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VALIDATION OF THE FLOOD MAPS OF BELO HORIZONTE: CASE STUDY OF RESSACA CATCHMENT

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ABSTRACT: The main Brazilian cities are lately passing through major challenges in urban drainage due to the rapidly and disordered urban growth, that causes major flooding events. In order to diagnose the causes of urban drainage problems and its integration with other urban systems, the Municipality initiates, in 1999, the elaboration of the drainage master plan, which in its first step performed catchments characterization; cadastral survey of the drainage system and creation of a georeferred drainage database. In 2006 the second stage of drainage master plan was initiated, resulting in the hydraulic and hydrological modeling of all channelized streams; identification of the areas potentially susceptible to floods with its association of risk level – here called Flood Inundation Maps; proposition of a management model for the city and implementation of a hydrological monitoring program. Among the products developed in the second stage of the drainage master plan, we highlight the Flood Inundation Maps and the hydrological monitoring program. The Flood Inundation Maps were developed based on the results of hydrological and hydraulic modeling of the drainage system, in which were identified channels reaches with hydraulic inadequacies, parameterized in terms of probability of occurrences of extreme flows, besides no flow and water level measurements existed. The association between the water levels of flooding and rainfall were performed using equation the IDF (Intensity Duration Frequence) in a Risk Chart. With the hydrological monitoring, program that begins its operation in October 2011, it is possible to validate the Flood Inundation Maps and the Risk Charts. These Risk Charts consists in a graphical tool linking rain heights and duration to a flooding risk level, allowing flood forecasting. It was elaborated for each stream where flood occurrences were identified. The present work concerns the validation the Risk Chart of the Ressaca's Catchment.

Key Words: Flood Management, Flood Inundation Maps, Floods alerts, Monitoring.

1. INTRODUCTION

Most of the Brazilian urban centers are passing lately by major challenges to manage urban drainage due to intense and disordered urban growth, which promotes changes in the hydrological cycle, leading to more frequent flood events with serious consequences.

In the city of Belo Horizonte, municipality with 2,395,785 inhabitants (IBGE, 2012), the reality is not different; problems with floods are frequent, specially flash floods. The municipality is located in the São Francisco River basin, having as main catchments the Onça and Arrudas, tributaries of the Velhas stream. The municipal territory is located in a mountainous area, characterized by the presence of dozens of small watercourses, typical of mountainous areas.

In order to diagnose the causes of urban drainage problems and its integration with other urban systems, the Municipality initiated in 1999 the elaboration of the drainage master plan (DMP). The first step of the DMP, already concluded, comprise characterization of the elementary catchments; a cadastral survey of the drainage infrastructure – integrating a GIS (Geographic Information System) (Champs *et al*., 2001).

In 2006 the second stage of drainage master plan was initiated, resulting in the hydraulic and hydrological modeling of all channelized streams; identification of the areas potentially susceptible to floods with its association of risk level – Flood Inundation Maps; update of the GIS databases and development of the GIS in web environment; proposition of a management model for the city and implementation of a hydrological monitoring program.

Among the products developed in the second stage of the drainage master plan, we highlight the Flood Maps and the hydrological monitoring program. As the Belo Horizonte Flood Inundation Maps were developed exclusively based on hydraulic - hydrological modeling their validation is essential to assure their performance. Based on the Flood Inundation Maps Risk Charts were created. These Risk Charts consists in a graphical tool linking rain heights and duration to a flooding risk level. Therefore, this article aims to evaluate the Flood Maps thought the data provided by the Hydrological monitoring system (data of rainfall and water level in the steams), regarding the validation of the Risk charts.

In order to perform the validation, the present work proposes the application of rainfall and water levels obtained through the hydrological monitoring system for the Ressaca/Sarandi catchment. All the monitored events that generated warnings will be used in this validation.

