**Ambiente & Água - An Interdisciplinary Journal of Applied Science**
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
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# Overflow risk analysis on the Presidente Dutra highway using the quota-volume curve in the Una River Basin in Taubaté, SP, Brazil

**ARTICLES doi:10.4136/ambi-agua.2580**

**Received: 15 Sep. 2020; Accepted: 10 Nov. 2020**

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## ABSTRACT

Anthropic interventions and vectors of urban occupation have caused changes in the infiltration and runoff regime that can cause or accelerate erosion processes, silting and flooding in river basins. Flooding, as a stochastic phenomenon, can occur at any time and in any place, influenced by climatic factors, physical characteristics of the basin and mainly by human interference in the use and occupation of the land, which affects the type, quality and quantity of vegetation and increases soil impermeability. The aspects of regional urbanization led the State in 2012 to create the Metropolitan Region of Vale do Paraíba and the North Coast (RMVPLN), attracting large real estate investors. In the hydrographic basin of the river Una in the municipality of Taubaté, there has been an increase in flooding episodes and the possibility of worsening due to changes in land use and occupation. In this study, we sought to determine runoff as a function of changes in land use and occupation expressed by the variation in runoff coefficient (C) recommended by the Department of Water and Electricity of the State of São Paulo, (DAEE-SP) for licensing and intervention projects in water resources. The lower limits C = 0.35 and upper C = 0.70 were used admitting variations of 0.05 points in this interval to calculate the water flow (QE) and Intake Volumes (VE) in the basin from an intense precipitation of 100 years of recurrence time, from the use of the UEHARA Method (DAEE, 2006), to the control point located at the intersection of the Una River and the Presidente Eurico Gaspar Dutra Highway (BR 116-SP) and from this the Quota-Volume curve was drawn. The flood shares were obtained by hitting the reserve volumes found on the quota-volume curve. The current runoff coefficient of the basin is C = 0.35, which allows water to pass through the Dutra highway bridge. However, the modification of C = 0.50 due to the advance of urbanization, the level of flooding would reach 557.40 m. That exceeds the level of the lower base of the bridge (556.72 m) and, with C = 0.60, would reach the quota of 558.90 m, which would cover the asphalt surface of the highway. Given the real estate pressures in the metropolitan region, special care is recommended in the conservation, preservation and expansion of native forest vegetation with actions for Payments for Environmental Services

(PSAs), de-silting actions of the main gutter and Una's tributaries, to contain the identified advance of urbanization in the basin, as well as the definition and installation of detention and retention basins.

**Keywords:** environmental sciences, hydrographic basin, surface runoff.

# Análise de risco de transbordamento na rodovia Presidente Dutra com o uso da curva cota-volume na bacia hidrográfica do rio Una em Taubaté, SP, Brasil

## RESUMO

As intervenções antrópicas e vetores de ocupação urbana têm causado mudanças no regime de infiltração e escoamento que podem causar ou acelerar processos erosivos, assoreamentos e inundações em bacias hidrográficas. As inundações, como fenômeno estocástico, podem ocorrer a qualquer momento e em qualquer lugar, influenciadas por fatores climáticos, características físicas da bacia e principalmente pela interferência humana no uso e ocupação do solo, que afeta o tipo, qualidade e quantidade de vegetação, aumenta a impermeabilidade do solo. Os aspectos de urbanização regional levaram o Estado, em 2012, a criar a Região Metropolitana do Vale do Paraíba e Litoral Norte (RMVPLN), atraindo grandes investidores imobiliários. Na bacia hidrográfica do rio Una, no município de Taubaté, houve aumento dos episódios de enchentes e possibilidade de agravamento devido às mudanças no uso e ocupação do solo. Neste estudo, buscou-se determinar o escoamento em função das mudanças no uso e ocupação do solo expressas pela variação do coeficiente de escoamento (C) recomendado pelo Departamento de Águas e Energia Elétrica do Estado de São Paulo (DAEE-SP) para projetos de licenciamento e intervenção em recursos hídricos. Os limites inferiores C = 0,35 e C superior = 0,70 foram utilizados admitindo variações de 0,05 pontos neste intervalo para calcular a vazão de água (QE) e Volumes de Captação (VE) na bacia a partir de uma precipitação intensa de 100 anos de tempo de recorrência, a partir de a utilização do Método UEHARA (DAEE, 2006), até o ponto de controle localizado na interseção do rio Una com a Rodovia Presidente Eurico Gaspar Dutra (BR 116-SP) e traçada a curva Cota-Volume. As cotas de inundação foram obtidas pelo rebatimento dos volumes de reservação encontrados, na curva cota-volume. O coeficiente de escoamento atual da bacia é C = 0,35, o que permite que a água passe pela ponte da rodovia Dutra. Porém, na modificação de C = 0,50 devido ao avanço da urbanização, o nível de inundação chegaria a 557,40 m que ultrapassa o nível da base inferior da ponte (556,72 m) e, com C = 0,60, atingiria a cota de 558,90 m, que cobriria a superfície asfáltica da rodovia. Dadas as pressões imobiliárias na região metropolitana, recomenda-se cuidados especiais na conservação, preservação e expansão da vegetação florestal nativa com ações de Pagamentos por Serviços Ambientais (PSAs), ações de desassoreamento da calha principal e afluentes do Una, para contenção o avanço identificado da urbanização na bacia, bem como a definição e instalação de bacias de detenção e retenção.

