FLOOD PRONE AREAS IN SANTO AMARO DA IMPERATRIZ MUNICIPALITY

D. E. Mendes[1*] and P. L. B. Chaffe[2]

1. *Undergraduate course of Civil Engineering, Federal University of Santa Catarina, Brazil, hy.etchegaray@gmail.com*
2. *Department of Sanitary and Environmental Engineering, Federal University of Santa Catarina, Brazil, pedro.chaffe@ufsc.br*

** Currently at GeoEnergy Engenharia, Brazil*

ABSTRACT: The Santo Amaro da Imperatriz municipality (SAIM) is located in the downstream area of Cubatão do Sul river basin (CSRB) in Santa Catarina State, Brazil. Since the city has suffered with flood, the knowledge about flood prone areas in is critical for better design practices and disaster prevention plan. The objective of this paper was to analyze the changes in inundated areas due to different design rainfalls for the Santo Amaro da Imperatriz municipality. The CSRB with 740 km^2 is the main drinking water supply for more than 700,000 inhabitants of the region. Water level and discharge data were obtained from 2 gauging stations: one upstream of the SAIM with a 57 years historical record; and the other downstream of the SAIM and with a 19 years historical record. Design rainfall of 20, 50 and 100 years return period were obtained using IDF curves for the location. We divided the total basin area in 4 subbasins. Design flood was calculated for each of the subbasins. Flood routing and inundation were calculated using the HEC-RAS model. The calibration was done by comparison of the discharge and water level obtained with the model and the measured ones in both gauging stations. The errors for the simulated water level were within 1% and 10% for the Poço Fundo station and the ETA CASAN station respectively. The simulated inundation areas also accurately corresponded to the neighborhoods which were reported to being flooded in past flood events. In general, the inundation behavior and inundated area found for the 20, 50 and 100 year return periods were very similar. Despite the reasonable results, our simulations were limited by the lack of more detailed river cross sections and for not considering some of the hydraulic structures such as bridges.

Key Words: Cubatão do Sul River, Flood Mapping, HEC-RAS, Santa Catarina – Brazil.

1. INTRODUCTION

Flooding of areas happen mainly in two cases: in the natural riparian areas composed by low terrain elevation levels or due to the urbanization process occurred in the watershed, causing the land cover to become more impermeable (Tucci 1993). The following problems related to the urban drainage have been identified in Santa Catarina's municipalities (Nerilo *et al*., 2002): out of the 223 surveyed municipalities, 79% have had street flooded due to insufficient drainage structures; out of the 215 surveyed municipalities, 76% have had overflowing channels, streams and rivers; out of the 190 surveyed municipalities, 67% have had streets flooded due to channel overflowing; and, out of the 131 surveyed municipalities, 46% have had channels with bridges overflowed by flooding.

The Santo Amaro da Imperatriz Municipality (SAIM) is located in Santa Catarina, Brazil, has a population estimated in 21,221 inhabitants, with a GNP per capita of R$ 13,985 and the economy is based on activities related to ecologic tourism and rural culture. The SAIM is inside the Cubatão do Sul river basin (CSRB) which is a major water supply for the Santa Catarina State Company for Water and Sanitation (CASAN) used to provide water to over 700.000 inhabitants from all over the Great Florianopolis area. Flooding of varied proportions occur frequently in the SAIM and the events occurred in 1964 and 1998 may be mentioned as two of the worsts flood events from the last decades, leaving dozens of families unhoused and districts in the city inaccessible. Furthermore, the last event ended up with a bridge been carried by rivers flow.

The objective of this paper was to analyse the changes in inundated areas due to different design rainfalls for the Santo Amaro da Imperatriz Municipality and to describe districts with higher propensity to floods Hydrograph for flood situations were obtained based on the SCS and the Triangular Unit Hydrograph both proposed by the Natural Resources Conservation Service (NRCS). The flood was routedwith HEC-RAS Model, combined with the channel geometry provided by the Digital Elevation Model (DEM) with 30m resolution.

2. STUDY SITE AND AREA

The CSRB is situated in Santa Catarina State, southern Brazil, between coordinates. Its total drainage area is 740 km². There were considered 03 main rivers on the calculation of the floodplain zones in SAIM: Cubatão do Sul river – where the water intake is located -, Matias river – CSR tributary by the left bank side – and Vargem do Braço river – CSR tributary by the right bank side. Their graphic representation is presented in Figure 1.

