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Geospatial Modeling for a Surface Hydrology Analysis in the West Part of the Sierra de Juarez, Chihuahua, Mexico

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ABSTRACT

The present study refers to the regime of maximum water runoffs applicable to the streams that discharge to the Rio Grande/Rio Bravo, originating from the Sierra de Juarez, Chihuahua, Mexico. The study sets up the maximum discharges and its corresponding hydrographs for return periods, from two to 100 years. The objective of this document is to integrate the Geographical Information System (GIS) and the prediction water runoff model WIN TR-55 to help in the making decisions process by viewing techniques and the results analysis of the model. A secondary objective of this study is to provide reliable information for preserving and improving the hydro ecological functions and aesthetic of the landscape of the urban zone of Ciudad Juarez, Chihuahua, Mexico. The hydrologic model WinTR-55 for the analysis of six basins, which are subdivided in 24 sub-basins, for a total area of 6,821.47 hectares, is utilized. Subsequently, it is proceeded to convert the storm in runoff, according to the established hydrologic practices. The model calculates the maximum discharges and the corresponding hydrographs for return periods of 2, 5, 10, 25, 50 and 100 years. The results indicate that the concentration times in the area of study vary from 0.1 to 2.431 h for the different return periods; the flow rate vary from 8.07 m^3/s for a year, to 308.77 m^3/s for 100 years. The study area has an approximate population of 35 houses/ha, representing a population of 398,062 inhabitants exposed to meteorological events. The results will support the environmental and hydraulic designs that are necessary to materialize the urban projects of interest of the Mexican authorities in Chihuahua.

I. INTRODUCTION

Chihuahua is the largest state of the Mexican Republic, with an extension of 247,087 km^2 that represents 12.5% of the total surface of Mexico; it is located in the north part of the country, bordering to the north with the United States of America (US); to the east with the US, Coahuila of Zaragoza and Durango; to the south with the states of Durango and Sinaloa and to the west with Sinaloa and the US.

The urban zone of Ciudad Juarez is located on the right margin of the Rio Grande/Rio Bravo, in the point in which the river leaves the narrowing produced by the Sierra de Muleros and of the Franklin Mountains, and that forms the so-called Valle of Juarez. The Valley has a length of 150 km and a wide average from 0.5 to 10 km (Lemus, 1998).

The municipality of Juarez is located in a desert zone of the country, limits to the north with the US being the Rio Grande/Rio Bravo the border that divides Ciudad Juarez and El Paso, Texas, to the south with Villa Ahumada, to the east with the US and Guadalupe; to the west with Ascención. The municipality counts on 149 localities; the main population centers are from Ciudad Juarez, as well as the localities of Nuevo Zaragoza, El Sauzal, San Augustin, San Isidro (Rio Grande), Zaragoza and Ávila Satelite, (ANC, IIASA. 1997). The study area is located in the north of the Sierra de Juarez, in Ciudad Juárez, Chihuahua, Mexico, and is characterized due its streams discharge directly Rio Grande/Rio Bravo, between the American Dam and the International Dam. The Rio Grande/Rio Bravo in this section counts on embankments and some sliding floodgates for water runoffs, whose function is to avoid floods. These mechanisms were implemented given the antecedents of floods in the adjacent dwellings to the river bed, in the proximity of the confluence with the Rio Grande/Rio Bravo. This zone counts on 19 dikes and three embankments that have a storage capacity of 1´828,200 cubic meters as a whole.

In this zone the regulation is scarce, given that in spite of having an important number of water runoff control works (thirty-three), ten of them function like drains, and the remainder like dikes or embankments (some of which have lost a great percentage of their storage capacity and of sediment control); the other control water works are located in the high part of the study area. At present, there is no flood protection for an important urban area. The dikes have vents that permit the exit of practically of total water, in such a way that are working only as runoff control works that have functioned adequately so far. Nevertheless, in this urban zone there is a lack of maintenance of these structures, their operation is reduced significantly the sediment storage capacity. I n the confluence with the Rio Grande/Rio Bravo there are floodgates that avoid that during the storms the water of the River enter to it, causing thus floods in the urban zone downstream.