**Palavras-chave:** bacia hidrográfica, ciências Ambientais, escoamento superficial.

## 1. INTRODUCTION

Brazil is one of the countries most affected by floods (Souza *et al.*, 2017), which are characterized by the overflow of water from watercourses from their natural beds to marginal areas.

The increase in the frequency and intensity of flood events may be associated with anthropogenic activities that cause environmental degradation in river basins, such as disordered urbanization (Tasca *et al.*, 2017), the industrialization, deforestation and occupation of improper areas (Sousa and Gonçalves, 2018) and the insufficient capacity of many hydraulic structures. Among these structures are large and small dams, bridges, culverts, drainage systems, mainly on highways and railways. Given that many of these structures are from the 1950s, changes in land use and occupation interfere in the dynamics of water in the basin, mainly in the infiltration and runoff processes.

The quota-volume curve methodology has been applied to define the water storage capacity in dams for purposes of power generation, flood control, supply, waste disposal in ponds, etc. Studies of volume quota curves for large dams were developed by Correa Filho *et al.* (2005), Collischonn and Clarke (2016), while studies on detention basins were developed by Maria Filho *et al.* (2016), Kaboosi and Jelini (2017), Ngo *et al.* (2018), Peroni (2018) and Wellerson and Da Silva (2019).

This study estimates flood flows and quotas using the quota - volume curve for the hydrographic basin of the Una River, in Taubaté, SP, in the Paraíba do Sul Valley region, specifically at the Rio Una crossing point with the Presidente Eurico Gaspar Dutra Highway - BR 116-SP based on the adoption of runoff coefficient.

## 2. MATERIAL AND METHODS

### 2.1. Location of the watershed

The study was carried out in the hydrographic basin of the Una River, in the Paraíba do Sul Valley region, in the municipality of Taubaté, SP, Brazil. The Una Basin (Figure 1) is composed of the sub-basins of the Pouso Frio Stream (1), the Sete Voltas Stream (2), the Rocinha River (3) the Antas Stream (4) of the Itaim Stream (5), from the medium Una (6) of the Ipiranga Stream (7). The Una Basin, until it flows into the Paraíba do Sul River, is 476.76 km² long, of which 84% are in the municipality of Taubaté and 16% are divided between the municipalities of Pindamonhangaba, Tremembé and Redenção da Serra (Batista *et al.*, 2005). For this study, the basin was considered until the crossing point of the Rio Una with the Presidente Eurico Gaspar Dutra Highway - BR 116-SP, a place where flood problems and risks to the highway often occur during summer.

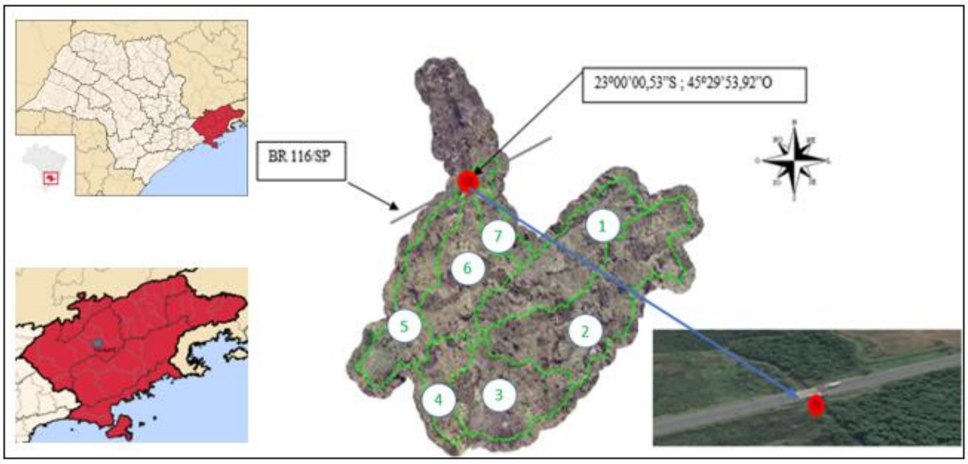


**Figure 1.** Location of the Una River Basin, with emphasis on the sub-basins and the highway BR-116 (Presidente Dutra) in the municipality of Taubate, São Paulo, Brazil.

