SUSTAINABLE HANDLING OF THE RIVER BASIN/RIVER/FLOODPLAIN SYSTEM FOR THE CONSERVATION OF WATER RESOURCES IN URBAN AREAS

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ABSTRACT

This paper focuses an integrated management system of the river basin/river/flood plain complex in urban areas, based on a sustainable handling management concept of urban basins, directed to river ecology aspects, and to a including quantitative-qualitative management of the concepts of "detention" and "retention" at urban building lots scale, as decentralized steps for maintenance and preservation of river basin water quality and river ecosystem. The "detention" concept uses a selective storage technology for surface water volumes by house cisterns to improve the rainwater management deriving from impermeable areas of urban building lots. The "retention" concept uses a controlled reuse technology of surface and subsurface wastewater volumes, derived from domestic sewage treatment with a previous treatment and by using a safe fertirrigation (providing plants with the nutrients they need), under controlling of the infiltration capacity in the permeable areas of urban building lots.

KEYWORDS

River basin; River ecology; Rainwater management; Urban waters; Sustainable handling; Sustainable sanitation; Water reuse.

1 INTRODUCTION AND OBJECTIVES

Water resources are considered a common good, and because of that, they must be handled in an integrated way, thus assuring an optimal use with minimum conflicts [1]. The National Water Resources Policy (Law No. 9433, from January 8th, 1997) says in its fundaments (1st Article) that "the management of water resources must be decentralized and it must also count on the Public Power, the users and the community". Such approach aims reduced scale decentralized measures, such as an urban lot [2].

Likewise Law No. 11.445, from January 5th, 2007, which establishes national guidelines for basic sanitation, in its 2nd Article, institutes that public services of basic sanitation will be provided based on determined fundamental principles, such as: availability, in all urban areas,

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of drainage services and the handling of rainwater adequate to public health and to the safety of life and the public and private patrimony; use of methods, techniques and processes that consider local and regional peculiarities; efficiency and economical sustainability; use of appropriate technologies, considering the capacity of payment from the users and the use of gradual and progressive solutions; and the integration of infrastructure and services [of basic sanitation] with the efficient management of the water resources. The integrating vision between water resources and sanitation promoted by Law N° 11.445 allies important and pertinent sustainable handling aspects of the river basin/river/floodplain system [3].

Throughout the years, research has been developed proving the importance of natural floodplains in the maintenance and preservation of the fluvial ecosystem and water quality. This fact, associated to the importance of the river/floodplain system, makes its investigation and preservation to be considered priority [4]. Such studies are of extreme importance for the maintenance and preservation of water quality, as well as for its role in impounding/re-processing of nutrients so that they contribute to these ecosystems for the improvement of water quality [5]. The sustainable use of a river depends on a basic and deep knowledge of its structure, function and ecological processes hierarchy. Therefore, when the ecological processes hierarchy is thought about, it is necessary to identify controllable (nutrient pulse and toxic substances) and non-controllable (precipitation, flow, wind and solar radiation) power functions [2].

The water quality of water supply sources that make up a river basin is related to the use of soil in the basin and the level of control on the sources of pollution. The control of pollution sources takes place basically through the treatment of sanitary and industrial wastewater. There is available technology and its implantation depends on financial availability for the implantation of construction and engineering [6]. For some time now researches that observe the consequences of human occupation associate urbanization to the pollution of water bodies due to sanitary wastewater, partially treated or not treated at all, besides industrial waste. More recently, it was noticed that part of the pollution that is generated in urban areas also comes from rainwater runoff over impermeable areas and drainage networks.

The results presented in literature show that the rainwater's quality is no better than the quality of an effluent from a sanitary wastewater secondary treatment system, and it depends on several factors: urban cleaning and its frequency, precipitation intensity and its temporal and spatial distribution, the time of the year and how the urban area is used [7]. Rainwater runoff carries suspended or soluble organic and inorganic matter to water sources, significantly increasing its load of pollutants. The origin of these pollutants are diversified and it contributes to its appearance to abrasion and the erosion of public pathways by vehicular traffic, the trash accumulated on streets and sidewalks, the organic waste of birds and domestic animals, construction activities, fuel residues, automotive grease and oil, atmospheric pollutants, etc. From a sustainable handling of a river basin viewpoint, this article proposes an integrated handling of the river basin/river/floodplain system in urban areas, it will present some research and/or projects with this approach, developed ones as well as ongoing in diversified basins. In such urban areas, the focus is the fluvial ecological aspects, and the integral and quali-quantitative management of 'detention' and 'retention' concepts in urban lot scale, as decentralized measures for the maintenance and preservation of the fluvial ecosystem and water quality. "Detention" uses the selective reservation of surface water volumes technology, by means of cisterns to use rainwater coming from urban lots impermeable drainage areas. "Retention" uses the controlled reuse technology of subsurface water volumes, originating from previously treated sanitary wastewater through safe fertirrigation, subject to infiltration effects in permeable areas of the lot.

