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Urban drainage case study – watershed of the city of Rio de Janeiro, Brazil

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Abstract

This work proposes a new approach related to urban floods in which the traditional concept of enlarging the main drainage net is substituted by a systemic view, with distributed actions over the watershed. These actions must be done to restore the original flow conditions of the watershed before the urbanising process. For the purpose of this analysis a Mathematical Cell Model is applied to a portion of the watershed of the city of Rio de Janeiro, in Brazil.

Introduction

Well-posed measures for the solution of many problems relating to urban spaces are presently being considered in an increasing way. These measures go towards the self-sustainability concept, in achieving a more favourable and harmonic environmental cohabitation. This perception necessarily encompasses the systemic and integrated way in which the environment functions. The occupation of urban areas frequently results in the problems related to urban flood processes, among others.

The secondary river channel occupation with the local vegetation disappearing and the resulting process of making the soil impervious, promotes the aggravation of flooding conditions, with the enlargement and acceleration of peak values, in such a way that the flood waves start to run over a partially occupied river bed. Social questions then also arise, since it is known that risk areas are often inhabited by people of lower income. These people usually are grouped into communities where conditions of substructure are improper, mainly in developing countries.

Traditionally this flood problem is treated with respect to its consequence, when one tries to adapt rivers and channels to the new discharges by canalising and enlarging flow sections and sections of the tributary drain galleries. These works sometimes come into conflict with the existing urbanisation, and are made without taking into consideration recovering the conditions prior to the urbanisation itself.

A look over the urban flood problem and the integration of its solution inside a city scenery

According to a modern point of view, the urban flood problem is now being analysed under a new approach, which is taking strong appearance in the technical and scientific discussions. Presently it is considered more important to treat the problem at its root, with distributed actions over the urban scenery, in order to decrease and retard flood peak values, allowing also the ground water recharge, and searching for a way to recovering the approximate natural flow conditions.

Following these considerations, temporary storage reservoirs may be a good solution for obtaining the goals above described, and at the same time they can help in the harmonic integration process with the urban environment. This is particularly true when one considers that those reservoirs can be designed as recreation areas in the dry seasons. Examples of this kind of use may be referred to football fields bordered by embankments, acting as people seats, or even public squares with green areas subjected to overflow from natural lakes. These elements then help to compose the urban landscape aspect. When it is possible, water output control from allotments to micro drainage is desirable: small underground reservoirs or even storage areas associated to garden spaces, with spilling output to the drainage net, may be very useful (e.g. Tucci et alli [4]). These joint solutions compose an integrated miscellany, which treats the watershed as an entire system, turning away from the unique point of view generated by the direct observation of the channel net.

System representation

As a fundamental tool for the effects simulation of the proposed distributed works over the whole urban watershed, mathematical modelling arises, in order to integrate and promote the interaction of different hydraulic structures in the flow net, as well the common structures of the urban scenery. The latter are then subjected to present a hydraulic behaviour when a flood occurs, generating generalised overflow. Considering these aspects, it is proposed the use of a Mathematical Flow Cell Model, developed by Miguez and Mascarenhas [2], that allows the simulation of a entire watershed and not only the drainage net. From a more systemic viewpoint, it is proposed the complete knowledge of the processes, in order to find the causes and to recover the flow conditions prior to the urbanisation. This is done through the introduction of artificial structures, distributed over the watershed and designed to retain water, retard surface runoff and increase infiltration, correcting the undesirable effects of urban occupation.

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Aiming these goals, the Cell Modelling takes a set of uniform sub-areas that are combined into proper arrangements composing more complex structures. The sub-areas may be able to reproduce the flow over the urban scenery, resulting in an integrated discrete mesh where several hydraulic relations are introduced. This kind of modelling is based on the fundamentals of cells and its topological representation (e.g. Zanobetti, Lorgeré, Preissmann and Cunge, [5]; Cunge, Holly and Verwey, [1]).

