

Planning and sizing of urban macro-drainage systems: hydrological and hydraulic analysis applied to the Mandi River Basinⁱ

Leonardo Evangelista Ribeiro

Civil Engineering and Infrastructure, Uneatlântico, Spain

Abstract: This article focuses on the planning and sizing of urban macro-drainage systems, with emphasis on hydrological and hydraulic analysis applied to the Mandi River Basin. The research seeks to understand how well-established theoretical and methodological foundations in existing literature guide the definition of design storms, discharge estimation, and verification of the conveyance capacity of structures in urban basins. Its core objective is to explore how these references can be integrated to support basin-scale urban macro-drainage planning, taking full account of the characteristics of watercourses and their adjacent urban areas. The theoretical framework draws on classical and technical studies concerning urban hydrology, rainfall-runoff modeling, hydraulic sizing and integrated drainage management. Methodologically, an integrative-descriptive literature review is adopted, selecting and analyzing widely-used scientific publications, technical books and institutional manuals within this field. The main findings reveal that the combined consideration of hydrological analysis, hydraulic sizing and basin scale provides a sound basis for understanding the operation of macro-drainage systems and guiding technical decisions for urban drainage design and management. This study identifies theoretical and methodological pathways suitable for macro-drainage planning in urban basins and further highlights the value of integrated approaches for urban engineering and water-resource disciplines.

Key words: urban macro-drainage; hydrological analysis; hydraulic sizing; river basin

1 Introduction

The expansion of urban areas has increased the coverage of impervious surfaces and modified the natural hydrological behaviour of river basins, leading to greater surface runoff and more-frequent waterlogging and flooding. Under such circumstances, urban macro-drainage systems play a central role in conveying and controlling discharges generated by rainfall events, requiring planning and hydraulic sizing compatible with the physical characteristics of the basin and urban space (TUCCI, 2004; CANHOLI, 2014).

Urban macro-drainage refers to the set of structures responsible for conveying large volumes of water, such as channels, main galleries and urban watercourses, which differs from micro-drainage that operates at the local scale. The performance of these systems relies on integrated hydrological and hydraulic analyses, which can convert precipitation data into discharge estimates and assess the conveyance capacity of the designed structures (DAEE, 2005; DNIT, 2006).

Hydrological analysis is the stage at which design discharges are estimated based on the characterization of rainfall and the properties of the river basin. Classic studies show that the temporal distribution of precipitation exerts a direct

influence on peak discharges and is essential for the correct hydraulic sizing of drainage systems (HUFF, 1967; GUIMARÃES; NAGHETTINI, 1998). The definition of design storms adapted to local conditions is therefore a structural element of macro-drainage planning (ARNELL; MELIN, 1984).

Within the Brazilian context, various studies have highlighted the need to assess the applicability of rainfall patterns to regional conditions, avoiding the automatic adoption of models that fail to adequately represent the hydrological behaviour of urban basins. Studies carried out in urban areas of southern Brazil indicate that the careful selection of these patterns directly influences the hydraulic safety of drainage works (BEMFICA, 1999; SILVEIRA; BEMFICA; GOLDENFUM, 2000).

The hydraulic stage, in turn, focuses on verifying whether conveyance structures can carry the estimated discharges without causing overflows. Studies on the hydraulic efficiency of urban galleries and channels show that section geometry and flow conditions are decisive for the performance of macro-drainage systems (CAMPOS; NUNES; DE OLIVEIRA, 2015). This analysis becomes essential in urbanized areas, where spatial constraints condition the adopted solutions.

Beyond technical aspects, the literature indicates that macro-drainage planning should take the river basin as the analysis unit, integrating physical characteristics, land use and hydrological dynamics. The basin-scale approach makes it possible to understand the processes that govern runoff generation and identify sites with the highest flood susceptibility, supporting more robust decisions in urban planning (PALARETTI, 2013; UNITED STATES DEPARTMENT OF AGRICULTURE, 1986).

In this regard, studies focused on mapping flood-prone areas reinforce the importance of integrating hydrological and hydraulic analyses into territorial planning, so as to reduce risks linked to inappropriate urban occupation. The identification of such areas provides relevant technical support for the hydraulic sizing of macro-drainage systems and for mitigating impacts caused by intense rainfall events (GOERL; KOBIYAMA; PELLERIN, 2012).

Despite the methodological advances reported in the literature, it is observed that many studies still treat the hydrological and hydraulic stages in a dissociated manner, or apply models without adequate contextualization for the specific characteristics of the analyzed basins. This finding highlights the need for research that integrately combines discharge estimation and verification of the hydraulic capacity of macro-drainage systems, taking local particularities into account (ALMEIDA; VALDÉS SERRA, 2017; CHRISTOFIDIS; ASSUMPÇÃO; KLIGERMAN, 2019).

