

STRATEGIES FOR DESIGNING URBAN DRAINAGE CHARGES IN PORTO ALEGRE – RS – BRAZIL

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ABSTRACT: Over recent decades, Brazilian cities have been through chaotic urbanization, producing changes on hydrological processes. Economic instruments for inducing the reduction of such impacts have been studied and employment, especially charges on urban drainage services. This study aimed to assess how different strategies for designing a drainage tax would charge developments under different stormwater systems, namely hygienist, BMP and LID systems. The methodology consisted of applying an unitary cost for repairing, maintaining and operating drainage systems in the city of Porto Alegre, Brazil, on numerically simulated discharges from three 1.5 ha condos, under hygienist, BMP's detention pond and LID facilities stormwater systems, and evaluating resulting urban drainage charges based on 5 designing strategies for rating costs. The strategies applied were: (1) Total Impermeable Area (TIA); (2) Effective Impermeable Area (EIA-Poa) from Porto Alegre's Decree # 15,371/2006 criteria for alleviating detention pond's volume; (3) Effective Impermeable Area (EIA-Shuster) computed when there is impermeable area connection; (4) alteration on discharge's volume (ΔV) from pristine conditions, and; (5) alteration on peak flows (ΔQ_{\max}) from pristine conditions. Considering Porto Alegre's 2004 urbanization features, as assessed by Cruz (2004), we obtained an annual unitary cost of US\$ 0.29m². Taxes based on TIA and EIA-PoA failed to encourage the conservation of hydrological processes, given that they charged almost equally the three condos. Charges based on the ΔQ_{\max} strategy encourages BMP and LID condos equally. LID condo presented lower charges for every strategy, especially on ΔV and EIA-Shuster ones. Thus, these strategies are recommended, once they penalize the effective production of runoff.

Keywords: urban drainage charges, low impact development, hydrological processes.

1 – INTRODUCTION

Over recent decades, Brazilian cities went through accelerated and chaotic urbanization. This process produced major changes in the urban environment, especially significant impacts on water resources. Greater and more frequent floodings and contamination of surface and groundwater sources are major responsables for worse population well-being.

Urbanization of Brazilian cities has been marked by the removal of native vegetation, impermeabilization, piping and occupation of lowland and riparian areas, which, in general, tends to aggravate natural floods. That situation provides opportunity for applying alternatives on stormwater controls towards close-to-pristine conditions. Some cities in Brazil, e.g. Santo André and Porto Alegre, are already employing interesting techniques as Best Management Practices (BMPs), while other countries work on promising systems as Low Impact Development (LID) in the United States and Water Sensitive Urban Design (WSUD) in Australia.

Cruz et al. (2007) commented the difficulties on adopting detention ponds by developers in Porto Alegre, reinforcing the need to apply incentive mechanisms for the implementation of stormwater control facilities. According to Baptista et al. (2005), the adoption of mechanisms to induce reductions urbanization impacts on the hydrological cycle has been discussed in Brazil, mainly charges over urban drainage services.

This study aimed to assess how different strategies for designing a drainage tax would charge developments under different stormwater systems, namely hygienist, BMP and LID systems.

2 – TOWARDS SUSTAINABLE URBAN DRAINAGE

2.1 – Evolution of urban drainage planning

Urban stormwater management changed significantly in the last forty years. According to SNSA (2005), there were three distinct stages: hygienist, corrective and sustainable (Table 1).

Table 1. Urban Drainage Stages in developed countries (SNSA, 2005)

Years	Period	Features
Prior to 1970	Hygienist (Piping)	Put runoff away through <u>piping</u>
1970 – 1990	Corrective (BMP or Compensatory)	<u>Dampening</u> and treatment of stormwater through impact focused actions.
1990* - ?	Sustainable (LID)	Planning urban space occupation to keep <u>natural rates of hydrological processes</u> ; source-control of micro-pollutants, diffuse pollution

* Period that started this kind of vision.

Baptista et al. (2005) argue that hygienist systems (also known as traditional or classic) transfers floods downstream, demanding, generally, more expensive water works. Furthermore, the hygienist solutions do not consider water quality problems, resulting in virtually irreversible situations to land and water uses, such as recreation and landscaping.