Case study and the modelled area

This work has as main objective to perform a qualitative and quantitative study from the effects of a drainage design concept, for a critical area of the city of Rio de Janeiro, Brazil. This area and its urbanisation may be seen in figures 1 and 2. The street named "Haddock Lobo" is the heart of that area, where it is proposed a set of drain galleries, according to traditional urban drainage concept, as part of a urban revitalising program under analysis by the City Mayor Office. In that area it is being studied the construction of three small reservoirs, named "Valparaiso", "Chacrinha" and "Villa Lobos". These reservoirs are supposed to promote the attenuation and retardation of flood peak values that usually occur at the area, mainly in the summer season when tropical rainfalls drop over the city. It must be pointed out that this direct comparison considers the watershed divided and does not take into account other upstream interventions. This is done aiming to work with the more unfavourable situation and then to observe the local effects in the flood flow. The area situated downstream is also a critical one with respect to flooding and is a square named "Praça da Bandeira".

The modelled area is part of the sub-basins of two important urban rivers, named "Comprido" and "Trapicheiros", and it is near the central zone of the city of Rio de Janeiro. These two rivers give runoff contribution to the urban channel named "Canal do Mangue", that also receives water contribution from another three urban rivers running through historical and traditional city zones that are frequently damaged by urban floods. All this area is being studied in a joint research between the Federal University of Rio de Janeiro and the City Mayor Office. So the modelled area is only a part of a larger study related to the entire urban watershed modelling.

Proposed simulation scenarios

There were initially identified a set of three situations considered to be of interest to give elements for the planning and decision project, as follows.

- Scenario 1: Simulation of the present situation with the observation of flooding results in the area for a design rainfall with ten years of time recurrence.
- Scenario 2: Simulation of the situation modified by the project of the drain galleries, for the same design rainfall.
- Scenario 3: Simulation of the situation modified by the construction of the three upstream reservoirs, for the same design rainfall.

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In all scenarios the exit sections of the rivers "Trapicheiros" and "Comprido" were assumed to be obstructed by the flooding of lower areas of the contribution basins to the downstream urban channel ("Canal do Mangue"). This means that the scenarios are related to a situation of submerged outlets.