### 2.2. Quota-volume curve

The quota-volume curve assists in understanding the phenomenon of damping of flood waves in reservoirs, allowing assessment of the occurrences and risks of floods and droughts based on the accounting of accumulation volumes through each quota or level reached across the river at any given time. Many highways and railways with their embankments resemble dams when crossing water courses. In this study, we used the adaptation of the Quota-Volume Curve methodology (DAEE, 2006) applied to small basins to determine the quota to be reached on the Presidente Eurico Gaspar Dutra Highway (BR116/SP) at the crossing with Rio Una in the municipality de Taubaté, SP, due to precipitation with 100 years of return.

By this methodology, the Resulting Volume (VR) that defines the flood level and obtained by the difference between the inlet (VE) and outlet (VS) volumes, from the maximum flow of the watercourse. In this study, the maximum precipitation with a return time of 100 years by Martinez Junior and Magni (1999) was used.

VE and VS volumes obtained by the Triangular Unit Hydrograph (HUT) method using Equation 1 as recommended by DAEE, (2006). The Hydrogram (HUT), consists of a graphical representation (Figure 2) of the elevation of the flow in the control section, and which considers the unit flow as a function of the previous precipitation, of the soil impermeability characteristics, of the vegetation cover, of the use of the soil and soil management practices, grouping all these elements in a single coefficient, which turns total precipitation into effective precipitation.

$$V = \frac{tb * Q}{2} \tag{1}$$

Where:

V = volume (m³)

Tb = Base time of the hydrograph (h)

Q = Flow corresponding to a maximum precipitation (m³. s$^{-1}$).

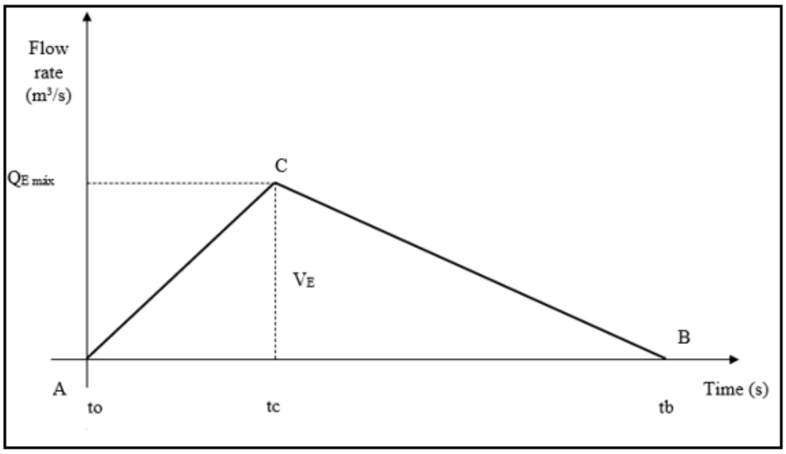


**Figure 2.** Triangular Unit Hydrograph (HUT).
**Source:** DAEE (2006).

## 2.3. Flow rate estimation and methodology parameters.

Given the existence of information and planialtimetric data for the basin areas, the equivalent slope will be determined from the lengths and differences in the level of each stretch of the watercourse using Equation 2.

$$I_{eq} = \left( \frac{L}{\frac{L_1}{\sqrt{j_1}} + \frac{L_2}{\sqrt{j_2}} + \frac{L_n}{\sqrt{j_n}}} \right)^2 \tag{2}$$

Where:

Ieq is the equivalent slope in $m.km^{-1}$

L is the total length of the thalweg (L1 + L2 + Ln)

Jn is the Declivity of each section n.

In the maximum flow estimate, based on a conservative choice, the maximum values of the runoff coefficient C were used (DAEE, 2006), described in Table 1, with a variation of 0.05, therefore, the values used were 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, and 0.70.

