FLOOD FORECAST QUICK MODELING

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ABSTRACT: The aim of this project is to provide a quick tool for water level variation forecasting and early warnings at telemetric river gauges supporting Civil Defense activities. Its use is meant for river basins with natural flow patterns under the coverage of meteorological radar and no hydrological forecasting available.

Key Words: Flood Management, Flood Early Warning, Forecasting, Geoprocessing, Runoff.

1. INTRODUCTION

This article presents a quick modeling tool used at watershed within the state of Rio de Janeiro, Brazil. The modeled basins have contribution areas from 35 to 7200 km² and flood waves with occurrences varying from hours to several days. The goal is to predict the sign of the water surface inclination, whether it is positive (ascending) or negative (descending), for a specific period of time. This parameter is very robust and it maintains itself stabilized even with the interferences caused by the strong simplifications adopted by the present model. This information is very useful for the Civil Defense logistic operation crew. The modeling approach does not consider the hydrograph partition (subsurface and underground flows) as all precipitation flows to the rivers. Hence, the hydrograph generated does not represent the level or flow properly. On the other hand, flood wave phase delivers a realistic result, thus enabling forecasts of the rise and fall of the river surface.

2. METHODOLOGICAL APPROACH

The Quick Modeling essentially calculates the isochrone lines at the watershed using the Time Histogram / Geoprocessed Area (HTA-Geo). From there, the precipitation occurred in each isochrone is fully stored and used for the construction of the basin hydrograph. A detailed description of the construction of Geo-HT can be found in Maziero (2010). The layers used are: synthetic hydrology, native vegetation, urban areas and other relevant land uses.

2.1 Steps Towards Buiding The Model

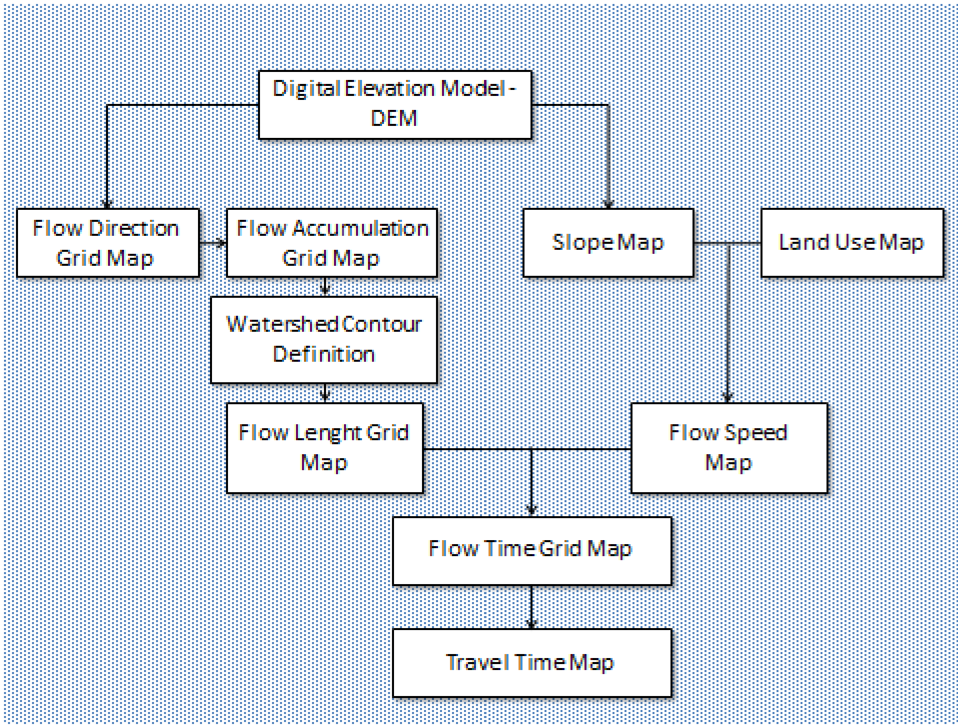

Figure 1: GIS Data Flow Disposure

2.2 Model Components

The model has the following components:

2.2.1 Precipitation field

It was provided by weather precipitation radar data (INPE, 2013). Although not as accurate in quantifying the rain as a traditional rainfall station, the radar provides the precipitation field of the whole area of interest. As the parameter of interest is the phase of the flood wave, it does not require high accuracy rain measurements, and by the use of a spatialized radar field, it makes this a more relevant source.

