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Stormwater master planning in developing tropical countries

LUIZ AUGUSTO KAUARK-LEITE
SAFEGE, Consulting Engineers, 15/27, Rue du Port, F-92007 Nanterre, France
e-mail: luiz_kauarkleite@safege.fr

NILO OLIVEIRA NASCIMENTO & MÁRCIO BENEDITO BAPTISTA
Federal University of Minas Gerais, Av. Contorno 842, 30110-060 Belo Horizonte, MG, Brazil

Abstract In the present paper a methodology to design urban drainage master plans suited to cities located in tropical regions of developing countries is presented. The role of master planning in urban drainage and its objectives are reviewed and discussed. Fundamental methodological principles that should guide master planning are presented and a structure for its elaboration is suggested. A discussion is presented on the main actions and programmes that a master plan could lead to such as technical, institutional and legal initiatives.

INTRODUCTION

The main objective of this paper is to suggest and discuss a methodology for stormwater master planning in cities of developing tropical countries. The underlying thesis is that long-term planning of stormwater management is essential to properly deal with the problems of flooding, erosion and water pollution in the context of tropical cities. This kind of master plan integrates the technical, institutional, legal and financial aspects directly linked to stormwater management, together with a set of other municipal responsibility domains that are also closely related to stormwater management like the management of solid waste, wastewater, erosion due to urbanization, waterborne diseases, etc.

One may argue that the same kind of long-term planning is also relevant in urban areas located in developed temperate countries, which is certainly true. However, rapid urban growth, unequal income distribution and economic, institutional and regulatory weaknesses are common, distinct features in developing municipalities that call for specific stormwater management in these regions.

Since urban development planning at any level generally means planning in a local context, Belo Horizonte, a Brazilian city with a population of 3.5 million inhabitants, is used as a case study. The typical stormwater management problems of Belo Horizonte are presented and discussed in a companion paper (Nascimento *et al.*, 1999).

STORMWATER MASTER PLANNING OBJECTIVES AND MAIN ISSUES

Stormwater master planning starts with conceptualizing the objectives and principles that will guide its development and fulfilment. The following are crucial considerations:

(a) What are the typical stormwater problems of the master plan target area?
(b) What are the probable causes of the identified problems?
(c) What are the available financial and technical resources and legal, institutional and political support for stormwater master planning and once defined, for its implementation?
(d) What are the current and potential problems (technical, legal, institutional and political) that could compromise the stormwater master plan or its execution?

Answering these questions is an essential activity that will guide the identification of the objectives and methodology of the master plan and will help to define strategies for its implementation.

The overall objective of stormwater master planning is to develop a legal, institutional and technical tool to address current problems as well as guide the execution of long-term programmes that anticipate future problems resulting from urban development.

Specific objectives depend on the local context. The Belo Horizonte case study, reported by Nascimento *et al.* (1999), is an example. Tables 1 and 2 summarize the main stormwater problems and their causes. Therefore, specific objectives of a stormwater master plan that seeks to deal with the reported problems may include those listed in Table 3.

Considering the objectives listed in Table 3, it becomes evident that the actions and measures that result from stormwater master planning are numerous and complex. In the present paper it is impossible to relate in detail all the actions that could result from a master plan. Instead, selected issues have been chosen that are most relevant to stormwater management in developing countries.

Drainage technology development

Stormwater master planning is in itself an opportunity to develop drainage technology that should not be neglected. Data measurement, hydraulic drainage system inventory, GIS and hydrological and hydraulic modelling of the drainage system can contribute decisively to the improvement of the methodologies for the conception and design of drainage systems.

An example of a possible outcome of master planning is the improvement of methodologies for the design of drainage systems through comparative studies of different approaches using simulations based on observed data.

Table 1 Typical stormwater management problems in Belo Horizonte, Brazil.

Problem	Physical origin
Flooding	Urban development in risk areas New urban development in previously urbanized areas Inadequate functioning of hydraulic structures Sediment and garbage obstructing hydraulic structures
Water pollution	Illegal wastewater and solid waste dumping into water bodies Inadequate sewage sewer connections into drainage pipes Urban non point-source pollution
Erosion	Erosion processes intensified by new urban development Lack of or inadequate relief measures

Table 2 Major technical, institutional and legal causes of stormwater problems.

Cause	Description
Technical	Use of empirical, non-validated design methods Insufficient data, e.g. hydrological, hydraulic (streams, sewers, gates, etc.), present and future land use Preferential use of structural rather than non-structural flood control measures Ignorance of up-to-date drainage technologies, their design methods and maintenance requirements, e.g. detention basins, source control, non-structural flood control Design methods that do not account for environmental impact
Institutional	Drainage issues receive insufficient emphasis in urban planning and public policy creation Lack of planning and clear long-term objectives Lack of integrated planning, management and control of urban development No effectiveness indicators for executed measures Absence of a periodic maintenance programme for the drainage system Insufficient budget Little commitment to environmental problems
Legal	Inadequate regulation regarding the assessment and mitigation of urbanization effects on water quality, rainfall runoff and erosion processes Lack of regulation and control of risk-area occupation

Table 3 Examples of specific objectives of stormwater master planning.