**Table 1.** Runoff coefficients recommended for hydraulic works in the state of São Paulo, Brazil.

| GROUND USE OR DEGREE OF URBANIZATION | C - VALUES | |
|---|---|---|
| | MINIMUM | MAXIMUM |
| Fully urbanized area | 0.50 | 1.00 |
| Partly urbanized area | 0.35 | 0.50 |
| Area predominantly of plantations, pastures, etc. | 0.20 | 0.35 |

**Source:** DAEE (2006).

One procedure which can be used would be to estimate Surface Runoff Coefficient (C) from the definition of effective precipitation, using the Number Curve - CN method (NRCS, 2010), according to Equation 3.

$$C = \frac{Pe}{P} \tag{3}$$

Where:

C is the runoff coefficient

Pe is the effective precipitation (mm)

P is the Maximum precipitation (mm)

In the Number Curve method (Equations 4 and 5), the effective precipitation (Pe) of the river basin of the Una River that relates the surface characteristics such as use and cover, the type of soil and its antecedent humidity as well as the maximum precipitation over the basin relates runoff to soil type, land use and management practices (NRCS, 2010). The value of the CN may be weighted (Targa, 2011) according to the different uses and occupation of the soil through Equation 6.

$$Pe = \frac{(P-0{,}2S)^2}{(P+0{,}8S)} \tag{4}$$

$$s = \frac{25400}{CN} - 254 \tag{5}$$

On what:

$$CN_{pond} = \sum_i^n \frac{CNc*Ac}{A} \tag{6}$$

Where:

S is the Potential Infiltration, in mm.

CN is the Curve Number, dimensionless.

CNpond is the weighted, dimensionless Curve Number Value.

CNc is the value of the curve number of each class of use and land cover of the basin, dimensionless.

Ac is the Area of each class of use and land cover of the basin in ha.

A is the total area of the basin, in ha.

Flow estimates were obtained by the Uehara method (1989), which consists of an adaptation of the Snyder method applied to the conditions of Brazil and applied to basins with drainage area between 200 and 600 km² (DAEE, 2006). The calculations for obtaining the flow by this methodology are presented in Equations 7, 8, 9 and 10, 11, and 12.

$$tr = 0{,}75.Ct.(L.Lo)^{0{,}3} \quad (7)$$

$$td = \frac{tr}{4} \quad (8)$$

$$h1 = td.I \quad (9)$$

$$hexc = C.h1 * k \quad (10)$$

$$Vesc = \frac{A.hexc}{1000} \quad (11)$$

$$Q = \frac{2 * Vesc}{tb} \quad (12)$$

Where:

tr is the basin delay time, in h

Ct is the storage coefficient in the basin, admensional

L is the thalweg length, in km

Lo is the Distance between the basin and the basin's center of gravity, in km

Td is the Rain Duration Time, in h

h1 is the maximum precipitation in the basin, in mm

I is the maximum precipitation intensity, in mm.h-1

hexc is the excess rainfall in the watershed in mm

C is the runoff coefficient of the basin, dimensionless

A is the Watershed Area (m²)

k is the precipitation distribution coefficient, dimensionless

Vesc is the Flow Volume, in m³

The storage coefficient (Ct) is empirical, and according to McCuen, (1998) the typical values are in the range of 1.8 to 2.2. For Brazilian conditions, it is recommended to use values of 1.4 for Ct and the value of the rainfall distribution coefficient (K = 0.75) as a function of the basin area (DAEE, 1994).

The rainfall intensity equation (Equation 13) for Taubaté determined by Martines Junior and Magni (1999) was used to calculate the intensity of precipitation in this study, valid for the interval 10 min ≤ td ≤ 1440 min.

$$it,T = 54{,}5294\ (t + 30)^{-0{,}9637} + 11{,}0319\ (t + 20)^{-0{,}9116}.[-0{,}4740 - 0{,}8839 \ln \ln(T/T-1)] \quad (13)$$

Where:

i is the maximum precipitation intensity in $mm.min^{-1}$

t is the duration of precipitation, in min

TR is the Time of recurrence, in years

## 3. RESULTS AND DISCUSSION

The flow coefficient data recommended by the Department of Water and Electricity - DAEE for the State of São Paulo (Table 1) are applied in cases of licensing and in calculations of hydraulic works with interventions in water courses in the state of São Paulo. São Paulo. Table 1 contains a restricted number of situations of use and occupation of the soil with values of runoff coefficients (C) that are repeated, so that it is difficult to choose them, as they have closed intervals at both ends.

When calculating the maximum flood flow, the risks inherent to the Presidente Dutra Highway are considered after a precipitation with a statistical possibility of occurring once every 100 years. In Table 2, the values of the parameters necessary to calculate the volume and maximum flow of the basin by the Uehara method are shown (DAEE, 2006).