Against this background, this study aims to analyse the planning and hydraulic sizing of urban macro-drainage systems using an integrated hydrological and hydraulic approach, applied to the Mandi River Basin. It seeks to understand how well-established methods from the literature can be combined to support technical decisions better suited to the performance of the drainage system.

The research question guiding this study is to understand how the integration of hydrological and hydraulic analysis contributes to the planning and hydraulic sizing of urban macro-drainage systems within a specific river basin, taking into account the well-established methodological foundations in technical and scientific literature.

2 Theoretical framework

2.1 Urban macro-drainage planning and basin-scale approach

The planning of urban macro-drainage systems has been described in the literature as a process that goes beyond the simple implementation of conveyance structures, requiring an integrated understanding of the river basin and urban space. Studies indicate that adopting the basin as the unit of analysis enables a more consistent correlation between precipitation, land use and hydrological response, favouring solutions compatible with the natural dynamics of runoff (TUCCI, 2004; PALARETTI, 2013).

Authors highlight that point-scale interventions, when decoupled from the basin context, tend to transfer problems along the drainage system without effectively reducing flood risks. The literature therefore acknowledges that macro-drainage planning must consider physical, hydrological and spatial aspects in an integrated manner, avoiding isolated and inefficient solutions (CHRISTOFIDIS; ASSUMPÇÃO; KLIGERMAN, 2019).

In this regard, international technical documents reinforce that integrated basin analysis contributes to more realistic discharge estimation and the definition of design criteria adapted to the urban scale. This approach has been widely used in urban hydrology studies for small and medium-sized basins, with consistent results in reducing uncertainties in hydraulic sizing (UNITED STATES DEPARTMENT OF AGRICULTURE, 1986).

2.2 Hydrological analysis and determination of design storms

Hydrological analysis is one of the core stages in urban macrodrainage planning, as it enables the estimation of discharges associated with rainfall events. Literature indicates that precipitation characteristics, particularly intensity, duration and temporal distribution, directly affect peak discharges and surface runoff behaviour (HUFF, 1967; GUIMARÃES; NAGHETTINI, 1998).

Studies on the temporal distribution of rainfall show that different rainfall patterns can yield distinct hydrological responses, even for similar total precipitation volumes. For this reason, selecting design storms appropriate to regional conditions is identified as a fundamental step for the hydraulic safety of drainage systems (ARNELL; MELIN, 1984).

Within the Brazilian context, studies show that the direct application of generic rainfall patterns may lead to under- or over-dimensioning of structures. Analyses carried out in urban areas of Southern Brazil indicate the need to assess the compatibility of these patterns with local conditions, reinforcing the importance of regional studies when defining design storms (BEMFICA, 1999; SILVEIRA; BEMFICA; GOLDENFUM, 2000).

2.3 Hydrological models applied to urban drainage

Hydrological models have been widely used to represent the rainfall-runoff transformation in urban catchments. The literature describes these models as tools to simulate different hydrological scenarios, enabling the evaluation of system performance under various rainfall events (ALMEIDA; VALDÉS SERRA, 2017).

Studies indicate that model selection must take into account data availability, basin scale and analysis objectives, avoiding inappropriate applications that compromise the results. Conceptual and semi-empirical models are widely used in urban environments, as they provide a balance between operational simplicity and the ability to represent hydrological processes (ALMEIDA; VALDÉS SERRA, 2017).

The literature acknowledges that the judicious use of these models contributes to understanding the factors controlling runoff generation and supports better-informed decision-making in macrodrainage planning. Accordingly, hydrological models are presented as supporting tools, not substitutes for technical analysis and knowledge of the studied basin.

2.4 Hydraulic design and performance of macrodrainage structures

The hydraulic design of urban macrodrainage systems is directly related to the capacity of structures to safely convey the discharges estimated in the hydrological stage. Technical literature states that channels and conduits must be designed considering not only the design discharge but also cross-section geometry and flow conditions (CANHOLI, 2014).

Comparative studies of different hydraulic cross-sections indicate that the shape and sizing of conduits significantly affect flow efficiency. Research on urban drainage systems shows that an inappropriate cross-section selection can reduce hydraulic capacity and impair system performance (CAMPOS; NUNES; DE OLIVEIRA, 2015).

National technical manuals reinforce the importance of hydraulic verification as a complementary step to hydrological analysis, guiding the design and sizing criteria adopted in drainage works. These documents emphasize that consistency

between estimated discharges and structural capacity is essential for the performance of macrodrainage systems (DAEE, 2005; DNIT, 2006).

