SUPPORTING REPORT I

WATERSHED MANAGEMENT

SUPPORTING-I : WATERSHED MANAGEMENT

TABLE OF CONTENTS

SUPPORTING I : WATERSHED MANAGEMENT

LIST OF TABLES

SUPPORTING I : WATERSHED MANAGEMENT

LIST OF FIGURES

SUPPORTING-I
WATERSHED MANAGEMENT

1. GENERAL

1.1 BACKGROUND

The watersheds object of this study are located in the Central District of the Republic of Honduras comprising the urban and rural areas of the cities of Tegucigalpa and Comayaguela, both of them forming the Capital of Honduras.

The coordinates of the Study Area are:

Longitude: 87o 05' and 87o 27' West

Latitude: 13o 55' and 14o 11' North

The main watershed is the Choluteca River (Río Choluteca). It comprises the sub-basins of the main rivers of Guacerique (includes Los Laureles Dam), Grande (includes Concepcion Dam), Sabacuante, Tatumbla and Chiquito, which are object of the present study.

The Study Area basically has two seasons of six months each: rainy and dry. In general the rainy season is from May to October and the dry one from November to April.

The maximum daily rainfall occurred in the Toncontin Meteorological Station was of 185.5 mm on October 1998 during Hurricane Mitch. The maximum monthly rainfall was of 498.6 mm also on October 1998. The maximum annual rainfall has been 1,274.3 mm on 1955.

The maximum monthly temperature registered has been 37.8 oC on April 1973, and the minimum has been 3.9 oC on January 1956.

The Study Area basically is a mountainous land with elevations between 900 masl (area between Barrio El Chile and Buenos Aires) and 1,535 masl (area between El Picacho and Piliguin). However, most of the urban area is located in elevations between 1,000 and 1,300 masl.

The geology of the Study Area consist of sedimentary rocks of the Valle de Angeles group, at the central-eastern part of the Central District, including most of the traditionally regarded as business center of Tegucigalpa and Comayaguela. These rocks consist of characteristically red layers of shale, limolite, sandstone and quartz conglomerates. Such rocks correspond to the beginning of the Tertiary period at the Cenozoic, some 65 million years ago.

The previously mentioned area is surrounded from the south to the northeastern region by old clastic sediments alternating with flows of rhyolite, which is known as the Jutiapa formation. It becomes narrow at the central-western part of the Central District and widen at the south and north- east. This formation corresponds to the end of the Tertiary period.

At the Western side predominate the volcanic areas alternating andesite and basaltic rocks corresponding to the end of Tertiary and beginning of Quaternary, respectively, including several volcanic cones, been one of them and the most relevant the Pedregal Lagoon.

As a consequence of the geological and topographical conditions many wards of the city are prone to landslides, earth collapses, settlements, and floods during the rainy season, which on the other hand produces local migration to other areas within the Central District.

Historically most of the inhabited hilly areas have been located in the Tegucigalpa side and most of the inhabited flat areas have been in the Comayaguela side.

This is consequence of the mining origin of the settlement of Tegucigalpa at the end of 16th century without a formal foundation as a city. The Spaniards made houses at random, at the foot of hills, at the Grande River or Chiquito riverbanks, and at the crest of the La Leona hill. At the outskirts were living the black slaves. Meanwhile Comayaguela was a town of Indians dedicated to agriculture and livestock. When the villages were getting bigger they made a more appropriate urban and future looking layout.

However, at present as the flat areas have became already scarce, the remaining hillsides of both cities are increasingly demanded, especially by the low income population, which will increase further the areas with high gradients and then the problems for supplying the basic public services, and with danger of landslides and earth collapses in risky areas.

1.2 PROBLEMS IN WATERSHED MANAGEMENT

As consequence of the urban expansion in the micro-basins of Tegucigalpa, there has been a continuous deforestation in areas required for housing, industries or other facilities. Besides, in zones near to the urban areas the forest has been cut-off to fulfill the need of firewood. In some cases, due to uncontrolled growth of the urban areas, some human settlements are established legally or illegally in unstable lands which are sites of landslides such as Berrinche, Reparto, Nueva Esperanza, etc. where proper use should be for forest conservation.

Another factor that urban expansion contributes to erosion is the many forest fires which are generated every year at dry season. According to the Anuario Estadístico Forestal, 1997, most of them (54%) are produced by arsonists (incendiarios), and in less degree by agriculture or livestock activities. Forest fires leave the top soil without vegetative cover, making it prone to erosion.

Finally within the watershed there are several quarries for extraction of construction materials. They need to be controlled in order to minimize the erosion and consequent sedimentation. As the land losses its protective vegetative cover, the process of erosion-sedimentation starts, specially in areas of very steep gradients, accumulating much of these soils at the riverbeds. In other cases the riverbeds near bridges become convenient source of sand and gravel for concrete aggregates.

1.3 WATERSHED MANAGEMENT PLAN IN THE STUDY AREA

As described above problems of watershed management are closely related to flood and landslide disasters caused during Hurricane Mitch, and watershed management plan is one of the most important parts of the disaster prevention master plan.

In the Study, however, the relationship between human settlement and landslide dangerous areas were studied in Supporting Report B, Geological Survey. The sediment transport study was done in Supporting Report D, River Bed Material Survey.

Therefore, in this Supporting Report, legal framework of watershed management is studied and recommendations given. However, the main efforts were made for quantitative analysis of soil erosion and sedimentation for each micro-basin of the Study Area.

Through this study priority micro-basins were selected from soil erosion analysis and pilot projects were proposed as priority projects.

2. LEGAL FRAMEWORK

2.1 OVERVIEW

In order to decrease all the negative factors induced by the urban expansion it is necessary the compulsory implementation of the corresponding regulations related to watershed management which are already included in miscellaneous laws. Thus, in the following sections these regulations are reviewed.

2.2 LAW OF NATIONAL WATERS EXPLOITATION

According to the **Law of National Waters Exploitation**, dated from 1927 and still in use, the State has the full control of the rivers excepting those small streams that rise and end at a private property (Art.1). Regarding the water use this old law authorize the free use of waters running along natural and public rivers, either for drinking, washing clothes, containers or other objects, to take baths or drinking for livestock (Art. 9).

Nevertheless, due to its age this law does not consider the environmental aspects concerning the water resources management, and the limitations and compensations for rights of water use, which are now necessary to regulate in more strict way. Thus, a new law is being elaborated from several years ago. During last year and this, the draft of the General Law of Water has being under consideration of several institutions like SANAA, SERNA, ENEE, SAG and CIEL (Computing Center of Legislative Studies of the National Congress). It is expected a final approval to be given from the National Congress very soon.

According to the draft of the new Law of Water the Authority of Water will be designated for regulation of the uses of water. Also it establishes the creation of **water boards** (juntas de agua, in Spanish) and the concept of **ecological discharge** to be fixed for each water body by the Authority of Water according to by-laws (Art.27, 29). The by-laws will define the criteria and ways for estimation of the discharges, volumes, periods and other characteristics for each type of exploitation, for zones, basins or regions, and according to the own hydrological characteristics. It also will indicate the criteria and methods of defining the ecological discharge and calculation of the compensations and indemnities comprised within the law (Art. 29).

2.3 FORESTRY LAW

Decree No. 85 of 10/2/1972 dictated the Forestry Law. It states that the forest zones of the rivers and streams, which comprise the water system of Tegucigalpa, are Protected Forest Zones (Art. 138). Besides, this Decree establishes the prohibition of cutting or destroying trees in a belt of 150 m of each side of permanent rivers or lakes (Art. 95). Furthermore, it states that by no means the State would hand over the control of the public forest areas to private persons without the previous decision of the State Forestry Administration (Art. 37).

This law also introduced the concepts of special areas and national parks, and makes it compulsory the protection of forests against fires and plagues.

