Computer aided scheming of large flood plains using remote sensing data
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Abstract

The use of remote sensing data from satellite images is presently a wide world technique in the analysis of damage and dimensions of large flood plains. In large river basins with scarce hydrological and topographic data it is very difficult to accurately define the limits of flooded area from water levels and cartographic maps, as required to the mathematical modelling of flood propagation on a flood plain. This paper presents a methodology of analysis and scheming of flood plains using LANDSAT4 and 5 satellite images, which leads to the obtaining of the following information: the dimensions of the flooded area and their time evolution; the continuous distribution of the flood plain widths; the existence of non-flooded areas for different floods by superimposing two images; the potential lateral inflow/outflow using satellite sensor band that separates sediment laden flow (main channel) from clear water (flood plain flow). Those and other information were mathematically treated and used as input data for two kinds of flood plain models: a two-dimensional cell model and an one-dimensional one with lateral contribution. The methodology was applied to the basin of Upper Paraguay River, located in Brazil and presenting poor hydrological and topographic field data for modelling purposes.

1 Introduction

The accurate scheming of a flood plain is an important requirement for its mathematical modelling. This includes the correct delimitation of the flooded area and its classification as a storage plain and/or a dynamic one. In this
situation, the remote sensing may be used as a very reliable complementary tool for field measurements at places where access conditions are difficult or impossible, for instance dense rain forest areas. In this paper we search to show how satellite data may improve the mathematical modelling of large flood plains, using as case study the upper Paraguay river wetland area, known as Pantanal Matogrossense which is an important environmental system located in the southwest of Brazil.

2 Imagery Analysis Methodology

The scheming of a flood plain usually requires the combination of detailed topographic surveys with a dense network of water level data, providing information about flooded areas and inundated widths. The density of level gauges is more important in dynamic flood plains due to the large level gradient observed in the flood propagation. In the upper Paraguay river basin the water level information is scarce and the best existing chart scale is of 1:100,000 m with topographic level curves spaced each 50 m.

The use of remote sense data is possible in this flood plain because of its dimensions (about 1,000 km long and widths running from 5 km up to 180 km) and its large average complete flow time (5 to 6 months). The case study area and its location in South America and Brazil is shown in figure 1. The above mentioned properties of the area under study are compatible with satellite image resolution and frequency. The figures 2 to 5 show the upper Paraguay river flood plain in the areas near to the river channel. The figure 2 is a combination of topographic chart with level meters and its drawing had been possible because of the better data acquisition system in the upper river stretch. The figures 3 to 5 were made from satellite overlay scanning. The analysis of these figures has provided useful information and data for the choice of the mathematical models to be used in the simulation.

3 Mathematical Modelling

According to Cunge [1], there are four types of flood plains scheming for modelling purposes:

. One-dimensional model with water flowing across the entire valley section, assumed as being a compound section.

. One-dimensional model with a main flow section and the flood plain simulated as a storage zone. The water level is assumed constant over the entire section.

. The same model above, but with different water elevations in the flood plain and in the main channel. The exchange process between them is simulated as a weir type link.
Two-dimensional model, where river and flood plain are simulated as a box grid describing flow and storage areas. The connections between boxes may be of channel and/or weir type links (e.g. Zanobetti et al [3]).

The analysis of the images presented in the figures 2 and 3 shows a two-dimensional flood plain, and so a cell model derived from the model proposed by Zanobetti et al [3] has been used (e.g. Mascarenhas & Miguez [2]). After an analysis of the very great flood plain size of the area shown in the figure 4 we propose, as a fifth type, a reservoir mathematical model for its flood plain modelling. This model, based on the well-known SSARR model (U.S. Army Corps of Engineers [4]), is presently being developed by the authors and will be subjected to a careful calibration procedure to correctly simulate the associated flooded area. The figure 5 otherwise shows a nearly one-dimensional flood plain, and the Saint-Venant equations, with lateral inflow \( q_L \) representing the river-plain discharge exchanges, were applied to.

In the two-dimensional cell model the continuity equation is combined with the dynamic one, neglecting inertia terms, and is written for a generic cell \( i \) as:

\[
A_{si} \frac{dz_i}{dt} = P_i + \sum_k Q_{i,k}
\]

where
- \( z_i \) - water surface level at the center of cell \( i \)
- \( A_{si} \) - free surface area of the cell for the water level \( z_i \)
- \( P_i \) - rainfall flow over the cell \( i \)
- \( Q_{i,k} \) - discharge between cell \( i \) and its boundary cells \( j \)

The reservoir type model is based on the general balance equation that describes the water balance inside a wide area, involving inflow, outflow and volumetric storage variation:

\[
\left( \frac{I_1 + I_2}{2} \right) \Delta t - \left( \frac{O_1 + O_2}{2} \right) \Delta t = V_2 - V_1
\]

where
- \( I_1, I_2 \) - inflow rate at the beginning and the end of time \( \Delta t \)
- \( O_1, O_2 \) - outflow rate at the beginning and the end of time \( \Delta t \)
- \( V_1, V_2 \) - storage volume at the beginning and the end of time \( \Delta t \)
The Saint-Venant equations for the one-dimensional model, supposing a storage width $B_s$, are:

$$B_s \frac{\partial h}{\partial t} + vB \frac{\partial h}{\partial x} + \nu \left( \frac{\partial A}{\partial t} \right)_{h=\text{const}} + A \frac{\partial v}{\partial x} - \frac{q_L}{B_s} = 0 \quad (3)$$

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial x} + g \frac{\partial h}{\partial x} - g(S_0 - S_f) = 0 \quad (4)$$

where
- $g$ - gravity acceleration
- $B$, $B_s$ - main channel and storage widths
- $h$, $v$ - dependent variables of flow depth and mean velocity
- $x$, $t$ - independent variables of space and time
- $S_0$ - mean bottom slope
- $S_f$ - energy line slope
- $A$ - main channel wetted area
- $q_L$ - lateral inflow/outflow

The continuity equations of the type (1) for all the cells in the model and the system of Saint-Venant equations (3) and (4) are separately solved by finite differences. So the first model is two-dimensional, with hydraulic laws of channel and broad crested weir flow types for the discharge exchanges $Q_{ik}$, and the third one is one-dimensional, while the second is a so-called hydrologic model. The water level results of the cell model for a selected flood are presented in the figure 6.

From the obtained spatial integration grid of the area shown in the figure 5, the Saint-Venant equations (3) and (4) were solved for all discrete sections and for each time step by the Preissmann implicit finite difference method. The figure 7 shows an example of the computed and measured discharge-time curves in the location named Fecho dos Morros. In that gauge section the flood is entirely confined between natural terrain elevations, and so this station can be considered as a very reliable water control for all the flood amount that actually leaves the inundation plain and an exact internal boundary condition for the mathematical simulation.

4 References


Figure 1: Location Map in South America of the Case Study Area
Figure 2: Upper Paraguay River Flood Plain - 1st stretch - From Cartographic Chart.

Figure 3: Upper Paraguay River Flood Plain - Partial Image of 2nd stretch - from Satellite Image of June, 1979.
Figure 4: Upper Paraguay River Flood Plain - 3th stretch - From July, 1979.

Figure 5: Upper Paraguay River Flood Plain - 4th stretch - From August, 1979.
Figure 6: Computed Flood Plain from the Cell Model for 1970 Flood - 1st stretch.

Figure 7: Computed and Observed Hydrographs of the 1979 Flood for the 4th Stretch from an One-Dimensional Model.