RECURRENCE PERIODS OF FLOODING ASSOCIATED TO TM DATA WITHIN THE PANTANAL, BRAZIL.

João dos Santos Vila da Silva
EMBRAPA- Empresa Brasileira de Pesquisa Agropecuária,
CPAP- Centro de Pesquisa Agropecuária do Pantanal.
Caixa Postal 109, 79300 Corumbá, MS, Brasil
Fax (067) 231-1430

Hermann Johann Heinrich Kux
INPE- Instituto Nacional de Pesquisas Espaciais.
Caixa Postal 515, 12201 São José dos Campos, SP, Brasil.
Fax (0123) 21-8743

ABSTRACT

Within the Pantanal, vegetation, wildlife and extensive cattle raising is adapted to the yearly flooding cycle. Quantitative information on the dynamics of flooding is extremely important for any self-sustained management of this region. In this context, using temporal series of hydrographs located at the rio Paraguai (Ladário) and at rio Miranda (Tição de Fogo), the recurrence periods of flooding for 5, 10 and 15 years were estimated. These recurrence periods were associated to the flooded area, obtained during the hydrological year 1989 with TM-Landsat images, data takes from april 9, 89; may 11, 89; june 12, 89; july 14, 89 and september 16, 89.

KEY WORDS: Hydrology, Remote Sensing, Pantanal, Flooding, Cattle raising management.

1. INTRODUCTION

1.1 Problem identification and literature review

The Pantanal is located at the Upper Paraguai basin, including territories from as well Brazil, Bolivia and Paraguai. within Brazil it has an area of 139,111 sq/km and is located beween coordinates S 16 to 22 and WGr 55 to 58, (Brasil, 1979).

This large floodplain is drained by the Upper Paraguai and several affluents, channels and creeks, that are determinant for periodical flooding with variable intensities, extension and annual/interannual water residence time. The region is characterized by an extremely low surface slope: 30-50 cm/km in E-W direction and 3-15 cm/km in N-S direction (Franco & Pinheiro, 1982), causing an extremely slow water flow.

The more detailed knowledge on water movement with this floodplain, considering thematic maps or forecast, is of fundamental importance for wildlife management and for cattle raising, the main economic activity of this region. This knowledge is of further interest for the analysis of fishery resources and for limnological studies. In this frame, this study aims to associate hydrologic parameters (data from hydrographs) to TM-Landsat data.

1.1.1 Hydrology and remote sensing

According to Farnsworth et al. (1984), the description of the hydrologic cycle of a basin is called "hydrologic model". The use of mathematical models is one of the most practical ways to describe the relationships between precipitation, evaporation and water flow to estimate available water or to perform forecasts.

Presently remote sensing productc, such as orbital images, airborne radar images and aerial photographs are widely used in studies related to the detection and mapping of flooding (Rooy, 1982; Florenzano et al. 1988; Ali et al. 1989 and Vila da Silva & Kux, 1991) of the native vegetation of these environments (Ponzoni, 1989) but also for the development and adaptation of hydrologic models (Peck et al. 1981; Wilkening & Ragan 1982; Mauser 1984; Farnsworth et al. 1984; Allewijn, 1986; Miller 1986; France et al. 1987; Schultz 1988 and Silva et al. 1989).

Nevertheless, the precision obtained in each study depends on the quality and on the volume of data available to check the model. Remote sensing techniques allow the development or adaptation of methods for the fast acquisition of a considerable amount of data. These informations can be obtained today by aerial photographs and by the satellites SPOT, Landsat, NOAA/AVHRR or GOES.

Peck et al. (1981) evaluated the actual use and the perspectives of remote sensing data for hydrologic modelling. These authors discussed the characteristics of seven hydrologic models related to the evaluation of flow at river basins, in order to optimize the use of these data. They indicated the minimun modifications or adaptations needed, so that the variables obtained by remote sensing could be used on the actual configuration, e.g. those variables that can or cannot be used directly and at which phase of the study it should be implemented, such as calibration, actualization and/or feeding. These authors identified thirteen variables, obtained by remote sensing, that could be used at hydrologic models with a certain degree of success. As for the use of hydrologic models in Brazil, the most important variables refer to the size of inaccessible areas, to the extension of the flooded area, to vegetation density and type and to land use.