On 1974 the COHDEFOR was created. All the activities related to forestry sector (exploitation, industrializing, and commercializing) were transferred to it, as state's activities.

At present this law is being reviewed by the National Congress based on a law project submitted to it by the Secretariat of Agriculture. Purpose of the new law is to avoid legal dispersion or overlapping of regulations, to promote a sustainable forestry development and to provide better incentives for the conservation of forest and its industry.

2.4 PROTECTED FORESTRY ZONES

The Sub-basin of the Guacerique River was declared as Protected Forestry Zone through a Decree of 6/7/1972 published on 3/8/1972, comprising an area of 210.63 km^2.

In similar way, the Sub-basin of the Tatumbla River was declared as Protected Forestry Zone through a Decree of 6/7/1972 published on 3/8/1972, comprising an area of 62.29 km^2.

Concerning to the Sub-basin of the Sabacuante River, by Decree No. 72 of 27/10/1971, and published on 16/11/1972 it was declared as Protected Forestry Zone, comprising an area of 49.65 km^2. It was with the purpose of protecting the watersheds, which can provide water supply to the capital city. The Decree establishes that no one can acquire rights over the forestry areas nor can make forestry exploitations in the private lands without the previous authorization from the State Forestry Administration.

These above mentioned protected areas are located inside of the Study Area.

2.5 GENERAL LAW OF ENVIRONMENT

The General Law of Environment published in 1993 (Decree No. 104), prohibits the location of **human settlements, military bases, industrial or other installations** in the influence area of the water supply sources for the people (Art. 33). Moreover, for the purpose of protection of the dams and reservoirs hydrological ordering projects shall be executed. They will start from the concept of watershed as a unit of operation and management. A hydrologic ordering plan and Environmental Impact Assessment (EIA) shall precede any project of exploitation of water in large scale.

Related with the land use for agriculture and forestry purposes in Art. 50 of this law it is established that: " Soils located in steep gradients, where their exploitation can produce its rapid erosion or landslides, should be kept with permanent vegetative cover".

2.6 AGREEMENT BETWEEN SANAA AND COHDEFOR

There is an Agreement between SANAA and COHDEFOR, signed on 3/12/1991. This document establishes responsibilities of both institutions, in the case of SANAA: the protection and integrated management of the watersheds with water supply systems already constructed or to be in the future. Also SANAA will prepare the inventory of priority basins for the water supply, with the purpose of preparing studies, diagnostics, and management plans for short, medium and long term. These actions are to be undertaken through the department of Watersheds Management, which has to initiate the coverage from the basins of the capital city and later on at the national level. On the other hand, COHDEFOR would provide technical support for the elaboration of the management plans, and would determine its technical regulations. Moreover, the basins qualified as of priority would be declared as forestry protected zones.

This agreement was effective for 5 years up to Dec/1996 and was not renewed until 21/12/1999 for another 5 years with possibility of extension by simple note exchange. This renewal keeps the original purposes and involves the cooperation with the Municipalities where the water supplying watersheds are located, for projects of protection and management of natural resources.

2.7 LAW OF TERRITORY ORDINANCE (DRAFT)

Draft of this law was sent at middle of 2001 from SERNA to the National Congress as a project of law for its approval. However, considering the implications of the regulations on land use it may take long period before its final approval. Nevertheless, it is an international agreement reached during an Ecological Central American Summit held by the Central American presidents on Oct/12/1994. This meeting agreed to initiate the necessary actions for the establishment of the plans of territory ordering.

This project of law establish as basic instrument of the territory ordinance the socio-ecological-economic zoning, which will allow to identify, describe and explain the characteristics of the environmental systems, its potential and limitations.

The socio-ecological-economic zoning will determine 9 areas as follows:

1) Areas of strategic characteristics on the environment, economic, social, touristic, cultural-historic, biologic and others.

2) Agro-ecological spaces to orientate the location of agriculture exploitations including activities of livestock, fishing, forestry.

3) Areas of sustainable use for the formulation of strategies and watershed management

4) Areas of sustainable use for the formulation of strategies and management plans for seashores.

5) Areas for use of human settlements

6) Areas for mining and industrial settlements

7) Sites for storage and treatment of waste

8) Territorial areas under special regulation

9) Corridors or territorial belts for road system, transportation of energy, telecommunications, oil-lines, etc.

2.8 BY-LAWS OF ZONING, URBANIZING, LOTS DIVISION, AND CONSTRUCTION

This law was published in the official newspaper La Gaceta on August/28/1992, as a by-law of the Central District Municipality. Within it, there are several regulations concerning the watershed management.

According to this by-law, all the lands with gradients less than 20% and elevation less than 1,150 masl can be urbanized, excepting areas of landslides (Art.1). All the areas which do not fit into the previous category or those within the limits of landslides are considered afforestation areas (Art.2).

Besides, it establishes the obligation for the contractors who make urbanizations to plant trees in the corresponding streets and keep maintenance of them for at least three years (Art. 134).

Finally it is compulsory for the housing developers to afforest the hills with gradients larger than 20%, with the appropriate species in order to avoid erosion and sedimentation (Art. 136).

2.9 LAW FOR MODERNIZATION AND DEVELOPMENT OF THE AGRICULTURE SECTOR

This law was published in 1992 through Decree 3192. It returns the administration and usufruct (benefit) of forest to their owners in private or common lands (ejidales). AFE-COHDEFOR is assigned the responsibility of management of the national forests as well as to promote, regulate and control the forestry activities, and the administration of protected areas and the wild fauna.

3. SOIL EROSION

3.1 INTRODUCTION

For prioritization of critical degradation areas and planning of soil conservation measures in a watershed management project soil erosion is necessary to be estimated. It is also necessary for the estimation of sedimentation of basins as a ratio of the overall erosion within it.

In this study the erosive quality of the soil is estimated using the Universal Soil Loss Equation (USLE). Originally, the USLE was an experimental equation used to estimate erosion of large models of vast and comparatively flat lands. The values of soil erosion computed by the USLE are best estimates, not absolutes. They will generally be most accurate for medium-textured soils, slopes lengths of less than 122 m, gradients of 3% to 18%, and consistent cropping and management systems that have been represented in the erosion plot studies. The farther these limits are exceeded, the greater will be the possibility of significant extrapolation error.[1]

However, in this case, considering the limitation of methods for estimation erosion in populated areas, and taking into account the Study Area covers more than 70% of unpopulated and mostly forestry or agriculture areas the USLE equation is used as a first trial of estimation.

3.2 UNIVERSAL SOIL LOSS EQUATION (USLE)

The USLE is defined as:

$$A = R \times K \times LS \times C \times P$$

where:

A: Annual soil loss amount (ton/ha/year)

R: Rainfall and runoff factor[2] (J/ha/year)

K: Soil erodibility factor (ton/J)

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[1] Walter H. Wischmeier and Dwight D. Smith, 1978. page 47.

[2] W.H. Wischmeier & D.D. Smith, 1978. page 4.

LS: Slope length - steepness factor, dimensionless

C: Cover and management factor, dimensionless

P: Practice factor, dimensionless

Thus, USLE can be expressed in functions of its units as follows:

A (ton/ha/year) = R(J/ha/year) x K(ton/J) x LS x C x P

Each of these factors are evaluated as described in the following sections.

3.2.1 RAINFALL AND RUNOFF FACTOR, R

The factor R is also known as a rainfall erosion index[3] or rainfall erosivity index[4]. Can be defined as the erosive force of rainfall[5]. Is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant[6].

1) EI Parameter

By definition the EI parameter for a given rainstorm equals the product, total storm energy (E) times the maximum 30-min intensity (I30). EI is an abbreviation for energy-times-intensity.

