HYDROLOGICAL TOOLS FOR FLOOD EARLY WARNING SYSTEMS

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ABSTRACT

Monitoring the hydroclimatic conditions for floods early warning systems need to have a series of tools that allow the effective and quickly analysis of the information received from telemetric stations, in order to give a timely warning to the populations in relation to the possible increases of level of the rivers. The hydrological tools developed allow the identification of different stages: monitoring, pre-warning, warning, alert and emergency; for each one of which an action procedure has been established. Develop of these tools has been carried out based on statistical and hydrological observation and analysis of historical flood information.

Key words: river levels thresholds, precipitation thresholds, flood early warning systems, telemetric stations, transit times.

INTRODUCTION

The floods early warning systems are articulated procedures aim to alert the occurrence of increase in the river level or a possible flood, in order to protect populations lives located downstream in risk areas. These procedures include monitoring of hydroclimatic conditions (rain and river levels), analysis of this hydroclimatic information, the forecast of potential impacts, early dissemination of information to the population and the consequent action based in a series of procedures and protocols that must be established by the appropriate entities.

In El Salvador, the actors who are responsible for flood early warning systems are the Ministry of Environment (MARN) through the Department of Environmental Observatory (DOA), the Ministry of Interior through Civil Protection and the communities, in a coordinated work that has been developing and improving since 2002.

The research involved the development of tools that allow the analysis of hydroclimatic information of telemetric stations that send information in real time, effective and quickly, in order to identify variations that could generate some kind of impact; so hydrological parameters complement hydrological modeling developed in different basins of the country.

The hydrological parameters developed allow the identification of different stages: monitoring, pre-warning, warning, alert and emergency, for each one of which an action procedure has been established.

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These hydrological parameters are as follows: a) river levels thresholds; b) precipitation thresholds; c) transit times of the stream between hydrometric stations located in the same basin; d) relationship between river levels at stations located in the same basin; e) relationship between rainfall amounts and increases in river levels; f) isochronous curves that estimate the arrival time to areas of potential impact; and g) temporal distributions of rain. These tools are very effective for flood early warning systems (SAT), because they allow a quick analysis of collected information for the stations, which allows take necessary measures within SAT, besides complementing results of hydrological modeling, without subordinating the hydrological analysis to modeling results. The development of these tools has been carried out based on statistical and hydrological observation and analysis of historical flood information as well as information recorded by the telemetric stations, linking variables rain, river levels and effects. These tools are updated as land use change in the watersheds, for strong events of rain and as well as erosion or sediment deposition in river beds situations.

OBJECTIVE

To develop complementary hydrological tools with hydrological modeling, allowing a timely analysis of the hydroclimatic information in real time sent by telemetric stations, in order to give a timely warning to the populations in relation to the possible impacts by increases of level of the rivers.

METHODOLOGY

As part of the early warning system, it is essential to develop the tools that allow the analysis of the hydroclimatic information recorded by the telemetric stations, in a timely manner, to determine the corresponding actions regarding the warning to the population of a possible affectation by increases of level of the rivers.

In this way, a series of parameters and hydrological tools were developed that allow a rapid analysis of the information reported by the telemetric stations in real time, and that give results that are complemented in some cases with hydrological modeling. These tools and parameters are as follows: river level thresholds, precipitation thresholds, transit times of stream between hydrometric stations located in the same basin; relationship between river levels at stations located in the same basin; relationship between rainfall amounts and increases in river levels; isochronous curves that estimate the arrival time to areas of potential impact; temporary rainfall distributions.

Prior to the development of these tools, and as part of the early warning systems, five stages were defined (monitoring, pre-warning, warning, alert and emergency), as well as operating procedures and communication protocols.

The development of these parameters began in 2002 when the telemetric stations that send information in real time began to operate and it was necessary to be able to interpret the information received from them. This analysis was based on the observation and revision of historical information of floods, as well as of the information recorded by the telemetric stations, relating the variables of rainfall, river levels and affectations.

The parameters developed and the way in which they were determined are described below.

a) RIVER LEVELS THRESHOLDS

The first tool developed was river levels thresholds, to define stages (monitoring, pre-warning, warning, alert and emergency) and determining the river level from which a flood could be present in areas located downstream of telemetric hydrometric stations, to give the appropriate warning to the possible population affected.

For this, the concept "**Level Threshold**" was defined as the maximum value of the water level in a cross section of the river that delimits the stage of hydrological monitoring respect to the possibility of occurrence of overflows. From this concept, the following terms were defined:

Monitoring threshold: represents the river level where there is no possibility of overflow or flood.

Pre-warning threshold: represents the river level which there is a possibility a rapid increase and for whiat it is necessary to give a continuous and detailed monitoring of the evolution of the phenomenon.

Warning threshold: represents the river level where Civil Protection and the population located downstream of the hydrometric station should be notified, due to possible flooding.

Alert threshold: represents the river level where a river overflow is highly likely to occur.

Emergency threshold: represents the river level where an impending overflow and flood will occur.

In order to define the river levels corresponding to each of these thresholds, the historical records of floods were correlated with the river levels recorded by the conventional stations. From these records the value of the river level in which the flood was produced it was determined and denominated "**Flood Level**". For the other thresholds (monitoring, pre-warning, warning, alert and emergency), percentages were established from this "**Flood Level**", which were calibrated from the monitoring and continuous observation of the levels; values were finally established and are presented in table 1.

Table 1. Definition of river level thresholds

THRESHOLD	LEVEL
MONITORING	0 A 50% of Flood Level
PRE-WARNING	50% A 75% of Flood Level
WARNING	75% A 90% of Flood Level
ALERT	90% A 95% of Flood Level
EMERGENCY	95% A 100% of Flood Level

Figure 1 shows the thresholds defined in the cross section of the “Grande de San Miguel” river, in “Moropala” station.