Wilkening & Ragan (1982) came up with a model to use soil moisture close to surface, using remote sensing techiniques. They performed several numerical experiments using Richards equations for a set of conditions that would occur at hydrographic basins, in order to develop functional relationships that describe the temporal infiltration rate as a function of soil type and of the initial moisture conditions.

Mauser (1984) estimated the peak floods within a river basin in SW Germany, based on a hydrographic unit. Besides the basic hydrologic parameters, the model requires an input of other parameters obtained by a geographic data base originated from remote sensing, such as basin area, land use, soil types and slope. The flood recurrence periods were calculated by the Lognormal and Pearson distribution methods for 2, 5, 10, 50 and 100 years.

Another fundamental parameter for the application of hydrologic models at river basins, is the drainage net (hierarchy of fluvial channels and drainage density). France et al. (1987) evaluated TM and MSS images as well as aerial photographs at 1:50,000 to map the drainage net. The TM data was efficient to define the drainage net and very precise to delineate the form of basins and to estimate its'area, mainly at small basins. With this sensor information on the size of lakes (until 0,6ha small) and of creeks down to 3-5m large were obtained.

Schultz (1988) elaborated a detailed review on the use of remote sensing to hydrology. The main sensor platforms and systems relevant to hydrology were discussed and how these data are used for the analysis of the hydrologic mathematical models as both an "input" as also an estimate of model parameters. Furthermore, in this work the future applications of remote sensing data to hydrology are evaluated, referring specially to evapotranspiration, soil moisture, rain, surface waters, snow and ice, sedimentation and water quality.

Silva et al. (1989) analyzed the potential use of TM and MSS images to obtain parameters to calibrate a hydrologic mathematical model of a floodplain. They concluded that, using these images, one can delineate precisely the main river channels, the secondary channels derived from the main one, the size of the water surface as well as the occurrence of two consective flood peaks.

1.1.2 Flood forecast There are several hydrological methods to estimate floods along water courses. The results from these methods are mostly acceptable, depending always on the correct application of the results obtained (Pinto et al. 1976).

In fact the flood forecast is performed by the calculation of a flood for a certain area/river basin by extrapolation of historical data during more critical conditions. So, for instance, one could consider the calculation of the probable maximum flood to happen or to be superadded at least once every 20 years. This determination can be done by the calculus of the recurrence period for this given flood.

1.1.3 The recurrence period (Tr) The recurrence period of any event is defined as the average time, in years, that this event will be equalled or superadded at least once (Vilella & Mattos, 1975). If P is the probability that this event occurs or that it is superadded at any year, then we have the relation Tr = 1/P. Assuming the probability of non-occurence, the relation is p = 1-P.

According to Vilella & Mattos (1975), among the several existing methods to estimate P (normal curve, Foster. Gumbel and Fuller), one cannot select the best one. Nevertheless, Gumbel's method is considered as conceptually one of the most precise ones.

1.1.4 Gumbels' Method A detailed description of Gumbels' method is found in Vilella & Mattos (1975) and Pinto et al. (1976). The extreme values considered at this method, refer to maxima of the hydrographs considered.

Gumbel demonstrated that

$$P = 1 - e^{-e^{-y}} \quad (2.1)$$

where P is the probability of maximum height of the hydrograph (H) of any year, to be higher or similar to H;
e = 2,7128...
y is the reduced variable given by:

$$y = (H - Hf) * (Sm/Sh) \quad (2.2)$$

To calculate Hf (mode of extreme values) one uses:

$$Hf = Hm - Sh * (ym/Sm), \quad (2.3)$$

where Hm and Sh are respectively the average and standard variation of N maximum values of hydrographs, and ym and Sm are the average and the standard variation of variable y.

The recurrence period is:

$$Tr = 1/P \quad (2.4)$$

2. DESCRIPTION ON THE TEST-SITE

The test-site selected to perform this study is located at the southern Pantanal (Fig. 1) in the area around "Fazenda Acurizal", a huge (203,828ha) ranch for extensive cattle raising.

