is less efficient in removal of other pollutants. The particle trapping efficiency clearly depended on grass length and particle size. To a some extent, it also depended on sediment concentrations in inflow (Deletic, 2005).

However, some reservations must be made, as for example the need for more constant maintenance.

6. Final considerations

Like all other drainage systems, the SUDS system has its advantages and disadvantages. Therefore positive and negative points may be cited regarding its use, which may be useful for directing future studies and applications.

Among the different devices presented in this book, diverse positive points become evident, and among them are:

- Increase in the infiltration rates and reduction of surface runoff;
- Retaining of rainwater for later use in less refined activities (watering gardens, flushing toilets in bathrooms, washing sidewalks, etc.);
- Creation of leisure areas and a better landscaping aspect for cities.

Nevertheless, the challenges that must be overcome for improvement in performance and incentive for application of these systems must be kept in mind. Among the main problems are:

- Need for frequent maintenance;
- High cost of implementation when necessary adaptations in pre-existing systems are made;
- In general, these systems do not support high loads of sediments and present the risk of colmatation.

Even so, in a more general way, implementation of some component systems of SUDS do not have high cost; therefore, upon performing an analysis of economic-environmental viability, SUDS presents a good cost-benefit ratio.

The evolution of society and its systems occurs in two manners: first in the search for comfort and better quality of life, and later through the fundamental need for preservation of life. Thus, in the same way that rainwater drainage centered on channeling was of extreme necessity for prevention of diseases and epidemics, a new drainage model is necessary for resolution of conflicts from problems created between urbanization and Earth's water cycle.

In spite of being relatively new compared to the traditional system of urban drainage, SUDS already presents diverse implemented systems in operation as an alternative for improving urban drainage, effectively reducing peak flows of human creation. Although still little applied in Brazil, SUDS is being studied and applied in diverse developed countries, above all in the region of Scandinavia and the United Kingdom.

Therefore, it may be concluded that the application of SUDS systems means evolution in drainage systems, and results in improvement of quality of life for the population involved. It renews the search for sustainable environments in urban areas.

7. References

Abbot, C. L. & Comino-Mateos, L. 2003. In-situ hydraulic performance of a permeable pavement sustainable urban drainage system. Journal of the Chartered Institution of Water and Environmental Management, v.17, n.3, p. 187–90.

Agra, S. G. Estudo Experimental de Microrreservatórios para Controle do Escoamento Superficial. Dissertação submetida ao Programa de Pós-Graduação em Recursos Hídricos e Saneamento Ambiental da Universidade Federal do Rio Grande do Sul, 2001. 104p

Andoh, R. Y. G. & and Iwugo, K. O. 2002. Sustainable Urban Drainage Systems: - A UK Perspective. 9th International Conference on Urban Drainage (9 ICUD), Portland, Oregon

Araújo, P. R.; Goldenfum, J. A. & Tucci, C. E. M. Avaliação da eficiência dos pavimentos permeáveis na redução de escoamento superficial. In: Revista Brasileira de Recursos Hídricos. v.5, n.3, 2000. p. 21-29

Ashley, Richard; Blanksby, John; Cashman, Adrian; Jack, Lynne; Wright, Grant; Packman, John; Fewtrell, Lorna; Poole, Tony & Maksimovic, Cedo. 2007. Adaptable Urban Drainage: Addressing Change in Intensity, Occurrence and Uncertainty of Stormwater (AUDACIOUS). Built Environment, v.33, n.1, p. 70-84

Azzout, Y.; Barraud, S.; Cres, F. N. & Alfakih, E. Techniques alternatives en assainissement pluvial. Paris: GRAIE, 1994

Booth, D. B. Urbanization and the natural drainage system – impacts, solutions, and prognoses. The Institute for Environmental Studies, University of Washington: The Northwest Environmental Journal, v.7, n.1, 1991.

Brito, D. S. Metodologia para seleção de alternativas de sistemas de drenagem. Dissertação de Mestrado em Tecnologia Ambiental e Recursos Hídricos, Publicação PTARH.DM-094/06, Departamento de Engenharia Civil e Ambiental, Universidade Brasília, Brasília, DF, 2006. 117p.

