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Stormwater management problems in a tropical city – the Belo Horizonte case study

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Abstract In developing countries urban stormwater management shows a set of particularities when compared to that of developed countries. These particularities are mostly related to the lack of adequate urban planning and regulation, operation and maintenance of drainage systems, economic, health, educational, demographic and social questions. In the present paper, these questions are analysed and discussed using the Brazilian city of Belo Horizonte as a case study. The role of stormwater master planning as an instrument to adequately handle the reported problems is a major conclusion of the paper.

INTRODUCTION

The broad characteristics of urban stormwater management problems in the developed as well as in the developing world may include, among others, an increase in the frequency of floods, intensive erosion processes, water pollution and eutrophication of water bodies. To deal with the adverse impact of urbanization, municipalities can use a wide range of technical, organizational, legal and financial tools and resources. In tropical cities, these resources and tools are frequently lacking, thus aggravating the effects of urbanization.

In the present paper, these questions are analysed and discussed using the southeastern Brazilian city of Belo Horizonte as a case study. This overview of the typical stormwater management problems in Belo Horizonte serves as a reference for a stormwater master planning methodology proposal that is developed in a companion paper (Kauark-Leite *et al.*, 1999).

THE BELO HORIZONTE CASE STUDY – BACKGROUND INFORMATION

Belo Horizonte is located in southeast Brazil and has a population of 3.5 million inhabitants. The city lies at 20°S 44°W and has an altitude of 750–1300 m. It is located in a mountainous region of tropical soils that originated from the decomposition of metamorphic rock. Tropical highland weather systems predominate in this area, with an average yearly rainfall of 1500 mm. The rainy season lasts from October to March, when 90% of the total yearly rainfall occurs. The highest monthly average rainfall

(315 mm) takes place in December. The intensity of the rainfall is also relatively high, reaching 200 mm h^{-1} in events that last 5 min and have a 10 year return period (Baptista & Nascimento, 1996).

Planned to be the capital of the state of Minas Gerais, the construction of Belo Horizonte began at the end of the nineteenth century. The project was inspired by the strong positivist principles of the era and based on rigidly regular streets and broad avenues meeting at right angles to form square blocks. Thus, the adopted urban model completely ignored natural, existing local characteristics such as the region's topography and hydrography.

During the early years of urban development, most of the streams located in the planned urban area were lined following the road system (Fig. 1). Later, many of these streams were covered by concrete structures in order to enlarge streets and avenues to deal with traffic problems.

A separated sewer system, using independent networks to drain stormwater and sewage, was part of the original design and could be considered an innovative decision at a time when combined sewer systems were the norm. However, wastewater treatment plants have not been built as yet and sewage collected by the sewer system is usually dumped into streams, detention basins or the River das Velhas, downstream of the city. Wastewater treatment is projected to begin in the year 2000.

The plan for Belo Horizonte was strongly influenced by the then current concept of urbanism, called hygienism. The association of hygienism with the typical cultural and economic conditions that prevail in developing tropical countries in general, and in Brazil in particular, led to an equally typical set of stormwater problems. The influence of hygienism on stormwater management and a discussion of selected consequential stormwater problems are presented below using Belo Horizonte as a case study.

TYPICAL STORMWATER PROBLEMS

Hygiene and the stormwater system

Hygienism, a nineteenth century school of urbanism which stresses the importance of ensuring a healthy urban environment founded on strong scientific principles, has had

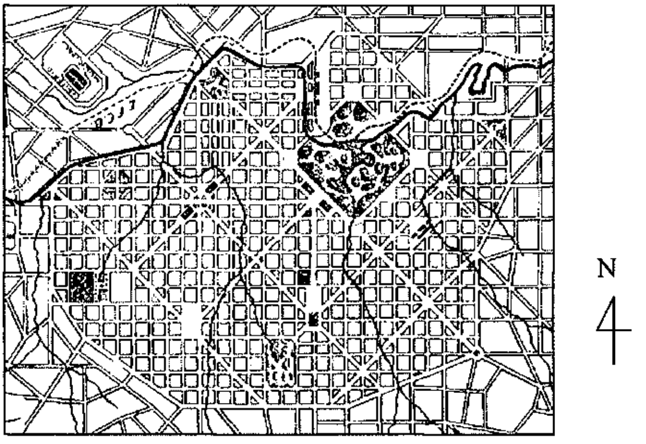

Fig. 1 Downtown Belo Horizonte (FJP, 1997).

a major influence on the development of the so-called classical concepts of stormwater management. According to these concepts, the main objective of urban drainage systems is to remove, as quickly as possible, sewage and stormwater from urban areas in order to reduce the risks of flooding and contagious water-borne diseases. Sewage and stormwater should be conveyed by underground systems, thus avoiding the nuisance of the presence of water in urban areas as well as aiding in circulation problems. The collection and disposal of sewage and stormwater should not restrict urban development.