The storm energy indicates the volume of rainfall and runoff, but a long, slow rain may have the same E value as a shorter rain at much higher intensity. The I30 component indicates the prolonged peak rates of detachment and runoff. The product term, EI, is a statistical interaction term that reflects how total energy and peak intensity are combined in each particular storm. Technically, it indicates how particle detachment is combined with transport capacity.

2) Selection Criteria of Erosive Rainfalls

Rainfall events of less than 12.5 mm (1/2 inch) occurring during an interval of more than 6 hours will not be used in the calculation of the erosivity factor because they are too small in consideration of the interval. However, rainfall events of at least 6.35 mm (1/4 inch) occurring during a 15 minute interval {or a maximum intensity of over 25 mm/hour(1”/hour}) will be used.

Preliminary analysis shows that the EI values of such rains are usually too small for practical use and that collectively they only slightly affect the monthly percentages of the yearly EI values.

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[3] S.J. Goldman, et al, 1986. Erosion and Sediment Control Handbook. McGraw-Hill Publishing Company. New York, page 5.6.
[4] N. Hudson, 1973. Soil Conservation. Batsford Limited, Great Britain, page 179.
[5] USDA, 1980(?). Universal Soil Loss Equation. Caribean Area, Technical Notes, page 4.
[6] W.H. Wischmeier & D.D. Smith, 1978, page 4.

Table I.3.1 Example of Calculation of Rainfall Erosivity Factor R

Date / time	PLUVIOGRAM		INCREMENTS PER RAIN			ENERGY	
	Depth	Dif. Depth	Duration	Quantity	Intensity	per cm	per Increment
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	acum. (mm)	h (mm)	t (min)	H(cm)	I (cm/h)	E′	E
				(3)/10	(5)x60/(4)		(5)x(7)
28/01/2000							
20:00	0.00						
:10	0.20	0.20	10	0.02	0.12	128	3
:20	2.50	2.30	10	**0.23**	1.38	222	51
:30	4.30	1.80	10	**0.18**	1.08	213	38
:40	5.50	1.20	10	**0.12**	0.72	197	24
:50	7.20	1.70	10	0.17	1.02	211	36
21:00	8.30	1.10	10	0.11	0.66	194	21
:10	9.80	1.50	10	0.15	0.90	206	31
:20	10.10	0.30	10	0.03	0.18	144	4
:30	10.20	0.10	10	0.01	0.06	101	1
:40	10.50	0.30	10	0.03	0.18	144	4
:50	10.80	0.30	10	0.03	0.18	144	4
22:00	11.10	0.30	10	0.03	0.18	144	4
:10	11.20	0.10	10	0.01	0.06	101	1
:20	11.50	0.30	10	0.03	0.18	144	4
:30	11.80	0.30	10	0.03	0.18	144	4
:40	11.90	0.10	10	0.01	0.06	101	1
:50	12.00	0.10	10	0.01	0.06	101	1
23:00	12.00	0.00	10	0	0.00	0	0
:10	12.00	0.00	10	0	0.00	0	0
:20	12.00	0.00	10	0	0.00	0	0
:30	12.10	0.10	10	0.01	0.06	101	1
:40	12.10	0.00	10	0	0.00	0	0
:50	12.20	0.10	10	0.01	0.06	101	1
00:00	12.20	0.00	10	0	0.00	0	0
:10	12.40	0.20	10	0.02	0.12	128	3
:20	12.50	0.10	10	0.01	0.06	101	1
		12.5	260	**0.53**	$=I_{30}$		239
KINETIC ENERGY OF THE STORM:						$Ex10^{-2}$=	2.39
						R = $ExI_{30}x2$=	3

Accordingly, setting the threshold at 12.5 mm largely reduces the costs involved in analyzing thousands of intensity data per year.

Studies have shown that the mean size of raindrops does not continue increasing for intensities over 7.6 cm/hour[7]. If the duration of rain is less than 30 minutes, I30 shall be twice the amount of rain for this duration.

[7] W.H. Wischmeier & D.D. Smith, 1978, page 5.

3) Calculation Method of Factor R

The kinetic energy of a given amount of rain depends on the final size and velocity of the raindrops, which are also related to the rain intensity. In *Table I.3.1* it is shown an example of the calculated energy for each centimeter of rain for every intensity. The energy (E) of a given rain depends on the rain intensity and amount, and R is influenced by E and the I30 value.

Intervals in the time of rainfall in column (1) of *Table I.3.1* leads to rainfall duration in column (4). The difference between the depths of rainfall in column (3) was used to determine the values in column (5). Multiplying the values in column (5) by 60 and dividing the result by the values in column (4) determined intensity in column (6). The energy per cm of rain in column (7) was obtained by using the formula E' = 210 + 89 × Log I, with the values in column (6) representing I, or by inferring the values in column (6) to the known values in *Table I.3.2*. Column (8) of *Table I.3.1* is the result of multiplying the values in column (5) by column (7).

Table I.3.2 Kinetic Energy of Rain, E', (ton-m/ha/cm)

Intensity (cm/h)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0 ..	0	121	148	163	175	184	191	197	202	206
1 ..	210	214	217	220	223	226	228	231	233	235
2 ..	237	239	241	242	244	246	247	249	250	251
3 ..	253	254	255	256	258	259	260	261	262	263
4 ..	264	265	266	267	268	268	269	270	271	272
5 ..	273	273	274	275	275	276	277	278	278	279
6 ..	280	280	281	281	282	283	283	284	284	285
7 ..	286	286	287	287	288	288	289			

The values were determined using the equation E' = 210 + 89 × LogI, where
E' = kinetic energy in ton-m/ha/cm
I = intensity of rain in cm/hour
The value of 289 in this Table is also applied to all rainfall intensities exceeding 7.6 cm/hour (or 3″).

The example of *Table I.3.1*, corresponds to the total energy of a 4h20' rainfall of January 28th, 2000, which is 239 tons - m/ha, that is then multiplied by a constant factor of 1/100 to convert the energy of rain to the dimensions in which the values of EI are expressed. Resulting 2.39, which multiplied by I30x2 gives the final value of R=3 for such rain.

The total amount of rainfall during a 30 minute period, from 20:10 to 20:40, was 0.53 cm (0.23 + 0.18 + 0.12). The R factor was calculated using the formula R = ExI30x2 = (2.39) × (0.53)× 2 =2.53 ~ 3.

The EI value for a specific time is the summation of the calculated values for all the significant rain periods within that time.

4) Average Value of R

The annual value of the Erosion Index R is the summation of all values within that year. The average for several years is the summation of the yearly values divided by the number of years.

It is advisable to analyze data taken for the past 10 years. In Tegucigalpa, only the Pluviographic station of Toncontin Airport has continuous data from 1965 (35 years), while the Pluviographic station of SOPTRAVI installed by JICA on 1994 has only 7 years data, although some years uncomplete. Thus, the Toncontin data were used.

Firstly the erosive rains produced in each station were duly classified for the period 1990-2000 as shown in *Table I.3.3.* Among them, it is observed that 1998 produced the largest number of erosive rains with 50 against the average, that is 32.

Table I.3.3 Number of Erosive Rains and Annual Rainfall (1990-2000)

Year	No. Erosive Rains	Annual Rainfall (mm)
1990	28	674.5
1991	25	595.3
1992	33	728.4
1993	34	948.1
1994	21	620.9
1995	44	1,146.0
1996	41	899.5
1997	25	865.6
1998	50	1,179.8
1999	30	885.6
2000	23	791.9
Average	**32**	**883.45**

Besides, it is worthy to mention that according to specific analyses performed for the period during Hurricane Mitch it produced seven (7) separated erosive rains, summing up a value of R=102 in one week period of the hurricane (October 27th through 31st of 1998).

With the purpose of reference in the same *Table I.3.3*, the annual rainfall during the analyzed period was compared. It can be observed that roughly there is some relationship between the amount of erosive rains and the final value of the rainfall for each year. This fact will induce to the looking of some correlation between both parameters.