Over the 1970's, a different approach on planning urban drainage systems was developed aiming to address hygienist systems problems. It was the planning of stormwater systems in a catchment basis and the adoption of corrective techniques through the application of facilities to control urbanization consequences on runoff, mainly detention ponds (USEPA, 1999). These stormwater systems, also known as BMPs, have been world-wide applied.

In Brazil, the term “Compensatory Technique” has been adopted by some researchers (such as Cruz et al. 2001; Goldenfum and Souza, 2001). Baptista et al. (2005) highlights its feature on reducing flows and volumes through storage or infiltration of stormwater. However, Cruz et al. (2007) emphasize that there is still considerable resistance to BMPs application in Brazil, due to poor public outreach, as well as natural opposition to innovations. Moreover, large quantities of solid and domestic waste reach drainage network, accumulating in reservoirs or detention ponds which may disturb public well-being.

Currently, closer to sustainability approaches (Marsalek, 2005) have been studied, namely: Low Impact Development (LID), in the USA and Canada; Sustainable Urban Drainage Systems (SUDS), in the United Kingdom; Water Sensitive Urban Design (WSUD), in the Australia; and Low Impact Urban Design and Development (LIUDD), in New Zealand.

LID systems present better hydrological, financial and aesthetical outcomes due to acknowledging natural systems, i.e., soil and vegetation, as infrastructure and to a multi-sector approach. Micro integrated management practices are applied to mitigate hydrological qualitative alterations from unavoidable impermeable surfaces, while addressing other purposes, e.g. green roofs, permeable pavers and bio-retentions. Phytoremediation and phytotechnologies address quality and quantity problems while meeting society's demands for amenable landscapes for recreation. In the United States, local institutions have been applying LID outreaching professionals and the community by local guides and brochures (Portland Bureau of Environmental Services, 1999; Prince George's County, 2002; PSAT & WSU, 2005). In Brazil, LID has been explored only in academic studies (e.g. Souza, 2005) and recommended in the national manual for municipal drainage systems expansion by the Ministry of Cities (Brazil, 2006). Souza (2005) evaluated hydrological simulations of condos in Porto Alegre with drainage systems designed under hygienist, BMP and LID systems. Our assessments will be based in this study, which will be presented next.

2.2 – Hydrological numerical simulations of different drainage systems

LID techniques were numerically simulated by Souza (2005) in a hypothetical residential condo with the soil and rainfall conditions of Porto Alegre, to examine its pros and cons regarding current practices (hygienist and BMP). In that simulation, it was considered only the application of bioretention and impermeable areas disconnection to control runoff to natural conditions, without changing the structural and architectural designs. Yet for BMPs, the designs alteration was limited to the existence of a detention pond, as usually takes place in Porto Alegre (Cruz et al., 2007). Souza (2005) used the (Tr) 10-years and 1 hour duration event and established four condos configurations:

- Condo I: natural condition;
- Condo II (hygienist): condo design with no runoff on-development control;
- Condo III (detention pond - BMP): condo design according to local regulations, i.e., the control of peak flows to obtain natural conditions (pre-development) discharges, preferably through detention ponds;
- Condo IV (LID): condo design through impermeable areas disconnection, bio-retentions and reduction of impermeabilization to achieve natural runoff volume conditions.

The comparison of each condo simulation outputs, i.e. hydrographs, was the method chosen to assess which of them maintains natural hydrological conditions the most. Souza (2005) evaluated the performance of the entire condo, as well as, of each building lot individually, through the modification of the IPHS1 model (Tucci *et al.* 1987), mainly the application of NRCS' TR-20 and TR-55 Methods and creation of bio-retention and vegetated swale sub-routines.

The hypothetical condos arbitrated followed Porto Alegre's residential condos design, as provided in Figure 1 (Souza, 2005). Condos II, III and IV followed Brazilian conventional practice of designing stormwater systems after architectural and structural designs. Therefore, the use of devices that required changes to the architectural and structural designs was avoided.

Simulation results (Figure 2) for the design event showed that (Souza, 2005):

- The use of detention ponds only redistributes volumes, sending additional runoff volume downstream, as expected;
- The lack of on-condo control anticipates and increases the peak flow, besides increasing their volume and duration, also expected;
- LID condo achieve the duration and volume criteria;
- Peak discharge control in lots to natural conditions helps on controlling peak flows in the condos outlet;

- First flush control, and thus water quality, takes place only in the LID condo due to bioretention storage.

