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SUBSURFACE IRRIGATION OF ARBORIAL AREAS AS A MECHANISM FOR CARBON SEQUESTRATION THROUGH TREATED SANITARY WASTEWATER AS A RADICULAR NUTRIENT SOURCE

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ABSTRACT

Based on a research developed in the USA [1] for the subsurface irrigation of redwood forests (*Sequoiadendrum Gigantea*), this paper analyzes treated sanitary wastewater reuse as an alternative for carbon sequestration and oxygen generation through root assimilation of nutrients inside them, at rates that consider the transpiration, evapotranspiration and subsurface infiltration processes in arboreal areas of urban lots. Through buried ecochambers, the tree roots make contact with treated sanitary wastewater (stored in tanks in case its flow exceeds the evapotranspiration capacity of the arboreal area), and pumped according to its seasonal transpiration rate. This arboreal area will act as a nutrient pump to evapotranspirate purified water and oxygen while sequestrating carbon dioxide from its roots, without collecting, pumping, treatment and disposal of sanitary wastewater by the public systems, acting as a “Smart Drainage System” which comprises a local sanitary wastewater treatment, as well as the selective rainwater reservation at the urban lot, for multi-useful profits, such as: garden irrigation, sanitary installations, floor and pavement washing, among others.

KEYWORDS

Reuse; Urban waters; Carbon sequestration.

1 INTRODUCTION

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 could aim small scale decentralized measures, for example, in an urban lot. Thus, a preventive approach for the preservation of water resources from the urban basin where the lot is localized would be presented, also considering that sanitation technologies can be adapted to social-environmental purposes, regarding human and environmental health, safety for the user of the device and/or system, and economical aspects [2].
Also 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

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based on determined fundamental principles, such as: availability, in all urban areas, 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.

Such principles fundament in greater or smaller degree the conception of this article, being principles that will be able to permit the construction of a new vision, marked by a greater interaction between aspects of drainage/handling of rainwater and sanitary aspects (which is called "Smart Drainage System"), mainly based on the "integration of infrastructure and services [of basic sanitation] with an efficient water resources management", such a vision would be different from the one that has been focused up to now, even though "the water resources do not integrate the public services of basic sanitation (4th Article)".

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 [3].

Aiming to preserve natural resources, the health of aquatic environments and the human health, as well as following norms and legislations regarding effluent emission standards, pollution prevention or the minimization of waste generation in the source must be allied to the development of advanced technologies for its treatment. Sanitary wastewater cannot be considered only as waste and be disregarded; it must be reused, endowed with economical value, after adequate treatment [4]. Also the rainwater collected in the lot, properly stored and conveniently and adequately treated, can serve several purposes, such as garden irrigation, sanitary installations, floor and pavement washing, among others.

Inside this aim, the current article analyzes the reuse of treated sanitary wastewater as an alternative for carbon sequestration and oxygen generation through radicular assimilation of nutrients inside them, at rates that consider the processes of subsurface infiltration, transpiration and evapotranspiration, in arboreal areas of urban lots.

Through buried ecochambers, the tree's roots are in direct contact with treated sanitary wastewater (stored in tanks in case its flow exceeds the evapotranspiration capacity of the arboreal area), which is pumped according to its seasonal transpiration rate. This arboreal area will act as a nutrient pump to evapotranspirate purified water and oxygen while sequestrating carbon dioxide from its roots, eliminating the necessity of collection, pumping, treatment and disposal of sanitary wastewater by the public systems, acting as a "Smart Drainage System" which comprises an *in loco* sanitary wastewater treatment, and also the treatment and the selective rainwater reservation at the urban lot, for multi-purpose uses, such as: garden irrigation, sanitary installations, floor and pavement washing, among others.

2 BIBLIOGRAPHICAL REFERENCES

According to [5], 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.
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 [6]. 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 [7]. 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 [8].

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 [9]. 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 [10].
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 [11].

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 [12].
As a result of the depositing 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, adopt palliative solutions, without considering the context of the basin as a whole and the generation sources [13].
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 [12].