2 BIBLIOGRAPHICAL REFERENCES

2.1 General considerations

According to Mendiondo et al. [8] the 21st century is marked by the conflict between the offer and demand for freshwater in world scale. By 2025 it is expected that more than 4 billion people will have difficulties accessing freshwater. It is estimated that the monetary value of worldwide freshwater is around US$ 8,000 billion, of which US$ 300 billion are compromised each year due to the inherent uncertainty of climatic change. As a result, planning a world scale sustainable development presents social, economical and environmental challenges. The self-sustained use of water resources of any given region requires research of its availability in space and time, of potential demands for foreseen multiple uses, of projects and control construction work and the use of studies for the allocation of costs and benefits between the use, and for the determination of an optimal operation strategy [9].

In Brazil, urban development has produced a significant impact in water resources infrastructure. One of the main impacts has occurred in urban drainage, principally in the frequency and magnitude of floods and in environmental deterioration [10]. Urban development is frequently associated to the substitution of natural and seminatural environments (soil, vegetation, water resources) for constructed environments guiding rainwater and wastewater to water bodies adjacent to drainage channels [11]. Consequently, the movement of surface waters increases, thus decreasing the aquifers recharge. The use of water resources involves modifications in environmental conditions of a river basin. The management of these resources must be carried out with the minimum amount of damage to the environment [12].

Some examples of river basin degradation are: deforestation for agricultural purposes; engineering work for the construction of highways, railways or dams; open air mining; over exploitation of vegetation; activities with excessive use of agricultural pesticides; lack of conserving soil practices; and industrial/bio-industrial activities that pollute the soil [13]. Annually, millions of tons of soil are transported because of erosion to the water streams impacting urban and rural areas, increasing the magnitude of floods. Due to the continuous substitution process of the natural forest cover in the São Paulo State for agricultural areas and for the growth of urbanization, new strategies are being proposed to establish a viable policy for the recovery of river basins [14].

2.2 Fluvial ecology aspects and its relation with sustainable handling

According to Mendiondo [15], a fluvial ecology study must integrate the following concepts: river basin, diversity/dynamics, resilience/vulnerability, continuity, lotic system and floodplain (see *Figure 1*).

2.2.1 Continuity

The continuity of the environment is directly associated to the river flooding phases. During the flood season there is a connection between the river and the floodplain, and the water in this plain receives a lot of nutrients, due to the quick vegetation, animal remains or humification forest layer decomposition. This generates a rapid growth of microorganisms, followed by a boom in the growth of macro invertebrates (insects, crustaceous and mollusks) which feed the fish. The fish biomass rapidly increases during the flood season, and at the end of this period, when the water level lowers, many fish can be caught in ponds (possibly being the feeding source for innumerable birds). Meanwhile, other young fish can return to the main river (possibly suffering later depredation in the channels that connect the plain's lakes to the river) [16].

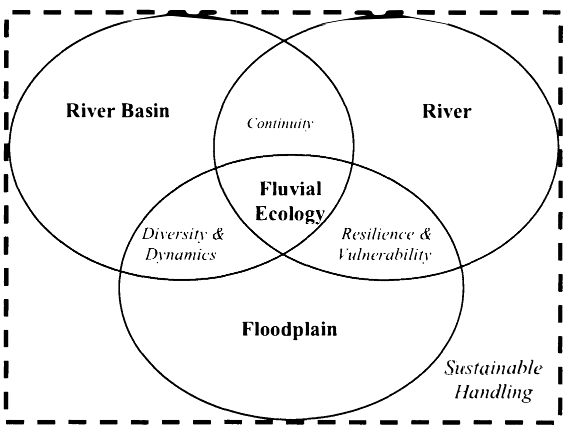


Figure 1. Systems (bold) and operational principles (italic) of the research. Source: [15, 17].

Figure 2 shows a flow hydrograph and its respective flooding phases, where in Phase 1 the river flow increases, but it does not overflow the riverbed. In Phase 2, the river flow reaches its maximum level, and the flooded area has also reached its maximum, at this moment the connection between the river and the floodplain is extremely elevated. Now in Phase 3, where the flow starts to decrease, the inundated area continues flooded due to the ecosystem's resistance.

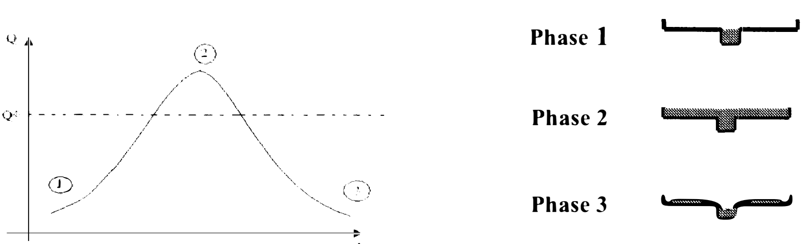


Figure 2. Flood hydrograph and its respective flooding phases. Source: [1].

The ratio between flood area and flow is better exemplified in *Figure 3*.