Table 2 shows the thresholds established for the different telemetric hydrometric national stations. It is important to mention that due to the continuous changes in the channels for effects of sedimentation or undermining, as a result of changes in land use, or due to the effects of strong hydrometeorological events, it is necessary to evaluate and validate these thresholds annually in order to guarantee a better information to the populations located in zones of risk.

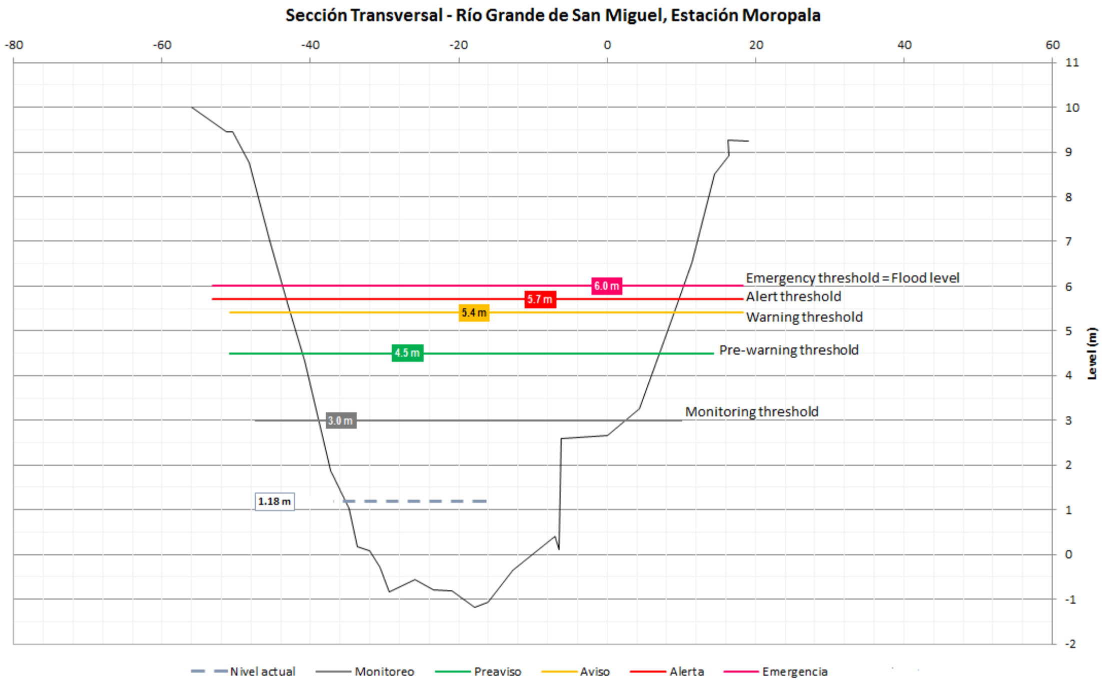

Figure 1. River level thresholds in the cross section of the Grande de San Miguel river at the Moropala station.

Table 2. River level thresholds for telemetric hydrometric stations.

UMBRALES DE ALERTA DE ESTACIONES HIDROMETRICAS TELEMETRICAS						
ESTACION	MONITOREO	PREAVISO	AVISO	ALERTA	EMERGENCIA	NIVEL DE INUNDACION
	0 - 50%	50% - 75%	75% - 90%	90% - 95%	> 95%	100%
CITALA	0 - 2.0	2.0 - 3.0	3.0 - 3.6	3.6 - 3.8	> 3.8	4
EL ZAPOTILLO	0 - 4.5	4.5 - 6.75	6.75 - 8.10	8.10 - 8.55	> 8.55	9
GUAZAPA	0 - 3.91	3.91 - 5.87	5.87 - 7.04	7.04 - 7.43	> 7.43	7.82
LA QUESERA	0 - 4.21	4.21 - 6.3	6.30 - 7.56	7.56 - 7.99	> 7.99	8.42
SAN ISIDRO	0 - 2.25	2.25 - 3.38	3.38 - 4.05	4.05 - 4.28	> 4.28	4.5
SAN MARCOS	0 - 3.0	3.0 - 4.5	4.5 - 5.40	5.40 - 5.70	> 5.70	6
EL JOCOTE	0 -3.74	3.74 - 5.6	5.60 - 6.27	6.27 - 7.10	> 7.10	7.48
OSICALA	0 - 2.25	2.25 - 3.38	3.38 - 4.05	4.05 - 4.28	> 4.28	4.5
EL JOBO	0 - 2.5	2.5 - 3.75	3.75 - 4.5	4.5 - 4.75	> 4.75	5
HACHADURA	0 - 2.40	2.40 - 3.6	3.60 - 4.32	4.32 -4.56	> 4.56	4.8
SANTA EMILIA	0 - 3.54	3.54 - 5.30	5.30 - 6.36	6.36 - 6.71	> 6.71	7.08
ATALAYA	0 - 2.99	2.99 - 4.49	4.49 - 5.38	5.38 - 5.68	> 5.68	5.98
PUENTE VIEJO	1 - 1.00	1.00 - 1.51	1.50 - 1.81	1.80 - 1.91	> 1.91	6
TALPETATE	0 - 3.0	3.0 - 4.50	4.50 - 5.40	5.40 - 5.70	> 5.7	0
LA CANOA	0 - 3.75	3.75 - 5.63	5.63 -6.75	6.75 - 7.13	> 7.13	0
VILLERIAS	0 - 2.74	2.74 - 4.11	4.11 - 4.93	4.93 - 5.21	> 5.21	0

B) PRECIPITATION THRESHOLDS

Different rainfall events occurring at the national level in which rainfall of considerable quantity or high intensity occurred that produced some type of impact in the population, generated the need to determine precipitation thresholds. One of these events, and perhaps one of the most shocking, was the event on July 3, 2008, where two heavy rainfall events occurred in the city of San Salvador. The first rainfall occurred in the afternoon and left a high level of the river; The second rainfall happened in the evening and although the amount of rain was around 40 mm, it had a high intensity, of 23.4 mm in 10 minutes, which generated a sudden increase of the river, leaving its channel in a sector of the city, producing the drag of a bus with 32 passengers who died in the river. Another event that also left human losses happened on November 7, 2009, in which a low pressure associated with hurricane Ida left a rainfall of more than 300 mm in 6 hours.