2. THE FLOOD INUNDATION MAPS AND THE RISK CHARTS OF BELO HORIZONTE

As mentioned above SUDECAP (2009), the Flood Maps was developed based on results of the hydrological and hydraulic modeling of the channelized drainage system of city of Belo Horizonte, in which channels reaches with hydraulic inadequacies were identified, and parameterized in terms of probability of extreme flows occurrences. The reaches with hydraulic inadequacies identified in the modeling studies, were verified in the field through technical visits and confirmed by locals. The flooded areas delimited on the Environmental recovery program of Belo Horizonte – called DRENURBS, which studied the streams with natural channels in the city – were also took into account in the flood mapping of Belo Horizonte.

From the treatment and evaluation of the studies carried out, considering the city's topographical information the flooded surfaces could be generated bordering the water courses.

To each inundation delimited area, Risk Charts were created. These Risk Charts consists in a graphical tool linking rain heights and duration to a flooding risk level and allow the forecasting floods based on the duration and height of the precipitation.

The association between the patches of flooding and rainfall was performed using equation IDF (intensity, duration and frequency of rains) proposed by Pinheiro and Naghettini (1998) for the metropolitan region of Belo Horizonte, whose curves are presented in Figure 1a. The same authors studied the statistic behavior of the rains distribution in time in the area, based on the Huff method (Huff, 1967).

Thus, on the basis of the hydrologic and hydraulic modeling developed the return periods in which the overflows occur could be assign. With this information risk charts were built for all areas potentially susceptible to flooding, where the duration and height of rain were associated with the risk of flooding. In this chart 04 (four) tracks of risks were set: Critical level, Emergency Level, Alert level and Normal situation, as shown in Figure 1b. The critical level was set according to the return period from which overflow occurs, according to the hydrologic and hydraulic models. The other levels have been associated with return periods below the overflow level.

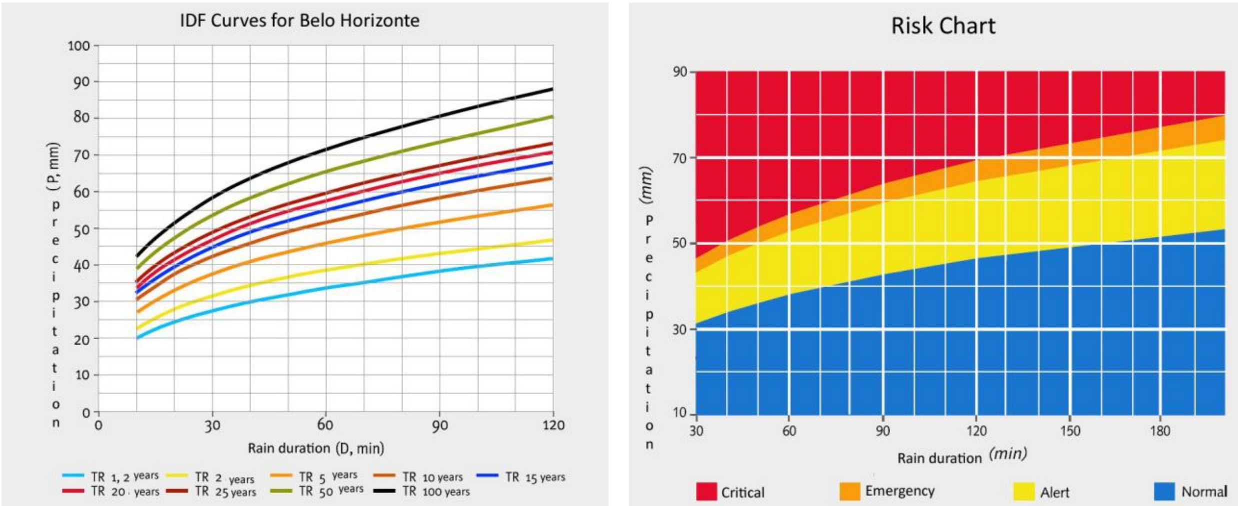

Figure 1: a) IDF curves for Belo Horizonte (SUDECAP, 2009) b) – Example of Risk Chart (SUDECAP, 2009).