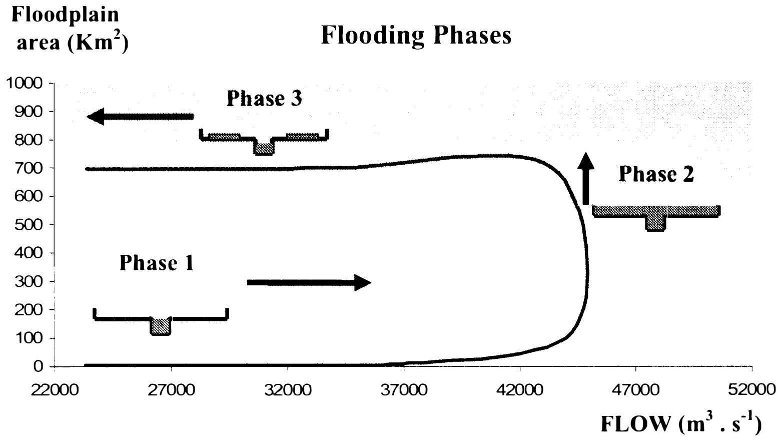


Figure 3. Ratio between floodplain and flow and its respective flood phases. Source: [4].

2.2.2 Resilience and vulnerability

Natural landscapes undergo changes in its structures during extraordinary floodings, without producing drastic modifications in the landscape patterns. This is due to the fact that relief forms of components, plants and animal populations contain a structure that has been selected and adapted for thousands of years. It is also characterized by its plasticity (resistance) and by the capacity of recovering equilibrium after a flood (resilience) (see *Figure 4*). However, if there is intense precipitation, it can generate a high inundation height with elevated duration period thus making it impossible for the floodplain to recover (see *Figure 5*). This is a result of the ecosystem's vulnerability.

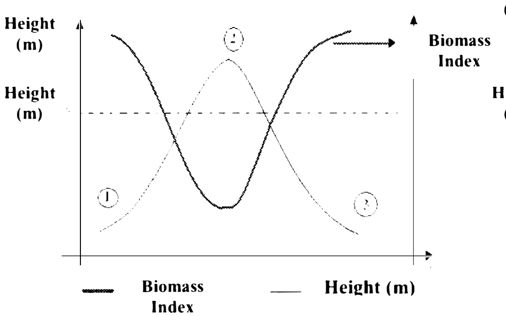


Figure 4. Resilience – ecosystem's recovery capacity. Source: [4].

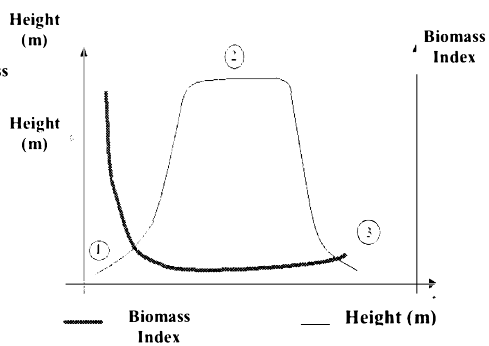


Figure 5. Vulnerability – ecosystem's recovery incapability. Source: [4].

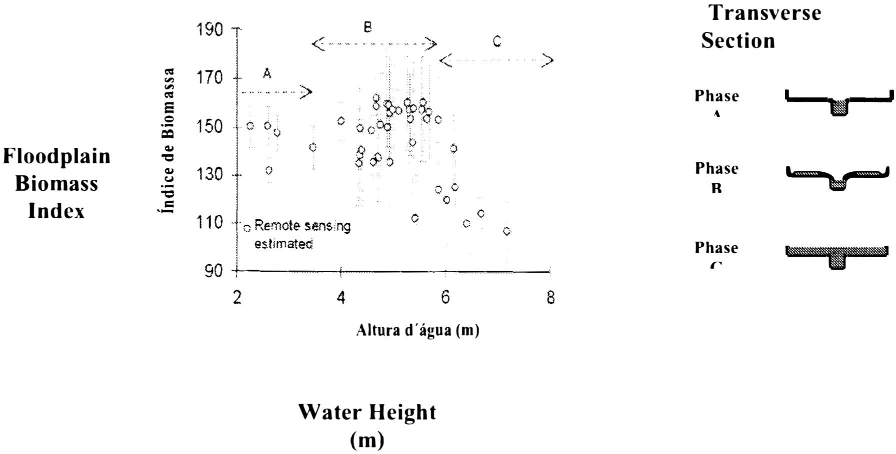


Figure 6. Behavior example of the Biomass Index related to the water height in floodplains Source: [4].

2.2.3 Diversity

The different species of an ecosystem associated to a river respond differently to hydrological events such as floods and droughts. A great flood can benefit a determined species of fish, which develops part of its life in a flooded plain; however, it can reduce the population of aquatic insects, whose larvae are carried downstream. Now, in years with inexistent, or small, floods the opposite can take place, that is, the fish can be less benefited than the insects. The natural hydrological regime provides the ecosystems with a mixture of good and bad years for each species, if assessed individually. Analyzing long periods, each individual species is benefited by a sufficient amount of good years and harmed by only a few bad years, thus maintaining the ecosystem [18]. Diversity can also influence biomass index recuperation of a flood plain. *Figure 7* shows how the biomass index recovers faster when flooding takes place in the preserved areas, while in non-preserved areas the biomass index is lower and its recovery is slower.