3 Methodology

This research adopted an integrative and descriptive literature review approach, aimed at systematizing studies concerning the planning and sizing of urban macrodrainage systems from hydrological and hydraulic perspectives. This methodological choice proved suitable for the study objectives, as it enables the collection, organization and interpretation of consolidated knowledge, highlighting recurrent technical fundamentals and diverse methodological approaches within this field.

Source selection was carried out in widely recognized scientific databases in the field of water resources and urban engineering, including Scopus, Web of Science and SciELO, complemented by searches in Google Scholar. These databases were selected owing to their thematic coverage and because they host journals, technical books and institutional documents relevant to studies on urban hydrology, drainage and basin-scale planning.

Searches were performed using descriptors related to urban macrodrainage, hydrological analysis, hydraulic sizing, design rainfall and urban watersheds. The combination of these terms allowed the inclusion of different approaches to the topic, ranging from conceptual discussions to studies focused on discharge estimation and the assessment of conveyance capacity of drainage structures.

The inclusion criteria prioritized studies that directly addressed the planning and sizing of urban drainage systems, focusing on the integration between hydrological and hydraulic analysis. Only full-text works were considered, including scientific journal articles, technical books, dissertations and widely-used institutional manuals in the field. Studies with no direct connection to the research scope were excluded from the analysis corpus.

The study-selection process followed successive stages of identification, screening, eligibility verification, and definition of the final set of references. Initially, titles and abstracts were read to check thematic relevance; subsequently, the full texts of selected documents were reviewed to assess their conceptual and methodological consistency. The final references were organized to enable a comparative analysis of the methods and concepts presented.

Data analysis focused on identifying the main theoretical and methodological foundations related to the determination of design rainfall, hydrological modelling and hydraulic sizing of urban macrodrainage structures. Classic contributions and widely-recognized national works were emphasized, ensuring consistency between the adopted theoretical framework and the study objectives.

From this systematization, the adopted methodology enabled the construction of a sound theoretical basis to support the analysis of the planning and hydraulic sizing of urban macrodrainage applied to the Rio Mandi basin. The chosen approach allows an integrated understanding of the involved hydrological and hydraulic processes, without resorting to the generation of primary data or to inferences unsupported by the reviewed literature.

4 Results and discussion

The results obtained from the reviewed literature indicate that the planning of urban macrodrainage is directly associated with how the hydrographic basin is understood and represented in hydrological and hydraulic studies. Studies adopting the basin as the analysis unit show greater consistency among precipitation, runoff generation and the conveyance capacity of structures, which is a relevant aspect for the analysis applied to the Rio Mandi basin (TUCCI, 2004; PALARETTI, 2013).

Within the scope of hydrological analysis, reviewed studies highlight that the definition of design rainfall is a decisive step in estimating discharges adopted for the sizing of macrodrainage systems. The literature shows that the temporal

distribution of precipitation modifies surface runoff behaviour, directly affecting the peak discharges considered in urban drainage projects (HUFF, 1967; GUIMARÃES; NAGHETTINI, 1998).

Research focused on the application of rainfall patterns in Brazilian urban areas indicates that fitting these parameters to the regional context is essential for the consistency of hydrological analyses. Studies carried out in cities in the southern region of the country show that the selection of rainfall patterns affects the obtained results, providing important support for the hydrological analysis of the Mandi River basin (BEMFICA, 1999; SILVEIRA; BEMFICA; GOLDENFUM, 2000).

The use of hydrological models is a recurrent strategy in the reviewed studies to represent the transformation of precipitation into discharge. The literature describes different types of models, whose application depends on the basin scale, data availability and study objectives. These factors guide the selection of suitable tools for analyzing hydrological behaviour in urban basins such as the Mandi River basin (ALMEIDA; VALDÉS SERRA, 2017; UNITED STATES DEPARTMENT OF AGRICULTURE, 1986).

Regarding hydraulic sizing, literature results indicate that the conveyance capacity of structures must be assessed consistently with the discharges estimated in the hydrological stage. Studies analyzing different gallery geometries show that cross-sectional shape affects hydraulic performance, providing support for the selection of suitable technical solutions in urban macrodrainage systems (CAMPOS; NUNES; DE OLIVEIRA, 2015).

National technical manuals describe design criteria that guide the hydraulic verification of channels and galleries, highlighting the importance of matching design discharges with the capacity of structures. These documents are widely used as references in urban drainage studies and provide parameters applicable to the analysis of the system associated with the Mandi River (DAEE, 2005; DNIT, 2006).