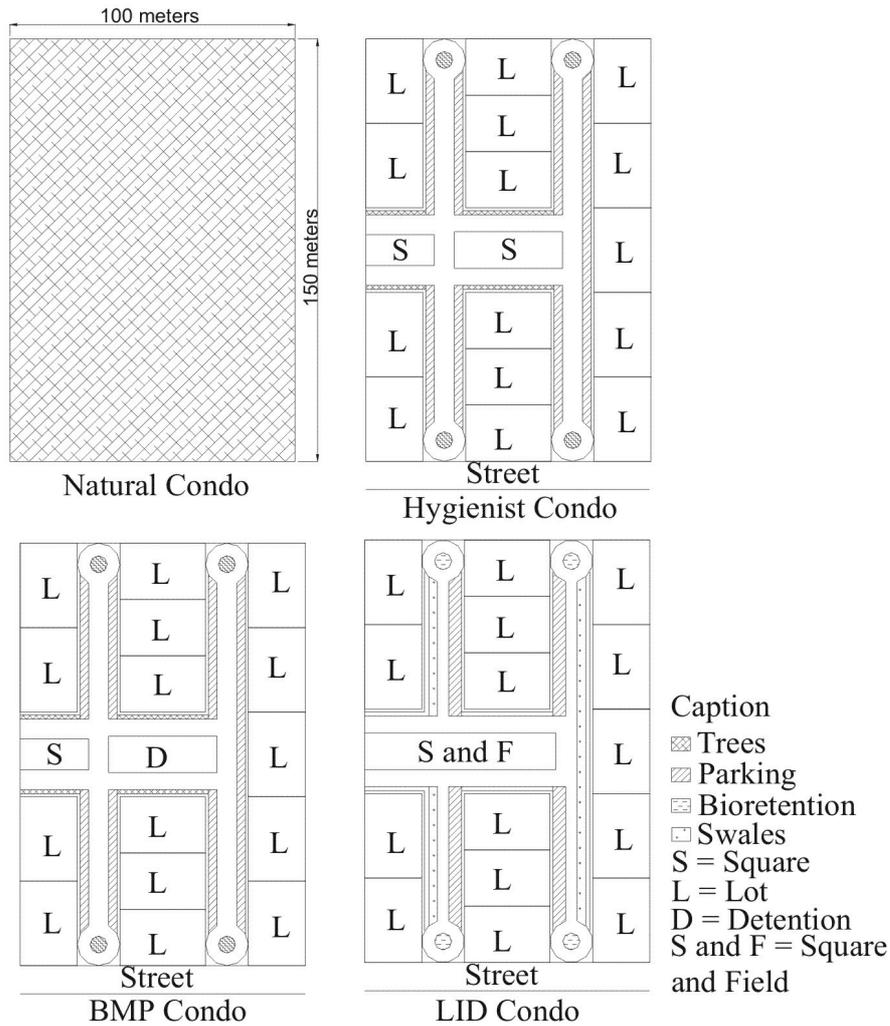


Figure 1. Configuration of condos (out of scale) (Souza, 2005).