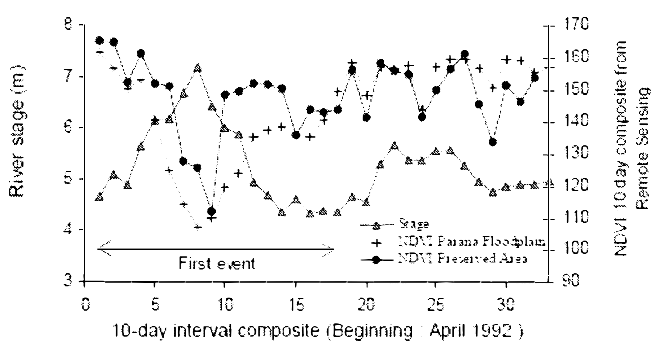


Figure 7. Ratio between biomass index (NDVI) and water layer/level height for preserved and non-preserved ecosystems. Source: [4].

2.3 Ecological flow

The amount of water needed to give ecological sustainability to a river is uncertain in time, and the definition criteria for remaining flow in the rivers must contemplate not only the minimum flow situations in dry periods, but also the other periods that characterize the hydrological regime [16]. The environmental quality of a river and of its associated ecosystems is highly dependable on the hydrological regime, including the magnitude of minimum flow, the magnitude of maximum flow, the drought period, the occurrence time of floods and droughts, among others [19]. In some cases the downstream flow is always superior to the flow defined as "ecological", and nonetheless important environmental damages take place [16].

The environmental impacts that caused greater preoccupation were the impacts from floods of a large forest area and the transformation of a typically river environment (lotic) into a typically lake environment (lentic) and the water quality alterations associated to this transformation. However, throughout time, the impacts caused downstream the dams and from the water collection points for irrigation became more evident. These impacts are almost always associated to modifications in the hydrological regime [16]. The first answer to these impacts was the search for restrictions in the amount of water that could be removed from a river, by means of a minimum flow specification that should remain in the river after all the water removal for human use, called ecological flow [16]. This answer aimed, mainly, to avoid that the remaining flow in the rivers during the droughts was so low that it could result in lack of oxygen for fish and in the consequent extinction of the species, or even its intermittence.

2.3.1 Ecological flow determination methods

Nowadays the ecological flow determination methods can be classified as: hydrological, hydraulic, habitat classification and holistic methods [16]. The hydrological methods do not analyze the environmental aspects, they only suppose that the maintenance of a reference flow, calculated based on some historical series statistic, can bring benefits to the ecosystem. The main advantage of these methods is on the small amount of needed information for its implementation, in general only the historical series of flow can do it. The hydraulic methods relate flow characteristics with the needs of aquatic biota. These methods have a greater ecological consideration than the hydrological ones, but for its correct application, the hydraulic methods require specific ratios for the studied region.

The habitat classification and holistic methods are more complete regarding environmental aspects [20]. These methods contemplate several steps, including identification of physical and environmental characteristics of the study local, an elaborate study plan made by a multi-disciplinary team, up to the analysis of different alternatives before any decision making takes place. These methods can consider economical aspects, valorizing the inclination of paying for environmental preservation and the benefits generated by the water use, seeking the optimal ecological flow quantification [21]. Almeida [4] used two hydrological methods to obtain the minimum flow, described herein:

2.3.1.1 7-day minimum mean flow method with a 10 year recurrence interval ($Q_{7,10}$)

This flow is obtained computing the variable averages from daily mean flows with a 7 day interval throughout the hydrological year. The lowest of this variable averages are retained. The process is repeated for each hydrological year of the historical series, obtaining a series of minimum values of mean flows in 7 consecutive days, for each year. These flows are ordered in growing magnitude order, where its occurrence accumulative probabilities and return period are estimated [20]. From this table, the minimum flow of 7 days with a 10 year return period can be determined. This flow, however, is considered by Stalnaker et al. [22] as being excessively low for the maintenance of aquatic habitats.

2.3.1.2 Flow permanence curve method

This method applies permanence curve values to establish ecological flows on a monthly or annual basis. The permanence curve is calculated by historical flow data, which are ordered in an increasing manner. The permanence of each observed flow is the percentage of times it was equalized or topped [2].