**Table 2.** Necessary parameters for calculating the volume and the maximum inlet flow of the Una River Basin, for a 100-year recurrence time for the passage section under the Rio Una Bridge, where it crosses the highway BR 116 (Presidente Dutra) in Taubaté, SP.

| PARAMETERS | UNIT OF MEASURE | VALUES |
|---|---|---|
| Length of the thalweg (L) | Km | 57.31 |
| Declivity. equivalent (Ieq) | $m.Km^{-1}$ | 3.13 |
| Basin area (A) | $Km^2$ | 449.49 |
| Concentration Time (Tc) | h | 13.83 |
| Base time (tb) | h | 46.88 |
| Distance to the Basin Center of gravity (Lo) | km | 29.93 |
| Delay time (tr) | h | 9.83 |
| Precipitation time (td) | h | 2.46 |

Using the data in Table 2, the flow coefficients (C) used were calculated using Equations 9, 10 and 11 and 12 for the maximum precipitation (h1), the excess precipitation (h - exc), the inlet flow values (QE), increased by 10%, according to the Uehara methodology (DAEE, 2006) and the Inlet volume (VE), which are shown in Table 3.

The Outlet Flow (QS) reached 149.50 $m^3\ s^{-1}$ and was calculated using the Manning Equation, with the water passage section under the Presidente Dutra Highway, with a diameter of 6.00 m, roughness (n) of the surface of the concrete hydraulic section (n = 0.014), and slope of 0.013 m/m. The Output Volume (VS) in the base time of the synthetic triangular hydrograph reached 12,616,554.37 $m^3$.

Considering then the differences between the Output Volume and the Input Volumes for each value of the runoff coefficients adopted, the Reservation Volume (VR) values were arrived at, which will accumulate in the floodplain areas and will reach different levels in the basin.

**Table 3.** Data of Inlet Flow and Inlet Volumes (VE) and Reservation for each value of runoff coefficient adopted.

| runoff Coefficient C | Inlet Flow QE ($m^3.s^{-1}$) | Inlet Volume VE ($m^3$) | Reservation Volume RV ($m^3$) |
|---|---|---|---|
| 0.35 | 168.49 | 14,219,067.52 | 1,602,513.15 |
| 0.40 | 192.56 | 16,250,362.88 | 3,633,807.51 |
| 0.45 | 216.63 | 18,281,658.25 | 5,665,101.88 |
| 0.50 | 240.70 | 20,312,953.61 | 7,696,396.24 |
| 0.55 | 264.77 | 22,344,248.97 | 9,727,690.60 |
| 0.60 | 288.84 | 24,375,544.33 | 11,758,984.96 |
| 0.65 | 312.91 | 26,406,839.69 | 13,790,279.32 |
| 0.70 | 336.98 | 28,438,135.05 | 15,821,573.68 |

Figure 3 shows the profile of the Una River thaw from its source to the control point on the highway BR 116 (Presidente Dutra) in Taubaté, SP.