2.2.2 Watershed contour definition

As an essential ingredient of this process, we used the DEM (Digital Elevation Model) derived from SRTM data, made available through the NASA (JPL, 2013) widely used for generation of altimetric cells compatible with a resolution of approximately 90 x 90 meters. The watersheds were captured by the use of selected fluviometric stations – represented by geo-referenced geographical points – superimposed on a map of accumulated flow. The map of cumulative flow – generated from the flow direction operation and the DEM – allowed individual pixel counts that accumulate along its trajectory to the outlet, thus formalizing the design of the basin, as well as its total area of contribution

2.2.3 Slope maps and land use

In order to construct a flow length map of the basin , both slope and land use maps were needed. First, with the limits of the watershed already known and the elevation model, a map of slopes was constructed, defining slope classes ranging from 2% to 75%. Next, for the land use map, three classes were defined: forest, pasture, urbanization, and hydrography.

The first class assigned (the hydrograph), had all its drainage networks defined from the cumulative flow map, adopting a standard of a minimum 2500 receptor flow cells to be computed in the hydrograph class.

Hereinafter, the class "forest" was obtained from a generalized classification made in PROBIO mapping project (MMA, 2007), while for the "urbanization" class, we used a mapped urban network census data conducted by IBGE Census data (IBGE, 2007), as well as a visual interpretation based on a mosaic of CCD images CBERS 2B. These images were obtained from the webpage of the National Institute for Space Research (INPE, 2013). Finally, the class "pasture" was assigned by elimination, considering all the remained areas not classified in the previous classes. This was done in order to reduce the number of variables in the process of calibration and it was possible due to the simplified landscape found in the country side of the state of Rio de Janeiro.

The final land use map classification was generated overlapping hydrography, urbanization, forest and pasture in this order of priority of exclusion (Figure 2).