The study area corresponds to six basins in the total drainage network that have influence in the water runoffs. In the figure 1, the main streams are identified. The Anapra basin, with approximately 2,670.267 ha, which drains downstream toward the Rio Grande/Rio Bravo, is delimited by the blue color; with black the Coyotla basin with an area of 98.007; with magenta color the Mimbre basin with an area of 339.617 ha; with green color the Viboras basin which has an area of 1,574.54 ha; with cyan color the Francisco Villa basin with an area of 153.58 ha; and finally with red color the Colorado Basin with an area of 1,985.46 ha. All these basins discharge directly to the Rio Grande/Rio Bravo, covering a total area of 6,821.47 hectares.

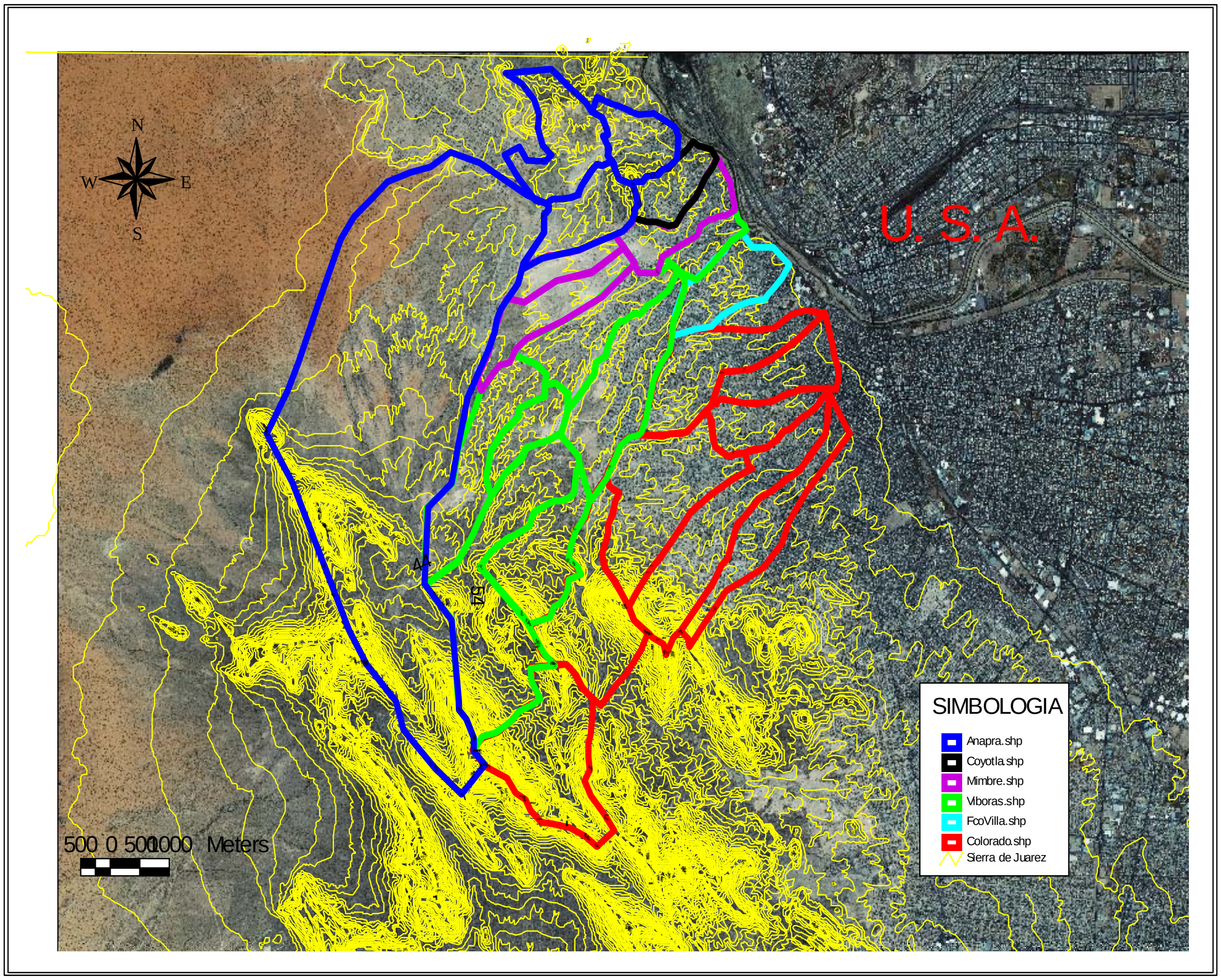

Figure 1. Basins of the study area

I.1 OBJECTIVE

The objective of this document is to integrate a GIS and a runoff prediction model WIN TR-55 to improve decision-making decisions process by viewing techniques and analysis of the results model, in order to determine the most vulnerable areas, exposed to climatological events.