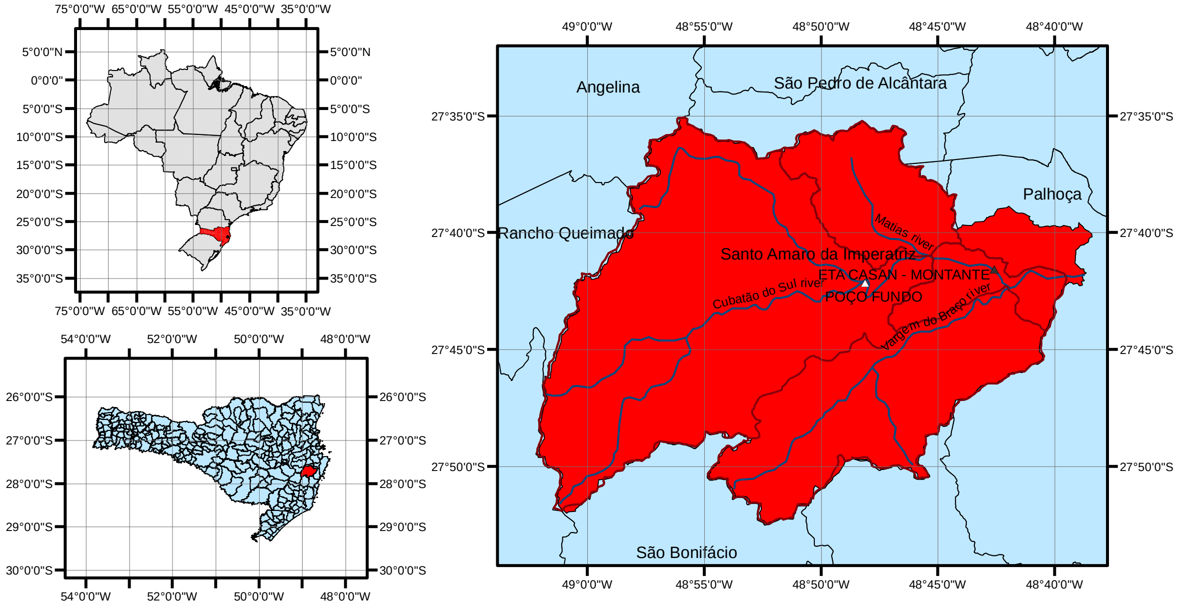


Figure 1: Cubatão do Sul river basin location.

The division of the CSRB in 4 other subbasins was made in order to characterize the influence caused by each subbasin in SAIM flooding. Four independent regions were delimited: Upper Cubatao do Sul river basin (UCS), Low Cubatao do Sul river basin (LCS), Matias river basin (MR) and Vargem do Braco river basin (VB). The main physiographic parameters – drainage area, main river length and slope – were calculated for each sub basin based on the DEM developed by EPAGRI.

The land cover map was based on topographic maps developed by the Brazilian Institute of Geography and Statistics (IBGE), dated between years 1974 and 1983. Six different land cover classification were listed in CSRB as proposed in Chow (1969), these being: heavy forest land, light forest land, open land, cultures land, rock cover land and urban land. In general, the sub basins feature soils with moderated absorption near to rivers source – where slopes were heavier and forest more preserved –with vast plains compound by organic and poorly drained material, with high tendency of flooding. In this paper, soil classified in B group by Chow (1969) were used, characterized by clay soils with moderate absorption. Table 1 lists the main parameters for each subbasin.

Table 1: Physiographic Parameters of Upper Cubatão do Sul basin (UCS), Low Cubatão do Sul basin (LCS), Matias river basin (MR) and Vargem do Braço river basin (VB).

Parameters	UCS	LCS	MR	VB
Drainage Area (km²)	425	42	86	187
Main Stream Length (km)	50.0	42.4	16.7	32.9
Main Stream Slope (m/m)	0.0006	0.0009	0.0013	0.0024
Time of Concentration (min)	913	296	334	559
Lag Time (min)	548	178	200	335
Land Cover (%)				
·Heavy Forest (CN=55)	51.7	41.2	23.8	85.9
·Light Forest (CN=66)	25.3	4.1	44.8	0.2
·Open Land (CN=79)	16.0	42.8	27.4	1.7
·Cultures (CN=81)	4.0	7.5	-	4.3
·Exposed Rock (CN=69)	1.6	-	-	7.9
·Urban Land (CN=85)	1.4	4.4	4.0	-

3. MATERIALS AND METHODS

The time of concentration (TC) for each sub basin was calculated by Equation 1, formulated by U. S. Corps of Engineers as presented in its original publication in MOPU (1987), relating the parameters of river length (L) and river slope (S) of the main stream. Its choice was made in accordance with the work done by Silveira (2005), which confronted some of the main equations used for calculation of concentration time with the results obtained in gauged basins.