2.3.2 Ecological hydrographs

The great limitation of methodologies based on the concept of ecological, remaining or residual flow, is that these methodologies are focused only on minimum flow. There is no concern in defining other aspects of the hydrological regime that are fundamental to the maintenance of the ecosystems [16]. It can be seen in *Figure 8* that the hydrograph upstream of the reservoir presents seasonal cycles of floods and droughts. In the period presented in the abovementioned figure, only relatively small floods that were completely absorbed in the reservoir take place, in such a way that the flow in Juazeiro does not present anymore recognizable seasonal cycle, making the flow values during the drought and the flood very similar. It can also be seen that, that in no moment did the existence of the reservoir disrespect the criteria for ecological flow. On the contrary, the reservoir's downstream flow during the droughts is even superior to the reservoir's affluent flow. As a result of this modification in the hydrological regime, and the retention of sediment in the reservoir, great changes take place in the fluvial and estuarial environment localized downstream [16].

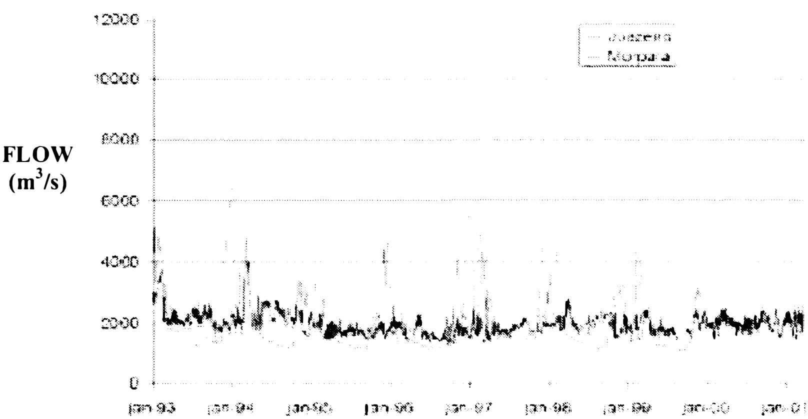


Figure 8. Hydrogram upstream (Morpará – pink line) and downstream (Juazeiro – blue line) the São Francisco River from the Sobradinho reservoir. Source: [16].

Several other variables are associated to the natural hydrological flow regime, such as water temperature, sediment concentration, nutrients and dissolved oxygen [19]. Each component of the hydrological regime is important for maintaining the ecosystems associated to the river; among these components are the droughts, floods, and the time and period of flood occurrence.

2.4 Aspects of the dynamics of floodable areas and its relations with pulse discharge in the rivers

One of the main functions of floodplains is to drain river water [23]. From the ecological standpoint, floodable areas are the ones that periodically receive the lateral inflow from river or lake water, from direct precipitation or from groundwater. The biggest biota controlling force in floodable areas is the river discharge pulse. The lateral exchanges between the floodable areas and the riverbed, as well as the recycling of nutrients inside the floodable plains, have impact on the biota. Still, in the last decades with an accelerated and disordered urban growth, the occupation of these areas was inevitable, bringing loss in environmental and economical order. From the analysis of some parameters, such as biomass index, it is possible to propose environmental recuperation measures for the floodplains. This way, through data obtained by Mendiondo et al. [24], the biomass index of a flooded area from the lower Paraná River was estimated. This area comprises 4,800 Km^2, part of it is preserved and the other part underwent anthropic interference. The difference between the biomass indexes throughout time and even between the two areas, suggests the resilience of the ecosystem, as well as its different responses in the course of time.

According to [25], in the river/floodplain systems, the temporal variability of physical, chemical and biological parameters is greatly accentuated, mainly due to the hydrological oscillations, which are defined according to pulse concept. The hydrological pulses embrace a flood phase and a dry phase, forming a strip of floodable land, situated throughout the main channel of the river that influences the system's physical, chemical and biotical variables [26]. [27] mention that hydrology is the most important phenomenon for the establishment and maintenance of flooded areas and the processes associated to it, attributing as principal function of these ecosystems:

- ✓ Retention and transformation of nutrients;
- ✓ Water quality improvement;
- ✓ Retention of sediments and toxic substances;
- ✓ Refuge and locals for animal reproduction;
- ✓ Absorbance of flood waves;
- ✓ Aquifer recharge;
- ✓ Erosion and silting control;
- ✓ Protection of the coast line, among others.

Many times, due to the unfamiliarity of these functions, great part of the flooded areas are destroyed because of urban growth, however, these losses are not only physical damages to the local, but also economical losses. [28] comment the great occurrence of floods in the confluence area of the Paraguai and Parana Rivers in South America, supposedly caused by the El Nino phenomenon. This author points out that the floodplain ecosystems respond positively to this kind of phenomenon, on the other hand disordered occupation and the lack of familiarity regarding the floodplain's dynamics cause flooding problems, bringing damages to society in a general way. The Prata Basin, due to current land use practices (agriculture, cattle breeding, etc) and to damages caused to flooded areas, suffered an increase in flow in its main rivers, bringing floods about in many locals in the last few years, besides losing soil used for agriculture [12].