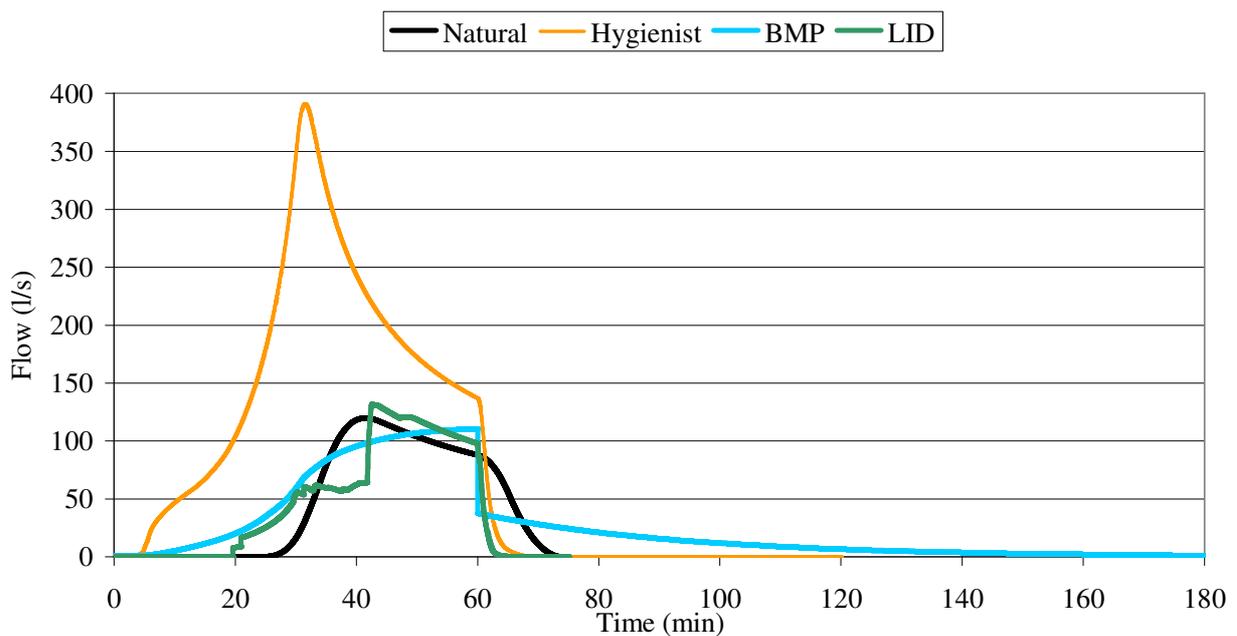


Figure 2. Condo responses to design storm (Souza, 2005).

3 –DESIGNING URBAN DRAINAGE CHARGES

The purpose of Economic Instruments (EI) is to internalize in decision-making the negative impacts of one's activity. Thus, the charge for urban drainage services intends to change user behaviour regarding his activity externalities on the environment. This charge might also aid on financing investments in infrastructure on covering operation and maintenance costs.

The drainage services have features of a public good, such as non-exclusion and non-rivalry (Cançado et al., 2006). It means that we can't exclude anyone off consumption: when supplied the services, anyone can or will necessarily consume. Cançado et al. (2006) emphasize that, depending on the "compulsory" use of the drainage system, the charge application on drainage services seems to be more appropriate from a legal perspective. However, unlike services, such as public lighting, it is possible to identify magnitude of drainage system uses through the volume released on the stormwater network.

Cançado et al. (2006) discuss ways of pricing urban drainage services. The authors argue that in Brazil, there aren't sufficient studies on methodologies that aim economic efficiency or maximization of social welfare to a given charge, such as the marginal cost or the rule of Ramsey. An alternative is to design the charge to cover the costs of production, prioritizing financing the system. Thus, the authors establish a charge on drainage services estimated by the average cost of installation, operation and maintenance of micro and macro-drainage systems. Nascimento et al. (2006) performed similar simulations to a hypothetical river basin in the city of Belo Horizonte, Minas Gerais State. The basis for rating the costs in the two studies is the lots total impermeable area (TIA). Tucci (2003) suggests, as a basic principle for financing Brazilian Urban Drainage Plans, to rate costs based on impermeable areas.

Tucci (2002) also proposed the application of a drainage charge to rate (i) operation and maintenance costs and (ii) installation costs of urban drainage devices of Porto Alegre's master plan. The author recommends charging over (i) permeable and impermeable areas in the former case, and (ii) impermeable areas only in the remainder. However, unlike the study of Cançado et al. (2006), the charge would be based on the volume of flow generated by each area, according to the runoff coefficient of permeable surfaces (0.15) and impermeable surfaces (0.95).

Shuster et al. (2005) advocates that, although TIA estimation may reflect well the magnitude of urban development, it doesn't reflect properly the differences between connected and disconnected impermeable areas runoff alterations. Such inability guides to consider "effective" impermeable areas (EIA) which would include only connected impermeable areas or impermeable areas that drain to the drainage system. The author emphasizes that besides connectivity, location and geometry should be considered to assess impermeable areas impact on the hydrological cycle. For instance, Church et al. (1999) found high runoff coefficient variability, c. 50%, for roads with similar impermeable area rates.