According to [14], water is classified, legally, in three categories: drinking water (public water supply); inappropriate water for consumption (rainwater, gray 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 [14], 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 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.

3 METHODOLOGY

According to [1], the proposed system seeks to serve as a complementary unit for an existent liquid residual treatment facility, however not seeking to direct it to existing collection, treatment, storage and final disposal system. It can, however, offer a solution that can be transferred to other treatment facilities in different locals in a same region, or even at a state or international level. It basically consists on taking wastewater and using it as a nutrient solution for the growth of forests, through subsurface irrigation, not using surface-spray irrigation methods, hence practically eliminating the possibility of pollution and/or contamination picked up by wind currents. The system can have its capacity increased in two ways:

- Long term: the system's capacity can be regularly incremented throughout time, according to the forest growth;
- Short term: as subsurface irrigation is not so inhibited due to severe weather, contrary to surface irrigation, a significant dispersion can take place in the winter, except during precipitation events that generate surface runoff.

In this system, the effluent is guided to the radicular zone of the trees by means of buried ecochambers made of PVC plastic pipes or HDPE, with a 30 cm diameter, and length of 75 cm. The volume of each chamber is of about 57 liters (*Figures 1 and 2*).

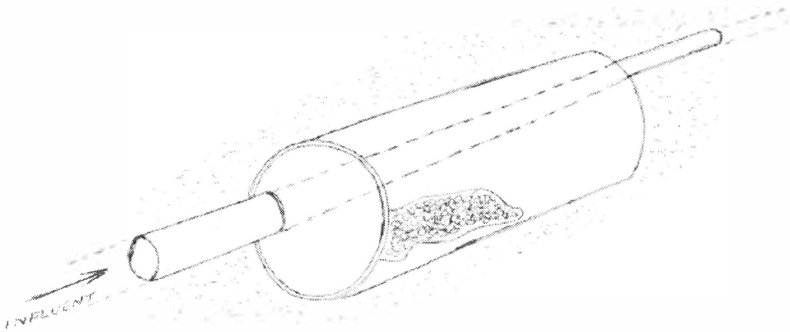

Figure 1. Buried ecochamber destined to the dispersion of treated sanitary wastewater in the trees' roots. In the detail, the internal filling of the buried ecochamber can be seen with sequoia bark, which allows a closer contact of the liquid phase with the roots of the trees.

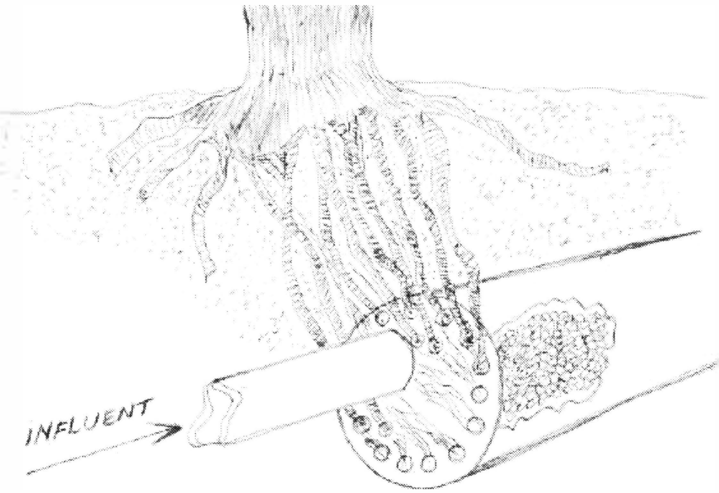

Figure 2. Detail showing the insertion of roots through perforated diaphragms in the extremities of the buried ecochamber.