Concepts inspired by hygienism led to rather simple, standardized stormwater management tasks and methods that include calculating peak flows, designing appropriate pipe networks and periodically performing maintenance checks on the sewer system. Thanks to gravity flow, the sewer systems work automatically and therefore do not require real-time operation.

Hygienism prompted considerable improvements in the quality of life in urban areas. However, it is probably one of the main causes of legal, institutional and technical problems in stormwater management, at least in Brazil, where its basic concepts are still widely employed.

Hydrological and hydraulic design methods and models

The apparent simplicity of stormwater management led to the use of very simple design methods for stormwater systems. Synthetic models were used which do not require observed data to calibrate parameters (e.g. rational method, synthetic unit hydrograph).

Since observed data were not necessary, Brazilian municipalities rarely invested in gathering data other than measuring rainfall. Therefore it is not possible to verify the accuracy of these design methods using calculated or observed data. For example, Ramos (1998) simulated rainfall-runoff events in three catchment areas in the Belo Horizonte urban area using different synthetic unit hydrograph models, including the one recommended by the Belo Horizonte municipality. Considering only peak flow estimates, the outcomes had differences of up to 70% between model calculations. Due to the lack of flow gauges, it was not possible to identify the most accurate model for the cases studied.

As in hydrological design, inadequate models and insufficient data are also commonplace in hydraulic structure design. Complex flow conditions, including the effects of stream confluence, flow transitions or unsteady flow, are infrequently regarded and model simulations of these conditions are rarely done. Only uniform flow conditions are regularly considered in the design of channel structures.

When a municipality adopts a particular empirical design methodology, as is the case in Belo Horizonte, it tends to become an unquestioned rule that is usually codified in ordinances and design manuals. Such ordinances and manuals are valuable tools that help to ensure uniformity in design criteria and methods. But, if design methods are not validated, they act as barriers to improvements in stormwater management.

Urban growth and the impact of urbanization

Previously urbanized areas are frequently impacted by new urban development. New urban development projects are not required by law to estimate or mitigate their impact on flow conditions downstream, nor to take into account the impact of future upstream development. Since municipalities do not demand impact assessments, new drainage projects are designed as independent, unconnected systems. The consequences usually include an increase in the frequency of floods downstream and the rapid obsolescence of existing drainage systems.

These problems are aggravated by factors like rapid urban growth and unequal income distribution among inhabitants, which generally leads to uncontrolled occupation of precarious areas such as floodplains and steep hillsides that risk landslides.

Municipalities rarely commission studies to delineate and regulate the occupation of these areas because, as mentioned above, they do not have the sophisticated models and databases required to do them. Moreover, the legal delineation of risk areas is not accounted for in urban zoning, which leaves the municipalities without the institutional means to control the problem. In many cases, poor people occupy these areas precisely because the land is less valued and inappropriate for legitimate construction. Removing people from these areas is a daunting political, economical and social problem with no easy solution.

Huge inequalities exist in the distribution of income in Brazil. The richest 20% of the population control 67% of GNP while the poorest 20% share only 2% of GNP (Bret & Théry, 1996). Due to the migration of poor people from rural to urban areas, income disparities are more evident in cities, where 78% of the total Brazilian population reside.

In Belo Horizonte, 15% of the city's residents live in favelas (shantytowns) which are normally located in high risk areas. The city was originally planned for 200 000 inhabitants and as previously mentioned, the metropolitan region is now home to 3.5 million people. Although planned in outline, the city has grown in a disorderly manner. Geologically unstable areas and regions that are prone to flooding have been occupied without proper planning and flood control measures, and without regard to urban watercourses. The impact of the above can be seen in Fig. 2 where the city's population growth and the frequency of serious flood events from 1925 to 1989 are plotted.

The most remarkable example of the effect of uncontrolled growth is seen in Belo Horizonte's main watercourse, the Arrudas creek, which drains 150 km^2 of highly urbanized watershed. From the beginning of the Arrudas watershed urbanization, various interventions on the main channel have been attempted. As described by Baptista & Nascimento (1996), the channel has been lined using different cross sections and materials. By the end of the 1970s, the maximum discharge that the channel could convey through downtown Belo Horizonte was about 300 $m^3\ s^{-1}$. The 200 year return period discharge for the same region was estimated at 600 $m^3\ s^{-1}$, as a result of urbanization. Frequent flooding prompted the construction of a new deeper and wider channel. The cost of the project was over US$10 million per kilometre.