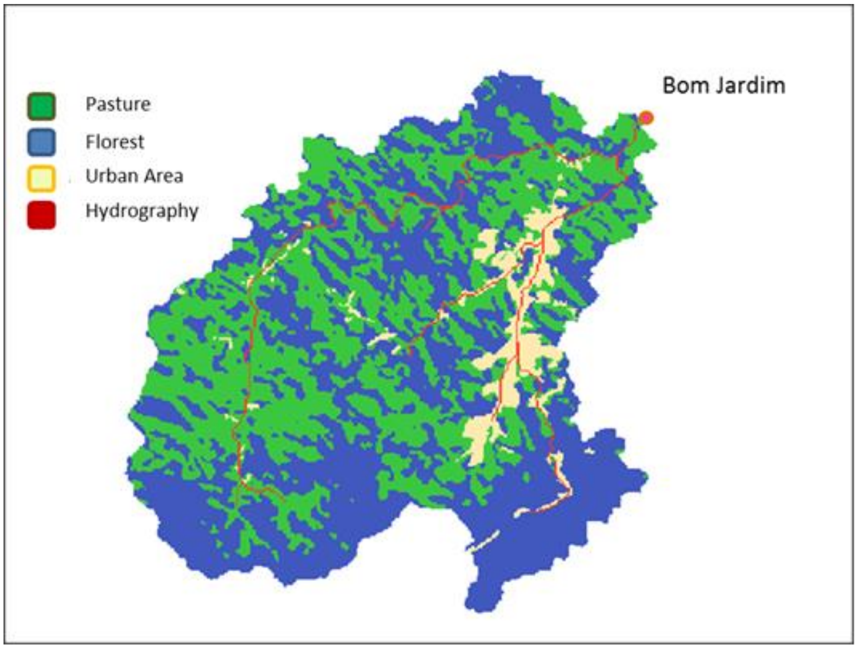

Figure 2: Land Use Map of Bom Jardin´s Watershed

2.2.4 Flow speed estimate

Using raster algebra, we applied the Upland's formula (HDM, 2006) by multiplying its empirical land use coefficients (Table 1) and the squared root slope maps we generated, generating estimates of flow speed from each cell of the basin.

$$V = k\sqrt{d} \quad [1]$$

where V [m/s] is the cell´s flow speed, k is a constant which depends on the type of soil coverage, and d [%] is the slope

Table 1: Land use coefficients

Land use type	k coefficient
forest with many leafs on the soil	0,076
pasture or low grass	0,213
urban - paved surface	0,610
river - natural channel - hydrography	0,457

2.2.5 Concentration time estimate

Having the flow speed value for each cell, and using the "flow length" tool from the GIS software Arc Gis 9.3, we´ve calculated the traveling time from each one of the cells of the basin to the outlet. The longest trip of the basin is defined as the concentration time of the basin.

Travel times were calculated for each 90 x 90m cell. The map was then re-sampled to 1km cells in order to match the resolution of the precipitation field and, at the same time, reducing by 98,4% the processing time of the original model.

2.2.6 Precipitation field estimate

The precipitation radar data for the Pico do Couto station (lat. 22 ° 27'51 "S, long:. 43 ° 17'50" W; alt:. 1771.94 m, maximum range: 250km; resolution: 1km) (INPE, 2013) was collected for the period from 01/25/2012 to 02/02/2012, and then converted to a raster format, by nearest neighbor interpolation, keeping the original resolution of data to be finally clipped to the boundaries of the study areas.

2.3 Model Calibration

It is important to note that the Upland's formula is an empirical formula and presents better results in places where it was developed. For this reason, the values in Table 1 should be taken as a starting point, but allows changes until it reaches satisfactory results.

The density of the synthetic hydrography is an important factor for the Quick Modeling calibration, as seen on Figure 3.

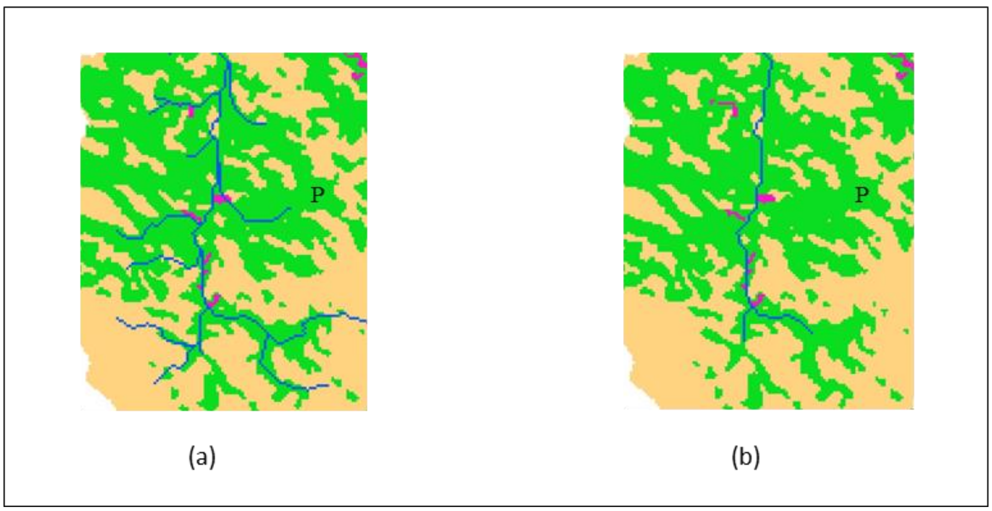

Figure 3: Variation of the synthetic hydrography density

Figure 3 illustrates the difference between the absence of a minimum number of cells receiving the stream flow to the drainage count (a) and the presence of a minimum of 2500 receptor cells (b). For a precipitation occurred at point P, after traveling on a land cover for a short distance (a), the flow encounters a natural channel. In case (b), the contribution of the rain should go a much greater length to reach the channel.