In order to determine these precipitation thresholds, rainfall events from different periods in the country were analyzed, which had some kind of consequence such as the cases mentioned above. The analysis allowed determining values of rain in quantity and intensity for different duration that generate some type of impact.

Also, in the analysis it was possible to identify that when rainfall occurs in the urban part of the basin, precipitation intensity thresholds are lower than when it occurs in the rural part of the basin. An example of this is that for the Acelhuate river basin where the San Salvador city is located, if the rainfall is recorded at one of the stations located in the San Salvador Volcano (rural area), the threshold is 2 millimeter per minute, while if it happens in the urban zone, the intensity of rain that generates some type of flood is of 1 millimeter per minute.

Table 3 shows the precipitation thresholds defined in general terms, which should be analyzed in detail for each basin in particular to adjust them to its land use conditions (rural or urban). The green areas represent stages of monitoring, the yellow areas represent stages of warning, orange areas represent alert stage, red areas represent emergengy stage. For exemple, a rain of 10 minutes of duration with a value of 30 milimeter represent a stage of emergency, while a rain of 1 hour with 20 milimeters represent a stage of monitoring. **Is important that this table to be analyzed and ajusted for the particular conditions of each basin.**

Table 3. Precipitation thresholds

TIEMPO	LLUVIA ACUMULADA (en milimetros)																		
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	180	200	220
10 minutos																			
20 minutis																			
30 minutos																			
1 hora																			
2 horas																			
3 horas																			
4 horas																			
5 horas																			
6 horas																			
9 horas																			
12 horas																			
18 horas																			
24 horas																			
36 horas																			
48 horas																			

Figure 2 shows rain intensity threshold for different duration of rain, which must be analyzed in detail for each case in particular, especially if it is a urban area.

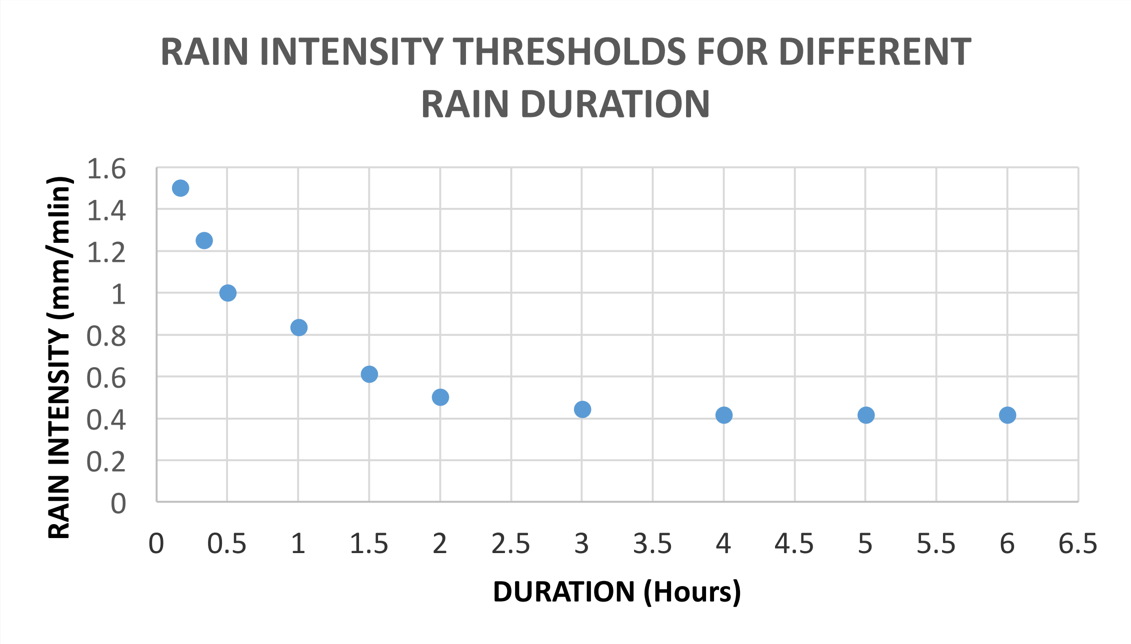

Figure 2. Rain intensity threshold for different rain duration.

C) TRANSIT TIMES OF STREAM BETWEEN HYDROMETRIC STATIONS LOCATED IN THE SAME BASIN

Despite having hydrological models that represent the response of the channel to rainfall events, it has the disadvantage that the rainfall information of the telemetric stations do not enter directly into the models. This implies that it must be typed into the model which causes delay in obtaining results, that in some watersheds represents a sensible time due to the importance to have info quickly, so it was thought in other types of tools that would allow a quick analysis of the information recorded by the telemetry stations.

Since several basins had telemetric information from two hydrometric stations, one located in the middle and the other in the lower part of the basin, the transit times between these stations were established for different rainfall events. Figure 3 shows an example of particular event where the hydrographs of two hydrometric stations located in Grande de San Miguel river are presented, where the transit times between the maximum values of the two hydrograms are identified, also other variables such as times between the occurrence of rainfall and maximum flows, recession times, level increases. Analyzing different events, the time transit values between the two stations were tabulated and graphed, with this is possible determined in advance the time it would take the stream to arrive from the station upstream to the station located downstream, knowing the level upstream. Figure 4 displays the graphical representation of the transit times for the river basin mentioned and figure 5 transit times for the Paz river.