Pollution and erosion processes

The lack of legal recourse and institutional oversight also has an effect on stormwater pollution and erosion processes intensified by urbanization in Brazil. Although separate sewer systems are used to drain stormwater and sewage, illegal dumping of wastewater into streams and illicit connections of sewers into the stormwater system

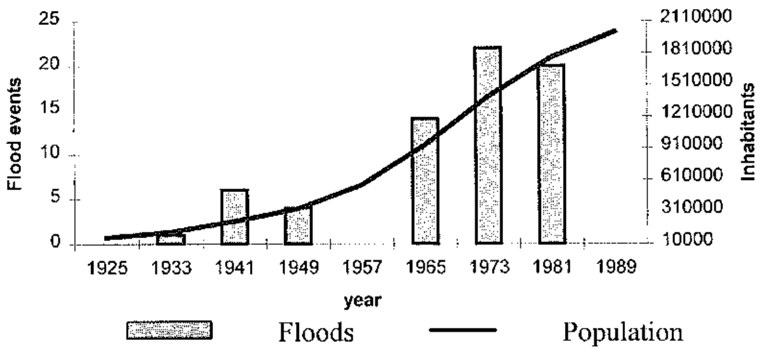

Fig. 2 Population growth and flood events in Belo Horizonte, 1925–1989 (Baptista *et al.*, 1998).

are common. Dumping of garbage into streams is also frequent in poor neighbourhoods, which are under-served by solid waste collection services.

The case of urban erosion is more severe because there are no entities that are responsible for monitoring and controlling erosion as there are for solid waste and wastewater. In Belo Horizonte, water pollution and intense erosion processes have resulted in the degradation of water quality and streams, and in the reduction of the capacity of sewers due to sediment deposits.

Detention basins have also been heavily impacted (Nascimento *et al.*, 1998). An example is the case of the Pampulha detention basin (PDB), part of one of the city's most important urban complexes. The PDB was conceived and built to accomplish multiple goals, namely, stormwater control, water supply and as a leisure and sports area for residents.

A combination of intense and disorganized urbanization with adverse climatic, pedologic and topographic variables in the Pampulha Creek catchment area led to intensive erosion processes and wastewater and solid waste production which heavily impaired the PDB. Due to silting, the PDB has already lost nearly 50% of its original storage capacity of 18 million cubic metres. The PDB also faces aesthetic and euthrophication problems due to illicit dumping of sewage and waste material that have prevented its use as a water supply. The detention basin has lost its various functions, including that of flood control. The attempts to recover the PDB so far have not yielded much despite investments of US$11 million.

Engineering of streams

The oversimplification of stormwater problems also leads to uniformity and conventionalism in the engineering of streams in the urban context. Urban streams have been impacted considerably by the urban concept, still in use, called "sanitary road". The main purposes of sanitary roads are to improve traffic circulation and to channel major creeks in urban areas. In sanitary roads, streams usually are lined with concrete rectangular cross-section structures. At the surface, a street or an avenue is built on the floodplain. Underground, intercepting sewers are installed to collect and conduct sewage to treatment plants.

Underlying the concept of sanitary roads is the assumption that stormwater is not heavily polluted. This is manifestly not the case, as described above. Using concrete box culverts as a "solution" to aesthetic, odour, garbage and water-borne disease problems related to heavily polluted streams is not uncommon, demonstrating once again an oversimplified approach.

In Belo Horizonte, polluted streams and traffic congestion have prompted the progressive paving of channels according to the concept of sanitary roads. Of about 350 km of the city's natural perennial watercourses, 193 km have already been lined (Baptista & Nascimento, 1996). Thus, a progressive and irreversible reduction in the role of natural water courses in the urban environment has occurred.

Legal and institutional issues

Solutions to urban drainage problems are inhibited by weak municipal institutions and poor organization. The lack of municipal offices devoted to stormwater management, the dependence on political support, the absence of a well-trained, up-to-date technical staff and an inadequate budget can certainly be pointed to as major causes of the problems described so far.

Furthermore, there are not adequate legal tools to effectively regulate and control the illegal dumping, illicit connections and uncontrolled growth that ultimately lead to flooding, sedimentation, erosion and pollution problems.

CONCLUSIONS

The severe economic, social, environmental and political repercussions of urban flooding and the growing environmental demand of the population point to the necessity of a conceptual, technical and political change in the way urban drainage problems are handled.

To use new approaches, including non-structural incentives and source control, there is a real need for adequate urban planning. This planning must consider stormwater management together with various aspects of urban infrastructure and environmental and social issues.

Stormwater master planning plays a crucial role in stormwater management. It is an indispensable tool that compels reflection on local drainage problems and considers long-term as well as immediate issues. Regulatory enforcement and strong leadership are also indispensable in effective stormwater management.

Principles and methodologies related to urban drainage plans in developing countries are discussed in a companion paper (Kauark-Leite *et al.*, 1999).

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