The treated sanitary wastewater can be stored in tanks, in case its flow exceeds the evapotranspiration capacity of the arboreal area. If such storage is indeed necessary, for safety it is convenient, after appropriate analyses of total and fecal coliforms concentration, to conduct the disinfection of the treated sanitary wastewater, which will be briefly commented in item 3.1 below. Once disinfected, the treated sanitary wastewater can be pumped according to the seasonal transpiration rate of the arboreal area. This storage capacity can be decreased when the size of the forest increases, due to the increase in the feeding demand. The pumping cycle can be established according to the buried ecochambers' storage capacity and the seasonal transpiration rate of the forest.
According to the research, several advantages come from the use of buried ecochambers regarding:

1) The use of infiltration trenches;
2) Water runoff directly over the soil;
3) Surface-spray irrigation.

Water is distributed on the soil without any direct physical impact, as well as without any flow impact, at a rate in which the soil and the trees can assimilate it. The entanglement of the vegetable surface, caused by the excessive surface moistening throughout time is avoided by depositing vegetable cover that acts as a protection barrier for the surface. The compacting of the surface by the energy resulting from the falling water drop is avoided through subsurface application. Besides, subsurface application does not allow the direct contact of human beings or animals with the effluent, such contact can occur due to surface flooding, surface runoff or aerosol formation.

The ecochambers are buried 45 cm deep at 3 m intervals. A tree is planted over each ecochamber. The ecochambers are filled with treated sanitary wastewater, which passes through the root zone of the trees. The trees send feeding roots toward the ecochambers as their source of nutrients and water. Pipes carry treated sanitary wastewater from one ecochamber to another, as it can be seen in *Figures 1 and 2*.

3.1 Disinfection as a preventive measure in the quali-quantitative management of water resources in urban basins

According to [15], there are a large number of water-borne diseases in Brazil resulting from the lack of an efficient treatment for the removal of pathogenic agents present in water. Thus, to ensure the control of these water-borne diseases and to maintain the quality of the water that will be supplied to the community, the disinfection process becomes indispensable.

The same author affirms that chlorination is widely used for the disinfection of supply and waste water; however its toxicity potential caused by its products makes the process less attractive. Now, the use of chlorine dioxide presents itself as an alternative, nonetheless its generation involves reactions that are dependant on reagent concentrations, on physical-chemical conditions, where it can generate byproducts that are harmful to the human health. Therefore, other alternative technologies, such as ozone and UV radiation arise as technically viable processes. In the aspects observed during the research, it was seen that, for the analyzed conditions, UV radiation disinfection was the most simple and efficient technique for total and fecal coliforms inactivation when compared to ozonation, presenting several favourable aspects regarding the operation method, the quality influence in the raw effluent and the process control, among others [15].

For the selection of the most appropriate disinfection technique, social, technical and economical factors must also be taken into account. Social organizations, capacity and available infrastructure influence the choice of disinfection alternatives in a way that the chosen system is not always the most efficient one, but the one that is most adequate to the situation [15].

Such aspects may bring incitement to the development and application of environmental sanitation technologies that consider: operational simplicity and practicability, with little or no need for user intervention; user's safety; and the economical aspects, considering that a sufficiently diffused use of this technology brings a reduction in equipment or apparatus cost used for the sanitary waste and rainwater treatment, through economy of scale.

This way, the use of UV radiation by LEDs can comprise an efficient alternative, safe (regarding environmental as well as human health), and economically viable, bringing benefits to the population. This new technology that uses UV radiation is being developed by researchers from The Optics and Photonics Study Center (CEPOF) from the São Carlos Physics Institute (IFSC) from São Paulo University (USP) in São Carlos, SP. Combining the already known effects of UV radiation with LED emitters, great benefits can be brought if the urban lot scale is made feasible.

4 RESULTS AND DISCUSSION

4.1 Capacity analyses and water balance

Using a sample of a Wastewater Dispersal and Redwood Forest Evapotranspiration System that was planted in 1979 in Martinez, CA, the following can be disclosed (*Table 1*):

Table 1. Tree age correlation and its evapotranspirative capacity.

