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Original Research Article

The Socio-Economic Viability of Urban-Fluvial Parks in the Urban Environment: A Case Study of Maricá, Rio de Janeiro

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ABSTRACT

Open spaces are fundamental in mitigating flooding. This research proposes a practical framework encompassing a business model that discuss the socio-economic viability of implementing urban fluvial parks, while considering expropriation and subsequent compensation for landowners. The method consists of two steps: the first assesses urban flood impacts at the watershed scale and compares to the implementation costs of blue-green infrastructure, which is defined by interconnected natural and human-made elements such as water bodies and vegetated areas. If this relation is positive, the second step addresses local scale issues, integrating urban-fluvial parks and new urban subdivisions in a win-win business model. Results showed that, over a 50-year horizon, the proposed interventions outweighed their implementation and maintenance costs. Locally, the assessment revealed an increase in total land value by approximately 40% compared to its original valuation. The study validates the framework, highlighting the importance of establishing a blue-green open space functional system.

KEYWORDS

Floodable parks, Public policy, Real state valuation, Real state devaluation, Resilience to urban flooding, Multifunctionality.

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INTRODUCTION

It is broadly accepted that open green spaces, such as parks, forests and urban greenery, provide a wide range of benefits for human beings. According to the World Health Organization, in addition to cooling effects, urban green spaces can increase quality of life through reducing stress, promoting a sense of community, improving the immune system, restoring the air quality, among others [1]. In general, mitigating the health effects of climate change, such as improving air quality, has a positive influence on economic productivity, healthcare costs, and personal finances [2]. The discussion about the open green spaces per capita has especially increased during the COVID-19 pandemic [3], where a series of studies have turned their attention to the importance of contact, proximity and access [4] to these areas as a support to physical and mental health [5]. Moreover, Konijnendijk [6] argues that the equitable access to trees and green spaces can be achieved by the 3–30–300 rule for urban forestry. In other words, every resident in a city should be able to have visual contact to at least 3 trees from their home or place of work, in addition to 30% of tree canopy cover in every neighborhood, and access to a large public green space within 300 m from home [6]. However, especially in developing countries, the differences in population's socioeconomic status are also perceived in the provision, access and utilization of public and private urban green spaces [7]. Therefore, the loss or fragmentation of urban nature is frequently noticed considering regions where the urban sprawl occurs in a disorderly way [6].

In another direction, the continuous process of urbanization and the changes regarding land use have led to direct impacts on reducing water infiltration and increasing surface runoff volumes. These actions increase the occurrence of urban floods and generate several impacts for the population, especially when combined with irregular occupation of floodplain areas and riverbanks [8] – which is a relatively common process in low income communities of developing countries. Consequently, the rapid growth of cities, especially without proper planning, overloads flood events that affect the city itself, creating a cycle of degradation that requires new urban interventions (and consequent investments) to reduce flood losses [9]. In this sense, open green spaces are increasingly being recognized worldwide for their capacity to fulfill hydraulic functions, especially through Blue-Green Infrastructure (BGI) approaches. The BGI concept defends that interconnected networks of natural and human-made elements [10], including water bodies, vegetated areas, detention or retention basins, and urban-fluvial parks, for instance, are able to alleviate the conventional and overloaded grey urban drainage system, reducing floods, improving urban resilience in multiple scales [11] and providing a series of co-benefits, [12]. BGI strategies naturally reduces stormwater runoff during flood events, minimizing property damage, mitigating the effects of urban heat islands, regulating land use, and enhancing community well-being [13]. Therefore, open green spaces can play a fundamental role in creating both water storage and public recreational areas. Moreover, if adequately planned and implemented, they can offer additional environmental opportunities and revitalize urban vicinity. However, open spaces in cities are not always related to a real fully functional system. Many times, part of the available open spaces is private and subject to changing their status through time, being possibly occupied by built areas. In this regard, Amback et al. [14] examine the potential exacerbation of flooding in a sprawling area of Rio de Janeiro, Brazil, by examining scenarios where open spaces are lost and not used to manage stormwater. Their study highlights the importance of integrating urban drainage, open spaces, and land-use planning.In recent literature, although researches present the benefits of BGI in urban environments as a main subject, such as flood management [15] and the provision of other ecosystem services [16], there is still a gap in the studies regarding the socio-economic viability of implementing these solutions. In particular, considering highly urbanized contexts where open green spaces are scarce, this discussion should be held together with expropriation strategies and subsequent compensation of local residents, in order to enable the implementation of multifunctional strategies for flood control and recreation, in a practical and feasible way. However, expropriation costs may be significant and moving people away from their original homes can be socially questioned. These aspects are barriers to the use of large scale BGI in expanding cities. Strategies to overcome these barriers must be addressed to enable the possibility of building a functional open space system, both offering social and ecological services.

Some researches, such as Kozak et al. [17] evaluated the trend of land-value increase in two design scenarios in the Medrano Stream Basin, in Argentina: the Scenario 1 was mainly composed of major grey infrastructure and minor BGI strategies, while the Scenario 2 comprised major BGI measures and minor grey infrastructure. The results showed an appreciation of US$ 192 million for Scenario 1, especially due to flood reduction, and a valorization between US$ 518–844 million for Scenario 2, which is related not only with flood mitigation, but also with the deculverting measures and the creation of public spaces. This is an interesting and promising finding, showing that green measures also act as urban valorization drivers. Similarly, Lategan et al. [7] used the principle of proximity to urban green spaces to evaluate properties with different socioeconomic status located in three districts of Potchefstroom, South Africa. In this sense, the hypothesis indicated that property prices would possibly increase as distance to urban green spaces decreases. The results showed that property valuations occurred and were higher for low-income and high-income properties closer to urban green spaces built in these places, and lower for middle-income areas. In this case, the lower price related to middle-income areas was associated to the low quality of the social functions and activities carried out in the public urban green spaces, indicating the need to improve local amenity destinations. Riley's et al. [13] conducted a case study in Waimanalo, Hawaii, which indicates that, although the initial costs for floating solar photovoltaic systems and a retention pond are relatively high, the approach is financially viable over time. Operational costs remain low, and after 25 years, it offers the potential to reduce energy expenses, particularly for low-income households, while simultaneously generating revenue for utility providers.

On the other hand, considering compensation policies and impacts on urban land uses, Holloway and BenDor [18] discuss the buyout of floodplain sites as a strategy to mitigate flood risk. According to the authors, recently-flooded properties are usually not desirable on the North American private market, which make owners apply for a government offer to purchase their properties for the pre-flood "fair market value" [18]. This information shows the deterioration potential of floods over real estate market. In Brazil, compensation policies include the "onerous grant of the right to build", foreseen in the Brazilian City Statute [19], which is a concession issued by the government that allows the property owner to build above the allowable building area in turn for a financial contribution [20]. Considering this legal instrument, it would be possible to imagine a situation where exchange lots in floodable areas in the river vicinity for a permission to build over the legal allowable building area in other urban lots, in safer places, could avoid great expropriation costs. Both compensation strategies cited can be useful in flood-prone areas, as a measure to protect the population against flood risk. The second case, however, can be especially useful in regions where urban growth is still in process of consolidation and there are void lots. These non-built spaces could be included in the macro interest area of intervention and used to provide compensation in terms of allowable building area to grant riverine areas to install BGI measures, like the urban-fluvial floodable parks.

Based on this background, this work aims to propose a practical framework encompassing a business model that considers the large-scale socio-economic impacts of implementing urban-fluvial parks in an urban watershed, in the context of using BGI measure to mitigate floods, but also taking into account the need for expropriation and compensation of local property private owners, identifying ways to establish a win-win procedure. Therefore, this study is based on the hypothesis that it is possible to make it viable for municipalities to work with BGI concepts, offering large scale projects where social and natural needs are considered in flood control initiatives, but without causing socioeconomic local losses. This possibility can be materialized if land value accounts for flooding safety, the presence of green areas and accepts larger building permits, when considering a target intervention area greater than that considered for the strictly flood control measures. The novelty of this proposal lies in the joint consideration of a flood control approach, that considers the hydraulic solution within a social-economic-environmental urban functional and viable arrangement.

In this work, an exploratory case study was taken as a practical lab, in the Municipality of Maricá, in Rio de Janeiro, Brazil, to test the proposed flood control arrangement, using urban-fluvial parks. The area was chosen due to the critical floods that usually occur and the intense ongoing process of urban sprawl, making it urgent to integrate sustainable actions into the urban planning to avoid future higher losses and damages.

The Method section outlines a two-step approach, first assessing urban flood impacts at the watershed scale and then focusing on the local intervention area to integrate multifunctional parks while considering property compensation. The Case Study section presents the Mumbuca/Ubatiba Watershed in Maricá, Rio de Janeiro, Brazil, as the study area. The Results section analyzes flood mitigation strategies at both watershed and local scales, comparing flood depths and estimating the benefits of a proposed Design Alternative. The Discussion evaluates the cost-effectiveness of the interventions, addresses study limitations, and explores social benefits to encourage public acceptance. Finally, the Conclusion summarizes the key findings and contributions of this research.

