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# Urban Water Quality after Flooding

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## 1. Introduction

Brazilian's growing urban areas present a threat to surface water and ground water quality. As urban areas grow, streams and aquatic systems, and ground water resources can be adversely affected. Urban development can increase the quantity of impervious surfaces (i.e. roads, parking lots) which prevents storm water from infiltrating the soil. Runoff draining from developed areas may also carry pollutants from impervious surfaces into storm drain systems and nearby streams. One of major aspects of urban flood hazards is related to the water quality after urban flooding. It is necessary to treat contaminated runoff, but depending on the contaminants present this process can be very costly especially when compared to its benefits. In fact, the first flush concentration of storm water runoff is significantly higher than the average or tail concentrations, which imposes several physical, chemical and biological impacts on receiving waters, only compared to primary water sewerage. When a city is planned so that each court, blending or condominium has a reserved area for the construction of a small device for flood control, both the cost to its construction as its integration with the landscape, can be optimised. However, in highly populated cities and with few open spaces, that is, in such ultra urban environments, there are required solutions less conventional, with high costs associated with and without a guarantee of effective control over the magnitude and extent of urban flooding. The water pollution in an urban basin may be diffuse or concentrated. The diffuse pollution is quite difficult to evaluate, as it comes from different areas of the urban watershed. Also it is very important to evaluate the behaviour of water quality parameters from concentrated sources. In this work we discuss the main aspects of urban water pollution and the methods and models employed to minimise the associate hazards. Nowadays measures known as BMP (Best Management Practice) and LID (Low Impact Developments) are used distributed over the urban basin in order to promote flood attenuation and to achieve water quality. These measures will be only enumerated in this chapter. The methodology developed by Driver & Tasker (1990) is revisited and then applied to a case study on the most traditional river of Rio de Janeiro. The results are commented on the uncertainties involved in the process of regionalization and also the need to implement the environmental monitoring of the sites studied. A second case study presents the construction and operation of two sand filters of the Washington DC type, showing the advantages and disadvantages of the sites selected. Although the municipality has not a relevant environmental regulations requiring the

construction of BMPs, as the problem of launching raw sewage is still the biggest problem of Brazilians urban basins, these filters are being tested under conditions of severe load because of deficient street sweeping.

## 2. The Problem

The research on pollution caused by runoff in urban areas has a long history in some countries of the world, but in Brazil is still in an early stage. In this chapter will be presented examples of the application of control devices following the U.S. standards; for that reason it was decided to present briefly, in this section, the history of events in the U.S. specifically on the control of diffuse pollution.

The Clean Water Act is the primary federal law in the United States governing water pollution. Commonly abbreviated as the CWA, the act established the symbolic goals of eliminating releases to water of high amounts of toxic substances, eliminating additional water pollution by 1985, and ensuring that surface waters would meet standards necessary for human sports and recreation by 1983. Point sources may not discharge pollutants to surface waters without a permit from the National Pollutant Discharge Elimination System (NPDES). This system is managed by the United States Environmental Protection Agency (EPA) in partnership with state environmental agencies. A growing body of research during the late 1970's and 1980's indicated that storm water runoff was a significant cause of water quality impairment in many parts of the U.S. In the early 1980's EPA conducted the Nationwide Urban Runoff Program (NURP) to document the extent of the urban storm water problem. The EPA agency began to develop regulations for storm water permit coverage, but encountered resistance from industry and municipalities, and there were additional rounds of litigation. In the Water Quality Act (1987), the Congress responded to the storm water problem by requiring that industrial storm water dischargers and municipal separate storm sewer systems (often called "MS4") obtain NPDES permits, by specific deadlines. The permit exemption for agricultural discharges continued, but the Congress created a non-point source pollution demonstration grant program at EPA to expand the research and development of non-point controls and management practices. The 1987 WQA expanded the program to cover storm water discharges from municipal separate storm sewer systems (MS4) and industrial sources. Many states administer the NPDES program with state statutory and EPA authorisation. The MS4 NPDES permits require regulated municipalities to use Best Management Practices to reduce pollutants to the Maximum Extent Practicable. The report "National Inventory of Water Quality" delivered to the Congress in 1995 said that 30% of identified cases of impacts on water quality are attributed to discharges of runoffs or distributed sources. Some of the cities in the U.S. and developed countries, that success in collecting and treatment of wastewater, according to new surveys have shown that the diffuse sources of pollution have become the major cause of degradation of the quality of surface water (Driscoll et al., 1990; US EPA, 1983). Moreover, the runoffs may contain significant amounts of toxic substances. Even after detailed investigations, there are still many uncertainties about the process of pollution generated by runoffs. These uncertainties reflect the lack of intensive field surveys for verification. The processes of diffuse origin are inherently complex and difficult to model because of the stochastic nature of the phenomenon. It is therefore to be expected that the studied process can not be predicted from a purely deterministic way. However, from the viewpoint of

engineering or management, the deterministic models (empirical) will continue to be very useful. The integrated management of urban flooding should cover both aspects of quantity as of quality of urban flows. The quantity controls reached a level of maturity due to efforts conducted in the past. The quality controls remain in the early stage of development. The human activities are already the most recognised as the most important affecting the quality, such as urbanisation and agriculture. In fact, most human activities seriously impact the flows because of the imperviousness processes of the surfaces. The success of a program to control pollution lies, among other aspects, in the systematic collection of environmental data and also consistent modelling of the processes of generation, accumulation and transport of pollutants.

## 3. Watershed Protection Approach (WPA)

### 3.1 Generalities

According to US EPA (1995) the WPA is a strategy for effectively protecting and restoring aquatic ecosystems and protecting human health. This strategy has as its premise that many water quality and ecosystem problems are best solved at the watershed level rather than at the individual water body or discharge level. The WPA allows managing a range of inputs for specific outputs. It emphasises all aspects of water quality including chemical water quality (e.g., toxicants and conventional pollutants), physical water quality (e.g., temperature, flow, circulation, ground and surface water interaction), habitat quality (e.g., channel morphology, substrate composition, and riparian zone characteristics), biological health and biodiversity (e.g., species abundance, diversity, and range) and subsurface bio-geochemistry. The Watershed Protection Approach has four major features: targeting priority problems, a high level of stakeholder involvement, integrated solutions that make use of the expertise and authority of multiple agencies, and measuring success through monitoring and other data gathering. To be comprehensive, the approach requires consideration of all environmental concerns, including needs to protect public health (including drinking water), critical habitats such as wetlands, biological integrity and surface and ground waters. This involves improved coordination among federal, state and local agencies so that all appropriate concerns are represented. Watershed protection provides states with a framework for protecting their watersheds and addressing all priority problems, not just those most readily solved. States already implementing a Watershed Protection Approach anticipate many benefits, including:

- More direct focus by stakeholders on achieving ecological goals and water quality standards rather than on measurement of program activities such as numbers of permits or samples;
- Improved basis for management decisions through consideration of both traditional stressors (e.g., toxins from point sources, biochemical oxygen demand, nutrients) and non chemical stressors (e.g., habitat loss, temperature, sediment, low flow);
- Enhanced program efficiency because activities such as monitoring or permit writing are focused on a limited number of watersheds at a time;
- Improved coordination among federal, state and local agencies and other organisations, including increased data sharing and pooling of resources;
- Enhanced public involvement, including better relations with permitted due to increased involvement and greater consistency and equitability in permit conditions;

- Innovative solutions such as ecological restoration, wetlands mitigation banking, and market-based solutions (e.g., pollutant trading or restoration in lieu of advanced wastewater treatment) (US EPA, 1995).

The features of the WPA include a strong monitoring and evaluation component. Using monitoring data, stakeholders identify stressors that may pose health and ecological risk in the watershed and any related aquifers, and prioritise these stressors. Monitoring is also essential to determining the effectiveness of management options chosen by stakeholders to address high-priority stressors. Because many watershed protection activities require long-term commitments from stakeholders, stakeholders need to know whether their efforts are achieving real improvements in water quality.

### 3.2 Source Water Protection

Source water can be simply defined as any water (surface or groundwater) that is used as a drinking water source by a Public Water Supply (PWS) system. Source water protection is a pollution prevention approach that includes the protection of rivers, lakes, streams, and groundwater that serve as a supply of public drinking water (US EPA, 1995). Pollution prevention and the source water protection approaches rely on two key concepts: a clear state lead in the development of source water protection programs and a strong public involvement in the development process. Source water protection can be a cost-effective alternative to the conventional practice of treating water exclusively at a drinking water treatment facility. Drinking water standards for PWS systems are much more stringent than the current ambient water quality standards for surface water bodies. For source water protection to work, ambient water quality standards for watersheds that supply drinking water reservoirs will have to become more stringent. As the water quality standards for the streams become more rigid, the regulation of runoff from highways and other facilities within the watershed will too. No significant advances have been made in water pollution control with the management and monitoring of point sources of pollution required by national standards. Now, the great majority of Brazilian rivers and streams, located at developed states/cities, still remain too polluted for fishing, swimming, and other recreational uses. The primary causative agent is the direct sewage spill, and the second main impact is the non-point sources of pollution such as silt, fertiliser, and storm water runoff. Many studies have recognised other causes of impairment including sewage from combined sewer overflow, disease-causing bacteria, toxic metals, and oil and grease (US EPA, 1995; Burton & Pitt, 2002). To address these pollutants, the National Water Agency of Brazil (ANA, 2004) is promoting a new integrated program called the watershed protection and soil conservation. The watershed protection approach is a comprehensive approach to water resource management that addresses multiple water quality problems, such as non-point source pollution, point source pollution, and habitat degradation. Watershed approach is likely to result in significant restoration and maintenance of water quality because of their broad range and focus.

### 3.3 Pollution Sources

Runoff pollution occurs every time rain or snowmelt flows across the ground and picks up contaminants. It occurs on farms or other agricultural sites, where the water carries away fertilisers, pesticides, and sediment from cropland or pastureland. It occurs during forestry

operations (particularly along timber roads), where the water carries away sediment, and the nutrients and other materials associated with that sediment, from land which no longer has enough living vegetation to hold soil in place.

This chapter, however, focuses on runoff pollution from developed areas, which occurs when storm water carries away a wide variety of contaminants as it runs across rooftops, roads, parking lots, construction sites, golf courses, lawns, and other surfaces in our cities and suburbs. The oily sheen on rainwater in roadside gutters is but one common example of urban runoff pollution.

Major sources of pollutants on highways are vehicles, dust fall and precipitation. Other possible, but less frequent, sources include accidental spills of oil and gas, and losses from accidents. Roadway maintenance practices such as sanding or the use of herbicides on highway right-of-ways, may also act as sources of pollutants. Kobringer (1984) provides a list of common highway runoff constituents and their primary sources.

The nature and extent of pollutant accumulation is affected by the following variables (Gupta et al., 1981): Traffic characteristics, Climate conditions, Maintenance policies, Surrounding land use, percent pervious and impervious areas, Age and condition of vehicles, Anti-litter laws and regulations covering vehicles emissions, Use of special additives in vehicle operation, Vegetation types on the vehicle right-of-way and Accidental spills. OF these factors, several have been identified as major influences on pollutant constituents and concentrations. These are the traffic characteristics (particularly volume), atmospheric deposition (wet and dry), and site-specific conditions (e.g., land use practices, highway surface, highway maintenance practices), (FHWA, 1996).

Storm water must be distinguished from other urban sources of pollution largely caused by wet weather since each separate source is regulated differently. In addition to storm water runoff, which is the focus of this study, there are two other significant sources of urban wet weather pollution: sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs). SSOs occur when sanitary sewers, often because of leaks and cracks, become surcharged in wet weather and overflow, often through manholes or into basements. CSOs occur when flows into combined sewer system (systems that receive storm water, sanitary sewer discharges from residences and businesses, and wastewater discharges from industrial facilities and transport it all through a single pipe) exceed the treatment and storage capacity of the sewer system and waste treatment facility. At that point, this combined waste stream overflows into creeks, rivers, lakes or estuaries through designated outfalls usually without treatment. CSOs and SSOs are more of a problem with older systems while storm water is an issue for all metropolitan areas, especially growing areas. Moreover, while prevention programs can be very important to efforts to reduce CSOs and SSOs, structural changes are usually necessary. By contrast, much storm water pollution can be prevented with proper planning in growing or redevelopment areas.

## 3.4 New Approach for Flood Control

However, the management of urban flooding under a new and innovative optical is beginning to be drawn. This is the sustainable development of urban drainage in order to mimic the natural water cycle. There are several practical examples where engineers, planners, landscapers and other specialists had success in the reintegration of water in the urban landscape. In many cases, water resources were the main focus on revitalising the central areas of the city. Similarly, arid areas see rain waters as a potential resource, where

the runoff is being used locally in a manner beneficial, rather than being quickly discharged as a kind of waste, (Heaney et al., 1999).