Year	Tree Age (in yrs)	Used Water Volume (Evapotranspirative capacity) (m^3/day/tree)
1979	2	0.1703
1980	3	0.2082
1981	4	0.2498
1982	5	0.2877
1983	6	0.3293
1984	7	0.3672
1985	8	0.4088
1986	9	0.4467
2017	*40*	*1.8927*

Table 1 shows the correlation between the age of the trees and their evapotranspirative capacity. The trees had more than quadrupled their average height in 7 years, from 5 feet (around 1.52 m) at planting in January 1979, to 23 feet (around 7 m) in 1986. *Table 1* also foresees the growth for 2017, when the trees will have reached the age of 40 and will then be able to use 500 gpd or 1.8927 m^3/day/tree.

It is also possible to show, according to the authors, that carbon sequestration rates, while different than evapotranspiration rates, are similar in their scale as the tree matures. The water in the tree is a transport system for minerals which are converted into cellulose, releasing oxygen to the environment.
The research carried out by The Ed Burton Company considered a flow of treated sanitary wastewater of 5000 gallons/day/acre (19.38 m^3/day), and a final project flow of 7500 gallons/day/acre (28.39 m^3/day) to attend the redwood forest (*Sequoiadendrum Gigantea or Sequoiadendrum semperviren* – the Canadian redwood). There are plans, once again according to the authors, to develop the cultivation of 400 acres of forest, therefore being able to receive 3 million gallons.day^{-1} (11,356 m^3/day) of treated sanitary wastewater. There are a number of variables that must be taken into account including the sandy and loamines of the soil and its ability to absorb water.

4.2 Forest transpiration and the carbon sequestration process

For them to be effective in the final disposal of treated sanitary wastewater, the species planted in the Forest Evapotranspiration System must transpire all year long and they must be tolerant to wide soil mixture variations, especially excesses. Coastal Redwoods (*Sequoiadendrum sempervirens)*, are highly suitable for these conditions. Smaller plantations of *Sequoiadendrum Gigantea* can also be included.

The authors comment that Redwood trees are giant nutrient pumps that lift water out of the ground and convert carbon dioxide into biomass while giving off oxygen and transpiring pure water vapor. The evapotranspiration capacity of a mature individual redwood tree has been reported to be as high as 1.9 m^3/day. Still according to the authors, around 1000 g of green wood contains 500 g of dry wood which is composed of 295 g of carbon. For most estimates one can assume that about 1/3 of the green weight of wood is carbon which is sequestered. Or expressed in another way, 45.32 kg of green wood has sequestered 15.12 kg of carbon. This mass includes the total weight of the redwood tree, including; trunk, branches and roots.

To be applied in Brazil, it would be convenient to assess what arboreal species would be more appropriate to the application of currently treated sanitary wastewater, with performances that would be comparable to the American or Canadian Redwood, so the maximum possible performance could be obtained in terms of evapotranspiration, carbon sequestration and forest growth.

4.3 "Smart Drainage System" aspects regarding the use of rainwater in urban lots and its interactions

The vision developed in the "Smart Drainage System", which involves the controlled reuse technology of 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.

In this new conceptual approach, the "R.U.A. (Water Use Rationalization) HydroSolidary Project: 'School-Basin' as Social Inclusion Action in the Urban and Peri-Urban Mean", currently under development by the NIBH (River Basins Integrated Nucleus), of the São Carlos Engineering School in the São Paulo University (EESC – USP), has as 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 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 $10m^2$, 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. (*Figures 3 and 4*).

The use of the EMBRAPA 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 4*, 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.