Therefore, the R-value used in the USLE calculation is the average R-values of eleven years records of rains in Toncontin Airport Station taken as a base. The correlation between Rainfall and Erosion Index R finally produced the equation Y=0.337X-3.5337 with a correlation coefficient of R2=0.7701 which is low, but the amount of data is few (11 years). It is expected with more data and preferably with other pluviographic stations located in mountainous areas the correlation would be better. Subsequently the R values of the other stations in the watershed have been calculated by using a correlation equation obtained from the monthly data of rainfall and R values of Toncontín Airport Station, as seen in *Figure I.3.1*.

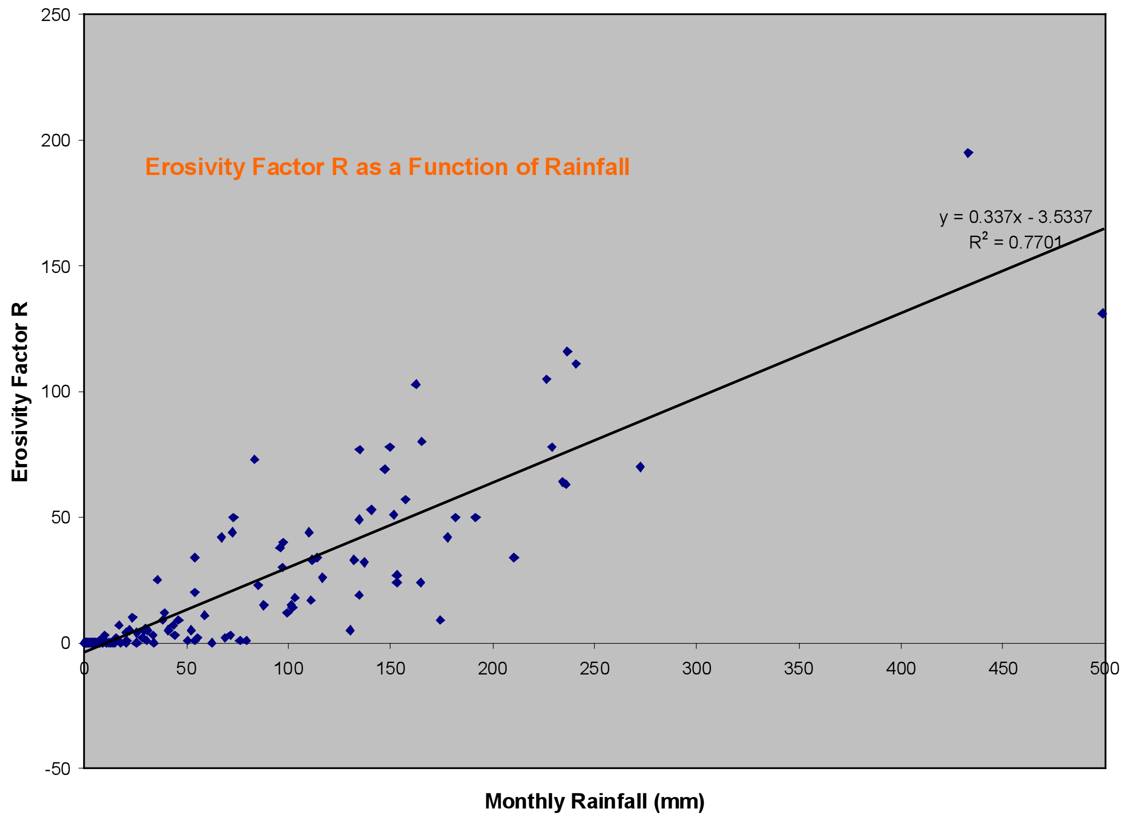

Figure I.3.1 Factor R as a Function of Rainfall

Thus, the corresponding values of R for the remaining eight (8) stations of the watershed were estimated as shown in *Table I.3.4* and *Figure I.3.2* and finally the distribution of R along the whole watershed is shown in the R map of *Figure I.3.3*.

Table I.3.4 Location of Pluviometric Stations and R Values

Code	Station Name	Latitude	Longitude	R Value
121	Concepción	14° 01' 00" N	87° 20' 00" W	331
176	Lepaterique	14° 03' 00" N	87° 27' 00" W	446
204	Toncontin	14° 03' 31" N	87° 13' 10" W	244
207	Santa Lucía	14° 07' 00" N	87° 07' 00" W	372
208	Col. 21 de Octubre	14° 06' 00" N	87° 12' 00" W	294
211	Villa Real	13° 59' 29" N	87° 09' 30" W	326
212	El Batallón	14° 04' 00" N	87° 15' 36" W	297
215	Quiebramontes	14° 05' 12" N	87° 18' 14" W	358
218	La Brea	14° 03' 12" N	87° 23' 29" W	457

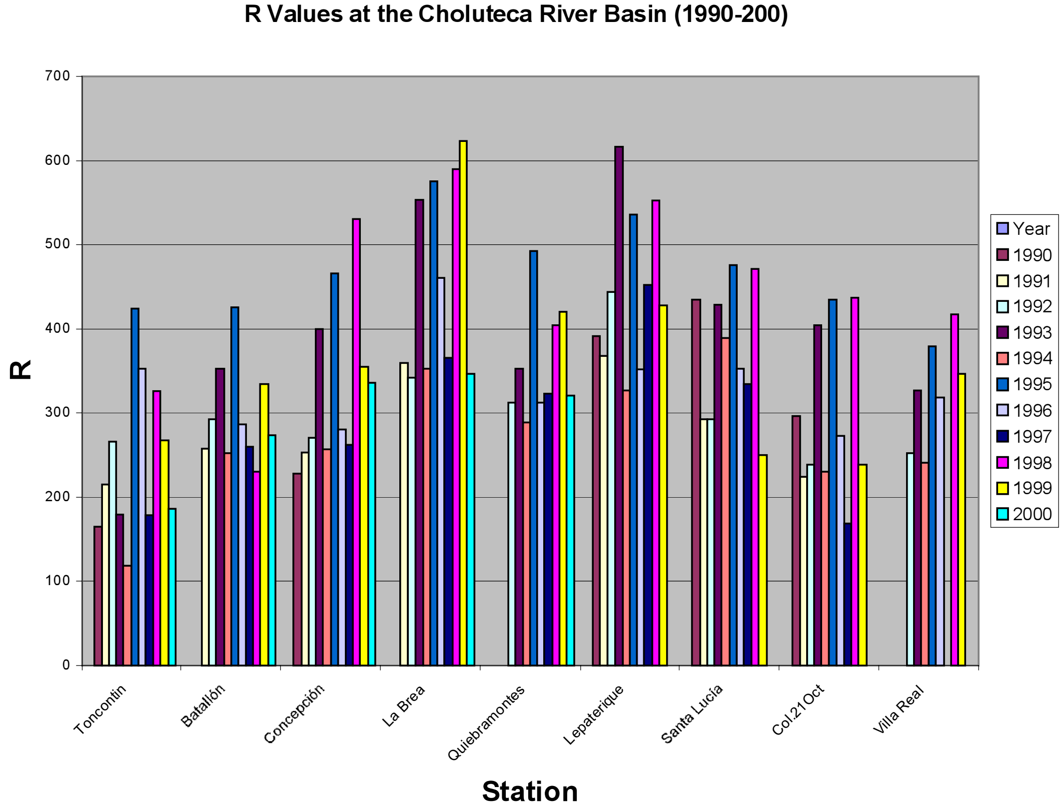

Figure I.3.2 Values of R at the Choluteca River Basin (1990-2000)