3. MONITORING SYSTEM DESCRIPTION

The hydrological monitoring program in Belo Horizonte municipality begins its operation in October 2011, in the beginning of the rainy season, having as main objectives:

- follow events of rainfall and water levels of streams in real time;
- allow permanent drainage system diagnostics;
- calibrate the hydrologic hydraulics models for the municipality catchments and validate the Risk Charts and the Flood Maps of Belo Horizonte;
- support the development of drainage projects;
- provide data to the Central of Risk Monitoring and Forecast – CEMAR, under the responsibility of the Municipal Civil Defense Coordination-COMDEC, aiming at the anticipation of actions for protection the population living in flooding and mudslide risk areas.

The monitoring system consists of 42 stations, being four weather, eleven rainfall and twenty seven fluviometric, which were deployed in strategic areas of the Municipality. The location definition of the stations was based on the diagnosis of the municipality drainage system that generated the Flood Maps of Belo Horizonte, in the characterization of elementary catchments considering the spatial representativeness of the data, and equipment safety criteria and interference with urban equipment (e.g. trees and buildings). Most of the stations were located in areas that suffer with floods.

The monitoring stations are equipped with precipitation gages sensors of the tipping bucket type, water level sensors (ultrasonic or Piezoresistive) and climatological sensors, which measures watercourses level, air temperature, atmospheric pressure, relative humidity, wind direction and speed. The data obtained by the sensors is transmitted via GPRS (General Packet Radio Service), in real time, each 10 minutes and subsequently stored and made available on the municipal hydrological database-BDH in form of tables, graphs and reports. Figure 2 illustrates the monitoring stations installed in Ressaca Stream basin.

Figure 2: Monitoring stations in Ressaca's catchment

Alert levels were defined to each water level measurement station considering the operative conditions of the channel aiming to provide alerts managers and to the population. The identified alert levels were defined as: Yellow alert, when the water level pass 50% of the channel height, Orange alert when the water level pass 80% of the channel height and the red alert, when the channel overflows.

It's important to remind that these alert levels have no relationship with those related to the Risk Chart, only the red alert presented here and the critical level of the Risk Chart matches, they correspond to the canal overflow level. The Figure 3 shows the longitudinal section of the Ressaca stream canal and alert levels.

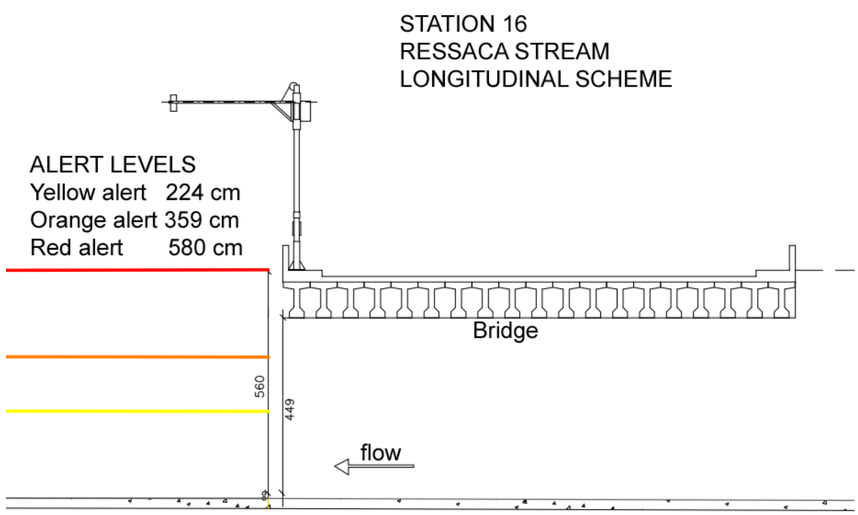

Figure 3: Alert levels in Ressaca's canal

4. CASE STUDY

In order to validate the Risk Chart of Belo Horizonte, applying the rainfall and water levels data, obtained through the municipal hydrological monitoring system, the Ressaca catchment was selected. Ressaca catchment has two fluviometric (stations 16 and 17) and one rain gauge (station19) stations. Figure 4 presents the map of the city highlighting the Ressaca catchment with the main streams and location of the monitoring stations. The catchment has a total surface of 2.038,69 hectares.