Brix, H. Functions of macrophytes in constructed wetlands. Water Sci. Tech., v.29, n.4, 1994. p. 71-78

Charlesworth S. 2010. A review of the adaptation and mitigation of Global Climate Change using Sustainable Drainage in cities. Journal of Water and Climate Change, v.1, n.3, pp. 165-180

Charlesworth S. M.; Harker, E. & Rickard, S. 2003. Sustainable Drainage Systems (SuDS): A soft option for hard drainage questions?. Geography, v.88, n.2, p. 99-107

Costa, L. L.; Ceballos, B. S. O.; Meira, C. M. B. S. & Cavalcanti, M. L. F. 2003. Eficiência de Wetlands construídos com dez dias de detenção hidráulica na remoção de colífagos e bacteriófagos. Revista De Biologia E Ciências Da Terra, v.3, n.1

Cruz, M. A. S.; Araújo, P. R. & Souza, V. C. B. 1999. Estruturas de controle do escoamento urbano na microdrenagem, XIII Simpósio Brasileiro de recursos hídricos, Belo Horizonte, 21p

Cruz, M. A. S.; Tucci, C. E. M. & Silveira, A. L. L. Controle do escoamento com detenção em lotes urbanos. RBRH – Revista Brasileira de Recursos Hídricos. v. 3, n. 4, 1998. p. 19-31

Deletic, A. 2005. Sediment transport in urban runoff over grassed areas. Journal of Hydrology, v. 301, issues 1-4, p. 108–122

Fendrich, R. Aplicabilidade do armazenamento utilização e infiltração das águas pluviais na drenagem urbana. 17 f. Tese (Doutorado em Geologia) – Programa de Pós-Graduação em Geologia, Universidade Federal do Paraná, Curitiba, 2003

Heneine, M. C. A. S. Cobertura Verde. Monografia apresentada ao Curso de Especialização em Construção Civil. Escola de Engenharia da UFMG. Belo Horizonte, 2008. 49 p

Jones, P. & Macdonald, N. Making space for unruly water: Sustainable drainage systems and the disciplining of surface runoff. Geoforum, n. 38, 2007. p. 534-544

Loganathan, V. G.; Delleur, J. W. & Segarra, R. I. Planning detention storage for stormwater management. Journal of Water Resourses Planning and Management. ASCE. New York, v. 111, n. 4, 1985. p. 382-398

Matos, J. S. Aspectos Históricos a Actuais da Evolução da Drenagem de Águas Residuais em Meio Urbano. Revista Engenharia Civil, Lisboa, n. 16, 2003. p. 13-23

Nascimento, N. O. 1996. Curso: Tecnologias Alternativas em Drenagem Urbana. Escola de Engenharia – UFMG

Oliveira, E. W. N. Telhados verdes para habitações de interesse social: retenção das águas pluviais e conforto térmico. Dissertação de mestrado. Rio de Janeiro: UERJ, 2009. 87p

Parkinson, J.; Milograna, J.; Campos, L. C. & Campos, R. Drenagem Urbana Sustentável no Brasil. Relatório do Workshop em Goiânia-GO, 2003

Pereira, L. R. Viabilidade Economico/Ambiental da implantação de um sistema de captação e aproveitamento de água pluvial em edificação de 100m² de cobertura. Monografia (Trabalho de Conclusão de Curso) – Pontifícia Universidade Católica de Goiás, 2008

Reis, R. P. A. Proposição de parâmetros de dimensionamento e avaliação de desempenho de poço de infiltração de água pluvial. Dissertação (Mestrado em Engenharia Civil) – Universidade Federal de Goiás, Goiânia, 2005. 228p

Reis, R. P. A.; Oliveira, L. H. & Sales, M. M. Sistemas de drenagem na fonte por poços de infiltração de águas pluviais. Associação Nacional de Tecnologia do Ambiente Construído. v. 8, n. 2, 2008. p. 99-117