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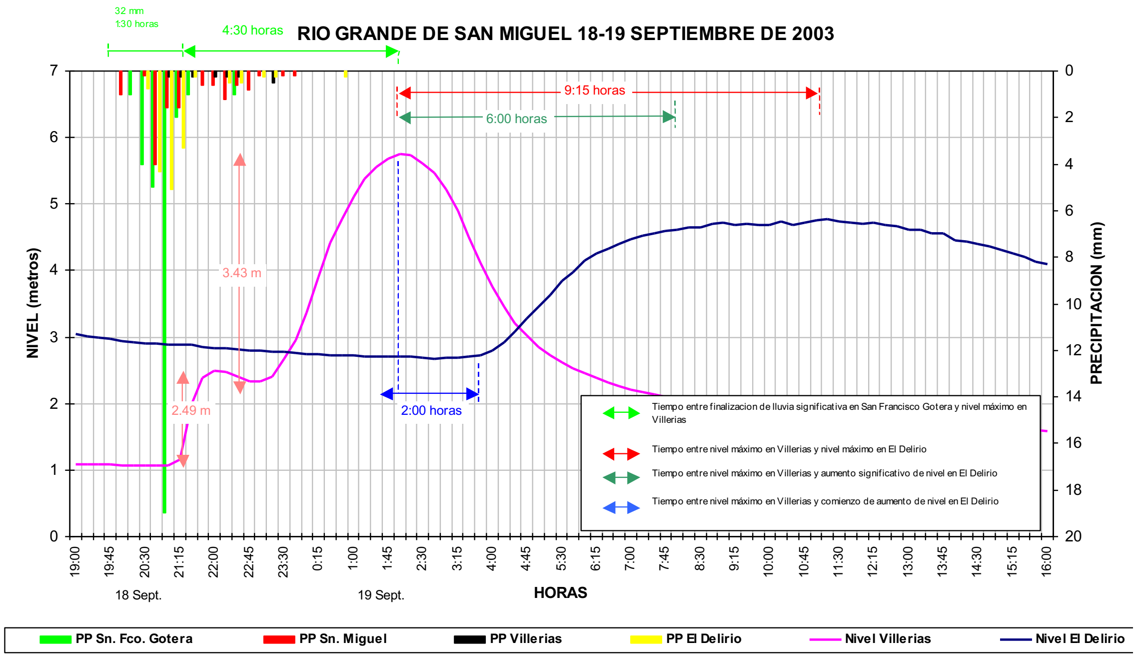

Figure 3. Analysis of rainfall and hydrographs in two telemetric stations located in the basin of the Grande de San Miguel river.

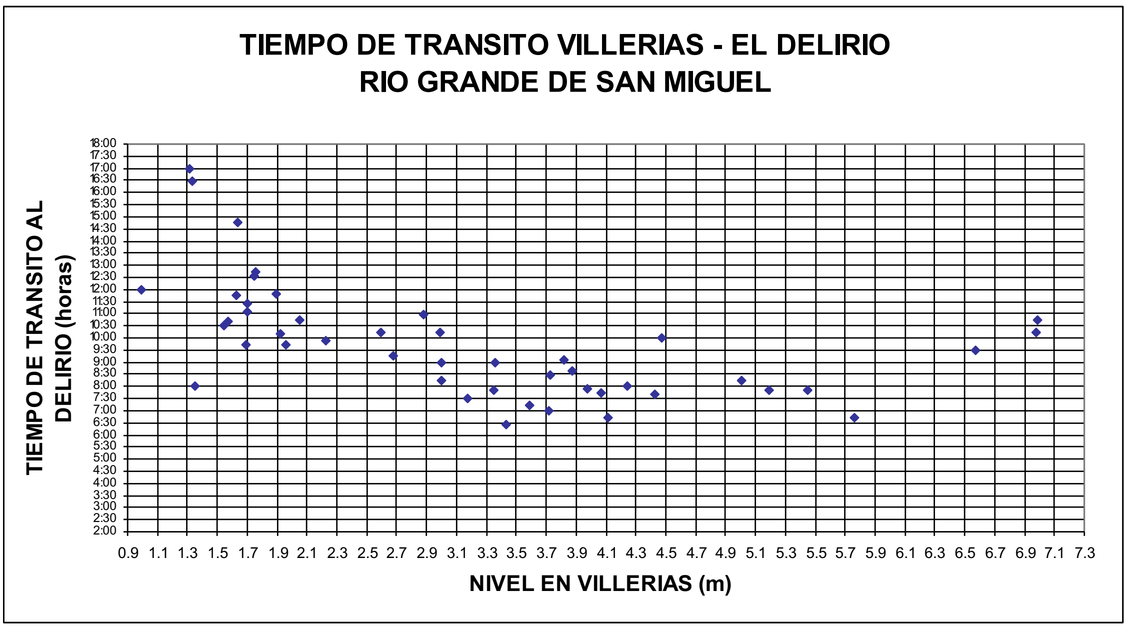

Figure 4. Transit times between the hydrometric stations Villerías and El Delirio of the Grande de San Miguel river.