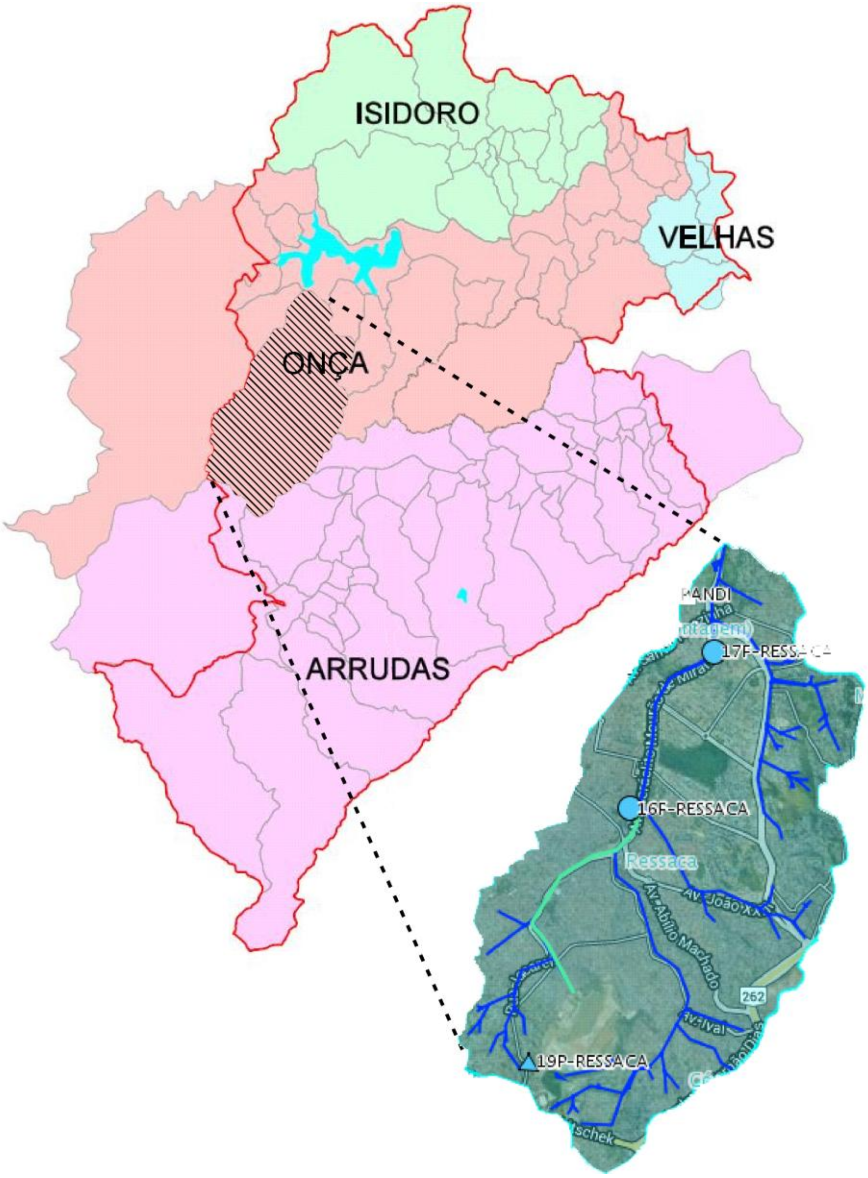

Figure 4: Belo Horizonte's main catchments with the municipal limits in red and the Ressaca catchment with the main streams and location of the monitoring stations

The Risk Chart of the station 16 was chose to be evaluated in the present article. To perform the evaluation all events that generated alerts, from the monitored period, in the 16 station were selected. During the monitored period no canal overflow was observed. From the monitored period twelve orange and nineteen yellow alerts were observed. The link between these alerts and the its precipitation characteristics was made taking into account 5 rain stations, which influence the Ressaca Catchment. The spatial distribution of the precipitation was evaluated according to Thiessen Polygon method. Table 1 presents, in chronological order, such events, containing the following characterization: event number, event date (Date), Rain gauge stations (Station), event duration in minutes (D min), event rainfall height, in millimeters (Pcum mm), average rain intensity in millimeters per hour (I mm/h), maximum water level in centimeters (water level cm), peak level time (Time), rainfall height until the alert in millimeters (Pcum alert mm) and event duration until the alert in minutes (D min). It was noted that for most events the alert occurred before the end of the rain event. In the column water level the highlighted colors represent the alert level. For same events the rain gauges were not available for the 5 stations; in that case the data of these stations were not taken into account.