Porto Alegre's Decree #15,371/2006 presents an equation for estimating required detention ponds volumes based on development's impermeable surfaces. It alleviates detention pond dimensions if some of the following actions are in place, which is an indirect consideration of EIA:

- Application of permeable pavements (open blocks filled with sand or grass, porous asphalt, concrete porous) - reduce its surface area by 50%;
- Downspout disconnection to drained permeable surfaces - reduce roof area by 40%;
- Downspout disconnection to undrained permeable surfaces - reduce roof area by 80%;
- Application of infiltration trenches - reduce areas that drain to the trenches by 80%.

4 – METHODOLOGY

This paper objective is to evaluate the effects of different designs of urban drainage services charges on developments with different stormwater systems. To achieve it, we estimated annual unit cost of Porto Alegre drainage services from Cruz (2004) and applied charges on Souza (2005) simulation outcomes, as shown in item 2.1.

4.1 - Annual unit cost of Porto Alegre's municipal drainage system

Cruz (2004) optimized solutions (minimum cost) to Porto Alegre's flooding problems through pipe enlargement and location and construction of detention ponds, a typical BMP approach. The obtained total cost for the twenty-seven basins accounted for US\$ 834,667,252.71 in 2007 figures.

Considering a hypothetical loan, amortization rates were estimated through equation 1 for a 30 years period, which is the average lifetime of macro-drainage systems. The interest rate was composed by RILT (Rate of Interest on Long Term of 6.50% a year), basic spread (1.00% a year) and spread of risk (1.50% a year) in June 2007 figures. The depreciation system adopted was the Price or French System, with equal payments.

$$\text{Payment} = \frac{\text{Total investment} * i * (1 + i)^n}{(1 + i)^n - 1} \quad (1)$$

Where:

n = number of years of depreciation (30 years);

i = interest rate (9.00%).

Besides the annual payments due to systems installation, system's operation and maintenance costs were added, c. 5% of installation costs (Cruz 2004) or US\$ 42 million. The unit cost was estimated by rating annual payments by city area (c. 430,000,000 m²; Cruz, 2004).

4.2 - Strategies for designing urban drainage charges

From the estimated annual unit cost and hydrological and layout features (Table 2) of the three condos simulated by Souza (2005), ratings of the product of conjoint areas, i.e. 4.5 ha, and annual unit cost were rating by the following criteria:

- Strategy I (TIA): charge based on Total Impermeable Area (TIA);
- Strategy II (EIA - PoA): charge based on Effective Impermeable Area (EIA), according to Porto Alegre's Decree #15,371/2006 ;
- Strategy III (EIA - Shuster): charge based on Effective Impermeable Area (EIA), according to Shuster (2005), i.e., area that drains to permeable surfaces are not considered;
- Strategy IV (ΔV): alteration in flow volume regarding pristine (natural) conditions, once greater flow volumes reflect reduction in evaporation and infiltration rates;
- Strategy V (ΔQ_{max}): alteration of peak flow regarding pristine (natural) conditions, once it is responsible for enlarging pipes.

Table 2. Hydrological and layout features of condos simulated by Souza(2005).

Condos	TIA (m ²)	EIA-PoA (m ²)	EIA-Shuster (m ²)	Volume (m ³)	Peak (l/s)
Natural	0.00	0.00	0.00	204.30	119.85
Hygienist	13,869.00	12,139.00	8,320.50	589.48	391.01
BMP	13,869.00	12,139.00	8,320.50	589.48	110.78
LID	12,699.00	9,983.00	0.00	189.65	131.62

5 – RESULTS

Annual figures to finance installation, operation and maintenance of Porto Alegre storwater system accounted for US\$ 122,976,827.64, with unit cost of US\$ 0.29/m². Thus, the set of condos charges perform US\$ 12,861.59. Table 3 and Figure 3 present the results on unit figures and charges on condos to each charge design strategy.

Table 3. Unit figures to charge urban drainage services by designing strategy (US\$).