METHOD

The proposed method consists of two main integrated steps. In the first step, the impacts and the damage caused by urban floods was analyzed at the watershed scale, using hydrodynamic modeling, Geographic Information Systems (GIS) tools and depth-damage curves, for a timeframe of 50 years, considering this period as reference because of the useful life of concrete structures (typical construction material used in Brazilian cities). Additionally, a set of flood control interventions based in a sustainable urban drainage approach was simulated to assess the overall benefits of their implementation. This sustainable approach introduces and integrates a blue-green infrastructure system following the main river path, mainly considering floodable compound urban-fluvial parks, which means that these parks will contain a floodable area, in which flood waters occupation will vary for different rainfall events, first occupying vegetated areas in the lower parts of the park and only occupying the upper parts in the rainfall design event. These upper areas can perform social functions, including leisure areas, cycle paths, etc. In this first step, the main intention refers to comparing the avoided flood losses with the costs of the proposed intervention.

If the benefit is promising, a second step is needed to make the intervention viable in the local scale, since urban areas are majorly composed by private properties and it is not possible to avoid compensations (and this is usually a barrier for BGI actions). Therefore, in the second step, a local scale emphasis is applied and the intervention area is re-shaped to include the near vicinity and compose a large enterprise area to accommodate the suggested multifunctional park, evaluating the expropriation of vacant lots and potential compensation measures to ensure that the value of the original existing properties is maintained. In this sense, this larger area is reconfigured as a multifunctional park and a multifamily buildable area, where the flood safety, the proximity of the park and the additional building permits compensate for the expropriation, configuring a win-win procedure, both in the city scale and the local neighborhood scale. **Figure 1** shows the general aspect of this framework.

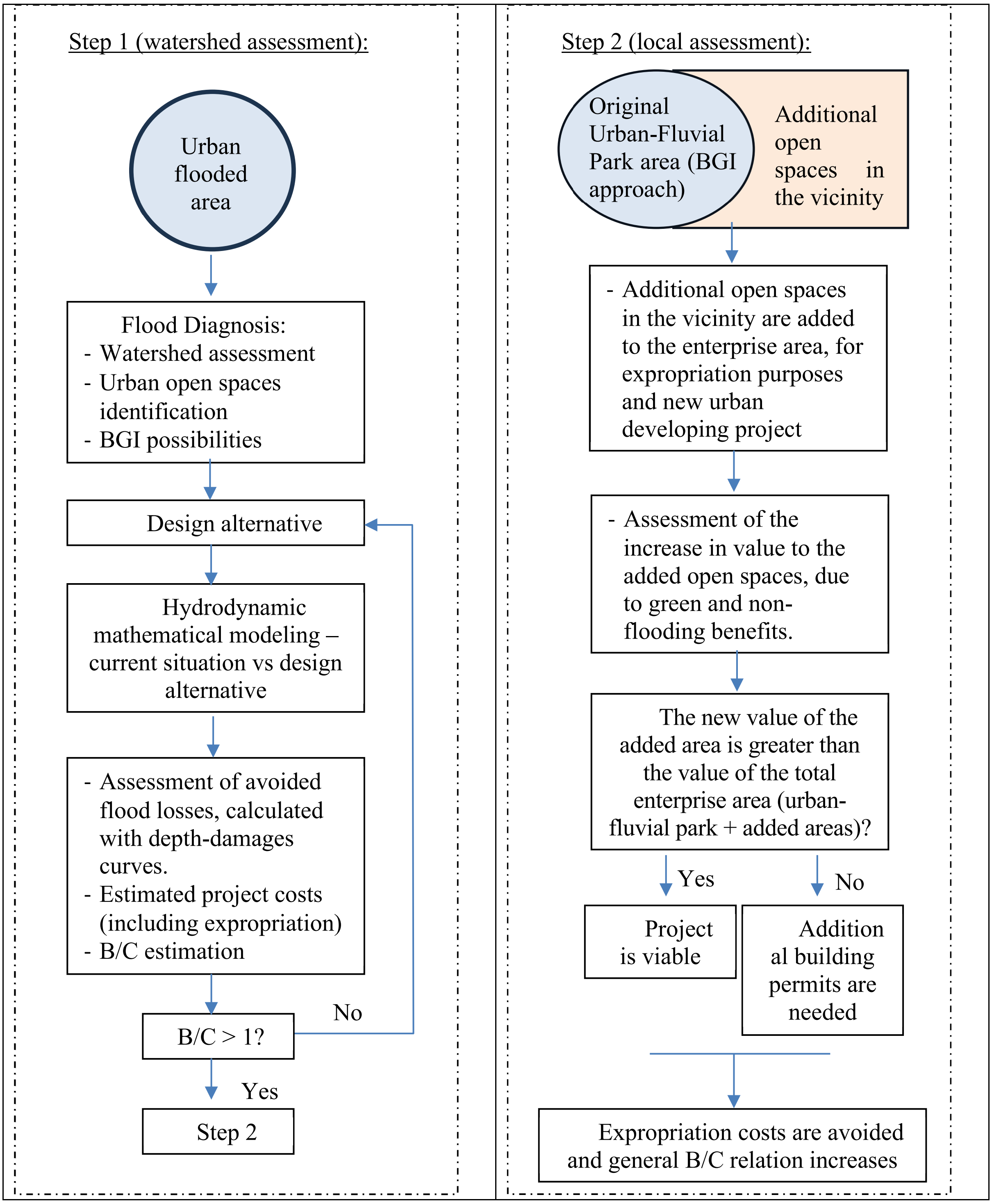

Figure 1: Flowchart of the proposed methodological approach.

Watershed scale assessment

Considering the watershed scale, the damage caused by urban floods in the Current Situation is compared to the expected damage after the implementation of a hypothetical Design Alternative, to calculate their expected benefits. Thus, the Urban Flow-Cell Model (MODCEL) [21], a hydrological-hydrodynamic tool that simulates surface runoff behavior during flood events in urban environments, connecting these surface flows to storm drains and open channels, was chosen to run the simulations of the Mumbuca/Ubatiba Watershed. In addition, an urban expansion scenario (Design Scenario) was created to simulate a possible future land use in a 10-year timeframe, considering a planned growth based on sustainable guidelines. This choice was made considering that a sustainable urbanization is consistent with the proposed blue-green approach used in the flood control project. The Design Scenario was built by an arithmetic projection of the population growth from 2021 until 2031, using data from the Brazilian Institute of Geography and Statistics (IBGE). This Scenario was used as reference to simulate the major drainage system responses in the long run. The choice of projecting the urbanization 10 year into the future intended to fulfill some premises. Since the timeframe assessment refers to 50 years, it is not expected that urbanization will remain static. The choice of 10 years covers the horizon of an urban plan in Brazil; after that, the plan must be revised. Besides, the Maricá has a new Urban Master Plan ongoing an approval process and this plan foresees some changes in the urban growth path. Additionally, it was considered interesting to add some environmental concerns, regarding the blue green approach, favoring the city compacity (which something proposed by the new plan), but also configuring a BGI system related to the urban open spaces system. The hydrodynamic simulations considered 1, 2, 5, 10, 25, 50 and 100-year return period rainfall events.

After obtaining the flood depths that affect the case study, they were "plotted" over the existent lots, to estimate the number of buildings affected by each return period flood map. In this analysis, it was assumed that lots that intersect with more than one flood depth tend to be impacted by the most critical one.

Then, flood depths were used to calculate two different types of damages caused by floods, based on Guimarães, Rezende and Miguez [22]: the damage to the building's structure, which is related to all components of the building itself, and the damage to the building's content, which comprises furniture, household appliances etc. Depth-damage curves are needed, in this case, to transform flood depths into flood losses. Firstly, to calculate the damage to the building's structure, Brazilian parameters that determine the construction standard of buildings were considered, correlating them with the socio-economic status of the inhabitants. In Brazil, socio-economic classes range from A to E (A, B1, B2, C1, C2, D, E), where A is represented by high-income populations and E by low-income classes. The construction standard and socio-economic status were associated with flood level ranges to create a percentage of damaged building, as defined by Nagem [23]. The curve of damage to the building's structure, adapted from Guimarães, Rezende and Miguez [22], is presented in Figure 2.