Table 1: Monitored events data

Event	Date	Station	D (min)	$P_{cum.}$ (mm)	i (mm/h)	Water Level (cm)	Time	$P_{cum. Alert}$ (mm)	D_{Alert} (min)
1	11/10/11	14	30	17.2	34.4	289	16:20	16.8	30
		15	30	13.2	26.4			13.2	30
		16	30	11.4	22.8			11.4	30
		19	30	20.6	41.2			20.2	30
2	14/11/11	14	160	20.8	7.8	283	21:00	12.8	40
		15	160	24.0	9.0			14.0	40
		16	110	23.6	12.9			17.6	40
		19	110	33.0	18.0			28.0	40
3	01/12/11	14	10	5.6	33.6	224	15:50	5.6	10
		15	20	10.8	32.4			10.8	20
		16	20	5.2	15.6			5.2	20
		19	10	5.0	30.0			5.0	10
4	02/12/11	14	140	23.6	10.1	227	12:50	12.8	30
		15	50	15.2	18.2			10.2	30
		16	110	17.8	9.7			16.0	30
		19	90	21.6	14.4			18.2	50
5	05/12/11	14	90	41.0	27.3	247	19:30	36.0	60
		15	60	19.2	19.2			13.6	40
		16	70	11.8	10.1			11.8	70
		19	40	5.0	7.5			5.0	40
6	10/12/11	14	70	17.8	15.3	253	14:50	15.0	50
		15	70	15.6	13.4			13.6	50
		16	70	17.4	14.9			15.4	50
		19	70	14.8	12.7			12.6	50
7	15/12/11	14	230	48.6	12.7	319	7:50	22.6	160
		15	230	46.8	12.2			32.8	160
		16	220	48.4	13.2			37.2	160
		19	230	52.0	13.6			33.6	170
8	26/12/11	14	190	31.6	10.0	324	22:30	24.8	140
		15	180	30.4	10.1			25.4	140
		16	180	31.8	10.6			28.0	150
		19	310	56.2	10.9			52.6	270
9	27/12/11	14	130	50.8	23.4	494	21:20	38.6	30
		15	130	49.4	22.8			37.2	40
		16	140	65.8	28.2			52.6	40
		19	120	40.0	20.0			28.8	40
10	30/12/11	14	80	36.2	27.2	247	19:20	35.2	70
		15	100	8.2	4.9			7.2	70
		16	70	16.4	14.1			13.0	30
		19	10	1.6	9.6			1.6	10
11	26/01/12	14	50	15.8	19.0	264	20:10	2.2	10
		15	60	22.2	22.2			17.0	20
		16	30	2.8	5.6			2.8	30
		19	10	1.6	9.6			1.6	10
12	29/01/12	14	120	24.4	12.2	398	19:30	22.0	90
		15	120	41.4	20.7			40.0	90
		17	110	18.2	9.9			15.4	90
		19	90	37.6	25.1			37.6	90
13	30/01/12	14	60	33.4	33.4	430	20:40	21.8	30
		15	40	34.0	51.0			30.0	30
		17	40	18.6	27.9			16.8	30

		19	50	41.4	49.7			40.6	40

Table 1: Monitored events data (continuation)

