**METEOROLOGICAL RADAR AND FLOOD FORECASTING**

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## 1. INTRODUCTION

The Aricanduva river basin is located in the east part of the city of Sao Paulo. Its area is approximately 100 km2 (figure 1). This basin presents serious problems related to floods mainly in its main course where there is an important avenue which cross the eastern part of city. Another important characteristic of this basin is the high river declivity leaving to flash floods, its time of concentration is around five hours but considering the rain distribution hard rains with less than two hours can cause tremendous impacts in the traffic and in the surround areas. In the last rainy season between October 2002 and March 2003 more than ten flash floods occurred in this basin causing enormous economic losses.

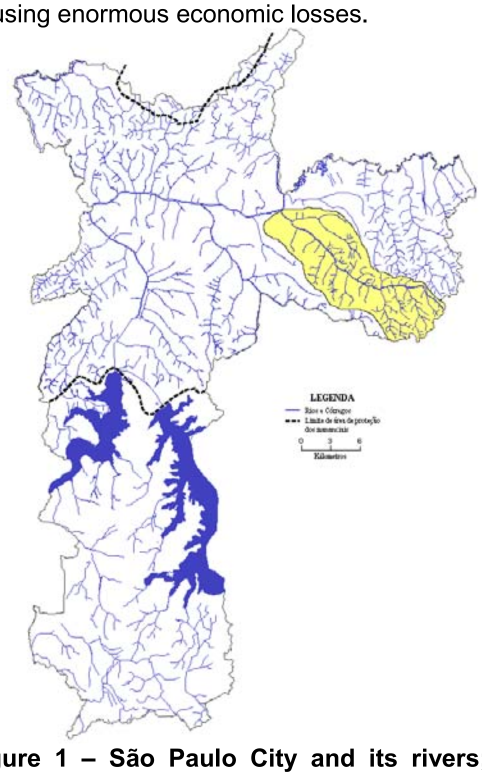


**Figure 1 – São Paulo City and its rivers; Aricanduva River Basin in yellow**

The São Paulo Flood Warning System (SAISP) (Barros et al., 1998) is a non structural measure for urban flood control. Its main objective is to minimize the negative impacts produced by the hard rains in risk areas, the Aricanduva River Basin is one of these areas. The SAISP system has two sources of real time hydrometeorological data: a meteorological radar and a telemetric network, both covering the Upper Tietê River Basin. This data set is used in many models to forecast rainfall and floods in many São Paulo areas. The forecast information is distributed to the users by internet. One important user is the São Paulo City Hall staff. This office is in charge of the traffic control and other civil works to support the population in risk situation. The traffic company (CET) can deviate the vehicles from flood areas and sometimes they closed part of the avenues and streets to protect the population.

## 2. THE MODEL MOPEH – HYDROLOGICAL STATES

The MOPEH model (SN, 1996) is used by the SAISP system to forecast floods. The model runs every tem minutes and forecasts floods for the next three hours considering time intervals of five minutes. MOPEH establishes different hydrological states for each element of a 2 km by 2 km grid covering the city of São Paulo. There are three different hydrological states: normal, attention and alert. Depending on the hydrological state a set of field activities is conducting by the civil defense and other municipality agencies. MOPEH uses an empirical algorithm base on the observed rainfall (present and accumulated precipitation) and nowcasting produced by the meteorological radar.

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Table 1 presents the hydrological situations and its description

**Table 1 – Hydrological State – MOPEH Model**

| Hydrological State | Description |
|---|---|
| **Normal** | Accumulated precipitation and the nowcasting do not forecast floods |
| **Attention** | Accumulated precipitation and the nowcasting forecast the possibility of flood occurrences in the next three hours |
| **Alert** | Accumulated precipitation and the nowcasting forecast high possibility of flood occurrences in the next three hours |

MOPEH has two modules, one for the micro drainage system and other for small channels and rivers, called macro system module. The micro drainage model forecast floods in areas where there are local hydraulic problems, mainly areas with old sewer systems. Rains with high intensity and short duration, convective storms for example, can produce flash floods in these areas. The macro problems appear when moderate to hard rains occur. This paper deals with the micro module, more critical for the Aricanduva basin and more critical to forecast due to the short time period involved. The experience along the years showed that for this kind of problem it is crucial to compare the present rainfall with critical values linked to return periods (Tr). Considering this condition the hydrological state is established comparing the observed rainfall with the critical indexes.

