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Risk of flood to the light of global climate change in Northeastern Argentina

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ABSTRACT

During the 20th century, several catastrophic pluvial and fluvial floods took place over the northeastern region of Argentina. These disastrous floods caused great damage worth hundreds of millions of US dollars. The rehabilitation programme was supported by regional economies. The idea of this paper is to point out the risks of greater floods as a consequence of the global climatic change.

The experiences obtained from the palaeogeomorphological research, historical data over the regional rivers, and the climatic and environmental changes are taken into account in this research.

The record of the geomorphological study of the region strongly suggests that in past epochs, different wet and dry periods occurred with the global climate change, especially in the Quaternary Period. It is possible to infer that the region is very sensitive to these changes and anthropogenic action. On the other hand, environmental and climatic conditions show a tendency of tropicalising the area. In this case, consequences are unpredictable if the processes are evolving rapidly.

It is possible to observe that after the 1960's, the characteristics of the fluvial courses are changing. The changes are in the direction of the maximum and minimum amplitudes with the same mean values. Besides, the frequency of large floods has increased from the 1960's. The Paraná River, the largest fluvial course of the region, serves as a model for the propositions mentioned above. This is because we have historical records from 1748 on high flood levels and hydrometrical measurements from 1900. The northeastern region is a very vast and flat plain with an inefficient drainage system. This physical framework induces pluvial flooding, which covers millions of hectares. True catastrophes develop when pluvial and fluvial floods coincide. The record of overflows has a recurrence period of less than 50 years. This strongly suggests a very high risk. In the 21st century, it is very probable that flooding phenomena greater than known will occur. But no mitigation measures are planned to face them.

INTRODUCTION

Northeastern Argentina is an extensive region bordering with Paraguay, Brazil, and Uruguay. It covers an area of more than 300,000 km^2 and corresponds to the provinces of Chaco, Corrientes, Formosa, Misiones, and the northern part of Santa Fe.

This region constitutes a typical landform of developed platform on the great Chaco-Paraná River basin, which is mainly an enormous sedimentary plain, except for the province of Misiones, which is almost entirely a subtropical plateau.

The area is dissected by many rivers, the sources of which are in the Brazilian massif and the mountains in the west. The most important rivers are the Paraná, the Paraguay (an affluent of the former), and the Uruguay.

In plain areas, the regional slopes are very low, around $1^0/_{00}$ (i.e. 1 m every 10 km), whereas the drainage networks are insufficient and in some parts there are none. Wetlands abound, some of them being immense, such as the Iberá Depression. Water partings are not frequently clearly marked and when there are heavy rains, transfluence processes take place among the river basins. As a consequence, it is necessary to differentiate the fluvial floods originated by precipitation in areas outside the region and in other climatic conditions, from the pluvial floods originated by local precipitation that floods wetlands known as "esteros" (marshy lands) and "cañadas" (gulches).

These phenomena are recurrent, and when they overlap in time and space, they create real catastrophes: thousands of square km of the area is flooded; there are hundreds of evacuees, and there are economic damages estimated at hundreds of millions of dollars.

The present study intends to briefly explain the possibility that the situation may worsen due to the global climate change, as some changes in the behaviour of the geomorphological system, fluvial courses, and precipitation are already observed.

CONTRIBUTIONS FROM PALAEOMORPHOLOGY

It is well known that important climatic changes took place during the Quaternary. These changes in turn originated the glacial and interglacial periods, and even minor but significant changes in the last thousand years since the withdrawal of the ice of the last Wisconsin glaciation.

Throughout previous studies, we were able to correlate the global changes with those taking place in the Northeastern region (Popolizio 1983b, 1984, 1989, 1995, 1997a, 1998a, 1998b).

For that end, it was necessary to take the concepts of the General Theory of Systems (Popolizio 1982a, 1983a, 1983b) and those of the Biostasics-Rexistasics Theory (Erhard 1967; Popolizio 1983b). They can be summarised by saying that during the glacial periods in the Northern Hemisphere there originated periods of dynamic equilibrium (biostasics) corresponding to dry or semiarid conditions of the region.

On the contrary, during the interglaciations there were more humid biostasic conditions than those at present and, as a consequence, there was some SW advance towards the forest, while during the dry periods there was a NE retrocession and some advance of the steppe.