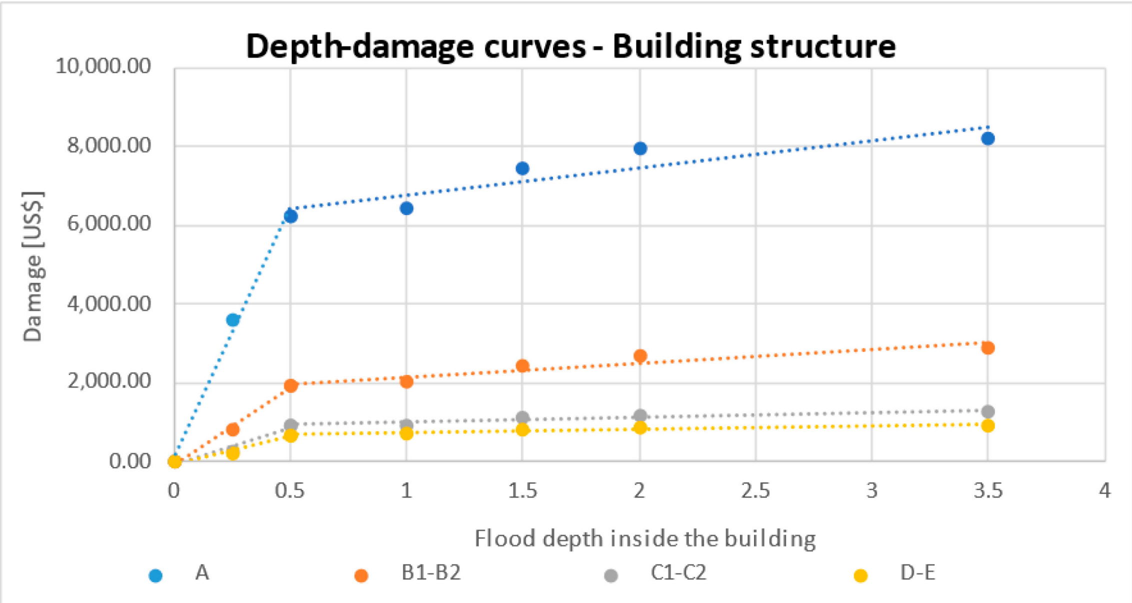

Figure 2. Depth-damage curves for building structure. Adapted from Guimarães, Rezende and Miguez [22].

Subsequently, to calculate the damage to building's content, Nagem's [23] survey of the main items found in homes according to social class was considered, as well as the height of the flood levels that could damage these items. The curve of damage to the building's content, adapted from Guimarães, Rezende and Miguez [22], is presented in Figure 3.

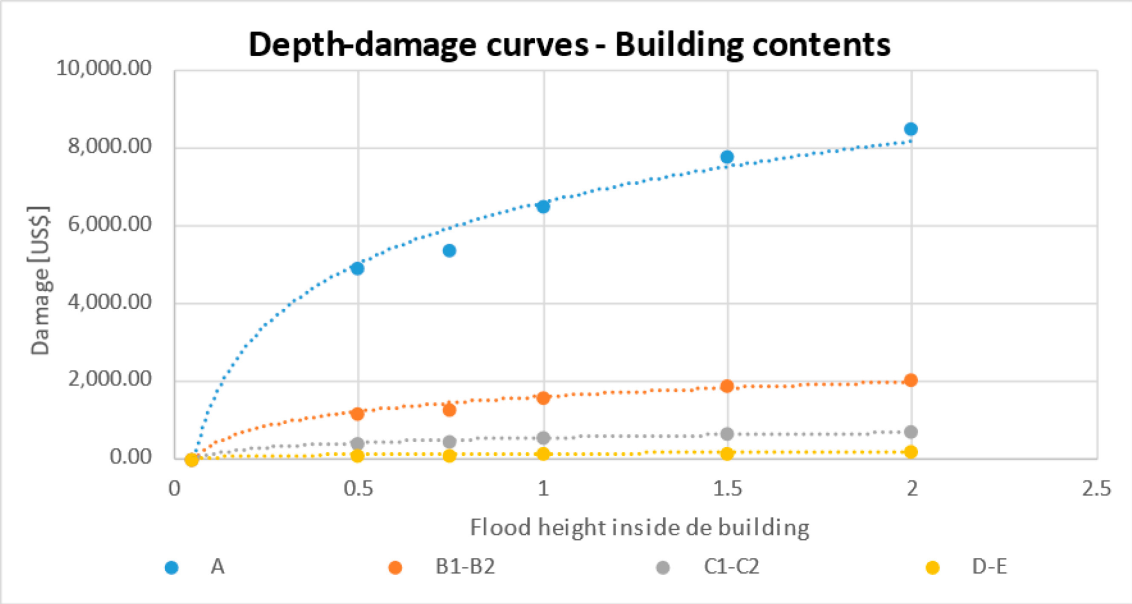

Figure 3. Depth-damage curves for building contents. Adapted from Guimarães, Rezende and Miguez [22].

In the current case study, only modeled water levels above 30 cm were considered for causing damage, considering the height to surpass door sills. Therefore, 30 cm were removed from the results of the hydrodynamic model to consider the height that actually reaches the buildings.

In the following step, it was calculated expected annual damage (EAD) in the current situation and in the design alternative. This process enables to estimate the benefits of the design alternative, since it is possible to compare the damage caused by flooding before and after their hypothetical implementation for a set of possible events considered with their probabilities. The numerical integration method, simultaneously explored by Yu, Qin, and Larsen [24] and Hellmers et al. [25] allows the calculation of the EAD by multiplying the mean damage by the increase in the probability of exceedance, according to Eq. (1), (2) and (3)

$$\Delta P_i = |P_i - P_{i-1}| \tag{1}$$

$$D_i = \frac{D_{Pi-1} + D_{Pi}}{2} \tag{2}$$

$$EAD = \sum_{i=1}^{m} D_i \times \Delta P_i \tag{3}$$

Where:
D_{Pi} = damages due to the flood event *i*;
P_i = probability of occurrence of the event *i* in a year.

The difference between the EAD in the current situation and the EAD in the design alternative corresponds to the benefit of the implementation of the proposed measures. This value is compared with the estimated cost of the urban river park, to evaluate its viability. The cost is composed by the value of land acquisition and the cost of the required dams, dikes, and excavation.

Local scale assessment

Considering the local scale, to face the property ownership problem, the assessment starts by defining the total area of intervention, which means the green open spaces to act as multifunctional recreational spaces that will also provide flood damping and the area to be destined for future lots. The estimated area for setting a single lot was considered with 720 m², being 600 m² for the lot itself and 120 m² for the street in front of it. Then, the area available for future subdivision is divided by the single lot area and the total number of lots that can be implemented in the area of intervention is estimated, occupying the near vicinity of the urban-fluvial park.

Considering the improvements provided by the implementation of the urban fluvial parks, Eq. **(4)** considers the expected increase in values of properties close to these urban green spaces that originally did not suffer from floods. This Equation was based on the research of Kozak et al. **[17]**, which estimated different percentages of valorization according to the proximity of the park. For this work, a new 500-meter strip was considered and introduced into the original Equation.

$$\begin{aligned} \mathrm{I}_{\text{amenities}} = {} & 0.2250 \times \mathrm{NH}_{0-50\ \mathrm{m}} + 0.150 \times \mathrm{NH}_{50-100\ \mathrm{m}} + 0.075 \times \mathrm{NH}_{100-200\ \mathrm{m}} \\ & + 0.0375 \times \mathrm{NH}_{200-300\ \mathrm{m}} + 0.01875 \times \mathrm{NH}_{300-500\ \mathrm{m}} \end{aligned} \tag{4}$$

Where:
$\mathrm{I}_{\text{amenities}}$ = Valorization due to amenities provided by the park;
$\mathrm{NH}_{0\text{-}50\ \mathrm{m}}$ = number of households in lots up to 50 m of the park and outside flooding area;
$\mathrm{NH}_{50\text{-}100\ \mathrm{m}}$ = number of households in lots between 50 m and 100 m of the park and outside flooding area;
$\mathrm{NH}_{100\text{-}200\ \mathrm{m}}$ = number of households in lots between 100 m and 200 m of the park and outside flooding area;
$\mathrm{NH}_{200\text{-}300\ \mathrm{m}}$ = number of households in lots between 200 m and 300 m of the park and outside flooding area.
$\mathrm{NH}_{300\text{-}500\ \mathrm{m}}$ = number of households in lots between 300 m and 500 m of the park and outside flooding area.

Moreover, some areas can be valued both by reducing flooding and by proximity to open green spaces, such as the fluvial park proposed. Considering this situation, land value increase can be valuated through Eq. **(5)**and Eq. **(6)**, which were proposed by Guimarães **[26]** based on Kozak et al. **[17]**. These Equations also considered a new 500-meter strip and they represent two different ranges of flood occurrence, being the most frequent flooded areas (the ones related to floods with return periods between 2 and 10 years) more sensible to valorization.

$$\begin{aligned} \mathrm{I}_{\text{flood}_1 \cap \text{amenities}} = {} & 0.7203 \times \mathrm{NH}_{\mathrm{F1}\cap 0-50\ \mathrm{m}} + 0.6149 \times \mathrm{NH}_{\mathrm{F1}\cap 50-100\ \mathrm{m}} \\ & + 0.5096 \times \mathrm{NH}_{\mathrm{F1}\cap 100-200\ \mathrm{m}} + 0.4570 \times \mathrm{NH}_{\mathrm{F1}\cap 200-300\ \mathrm{m}} \\ & + 0.4150 \times \mathrm{NH}_{\mathrm{F1}\cap 300-500\ \mathrm{m}} \end{aligned} \tag{5}$$

$$\begin{aligned} I_{flood\_2 \cap amenities} &= 0.4653 \times NH_{F1 \cap 0-50\ m} + 0.3756 \times NH_{F2 \cap 0-100\ m} \\ &+ 0.2859 \times NH_{F2 \cap 100-200\ m} + 0.2411 \times NH_{F2 \cap 200-300\ m} \\ &+ 0.215 \times NH_{F2 \cap 300-500\ m} \end{aligned} \tag{6}$$