2.5 Aspects of integrated handling between water resources and sanitation in urban river basins

Water and the health of the population are inseparable things. The availability of quality water is an indispensable condition for our own life and, moreover, water quality conditions our life quality [29]. In the last two years, in Brazil, around 1,200 cities suffered floods. The first national survey made on this subject showed that 78% of the cities have an urban drainage system, among which 85% dispose of an underground network for collection and transportation of rainwaters. Around 22% of these networks also receive wastewater [29]. As a result of the deposition of large residual loads in the environment, high levels of pollutants change the physical, chemical and biological characteristics of the material's state, which mainly derives from the generation source. The responsibility that should belong to the user is transferred to the public power that, in many cases, adopts palliative solutions, without considering the context of the basin as a whole and the generation sources [30].

2.6 Rainwater handling and reuse of treated sanitary wastewater in urban river basins

According [31] water is classified, legally, in three categories: drinking water (public water supply); inappropriate water for consumption (rainwater, grey water, etc) and wastewater. Rainwater, used in public bathrooms and pools, is limited, because of laws and Public Health rules. Water for public pools and bathrooms must be drinking water. If the rainwater is purified and its quality attends the standards, they can become drinking water. However, instead of being reserved, rainwater is still sent to the collecting network. In Tokyo [31], for example, rainwater constitutes a very important natural resource. For this potential water resource, it is possible to construct a large number of rainwater "mini-reservoirs" in urban areas, which is already being tested in residential lot scale, also allying grass rooftops [32] for retention and execution of a plan for water delivery to be consumed in a system that is independent from the public water supply system.

With the purpose of water resources conservation and considering an integrated management system of the river basin/river/flood plain in urban areas, it is important to control the discharged flow of urban building lots coming from rainfall events. This control contributes to retarding floods in urban basins, minimizing incidence of flooding in flood plain that suffers disordered inhabitation, and therefore diminishing damages induced for this type of event. The vision developed in the "Smart Drainage System", which involves the controlled reuse technology of surface and subsurface water volumes coming from previously treated sanitary wastewater and through safe fertirrigation, also comprises the selective reservation technology of subsurface water volumes through cisterns, for the use of rainwater deriving from the drainage of impermeable areas in urban lots. The "R.U.A." PROJECT aims to incorporate the knowledge of the university obtained from the SCHOOL-BASIN model and from the HYDRO-SOLIDARITY using hydro-territorial inclusion methods that lack the access to adequate knowledge for the preservation and conservation of urban and peri-urban water resources. Its resumed project work plan comprises:

(a) Install decentralized demonstrative R.U.A. experiments, of public utility, good re-applicability in urban areas of Brazilian biomes, that consolidate the monitoring of the hydro balance between offer and demand;

(b) Offer training and qualification of communitarian agents and teachers to encourage the co-guardianship of waters, from the possibilities and limits of the SCHOOL-BASIN concepts; and,
(c) Participate in concrete "university-community" actions creating new associations of peri-urban basin users.

It has also an objective to diffuse simple low cost solutions, decentralized by sub-basins and lot scale, to collaborate with the social inclusion of communities from urban and peri-urban river basins. This project presents a combined solution for the reuse of rainwater by means of selective reservation, and reuse of treated sanitary wastewater by anaerobic biodigestion in septic tanks through the EMBRAPA [12] model biodigestor, which is adaptable to urban and peri-urban areas. The generated effluent, with fertirrigation properties, is potentially destined as a reuse source for garden irrigation. The project needs an area of around 10 m^2, it is also rapidly assembled and executed. It is made up of 3 one thousand liters multi-chambered septic tanks, where the first two chambers are connected, in series, to the toilet and the third chamber is coupled to the first two, it serves for the collection of organic fertilizer that is generated (see *Figure 9*).

The use of the EMBRAPA [33] model biodigestor and of other low constructive cost, simplified operation and maintenance anaerobic reactors is a possible alternative for the pre-treatment of sanitary wastewater, which can possibly decrease organic loads and its variation, which consequently can imply in the decrease of the conventional public system wastewater treatment unit size, as well as in the removal of toxic and/or recalcitrant compounds possibly present in wastewater, and that are not subject to removal in these systems. The rainwater collecting and use system for the building is presented in *Figure 10*, aiming non-potable use. The accumulation reservoir (3) reckons the captivation of the deposit rooftop area and the current existing building; afterwards the volume will be stored and pumped to another superior reservoir inside the building. The distribution takes place through branches for the internal non-potable use in the residence, such as: toilet water, bathroom cleaning, external cleaning of sidewalks and pavement, irrigation and others.

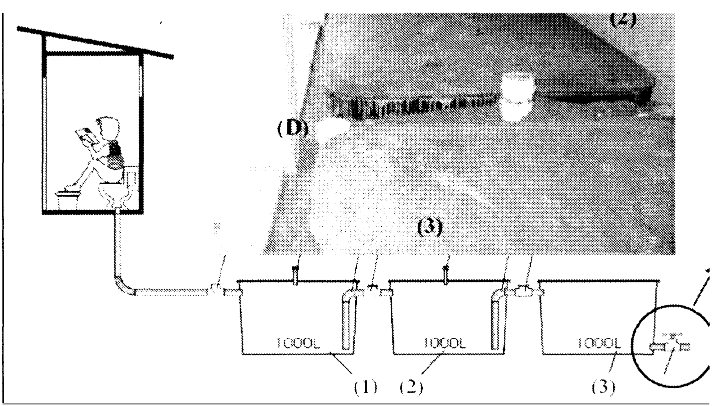


Figure 9. Scheme of the biodigesting patent concrete cesspit and pictures of the tanks (1), (2) e (3). Source: [30].