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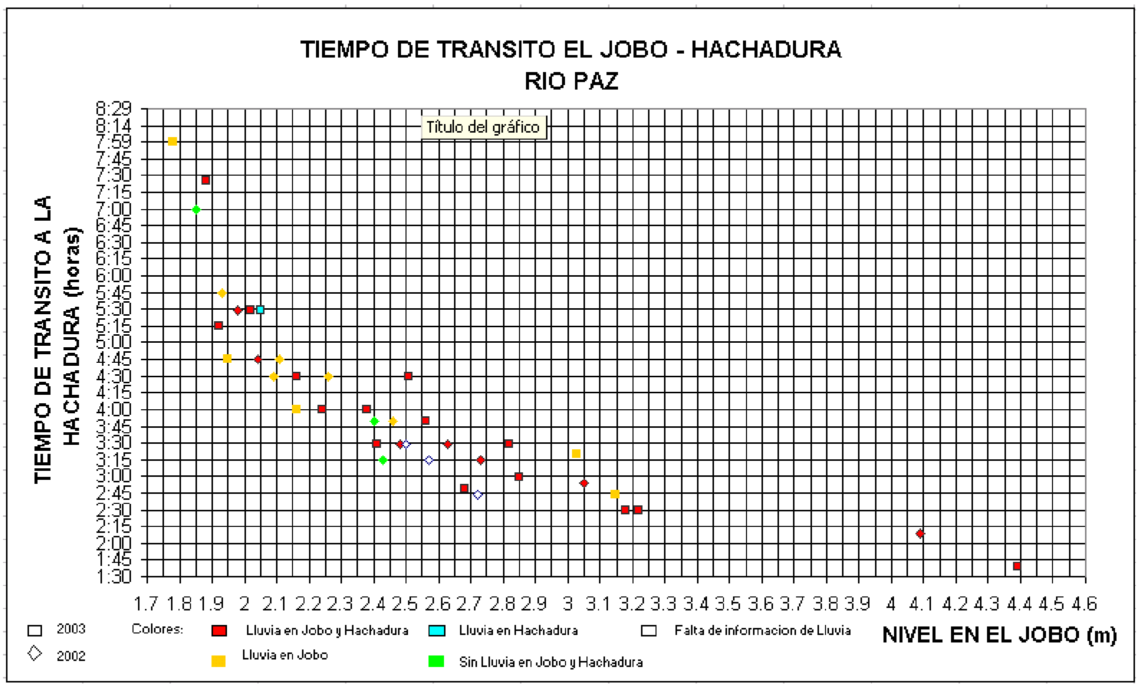

Figure 5. Transit times between the hydrometric stations El Jobo and La Hachadura of the Paz river.

D) RELATION OF RIVER LEVELS IN HYDROMETRIC STATIONS LOCATED IN THE SAME BASIN

Similarly for the previous parameter, the maximum values reached in the same rain events for two stations located in the same basin were tabulated and plotted. As follow it was possible to obtain graphs and correlation equations that allow to infer the level that the river will have downstream from the level that it has at a given moment in the station located upstream. In this way not only the level will be known but also the monitoring stage in which the river will be located and the time in which that level will be presented. **For watersheds where these transit times are high, this type of tool is very useful because it gives time to carry out the warning and evacuation actions with advance**. Figures 6 and 7 present the relation of levels graphs in stations located in the basins of the Grande de San Miguel and Paz rivers respectively.

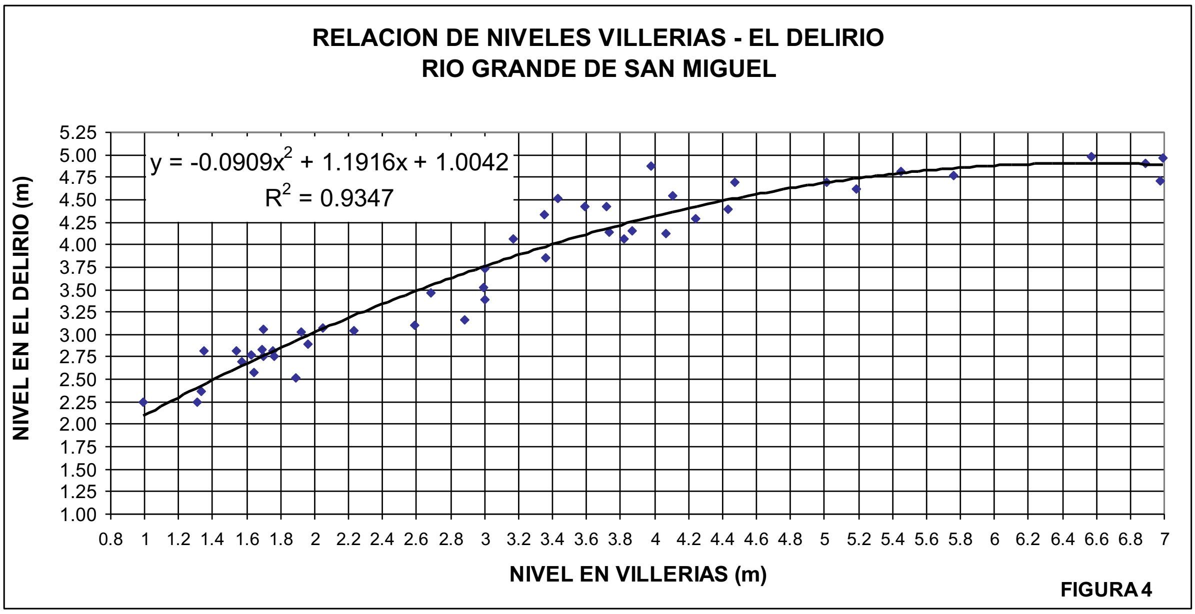

Figure 6. Relation of levels between the hydrometric stations Villerías and El Delirio of the Grande de San Miguel river.