Context	Objective
Technical	Define activities to control flooding, erosion, sedimentation and water pollution Promote updating drainage system project methodologies Promote the development and diffusion of new drainage technologies
Institutional	Promote the establishment of an autonomous office in the municipal structure to be in charge of stormwater management: the "drainage office" Create managerial and legal instruments for the drainage office Promote cooperation between municipal offices charged with managing matters related to drainage, e.g. urban zoning, transportation system, etc. Promote grass-roots participation in discussions of urban planning and drainage problems
Legal	Regulate the occupation of high-risk hydrological areas Regulate environmental impact assessments (flooding, erosion; water pollution) of urbanization and the use of relief measures Regulate the managerial tools to be used by the drainage office Devise strategies to enforce legal tools

Other outcomes include increasing the use of alternative drainage systems, like source-control, detention basins, wetlands and stream restoration, to control flooding and pollution in urban areas, as well as environmental enhancement, amenity, leisure and aesthetic purposes. In this particular case, criteria to select alternative drainage systems, their design and maintenance in the context of developed countries are already available (e.g. Urbonas & Stahre, 1993; Azzout *et al.*, 1994; Schueler, 1987). But the proper use of these drainage solutions in urban areas of developing countries is dependent on a more profound analysis of their advantages and limitations considering the physical, economic, social, public health, legal and institutional characteristics of these areas (Baptista & Nascimento, 1996). Furthermore, source-control, detention basins and water-course and floodplain improvements, like adopting the concept of multi-objective river corridors (Riley, 1998; Herson-Jones *et al.*, 1995), will be

successful only if they are accompanied by adequate control of erosion processes, wastewater and solid waste dumping into the drainage system.

Stormwater master planning can contribute decisively to the adoption of alternative drainage systems in urban areas of developing countries. This can be achieved by assessing operational problems of alternative drainage systems already in place as well as by promoting the development of pilot projects to determine criteria and methods to design and carry-out other alternative drainage systems.

Manuals for drainage system design, construction, monitoring and maintenance and training programmes on new drainage technologies for municipal engineers and technicians are products of master planning that will help disperse concepts related to drainage technologies. Information and technical exchanges between the team that developed the stormwater master plan, and the team that will implement, it is also indispensable in transferring the technologies developed during master planning.

Institutional and legal development

The establishment of an autonomous stormwater management office is one of the most important institutional issues of master planning. The drainage office is essential to ensure comprehensive actions, continuity in master plan implementation, political support and legal enforcement.

A key question regarding the autonomy of a drainage office is its financial independence. This can be achieved by earmarking a fixed percentage of the annual municipal budget for stormwater management or by instituting a drainage tax.

A drainage tax, in particular, could be implemented according to the "polluter-pays" principle, for instance adopting a tax linked to the percentage of impervious area on a given property. This would require studies to determine if the willingness to pay and the capacity to pay are economically, socially and politically compatible with the needs for investment in the infrastructure and management of the drainage system.

Another important point, regardless of the drainage office's funding source, is its capability to demonstrate the effectiveness of adopted measures and managerial decisions. Therefore, the master plan should recommend tools to help in decision-making and also indicators to assess the actions of the drainage office.

Drainage technology as well as institutional development will be effective only when significant legal and regulatory measures are adopted (Table 3).

METHODOLOGICAL ASPECTS

The creation of a global master plan, the type described here, is an involved task that may require three to four years of work. The plan is intended to guide stormwater management programmes for the next ten to twenty years, the typical timeline of global master plans. Therefore, master plans should be dynamic tools based on current conditions and identified problems, but they must also account for future conditions and be up-dated over time. These requirements necessitate a number of studies which may be organized according to the following methodological steps:

(a) characterize and diagnose current stormwater problems;
(b) anticipate potential future problems based on demographic projections, urban development projects and urban zoning;
(c) devise actions and programmes to deal with (a) and (b);
(d) evaluate the feasibility of the proposed actions in technical, political, legal, institutional, financial and environmental terms;
(e) define strategies for master plan implementation, on-going evaluation, control of the effectiveness of measures already executed, and periodic up-dates.

The reliability of problem assessment, the conception of actions to deal with them and the evaluation of their feasibility and effectiveness should be based on:
(a) observed hydrological and water quality data;
(b) a reliable inventory of the hydraulic drainage system covered by the plan;
(c) a reliable survey of current land use followed by predicted land use based on demographic projections and urban development projects and goals.