For each cell (2 km by 2 km) MOPEH model calculates the hydrological state considering the following steps:

(a) Translation Model forecasts the rainfall for the next three hours in 10 minutes time steps (P10(t), t=1,18);

(b) Compares each (P10(t), t=1,18) value with the following limits:

Pat(t) = Patmin+ (t-1).(Patmax - Patmin)/18 (1)

Pal(t) = Palmin + (t-1).(Palmax - Palmin)/18 (2)

These equations can be simplifying by:

Patmax = Palmin = P I0Tr (3)

Patmin = (1- 0,33) . P10Tr (4)

Palmax = (1 + 0,33) . P10Tr (5)

where: P 10Tr is the Tr 10 minutes rainfall, Tr (years) return period.
The limits are calculated using the São Paulo Rainfall Equation given by:

For rainfall between 10 minutes ≤ t ≤ 60 minutes:

$$\mathbf{i_{t,T} = 37{,}05\,(t+20)^{-0,914} + (t+20)^{-0,914} \cdot [-5{,}966 - 10{,}88\ \ln\ln (T / T-1)]} \quad (6)$$

where

i: intensity (mm/min), t: duration in minutes and Tr: return period in years.

c) defines hydrological state by: alert if at least for one block P 10(t) > Pal(t); attention if at least for one block P 10(t) > Pat(t); if not normal;

d) repeat the algorithm for the last 20 minutes rainfall;

e) repeat the algorithm for the last 30 minutes rainfall;

f) the hydrological state is the more critical one (10, 20 or 30 minutes rainfall).

***2.1 Critical Indexes***

Critical Indexes for each area is estimated in function of the return period (Tr) of the precipitation. Tr is the inverse of the probability of a certain hydrological event to be equalized or exceeded in any year. Precipitation is a random phenomenon and so Tr is the average number of years that the linked precipitation can be equalized or exceeded.

$$Tr = \frac{1}{p} \qquad (1)$$

p = probability

Table 2 shows the relationship between Tr and the critical indexes. The indexes are equal to 100 times the return period.

**Table 2 – Return Period, probability and Critical Indexes**.

| Tr | P | $N_{critico}$ |
|---|---|---|
| **1,11** | 0,9 | 90 |
| **1,25** | 0,8 | 80 |
| **2** | 0,5 | 50 |

| | | |
|---|---|---|
| **3** | 0,33 | 33 |
| **4** | 0,25 | 25 |
| **5** | 0,2 | 20 |
| **6** | 0,17 | 17 |
| **7** | 0,14 | 14 |
| **8** | 0,13 | 13 |
| **9** | 0,11 | 11 |
| **10** | 0,1 | 10 |

$N_{crítico}$ = critical index

$N_{crítico}$ = p*100 (2)

The model uses return periods between 1.1 and 10 years. With these critical indexes is possible to define empirically the flood probability for a certain area. To point the critical values for the areas is important the experience of the hydrologist and the quantity of observed data.

The indexes were calculated based on the observed floods occurred in two rainy seasons 1997/1998 and 1998/1999. Figure 2 shows the indexes for the Aricanduva Basin considering the grid defined by the meteorological radar (2 km by 2 km). Yellow and green areas are more sensitive to high intensity and short time rains (convective storms). In the last season (2002/2003) more than 10 critical events were observed in the yellow and green areas.

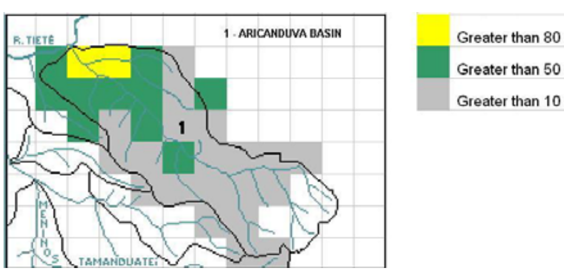


**Figure 2 – Aricanduva Basin, the radar grid (2 km by 2 km) and the critical indexes**

## 3. NOWCASTING RAINFALL MODEL (TRANSLATION MODEL)

The Translation Model was proposed by Shiiba et al. (1984) and Takasao and Shiiba (1985). This model was been used by the SAISP for short time rainfall forecasts. The model calculates the track vectors for each (x,y) component of the radar grid using a linear approach. It considerates not only the velocity component but rotation, deformation and the cell evolution. The model assumes in time the continuity equation for the horizontal rainfall distribution r(x,y,t):

$$\frac{\partial r}{\partial t} + u\frac{\partial r}{\partial x} + v\frac{\partial r}{\partial y} = w$$

(2)

In this equation (u,v) is the velocity vector (translation) in the (x,y) direction and w is the rate of evolution-decay, or the cell increasing or decreasing size along of its movement. Beyond that the model considerates linear variation for u, v and w in the (x,y) directions: $u(x,y) = c_1x + c_2y + c_3$;$v(x,y) = c_4x + c_5y + c_6$;

$w(x,y) = c_7x + c_8y + c_9$ (3)

where, c1,...,c9 are estimated parameters.

## 4. OBSERVED EVENTS IN THE ARICANDUVA BASIN

Ten events were analyzed to evaluate the model performance. Following one event is presented. In this event the floods were caused by sewer problems. The meteorological analyze is also presented.