Where:
$I_{flood\_1 \cap amenities}$ = Valorization due to flood mitigation in areas where floods of return period between 2 and 10 years used to occur, and amenities are provided by the park;
$I_{flood\_2 \cap amenities}$ = Valorization due to flood mitigation in areas where floods of more than 10-year return period used to occur and amenities are provided by the park;
$NH_{F1 \cap 0-50\ m}$ = number of households in lots up to 50 m of the park and flooded with return period between 2 and 10 years;
$NH_{F1 \cap 50-100\ m}$ = number of households in lots between 50 m and 100 m of the park and flooded with return period between 2 and 10 years;
$NH_{F1 \cap 100-200\ m}$ = number of households in lots between 100 m and 200 m of the park and flooded with return period between 2 and 10 years;
$NH_{F1 \cap 200-300\ m}$ = number of households in lots between 200 m and 300 m of the park and flooded with return period between 2 and 10 years;
$NH_{F1 \cap 300-500\ m}$ = number of households in lots between 300 m and 500 m of the park and flooded with return period between 2 and 10 years;
$NH_{F2 \cap 0-50\ m}$ = number of households in lots up to 50 m of the park and flooded with return period of 10-year or greater;
$NH_{F2 \cap 50-100\ m}$ = number of households in lots between 50 m and 100 m of the park and flooded with return period of 10-year or greater;
$NH_{F2 \cap 100-200\ m}$ = number of households in lots between 100 m and 200 m of the park and flooded with return period of 10-year or greater;
$NH_{F2 \cap 200-300\ m}$ = the number of households in lots between 200 m and 300 m of the park and flooded with return period of 10-year or greater;
$NH_{F2 \cap 300-500\ m}$ = the number of households in lots between 300 m and 350 m of the park and flooded with return period of 10-year or greater.

Therefore, this valuation was made for three possible situations: for lots that are valued by the park, but do not suffer from floods in the Current Situation; for lots located in the influence area of the park and that no longer suffer from floods for rainfall events under 10-year return period; and for lots located in the influence area of the park and no longer suffering from floods for rainfall events above 10-year return period.

Finally, this valuation is applied to the current available building potential, representing partial compensatory measures for the owners of the original lots. Additionally, the allowable building area can be raised to find a final satisfactory value to the remaining lots, after implementing the fluvial park.

THE MUNICIPALITY OF MARICÁ – EXPLORATORY CASE STUDY

The Mumbuca/Ubatiba Watershed, located in the Municipality of Maricá, in Rio de Janeiro, Brazil, was chosen as a case study (**Figure 4**) of interest, to assess the socio-economic viability of implementing urban fluvial parks in already occupied areas, constructing a win-win process. The watershed has an area of 73.9 km², with the Mumbuca/Ubatiba River being the largest of the municipality (19.8 km). The local altimetry shows a variation between 0 and 604 m in the watershed. The upstream reaches are smaller and presents a high gradient, while the downstream reaches are characterized by a long stretch of coastal lowlands. Despite of the level variation, most of the urbanized areas are located in floodplain regions, near to the lagoon system that marks the downstream landscape. These combined aspects foster the rapid concentration of water in floodplain areas, promoting social and economic impacts to the local dwellers.

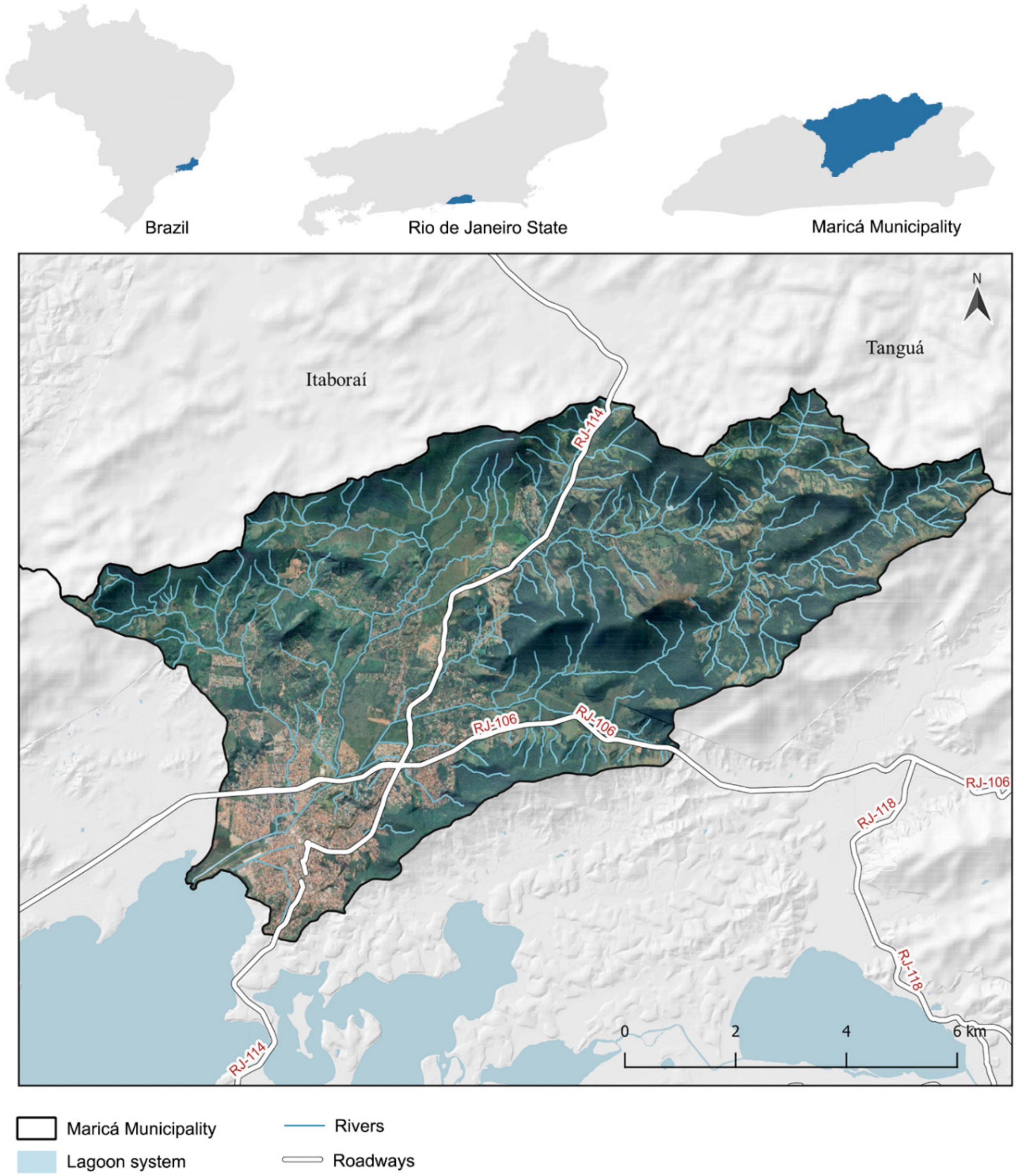

Figure 4. Location of Maricá Municipality and Mumbuca/Ubatiba Watershed.

Considering its urban aspects, the watershed can be described into two sections, using the transversal highway as a divider axis. To the south of the highway is the Center of Maricá comprising a high-density occupation, where some of the Municipality's oldest settlements are located, including commercial and administrative zones. Due to the quality of the urban infrastructure and the employment opportunities offered in the region, the area is dense and consolidated, with limited availability of vacant lots or open green spaces capable of locally acting in flood mitigation. On the other hand, to the north of the highway, a lower occupation density appears, characterized by private condominiums, unoccupied properties, rural zones and environmental protection areas. Despite the wide availability of open green spaces that can contribute to the well-functioning of the hydrological cycle, recent data from the Brazilian demographic census [27] showed that the Municipality is currently facing an accelerated urban growth, which can lead to an increasing loss of permeable areas. Moreover, various of the apparently free open spaces are already resultant of urban subdivision processes and are just waiting to be transformed into built-up areas.

In order to face the threats associated with the future urban sprawl of the Mumbuca/Ubatiba Watershed, coming from the city canter with a south to north orientation, or from downstream to upstream reaches when taking the watershed as reference, a range of open green spaces were selected to simulate the implementation of detention and retention reservoirs, and its consequent impact at the watershed scale. Particularly, an area of approximately 1.3 km², situated in a large open space in the Ubatiba neighborhood, just upstream the city center, was selected to illustrate the conceptual design of a multifunctional park, which combines storage and recreational strategies and integrates natural and urban needs. This park is very important to the local flood control initiative and, at the same time, can be a hotspot of litigation since private owners will be affected to make this arrangement viable. This case poses the typical setup that justifies our study and the proposed framework developed.

RESULTS

The following sections organize the results by scale assessment. The watershed scale assessment presents the main multifunctional interventions designed to mitigate urban floods in the Mumbuca/Ubatiba Watershed. It also compares flood depths between the Current Situation and the Design Scenario under various Return Periods (RP). The impact of urban floods in the Current Situation is compared to the projected damage after implementing a hypothetical Design Alternative to estimate the expected benefits. On the other hand, the proposed urban multifunctional park in the Ubatiba neighborhood and evaluates the benefits associated with its implementation.