To fulfil the above requirements, the methodology should adhere to the following directives:
(a) rainfall, water flow and water quality monitoring should be done in accordance with the objectives of the master plan;
(b) a hydrological and water quality database, as well as a geographic information system should be implemented and/or improved;
(c) hydrological and hydraulic simulations of current and future conditions should be done using distributed models calibrated to observed data and accompanied by uncertainty analysis.

Monitoring water quality and hydrological variables is one of the most expensive components of master planning. Thus, its design and execution should be done carefully. A cost-reduction strategy is to implement temporary stations that only function during the monitoring period which usually covers the hydrological year, but that are associated with permanent stations. After the monitoring campaign, the permanent stations will furnish data for system management and to evaluate the efficacy of the measures stated in the master plan.

Hydrological and hydraulic mathematical modelling based on reliable observed data and on-going inventory up-dates of the hydraulic structures that compose the drainage system is essential in master planning for the various reasons which are discussed below.

The number of alternative measures to treat stormwater problems is naturally very large. Evaluating and choosing the most appropriate option require studying scenarios that combine climatic factors, like intense rainfall, with urban development projections together with the stormwater management alternatives themselves. Choosing the best option depends on, among other factors, the ability to reliably and correctly simulate different stormwater management scenarios.

Mathematical modelling coupled with GIS and the database can also contribute decisively to the on-going adaptation of the master plan to changing conditions in urban areas. In addition, they are useful tools to evaluate the effectiveness of actions executed according to master plan directives.

As mentioned earlier, the studies that make up master planning require time to be done properly and this may be a drawback for cities located in tropical countries. On a

daily basis these cities deal with severe chronic and acute stormwater management problems that need to be dealt with before the proper completion of the master plan. Selected emergency measures are:

(a) structural restoration of damaged hydraulic structures;
(b) structural and non-structural measures to mitigate frequent flooding events;
(c) civil defence and health care programmes in cases of flooding;
(d) programmes to remove populations occupying areas at risk for floods and landslides.

Instead of only counting on emergency plans, municipalities should consider developing a set of measures and actions, even preliminary, to deal with drainage problems during the master planning itself. Thus, it may be convenient to divide master planning in to two main phases which will ultimately result in two plans, the preliminary and the final stormwater master plan.

The component that determines the division between the two plans is the monitoring campaign. Then, in the preliminary master plan, the characterization and diagnosis of the main problems and the preliminary proposal of actions are based on a literature review including previous studies of the urban area, terrain surveys, hydrological and hydraulic mathematical modelling, and interviews with the municipal staff in charge of stormwater management.

In the absence of hydrological data, modelling should be done by adopting parameter default values according to indicators provided in model manuals, the inventory of the drainage system and surveys on watershed topography and impervious areas. These simulations have three principle objectives. First, identify the most serious problems related to hydraulic functioning of the drainage system, even if there is a high level of uncertainty. Second, evaluate alternatives to preliminary actions to be implemented. Finally, design the monitoring network.

During this phase, studies related to water quality and to issues not directly dependent on hydrological monitoring can be initiated. These studies may include, in particular, institutional and legal aspects of master planning. The preliminary master plan should be concluded by the mid-point of the master plan timeline.

The second phase of master planning is composed of:

(a) a monitoring campaign;
(b) a detailed diagnosis of the problems of flooding and water pollution following hydrological and hydraulic simulations based on measured data;
(c) a stormwater master plan, which will revise the proposals of the preliminary plan and state new actions, measures and implementation strategies.

Another crucial methodological component of stormwater master planning is ensuring political support and participation as well as the participation of the public in the design and implementation of the plan. The support of both sectors, essential in ensuring the continuity of the project, is connected. Popular interest in and support of the project are factors that mobilize political support. Meanwhile, political support contributes to publicizing the project and mobilizing and organizing the participation of citizens.

Various communications and discussion tools can be used depending on the public to be addressed. These may include pamphlets, meetings (e.g. technical, publicity), an Internet site that contains updated information as well as means to receive contributions, and stimulating the participation of resident associations, environmentalists, users of a water body, etc.

CONCLUSIONS

Stormwater master planning unquestionably implies planning in a complex environment. Complexity exists because stormwater problems are not isolated; rather, they are closely related to other urban managerial issues like urban zoning, road systems, solid waste, wastewater, urban erosion and public health. Moreover, stormwater problems are seldom only technical; rather, their causes are closely linked to political, institutional, legal and financial issues.

The objectives, methodologies and typical issues of stormwater master planning presented in this paper are broad and general. They are also far from complete; the topics considered most essential in the context of tropical cities merited more attention throughout the paper. Thus, suggestions and discussions should be analysed and adapted taking into account the local characteristics of the master planning target area.

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