This new model incorporates innovative techniques of engineering as the construction of pervious pavements and open channels with vegetation, both seeking to attenuate the peak discharges and also reduce the concentration of pollutants of rain water in urban areas. The model defines as principles of modern urban drainage, (Parkinson et al., 2003):

▪ New developments can not increase the peak discharge of natural conditions (or previous) - control the discharge outflow;
▪ The planning of the basin must include control of the volume;
▪ Should be avoided for the transfer of impacts to downstream.

For water resources management is necessary to integrate the various agendas existing in a basin and that are associated with water resources (blue agenda), to the environment (green agenda) and to the city (brown agenda). These policies must also be turned compatible in this general planning unit, which is the watershed. In order that these engineering techniques are implemented and to ensure the sustainable operation of drainage systems, new methods of urban planning and management are necessary.

## 4. Best management practices and low impact development

### 4.1 Best Management Practices (BMPs)

NPS controls are typically established through implementation of management practices that are structural or non-structural in nature. Structural practices include diversions, temporary sediment basins, animal waste lagoons, fencing, terraces, rock check dams, and other constructed means of reducing impairments to surface water and ground water. Non-structural practices relate to resource management techniques, such as timing and rate of fertiliser or pesticide application, conservation tillage methods, livestock grazing rotation, riparian planting, upland re-vegetation, and other techniques.

BMPs should realistically represent the best combination of structural and/or non-structural management practices used to reduce or prevent impairments to water quality. These BMPs should be developed based on site-specific conditions where the practices are to be constructed, maintained, and/or implemented, and should be selected based on economic restraints and goals associated with the specific problem to be addressed. As BMPs are selected for specific applications and incorporated into a land use plan, many sources of technical information are available to assist in selection, design, and implementation.

Under ideal conditions, BMPs provide for protection of water quality. As with any pollution control measure, benefits gained are directly associated with degree of thought, analysis, and care given to selection, design, implementation, maintenance, and management. Further, as human influences to aquatic and terrestrial systems change, the response of those systems to runoff changes. Therefore, management practices must remain flexible and responsive to changing conditions, both spatially and temporally. By convention, this document refers to all practices as BMPs, recognising that any one practice may not be the "best" choice in all situations.

### 4.2 Low Impact Development - LID (US EPA, 2007)

LID is a storm water management strategy that has been adopted in many localities across the country in the past several years. It is a storm water management approach and set of

practices that can be used to reduce runoff and pollutant loadings by managing the runoff as close to its source(s) as possible. A set or system of small-scale practices, linked together on the site, is often used. LID approaches can be used to reduce the impacts of development and redevelopment activities on water resources. In the case of new development, LID is typically used to achieve or pursue the goal of maintaining or closely replicating the predevelopment hydrology of the site. In areas where development has already occurred, LID can be used as a retrofit practice to reduce runoff volumes, pollutant loadings, and the overall impacts of existing development on the affected receiving waters.

In general, implementing integrated LID practices can result in enhanced environmental performance while at the same time reducing development costs when compared to traditional storm water management approaches. LID techniques promote the use of natural systems, which can effectively remove nutrients, pathogens, and metals from storm water. Cost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimised through infiltration and evapotranspiration. By working to mimic the natural water cycle, LID practices protect downstream resources from adverse pollutant and hydrologic impacts that can degrade stream channels and harm aquatic life.

It is important to note that typical, real-world LID designs usually incorporate more than one type of practice or technique to provide integrated treatment of runoff from a site. For example, in lieu of a treatment pond serving a new subdivision, planners might incorporate a bio-retention area in each yard, disconnect downspouts from driveway surfaces, remove curbs, and install grassed swales in common areas. Integrating small practices throughout a site instead of using extended detention wet ponds to control runoff from a subdivision is the basis of the LID approach.

When conducting cost analyses of these practices, examples of projects where actual practice-by-practice costs were considered separately were found to be rare because material and labour costs are typically calculated for an entire site rather than for each element within a larger system. Similarly, it is difficult to calculate the economic benefits of individual LID practices on the basis of their effectiveness in reducing runoff volume and rates or in treating pollutants targeted for best management practice (BMP) performance monitoring. Tables and figures have to be made in high quality, which is suitable for reproduction and print, taking into account necessary size reduction. Photos have to be in high resolution.

## 5. Pollution Loads Assessment

Assessment is the process of determining levels of water quality and ecosystem impairment and identifying sources and causes of this impairment. Assessment typically involves comparing monitoring data to state water quality standards to determine whether each water body's designated uses (e.g., aquatic life, swimming, drinking) are being achieved. Statistical analyses also may be done to determine whether water quality is improving or declining over time. Thus, assessments are important because they provide the basis for evaluating the success of past management actions and targeting future management efforts. This type of monitoring is done in many Brazilian rivers, but they usually are rivers with large extensions and many times near river cities are treated as distributed sources. Monitoring stations, usually two, are placed before and after the limits of occupation of these cities.

Simulation of urban runoff quality is very inexact and complex by presenting a nature strongly random. Very large uncertainties arise both in the representation of the physical, chemical, biological and sociological processes and in the acquisition of data and parameters for model algorithms. The true mechanisms of build-up involve factors such as wind, traffic, atmospheric fallout, land surface activities, erosion, street cleaning and other imponderables. Although efforts have been made to include such factors in physically-based equations, it is unrealistic to assume that they can be represented with enough accuracy to determine a priori the amount of pollutants on the surface at the beginning of the storm. Equally naive is the idea that empirical wash off equations truly represent the complex hydrodynamic processes that occur while overland flow moves in random patterns over the land surface.

According to Huber & Dickinson (1988), such uncertainties can be dealt with in two ways. The first option is to collect enough calibration and verification data to calibrate the model equations used for quality simulation. Given sufficient data, the equations used in simulation models can usually be manipulated to reproduce observed concentrations and loads. This is essentially the option discussed at length in the following sections. The second option is to abandon the notion of detailed quality simulation altogether and use either (a) a constant concentration applied to quantity predictions (i.e., obtain storm loads by multiplying predicted volumes by an assumed concentration) or (b) a statistical method.

## 5.1 Storm Water Runoff

The urban flow and the loading of pollutants increase on a permanent basis with the development of the city and remains at a high level during the lifetime of the venture. This happens because of impervious surfaces such as streets, sidewalks, public tours, bike lanes, roads, roofs, sports courts, etc.., they permanently reduce the infiltration of rainfall and the flow to the subsoil.

Accelerated rates of surface flow also occur as function of urbanisation and can increase in a significant way due to the ability of water in separating sediment and pollutants associated with it, carrying them out of their way and being deposited further downstream. High rates of flow can also cause erosion of channels and their margins. The increased volumes of surface flow and also of the discharges also increase urban flooding, resulting in loss of life and property.