Nowadays the forest is confined only to the province of Misiones and a part of Formosa, or it appears as a gallery along the fluvial courses, with predominance of parks and savanna and mixed species that reflect the displacement of the vegetal physiognomy along a SW-NE axis.

However, we cannot avoid mentioning that the modifications and changes in the geomorphological process during the biostasic processes, although different in each case, were slow and the landform changed slightly.

The truly important modifications began in the rexistasic periods, i.e. periods of disequilibrium and transition from dry to humid and vice versa.

It cannot be overlooked the fact that the region was subjected to cortical deformations; the lateral areas being raised and the central sector being subsided. This seems to go together with the rexistasic periods, being the neotectonics still in action (Popolizio 1972, 1980a).

What it is considered to be the humid cycle (rexistasics + biostasics) was characterised by a rise in the ocean level and the lateral areas of the region, the advance of the forest and the tree deformations, to which it must be added the mammillation of the landform, the narrowing of the water courses, and the development of dendritic networks. The dry cycle starts from a new base level by sea regression thus originating a great mobilisation of the meteorised material in the previous circle, with formation of torrents, pediments, and pediplanes (Popolizio 1972, 1982b, 1982c).

The great river courses such as the Paraná, Bermejo, and Pilcomayo make huge alluvial fans with correlative deposits and erosion surfaces (Popolizio 1981a, b, 1982b).

Finally, semiarid or semidesertic conditions were established in vast plains with formations of aeolian deposits and sub structural deflation surfaces (Popolizio 1983c, 1984; Popolizio et al. 1978, 1980).

Above all, the present landforms reflect modelling conditions different from those in the past, which have hardly managed to remodel them. On the other hand, it is interesting to remark the great susceptibility of the region to climatic changes and, at present, to the anthropic action, especially that associated both with the removal of the vegetal cover for agricultural use and the abuse of the wetlands by means of hydraulic or road works that ignore the geomorphology of the region.

In Fig. 1 the main geomorphological units of the region (Popolizio 1989) are indicated, which were described in many previous studies (Popolizio 1972, 1975a, 1980b, 1982b, 1997a; Popolizio et al. 1978, 1980).

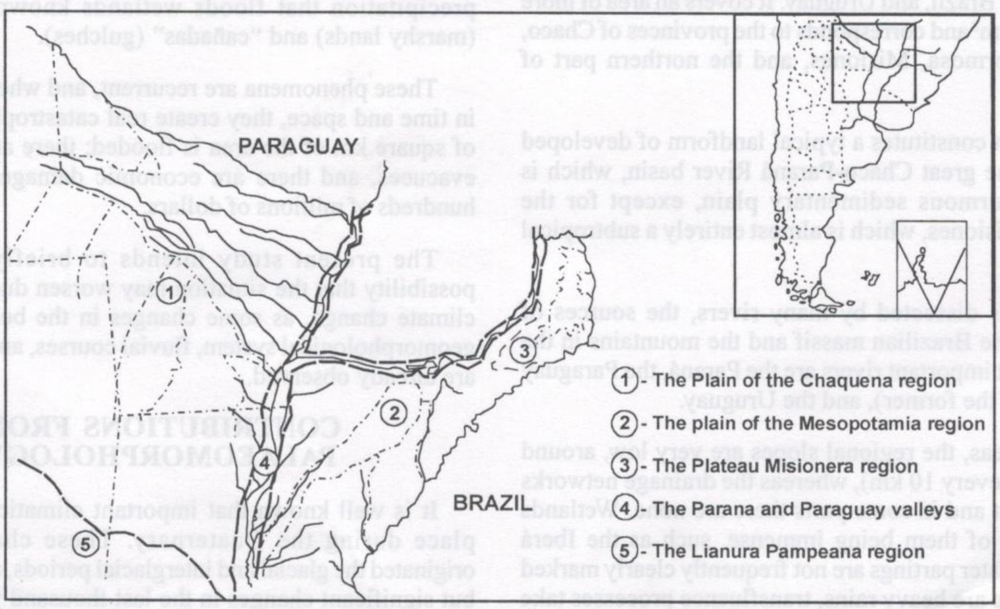

Fig. 1: The main geomorphological units of the Northeastern Argentina

The starting point of flood is the vast unit of the Chaqueña Plain, which goes beyond the region. Fig. 2 shows many subunits controlled by the neotectonics or the huge palaeoclimatic alluvial fans. A short description of them is given below.