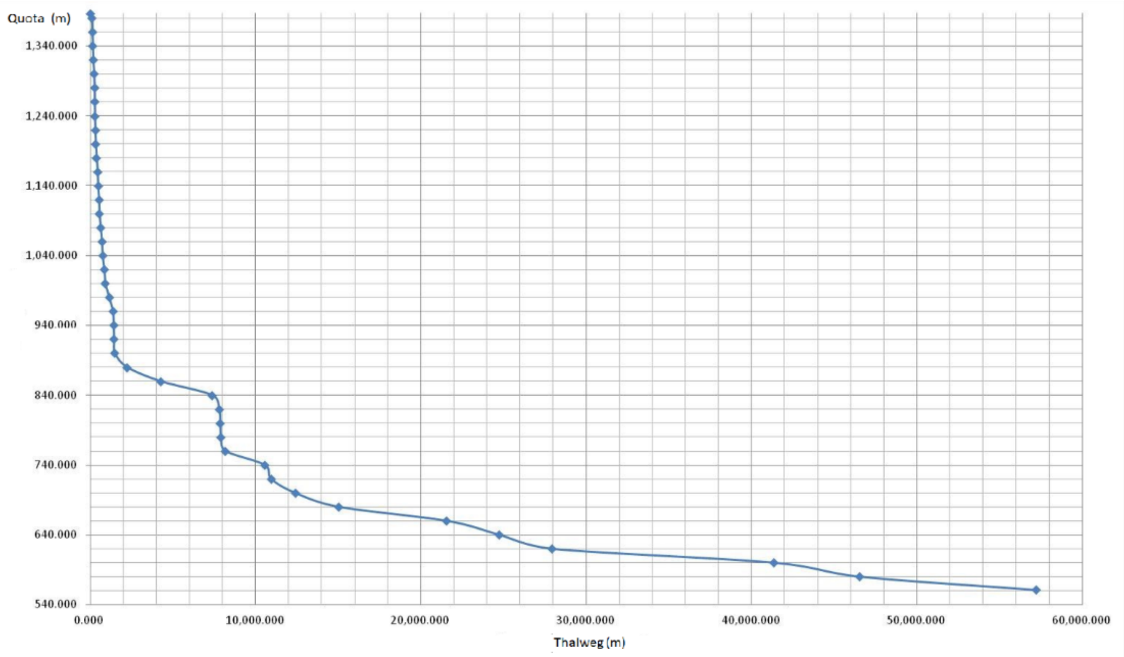


**Figure 3.** Profile of the river Una from its source to the control point on the highway BR 116 (Presidente Dutra) in Taubaté, SP.

As shown in Figure 3, the thalweg of the Una River has a steep slope of 300 m $km^{-1}$ in the first 1.7 km, and then changes to 18.75 m $km^{-1}$ in the following 6.4 km and a gentle slope of approximately 4.06 m $km^{-1}$ for 49.2 km until arriving at Rodovia Presidente Dutra.This last, flatter strip, annually undergoes episodes of flooding, affecting the Dr. Jose Luiz Cembranelli municipal road, immediately after the Department of Agrarian Sciences at the University of Taubaté, as well as the Presidente Dutra Highway, as shown in Figures 4 a, b, c, and d.

However, the intense rain with a recurrence time of 100 years has not yet occurred in the basin. The occurrences recorded in Figure 4, are recurrences of 1 to 2 years, and already cause economic losses.

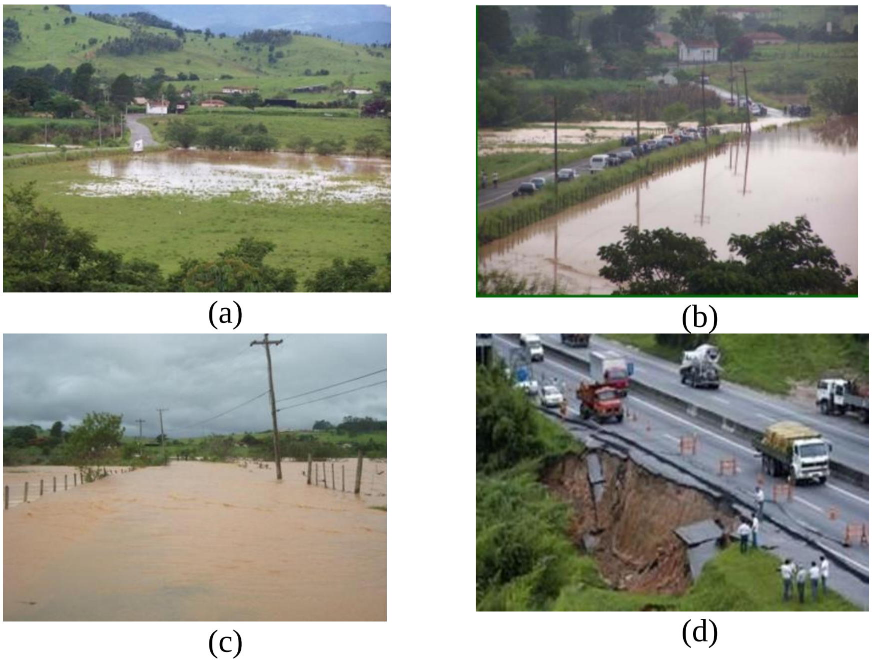


**Figure 4.** Flooding on Dr. Jose Luiz Cembranelli Municipal Road (a) early morning, (b) mid-morning and (c) late morning in February 2009, and the highway BR 116 (Presidente Dutra) in Taubaté, SP in January 2010.

The quota - volume curve is the graphical representation that makes it possible to obtain the volume that accumulates up to a certain level in response to the maximum precipitation that falls on the basin. Table 4 shows the result of the calculation of quotas and volumes of water that can be accumulated between the level curves that are observed at the site. Figure 5 shows the areas of influence of contour lines under the Google Earth image in the study area.