Schlüter, W.; Spitzer, A. & Jefferies, C. Performance of Three Sustainable Urban Drainage Systems in East Scotland. 9th International Conference on Urban Drainage (9 ICUD), Portland, Oregon

Silva, J. P. Estudos Preliminares para Implantação de Trincheiras de Infiltração. Dissertação de Mestrado em Geotecnia. Universidade de Brasília, 2007

Silva, L. C. Sistemas de Drenagem Urbana Não-convencionais. Trabalho de Conclusão de Curso. Universidade Anhembi Morumbi. São Paulo, 2004

Silveira, A. L. L. Apostila: Drenagem Urbana: aspectos de gestão. 1. Ed. Curso preparado por: Instituto de Pesquisas Hidráulicas, Universidade Federal do Rio Grande do Sul e Fundo Setorial de Recursos Hídricos (CNPq), 2002

Silveira, G. L. Cobrança pela Drenagem Urbana de Águas Pluviais: incentivo à sustentabilidade. Relatório de Pós-Doutorado, 2008

Souza, C. F. Mecanismos técnico-institucionais para a sustentabilidade da drenagem urbana, 2005, 174f. Dissertação (Mestrado) – Universidade Federal do Rio Grande do Sul. Programa de Pós-Graduação em Recursos Hídricos e Saneamento Ambiental, Porto Alegre, 2005

Souza, V. C. & Goldenfum, J. A. 1999. Trincheiras e infiltração como elemento de controle do escoamento superficial: um estudo experimental. XIII Simpósio Brasileiro de Recursos Hídricos. Belo Horizonte, 11p

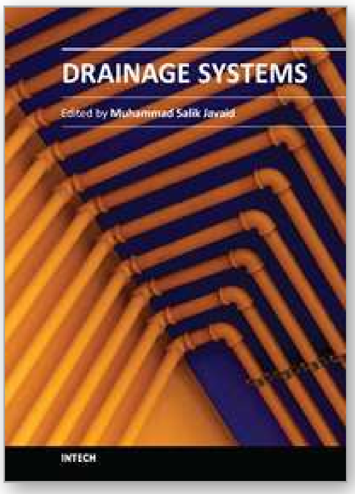
TIM-II - Trabalho de Integralização Multidisciplinar II. Universidade Federal de Minas Gerais, Escola de Engenharia, Curso de Engenharia Civil, Projeto de Infra-Estrutura e Equipamentos Urbanos: Termo de Referência, 2008. p.25

Urbonas, B. & Stahre, P. 1993. Stormwater Best management Practices and Detention. Prentice Hall, Englewood Cliffs, New Jersey. 450p

Woods, B. B.; Kellagher, R.; Martin, P.; Jefferies, C.; Bray R. & Shaffer, P. 2007. The SUDS manual (C697). Construction Industry Research and Information Association, London. 697p

Zheng, J.; Nanbakhsh, H. & Scholz, M. 2006. Case study: design and operation of sustainable urban infiltration ponds treating storm runoff. Journal of Urban Planning and Development – Am. Soc. Civ. Eng. 132, pp. 36–41

Zobrist, J.; Müller, S. R.; Ammannm, A.; Bucheli, T. D.; Mottier, V.; Ochs, M.; Schoenenberger, R.; Eugster, J. & Boller, M. 2000. Quality of roof runoff for groundwater infiltration. Wat. Res., v.34, n.5, p. 1455-1462



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The subject of 'drainage: draining the water off' is as important as 'irrigation: application of water', if not more. 'Drainage' has a deep impact on food security, agricultural activity, hygiene and sanitation, municipal usage, land reclamation and usage, flood and debris flow control, hydrological disaster management, ecological and environmental balance, and water resource management. 'Drainage Systems' provides the reader with a tri-dimensional expose of drainage in terms of sustainable systems, surface drainage and subsurface drainage. Ten eminent authors and their colleagues with varied technical backgrounds and experiences from around the world have dealt with extensive range of issues concerning the drainage phenomenon. Field engineers, hydrologists, academics and graduate students will find this book equally benefitting.