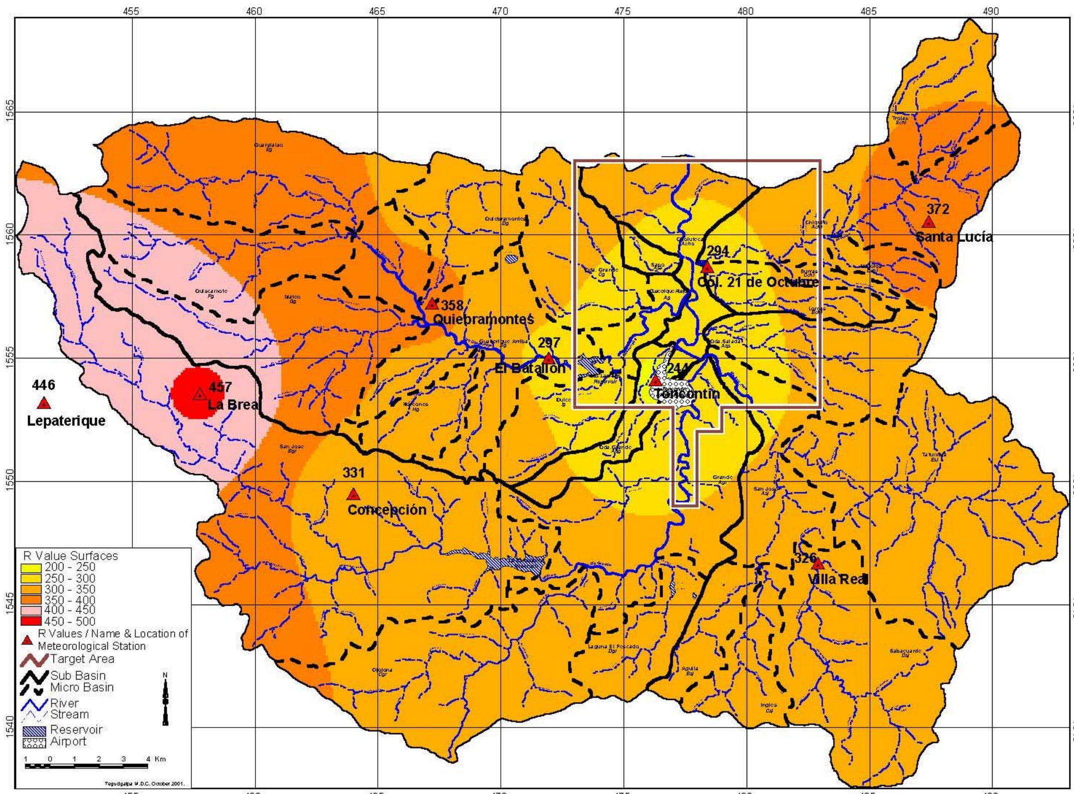

Figure I.3.3 Distribution of R along the Micro-basins in the Study Area

It can be observed that factor R is larger at the mountain side, influenced by the typical rainfall in those areas.

For more accurate values of R it is recommended in the future to analyze a larger series of data rainfall data as well as cover some other stations which could not be considered this time due to incomplete data.

3.2.2 SOIL ERODIBILITY FACTOR, K

The erodibility of the soil is the susceptibility to erosion, which is the reciprocal of its resistance to erosion. It is represented by K in the USLE. For a particular soil, the erodibility factor is the rate of soil loss per erosion index unit as measured on a "unit plot", arbitrarily defined as follows: A unit plot is 72.6 feet (22.13 m) long with a uniform lengthwise slope of 9 percent, tilled longitudinally and fallowed for more than 2 years.

In such a condition, the value $LS \times C \times P$ becomes 1 and then soil loss becomes A=RK, therefore $K = A/R = A/\Sigma(EI)$.

K can be estimated by using the following equation[8]:

$$K = 2.1 \times 10^{-6} \times M^{1.14} \times (12 - a) + 3.25 \times 10^{-2} \times (b - 2) + 2.5 \times 10^{-2} \times (c-3)$$

where:

M	=	(100 - clay ratio (%)) [% (silt + fine sand)] is a particle size parameter
a	=	organic matter ratio (%)
b	=	soil structure code
c	=	profile-permeability class

Estimation of the Particle Size Parameter, M

The factor M will be estimated in this study by the grain size analysis of soils in the basin.

Estimation of Organic Materials, a

Organic materials are to be analyzed for the top soils to be sampled.

Estimation of Soil Stucture Code, b

The soil structure code, b, is classified as follows:

1. very fine grained
2. fine grained
3. medium or coarse grained
4. blocky, platy, or massive

[8] W.H. Wischmeier & D.D. Smith, 1978, page 10

Estimation of Profile Permeability Class, c

The Profile Permeability Class is divided as follows (Whischmeier, 1978):

1. rapid
2. moderate to rapid
3. moderate
4. slow to moderate
5. slow
6. very slow

The Coefficient of Permeability is classified in *Table I.3.5*.

Table I.3.5 Soil Classification according to Coefficients of Permeability

Degree of Permeability	Coefficient of Permeability (cm/sec)	Typical Soil
High	more than 1×10^{-1}	coarse gravel
Medium	1×10^{-1} ---- 1×10^{-3}	sand, fine sand
Low	1×10^{-3} ---- 1×10^{-5}	silty sand, dirty sand
Very low	1×10^{-5} ---- 1×10^{-7}	silt, fine sandstone
Almost impermeable	less than 1×10^{-7}	clay

Sources: 1) Karl Terzaghi & Ralph B. Peck, 1967. Soil Mechanics in Engineering Practice, 2nd John Wiley &Sons, page 381. 2) George B.Sowers et al, 1972. Introducción a la Mecánica de Suelos y Cimentaciones, Limusa-Wiley S.A. México, page 130

Finally the results of K for 14 samples taken along the watershed are shown in *Table I.3.6* and Appendix I.1.

Table I.3.6 Values of K for Samples Taken along the Watershed

Sample No.	1	2	4	6	7	9	10	11	12	13	15	16	19	20
K	0.95	0.58	0.64	0.15	0.09	0.34	0.94	0.42	0.67	0.32	0.48	0.36	0.54	0.31

As can be observed, such values vary from 0.09, high resistance to erosion for a gravelly soil, to 0.97, highly susceptible to erosion for a fine sandy-silty soil.

3.2.3 Topographic Factor, LS

LS is the expected ratio of soil loss per unit area between a field slope and a model slope with a length of 72.6 feet (22.13 m) and a uniform lengthwise slope of 9%, under otherwise identical conditions.

The estimation of the soil loss can be obtained by the equation:

$$LS = (L/72.6)^m \times (65.41 \sin^2 Z + 4.56 \sin Z + 0.065)$$

where:

L = slope length in feet

Z = angle of slope

m = according to the following given values for slope % (*Table I.3.7*):

Table I.3.7 m Values in Function of Slope Gradient

Slope Gradient (%)	Value of m
<1.0	0.2
≥1.0 to ≤3.0	0.3
>3.0 to <5.0	0.4
≥5.0	0.5

Source: Walter H. Wischmeier and Dwight D. Smith, 1978.

The previous equation was derived for cropland slopes with a gradient ranging from 3 to 18% and a length of 30 to 300 feet (9 to 90 m), and natural rainfall conditions in these slopes. The corresponding values and areas to be affected by LS are measured by using aerial photographs or satellite images.

3.2.4 COVER AND MANAGEMENT FACTOR, C

Factor C in the soil loss equation is the ratio of soil loss in a land cropped under specific conditions to the corresponding loss in a clean-tilled, continuous fallow.

This factor measures the combined effect of all the interrelated cover and management variables.

The values of C used in this study are as shown in *Table I.3.8* below. Such factors are applied to the measured areas of the actual land use map obtained by analyzing aerial photographs. The classification of land use for the whole Study Area is shown in *Figure I.3.4* and *Table I.3.9*.