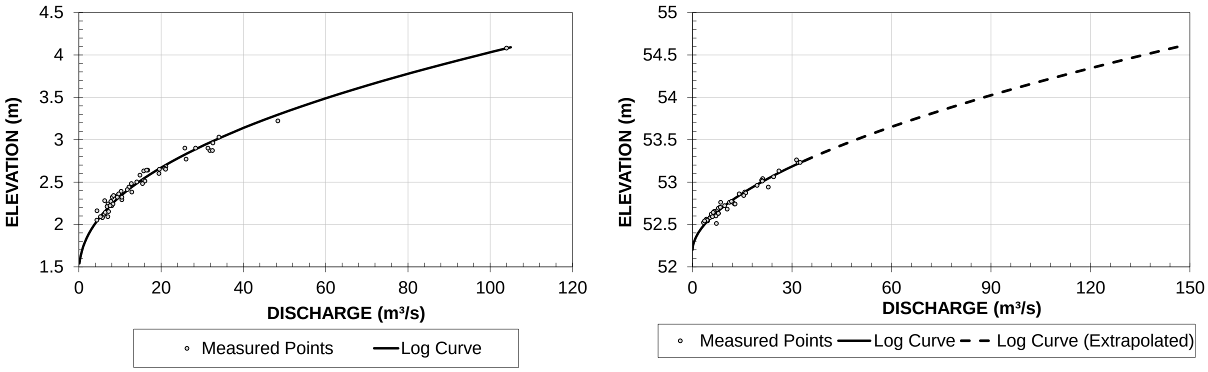
$$Tc = 0{,}191 \times L^{0.76} \times S^{-0.19} \qquad [1]$$

In CSRB are two precipitation station, located in Águas Mornas municipality (Poço Fundo station) and SAIM (ETA Casan Upstream station). The location of stations is presented in Figure 1 in previously item. The IDF curve was defined by Nerilo *et al*. (2002) for SAIM, based in rainfall height measured daily by ETA Casan Upstream station. The results obtained by Nerilo *et al*. (2002) in his work were used to formulate the IDF equation for SAIM as presented in Equation 2.

$$i = \frac{1157{,}8 \times T^{0.1904}}{(t+12)^{0.759617}} \qquad [2]$$

Equation 2 is valid for rainfall duration interval varying between 5 and 1440 minutes, and for recurrence times varying from 5 to 100 years. The IDF equation was used to define precipitation height of effective rainfall over CSRB for different recurrence times. Discharge curves from both stations where used in calibration for HEC-RAS Model, in order to define floodplain areas in SAIM.

The discharge measurement registries available in each gauge station – covering periods from 1988 to 2012 in ETA Casan Upstream station and from 1950 to 2012 in Poço Fundo station – were used to extrapolate discharge curves, assuming the Logarithmic Method as showed in Santos *et al*. (2001). For the purpose for this study, staff gauge readings were adjusted in order to represent absolute elevation showed in DEM. The stage-discharge curves, their equations and river sections are presented in Figure 2.