Watershed scale assessment

Suggested interventions. In order to protect the households of the Mumbuca/Ubatiba Watershed from urban floods, a set of open spaces was used in a hybrid blue-green-grey infrastructure project. These interventions include dredging and widening of the mouth of the main river, to restore its discharge capacity into the lagoon system, which has been lost due to sedimentation; the introduction of upstream reservoirs in sparsely occupied areas; and the introduction of multifunctional detention and retention ponds (floodable parks) in locations closer to urban settlements. The set of upstream reservoirs act as the first protective initiative, laminating flood discharges before they reach urban areas, while the multifunctional ponds act in the critical areas, offering additional storage volumes to avoid river overflows to occupied urban areas. In particular, a multifunctional park in the core of the Watershed was selected to simulate its economic viability. Actions such as excavation, dikes, weirs, orifices, and the introduction of public facilities were considered to account the total costs of the interventions. **Figure 5** spatialize these interventions.

Economic viability. From the outcome of the mathematical hydrodynamic simulation, it was possible to compare the flood depths of the Current Situation and the Design Scenario, considering different Return Periods (RP).

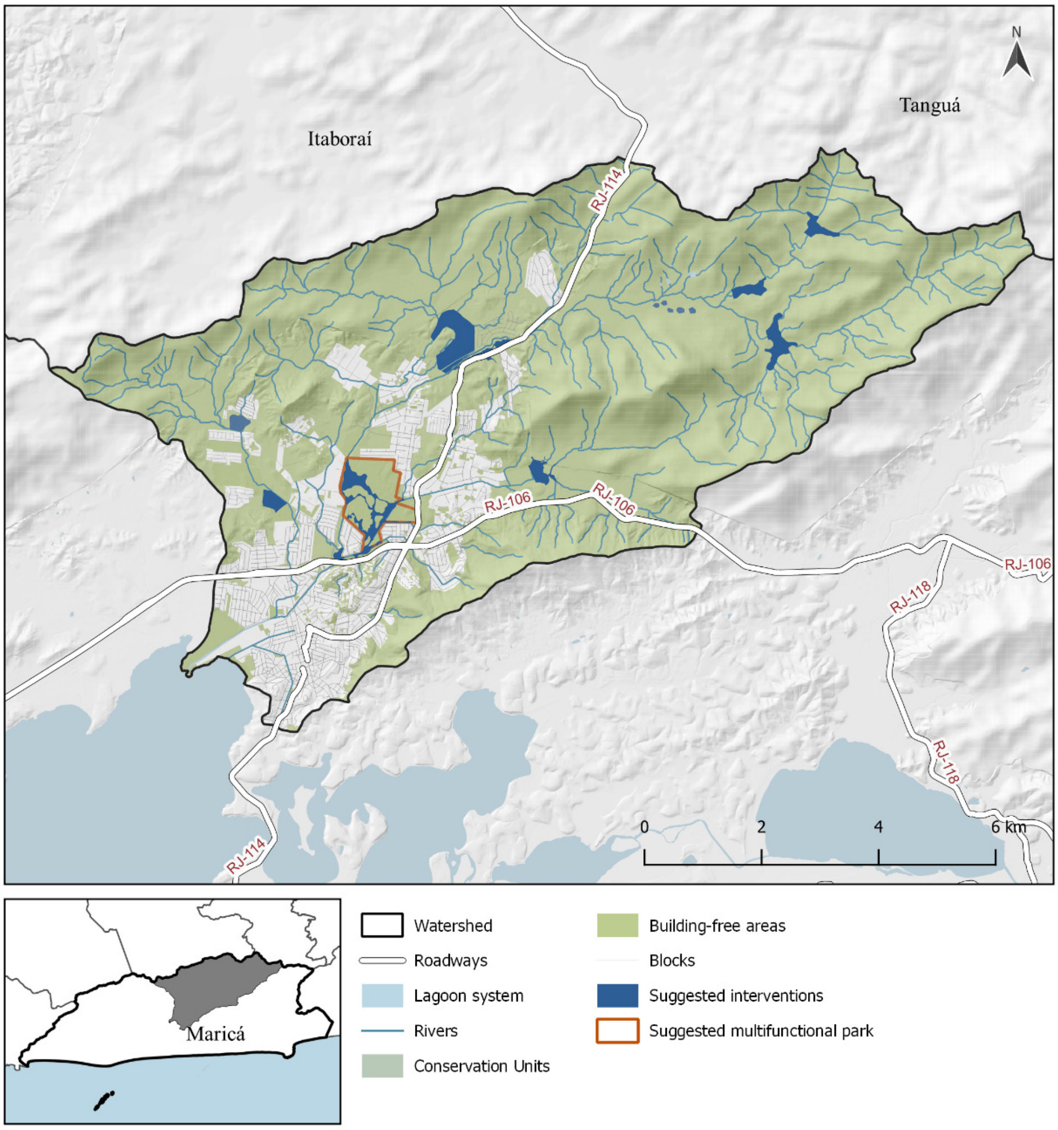

Figure 5. Suggested interventions for the Mumbuca/Ubatiba Watershed.

In the Current Situation, presented in **Figure 6** and **Figure 7**, it is noted that flooding areas, represented in a blue gradient, become gradually visible as the RP increases. Comparing the RP of 10 and 25 years, for instance, it is observed an increase in the water depths that affect the most populated neighborhoods of the watershed, located on the south of the transversal highway (RJ-106). The 50 and 100-year RP events show that flood depths spread to the surroundings of the proposed multifunctional park, and even to areas located upstream, close to rural zones. Consequently, as expected, the number of households and vacant lots exposed to flood risk increases with the RP. Therefore, the simulations demonstrate the need to order future territory occupation and optimize the use of green open spaces to storage water volumes.

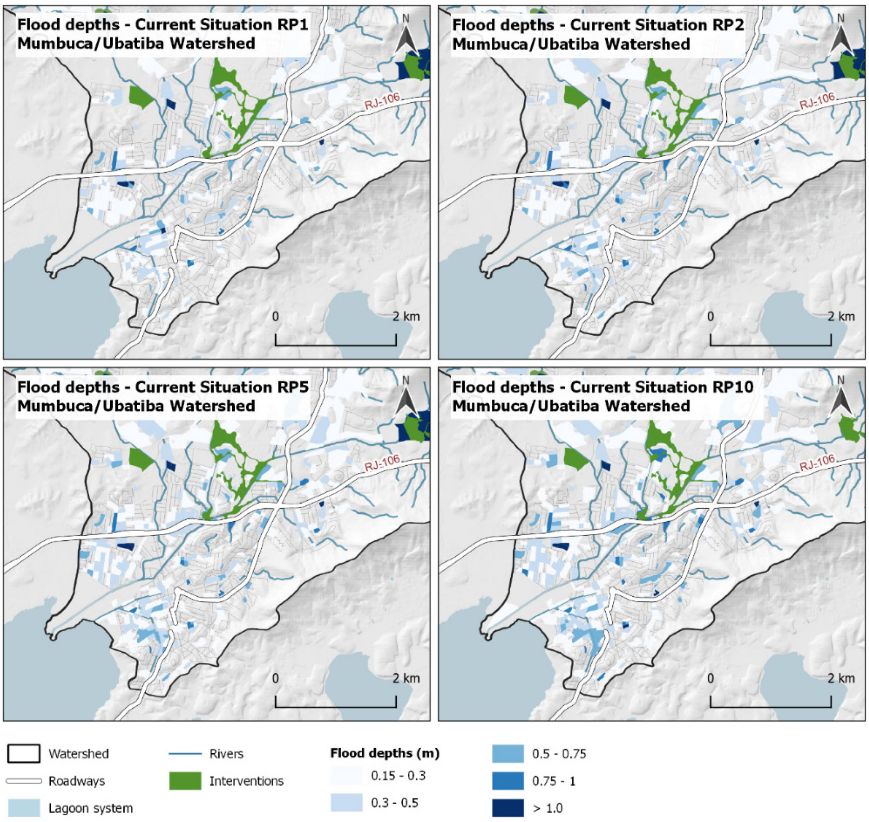

Figure 6. Flood depths for the Current Situation, considering Return Periods of 1, 2, 5 and 10 years.