The inundation cycle within this region is highly complex because the fluvial overflow is caused by several rivers (Adámoli & Azevedo, 1983), besides the influence of orographic precipitation at the western slopes of Serra da Bodoquena (Vila da Silva, 1991). The inundation in this area is due to the overflow of rivers Taquari, Negro, Miranda, Vermelho, Aquidauana and Paraguai. The peaks of flooding from both Aquidauana and Miranda during januray/february, whereas the Taquari, Vermelho and Negro, with its'flood season between january and march have their peak in february. The Paraguai, after receiving the contribution of its' tributaries within brazilian territory, presents two flood cycles in Ladário and Porto Esperança: the first, influenced by the Aquidauana, Miranda, Negro, Vermelho and Taquari, with inundations during february/march, and the second, that is the main one, with the contribution of the affluents from its'upper basin during the april/june timespan.

The vegetation formations occuring in this area were defined, afeter Boock et al. (1988), following a definition of structural categories, adapted from Eiten (1968), as follows: open woods ("Paratudal" and "Carandazal"), dense woods ("Mata" and "Caapão"), open bush ("Canjiqueiral"), dense buch ("Espinheiral") and meadows of grass and herbs ("Campo"). The names between parentheses are the regional designations for these vegetation units.

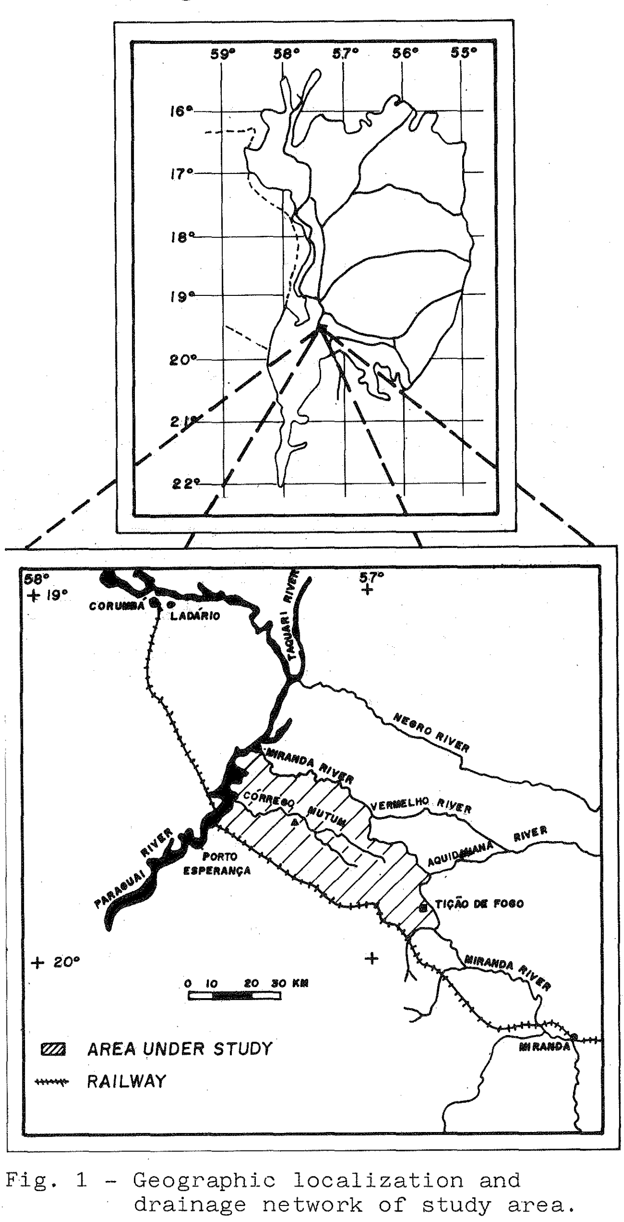

Fig. 1 - Geographic localization and drainage network of study area.

3. MATERIALS AND METHODS

3.1 Materials

Five Landsat-TM datasets, referring to five dates during the hydrologic year 1989 (october '88 to september'89), B & W paper prints, band 4, scale 1:100,000, UTM projection, were obtained from the area of interest (orbit/point: 226/74A).

One of the major problems to this type of study was the acquisition of cloud-free images, since the floods coincide with the rainy season.

Further materials used were: 35mm aerial photographs obtained during field campaigns, topographic maps at 1:100,000 that were used as a cartographic base and data from hydrographs. The hydrographic data refer to temporal series of water height measurements at the hydrographic stations of Ladário (rio Paraguai) and Tição de Fogo (rio Miranda) with respectively 92 and 17 years of observations.

3.2 Methodology

In order to perform this study, both remote sensing (digital and visual image interpretation) and field work techniques were used. The cartographic and thematic products were processed using specific algorithms implemented at INPEs' Geographic Informations System.