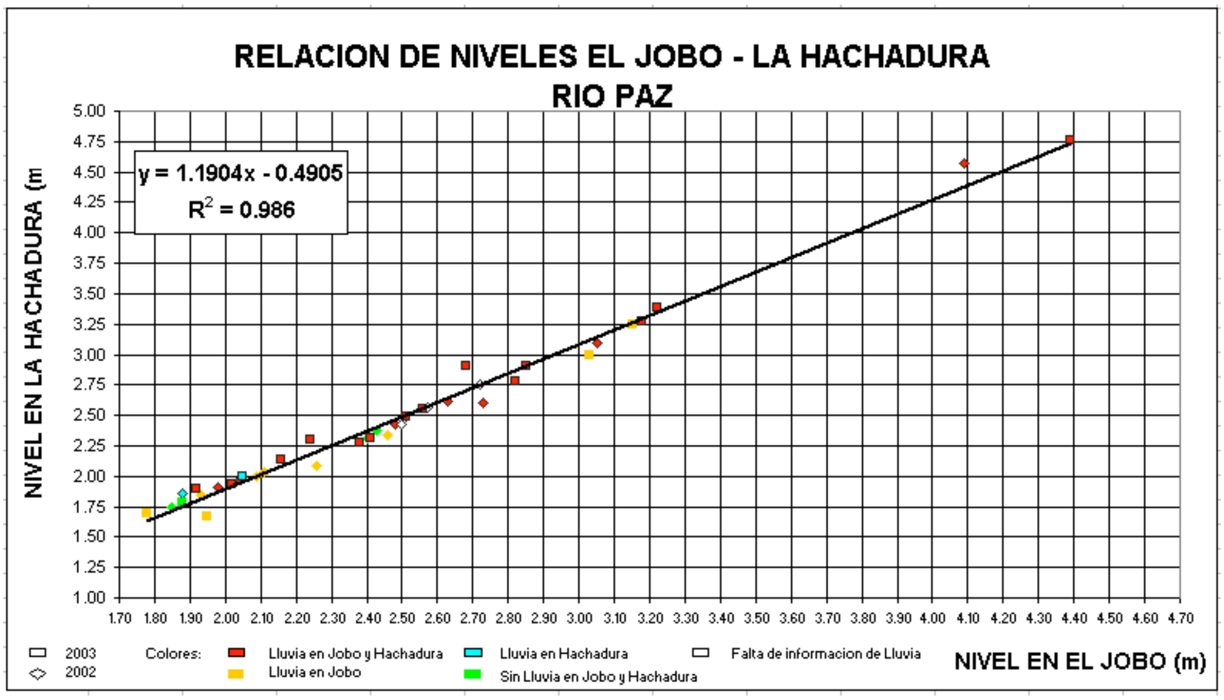

Figure 7. Relation of levels between the hydrometric stations El Jobo and La Hachadura of the Paz river.

E) RELATIONSHIP BETWEEN AMOUNTS OF RAIN AND INCREASE OF RIVER LEVELS

In order to have an idea of the level increases that the rivers could have, before performing some hydrological modeling, the values of different amounts of rain vs the increases of river level were plotted. Thus there are distinguished different seasons:

begining of rainy season and end of the rainy season, the latter where the soils are more saturated and therefore for the same rain the level increase is higher. Figure 8 presents the level increases for different amounts of rain, where it is shown that for a same amount of rain this increase of level varies, according to the season in which the rain is presented by the moisture content that the soil.

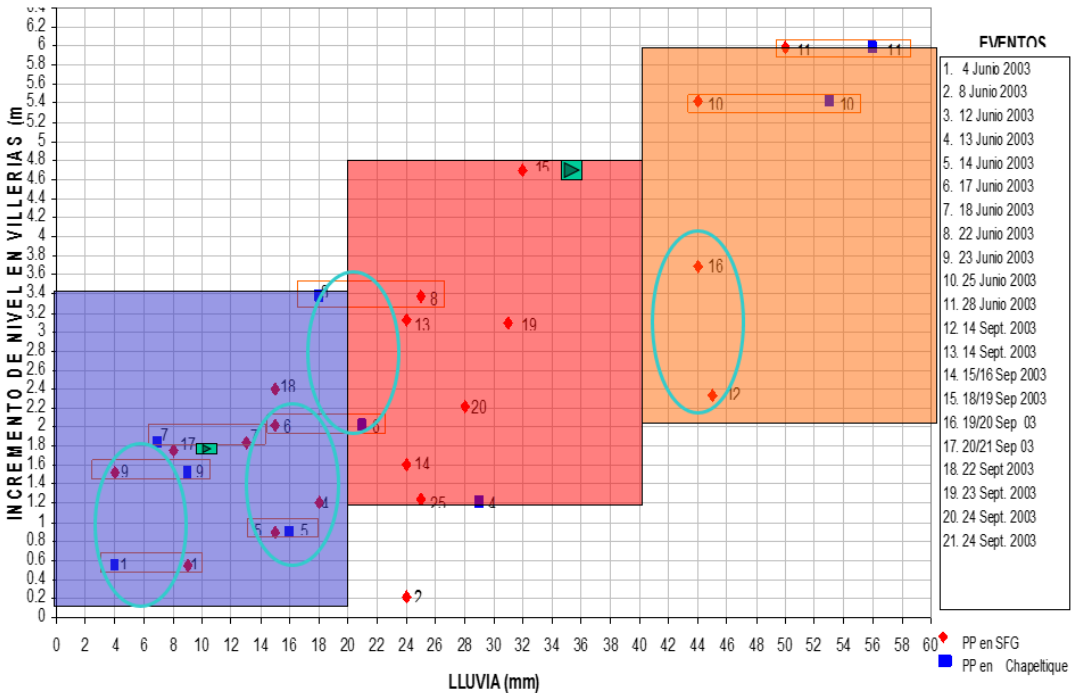

Figure 8. Increases river level (m) for different amounts of rainfall (mm) at Villerías station.

F) ISOCHRONOUS CURVES

For different basins, isochronous curve maps were established, in which with a possible velocity value between 2 and 3 meters per second according to the slope of the channel, is possible to establish the arrive times until flood risk zones for the rainfall occurring somewhere in the basin and that is recorded by existing radars, or by the rainfall telemetric stations. Figure 9 presents the map of the isochronous curves for the Paz river basin.