Subunit 1.3.2 constitutes a palaeolised sub structural plain with no fluvial courses, with depressions enclosed by early ranges and very extensive low aeolian dunes, formerly covered by pyrogenic savannas and woods respectively. At present it is the most productive area in the province, having steady agrarian activity with intensive parcelling. During rainy seasons, the depressions flood until they get in contact and drain slowly towards the southeast, which is often obstructed by the road embankments built transversally, with insufficient drainage structures. We should mention that there are ancient wadies that re-activate with floods. These wadies are not seen with the naked eye but by means of aerial photographs (Popolizio 1975b; Popolizio et al. 1980).

Subunit 1.4.1.gets in contact with the above-mentioned sub-unit by means of an approximately 10 m topographic unevenness, which has partly a neotectonic and a back-waistering origin (Popolizio et al. 1980). There can be found palaeotorrents whose sources are in the former subunit, and whose drainage channels are in the talus and debris cones. This subunit constitutes as a plain inserted between Subunits 1.3.2 (Chaco Central Dorsum) and 1.4.2 (Eastern Dorsum) having also a neotectonic origin, such as shown in Fig. 2.

This area is a typical wetland with "esteros" (marshy lands) and "cañadas" (gulch), when there is significant precipitation it also receives the waters from Subunit 1.3.2 and becomes a real huge hydric lamina, held back by the unevenness of Subunit 1.4.2. Then it flows towards the province of Santa Fe where real disasters and serious damage to the cattle-raising activity take place.

Subunit 1.4.2 is a raised dorsum, covered by woods, which extend southwards and are known as "Cuña Boscosa" (a woody wedge). This subunit is a little over-elevated in relation with Subunit 1.4.1, but in the plain this is enough to cause great floods.

Some courses of Subunit 1.4.1 manage to go through Subunit 1.4.2 due to the effect of back waistering and captures or superimpositions, but they cannot evacuate the enormous hydric volume accumulated in Subunit 1.4.1. (Fig. 2)

Subunit 1.5 is formed by two huge alluvial palaeocones of the Bermejo and Pilcomayo rivers, which were modelled in a dry climate and are characterised by lateral overflow located on both sides of the early branches of the conoids. The palaeocones are elevated over the plain levels and they hold high and thick forests, which have been much affected by forestry activities or the introduction of farm-like activities (Fig. 3).

When heavy rains take place, the inlaid plains covered by savannas are completely flooded and waters run with difficulty eastwards and southeastwards, being often obstructed by road embankments with insufficient road drains, thus often blocking the transportation (Fig. 4).

Downstream of the confluence, the Paraná valley widens significantly and reaches 30 km in width. It has a vast meander plain with two main low-water channels in dry seasons and two high terraces.

The Paraná freshets are controlled by the conditions existing in the upper basin, in Brazil. They can be great, long-lasting, and strongly influenced by the behaviour of