$$Q = 11{,}892 \times (H - 1{,}405)^{2{,}205}$$

$$Q = 30{,}906 \times (H - 52{,}2)^{1{,}779}$$

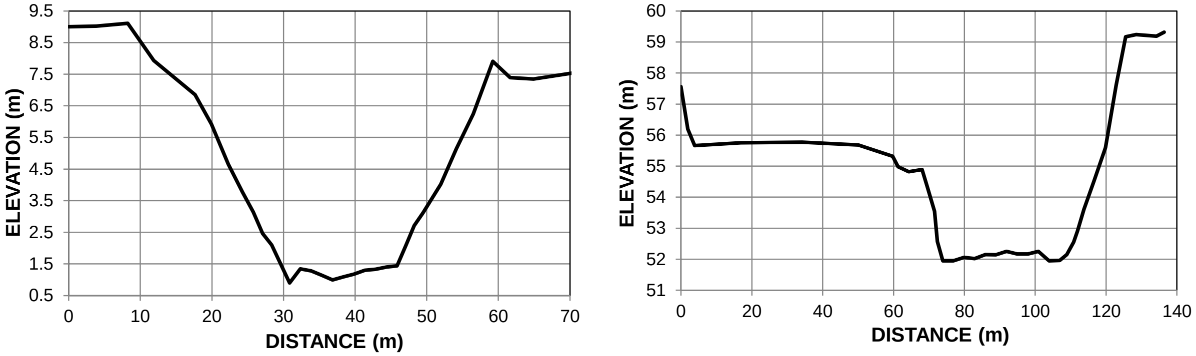


Figure 2: Discharge Curve, Equation and Cross Section – ETA Casan Montante (left) and Poço Fundo (right)

The parameters obtained were used as input in HEC-RAS Model for calculating flood prone areas in SAIM, for recurrence times of 20, 50 and 100 years. The simulation adopted the following assumptions: Cross sections from flow stations were used to compose river bottom form along studied path; Sections margins were defined by DEM developed by EPAGRI; Effective rainfall occurred over all sub basin simultaneously; Initial soil intermediate saturation adopted (condition II); Manning coefficients based on lad cover as showed in Table 2. We disregarded buildings interferences and considered tidal effects as downstream boundary condition, varying from 0 (zero) to 1.2 m.

Table 2: Manning Coefficient (font: CHOW)

Parameters	Main Channel	Open Land/ Cultures	Urban Land	Sparse Forest	Dense Forest
Manning	0.035	0.05	0.05	0.06	0.08
Description	Mainly natural mainstream, with rocks and light bushes	Bushes and land covered by grass/cultures	Same as assumed for open land/ cultures	Scattered trees with bushes	Heavy trees and bushes

The HEC-RAS Model is a numeric model developed by the U. S. Army Corps of Engineers for waterstream level calculation based on Standard Step Method equation. This model uses Conservation Equation, Continuity Equation and Manning Equation to calculate the difference between water levels in consecutive cross sections, repeating as much iteration as necessary for an error lower than a determined value, adopted as 0.05m for this studies. The channel geometry was defined with ArcGIS 10.1 software, and the interface between this program and HEC-RAS 4.1.0 was made by HEC-GeoRAS 10.1. The region covered by the HEC-RAS Model goes from upstream of Poco Fundo station to the pour point in BR-101 highway.

4. RESULTS AND DISCUSSION

4.1 DESIGN RAINFALL

As assumption for the effective rainfall, the duration of precipitation was assumed to be the same as the concentration time calculated for each sub basin, in order to characterize critical event occurring in watershed where every rainfall drop has become runoff and it's contributing in the pour point assumed. The rainfall blocks were discretized with durations as proposed in Bedient *et al*. (2001) equivalent to 0.2 x Lag Time to fit convolution method of UTH. The blocks distribution were made in accord to the alternated block method, as presented by Canholi (2009).

Losses in sub basins were calculated following the methodology of Curve Number proposed by NRCS and based on a coefficient (CN) adopted for each type of soil and land cover over the basin, as presented by Chow (1969). The CN composition was made by the percentage part of every land cover over basin, as showed in Table 1. The values from CN adopted refer to an intermediate saturation condition of the soil (condition II), defined by the accumulated amount of rainfall precipitated in the 5 days preceding the event, varying from 1.27 to 5.33mm depending on the season of the year. The parameters defined in this item are synthesized in Table 3. The Figure 3 brings the distribution for the effective rainfall over each sub basin.

4.2 DESIGN HYDROGRAPH

The effective flow hydrograph were based on the UTH Method, proposed by NRCS, been characterized as a synthetic hydrograph calculated from physiography parameters of basin, caused by a single precipitation pulse equivalent to 01 unit (01 centimeter). Its use was based on the following assumptions: Effective rainfall uniform all over the duration interval; Effective rainfall evenly distributed over the whole basin; Basis time of UTH constant for the unit duration; Proportionality principle: ordinates of UTH are mutually proportional and can be added or superimposed; and Time invariance principle: the UTH calculated with a standard effective rainfall for any recurrence time is invariable. Based on assumptions made, the UTHs were calculated for each subbasin and are presented in Figure 4.