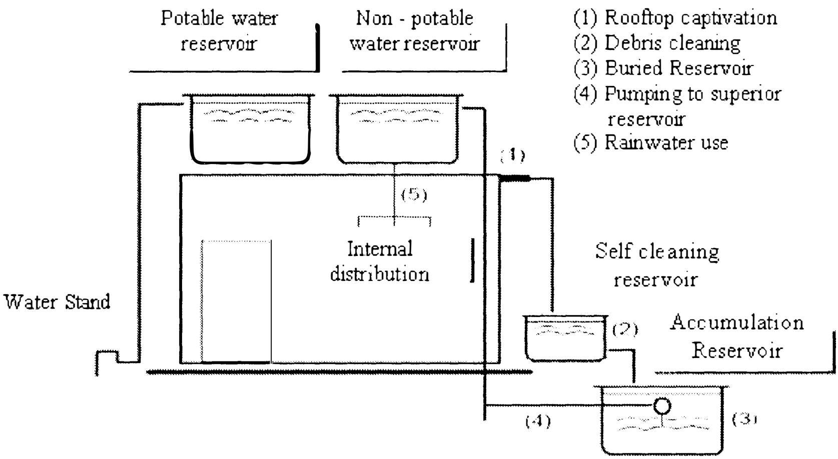


Figure 10. Rainwater use system in an urban lot. Source: [30].

Nowadays, three different rainwater harvesting and handling system are being installed in three different lots of the city of São Carlos, as pilot plants that aiming to evaluate rainwater quality and the levels for rainwater treatment, deriving from three different roof types: ceramics (very usual in brazilian buildings); special tiles made from recycled long life packages; and planted roofs, made of green grass (named "Slight Green Coverage – S.G.C. – see *Figures 11 to 13*).

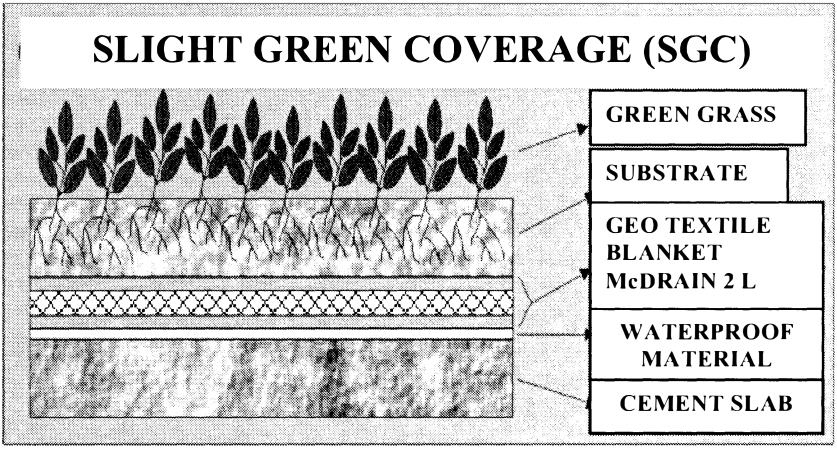


Figure 11. Composition of the "Slight Green Coverageö – S.G.C. Source: [32].

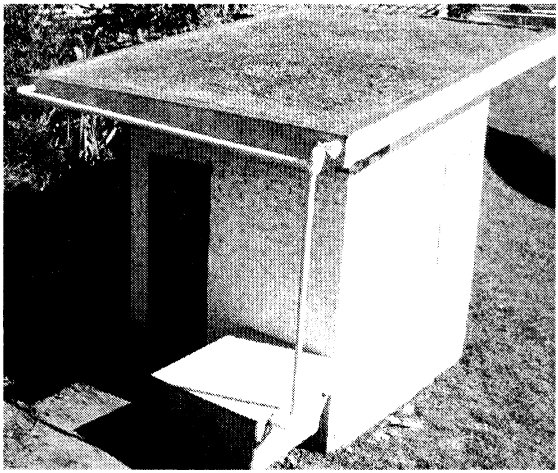


Figure 12. The "Slight Green Coverage"- S.G.C. Source: [32].