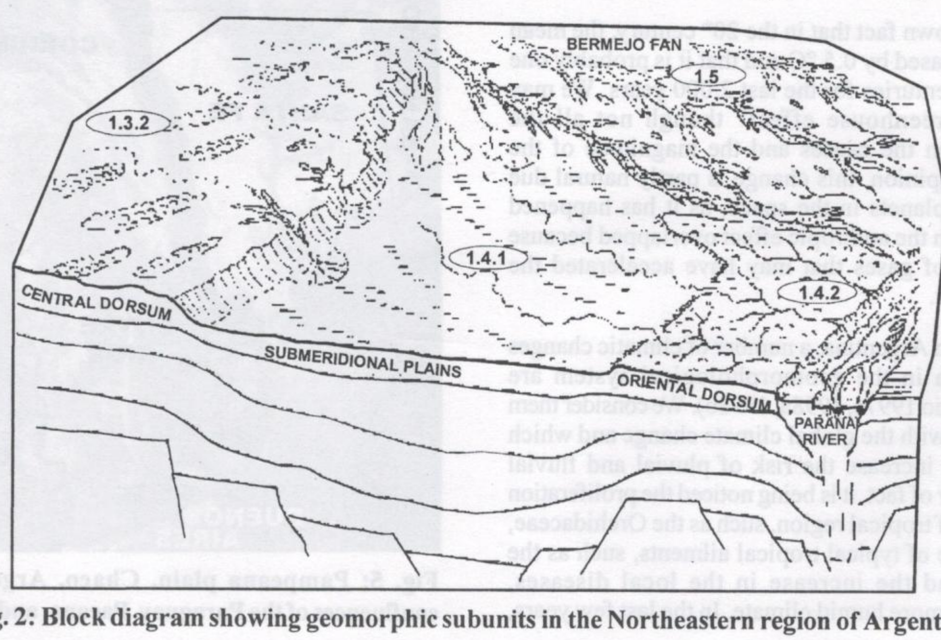

Fig. 2: Block diagram showing geomorphic subunits in the Northeastern region of Argentina

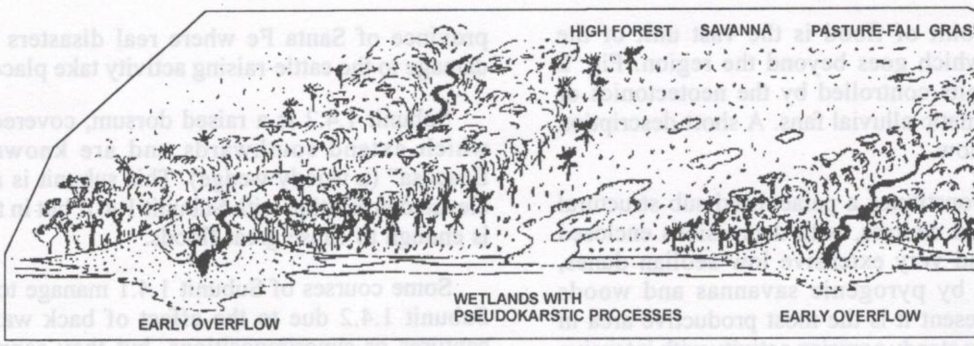

Fig. 3: Block diagram showing main features of subunit 1.5 (see text for details).

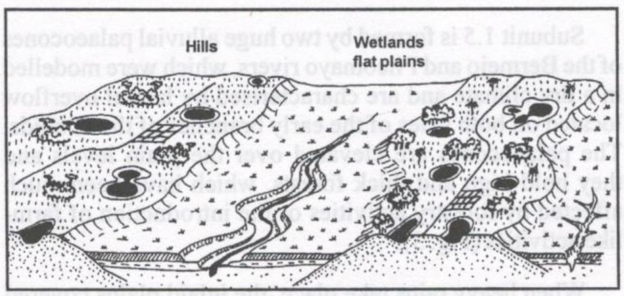

Fig. 4: Block diagram showing inland plains

its tributary: the Iguazú River. The freshets of the Paraguay River also depend on its upper basin in Brazil and they are regulated by the largest wetland in South America known as "El Pantanal", similar to that of "El Iberá", but larger. When the freshets of both courses overlap the volume reaches its peak, as it was the case in 1983 when it reached 60,000 m^3/sec. in front of Corrientes (downstream of the confluence; Fig. 5).

RISK OF FLOOD AND GLOBAL CLIMATE CHANGE

It is a well-known fact that in the 20th century, the mean temperature increased by 0.5 °C and that it is probably one of the "hottest" centuries for the last 2,000 years. We may speak of the "greenhouse effect" though not all the scientists agree on the causes and the magnitude of the increase. In our opinion, this change is partly natural due to movement of planets in the space, as it has happened before, with which the anthropic effect overlapped because of the emission of gases that may have accelerated the greenhouse effect.

In northeastern Argentina, a number of climatic changes and modification in the geomorphological system are occurring (Popolizio 1997c, 1998a, 1998b). We consider them being associated with the global climate change and which will undoubtedly increase the risk of pluvial and fluvial floods. As a matter of fact, it is being noticed the proliferation of some species of tropical region, such as the Orchidaceae, or the appearance of typical tropical ailments, such as the dengue fever and the increase in the local diseases, associated with a more humid climate. In the last few years, the isohyets have displaced more than 150 km westwards, and amount and intensity of the precipitation have risen. Likewise, it seems that the turbulent phenomena in the atmosphere are increasing.