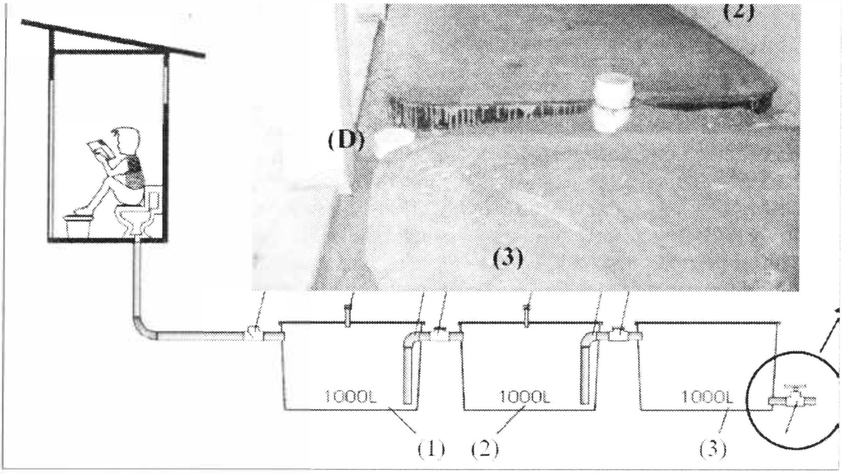

Figure 3. Scheme of the biodigesting patent concrete cesspit and pictures of the boxes (1), (2) e (3). [16].

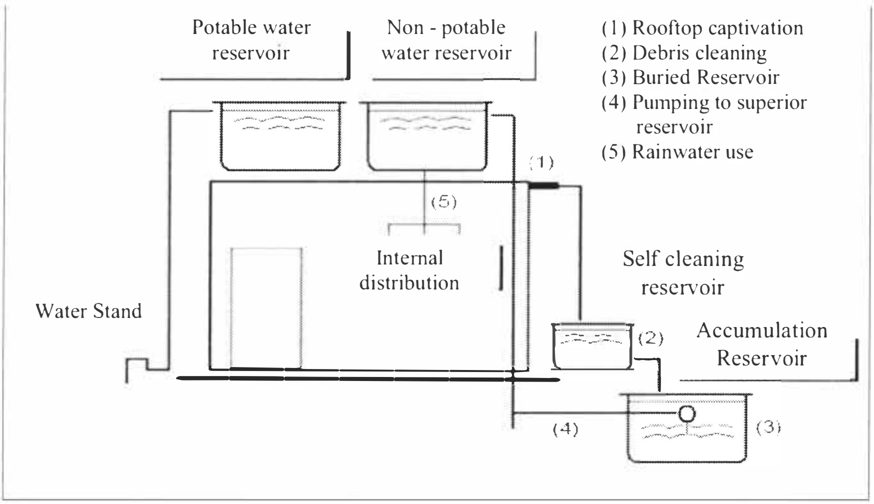

Figure 4. Rainwater use system in an urban lot [16].

5 CONCLUSIONS

Subsurface irrigation of American and Canadian Redwood Forests (*Sequoiadendrum Gigantea* e *Sequoiadendrum sempervirens*) through the reuse of treated sanitary wastewater, presents itself as a current alternative for carbon sequestration, as well as a treated sanitary wastewater post-treatment proposal from the radicular assimilation of nutrients present in them, at rates that consider the subsurface infiltration, transpiration and evapotranspiration processes in such forests, hence eliminating the need for collection, pumping, treatment and final disposal of wastewater, for the carrying out of post-treatment in public systems. The application of this method can be analyzed for Brazilian environmental conditions, adjusting, for example, the arboreal areas in urban lots to the integrated "Smart Drainage System".

The "Smart Drainage System" also comprises the decentralized sanitary wastewater treatment generated in urban lots through biodigestors and other low constructive cost, simplified operation and maintenance anaerobic reactors, allied to the properly applied LED-UV radiation disinfection technology. Comprising an integral, quali-quantitative and decentralized management of 'detention' and 'retention' concepts in lot scale, the "Smart Drainage System" encloses, in a first step, detention, using the selective reservation of surface water volumes technology, by means of cisterns to use rainwater coming from urban lots impermeable drainage areas; and in a second step, it encloses retention, using 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.

REFERENCES

[1] The Ed Burton Company, 2006. Wastewater Forests. Available at: http://www.edburtoncompany.com/wforest/WASTEWATERFORESTS.pdf. Acess: January 1th, 2007.