**Table 4.** Quota-volume relationship at the intersection point of Highway BR 116 (Presidente Dutra) with the Rio Una in Taubaté, SP.

| Quota (m) | Area ($m^2$) | Average area ($m^2$) | Level (m) | Partial Volume ($m^3$) | Accumulated Volume ($m^3$) |
|---|---|---|---|---|---|
| 550 | 2,420,27 | 1,210.14 | 0,00 | 0,00 | 0,00 |
| 555 | 1,369,484,67 | 685,952.47 | 5,00 | 3,429,762.35 | 3,429,762.35 |
| 558 | 2,382,318,09 | 1,875,901.38 | 3,00 | 5,627,704.14 | 9,057,466.49 |
| 560 | 4,222,270,53 | 3,302,294.31 | 2,00 | 6,604,588.62 | 15,662,055.11 |
| 562 | 5,293,351,22 | 4,757,810.88 | 2,00 | 9,515,621.75 | 25,177,676.86 |

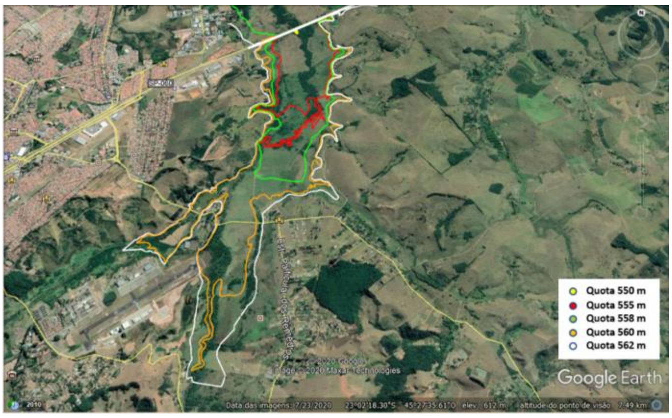


**Figure 5.** Contour lines with their areas of influence from the dam by the slope of the highway BR 116 (Presidente Dutra) with the Una River in Taubaté, SP.

With the accumulated quota and volume data from Table 4, the quota-volume curve was constructed (Figure 6), in which the quotas that will be reached according to each runoff coefficient and respective reserve volume (VR) were found.

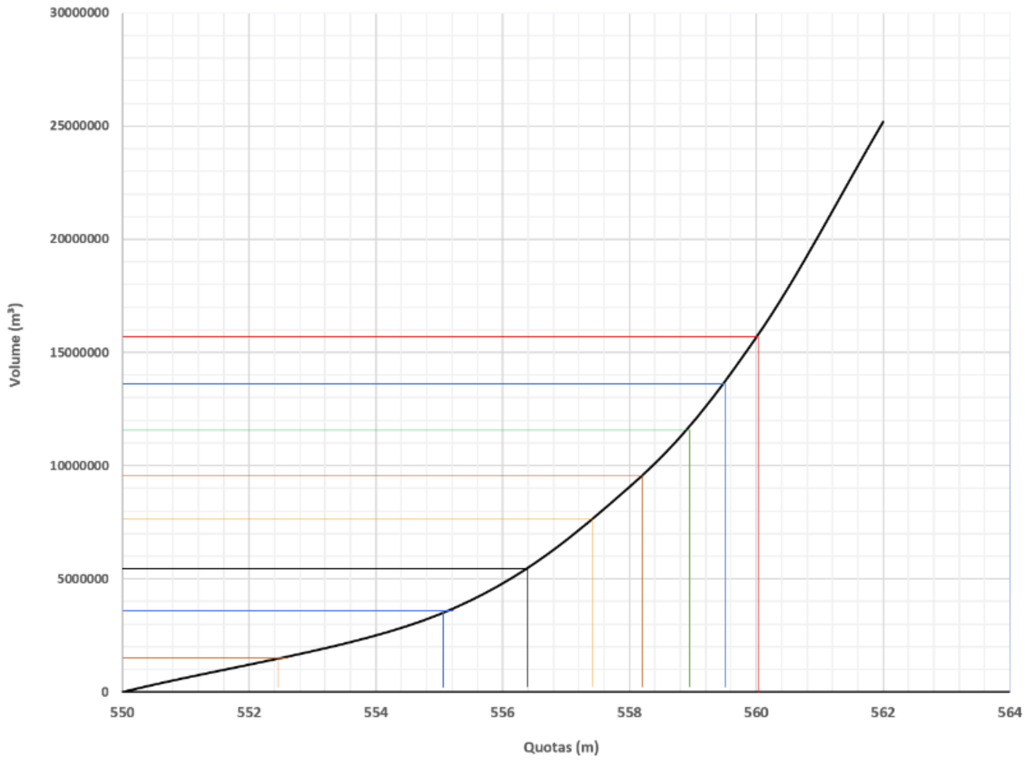


**Figure 6.** Quotas reached on the Quota-Volume Curve of the Una River Basin until the meeting with Highway BR 116 (Presidente Dutra) in Taubaté, SP, due to the different Reservation Volumes (VR) and flow coefficients (C).