Table 3: Effective Rainfall of Upper Cubatão do Sul basin (UCS), Low Cubatão do Sul basin (LCS), Matias river basin (MR) and Vargem do Braço river basin (VB).

Subbasin	**UCS**			**LCS**			**MR**			**VB**		
Recurrence Time	**20 y**	**50 y**	**100 y**	**20 y**	**50 y**	**100 y**	**20 y**	**50 y**	**100 y**	**20 y**	**50 y**	**100 y**
CN	63.3			69.0			67.7			57.7		
Block Duration (min)	109.6			32.5			138.1			74.0		
Total Precipitation (mm)	172.2	205.1	234.0	128.6	153.1	174.8	132.9	158.3	180.6	152.1	181.1	206.6

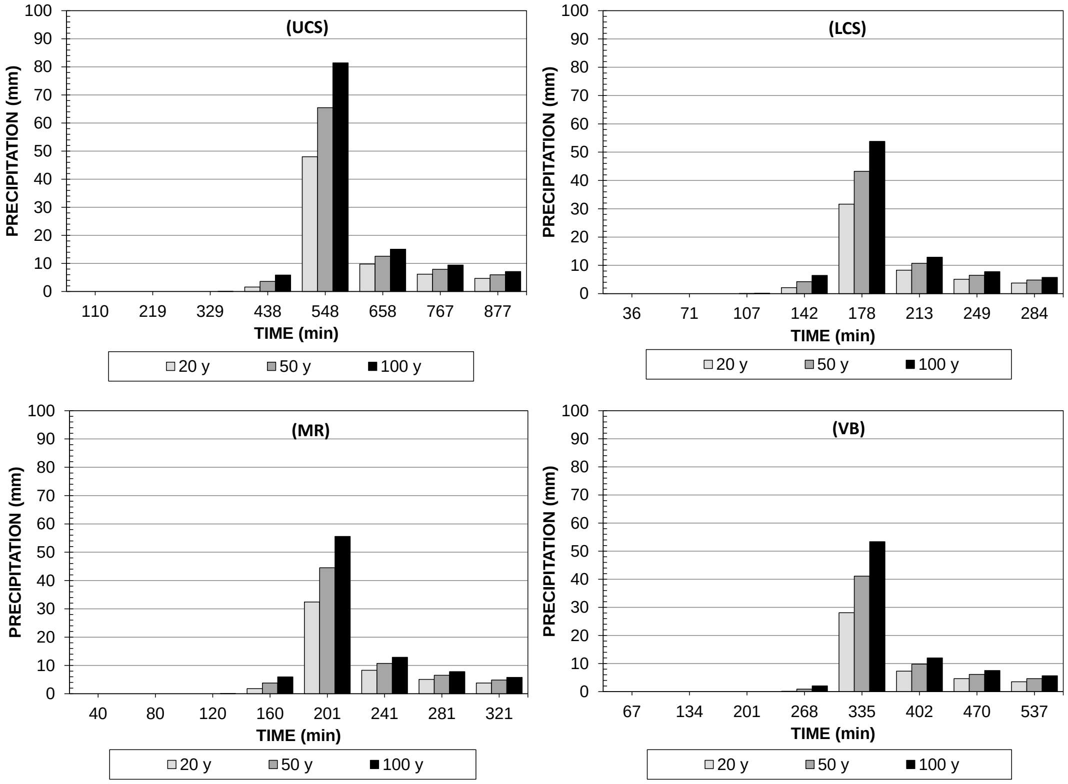


Figure 3: Effective Rainfall Distribution of Upper Cubatão do Sul basin (UCS), Lower Cubatão do Sul basin (LCS), Matias river basin (MR) and Vargem do Braço river basin (VB).

The UTH calculated in previously paragraph, combined with the effective rainfall obtained in item 2, were used in effective flow hydrograph convolution. As assumed before, the UTH had its basis time invariable for each of the effective rainfall blocks and ordinate were added proportionally to rainfall height. The results are presented in Figure 5.

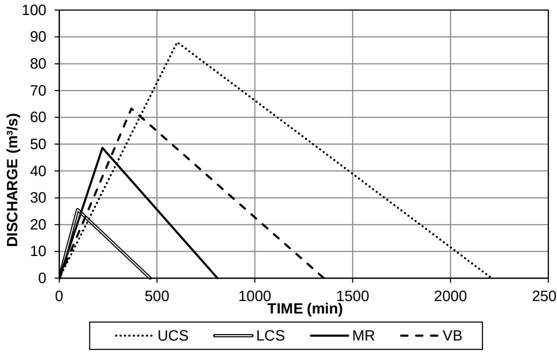


Figure 4: UTH of Upper Cubatão do Sul basin (UCS), Lower Cubatão do Sul basin (LCS), Matias river basin (MR) and Vargem do Braço river basin (VB).