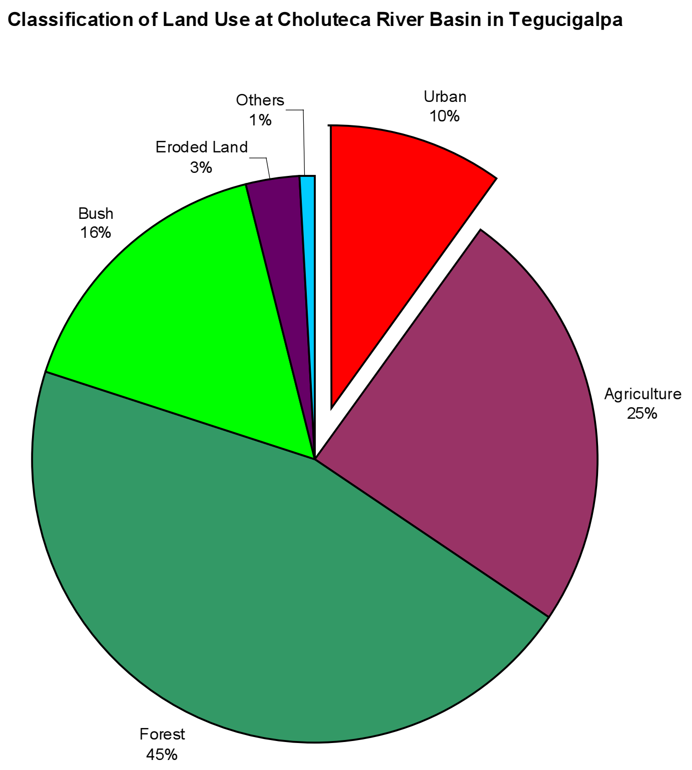

Figure I.3.4 Classification of Land Use at the Study Area

(Sources: 1) Aerial photographs of February 2001 (this study) 2)Land Use Map scale 1:100,000 of ITS/C. Lotti & Associati, 1987, Proyecto Agua Subterránea y Montaña El Chile para Tegucigalpa.)

Table I.3.8 Values of C Factor for Several Land Use Conditions

CODE	Land Use Type	C Factor
101	Urban area, high density pop., capital city (Area urbana, alta densidad poblacional, ciudad capital)	0.01
110	Urban area, medium density pop., municipalities, main cities (area urbana, densidad poblacional media, munipios y ciudades principales)	0.015
120	Urban area, low density pop., town, hamlets (area urbana, baja densidad poblacional, pueblos y aldeas)	0.02
402	Citrics (cítricos)	0.01
409	Basic cereals (granos básicos)	0.3
415	Basic grain and vegetable rotation (rotación granos básicos y verduras)	0.3
425	Natural pasture (pasto natural)	0.032
424	Cultivated pasture (pasto cultivado)	0.005
427, 428	Basic grain pasture rotation (rotación granos básicos y pasto)	0.037
451	Pine Forest (bosque de pino)	0.021
452	Wide leaf forest (bosque latifoliado)	0.014
453	Mixed forest, pines predominant, (bosque mixto, pino predominante)	0.036
454, 456	Mixed forest, wide leaf predominant (bosque mixto, latifoliado predominante)	0.023
457	Oak forest constituted by oak, though occasionally there may be pines (bosque de roble, aunque ocasionalmente puede haber pino)	0.020
458	Thicket, wide leaf trees forest made up of many species with may be pines (maleza, bosque de latifoliado de muchas especies, donde puede haber pinos)	0.087
460	Erosioned and vacant lands, landslides, etc. (tierras erosionadas, deslizamientos, etc.)	0.65
1,000	Water surfaces, reservoirs, rivers (superficies de agua, embalses, ríos)	0.000

Sources: 1) Aerial photographs of February 2001 (this study) 2) Land Use Map scale 1:100,000 of ITS/C. Lotti & Associati, 1987, Proyecto Agua Subterránea y Montaña El Chile para Tegucigalpa. 3) S. Savgoroniadya de C., 1990. Trabajos Geomorfológicos Cuantitativos. Proyecto de Manejo y Conservación de los Recursos Naturales Renovables de la Cuenca del Embalse El Cajón.

In *Table I.3.9* the percentages are referred to the whole Study Area. In general it can be observed that forest cover still remains as 45.7% of the total. Agriculture lands makes about 25% at the highlands. The urban areas correspond to 10% in total and they produce the pressure to convert bush areas (16.1%) in urbanized lands in the near future.

At the category of sub-basins we have that forest is remaining only in some of them such as the Grande River (17.4%) and Guacerique (12.5%) while the San José River (9.3%) and the Chiquito River (4.4%) have less portion of forest. This condition will have effect in similar magnitude on the susceptibility to erosion for each of the sub-basins.

3.2.5 SUPPORT PRACTICE FACTOR, P

The support practice factor, P, is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope cultivation.

P was assumed as P=0.95, considering almost lacking of soil conservation practices within the basin.

3.2.6 INTER-RELATIONSHIP AMONG USLE PARAMETERS

The inter-relationship among all these factors is shown in the Flow Chart of USLE (*Figure I.3.5*).

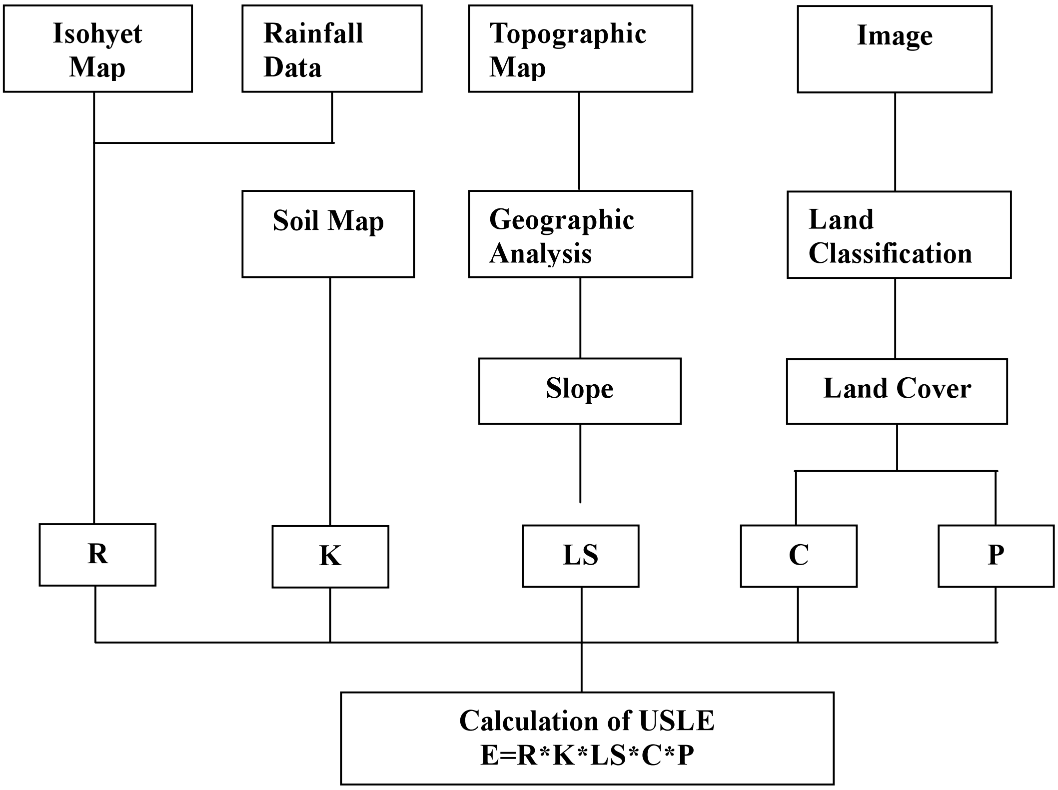

Figure I.3.5 Flow Chart for Soil Erosion Estimation by USLE

3.3 RESULTS OF POTENTIAL EROSION

The values of potential erosion were ordered according to the "Provisional Classification for the Evaluation of Degradation of Soils" (Clasificación Provisional para la Evaluación de la Degradación de los Suelos) established by FAO/PNUMA/UNESCO (1981), as follows:

Soil Loss (Ton/ha/year)

‹10	None or slight
10-50	Medium
50-200	High
›200	Very high

Table I.3.10 Distribution of Soil Losses in the Study Area

No.	Code	Sub-Basin	Micro-basin	Soil Loss (mm/year)	Potential Erosion E (Ton/ha/year)
					High:
1	Acho	Choluteca	Choluteca	12.6	157.74
2	Achi	Chiquito	Chiquito	6.9	85.64
3	Dsj	San Jose	Sabacuante	6.3	78.88
4	Cg	Guacerique	Qda. Grande	6.2	77.07
5	Dgr	Grande	Lag. El Pescado	6.0	75.38
6	Dchi	Chiquito	Mololoa	4.8	60.10
					Medium:
7	Cgr	Grande	Ojojona	3.8	47.74
8	Csj	San Jose	Ingles	3.6	45.63
9	Agr	Grande	Grande	3.6	45.03
10	Esj	San Jose	Tatumbla	3.5	43.90
11	Asa	Sapo	Sapo	3.4	42.44
12	Dg	Guacerique	Quiebramontes	3.1	38.42
13	Echi	Chiquito	Trojas	2.8	34.87
14	Bchi	Chiquito	Lomas	2.7	33.84
15	Asj	San Jose	San Jose	2.4	30.50
16	Bg	Guacerique	Guacerique Arriba	2.0	25.26
17	Hg	Guacerique	Horcones	2.0	25.02
18	Cchi	Chiquito	Burras	2.0	24.67
19	Bsj	San Jose	Aguila	1.9	24.33
20	Bgr	Grande	San Jose	1.9	23.70
21	Ag	Guacerique	Guacerique Abajo	1.4	17.41
22	Aqs	Qda. Salada	Qda.Salada	1.3	16.29
23	Ig	Guacerique	Dulce	1.3	16.29
24	Eg	Guacerique	Guaralalao	1.0	12.51
25	Aqg	Qda.Grande	Qda.Grande	1.0	12.22
26	Fg	Guacerique	Quiscamote	1.0	12.07
					Slight:
27	Gg	Guacerique	Mateo	0.8	9.71
		TOTAL:		3.3	41.36

Table I.3.10 shows the general results of potential erosion. Besides, *Figure I.3.6* and a map scale 1:50,000 attached to this report, show the distribution of potential erosion along the watershed. It can be observed that there are six (6) micro-basins classified as of heavy potential erosion. The remaining correspond to moderate and slight potential erosion.

According to field observation it could be confirmed that the theoretical results fit rather well with the present conditions at the field. However, it must be pointed out that the land use data corresponding to the Target Area (105 km^2 within the watershed) were obtained from aerial photographs taken on February 2001 during this study, while the land use data corresponding to the rest of the area (715 km^2) were obtained from the Land Use Map scale 1:100,000 of ITS/C. Lotti & Associati, 1987, Proyecto Agua Subterránea y Montaña El Chile para Tegucigalpa.

Thus, although absolute values of potential erosion may not be highly accurate for each micro-basin, as there is no method enough precise for so large watershed, what we can say after the field inspection is that trend of erosion is consistent with the numerical results.

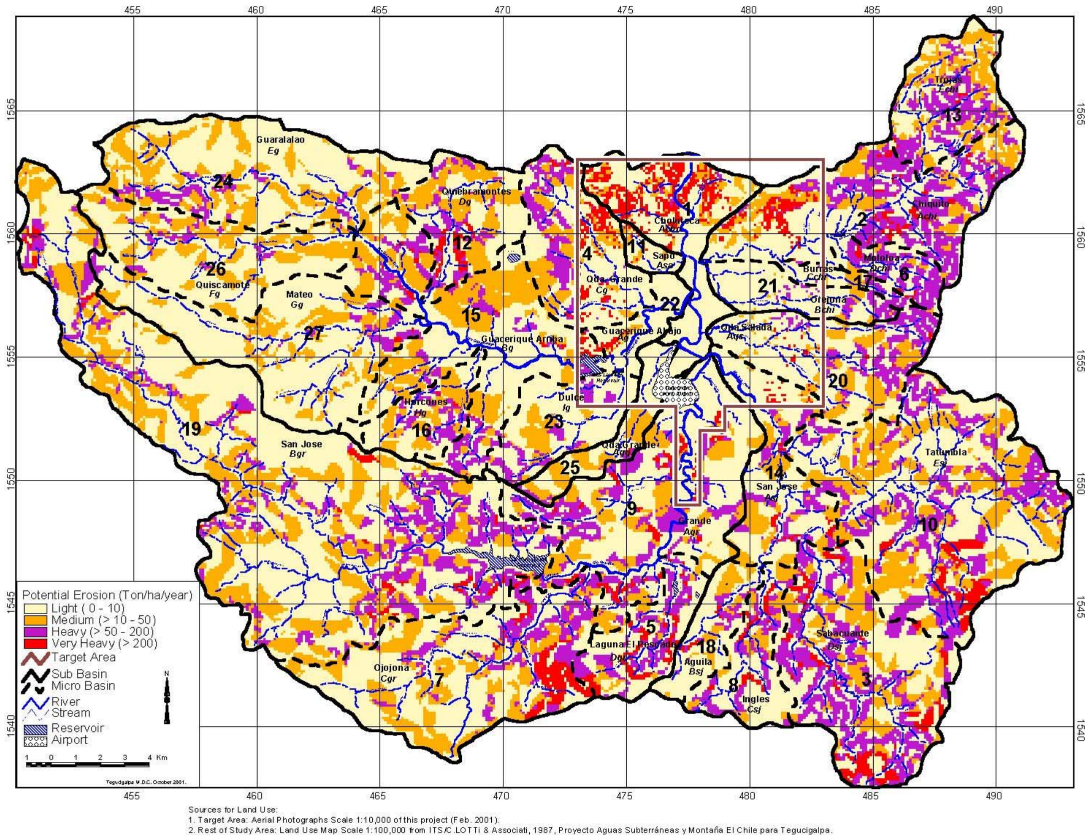

Figure I.3.6 Map of Potential Erosion at the Micro-basins of Tegucigalpa Area

Therefore considering the mathematical results of potential erosion the order of priority is that shown previously.

Table I.3.11 shows the land use conditions in the six most priority micro-basins. Percentages are referred to the several land use components. It can be observed that in general the degradation of these areas is highly related with the urban developments, the lack of forest or the intensive agricultures activities.