In the first situation, the influence of pasture cover is not as relevant as a shorter path does not significantly contribute to the calculation of travel time from the point "P". The adequate number of receptor cells used for the construction of synthetic hydrography can be quickly established after some test values, thus allowing the coverage of land use to impact, as indeed they do, the values of travel time for each cell of the basin. Quick Modeling ignores the dispersion mechanisms of the flood wave and, except for the estimate of speed, where frictional forces are embedded in the coefficient k, all other processes are ignored. Each element of the time hydrograph built is the simple sum of the basin isochronous contributions. For this reason, you should not concentrate efforts in getting a precise calibration of the resulting hydrograph, giving the risk of over calibrating the model for a particular event. Over calibration also implies in the loss of real physical meanings from calibrated variables. The sign of the variation of the water line proved to be very robust prevailing through the strong simplifications of the model. Nevertheless, its temporal precision should be assessed by the local Civil Defense operation team for every individual water basin case, in order to check its appropriateness for the regional logistics needs.

3. CASE STUDIES

The following presents the application of Quick Modeling in different contribution areas and hydrological conditions. The frequency of measurements and simulations is hourly. The stream flow data used to check the results of modeling comes from a warning system developed from the state of Rio de Janeiro Environmental Institute – INEA, RJ. It is important to keep in mind that the river water levels are compared with the output of Quick Modeling (which is basically the flow rate due to the precipitation ocurred passing through the outlet of the modeled basin). For this reason, the modelled values from the ordinates are multiplied by a constant which enables visualization of comparative curves.

The basin that contributes to Vendas das Pedras fluviometric station is located at the Córrego Dantas district of Nova Friburgo and has 33 km². The coefficients that differ from Table 1 are kpasture = 0.153 and kforest = 0.333, corresponding to the prevailing coverage in the basin. The highest elevation of the peak from its initial quota was 2.0 meters.

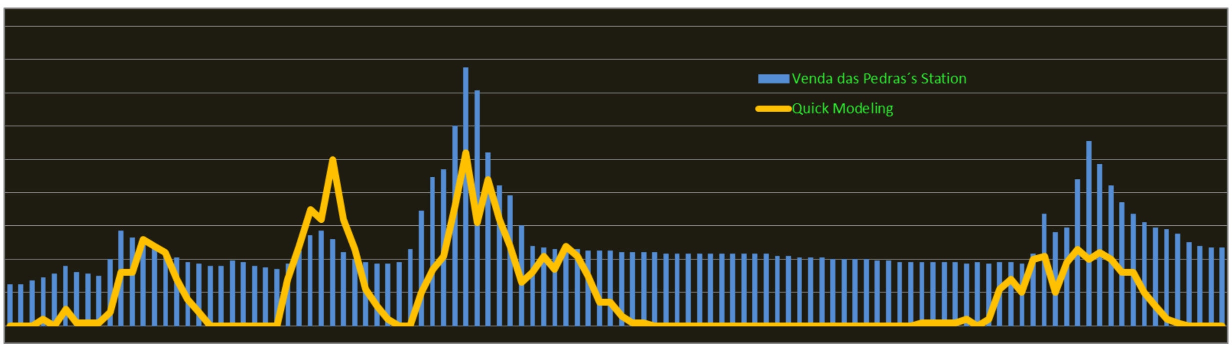

Figure 4: Venda das Pedra station

The Suspiro fluviometric station (Figure 5) is located downtown in Nova Friburgo and just downstream of the confluence of the San Antonio River. This river forms a long and narrow basin with the presence of the Atlantic Forest, while the Cônego river, whose headwaters is located in a fan-shaped urban watershed, is naturally prone to torrents. The basin that contributes to the Suspiro fluviometric station is 93 km² and the coefficients used were the references of Table 1. The largest variation of the water line was about 2.5 meters.