The urbanisation can also severely affect the groundwater. In some cases, the flow of polluted water contaminates the groundwater. More often, the impervious surfaces block the infiltration affecting not only the levels of the water table, but also the amount of water released by the aquifer into the river during the drought. From the standpoint of water quality, periods of drought are considered critical because the amount available to dilute the pollutants reaches a minimum during this period. Reduced discharges over a long period of drought also adversely affect aquatic life.

The surface flows, composed by the rain waters, by flows of areas in construction and by the base flow (contaminated), have been identified with the cause of significant impacts on receiver water bodies and the aquatic habitat. These effects are obviously more severe for small receivers' bodies that receive flows of free developing drainage basins and with high rates of urbanisation. However, some studies have demonstrated the existence of significant impacts on aquatic life in rivers with degree of urbanisation less than 10%.

In order to better identify and understand these impacts it is necessary to include a biological monitoring and reviewing the quality of sediments as well. The majority of impacts on aquatic life are probably related to the chronic problems of long duration, caused by destruction of habitat by contaminated sediments and breaking the food chain. Several lines of research indicate that a proper analysis of biological environmental impacts of the receiver bodies must include the investigation of a number of groups of living organisms (fishes, benthic macro-invertebrates, algae, macrophytes, etc.), in complementation to the studies of water quality and of sediment. Simplified studies with only the quality of water, even realising possible comparisons with the standards of water quality for the protection of aquatic life, are usually inadequate to predict associated biological impacts, Burton & Pitt (2002).

The biggest problem with traditional approach when applied to urban runoff is the complexity of pollutant sources, the problems of tracking during the heavy rains and limitations when using the legal standards of quality of water to assess the severity of the problems of the bodies during the receivers rainy season. In Brazil, we do not have a specific law regulating the quality standards of water from water bodies located in urban areas.

### 5.2 Techniques for Estimation of Pollution Loads

Knowledge of existing information and expertise may be of great value to researchers and decision-makers. Having this information may facilitate enhancement of existing knowledge rather than repeating efforts when evaluating the characteristics of highway-runoff water quality and the potential effects, and mitigation of highway-runoff constituents on water quality and ecosystems in receiving waters. Knowledge of the existing literature also may provide information necessary to address regulatory issues such as for Non-Point-source Discharge Elimination System (NPDES) permits (Swietlik et al., 1995) or for assessments of total maximum daily loads (TMDLs) in receiving waters potentially affected by highway runoff discharges (Rossman, 1991).

Although the conceptualisation of the quality processes is not difficult, the reliability and credibility of quality parameter simulation is very difficult to establish. In fact, quality predictions are almost useless without local data for calibration and validation. If such data are lacking, results may still be used to compare relative effects of changes, but parameter magnitudes (e.g. predicted concentrations) will forever be in doubt. This is in marked contrast to quantity prediction for which reasonable estimates of hydrographs may be made in advance of calibration.

Early quality modelling efforts with many simulation models, like SWMM, emphasised generation of detailed pollutographs (concentration versus time), in which concentrations versus time were generated for short time increments during a storm event. In most applications, such detail is entirely unnecessary because the receiving waters cannot respond to such rapid changes in concentration or loads. Instead, only the total storm event load is necessary for most studies of receiving water quality. Time scales for the response of various receiving waters are presented in Table 1. Concentration transients occurring within a storm event are unlikely to affect any common quality parameter within the receiving water, with the possible exception of bacteria. The only time that detailed temporal concentration variations might be needed within a storm event is when they will affect control alternatives. For example, a storage device may need to trap the "first flush" of pollutants.

| Type of Receiving Water | Key Constituents | Response Time |
|---|---|---|
| Lakes, Bays | Nutrients | Weeks – Years |
| Estuaries | Nutrients, DO | Days – Weeks |
| Large Rivers | DO, Nitrogen | Days |
| Streams | DO, Nitrogen | Hours – Days |
| | Bacteria | Hours |
| Ponds | DO, Nutrients | Hours – Weeks |
| Beaches | Bacteria | Hours |

Table 1. Required Temporal Detail for Receiving Water Analysis (Driscoll, 1979)

The significant point is that calibration and verification ordinarily need only be performed on total storm event loads, or on event mean concentrations. This is a much easier task than trying to match detailed concentration transients within a storm event.

## 5.3 Regression Rating Curve Approaches
With the completion of the NURP studies in 1983, there are measurements of rainfall, runoff and water quality at well over 100 sites in over 30 cities. Some regression analysis has been performed to try to relate loads and EMCs to catchment's demographic and hydrologic characteristics.

Driver & Tasker (1990) developed four sets of equations for analysis of runoff pollutant load. The equations allows for calculation of storm pollutant constituent loads, storm runoff volume, storm runoff mean concentration and the mean annual and seasonal pollutant loads. The linear regression models were determined by the use of multiple regression analysis, including techniques of least squares. These models can be used to estimate the load of pollutants, the volume of water, the average concentration of pollutants and the average annual (or seasonal) of the load of pollutants in river basins instrumented or not.

The most significant explanatory variables in all linear regression models were the total precipitation and total contributing drainage area. The impervious area, the use of soil and the annual averages climatic characteristics are also significant in some models. The models to estimate the loads of dissolved solids, total nitrogen and total ammonia plus organic nitrogen are more a rule the most precise; on the other hand the models for suspended solid were less precise. The storms were selected from the database according to certain attributes and availability of specific variables. When a variable selected for a particular analysis was unavailable for an event, this event was removed from the analysis. No attempt was made to estimate flaw in the data. Due to shortages of data, not all records of events rainy 2813 were used in most analyses.

Models of regional regression were developed for 11 types of constituent more the volume of flow. The 11 types of constituents calculated in loads of runoffs, originally denominated in pounds, are: chemical oxygen demand (COD), suspended solids (SS); dissolved solids (DS), total nitrogen (TN), total ammonia nitrogen more organic as nitrogen (TKN), total phosphorus (TP); dissolved phosphorus (PA); cadmium total recoverable (CD); total recoverable copper (UC); lead recoverable total (CP) and total recoverable zinc (Zn). The volumes of runoff (RUN) are expressed in inches. The computer program and Excel spreadsheet developed for this work are able to manipulate both English units as in the international system (metric).