II. METHODOLOGY

The methodology comprises the description of the model and the required data. The computer program is the WinTR-55, developed by the Natural Resources Conservation Service (NRCS). WinTR-55 is a computer program for hydrologic models of small basins (<of 100 ha). The model generates storm hydrographs, in agricultural and urban areas and in the points selected along the stream flow system. The corresponding hydrographs were obtained. The multiple sub-zones were modeled inside the sub-basin, knowing the physiographic, topographical, hidraulical and hydrological characteristics.

The development of a digital database related to the water resources was based on a GIS system, producing a base map. This base map included the topics related to the surface hydrology, hydrography, hydrographic soils, geomorphology, lithology, and orthoimages. That information was managed in the software package Arc View, to create a Model of the Digital Elevation (MDE) for interpreting the drainage network characteristics and the surface hydrology such as streams, located in the study area. An important task of this project was to acquire new data, and to evaluate the existing digital data. The generation of the new standardized information was utilized as input for the modeling of the Sierra of Juarez. It developed an overall digital map comparable with the natural land cover, in which the main hydrologic soils in the area were determined in the scale 1:50,000 based on their slope and locating geomorphological location. This task was obtained by using a system of the existing images of the thematic map of Landsat-TM7 and of IKONOS available in the Center of Geographical Information (CIG-UACJ). The activity required the process of at least one image of Landsat-TM7, and the use of other processes to the other platforms based on satellites (that is to say, geometric and radiometric corrections as well as georeference). For this purpose, the geometric and radiometric corrections and registration of the individual images were carried out by using the existing topographical digital scale map of 1:50,000 of the National Institute of Statistics, Geography and Informatics (INEGI), and the quadrants of digital orthophotos of the United States Geological Survey (USGS).

Information referring to the physical, chemistry and morphological soils characteristics was obtained. Through colors and keys, the type of existing soil, sodium and saline phases and the dominant surface texture were indicated. Besides, information of the zones covered by pasturelands, forests, etc., as well as data on the types of vegetation of the study area was gathered. The main source of cartographic information in Mexico is INEGI, which is the responsible for generating all the thematic maps on the national geography; other sources of cartographic information are institutions like SAGARPA, SEMARNAT, CNA or universities and research institutions like the National Autonomous University of Mexico (UNAM) and The Mexican Institute of Water Technology (IMTA).

The program WinTR-55 is a computational program for hydrologic models of small sub-basins. The model generates hydrographs of agricultural and urban areas and in the points selected along the stream system. The basin is divided into several sub-basins for modeling purposes. For each sub-basin, the characteristics include the drainage area, stream length, average soil slope, average stream slope, soil type, and land use.

The program WinTR-55 that was utilized for the model of this study area reproduces in a schematic way the arborescent structure of the river system of the basin, formed by tributary stream collectors of different orders.

The topologic model considers two types of sub-basins, head and section. The sub-basin of head drains to a sub-basin section. The sub-basin section may receive the drainage of a head sub-basin or another sub-basin section, and is located upstream of that.

In the WinTR-55, the total rain is specified for each sub-basin as a value of depth (cm) for a given storm. Usually, it is chosen for modeling purposes from one of the four typical storms (I, IA, II or III) developed by the Natural Resources Conservation Service (NCRS) (Ponce, 1989). In this case, it is considered appropriate the storm Type II, applicable to a desert zone.

The hydrologic abstraction is performed with the Method of the Curve Number, developed by the Natural Resources Conservation Service (Ponce, 1989). This method converts the total rain (P) in effective rain (Q), continuing the conceptual method of hydrologic abstraction developed by Víctor Mockus and his collaborators in the last century (Ponce, 1996). The process of abstraction is based on four characteristics of the sub-basin: (1) the hydrologic type of soil (A, B, C, or D); (2) the land use (forest, plain, agricultural, or urban); (3) the surface hydrologic condition (good, regular, or bad), and (4) the preceding condition of humidity (wet, average, or drought) (Ponce, 1989).

The rain-runoff transformation is carried out with the unit hydrograph method, which is based on the hydrograph pertaining to a unit rain of 1 cm of effective rain. Once it is obtained the unit hydrograph, this is convolutioned with the hydrograph of effective rain to obtain the corresponding stream hydrograph, defined in the mouth of each sub-basin (Ponce, 1989).