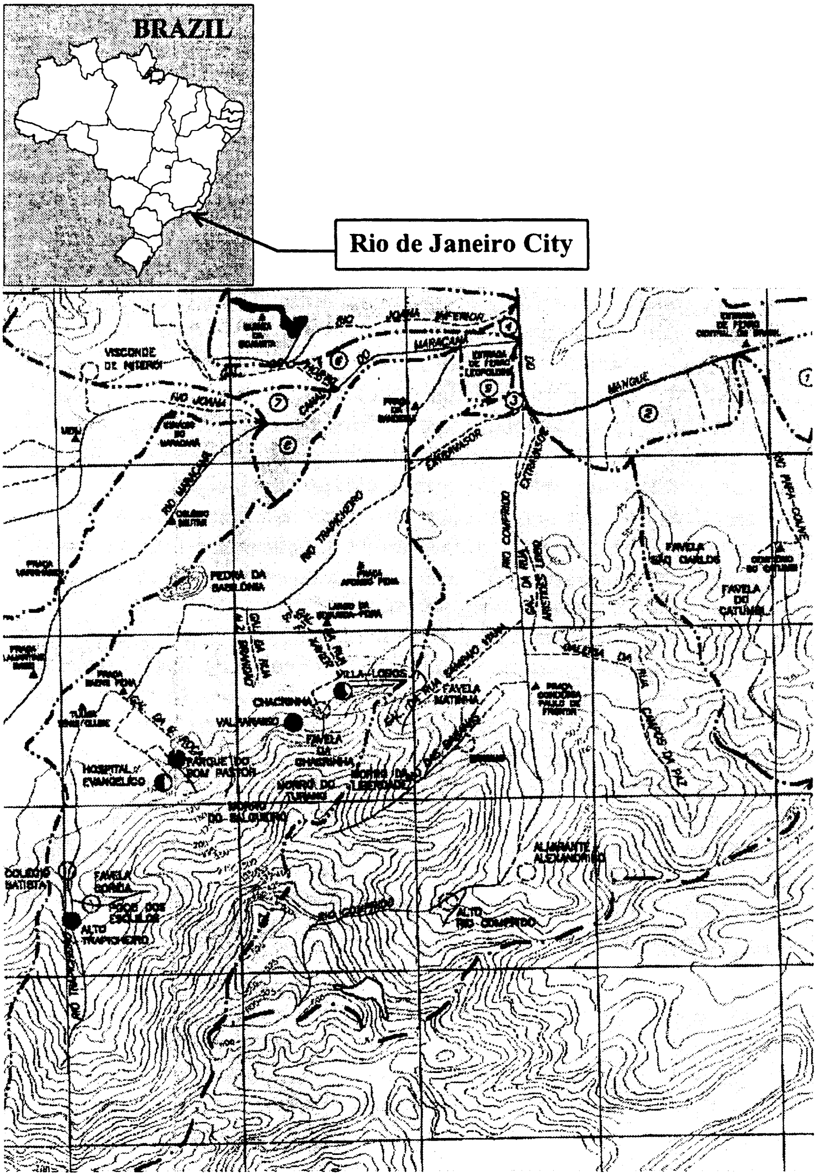

Figure 1: Location of the city in the map of Brazil and a zoom view of the urban watershed under study

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Figure 2: Detail of the urbanisation of the studied area, including the proposed reservoirs, marked with dark circles over the figure.

Methodology for the application of the cell model

It was made a division of the area under study into cells, which were grouped, in a topological structure that can be seen in figure 3. At slope locations the more elevated areas were taken as slope cells, receiving rainfall water which is carried inside the model. These cells are used later to represent the storage reservoirs of the design project. In the upstream zones of the rivers “Trapicheiros” and “Comprido” it was considered the discharge contribution of the upstream basin, through the application of the U.S. Soil Conservation Service Method [3]. The several water outlets related to the flow over the streets were estimated by a rating curve evaluated from the relationship for steady and uniform flow, given by the Manning’s equation. This approximation can be considered valid at the streets since the hydraulic radius may be easily approximated by the section’s depth, which is usually small when compared with the street width.

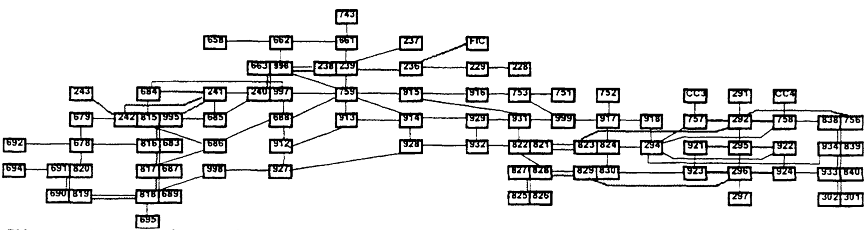

Figure 3: Topological scheme for the studied basin – 89 cells, present situation.

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Simulations and results

The resulting simulations are water surface elevations (varying in time) at the centres of all cells. The actual situation presents 89 cells, the same number of the modified situation with the storage detention reservoirs. This is due to the conversion of some original cells into reservoirs, to the adapting cells rating curve and also to the redefining of the equations related to cell outflow. These equations then turn to represent hydraulic laws of flow through orifices and over weirs. For the simulation of the drain galleries there were included 12 more cells of the underground type in the model. The total simulation time adopted was 4.2 hours, which is considered to be sufficient to represent the situation where all the basins of the urban watershed can contribute to the downstream sections. The time step for the simulations was 7.2 minutes.

The figures 4 to 9 show significant simulation zones, presenting results for the flow over the streets. The graphics are presented comparing the conditions in the present situation with those modified by the drain galleries and also with those modified by the reservoirs.