The quotas found in Figure 6 for each Reservation volume as a function of the respective flow coefficients adopted are shown in Table 5.

**Table 5.** Quotas reached on the quota-volume curve of the Una River Basin until the meeting with Highway BR 116 (Presidente Dutra) in Taubaté, SP, due to the different Reservation Volumes (VR) and flow coefficients (C).

| Runoff Coefficient C | Reservation Volume RV (m³) | Quota reached (m) |
|---|---|---|
| 0.35 | 1,602,513.15 | 552.40 |
| 0.40 | 3,633,807.51 | 555.20 |
| 0.45 | 5,665,101.88 | 556.40 |
| 0.50 | 7,696,396.24 | 557.50 |
| 0.55 | 9,727,690.60 | 558.20 |
| 0.60 | 11,758,984.96 | 558.90 |
| 0.65 | 13,790,279.32 | 559.50 |
| 0.70 | 15,821,573.68 | 560.10 |

As shown in Table 5, in the event of a 109.55 mm precipitation that has 100 years of recurrence from possible changes in the use and occupation of the soil in the Una River Basin, the runoff would change. Surveys of the project “Macrodrainage plan for the Una River Basin” show that 556.72 m is the lower level of the bridge over the Una River on Highway BR 116

(Presidente Dutra) and 558.63 m is the asphalt level of the highway. Thus, with a flow coefficient C = 0.50, the water from such intense rainfall would exceed the hydraulic capacity of the bridge and with C = 0.60 the water would cover the asphalt surface of the road. Therefore, several hydraulic structures would have to be resized. However, requests for the resizing of hydraulic structures to allow greater flow rates to pass, as a rule, are not authorized by the state regulatory agency, the Department of Water and Electricity of the State of São Paulo (DAEE-SP), because problems of flooding to areas downstream of the point of interest in the basin. The solution is to act upstream of the point of interest, initially, not allowing the use and occupation of the basin to be considerably altered, the basins for detention and retention of runoff to be built, and ensuring that legislation relating to the preservation and conservation of waters is complied with. Permanent Preservation Areas (APPs) must be created, in addition to the maintenance of 20% legal reserve.

This study conducted of the Macrodrainage Plan of the Una River Basin (Targa *et al.*, 2019), using the number curve method (CN) as described in the Equations 4, 5 and 6, found that the coefficient runoff (C = 0.35) most nearly expresses the reality of the use and coverage of the Una River basin, which is consistent with the surface area type of predominantly plantations, pastures, etc., as shown in Table 1. Observing the coefficient C = 0.35 in Table 5, the level reached will be only 542.40 m, allowing the passage of water through the section under the bridge on the Presidente Dutra Highway, but it would certainly cause a greater water depth over the Dr. Jose municipal road Luiz Cembranelli, upstream of the Presidente Dutra Highway.

However, given the changes that occurred in the Physical Municipal Master Plan of Taubaté (Law 412/2017), Targa *et al.* (2019) demonstrated that the urban infrastructure is advancing over the Una River Basin, starting with the Itaim Stream Sub-Basin, whose limits reach the urban area of the city of Taubaté, and whose vectors of urban occupation and pressure from the real estate market are focused on this sub-basin, forcing a reflection on what precautions must be taken so that there are no advances on the Rural Macrozona in (Taubaté, 2017).

In the case of the Itaim Sub-Basin, Macrozona Rural corresponds to approximately 64% of the basin area and has a high infiltration potential (S = 115 mm), resulting in an effective precipitation of only 40 mm for the recurrence period of 100 years.

## 4. CONCLUSION

In view of the results of this study, it can be concluded from the construction of the quota-volume curve, that the Reserve Volumes (VR), as a result of the simulation of the increase and modification of the use and occupation of the soil of the Una River Basin in Taubate-SP and the occurrence of extreme precipitation events, with 100 years of recurrence time, the crossing section may become insufficient, and the flood volume can pass over the Presidente Dutra Highway and cause great economic loss. Conservation and preservation measures must be taken by the municipal government of Taubaté, such as the de-silting of the Una River channel and its tributaries, the implementation of detention basins and the retention of runoff, as well as the implementation of a payment program for environmental services to conserve and restore forest vegetation in the basin.

## 5. REFERENCES

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