The literature also addresses urban macrodrainage from a historical and territorial planning perspective, relating the evolution of drainage practices to transformations in urban space. These studies reinforce the need to understand the role of urban watercourses in the operation of the drainage system, a central aspect for the analysis of the Mandi River basin within the urban context (CHRISTOFIDIS; ASSUMPÇÃO; KLIGERMAN, 2019).

The synthesis of the main findings identified in the literature and their implications for the analysis of urban macrodrainage applied to the Mandi River basin is presented in Table 1, organized according to the analytical axes discussed in this section.

Table 1. Main findings from the literature and their implications for urban macrodrainage in the Mandi River basin

Identified findings	Literature basis	Implications for the Mandi River basin
Definition of design rainfall	HUFF (1967); GUIMARÃES; NAGHETTINI (1998)	Guides discharge estimation associadas ao curso d'água
Adaptation of rainfall standards	BEMFICA (1999); SILVEIRA et al. (2000)SILVEIRA et al. (2000)	Supports the selection of local hydrological parameters
Application of hydrological models	ALMEIDA; VALDÉS SERRA (2017); USDA (1986)	Provides support for runoff analysis in the urban basin
Hydraulic sizing hidráulico	CAMPOS et al. (2015); CANHOLI (2014)	Verification of the capacity of structures
Normative criteria	DAEE (2005); DNIT (2006)	Supports technical design decisions
Basin-scale planning	TUCCI (2004); GOERL et al. (2012)	Integrated understanding of the dynamics of the Mandi River

Source: Own elaboration based on the reviewed literature.

The discussion of the results shows that the elements presented in the literature provide consistent foundations for the analysis of planning and sizing of urban macrodrainage applied to the Mandi River basin. The integration of hydrological analysis, hydraulic sizing and basin-scale approach supports the interpretation of the findings and guides the understanding

of the operation of the drainage system associated with the studied watercourse.

5 Final considerations

This study aimed to analyze the planning and sizing of urban macrodrainage systems using a hydrological and hydraulic approach applied to the Mandi River basin. The literature review enabled the organization of theoretical and methodological foundations related to the definition of design rainfall, discharge estimation, and the verification of conveyance capacity of structures, which are essential elements for understanding the operation of the drainage system associated with the analyzed watercourse (TUCCI, 2004).

The synthesis of the findings demonstrates that watershed-scale analysis forms a consistent framework for urban macrodrainage planning, enabling the integration of precipitation, land use and hydrological response. This perspective supports the interpretation of surface runoff behaviour and guides technical decisions related to hydraulic sizing, contributing to more consistent analyses within the context of the Mandi River basin.

In terms of practical implications, the reviewed literature shows that the adoption of suitable hydrological criteria, combined with hydraulic verification based on consolidated technical parameters, provides relevant support for the planning of macrodrainage systems compatible with local dynamics. These frameworks can support urban management measures and guide structural interventions aligned with the physical and territorial characteristics of the studied basin.

From a theoretical perspective, the reviewed studies reinforce the role of hydrological models as supporting tools for runoff analysis, provided that they are applied in a manner compatible with the basin scale and planning objectives. The use of these models improves the understanding of the involved hydrological processes and facilitates the integration of hydrological analysis and hydraulic sizing within the urban context (ALMEIDA; VALDÉS; SERRA, 2017).

The application of the discussed propositions presupposes the availability of hydrological data and information on urban occupation, together with the use of modelling tools and consolidated technical frameworks. The literature indicates that the integration of these resources enables more consistent analyses and contributes to the improvement of urban macrodrainage planning for basins such as the Mandi River basin (UNITED STATES DEPARTMENT OF AGRICULTURE, 1986).

Finally, the compiled findings indicate opportunities for further research focused on the integrated application of hydrological and hydraulic methods in different urban contexts. Expanding this type of analysis can strengthen the dialogue between technical knowledge, territorial management and public policies related to urban drainage, contributing to planning practices better aligned with the specificities of hydrographic basins.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] ALMEIDA, L.; VALDÉS SERRA, J. C. Modelos hidrológicos, tipos e aplicações mais utilizadas. *Revista da FAE*, Curitiba, v. 20, n. 1, p. 129–137, 2017. Disponível em: <https://revistafae.fae.edu/revistafae/article/view/113>. Acesso em: 14 jan. 2026.
- [2] ARNELL, V.; MELIN, H. Rainfall design of detention data for sewer basins. Göteborg: Chalmers Tekniska Högskola, 1984. Disponível em: https://publications.lib.chalmers.se/records/fulltext/179510/local_179510.pdf. Acesso em: 14 jan. 2026.
- [3] BEMFICA, D. da C. Análise da aplicabilidade de padrões de chuva de projeto a Porto Alegre. 1999. Dissertação (Mestrado em Recursos Hídricos) – Universidade Federal do Rio Grande do Sul, Porto Alegre, 1999.
- [4] CAMPOS, R.; NUNES, J.; DE OLIVEIRA, G. Avaliação da eficiência hidráulica de galerias de drenagem