Event	Date	Station	D (min)	$P_{cum.}$ (mm)	i (mm/h)	Water Level (cm)	Time	$P_{cum. Alert}$ (mm)	D_{Alert} (min)
14	10/02/12	14	40	3.0	4.5	230	15:50	3.0	40
		15	30	7.6	15.2			7.6	30
		17	40	11.4	17.1			11.4	40
15	11/03/12	14	30	2.6	5.2	234	19:50	1.2	10
		15	30	5.0	10.0			5.0	30
		17	140	33.4	14.3			17.6	30
		19	20	4.4	13.2			4.4	20
16	15/03/12	14	180	57.4	19.1	227	17:50	35.8	30
		15	30	27.4	54.8			27.4	30
		16	0	0.0	0.0			0.0	0
		17	150	31.2	12.5			11.6	40
		19	20	1.6	4.8			0.0	0
17	23/03/12	14	40	13.2	19.8	260	9:50	12.6	30
		15	60	18	18.0			17.2	50
		16	60	16.8	16.8			15.0	30
		17	70	19.6	16.8			17.8	40
		19	110	10.6	5.8			8.8	80
18	25/03/12	14	50	18.4	22.1	311	17:50	17.4	40
		15	70	20.0	17.1			18.6	60
		16	200	35.4	10.6			22.8	60
		17	50	5.4	6.5			5.4	50
		19	110	30.6	16.7			29.8	100
19	28/03/12	14	100	37.0	22.2	289	22:20	32.8	100
		15	190	17.4	5.5			10.6	90
		16	190	48.2	15.2			30.6	100
		17	170	49.8	17.6			32.8	90
		19	20	10.4	31.2			10.4	20
20	15/11/12	14	100	47.2	28.3	422	18:50	31.8	30
		15	100	49.0	29.4			34.2	30
		16	100	33.0	19.8			21.2	30
		17	80	27.2	20.4			16.2	20
		19	100	42.6	25.6			26.2	30
21	03/12/12	14	50	14.8	17.8	361	17:20	8.2	30
		15	70	50.6	43.4			46.0	50
		16	60	26.0	26.0			24.8	50
		17	50	23.8	28.6			21.8	40
		19	70	33.6	28.8			33.6	70
22	10/12/12	14	60	59.8	59.8	396	18:30	54.0	40
		15	40	33.2	49.8			31.8	30
		16	40	33.6	50.4			13.4	20
		17	50	19.4	23.3			5.6	10
		19	30	19.6	39.2			17.6	20
23	12/12/12	14	30	5.6	11.2	263	12:10	0.0	0
		15	60	9.8	9.8			5.6	10
		16	20	1.2	3.6			0.0	0
		17	30	1.4	2.8			0.0	0
		19	70	30.0	25.7			26.2	40
24	02/02/13	14	160	43.0	16.1	379	19:00	36.4	80
		15	160	50.0	18.8			41.4	70
		16	190	62.4	19.7			54.8	100
		17	190	66.2	20.9			58.8	100

		19	180	64.0	21.3			54.6	90

Table 1: Monitored events data (continuation)

Event	Date	Station	D (min)	$P_{cum.}$ (mm)	i (mm/h)	Water Level (cm)	Time	$P_{cum. Alert}$ (mm)	D_{Alert} (min)
25	27/02/13	14	70	18.4	15.8	344	17:20	16.8	60
		15	70	26.2	22.5			25.4	60
		16	60	30.6	30.6			30.6	60
		17	60	19.0	19.0			18.4	50
		19	50	25.0	30.0			25.0	50
26	08/04/13	14	70	35.4	30.3	398	14:40	28.4	50
		15	90	34.8	23.2			29.0	60
		16	70	43.6	37.4			39.4	40
		17	40	35.6	53.4			35.6	40
		19	30	12.6	25.2			9.2	10
27	30/11/13	14	120	25.6	12.8	401	16:40	16.2	30
		15	100	31.6	19.0			23.4	40
		16	110	32.6	17.8			26.4	50
		17	110	33.0	18.0			26.6	40
		19	120	57.0	28.5			49.8	60
28	06/12/13	14	40	23.2	34.8	415	2:20	20.8	20
		15	40	26.2	39.3			24.8	30
		16	40	21.4	32.1			20.2	30
		17	40	23.4	35.1			21.6	30
		19	40	31.4	47.1			31.4	40
29	07/12/13	14	150	43.4	17.4	443	17:40	32.6	40
		15	130	47.8	22.1			31.4	30
		16	160	72.2	27.1			58.6	40
		17	150	69.4	27.8			57.2	40
		19	140	37.4	16.0			22.4	30
30	11/12/13	14	330	81.8	14.9	459	18:40	25.8	20
		15	360	52.2	8.7			12.4	20
		16	320	69.2	13.0			25.4	20
		17	320	67.4	12.6			28.4	20
		19	380	61.0	9.6			21.0	60
31	22/12/13	14	140	43.4	18.6	354	23:00	35.4	80
		15	140	35.8	15.3			29.6	80
		16	90	16.6	11.1			13.6	60
		17	80	19.4	14.6			16.0	50
		19	80	24.8	18.6			18.2	40