At a geomorphological level, it can be observed, for instance, the development of neonetworks with a tendency towards the dendritic model, the increase in the erosion of the landforms by hydric action, and the development of pseudokarstic processes (Popolizio 1976, 1978, 1997b). All this seems to be more and more strongly marked since the 1960's, although it is probable that the change initiated

Fig. 5: Pampeana plain, Chaco, Argentina, and the confluences of the Paraguay, Paeana, and Uruguay Rivers

beforehand and the homeostasic mechanisms of the geomorphic system may have hidden the effects until the dentritic networks began to collapse (Fig. 6). In short, we say that it is beginning a rexistasic period or period of disequilibrium, with which the anthropic effect is overlapping.

Many authors have discussed the possible future scenery if the tendency to change and the effects on the environment and the regional economies continue (Nunez 1987; Vargas and Nunez 1989, 1990). These studies illustrate the behaviour of the Paraná river off Corrientes (Fig. 5), where there are reliable registers of the whole century and also the historical data of 18th and 19th centuries, since the city is more than 400 years old, and it was possible to relate the historical data to the hydrometrical values of the 20th century (Vasallo 1979, 1983). There area also some data of the 17th century (Viladrich 1984).

We have been studying the behaviour of the river for many years and in the 80´s we made a graph (Fig. 7) showing the height registered by the hydrometer during the top freshets in that city. The tangent to those values was almost a perfect straight line, with negative slope until the 60´s, and from that date onwards it became positive and with a greater gradient. Besides, we made plots of the annual maximum and minimum freshets corresponding to the 20th century, of which we have properly documented registers (Fig. 8). Both graphs lead us to the conclusion that the highest freshets since 1748 (and maybe even since 1600), were decreasing until the 60´s, and then they began to increase. In other words, the probability of occurrence of freshets greater than that of 1983 (the greatest in the century) was high, including the hazards that this implied.