The variables of response (loads and volume) were selected according to the frequency of this variable in the database and in accordance with the general importance in urban planning. Table 2 shows the parameters, or the explanatory variables used in the regression models in question, its units and the corresponding symbols.

| | | |
|---|---|---|
| Physical and Land Use | A | Total contributing drainage area, mi² or km² |
| | I | Impervious area, percentage of A |
| | LUI | Industrial land use, percentage of A |
| | LUC | Commercial land use, percentage of A |
| | LUR | Residential land use, percentage of A |
| | LUN | Non-urban land use, percentage of A |
| | PD | Population density, people per mi² or m² |
| Climatic | $H_r$ | Total storm rainfall, inches or mm |
| | $t_R$ | Storm duration, min |
| | INT | Maximum 24-hours precipitation intensity that has a 2-yr recurrence interval, inches or mm |
| | $H_{MAR}$ | Mean annual rainfall, inches or mm |
| | MNL | Mean annual nitrogen load in precipitation, in pounds per acre or kilos by square kilometre |
| | $T_J$ | Mean minimum January temperature ($T_J$), F or °C |

Table 2. Characteristics, symbols and units

### 5.4 Procedures for the Determination of Loads and Volumes of Stormwater

The equation (1) applies to calculate the loads. When the equation (1) is applied in calculating the volume of water, you must multiply by 0.02832 to convert from ft³ to m³ instead of 0.4536.

$$L_p = \left[ \hat{\beta}_0' \times X_1^{\hat{\beta}_1} \times X_2^{\hat{\beta}_2} \ldots \times X_n^{\hat{\beta}_n} \times BCF \right] \times 0.4536 \tag{1}$$

Where: $L_P$ = estimated storm load or volume in kg or m³; $\hat{\beta}_0', \hat{\beta}_1, \hat{\beta}_2 \ldots \hat{\beta}_n$ = regression coefficients; $X_1, X_2 \ldots X_n$ = physical, land use or climatic characteristics; $n$ = number of physical, land use or climatic characteristics in the model; and $BCF$ = Bias correction factor which corrects for bias towards the mean response and for underestimation of the mean response.

The parameters that are used for the equations vary from region to region and for each different type of constituents. Table 3, condensed from the original, lists the coefficients of regression models developed for load and volume of water in a particular case of Region III. All constituents are listed, followed by RUN, or volume of runoff. The value for the variable

$X$ is listed at the top of the table. It should be noted that the original study was done entirely in English units, so all values obtained in metric units should be converted to English before they enter the equation.

| Response Variable | $\beta_0$ | $H_r$ | A | I+1 (%) | LUI+1 (%) | LUC+1 (%) | LUR+1 (%) | LUN+2 (%) | $H_{mar}$ | MNL | Tj | BCF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DQO | 479 | 0.857 | 0.634 | -- | 0.321 | 0.217 | -- | -0.111 | -- | -- | -- | 1.865 |
| SS | 1990 | 1.017 | 0.984 | -- | 0.226 | 0.228 | -- | -0.286 | -- | -- | -- | 2.477 |
| TN | 0.361 | 0.776 | 0.474 | 0.611 | -- | -- | -- | -- | -- | 0.863 | -- | 1.709 |
| TKN | 199572 | 0.875 | 0.393 | -- | -- | -- | -- | 0.082 | -2.643 | -- | -- | 1.736 |
| TP | 53.2 | 1.019 | 0.846 | -- | -- | 0.189 | 0.103 | -0.16 | -- | -- | -0.754 | 2.059 |
| DP | 0.369 | 0.955 | 0.471 | -- | -- | -- | -- | 0.364 | -- | -- | -- | 2.027 |
| CU | 4.508 | 0.896 | 0.609 | -- | 0.648 | 0.253 | -- | -0.328 | -- | -- | -- | 2.149 |
| PB | 0.081 | 0.852 | 0.857 | 0.999 | -- | -- | -- | -- | -- | -- | -- | 2.314 |
| ZN III | 4.355 | 0.83 | 0.555 | -- | 0.402 | 0.287 | -0.191 | -- | -- | -- | -0.5 | 1.942 |
| RUN III | 32196 | 1.042 | 0.826 | 0.669 | -- | -- | -- | -- | -- | -- | -- | 1.525 |

Table 3. Summary of regression coefficients for storm-runoff load and volumes (adapted from FHWA, 1996)

## 6. Case Study

### 6.1 Regression Rating Curve Applied to Carioca River

Many existing drainage systems in Brazil are combined in that they carry both domestic and industrial effluents and the runoff of rainfall from catchments surfaces during storm events. During periods of high rainfall it is not practical, due to economic constraints, to transport the large volume of flows derived from catchments runoff to the treatment works. Combined sewer overflows therefore discharge excess storm flows above the capacity of the treatment works or the hydraulic capacity of the local sewer network, to local receiving waters that are usually rivers or coastal waters. These discharges contain foul sewage derived from domestic and industrial sources, and storm water, contaminated by sediments eroded from catchment's surfaces. As a consequence, the overflow discharges contain large amounts of finely suspended solids or pollutants in solution. Therefore these flows can have a significant oxygen demand or toxic impact on the receiving waters, (Skipworth et al, 2000). The urbanisation of the city of Rio de Janeiro was marked by intense change in the environment and its water bodies. Rivalling with the native cultures, which are suited to the environment, the European colonisation of the 16th century, tried to turn in a short time a tropical region in a European way to the city. This meant a change of space before endowed with large number of rivers. Today, almost all of them had their courses or modified, or are hidden in the form of storm sewers, and still has those that no longer exist. From this perspective the Carioca River stands out. With its original course going through oldest locals of the city, it followed up early the profound changes in space and its history confused with the city. The Carioca River rises in the Massif of Tijuca. Today it is only visible at free surface from its rising to the *Largo do Boticário*, in front of the *Ladeira "Ascurra"*, then runs by underground galleries and at by the street named Baron of Flamengo, it outflows in the Guanabara Bay. Its history is as important as the history of the