pluviais com seções retangulares e circulares. In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 21., 2015. *Anais* [...]. Disponível em: <https://files.abrhidro.org.br/Eventos/Trabalhos/4/PAP020901.pdf>. Acesso em: 14 jan. 2026.

[5] CANHOLI, A. P. Drenagem urbana e controle de enchentes. São Paulo: Oficina de Textos, 2014.

[6] CHRISTOFIDIS, D.; ASSUMPÇÃO, R. dos S. F. V.; KLIGERMAN, D. C. A evolução histórica da drenagem urbana: da drenagem tradicional à sintonia com a natureza. *Saúde em Debate, Rio de Janeiro*, v. 43, p. 94–108, 2019. DOI: <https://doi.org/10.1590/0103-11042019s307>.

[7] DAEE – DEPARTAMENTO DE ÁGUAS E ENERGIA ELÉTRICA DO ESTADO DE SÃO PAULO. Guia prático para projetos de pequenas obras hidráulicas. São Paulo: DAEE, 2005. Disponível em: http://www.dae.sp.gov.br/site/wp-content/uploads/2024/05/GuiaPratico_Dae_2005.pdf. Acesso em: 14 jan. 2026.

[8] DNIT – DEPARTAMENTO NACIONAL DE INFRAESTRUTURA DE TRANSPORTES. Manual de drenagem de rodovias. Brasília: DNIT, 2006. (Publicação IPR-724). Disponível em: https://www.gov.br/dnit/pt-br/assuntos/planejamento-e-pesquisa/ipr/coletanea-de-manuais/vigentes/724_manual_drenagem_rodovias.pdf. Acesso em: 14 jan. 2026.

[9] GOERL, R. F.; KOBIYAMA, M.; PELLERIN, J. R. G. M. Proposta metodológica para mapeamento de áreas de risco a inundação. *Boletim de Geografia, Maringá*, v. 30, n. 1, p. 81–100, 2012.

DOI: <https://doi.org/10.4025/bolgeogr.v30i1.13519>.

[10] GUIMARÃES, M. G.; NAGHETTINI, M. C. Análise regional de frequência e distribuição temporal das precipitações intensas na Região Metropolitana de Belo Horizonte. *Revista Brasileira de Recursos Hídricos*, Porto Alegre, v. 3, n. 4, p. 73–88, 1998.

[11] HUFF, F. A. Time distribution of rainfall in heavy storms. *Water Resources Research*, Washington, v. 3, n. 4, p. 1007–1019, 1967. DOI: <https://doi.org/10.1029/WR003I004P01007>.

[12] PALARETTI, F. L. Notas de aula: manejo de bacias hidrográficas. Jaboticabal: UNESP, 2013. Disponível em: <https://www.fcav.unesp.br/Home/departamentos/engenhariarural/luizfabianopalaretti/bacia-hidrografica.pdf>. Acesso em: 14 jan. 2026.

[13] SILVEIRA, A.; BEMFICA, D.; GOLDENFUM, J. Análise da aplicabilidade de padrões de chuva de projeto a Porto Alegre. *Revista Brasileira de Recursos Hídricos*, Porto Alegre, v. 5, n. 4, p. 5–16, 2000.

DOI: <https://doi.org/10.21168/rbrh.v5n4.p5-16>.

[14] TUCCI, C. E. M. Gerenciamento integrado das inundações urbanas no Brasil. *Revista de Gestão de Água da América Latina*, Porto Alegre, v. 1, n. 1, p. 59–73, 2004. DOI: <https://doi.org/10.21168/rega.v1n1.p59-73>.

[15] UNITED STATES DEPARTMENT OF AGRICULTURE. Urban hydrology for small watersheds. Washington, DC: USDA, 1986. Disponível em: <https://www.nrc.gov/docs/ML1421/ML14219A437.pdf>. Acesso em: 14 jan. 2026.

ⁱ This article is the full-text English translation of the original Portuguese-language paper published in *REMUNOM* (DOI: 10.61164/gqt3r140, ISSN 2178-6925). English translation and publication are permitted with written authorization from the original author. Copyright of the original Portuguese work is retained by the original author and the journal *REMUNOM*.