The Thematic Mapper band 4 was used to delineate the flooded area due to the high separability between vegetation and water at this spectral band, since vegetation reflects much energy at this wavelenght, whereas water absorbs it. Even so, this separability is quite difficult due to the different densities of vegetation cover, where the radiation does not reach the bottom.

During the hydrologic years 1989 to 1991, 22 campaigns were performed at the test site using as well motorboat, jeep and aircraft.

The visual image interpretation to obtain the thematic classes "inundated" and "dry" areas was carried out taking into account the patterns of tone, form and texture at the different environments for the analysed time. This interpretation is based on studies by Philipson & Hafker (1981), Roy (1982), Novo et al. (1982), Novo & Santos (1982), Pinto & Niero (1985), Pinto et al. (1985), Florenzano et al. (1988) e Ponzoni et al. (1989).

The estimatte of flood recurrence periods was made using Gumbels' methods. Due to non-availability of flow data the flood height was used as the parameter to be evaluated. Besides the calculation of recurrence periods using the annual maxima values, as proposed by this method, the monthly recurrence periods were estimated, using monthly maxima.

4. RESULTS AND DISCUSSION

4.1 Digitization and calculations of flooded areas

The existing cartographic bases as well as the thematic informations obtained by visual interpretation, were inserted in a GIS, via digitizing table, for further manipulation.

Afterwards the thamatic map was rasterized, i.e. the poligonal thematic informations were transformed in thematic images, each with 30m spatial resolution. This procedure is necessary to perform the area calculation. Table 1 shows the calculated area of the themes for each month of the period analysed

TABLE 1 - AREA (in ha) OF FLOODED AND DRY SECTIONS, OBTAINED BY GIS, DURING 5 MONTHS IN 1989.

Themes	May	June	July	August	September
Flooded	147120	134445	118492	68153	23070
Dry	56708	69383	85336	135675	180758
Total	203828	203828	203828	203828	203828
% flooded	72	66	5	33	11
Nr.of Poligons	779	1089	922	596	857

4.2 Recurrence period of inundations associated to the extent of flooded area

Gumbels'Method was used to calculate the recurrence period of inundations for the hydrographic stations of Tição de Fogo (Tfg) and Ladário (Lad). The results, listed at Table 2, refer to the estimates of recurrence periods, in years.

TABLE 2 - RECURRENCE PERIOD (Tr) IN YEARS OF INUNDATIONS.

Time	Hm	Sh	N	Hf	Tr from H occur or be superadded 5	10	20
Miranda River at Tição de Fogo							
April	430	62	18	400	487	530	572
May	415	54	17	388	464	503	539
June	358	90	18	314	441	505	566
July	325	89	19	282	408	471	531
Sept.	271	96	18	224	360	429	494
Annual	474	17	20	466	490	502	514
Paraguai River at Ladário							
April	359	155	92	287	480	577	614
May	397	154	92	325	517	613	705
June	405	146	92	337	518	609	696
July	389	141	92	324	499	587	671
Sept.	290	149	92	220	406	499	588
Annual	421	147	92	352	535	626	714

H = maximum expected height of hydrograph; Hm = average; Sh = standard deviation; Hf = mode; N = number of observations.

Comparing the probable height of hydrographs expected for TFg and Lad, one can observed that, since there is only a short time series of data availabrem the model did not show coherent results, due to the high variability of hydrograph height values for the months analysed. The variability was estimated by the standard deviation.

So for instance one expects that, for a period of 10 years, the hydrograph at this station would attain, during the month of april and with 90% of probability, a maxima of 530cm height. This is unlikely to happen, because, for these same conditions, the probable annual height is 502cm.

As for the Ladário station, with 92 years of observation data, the model showed higher consistency. At Table 2 one can observe the small variability among the estimates of standard deviation. Nevertheless, when the variation coefficient is high, such as in september (51%), the expected height of the hydrograph deviates considerably from the reality.

If one is interested on the estimation of other inundation recurrence periods, for each on of the times presented at Table 2, one should use figures 2 and 3 for the case of Tição de Fogo and Ladário hydrographic stations respectively. At these figures, two parameters wer plotted: the reduced variable (y) against the recurrence period (Tr) in years, using Gumbels'form.