With the goal of understanding the events in their temporal distribution and the catchment response, graphics were prepared for all events, as shown in Figure 5 the graphic related to the event 24, occurred in 02feb2013 and in Figure 6 the event 29, occurred in 07dec2013. Both events were plotted with the mean precipitation in the 5 stations in every 10 minutes, the water level recorded, and alert levels.

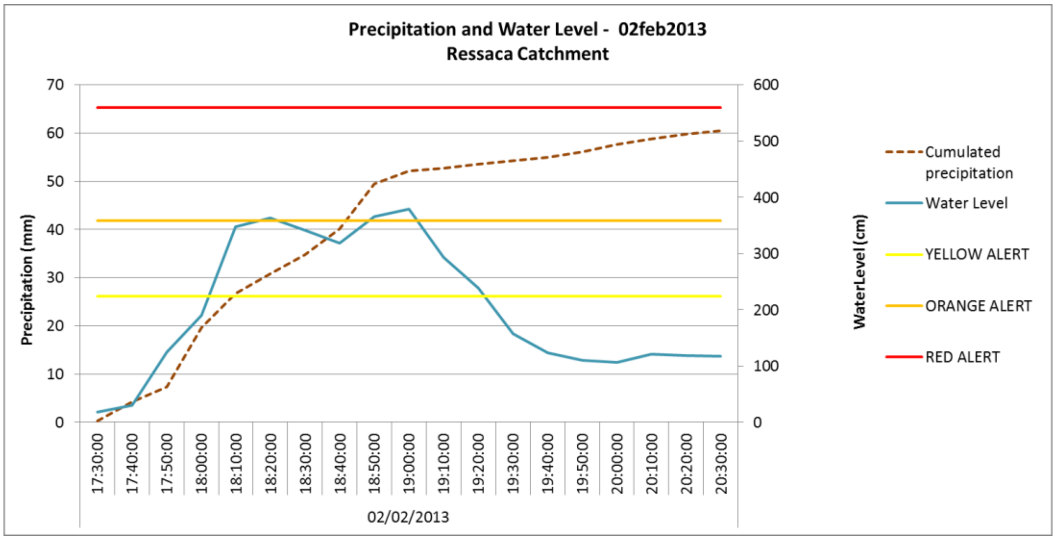

Figure 5: Event 24 – water level and precipitation heights

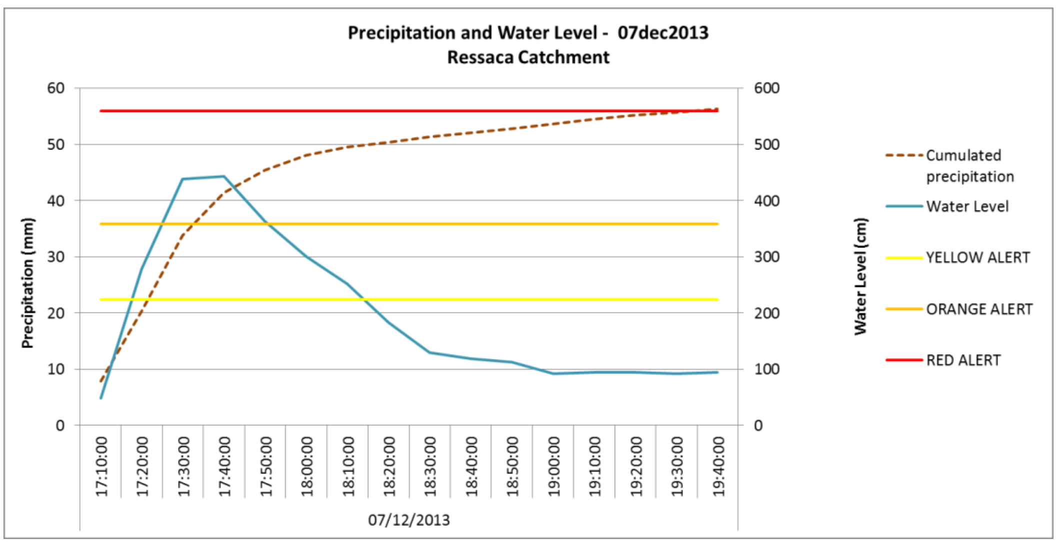

Figure 6: Event 29 – water level and precipitation heights

To evaluate the recorded data against the Risk Chart, the selected events were analyzed considering as representative of the events the arithmetic means of the rain duration until the time of the alert (shown in table 1) and the weighted average of the rainfall obtained through the Thiessen Polygon method of the data stations with available data. The data of the thirty one events observed were plotted on the Risk Chart for the Ressaca Catchment, as shown in Figure 7.

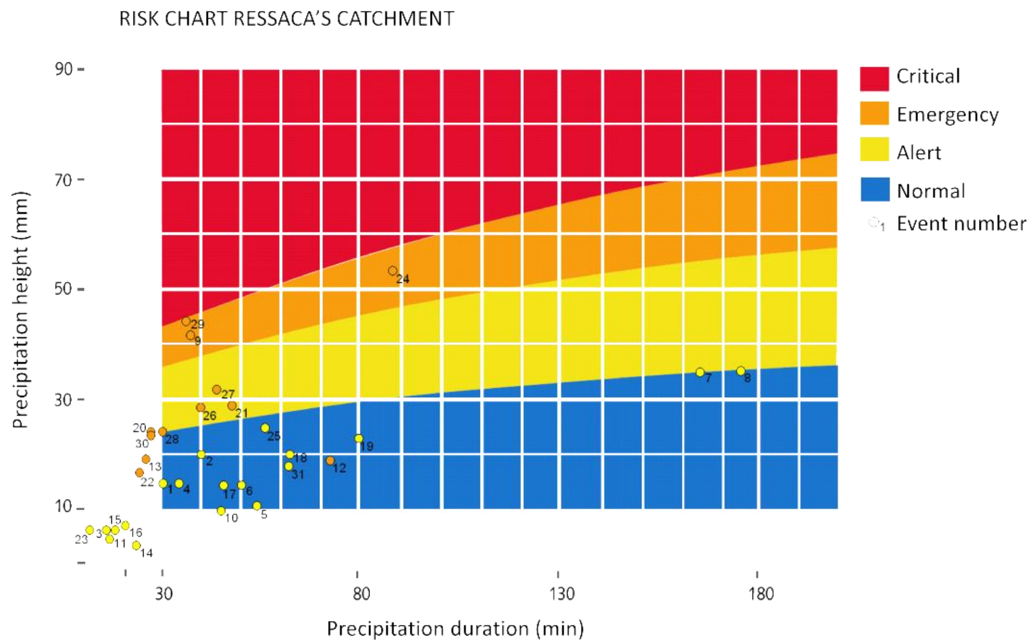

Figure 7: Risk chart for the Ressaca's catchment with the monitored data inserted

It should be noted that the colors corresponding to the alerts in the two methodologies are not coincident, except for the red alert, which corresponds to the channel overflow. It can be observed that the events not validate the Risk chart. Most of the alerts are in the normal functioning according to the Risk Chart.

5. CONCLUSIONS

This paper presented an evaluation of the Risk Chart of Ressaca catchment using rainfall events with monitored having at the same time water levels monitoring. On the thirty one events that generated flood alert, no overflow has been observed.

The Risk Charts are an important tool for issuing alerts in advance for the population living in areas at flooding risk. It is recommended that the validation of the Risk Charts for all the catchments with flood risk in Belo Horizonte must be performed from the observations collected so far and that as new data is being acquired Risk charts should be gradually improved. In addition, it is recommended the improvement of hydrological and hydraulic models of the municipality through the inclusion in these observed events, in order to calibrate those models.

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