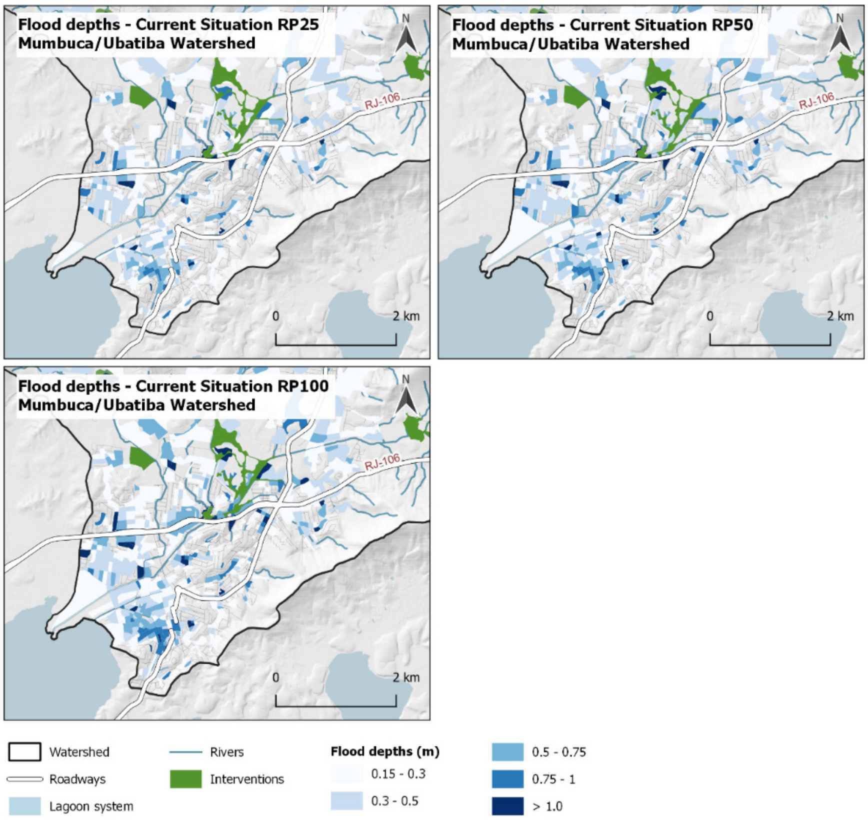

Figure 7. Flood depths for the Current Situation, considering Return Periods of 25, 50 and 100 years.

However, significant flood reduction is observed in the Design Scenario, highlighting the efficiency of the combined interventions. In Figure 8 and Figure 9, it is notable that flood depths are considerably lower when compared to the Current Situation, especially downtown. Therefore, the introduction of upstream reservoirs can significantly dampen flows, reducing floods downstream. At the same time, most of the households surrounding the suggested multifunctional park, which were affected by flood depths above 1.0 m in the Current Situation, are now affected by less significant flood levels. The remaining flooding areas can be related to minor drainage deficiencies.

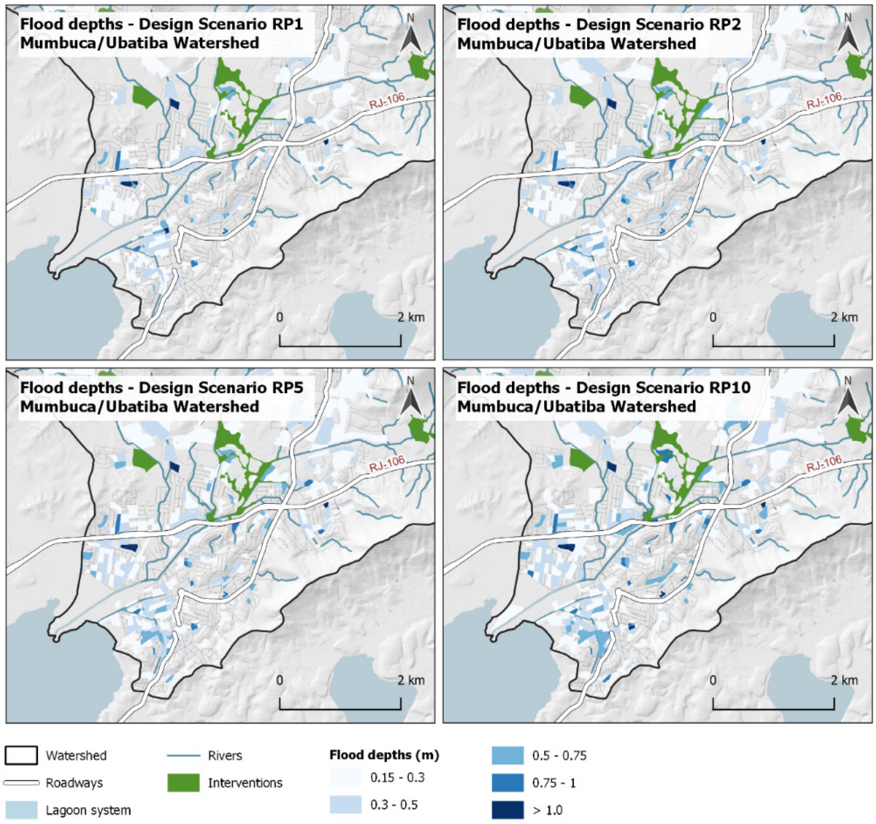

Figure 8. Flood depths for the Design Scenario, considering Return Periods of 1, 2, 5 and 10 years.

Next, the results of the hydrodynamic modeling were used to calculate flood damages to the households. Table 1 shows the comparison of expected damages for the building structure, considering different RP for the Current Situation and the Design Scenario. Even though financial losses (calculated in Brazilian Reais) increase significantly according to the RP, the Design Scenario shows a considerable reduction of costs in comparison with the Current Situation, decreasing more than 45% of the building structure damage for each RP. In this sense, it is important to note that the financial building structure damage due to a 50-year event in the Design Scenario is still less damaging than a 5-year event in the Current Scenario. The same findings are highlighted in Table 2, which shows a decreasing of more than 45% in financial damages related to the building content for each RP. Table 3 shows the sum of the total expected damages for the Current Situation and the Design Scenario, showing a decrease of more than 50% in financial damages (the exception is the RP1 with a 49% decrease), which is similar to the results presented by Ramos and Besharat [28]. These authors compared the current situation of Tagus estuary and a design scenario with BGI combined techniques (detention basin and permeable pavement), obtaining a 58% damage reduction.

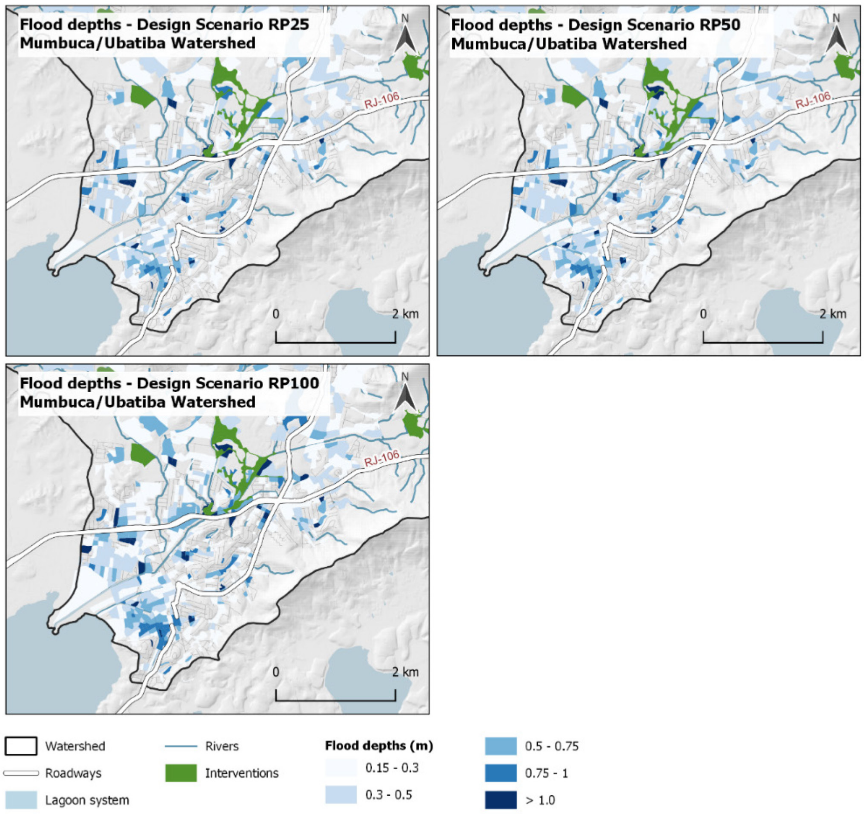

Figure 9. Flood depths for the Design Scenario, considering Return Periods of 25, 50 and 100 years.

Table 1. Comparison of expected damages for the building structure.

Damage of building structure – Current Situation (US$)						
RP1	RP2	RP5	RP10	RP25	RP50	RP100
1,415,731	1,770,220	2,571,105	3,627,266	5,151,971	6,827,531	7,683,200
Damage of building structure – Design Scenario (US$)						
RP1	RP2	RP5	RP10	RP25	RP50	RP100
720,029	810,442	1,073,033	1,387,122	1,886,888	2,346,482	2,841,017

Table 2. Comparison of expected damages for the building content.

Damage of building content – Current Situation (US$)						
RP1	RP2	RP5	RP10	RP25	RP50	RP100
978,252	1,255,025	1,787,190	2,295,852	3,189,092	3,815,946	4,463,113
Damage of building content – Design Scenario (US$)						
RP1	RP2	RP5	RP10	RP25	RP50	RP100
508,713	569,873	743,000	968,264	1,303,958	1,632,423	1,957,501

Table 3. Total expected damages for Current Situation and Project Scenario.