### *4.1 November 11, 2002 Event*

This event was produced by a convective storm. The Goes-8 image (figure 3) time 18:10 GMT (-2h local time, during summertime) shows the city of São Paulo (eastern part of the State of São Paulo), a high cloud nucleus can be observed, with clear gray in its top. In the radar image – CAPPI - 18:37 GMT (figure 4) can be observed some intense rainfall nucleus mainly in the Aricanduva area. Convective storms are generally formed by intense and short time rains covering small areas.

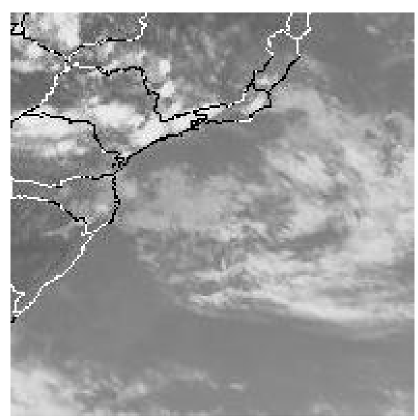

**Figure 3 – Góes-8 Image 18:10 GMT.**

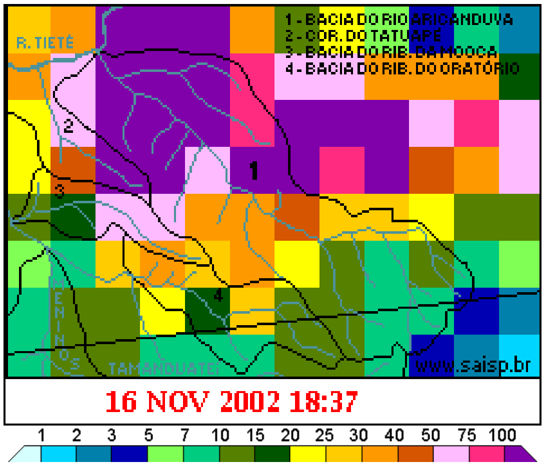


**Figure 4 – Radar CAPPI, 18:37 GMT, and its scale in (mm/h).**

### *4.1.1 Observed Floods*

This day five areas suffered floods. These areas cover three pixels in the radar grid.. Figure 5 shows these areas.


**Figure 5 – Floods in November, 16th, 2002. (CET)**

The first flood occurred at 18:34 GMT. The avenue in this area was completely covered by water and the traffic stopped until 19:15 GMT.

### *4.1.2 MOPEH Performance*

At 18:07 GMT the MOPEH model indicated alert state in one of the pixels. At 18:12 GMT all pixels were in alert state. This means that one hour before the floods the model was indicating emergency situation in the red areas. Figures 6 and 7 show the MOPEH maps for this day.

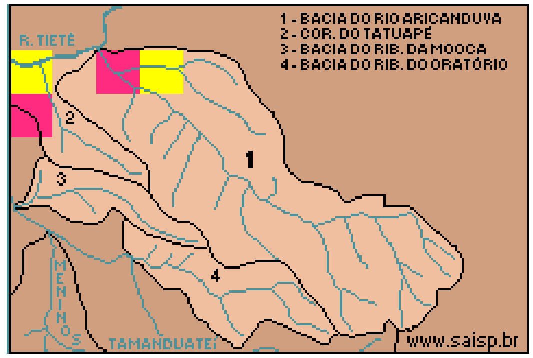


**Figure 6 – MOPEH Map - image 18:07 GMT**

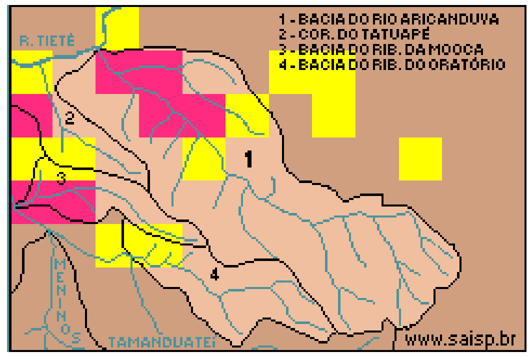


**Figure 7 – MOPEH Map - image 18:12 GMT**


It is important to point out that a forecasting done one hour ahead for a convective storm is really satisfactory due to its meteorological characteristics, high intensity and short duration. Another constraint for the São Paulo Meteorological radar is its technology, it is not a Doppler radar.

## 5. FINAL COMMENTS

The Aricanduva Basin is a very important area in the city of São Paulo. It covers part of its eastern region. It is a risk area due to the summertime floods. The SAISP alert system has reduced its economic losses mainly the one produced by the interruption of the traffic. The SAISP system covering this area produces rainfall and flood forecasts with good performance. MOPEH model can be used to established hydrological states in rainy days. Although the MOPEH has a simply methodology it performs very well for convective storms. This result confirms previous experiences that show the gap between real time sophisticated models and its performance in real time systems. In real time operation when you have many sources of errors simply models performs very well. It is more important a simply scheme that can be operated in a fast decision support system with many real time data than a sophisticated model with many parameters and not easy to run in short time.

## 6. REFERENCES:


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