Table I.3.11 Distribution of Land Use in the Critical Micro-basins (Km^2)

No	Code	Micro-basin	TotalArea	Urban	%	Agric	%	Forest	%	Bush	%	Eroded	%	Others	%
1	Acho	Choluteca	24.89	10.52	42.3	0.11	0.4	3.69	14.8	0.35	1.4	9.54	38.3	0.69	2.8
2	Achi	Chiquito	41.43	7.13	17.2	7.47	18.0	16.61	40.1	6.85	16.5	3.16	7.6	0.22	0.5
3	Dsj	Sabacuante	47.49	5.63	11.8	23.17	48.8	3.66	28.8	5.04	10.6	-	-	-	-
4	Aqg	Qda.Grande	10.42	2.15	20.6	0.74	7.1	2.39	22.9	3.89	37.3	0.20	1.9	1.06	10.2
5	Dgr	Lg. Pescado	15.51	0.94	6.1	6.65	42.9	4.25	27.4	3.49	22.5	-	-	0.18	1.2
6	Dchi	Mololoa	7.30	0.22	3.0	2.26	31.0	3.23	44.2	1.59	21.8	-	-	-	-

Here it is worthy to analyze the top critical micro-basins as follows:

3.3.1 MICRO-BASIN OF CHOLUTECA *(PHOTO I.3.1)*

Total area of this micro-basin is 24.89 km^2, and start at confluence of the San José River and Quebrada Grande with the main Choluteca River at the North of the Toncontin Airport. However, the critical areas of highly potential erosion are only 5.3 km^2 (21% of the total), although eroded areas in different degrees arise to 9.5 Km^2 (38%) and according to the Erosion Map are located just from Berrinche Landslide following to the north until Point A at the exit of the basin at both sides of the Choluteca River. Most of it correspond to steep gradient areas suitable for dense forest. At present it has been converted into bush after having a forest cover of pine as still can be seen in areas where this tree scarcely remains. It can be observed a great pressure of urbanizing this area which is the exit to the main roads (old at right and new at left margin) to Olancho Province. Consequently, people of neighborhood has cut trees either for own domestic use of for selling as firewood. As at present this area has more than 42% of urban area it is estimated in several years more of this would become urbanized area, as several housing developments are underway. Several urban developments initiated as settlements ("invasiones") in rather unstable areas like Miramesí, Sagastume and others, which are located in ancient landslides from El Picacho Hill. Thus, in practice the development of erosion/sediment control works in these areas, besides the ones already in planning stage for Berrinche area in the same micro-basin, comparatively may become rather difficult due to the land tenure and future use within urban areas. Besides, the erosion/sediment control effects for the Study Area (including the Tegucigalpa city) are insignificant because the zone is the outer of the watershed, and no considerable benefit can be expected for upstream areas of the watershed.

Nevertheless, for areas where still urbanizing may be delayed it is recommended the afforestation with native trees specially pine and simultaneously soil protection with local grasses like Vetiver grass (Valeriana).

Photo I.3.1 Deforested Lands Converted to Bush at Choluteca Micro-basin at the Exit of Watershed.

3.3.2 MICRO-BASIN OF THE CHIQUITO RIVER *(PHOTO I.3.2)*

The micro-basin has a total area of 41.43 km^2. It has about 15 km^2 (36%) of high potential erosion, i.e. three times area of that of Choluteca micro-basin. The critical areas are widespread along the micro-basin from the upstream of the Chiquito River at the Santa Elena and Jabonera streams where the river start at the norht-east, up to several small streams areas at Barrio El Rincón at the north near El Reparto Landslide.

This micro-basin still has a 40% of forest cover, the north portion belongs to La Tigra National Park. Forest is distributed as: pine trees below 1,500 masl, mixed forest between 1,500 and 1,700 masl, and broadleaves above 1700 masl. The urban areas and agriculture activities are increasing (17% and 18% respectively). So it is urgent to start erosion-sediment control works in these areas.

Inside of this micro-basin there are two big landslides, one of about 700mx350m (similar magnitude than Berrinche landslide), and other of about 100mx50m. During Hurricane Mitch both of them became debris flows totally (smallest one) or in portions (biggest one) and produced many damages cutting the road from Tegucigalpa to Valle de Angeles city, and washing out several houses on the way.

The landslides have been triggered by the long rainfalls of the Hurricane Mitch. However, the instability of these areas is related with their geological origin. Although the basement is composed of very faulted Cretaceous rocks (shale, siltstone and sandstone) of the Chiquito River Formation (Valle de Angeles Group), the surface materials in the largest landslide correspond to a layer of several meters of volcanic rocks belonging to the Padre Miguel Group of the Tertiary period, younger than the basement, and is composed of a sequence of ignimbrites of rhyolitic/dacitic/andesitic tuffs. This is mainly located at Cerro El Granadillo (a hill of 2,000 masl) where the landslide seems to come from. It can be say too that the remaining volcanic material of the surface is sliding on the sedimentary basement.

Other factors which influence the instability are the topographical conditions (33% to 63% gradients) and the sudden change of land use (from dense forest to agriculture), which has occurred in this area in the last decades.

Anyway, for these areas of landslides a detailed geological and geotechnical study is necessary in order to determine the sliding mechanism and its stabilization procedure.

Nevertheless, all the possible these areas should be returned to its original use as forest, because it is established by law as it belongs to La Tigra National Park, which do not allow intensive agriculture activities.

Besides the structural measures proposed in this study, the concerned institutions like SOPTRAVI, COHDEFOR, SANAA, and AMDC should negotiate with the local farmers in order to shift from the present land use, initiating a large scale afforestation program in exchange of incentives which can be given in the way of technical cooperation or economic one. Alternatively, the Secretariat of Agriculture should extend technical cooperation on soil conservation technology.

After Hurricane Mitch FAO acknowledged the importance of this area for conservation and was working about two years in this zone to make afforestation with coffee trees and Vetiver grass terraces, but failed because of deficient nurseries. Also before Mitch, USA-AID was giving technical cooperation local peasants with the aim to work in hillsides. This was done through the project called LUPE, or Land Use Productivity Enhancement (?), which is not operating any more. The effects of their work cannot be observed now.

Photo I.3.2 Location of Landslides at Santa Elena Stream (right up), and Jabonera Stream (left up). This Zone is Selected for the Pilot Project Area due to its Degradation Condition.

3.3.3 MICRO-BASIN OF SABACUANTE *(PHOTO I.3.3)*

The micro-basin has a total area of 47.49 km^2. It has about 18 km^2 (38%) of high potential erosion. The critical areas are widespread along the micro-basin but specially large in areas of elevations between 1800 to 1900 masl at the southern portion of the watershed, at Montaña de Izopo, where forest (29%) is gradually been replaced by agriculture activities and bush (60%). Land use is distributed as follows: pine trees at the south, oak trees at west, bush, mixed forest and agriculture lands at center.

Photo I.3.3 Deforested Highlands at Sabacuante Micro-basin. Eroded Areas Can be Observed Inside.

3.3.4 MICRO-BASIN OF QUEBRADA GRANDE (PHOTO I.3.4)

The micro-basin has a total area of 25.14 km^2. It has about 4 km^2 (16%) of high potential erosion. The critical areas are located upstream in almost urbanized zones bordering with the micro-basin of the Choluteca River. About 57% of the total area is occupied by urban and bush areas, thus decreasing the forest area which is estimated in 23%.

Photo I.3.4 Urban Expansion at Quebrada Grande Micro-basin (Guacerique Sub-basin). At the Bottom of Cerro Pedregal New Illegal Human Settlements of Cardboard Houses Can be Observed (Upper Center)

3.3.5 MICRO-BASIN OF LAGUNA EL PESCADO (PHOTO I.3.5)

The micro-basin has a total area of 15.51 km^2. It has has about 5.8 km^2 (37%) of high potential erosion. The critical areas are located upstream bordering the micro-basin of Ojojona at Cerro de Hule. About 65% of the total area is occupied by agriculture activities and bush areas, decreasing the forest area estimated in 27%. However, after Hurricane Mitch, the neighbors and some NGO´s are taken awareness and are planting trees for afforestation of the upper areas.

Photo I.3.5 Start of Micro-basin of Laguna El Pescado at Cerro de Hule.

3.3.6 MICRO-BASIN OF MOLOLOA. *(PHOTO I.3.6)*

The micro-basin has a total area of 7.30 km^2. It has about 3.6 km^2 (49%) of high potential erosion. The critical areas are located in recently deforested areas becoming urban settlements of wood and carboard houses which are being installed at the hills aside of the Mololoa stream. About 53% of the total area is occupied by agriculture activities and bush areas.

Photo I.3.6 Micro-basin of Mololoa