A sub-basin is composed of the sub-zones (areas of the land) and of the streams (important flow paths in the sub-basin). Each sub-zone has a hydrograph generated of the area of the land based on the land characteristics and climate. The streams may be indicated like any river bed of the channel where the hydrographs are developed based on physical characteristics of the stream or as the systems of storage where the hydrographs are directed through a deposit based on characteristics of the temporary storage of the dike. The accumulation of all the sub-basin is represented in the intersection of sub-basins. To ten sub-zones and ten streams may be included in the dividing line of the sub-basin.

III. RESULTS

The rain (in inches and centimeters) for return periods from 1 to 100 years was provided by the Center of Meteorology of the Autonomous University of Ciudad Juarez. The information is shown in the Table 1.

Table 1. Return periods and rain for Ciudad Juarez

Rain in 24-hours (mm) for Return Period						
1-year	2-years	5-years	10-years	25-years	50-years	100-years
52	64	75	90	102	140	160

Source: Center of Meteorology of the UACJ, 2006

The curve numbers (CN) pertaining to the zone were obtained following the procedures established in the Manual of Hydrology of the NCRS. The maps of soils and vegetable cover were obtained form the Center of Geographical Information of the Autonomous University of Ciudad Juarez. The curve numbers for the portions of the sub-basins in the Mexican territory were estimated based on the proximity and hydrologic similarity with their counterparts in the US.

Figure 3 shows the hydrographs of the study area for different return periods.