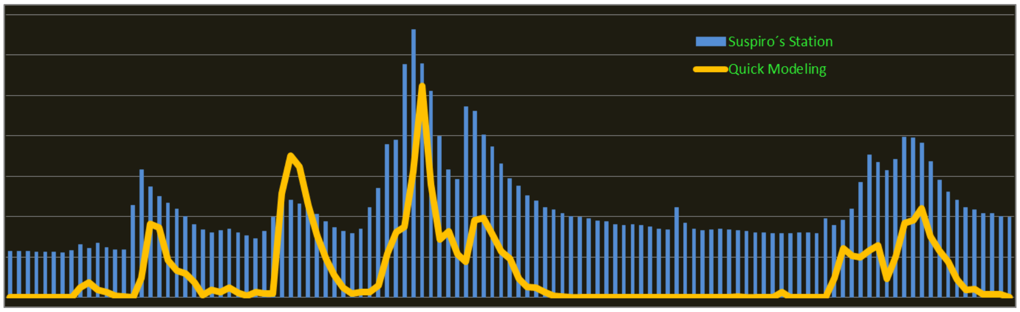

Figure 5: Suspiro station

Banquete fluviometric station (Figure 6) is located in Bom Jardim downtown area, just downstream of the confluence of the Rio Grande and São José. The basin has an area of 485 km². The model was calibrated with the values in Table 1. The largest variation of the water line was 2.5 meters.

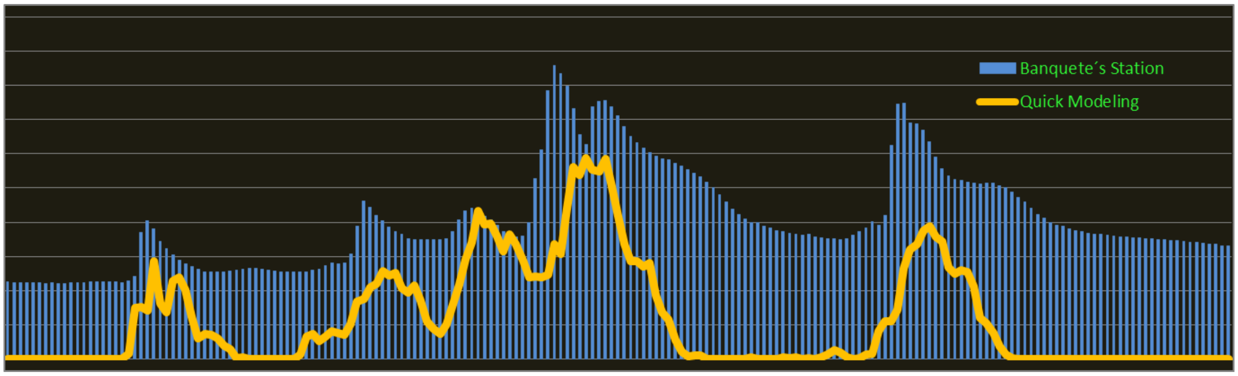

Figure 6: Banquete station

The fluviometric station of Lajé do Muriaé (Figure 7) is located at the downtown area of Muriaé, which accounts for a total of 3137 km² upstream the area. The coefficients that, in this case differs from Table 1, are kpasture = 0.153 and = 0.400 kriver. The largest variation of the water line was 1.4 meters.