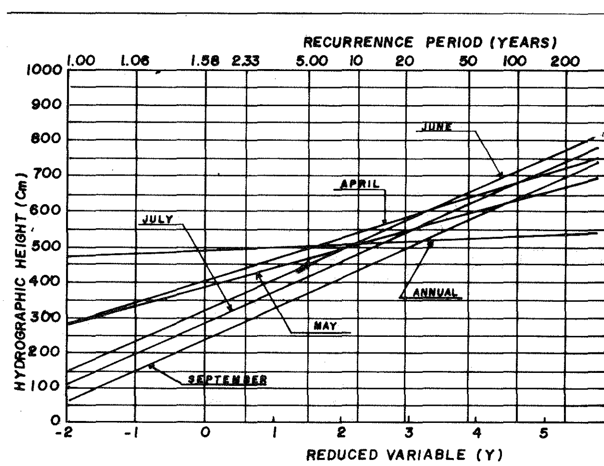

Fig. 2 - Inundation recurrence periods for the rio Miranda at Tição de Fogo.

Taking into account the high correlation among the height of the hydrographs of rio Miranda at TFg and rio Paraguai at Ladário, with the inundated area of the floodplain, evaluated by Vila da Silva (1991), it is feasible to associate the extent of the inundated areas with the estimated recurrence periods for these rivers. Table 3 presents these estimates.

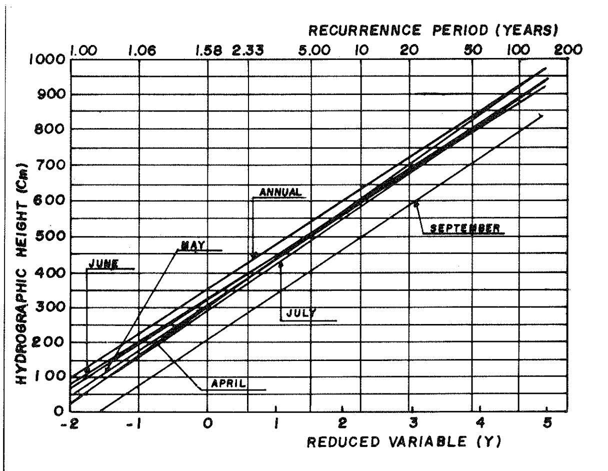

Fig. 3 - Inundation recurrence periods for the rio Paraguai at Ladário.

Considering for instance the month of april for such as evaluation - taking into account that both rivers were overflowing in april'89 - one can observe at Table 3 that, for Tição de Fogo in the coming 4 years, the river would attain the level of 458cm, at least once, with a chance of 75%.

TABLE 3 - INUNDATED AREA (ha) ASSOCIATED TO RECURRENCE PERIODS (Tr) IN YEARS AND PROBABILITY (P) OF INUNDATION.

TIME	Area (ha)	Height (H) cm TFg	Lad	Tr from H to occur or to be superadded TFg	Lad
April	147120	458	578	4,00	7,47
May	134445	405	611	1,94	7,43
June	118492	264	592	1,00	6,97
July	68153	240	532	1,00	5,89
September	23070	237	414	1,74	5,24

For the Ladário hydrografic station, the probability of height 578cm to be attained at least once in 7,47 years is of 87%. Extrapolating this relation to the values of inundated areas, obtained by satallite image, one can conclude, taking into account these conditions, that in the coming 4 years, there is a probability between 75-87%, that those 147120ha of land would be inundated, at least once, during the month of april.

5. FINAL REMARKS

The association of the probability of inundation occurrance with the calculus of inundated areas based on TM imagery, give the ranchers previous informations on: chances thar this farm wiil be inundated, where and how many land (in ha) will be inundated. Being so, the concrete information that can be delivered to the landwners by this study is to give them an idea on the risks of investment at certain sections of his property.

Since the Pantanal is a region subject to annual inundations, its'plants are adapted to the strongly water fluctuation. This characteristic of vegetation, strongly reduces the possibilities for the interpretation of these areas in terms of water stress or plant death. It is expected to find other descriptive characteristics for the water/vegetation interface of this region, by using radar images from the recently-launched ESA/ERS-1 satellite systen.

All the informations obtained by this study are being integrated with informations on soils and on the quality of native pasture from this region. This will be hopefully a contribution to the improvement of cattle raising management within the Pantanal.

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