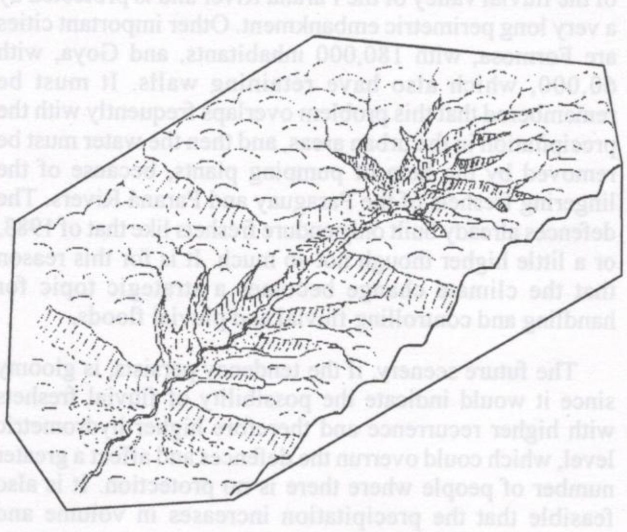

Fig. 6: Sketch of a palaeotorrent from the Misiones Province

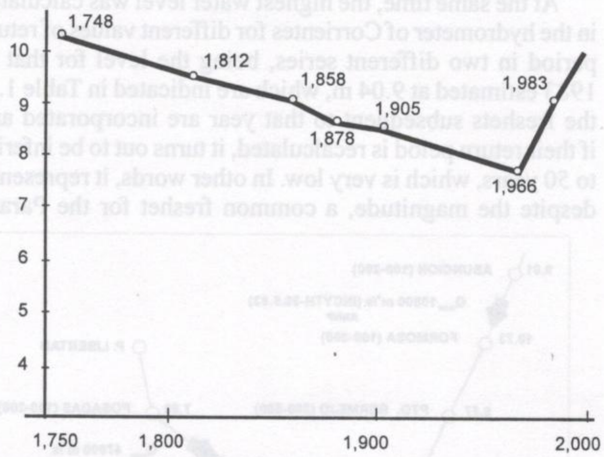

Fig. 7: Great floods in the Corrientes City

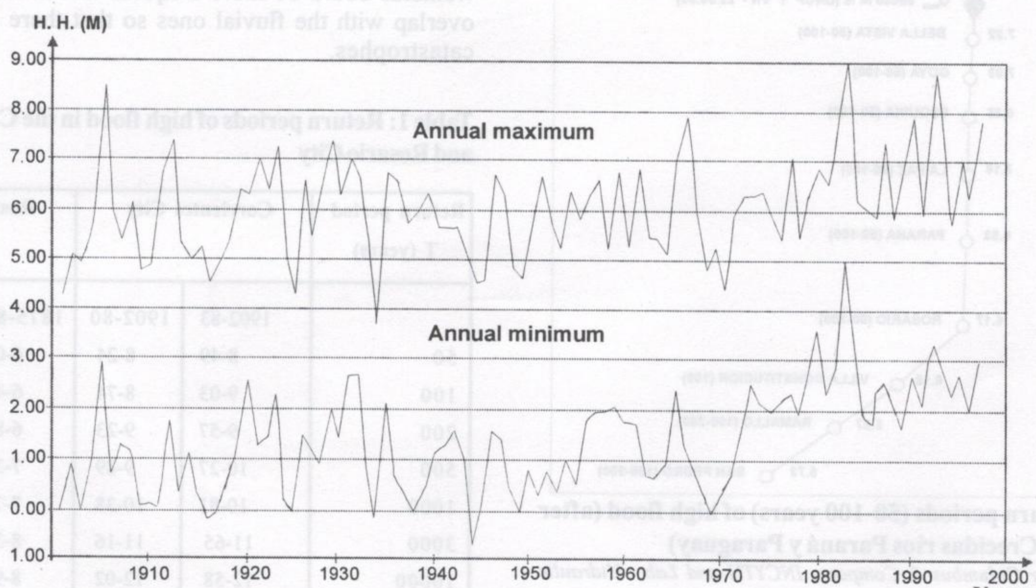

Fig. 8: Hydrometric highs in the Corrientes City, Argentina

But if Fig. 8 is carefully analysed, it can be noticed that the average of maximum and minimum tends to rise and the frequency and oscillation amplitude increase. Everything indicates that we are facing a change in the hydrological system, which was also noticed in an expert study in the Pilcomayo River, in other rivers in the region and nearby areas, also by other authors. The graph reveals a greater excitation of the system, and that the recurrence of greater floods turns increasingly higher.

This is an aspect we want to emphasise since on the occasion of the great freshet in 1983, the recurrence was calculated in different parts of the region, as it is indicated in Fig. 9. There it can be observed that the recurrence in Corrientes was estimated between 100 and 200 years, which is a very small amount, if we take into account that upstream, some 250 km far, there is the Yacyretá dam, which was built to endure 10,000-year-recurrence freshets.

At the same time, the highest water level was calculated in the hydrometer of Corrientes for different values of return period in two different series, being the level for that of 1983 estimated at 9.04 m, which are indicated in Table 1. If the freshets subsequent to that year are incorporated and if their return peiod is recalculated, it turns out to be inferior to 50 years, which is very low. In other words, it represents, despite the magnitude, a common freshet for the Paraná River and the possibility that it repeats itself in a short time or it is greater, as it happened last year.