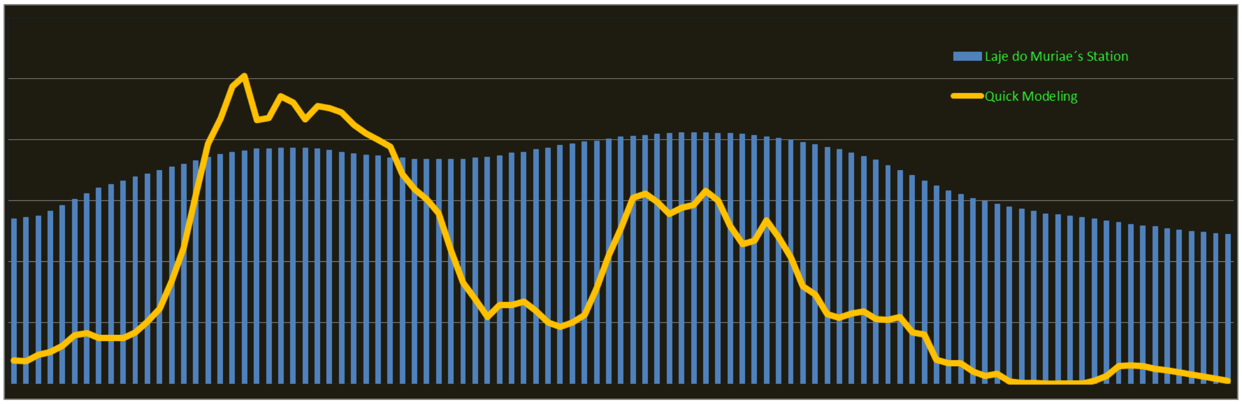

Figure 7: Laje de Muriaé station

The Cardoso Moreira station (Figure 8) is located at the center of the town of Cardoso Moreira, receiving an upstream contribution of 7209 km². The kriver coefficient was adapted from the references on Table 1 and set to 0.380. The largest variation of the water line was 1.0 meters.

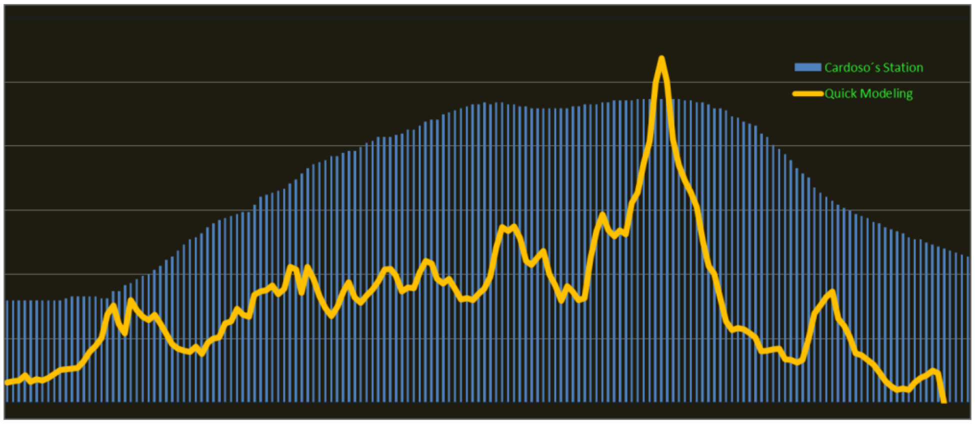

Figure 8: Cardoso Moreira station

4. FINAL COMMENTS

In the examples above we noted that the Quick Modeling has presented good results either in the large variation in the size of the watershed areas (35-7200 km²), as in the small variations in the water line (as seen in Cardoso Moreira - 1.0 m). It is important to stress that the parameter sought in this model is the sign of the variation of the water level and not its slope. This parameter has shown to be very robust overcoming the drastic simplifications made by the present modeling approach. We´ve also noticed that the smaller basins, with greater variation on the water line, the response of the model tends to follow the shape of the actual hydrograph.

Phase errors increase with the size of the water basin, but are compensated with a longer forecast horizon that the hydrological response of these basins provide.

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