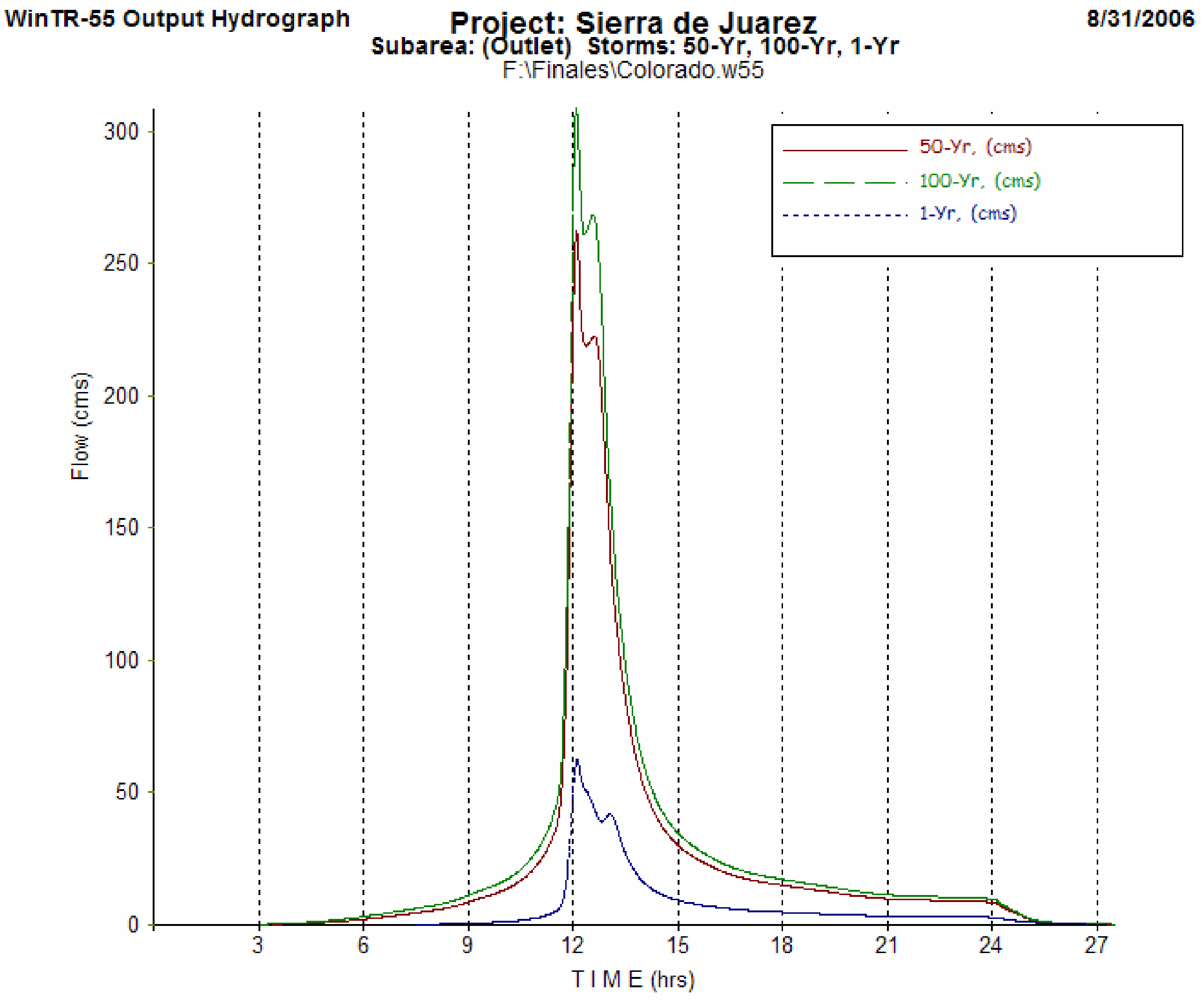

Figure 2. Hydrographs of the study area for different return periods

Table 2. Areas, discharge peak and storage capacity by basin

BASIN	AREA (ha)	Total Discharged Volumen for TR							Descharge pico in m3/s (TR)							Capacidad de almacenamiento Mm^3
		1 Año	2 Años	5 Años	10 Años	25 años	50 Años	100 Años	2 Años	5 Años	10 Años	25 Años	50 Años	100 Años	1 Año	
Anapra	2,675.91	1.39	1.71	2.01	2.41	2.73	3.75	4.28	235.88	307	496.34	486.32	746.23	883.97	162.94	1
Coyotla	98	0.05	0.06	0.07	0.09	0.10	0.14	0.16	11.91	15.62	20.86	25.15	38.95	46.25	8.07	0
Mimbre	339.62	0.18	0.22	0.25	0.31	0.35	0.48	0.54	19.38	24.8	32.61	38.89	59.05	69.45	13.65	1
Víboras	1,574.55	0.82	1.01	1.18	1.42	1.61	2.20	2.52	84.68	109.12	143.05	170.58	258.1	304.46	58.78	0.58
Francisco Villa	153.58	0.08	0.10	0.12	0.14	0.16	0.22	0.25	20.17	25.15	31.95	37.43	54.63	63.62	14.88	0
Colorado	1,985.44	1.03	1.27	1.49	1.79	2.03	2.78	3.18	88.03	112.21	146.23	173.83	261.96	308.77	62.29	0.908

III. RESULTS

The transformation rain-runoff was performed through the convolution of the unit hydrograph with the histogram of effective rain (Ponce, 1989). The hydrograph adopted is the adimentional unit hydrograph of the NRCS. For sub-basins of 16 km^2 (1600 hectares), the response time is based on the following characteristics: (1) the hydraulic length, (2) slope average of the land, and (3) curve number (Ponce, 1989). The hydraulic length was obtained from topographical maps. The average slope of the land was obtained as the average of the values in the intersections of a grid of appropriate size, following the procedure recommended by the NRCS. The average slope of the channel or stream, used in the calculation of the concentration time and the storm water runoff transit, was obtained from digital topographical maps. For areas over 16 km^2 (1600 hectares), the response time of the sub-basin is assumed equal al 60% of the concentration time (USDA SCS, 1972).

For the Anapra basin, curve number value of 88 was found and a concentration time of 0.43 h, for the different return periods of 1, 2, 5, 10, 25, 50 and 100 years with flow rates from 162 m^3/s for 1 year, to 883 m^3/s for 100 years.

For the Coyotla basin, curve number value of 84 was found and a concentration time of 0.10 h, for the different return periods of 1, 2, 5, 10, 25, 50 and 100 years with flow rates for 8.07 m^3/s 1 year, to 46.25 m^3/s for 100 years.

For the Mimbre basin, curve number values of 88 and 90 were found and concentration times from 0.34 1.594 h, for the different return periods of 1, 2, 5, 10, 25, 50 and 100 years with flow rates form 3.65 m^3/s for 1 year, to 69.45 m^3/s for 100 years.