[2] Galavoti, R. C., Ohnuma Jr., A. A., Andrade, J. P. M., Mendiondo, E. M., 2007. Sanitation Technologies as Decentralized Steps for the Preservation of Water Resources in Urban Basins. VII Encontro Nacional de Águas Urbanas, Associação Brasileira de Recursos Hídricos (ABRH). São Carlos, S. P. (in Portuguese).

[3] Benetti & Bidone, IN: TUCCI, C. E. M., 2001. Hydrology - Science and Application. ABRH Water Resources Collection. Brazilian Water Resources Association (ABRH), vol. 4, EDUSP/ABRH, 1993: 943p., Brazil (in Portuguese).

[4] Ferreira, I. V. L., 2005. TiO_2 Heterogeneous Photocatalysis In Secondary Wastewater Treatment. Ph.D. Thesis. School Of Engineering of São Carlos, University Of São Paulo, Brazil (in Portuguese).

[5] Mendiondo, E. M., Martins, E. S. R. P., Bertoni, J.eC., 2002. Hydrological Uncertainties Management Aiming for Water Policies to the Integrated Handling of River Basins. In: XIX Congreso Nacional del Água, Villa Carlos Paz, Córdoba, Argentina – Anales – 13 to 16 August, 2002.

[6] Tucci, C. E. M., 2002. Urban Drainage Management. In: Brazilian Water Resources Review, ABRH, Porto Alegre, v/7, n.1, Jan./Mar.2002, p.5-28, 2002. (in Portuguese).

[7] Haughton, G., Hunter, C., 1994. Sustainable Cities. Regional Policies and Development Series 7. Jessica Kingsley Publishers and Regional Studies Association, 357 p.

[8] Tucci, C. E. M., 1998. Hydrological Models, 1ª ed., Editora da Universidade, 669 p. (in Portuguese).
[9] Dias, L.E. & Griffith, J.J. Conceptualization and Characterization of Degraded Areas. In: Dias, L.E.& Mello, J.W.U. (eds.). Recovery of Degraded Areas. Viçosa: UFV, Brazil, p. 1-7, 1998. (in Portuguese).
[10] Benini, R. M., Mendiondo, E. M., Martioli, C., Tonissi, F. B., 2003. Environmental Scenarios Aiming Mitigation Of Floods Due To The Implantation Of Campus II - USP, São Carlos – SP. M. Sc. Dissertation. SHS-EESC-USP, São Carlos, SP, Brazil, 122p. (in Portuguese).
[11] Chaudhry, F. H., 2000. Water Resources Management. In: Castellano, E. G.; Chaudhry, F. H. (eds.). Sustainable Development: Problems And Strategies. School Of Engineering of São Carlos, University Of São Paulo, Brazil (in Portuguese). São Carlos, p. 27 – 37 (in Portuguese).
[12] PAHO/WHO – Water and Health, 1998. Washington, D.C. Available at: http://www.idec.org.br/. Acess: July 12th, 2007.
[13] Ohnuma Jr., A. A., 2006. Unconventional Measures of Water Reservation for Pollution Control in Urban Lots. Qualification Report. São Carlos, SP. 40 p. São Carlos/SP - School Of Engineering of São Carlos, University Of São Paulo, Brazil – 199 p. (in Portuguese).
[14] Fendrich & Oliynik, 2002. Rainwater Management Handbook: 100 Easy-To-Use Ways. 1ª Edition. 190 p. Editora Chain. Curitiba, PR. (in Portuguese).
[15] Dias, V. D., 2001. Alternative Methods for the Disinfection of Wastewater Secondary Effluents Applying Ultraviolet Radiation and Ozone. Dissertation (Master) – School Of Engineering of São Carlos, University Of São Paulo, Brazil. 150 p. (in Portuguese).
[16] Ohnuma Jr., A. A., 2005. Scenarios of Rainwater Reuse and Control of Urban Drainage to Environmental Recovering the Alto Tijuco Preto Micro Basin, São Carlos-SP, Brazil. Dissertation (Master). São Carlos/SP - School of Engineering of São Carlos, University of São Paulo, Brazil - 199 p. (in Portuguese).