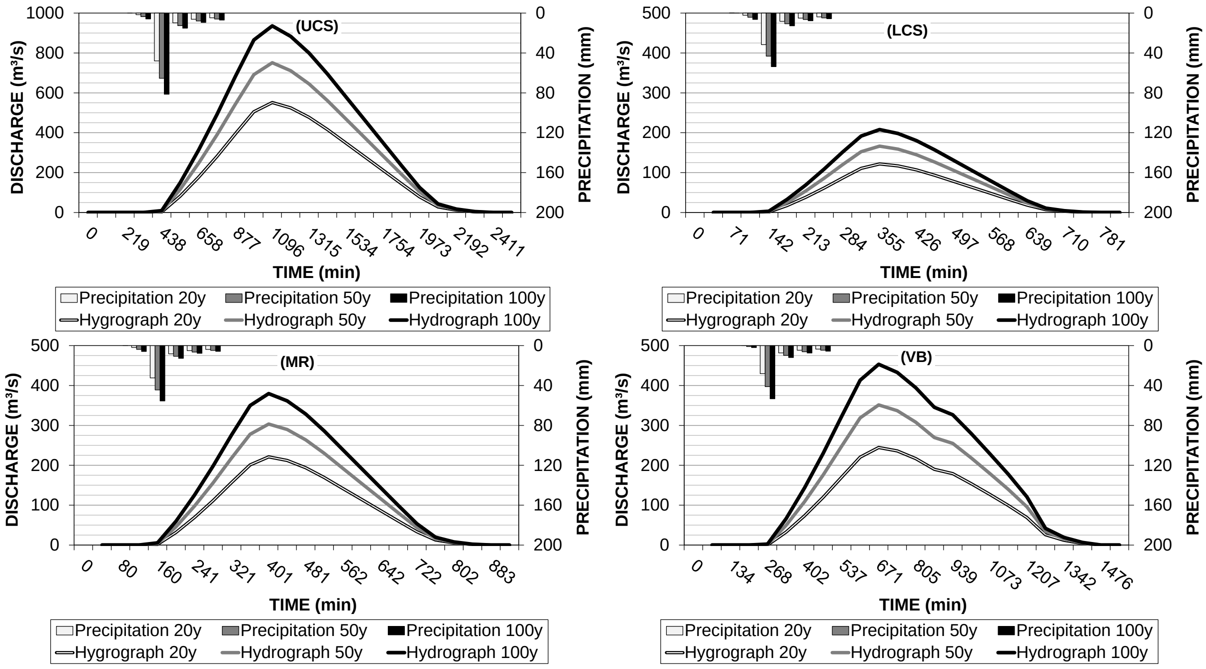


Figure 5: Effective Flow Hydrograph of Upper Cubatao do Sul basin (UCS), Low Cubatao do Sul basin (LCS), Matias river basin (MR) and Vargem do Braco river basin (VB).

4.3 FLOOD ROUTING AND MAPPING

The calibration of HEC-RAS Model was based in discharge curves obtained for each flow stations in item 3. Discharges of 10, 20, 50 and 100 m³/s were simulated until the curve observed in HEC-RAS Model was the same as expected in flow stations. The hydraulic control of each cross section was reproduced in the model – such as water rapids for Poço Fundo station and a small dam used in water capitation for ETA Casan Upstream station – until the results presented errors not larger than 10%.

The area affected by floods caused for passage of flow hydrographs varied from 3.72 km^2 to 5.37 km^2 for recurrence times of 20 and 1000, respectively. Due to the difference between peak times in UCS and MR, the arrival of flow hydrographs generated by rainfall over sub basins occurred in misaligned way, presenting two distinct peaks resulting for each channel. The simulation showed that some of the cross sections in the model had two different peaks in their level hydrograph for flood events, presenting even flow inversion during a determined interval in Matias river, when hydraulic control became the water level observed in Cubatão do Sul river. In the specific simulation run, the backwater caused by Cubatão do Sul river over Matias river extended for over 2.7 km from the outfall, while the opposite extended for about 1.5 km. The flood prone areas for SAIM due to the events for recurrence of 20, 50 and 100 years are presented in Figure 6.