development of the city, for the reason which because of its location which emerged the first neighbourhoods of Rio de Janeiro. The name "Carioca" was given around the year of 1503, when, in one of the river stretches near the a hill called *Morro da Viúva* the Portuguese built a house of masters of slaves, called by the Tamoios Indians "Cari-Óca" (White Man's House, in Indian language). Where this house existed, disappeared already in the 17th century, today is a modern building in the present corner of the Cruz Lima Street with the Flamengo Beach. In 1719 the first aqueduct was built linking the slopes of Santa Teresa (hill) to *Campo de Santo Antonio* (downtown). The aqueduct led water to a fountain made all of stone with 16 waterspouts made of bronze. In 1740 an aqueduct was built longer, higher and stronger to bring water closer to residents. In 1750, it was inaugurated the Carioca Aqueduct, built by slaves, made of stone, lime, sand, brick and whale oil, with 270 meters long, 18 meters high average and with 42 classic Roman-style arches (see Figure 1).
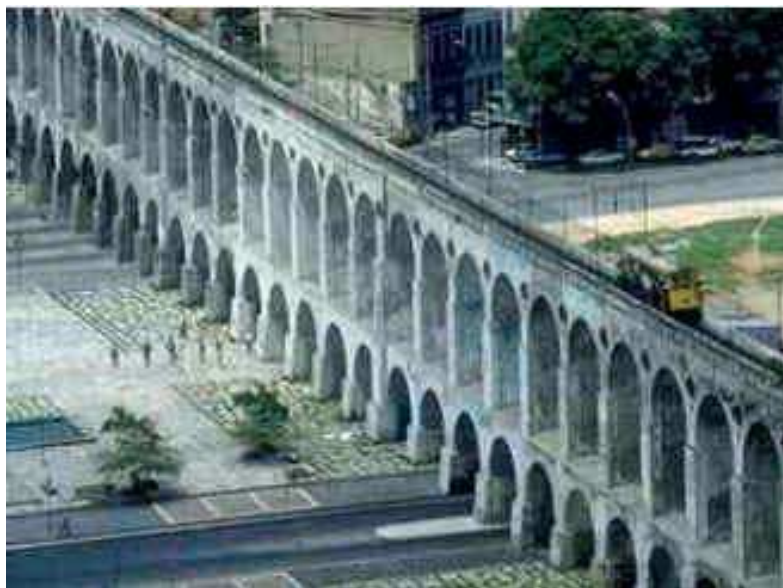


Fig. 1. Arches of Lapa, aqueduct where Carioca River ran in the past

At the end of the 19th century, the aqueduct lost its primitive function, becoming route of access to the neighbourhood of Santa Teresa. The cable cars began to traffic in the arches, carrying passengers from the Carioca Square for different points of the neighbourhood. Another intervention in the basin of Rio Carioca also occurred at the end of the 19th century. What is now the Tijuca Forest there was nothing there two centuries ago. In place of it, what was there was a lot of plantations of sugar cane and coffee to the few that has spread throughout the Sierra Carioca by the Tijuca Forest, causing the devastation of both. The action caused the decline of predatory coffee plantations, by the rapid decline in productivity in the first half of the 19th century. Then D. Pedro II turned to the Forest for the purpose of obtaining water for the city. In 1861, after the expropriation of several farms, began the reforestation with the planting of more than 75 thousand species of trees many of them from other tropical countries. It is recognised as the largest artificial urban forest in the world.

Currently, the basin of Rio Carioca has a heterogeneous occupation. Near its source there are green areas as the Tijuca Forest which resists to the advance of slums while over its route, the river crosses with a more urban areas of the city receiving sewers (see Figures 2

and 3). This heterogeneity in the occupation is also observed in the quality of water in each section. That is, the river rises with good quality and takes over his journey polluting the loads that change to its mouth on a river of dark and unpleasant odour.
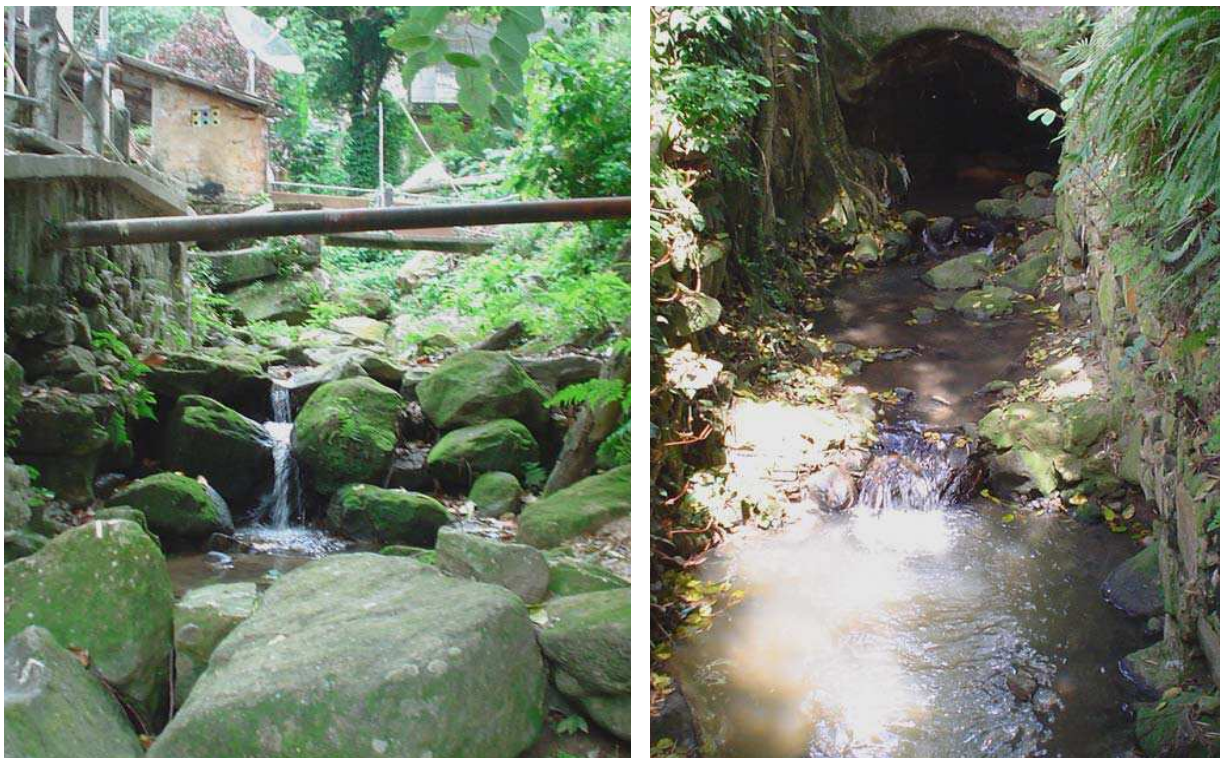


Fig. 2 and 3. Community of Guararapes

In order to study the different degrees of pollution for different types of occupation, the basin has been divided into three regions with distinct characteristics. Each one offers an internship that ranges from the absence of urbanisation in a highly urbanised region.

The first area is within the Park of Tijuca, which is an area of environmental preservation that houses the Tijuca Forest. Visiting the site was observed a dense forest and the virtual absence of occupation. About the quality of the river, it was first observed that it is of great quality and without strong odours.