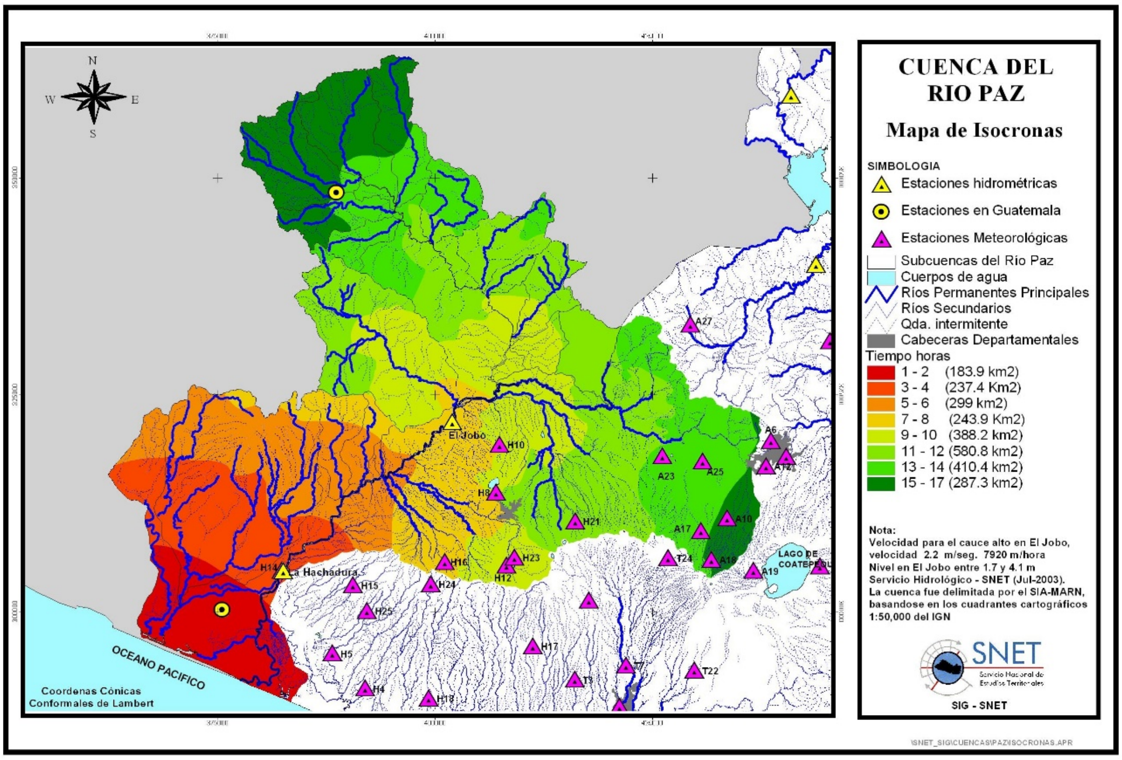

Figure 9. Isochronous curves for the Paz River basin.

G) TEMPORARY RAINFALL DISTRIBUTIONS.

Another important aspect to be considered in the monitoring of rainfall is the temporal distribution pattern that these present, especially for convective rains, which are of short duration and with high intensities, since this directly affects the hydrological response of the rivers.

For this reason, different rainfall events, with different duration, were analyzed between 2003 and 2009 for rainfall stations located in different zones of the country, in order to determine the temporal distribution patterns and to identify if these varied for the different areas or if it could be considered a standard pattern. Rainfall above 20 mm was analyzed, with durations from 20 minutes until rainfall longer than two hours.

For each of the rain events analyzed, rain duration was divided into 10-minute intervals. For each of these intervals was determined the percentage of rain falling in it, it being observed that in most cases the greatest amount of rain happens in the second and third intervals, in the intervals of 10 to 20 minutes and 20 to 30 minutes.

Because a pattern was searched, those rains that were statistically out of this behavior were removed from the analysis. It was found that for the different zones, the behavior of the convective rains presented a homogeneous pattern, so that a single pattern was determined at national level, determining the percentage of the amount of rain that fell for the different percentages of the total duration of the rain, establishing patterns for minor and greater rains than 2 hours. Figure 10 presents the temporary distribution for rains less than two hours, and figure 11 presents the cumulative temporary distribution.