TIA	EIA - PoA	EIA - Shuster	Alteration in Volume	Alteration in Peak
0.32	0.38	0.77	16.69	45.46

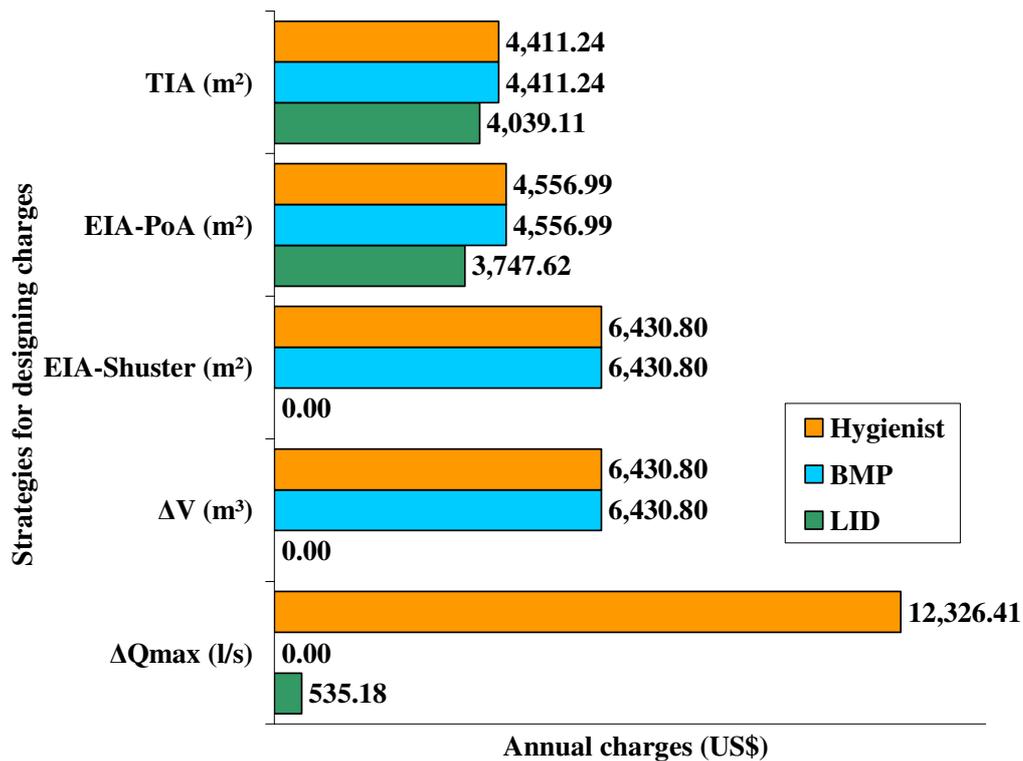


Figure 3. Charges on each condo and designing strategy.

Charges designed over TIA don't stimulate either the adoption of BMP or LID techniques since it charged almost equally every condo. Slight differences are due to LID's greater usage of open vegetated areas.

EIA-PoA charges showed smaller figures over the LID condo, which could be greater if bioretentions were considered in the municipal decree. That occurred due to its lack of application in the city.

In contrast, EIA-Shuster strategy didn't charge the LID condo. We emphasize, however, the need to consider impermeable areas that alter runoff patterns, since permeable and impermeable areas features change runoff control, e.g. 25 m² roof draining to 0.5 m² grassed area that drains to the stormwater system.

ΔQ_{max} charges privileged equally BMP and LID systems. However it does not consider potential externalities of applying detention ponds as alteration of other hydrological processes, reduction of open spaces and threats to human health.

LID systems received lower charges in every scenario, especially ΔV strategy. These results and lower financial construction costs of storwater systems (Souza, 2005) highlight urban drainage advances towards financial sustainability.

6 – CONCLUDING REMARKS

Urban drainage services charging may, fortunately, lead to a greater awareness on the impact that property (and the way it was built) and to a more rational land use. In this study, we aimed to assess how each criteria on designing charges would qualitatively affect landowners of developments with different stormwater systems.

We reinforce that instead of examining the extent of impermeable areas, the effective production of runoff should be considered. From that, charges based on flow volume alteration from pristine conditions and on effective impermeable area encourage the adoption closer to sustainability approaches.

However, operational difficulties on applying strategies based on effective runoff production should be considered, given its estimation difficulty. In this sense, Santo André's (SEMASA, 2007) evaluation of drainage charges based on generated volume by each property is remarkable. Porto Alegre's (2006) requirement on landowner conprovation of pre-occupation hydrological conditions maintenance might also be replicated. Such definitions puts in jeopardy the accuracy of data acquisition (evaluation of the effectiveness of impermeable areas) for monitoring, charge and tracking.

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