The second region is heterogeneous and composed of the neighbourhoods of *Santa Tereza* and *Cosme Velho*, noble and traditional neighbourhoods with predominantly of houses, slums, express routes (Rebouças Tunnel) and even a little forest. The limit of this region is the *Largo do Boticário*, where the river flows freely for the last time. It is observed a change in water quality, because at this point the river is cloudy and unpleasant odour, which was also confirmed by the laboratory analysis.

The third area is the plain of the basin, very urbanised. The river runs under the streets until you get to the treatment plant in the coastal region.

Before arriving on the Flamengo Beach the river is diverted twice. His flow in dry weather is collected by sewer network operator and washed to a sea outfall. The flow surplus is intercepted by a gallery of waist and diverted to a treatment station (Fig. 4), after passing by the station the river outflows in Guanabara Bay.

Table 4 shows the result of the above methodology proposed for the land use.

Fig. 4. Treatment station of Flamengo Beach

| Region | description | Area | I | LUI | LUC | LUR | LUN | PD | Temp |
|--------|-------------|------|---|-----|-----|-----|-----|-----|------|
| 1 | Tijuca Forest Park | 1 | 10 | 0 | 0 | 0 | 100 | 0 | 22,5°C |
| 2 | mixed (forest, houses, slum) | 1,8 | 65 | < 1 | 4 | 46 | 40 | 9200 | 26,5°C |
| 3 | Ultra urban | 5,1 | 80 | < 1 | 26 | 61 | 13 | 23000 | 27,5°C |

Table 4. Land use of Carioca catchments

Applying the methodology presented in Section 5, the results arrived for the annual total load, shown in Table 5.

| Response variable | Load (Kg) Pk Tijuca | Load (Kg) Mixed | Load (Kg) Ultra urban |
|-------------------|---------------------|-----------------|------------------------|
| DQO | 130.86 | 297.23 | 929.84 |
| SS | 229.77 | 762.18 | 4187.86 |
| TN | 731.37 | 2887.95 | 5361.93 |
| TKN | 3.24 | 3.80 | 5.26 |
| TP | 0.61 | 2.33 | 9.39 |
| DP | 1.15 | 1.10 | 1.23 |
| CD | 0.00 | 0.00 | 0.00 |
| CU | 2.52 | 7.23 | 29.29 |
| PB | 0.41 | 4.04 | 12.09 |
| ZN | 0.34 | 0.36 | 0.98 |

Table 5. Final result from the method of Driver & Tasker (1990)

### 6.2 Wet Sedimentation Chambers Constructed at Guerengue Catchments

A Washington D.C. vault sand filter is an underground storm water sand filter contained in a structural shell with three chambers (see Fig. 5). It is a multichamber structure designed to treat storm water runoff through filtration, using a sediment forebay and a sand bed as its primary filter media. The shell may be either pre-cast or cast-in-place concrete, corrugated metal pipe, or fibreglass tanks. This BMP was developed by Mr. Hung V. Truong of the D.C. Environmental Regulation Administration. A typical use is for high density/ultra-urban location where available land is restricted, such as a receiving area for runoff from an impervious site.
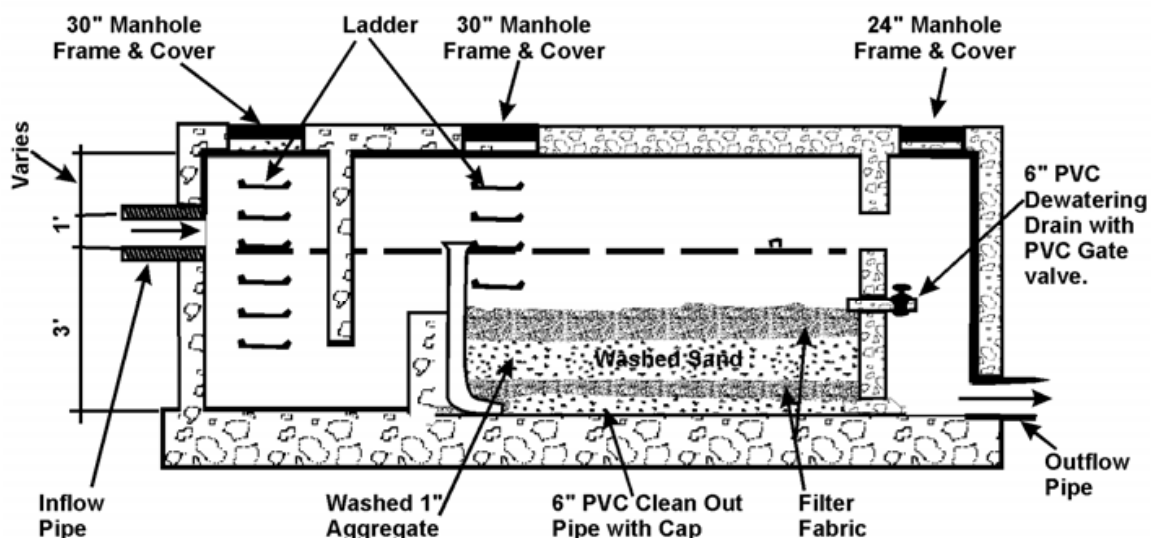


Fig. 5. Typical Washington D.C. sand filter

The three feet deep plunge pool in the first chamber and the throat of the second chamber, which are hydraulically connected by an underwater rectangular opening, absorbs energy and provides pre-treatment, trapping grit and floating organic material such as oil, grease, and tree leaves.

The second chamber also contains a typical intermittent sand filter. The filter material consists of gravel, sand, and filter fabric. At the bottom is a subsurface drainage system of pierced PVC pipe in a gravel bed. The primary filter media is 18-24 inches of sand. A layer of plastic reinforced geo-textile filter cloth secured by gravel ballast is placed on top of the sand. The top filter cloth is a pre-planned failure plane which can readily be replaced when the filter surface becomes clogged. A dewatering drain controlled by a gate valve must be installed to facilitate maintenance.

The third chamber, or clear well, collects the flow from the under drain pipes and directs it to the storm sewer.

D.C. Sand Filters are primarily used for water quality control. However, they do provide detention and slow release of the water quality volume from the site being treated. Whether this amount will be sufficient to provide the necessary peak flow rate reductions required for channel erosion control is dependent upon site conditions (hydrology) and required discharge reductions. The 10-year and 100-year flows will usually exceed the detention capacity of a sand media filter. When this occurs, separate quantity must be provided.