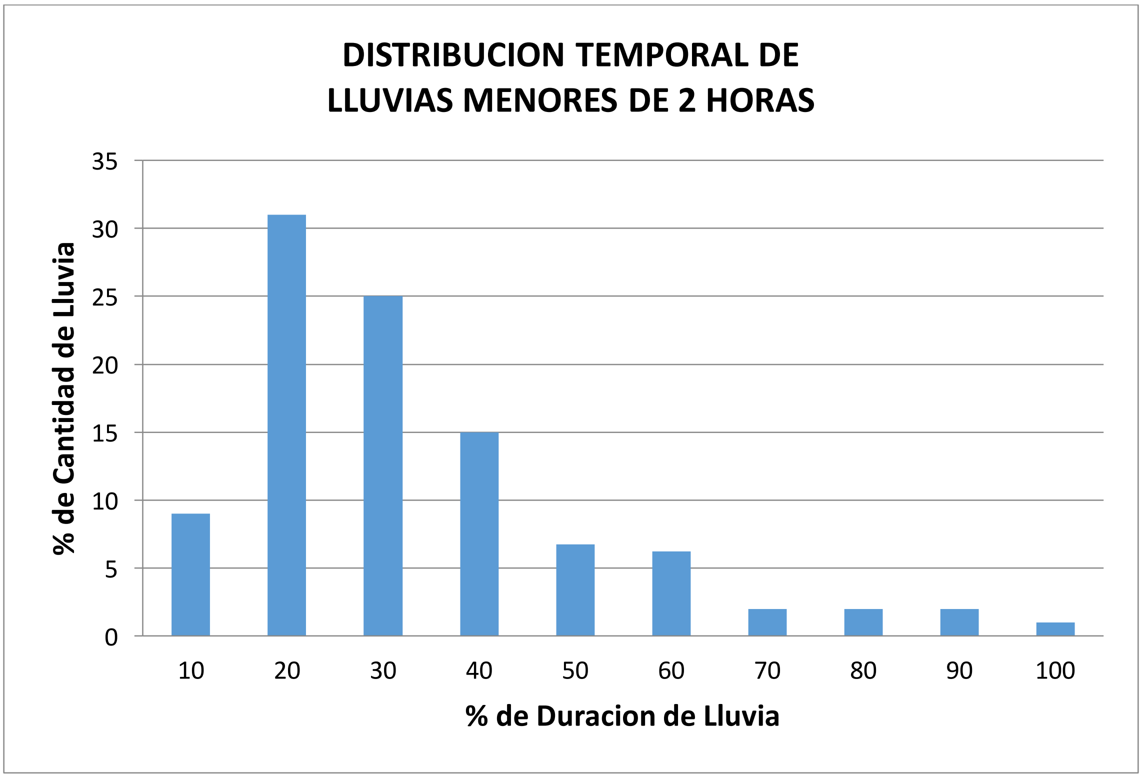

Figure 10. Temporary distribution for rains less than two hours

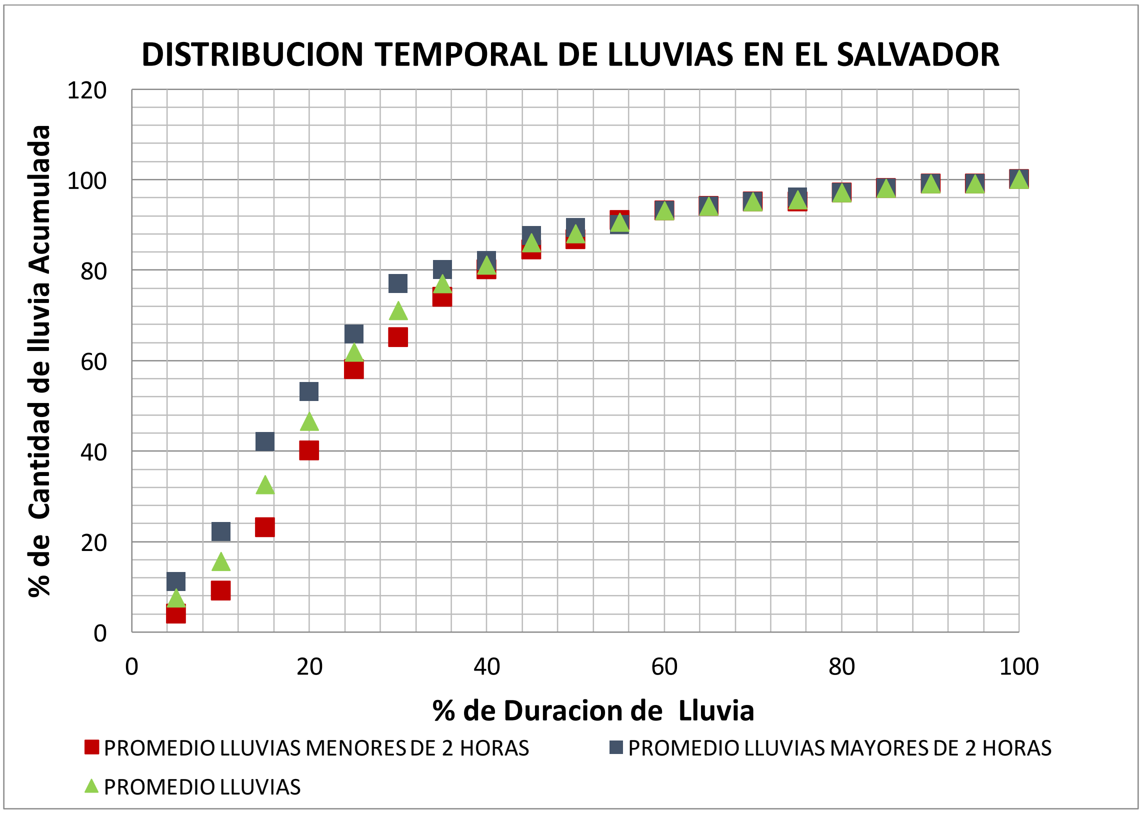

Figure 11. Cumulative temporary distribution

CONCLUSIONS

To monitor of the hydroclimatic conditions for flood early warning systems it is necessary and very important to have a series of tools that allow the effectively and quickly analysis of the information received for the telemetric stations, in order to give a timely warning to the populations in relation to the possible increases of level of the rivers.

The tools presented are complementary with hydrological modeling and are very effective for flood early warning systems because no subordinating the hydrological analysis to modeling results.

Is necessary to look for, to collect, and to analyze all information about floods and link it with levels river, amount and intensity of precipitation for determining tools and parameters that allow a quickly analysis of the information.

River levels thresholds determined for different watersheds must to be evaluated and validated each hydrological year, due to changes in channel conditions product of land use change in the basin and the impact of the hydrometeorological events.

Hydrological response of the basins depends among other factors of the land use, reason why it is important analize and validate the precipitation threshold presented in this document for to be aplicated in other basin.

Is very important to know the hydrological behavior of each basin that are monitoring, because each one is very different.

REFERENCES

Caamaño G.N, Dasso. C.M. (2003). Lluvias de diseño. UNIVERSITAS Editorial científica Universitaria. Córdoba Argentina.

Ministerio de Medio Ambiente y Recursos Naturales. (2016). Protocolo de alerta temprana por inundaciones. El Salvador.

Ven Te Chow. (1994) Hidrología Aplicada.McGRAW-HILL