The results were analysed in four cross sections used as reference, located in the district of City centre, Natividade, Alto da Varginha and Sul do Rio, in order to observe the effects of flood events cause in different places in the SAIM. The elevation of water level was measured in relation to the normal depth calculated for each of the channels, computed in the moment where water level where the highest during the duration of the event, for each cross section.

The highest variations in water elevation calculated were observed in Sul do Rio’s cross section, downstream from the confluence of Cubatão do Sul and Matias rivers, reaching gradients of 5,.80 to 7.04 m for the recurrence times of 20 and 100 years, respectively. The other cross sections presented variations of 3.78 to 4.57 m (City Centre), 2.28 to 3.60 m (Natividade) and 1.88 to 2.15 m (Alto da Varginha). The elevation calculated for each cross section is presented in Figure 7.

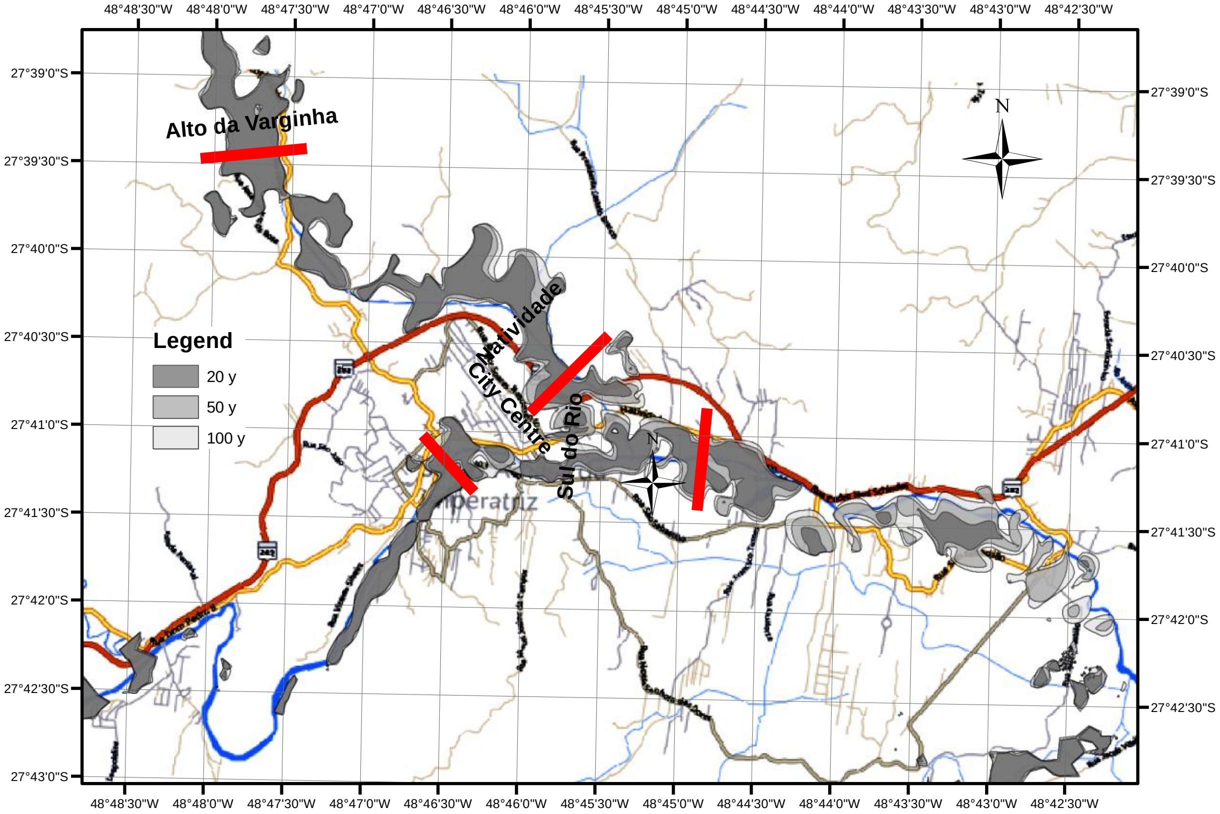


Figure 6: Floodplain Prone Areas of SAIM

Floods observed near to City Centre Section were caused exclusively by precipitation over UCS, with no interference due to water elevation observed in Matias river. The opposite situation can be observed in Alto da Varginha section, where Matias river is the main cause of flood events. For other sections, flood events are caused by both Cubatão do Sul and Matias rivers.