D.C. Sand Filters are ultra-urban BMPs best suited for use in situations where space is too constrained and/or real estate values are too high to allow the use of conventional retention ponds. Where possible, runoff treated should come only from impervious surfaces.

Advantages/benefits:
- Storm water filters have their greatest applicability for small development sites – drainage areas of up to 5 surface acres;
- Good for highly impervious areas; good retrofit capability – good for areas with extremely limited space;
- Can provide runoff quality control, especially for smaller storms; generally provide reliable rates of pollutant removal through careful design and regular maintenance;
- High removal rates for sediment, BOD, and faecal coliform bacteria;
- Precast concrete shells available, which decreases construction costs;
- No restrictions on soils at installation site, if filtered runoff is returned to the conveyance system.

Disadvantages/limitations:
- Intended for space-limited applications;
- High maintenance requirements;
- Not recommended for areas with high sediment content in storm water, or areas receiving significant clay/silt runoff;
- Relatively costly;
- Possible odour problems;
- Porous soil required at site, if filtered runoff is to be ex-filtrated back into the soil;
- Not recommended for residential developments due to higher maintenance burden.

Maintenance requirements:
- Inspect for clogging – rake first inch of sand;
- Remove sediment from fore-bay/chamber.

Treatment effectiveness: depends on a number of factors: treatment volume; whether the filter is on-line or off-line, confined or unconfined; and the type of land use in the contributing drainage area. Normally sand filter removal rates are "high" for sediment and trace metals and "moderate" for nutrients, BOD, and faecal coliform. Removal rates can be increased slightly by using a peat/sand mixture as the filter medium due to the adsorptive properties of peat. An estimated pollutant removal capability for various storm water sediment filter systems is shown in Table 6 (Galli, 1990).

| Pollutant | Percent Removal |
|---|---|
| Faecal Coliform | 76 |
| Biochemical Oxygen Demand (BOD) | 70 |
| Total Suspended Solids (TSS) | 70 |
| Total Organic Carbon (TOC) | 48 |
| Total Nitrogen (TN) | 21 |
| Total Kjeldahl Nitrogen (TKN) | 46 |
| Nitrate as Nitrogen ($NO_3$-N) | 0 |
| Total Phosphorus (TP) | 33 |
| Iron (Fe) | 45 |
| Lead (Pb) | 45 |

Table 6. Typical Pollutant removal efficiencies (Galli, 1990)

The municipal operator responsible for urban drainage, called *Rio-Águas*, in cooperation with the Federal University of Rio de Janeiro, constructed and installed two underground sand filters to manage 0.250 acre, mostly impervious, catchments. Figure 6 shows a scheme with a side view of the project. It consists of a sedimentation chamber with overflow pipes designed to skim off floatable debris and a sand filter chamber. The sand filter was constructed with structural concrete designed for load and soil conditions, a wet pool sedimentation chamber, a submerged slot to maintain water seal, an overflows weir, a PVC-clean-out standpipe and four heavy concrete access doors. The sand filter layer has 19 inches in depth, geo-technical fabric and 1" filter gravel above it, and a filter cloth. The system has three 6" perforated PVC collection pipes (equally spaced) was underlain by a 12-inch gravel layer. A gate valve for dewatering and steps to bottom was not installed.

Figure 7 depicts the sand filter constructed at Guerengue road after 6 months of operation.



Fig. 6. Design of Guerengue sand filter



Fig. 7. Photo of the Guerengue road sand filter

## 7. Final Considerations

### 7.1 Regression Rating Curve

The goal in water quality modelling is to adequately simulate the various processes and interactions of storm water pollution. Water quality models have been developed with an ability to predict loadings of various types of storm water pollutants.

Despite the fact that the regression equations were developed in different places of the study area, the authors believe that the numerical results presented by these equations are important to alert the municipality and the public about the potential impacts of diffuse pollution.

Detailed short time increment predictions of "pollutographs" are seldom needed for the assessment of receiving water quality. Hence, the total storm event loads or mean concentrations are normally adequate. Simple spreadsheet-based loading models involve an estimate of the runoff volume which, when multiplied by an event mean concentration, provide an estimate of pollution loading. Because of the lack of ability to calibrate such models for variable physical parameters, such simple models tend to be more accurate the longer the time period over which the pollution load is averaged.

### 7.2 Carioca On-River Treatment Plant

The construction and operation of treatment plants combined sewage and rainwater in Rio de Janeiro city was until now the object of study and technical support to local authorities. However, works aimed at separating the raw sewage of rain water must be continuously subject to the municipal investment, so that the aquatic habitat is really restored. The mixed treatment can be considered a temporary alternative passenger and so detailed studies of the impacts and measurements of urban pollutants must be intensified.

### 7.3 Wet Sedimentation Chambers

Although the construction of only two such filters have been built, one should consider this fact as a milestone because the process of revitalisation of water bodies is a phenomenon rather slow and unpredictable. It is known that the worst problem of quality of water from Brazilian rivers is caused by the release of sewage in nature. In the basin of the river Guerengue there is a work in progress for the collection and proper disposal of sewage, but it is not reasonable to expect the end of this phase so that only then initiate the implementation of such BMP and LID practices.

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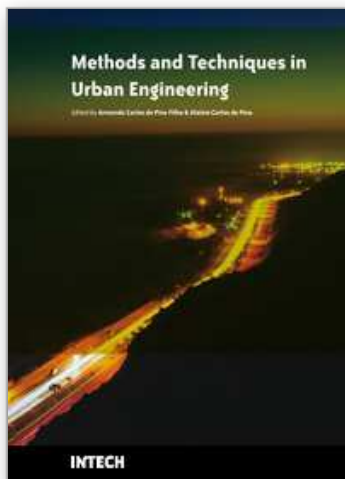
**Methods and Techniques in Urban Engineering**

Edited by Armando Carlos de Pina Filho and Aloisio Carlos de Pina

A series of urban problems such as dwelling deficit, infrastructure problems, inefficient services, environmental pollution, etc. can be observed in many countries. Urban Engineering searches solutions for these problems using a conjoined system of planning, management and technology. A great deal of research is devoted to application of instruments, methodologies and tools for monitoring and acquisition of data, based on the factual experience and computational modeling. The objective of the book was to present works related to urban automation, geographic information systems (GIS), analysis, monitoring and management of urban noise, floods and transports, information technology applied to the cities, tools for urban simulation, social monitoring and control of urban policies, sustainability, etc., demonstrating methods and techniques applied in Urban Engineering. Considering all the interesting information presented, the book can offer some aid in creating new research, as well as incite the interest of people for this area of study, since Urban Engineering is fundamental for city development.

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