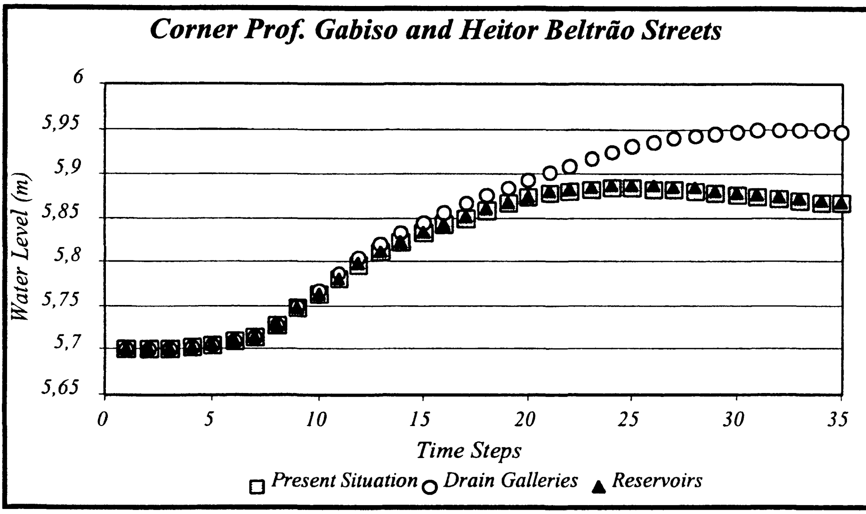

Figure 4: This cell is located over a stretch of the "Trapicheiros" river that runs into an underground drain gallery. In this zone one can notice the negative influence related to the flow acceleration caused by the implementation of new drain galleries. The overflow is accentuated by the faster concentration of downstream flows. The influence of the simulated reservoirs does not seem to be noticed here. It is observed that the street "Haddock Lobo" presents a small elevation at the crossing zone with the street "Tenente Villas-Boas". This elevation is responsible to confine the positive results of the reservoirs into the region located between the latter street and the location named "Largo da Segunda-Feira".

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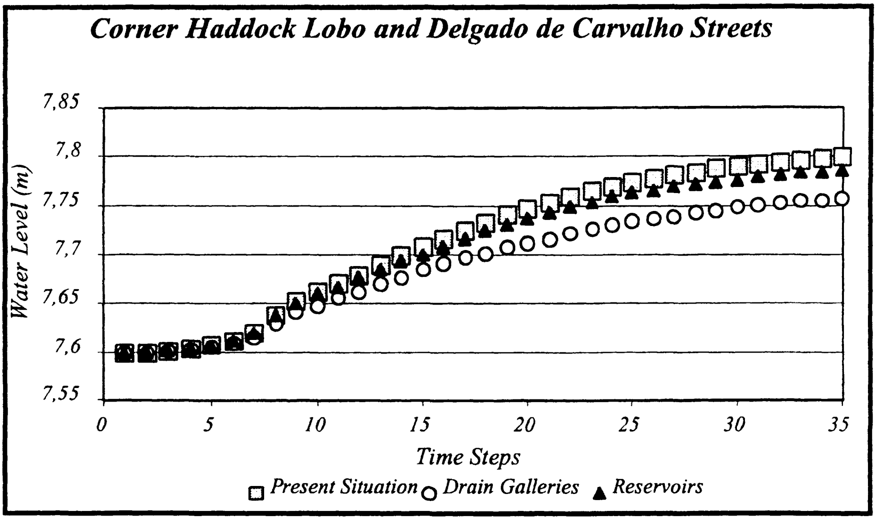

Figure 5: This cell is located in the beginning point of a drain gallery enlargement at "São Francisco Xavier" street. At this point the enlargement of the underground galleries promote a more pronounced benefit on the surface overflow, since those galleries are not still submerged due to its upstream location.