Among affected areas, most of them are open land used for cultures, located in riparian zones. The city centre also figured out as prone to flood events, once its elevation is lower than the other zones studied in this paper. Therefore, passage of flood with recurrence time considered low – equivalent to 20 years – are already causing flooding and losses, affecting mainly the municipality commercial zone.

5. CONCLUSIONS

The SAIM, as its location near to a confluence between two major streams and due to its low elevations, figured out as a vulnerable to floods even in low recurrence times, presenting flood prone areas with no big variances in comparison of recurrence times between 20 and 100 years. Despite the water level obtained in this paper keep up relatively low, not representing human hazard – excluding the hypothesis of landslides – the constant rate of the events is shown to be concerning once it affects urban zones in SAIM, causing losses and expenses.

Thereby, the occurrences of regulars events of flooding may be minimized for adopting structures for flow containment, such as dredging, heightening of banks in urban zones and construction of linear parks and detention basins along main channels that, associated to urbanism works and infrastructure that offer leisure areas for the inhabitants, may become an environmental solution for mitigation of the effects caused by floods in SAIM.

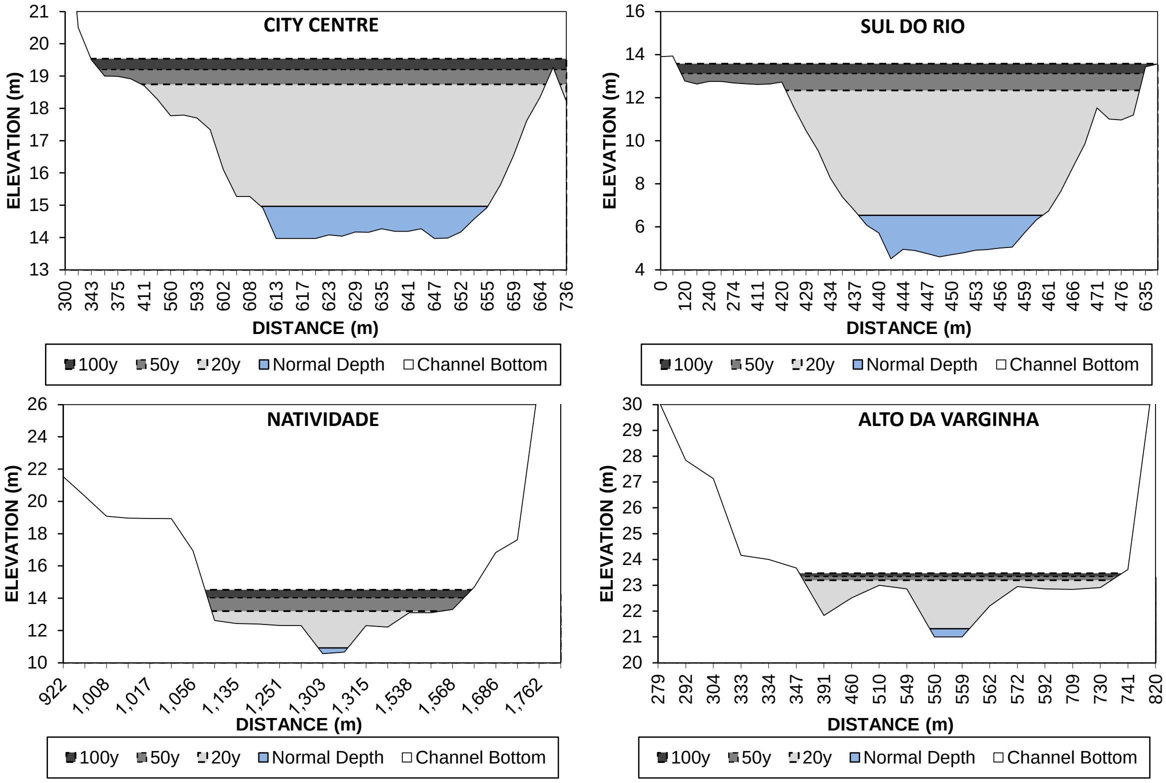


Figure 7: Water Levels Calculated for Reference Cross Sections

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