Expected damage from an event – Current Situation (US$)						
RP1	RP2	RP5	RP10	RP25	RP50	RP100
2,393,983	3,025,245	4,358,295	5,923,119	8,341,064	10,643,477	12,119,313
Expected damage from an event – Design Scenario (US$)						
RP1	RP2	RP5	RP10	RP25	RP50	RP100
1,228,742	1,380,316	1,816,034	2,355,386	3,190,847	3,978,905	4,798,519

Finally, to calculate the economic viability of the project, the costs of the reservoirs (including excavation, dikes, land acquisition and dam construction), of the multifunctional parks (including urbanization and land acquisition), of the proposed local drainage system and of dredging the watercourses were considered. It should be noted that the dredging calculation took into account 2 components: (1) the implementation volume dredged multiplied by the cost per m³, and (2) the maintenance calculation, considering the multiplication of the volume of sediment input simulated to the contributing watershed and the cost per m³, over a 50-year horizon. The approximate costs of implementation and maintenance over 50 years were based on prices of The Public Works Division of the Rio de Janeiro State (*Empresa de Obras Públicas*-EMOP, in Portuguese) [29], which is a reference for construction costs in the Rio de Janeiro State. The final costs of the proposal are presented in Table 4. Therefore, it is concluded that the benefits provided by the avoided damages exceed the costs of implementing and maintaining the suggested interventions in a 50-year horizon, confirming the economic viability of the project.

Table 4. Final costs and benefits of the project.

Cost of implementing and maintaining the interventions (50-year horizon)	Benefits from avoided damage (50-year horizon)
US$ 84,534,161.35	US$ 107,947,107.67

It is noteworthy that the benefits from avoided damage indicated in Table 4 considered only damages to residential buildings. Considering the results presented in Gibson et al. [30] as a reference, it is possible to extrapolate these benefits to other buildings (commercial, public, hotels and other/tourism) located in Maricá. In this case, the benefits from avoided damage could reach US$ 215,894,215.33.

Local scale assessment

Suggested intervention. The selected area to simulate an urban multifunctional park can be considered as a centrality, which connects different neighborhoods and is located at the junction of two main highways. The area of approximately 1.3 km² is located in the Ubatiba neighborhood, in a large open space where immediate surroundings are composed by a mixed occupation pattern: a higher population density near the Center of Maricá, and a lower density near private residential condominiums. From the evaluation of local public facilities, it was noted that there is a lack of recreational spaces for residents located on the north of the highway, since most of the existing squares are located inside private condominiums. The area is also located between the Ubatiba and Itapeteiú Rivers, which contribute to the Mumbuca/Ubatiba River. In these areas, great availability of trees and riparian vegetation was noticed. Due to its topographic conformation, the region is naturally affected by floods, which consequently impact the surrounding households, with water depths exceeding 1.0 meter when considering a 25-year RP event.

Based on the local diagnosis, the conceptual proposal had three main goals: (1) its use as an urban reservoir, to storage water and protect local households; (2) the development of an urban park capable of improving connectivity, providing recreation and revitalizing the urban neighborhood; and (3) the design of a new urban subdivision. To do this, however, it is necessary to plan the compensatory processes for the lots that will be used to implement the park, as well as to evaluate the urban and real estate benefits related to it, in order to justify its implementation.

Considering the first goal, the starting point of the conceptual proposal was a topographical analysis to identify suitable areas for water storage. The topographical analysis led to the design of a set of interconnected reservoirs, dividing them into three distinct levels (shallow, intermediate, and deep), which allows activities to be gradually interrupted when a rainfall event begins. The deepest reservoirs would preserve a permanent water level, visually identifying these as water-places. Existing water bodies would be transformed into meandering rivers, reducing the time and speed that water reaches urban areas, and also favoring overflows to the storage areas of the park.

To accomplish the second goal, recreational areas were created, such as sports courts, playgrounds, and small squares with a variety of uses. These areas were complemented with local roads within the park, in order to improve connectivity between the neighborhoods adjacent to the park. Finally, to reach the third goal, the implementation of a residential enterprise was suggested. This decision stems from the recognition that, in the coming decades, the centrality may experience occupation pressure, which will reduce availability of green and permeable spaces. Moreover, it allows to produce compensations for the area used to build the park and avoid great expropriation costs and relocation of people to different places. **Figure 10** shows the Central Park of the Mumbuca/Ubatiba Watershed.

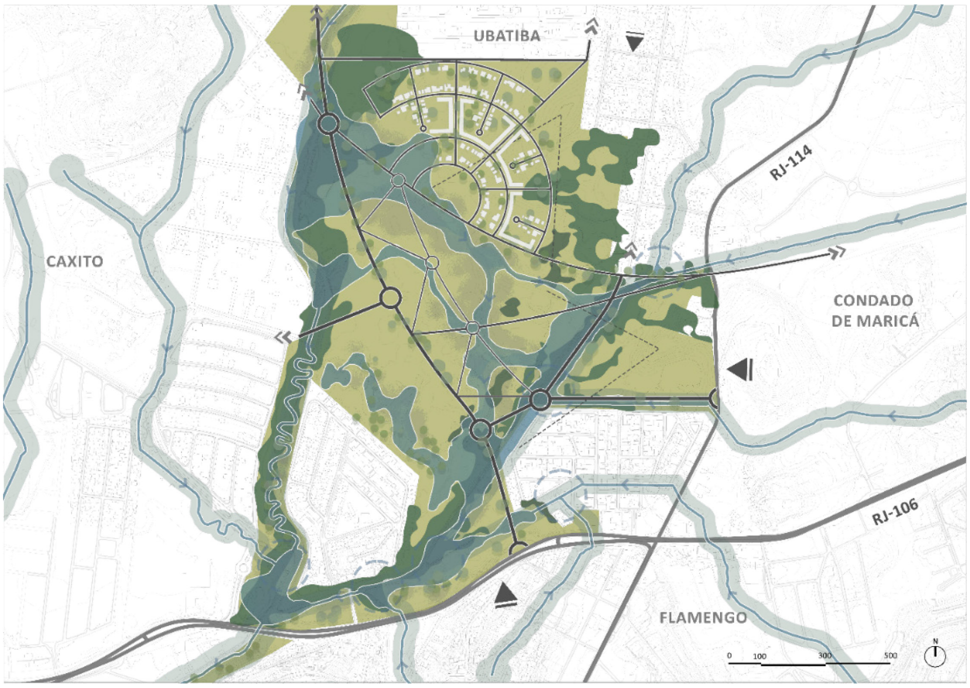

Figure 10. Central Park of the Mumbuca/Ubatiba Watershed.

<u>Economic viability.</u> From the analysis of the local scale, it was noted that the total buildable area is approximately 854,332 m², with 439,875 m² designated to the park and 414,457 m², to the area that will be allotted. This total buildable area, calculated from the perimeter of the site, disregards the marginal protection strips, considering only the areas where it is possible to develop larger urban subdivisions. In addition, it is noted that a total of 1,186 lots could exist within the intervention area, but only 575 can be considered in the area destined for the subdivision (which is equivalent to 48.5% of the open area), considering the same allowable building area.

When considering lots within the park's 500 m radius of influence, it was observed that 354 did not flood in Current Situation and 210 were affected by floods considering RP<10 and RP>10 years. The valuation of the region is expected to be of 5% for lots that are valued solely because of their proximity to the park, but which were not previously affected by flooding; 13% for lots located in the area of influence of the park and which stopped flooding for events of RP>10; and 20% for lots that are in the area of influence of the park and stopped flooding for events of RP<10. When comparing the increase in value with the previous construction potential, a new percentage of 69% was obtained. Therefore, it is necessary to study measures to compensate the current owners of the property.

Among the possibilities of compensation, some alternatives seemed to be promising, like the possibility of transferring of construction rights to other places, and of constructing above the building limits established by local zoning, to compensate for areas exchanged with private owners to build the park. The sum of positive incentives with avoided flood losses and higher real estate values, associated with both non-flooded areas and near green spaces to the properties, compose a practical possibility to make it viable to build floodable parks in already occupied urban areas. Therefore, in this work, the adoption of the "onerous grant of the right to build", foreseen in the Brazilian City Statute, were used as main compensatory measure, along with the appreciation of the area itself. In other words, by increasing the height of the construction in 1.5x, the valuation of the land could be 104%, while an increase of 2.0x in height of the construction would increase its value in 138%. This last result shows that it would be possible to propose a business model where property owners obtain financial advantages, in the long run, the Municipality does not have to pay large expropriation costs (making even better the watershed scale results previously calculated) and the city as a whole greatly reduces flood costs. **Table 5** summarize the specific results to the local scale enterprise of the multifunctional park called Central Park of Mumbuca/Ubatiba Watershed.

Table 5. Valuation provided by the multifunctional park.