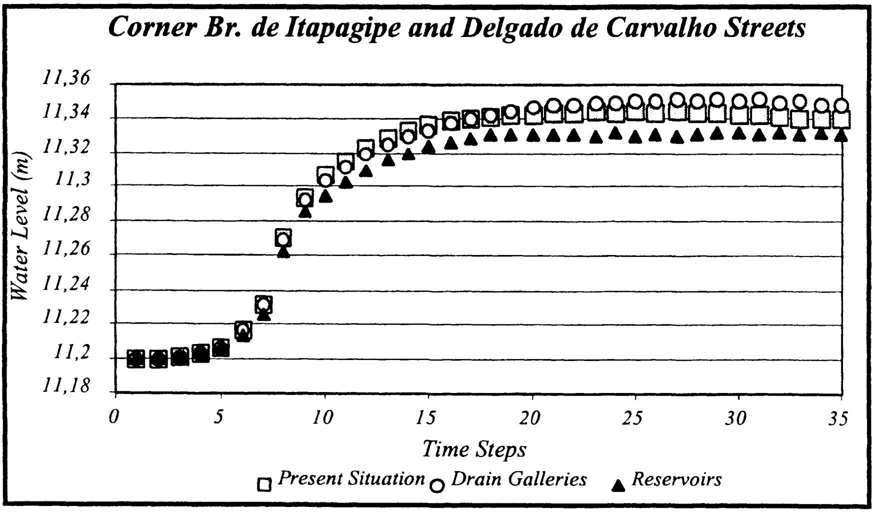

Figure 6: From this cell, climbing in the direction of a little hill named "Morro do Turano", the influence of the reservoirs "Valparaiso" and "Chacrinha" begins to be noticed in a more intensive way. The reservoir situation presents better quantitative results than those observed in the present situation and also than those related to the introduction of the drain galleries.

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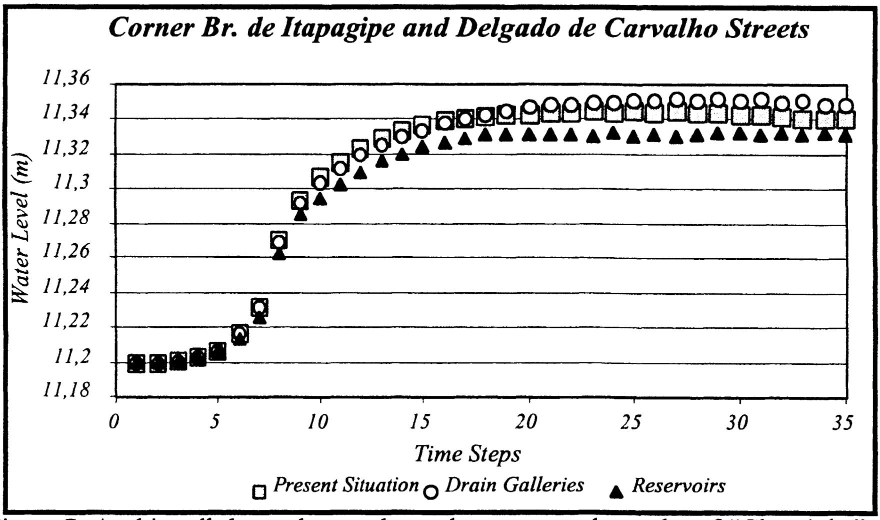

Figure 7: At this cell, located very closes downstream the outlet of "Chacrinha" reservoir, the influence of that reservoir is quite noticed. In this situation the drain galleries do not promote any practical benefit.

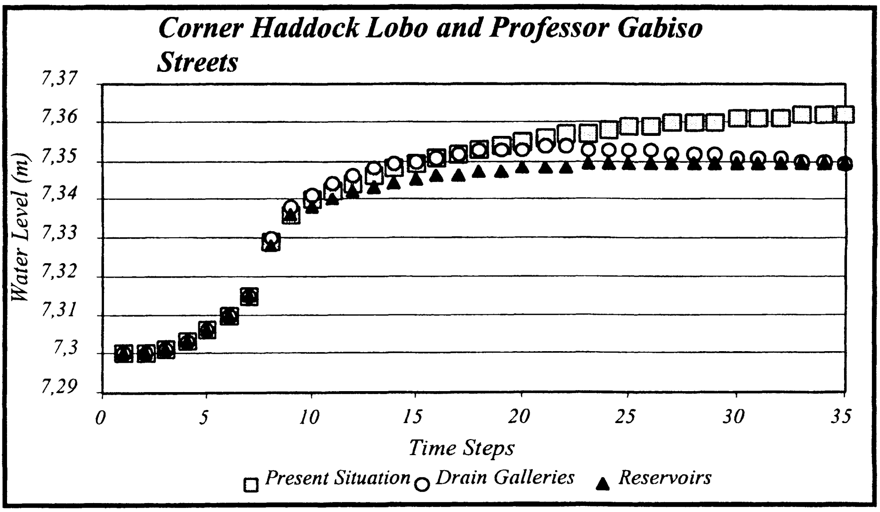

Figure 8: In the simulation the retained water volume at the surface of this cell is smaller on the situation modified by the reservoirs. The drain gallery project generally also improves the present situation but with less efficacy. It must be noticed that here it is located the middle stretch of one of the new proposed drain galleries.