For the Víboras basin curve numbers values from 85 to 91 were found and concentration times from 0.136 to 2.431 h, for the different return periods of 1, 2, 5, 10, 25, 50 and 100 years with flow rates from 58.78 m^3/s for 1 year, to 304.46 m^3/s for 100 years.

For the Francisco Villa basin a curve number value of 90 was found and a concentration time of 0.263 h, for the different return periods of 1, 2, 5, 10, 25, 50 and 100 years flow rates from 14.88 m^3/s for 1 year, to 63.62 m^3/s for 100 years.

For the Colorado basin a curve number value of 85 and 91 were found and a concentration times from 0.244 to 1.826 h, for the different return periods of 1, 2, 5, 10, 25, 50 and 100 years with flow rates from 62.29 m^3/s for 1 year, to 308.77 m^3/s for 100 years.

The 33.08% of the study area is of housing type corresponding to 2,256.95 ha, with an approximate population of 35 houses/ha, and 5 inhabitants by dwelling, for an approximate population of 394,967,825 inhabitants, which are potentially exposed to extreme events.

IV. CONCLUSIONS

It was carried out a successful integration of the Geographical Information System (GIS) and the prediction water runoff model WIN TR-55 to help in the making decisions process by viewing techniques and the results analysis of the model. Of the six basins that comprise the study area, only the one corresponding to Mimbre does not represent an extreme risk event according to the data obtained in the hydrologic model. Nevertheless, due to its neighborhood with the Anapra basin and the arroyo Las Víboras, its risk condition may change drastically.

V. RECOMMENDATIONS

Sustainable development takes into consideration the hydrologic variability in all the regions through the appropriate risk management. The integrated water resources management should incorporate risks management principles to face the extreme hydrologic events, such as floods. An integrated risk management provides measures to prevent that a danger becomes a natural disaster. It consists of systematic actions in a cycle of preparation, response and recovery, and should form part of the integrated water resources management.

The preparation consists of preventive and precautionary measures in order to be ready for facing an event before it occurs. It tends to minimize the effect of the activities of economic development which exacerbate the magnitude of the danger, to reduce the exposition to natural dangers and to minimize the vulnerability of people and private properties exposed to these hazards. The prevention has to do with the long-term planning and is incorporated into the development process.

The prevention has an impact on the three elements of risk: magnitude, exposition and vulnerability to hazard. In this sense, prevention means protection through structural measures and building dikes to prevent flooding.

- Structural design: Construction of water resources infrastructure requires an evaluation of the present hydrologic variability.
- Protection water works: Multiple structural protection works exist and they should be adapted to the kind of hazard. In all these cases, prevention measures have to be accompanied by planning for the worst case scenarios. The hazard knowledge is a prerequisite for a successful mitigation. Maps of hazard and risk should be established, even if only a residual risk exists.
- Codes of Infrastructure and Construction: The house is the first line of defense against hazards. A solid house can bear the impact of a variety of dangers. The codes of adequate construction can improve the resistance of constructions before various extreme events, including earthquakes, landslides or avalanches if integrated regulations are established. There is a need of greater technological and scientific materials for house construction at low cost and resistant to extreme events.

The infrastructure development that constitutes the vital economic and social resources of a country, like highways, hospitals, etc., should be designed to bear the most severe natural hazards and should be functional, even in a disaster situation. Besides, this infrastructure should not increase the magnitude of the dangers.

Unless the population in risk is aware of the risks, the local energies cannot be mobilized to develop the capacity for resistance, as for example, to be displaced to a safe place in case of an event or to minimize the vulnerability before an event. The awareness only can be provided through education and training, particularly in areas exposed to frequent dangers or in new settlements.

The school is one of the best places for learning about risks and the associated vulnerabilities. Younger people represent the future of a country. When the children learn in the school about disasters, they can act as catalysers influencing the community to enlarge its capacity of long-term protection, therefore their preparation pose the needs of preparation against short-term disasters, as well as long-term behavior changes of the community.

- Emergency Operations: The necessary operations to rescue and to protect the people, to offer them food, water and medical attention, are quite independent of the type of disaster. Nevertheless, the logistic to evaluate the needs of the victims, health risks, disaster shelters, etc. depend on the type of hazard, the local knowledge and the time of anticipation. Training should be part of the emergency planning.
- Funds of Insurance and Solidarity: Once the disaster is over, the survivors often have lost all their possessions and should begin again their lives from zero. Should be available options to satisfy the needs of financial resources for reconstruction purposes.

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