	Area percentage		Valuation of the open spaces			Value with compensatory measures	
Total	Park area	Open area	Ipark	Ipark RT<10	Ipark RT>10	1.5x height	2.0x height
100%	51.5%	48.5%	5%	20%	13%	104%	138%

Two final observations are pertinent. First, the only economic benefit considered in this approach answered by residential avoided losses, which is expected to be just a part of total losses and several additional co-benefits could also be considered. Second: even if not increasing the building allowable area (in this case by multiplying the two-story building by 1.5 or by 2.0, the increase in the area of the park plus new subdivision enterprise could provide more lots to guaranteeing compensation only by non-flooding and greening bonuses.

DISCUSSION

In this work, the economic viability of developing urban multifunctional parks in a business model that considers the use of BGI in multiple scales, acting to mitigate floods in the watershed scale, but also creating real estate opportunities in the local scale, avoiding expropriation costs and establishing a win-win approach, has been evaluated and verified in the context of the Mumbuca/Ubatiba Watershed.

The results at the watershed scale showed that the costs of implementing and maintaining the suggested interventions would be paid for by the benefits provided by the avoided damages, while the local approach, combining an additional area into the total enterprise, composing an intervention site greater than that needed to settle the urban-fluvial park, showed that it is possible to enable an attractive solution, including a controlled urban subdivision project, capable to equal or surpass the value of the original area (including the new park). However, some gaps can still be addressed to the local scale assessment. In this sense, given that the multifunctional park will not be implemented instantly, due to its construction schedule, the benefit expected to favor the owners of the expropriated lots is not immediate. For this reason, negotiation tools should be implemented to encourage this partnership. One possibility refers to bringing all calculation to present date and paying an anticipated amount to compensate for the total time of the project. This negotiation, however, can be difficult depending on finding open spaces, even if private, and local regulation over the public partner. This is something that deserves future investigation.

Since the majority of urban open spaces are composed of private lands, this work focused on prioritizing vacant sites and lots to implement the multifunctional park, creating compensation strategies for local land owners. Therefore, considering the social impacts, the project does not envisage the expropriation of families from their homes, which could weaken ties between communities and promote social exclusion. In this case, the suggested residential enterprise was positioned alongside the urban park, in an empty space that can even suffer from future disorderly occupation if immediate actions were not taken, worsening the local socioeconomic losses. However, in denser urban areas, the proposed approach can still be valuable, but expropriating existing dwellings is a greater challenge. Possibly, considering the high benefit-cost ratio obtained, a new urban subdivision project could be integrated with a retrofit project (to enable the maintenance of part of the existing houses in the enterprise area and integrating them into the proposed solution as much as possible). The unavoidable people relocation should be made to the same renewed site.

Regarding the public partner regulation, other possible compensation mechanism would be a temporary reduction or waive in urban land taxes, while the project is not implemented. A complementary measure to enhance the strategies discussed in this work, could be dissemination of what is called "IPTU Verde", a Brazilian initiative regarding a different way of taxing constructions, considering a sustainable bias. This initiative conceives discounts in the Urban Property Tax (named IPTU, in Portuguese) as long as the new buildings adopt sustainable measures, such as water collection and reuse systems, the use of green roofs, increased green yards, the use of clean energy, among others. In this context, new or retrofitted housing developments can also act in favor of the hydrological cycle and environmental services.

Additionally, this research considered only household damage losses as a direct damage, although losses related to the city infrastructure, such as for roads, urban mobiliary, institutional buildings, hospitals, pharmacies, schools, etc., were not considered. Furthermore, functional aspects such as electricity shortages, gas distribution network failure, and asphalt damage, for example, were not included in the analysis. Indirect damages such as health effects, urban cleaning and commerce closure could also be analyzed and taken into account in future research, since the interruption of services is also linked to economic losses. These benefits not considered in this research can be meaningful, increasing the viability of the proposed measures. Other studies, such as Locatelli et al. **[31]** performed a cost-benefit analysis of the implementation of green infrastructure in urban areas considering, in addition to the avoided direct damage to buildings, other benefits, such as the avoided environmental damage due to combined sewer overflows to receiving waters, the avoided cost of combined waste water treatment, the avoided indirect damages to coastal economies, the added aesthetic value, the air quality improvement, the habitat provision and the reduction of urban heat island effect and energy consumption. The benefits obtained by these authors can be compared to the ones presented in this study considering a 50-year horizon. Both results indicate that the avoided damage to buildings exceeded the costs of implementing and maintaining BGI by 28%, considering only residential buildings, and by 155%, considering the extrapolating to other buildings. Besides, if all the benefits estimated by Locatelli et al. **[31]** are taken into account, benefits could exceed costs by 356%.. Both cited studies highlight the importance of incorporating multiple benefits in the BGI socio-economic viability, since they respond for more than 40% of the total benefits. Therefore, this estimation could additionally be used as reference to extrapolate benefits not evaluated for the Design Scenario.

It is also worth highlighting the direct and indirect social benefits provided through this type of intervention, in order to encourage the public acceptance of the solutions. Essentially, the main social benefit of the urban fluvial park relies on improving the flood safety, while minimizing the damages and losses to the structure and contents of the surrounding buildings. In the Brazilian context, where the population in greater socio-economic vulnerability often does not fully recover financially from the losses caused by flooding, the introduction of BGI strategies as a complement to traditional urban drainage measures is capable of both protecting and integrating the population with the natural environment, offering a better quality of life.

Preserving open green spaces in highly urbanized areas can offer indirect benefits to the inhabitants, since it can act on thermal comfort, improve air quality, promote suitable spaces for outdoor sports, and requalify the public space. In the case studied, since most of the existing recreational areas are located inside private condominiums, the creation of a high-quality urban park with a wide range of uses is directly related to social equity, promoting the democratization of access and use of public urban green spaces. In this sense, the discussion on accessibility is reinforced in its definition of improving people's ability to reach places and opportunities, especially public goods and services. In the proposed park, accessibility can also be related to mobility, since the creation of internal roads in the urban park improves travel options by non-motorized transport, as well as improve connections between the surrounding neighborhoods.

CONCLUSIONS

In urban environments, the suppression of open green spaces for new housing developments is frequent, significantly impacting the hydrological cycle and increasing urban flooding. Given the limited availability of open spaces and the challenges of expropriation, this study proposed an innovative framework that integrates a business model considering the large-scale socio-economic impacts of BGI for flood mitigation. The approach aims to establish a win-win strategy for local property owners while addressing urban and environmental demands. This proposal was developed through a design approach applied to the Mumbuca/Ubatiba River watershed in Maricá, Rio de Janeiro, an area undergoing rapid urbanization. The method involved two integrated steps: a watershed scale assessment and a local scale evaluation based on a proposed Design Scenario.

The Design Scenario incorporated BGI strategies alongside structural measures to mitigate floods across different intervention scales. A key insight was that local scale solutions alone are insufficient for urban flood control; an integrated watershed perspective is essential to correlate land use with sustainable hydrological management. Hydrodynamic mathematical modeling showed that upstream reservoirs significantly reduced watershed flows, decreasing financial losses related to buildings and contents by over 45%. A comparison of the Current Situation and the Design Scenario revealed more than 50% reduction in financial damages, except for RP1 events. The total cost of implementing and maintaining the interventions over 50 years was US$ 84,534,161.35, while the avoided damages over the same period amounted to US$ 107,947,107.67, confirming the study's hypothesis. In broad terms, the avoided damage exceeded intervention costs by 28%, enabling the viability of implementing a multifunctional park.

The main challenge at the urban park scale was securing vacant lots for implementation. To address this, a larger area than that necessary was selected, accommodating both floodable zones for water storage and a new urban development project. The goal was to ensure that the value generated by the project exceeded expropriation costs and met property owners' expectations. A compensation strategy was proposed through an increase in allowable building height, balancing landowners' interests and real estate market conditions. Key findings include: the proximity to the park increased the value of non-flooded lots by 5%; lots that stopped flooding for RP>10 saw a 13% increase in value; lots that stopped flooding for RP<10 experienced a 20% increase in value; and the combined valorization of the remaining lots reached 69% of the original construction potential. To further compensate local owners, the adoption of the "onerous grant of the right to build", as outlined in the Brazilian City Statute, was applied. Increasing building height by 1.5 times allowed properties to reach 104% of the original value, while a 2.0 times increase raised their value to 138%, making the project attractive. If implemented, final benefits would be over 4 times the investment costs, excluding expropriation expenses. Additionally, by reducing the need for expropriation, the project minimizes social displacement while curbing urban sprawl.

The economic viability of multifunctional parks remains a gap in the literature, and this research contributes by proposing an innovative approach to financially assess urban-fluvial parks, in the context of BGI for flood mitigation. The framework was validated in the Mumbuca/Ubatiba Watershed case study, reinforcing the importance of open spaces as complementary support systems for urban drainage. Comparing this framework with existing cost-benefit analysis of BGI strategies revealed consistent results, further validating its approach. Future research should expand on the broader social and urban benefits, as this study primarily computed direct financial advantages. A promising extension would be to explore the provision and evaluation of ecosystem services, recognizing BGI as a formal component of urban infrastructure.

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NOMENCLATURE

Abbreviations

BGI	Blue-Green Infrastructure
GIS	Geographic Information Systems
IBGE	Brazilian Institute of Geography and Statistics
IPTU	Urban Property Tax
MODCEL	Urban Flow-Cell Model
RP	Return Periods

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