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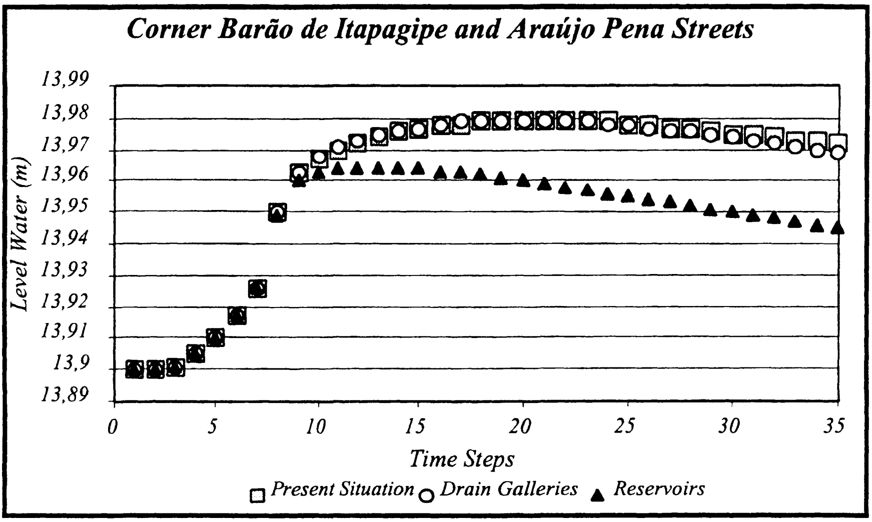

Figure 9: At this area it can be noticed the effect of the "Villa-Lobos" reservoir, which stores and retard the upstream slope waters. The present and the drain gallery situations are practically the same.

Remarks

- In the present situation there are distributed overflow over the watershed and near the rivers.
- In a general way, the absolute overflow results are not very strong as expected, but they may be underestimated due to the lack of data for the calibration process.
- Due to the preceding remark, the quantitative results may not be exactly correct, but the qualitative ones, comparing different approaches, carry important information to the planners and management people.
- The reservoirs present direct influence on the neighbour zones, and from them the waters are deviated to their retard in the reservoir.
- The observed results at the reservoir boundary zones, where the overflow is decreased, have its effects propagated on downstream direction although with a decreasing effectiveness.
- The introduction of drain galleries obtains some significant results at upstream areas, where they begin. But as one looks on downstream direction it can be noticed that the results of the flow acceleration promote negative influence on the overflow at lower areas located near the rivers.
- In the submerged situation the drain galleries loose their importance and simply do not work at the lower stretches.
- The reservoir situation presents clearly a potential improvement, with aspects of systemic analysis and integrated in a harmonic way to the urban

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scenery. The simulations done in this work should take into account all the set of proposed works included those located outside the area modelled in this study. So the simulation results presented for the case of the reservoirs are related to a partial representation of the watershed. For instance these simulations do not take into account the upstream improvements caused by the influence of another 8 reservoirs projected for this sub-basin as well those related to more 14 reservoirs proposed for the whole urban "Canal do Mangue" watershed.

Conclusions

The drain galleries promote some positive local effects but in a systemic point of view the flow is accelerated and concentrated specially at lower zones, near the river junctions. In a situation without generalised overflow they could be a good solution, even for a short time. But in the present situation with intense urbanising process they may carry serious risks related to overflow enlargement.

In none situations the simulation with the reservoirs turns worst the overflow. On the other hand, the situations with the drain galleries cause increasing overflow at the lower downstream zones near the main urban channels. This localised overflow then will probably promote a negative direct influence in a very critical downstream city large square, named "Praça da Bandeira", which suffers frequently flooding effects in the summer season.

The simulation of the upstream area was not done and this fact may be of great importance for the study. In that area there is a prevision for the construction of other reservoirs, allowing the reduction of the inflow hydrographs to the studied area, which was not simulated in this work.

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