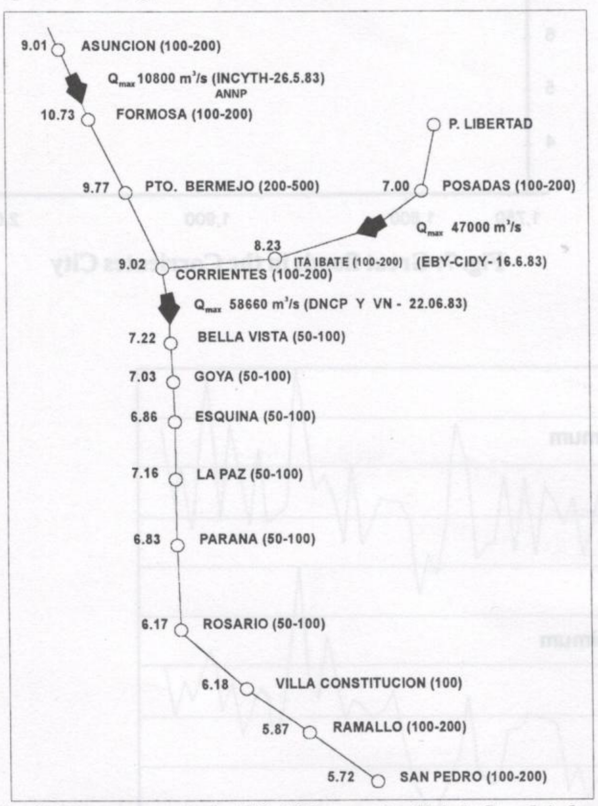

Fig. 9: Return periods (50-100 years) of high flood (after Estudio de Crecidas ríos Paraná y Paraguay)

Source: Motor Columbus & Company, INCYTH and Lab. Hidraulic (UNNE)

In order to have a bare idea of what this may imply, in a previous study the calculated discharge of the Decamilemarian freshet was 115,000 m³/sec. As we can see in Table 1 this would originate a hydrometric height of 12.56 m in Corrientes, i.e. 3.52 more metres than in 1983.

In that event, 95,000 m³/sec would flow through the Yacyretá dam and the rest would be brought by the Paraguay River. All along these rivers, and even the Uruguay River, there are an important number of cities that were repeatedly flooded and some of which have built huge defences. That is the case of the city of Resistencia, with 350,000 inhabitants, which is totally located in the terraces of the fluvial valley of the Paraná River and is protected by a very long perimetric embankment. Other important cities are Formosa, with 180,000 inhabitants, and Goya, with 60,000, which also have retaining walls. It must be remembered that this problem overlaps frequently with the precipitation in the urban areas, and then the water must be removed by the help of pumping plants, because of the lingering freshets of the Paraguay and Paraná Rivers. The defences already built only endure freshets like that of 1983, or a little higher though not so much. It is for this reason that the climate change becomes a strategic topic for handling and controlling fluvial and pluvial floods.

The future scenery, if the tendency persists, is gloomy since it would indicate the possibility of fluvial freshets with higher recurrence and therefore higher hydrometric level, which could overrun the defences and affect a greater number of people where there is no protection. It is also feasible that the precipitation increases in volume and intensity, which would surpass the pumping capacity in unprotected cities. At the same time, the floods in the wetlands could be more frequent and intense, getting to overlap with the fluvial ones so that there could be real catastrophes.

Table 1: Return periods of high flood in the Corrientes City and Rosario City

Return period T (years)	Corrientes City		Rosario City	
	1902-83	1902-80	1875-83	1875-80
50	8-49	8-24	6-06	5-94
100	9-03	8-74	6-45	6-30
200	9-57	9-23	6-83	6-67
500	10-27	9-89	7-33	7-15
1000	10-81	10-38	7-71	7-51
3000	11-65	11-16	8-32	8-07
10000	12-58	12-02	8-98	8-72

CONCLUSIONS

The geomorphological characteristics of Northeastern Argentina make the region extremely susceptible to fluvial and pluvial floods. This is a consequence of the fact that it is mostly constituted by extensive plains and wetlands with very low slopes and inadequate drainage networks. On the other hand, the region is run through by important fluvial courses, that have their sources located outside the region, and is subject to different climatic conditions with a volume of precipitation higher than the local ones.

Both types of floods are recurrent phenomena that affect millions of hectares of land and a considerable number of people causing damage estimated at millions of dollars, losses in the agricultural sector, damages of the infrastructure and the evacuation of people.

The Palaeomorphology reveals that the region is highly susceptible to climate and anthropic changes and that the former have repeatedly occurred during the Quaternary and historical times.

Significant modifications in the behaviour of the natural system are being observed. They seem to be related to the global climate change and they imply a greater oscillation of the systems and a higher recurrence of floods.

The hydrological system is one of the best examples of the changes that are taking place and it indicates that the tendency has reverted since the 1960´s. Thus the risk of fluvial and pluvial floods superior to that of 1983, which was the greatest in the century in the city of Corrientes, is increasing and therefore it is necessary to study the possible scenery for the next few years in order to develop policies and strategies that may handle possible natural catastrophes.

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