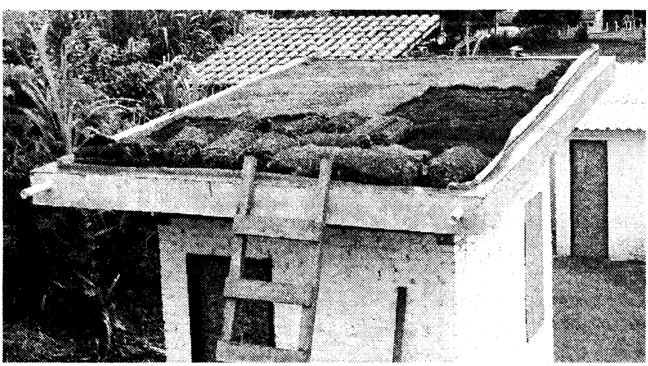
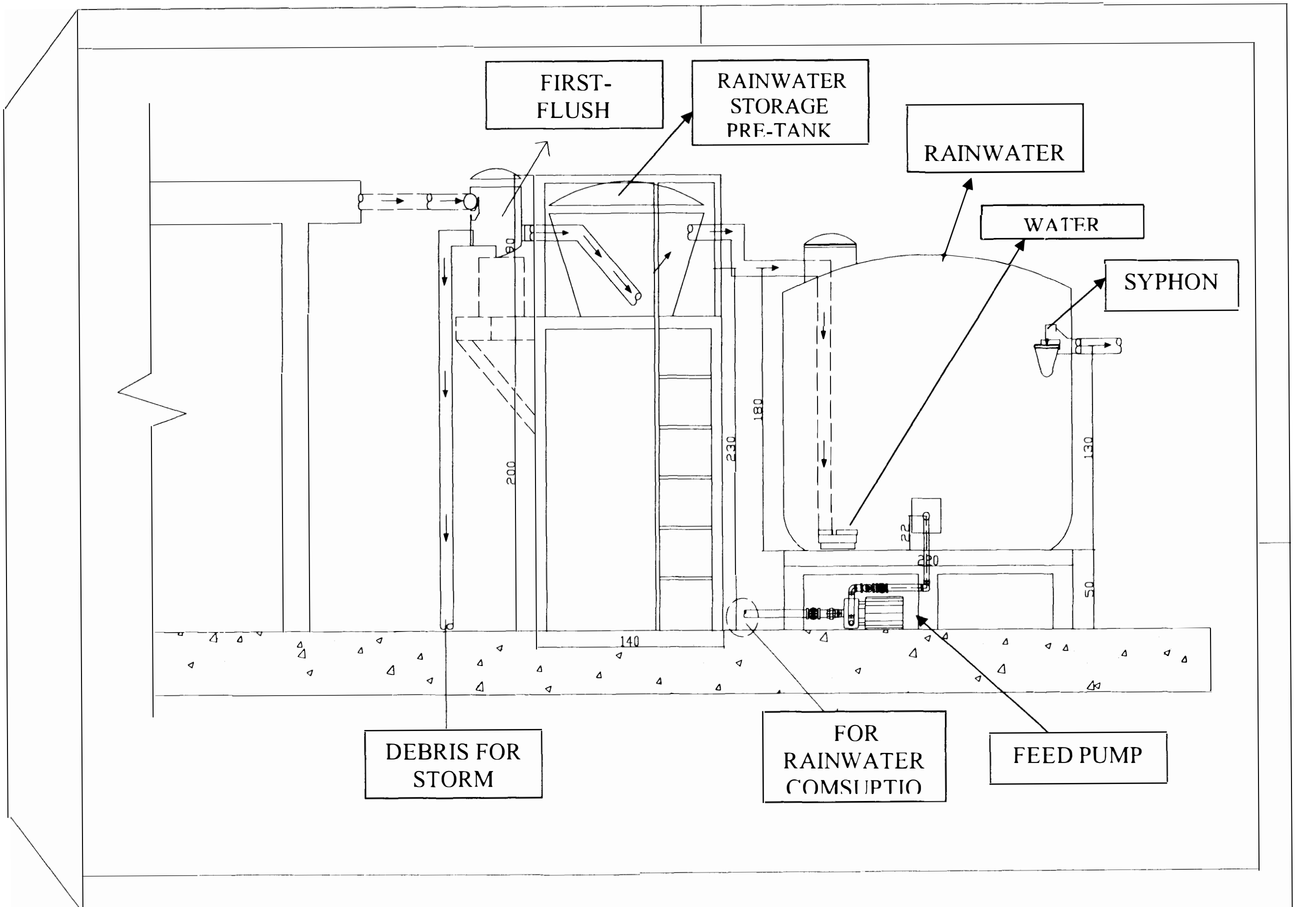


Figure 13. The "Slight Green Coverage"- S.G.C. - Assembling details. Source: [32].

The system is composed by gutters that collect rainwater from rooftops and direct them to a self cleaning reservoir, decreasing pollutants load for the accumulation reservoir. There is still a filter to remove debris such dead leaves, branches and dead animals directing the rainwater to the rainwater sewer. In the outlet of accumulation reservoir there is a column filter through all influent rainwater passes. Thus, all rainwater derived from accumulation reservoir present minor risks to the users due to its better quality (see *Figure 14*).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FLUSH
RAINWATER
STORAGE
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22
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140
DEBRIS FOR
STORM
FOR
RAINWATER
COMSUPTIO
FEED PUMP

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