- Sampling sites were located using available topographical maps made in 1970. However, during the sampling campaign, it was discovered that many roads and access to sampling sites no longer existed or could be accessed only by mules, so it was impossible to get the sampling sites within the available time.

- Many farmers in the basin did not allow entering their properties to take soil samples. They claimed not to be interested in collaborating with the project.

Table 3.25 shows how the final sampling sites were distributed along the different criteria used in the sampling design (GEOLOGY, LANDUSE or EDAPHOLOGY). Zones not important from the project point of view get less sampling weight or no samples at all, mainly based on following considerations:

- Pesticides are mostly used in the banana sector.
- The banana sector is mainly located in alluvial deposits which primarily consist of silty sandy soils.
- From the point of view of edaphology, the banana sector is mainly located in Tropofluvents Soils.

Table 3.25. Zoning of soil samples based on available information for the Chaguana river basin

Information type used in sampling design		Distribution of samples in a zone	
Geology	Alluvial Deposits [a]	22	78.57 %
	Cretasic Formation	5	17.86 %
	Metamorphic Formation	1	3.57 %
	Intrusive rock	0	0.00 %
Land use	Banana Sector [a]	15	53.57 %
	Pasture Areas and Other Crops	5	17.86 %
	Hilly Areas	8	28.57 %
	Shrimp Farms Area	0	0.00 %
Edaphology	Tropofluvents [a]	10	35.71 %
	Skeletal Haplustalfs	6	21.43 %
	Dystropets	6	21.43 %
	Tropaquepts	3	10.71 %
	Haplustalfs	2	7.15 %
	Typic Ustifluvents	1	3.57 %
	Salorthids	0	0.00 %

(a) Zones where banana farms are located

3.7.2. LAB ANALYSIS AND RESULTS

Every sample was tested to determine parameters such as organic matter content, soil-water content, bulk density and texture. A summary of test results and some statistics are presented in Table 3.26. In the table, it is also shown the testing methods used during lab analysis. The reader should refer to those methods for further details. Each parameter can be grouped in such a way that a normal distribution can be obtained. For this type of distribution, it is expected that around 68% of the data is found within one standard deviation for the total sampling population.

Table 3.26. Statistical parameters obtained from the analysis results

	%Organic Matter	*% Water Content*	*Bulk Density (kg/m³)*	*% Sand*	*% Silt*	*% Clay*
Testing Method	ASTM-D2974-00	ASTM-D2216-98	ASTM-D2937-00e1	ASTM-D422-63	ASTM-D422-63	ASTM-D422-63
Range	0.13 – 2.01	7.53 – 53.15	1777 – 1078	6 – 99.5	0.4 – 78	0.1 – 73
Mean (X)	1.16	31.11	1409.62	41.3	40.58	18.11
Stand. deviation (s)	0.51	10.44	186.65	24.82	20.92	15.33

When evaluating the stratified sampling, it is desired that every stratum gets a representative number of samples within one standard deviation region and this for each sampling criterion. This statement should hold for every measured parameter. For every parameter data can fall in any of the following regions:

- Region S1:   -1 standard deviation (s) to 1 standard deviation (s)
- Region S2:   -2s to -1s, and 1s to 2s
- Region S3:   -3s to -2s, and 2s to 3s

Table 3.27 shows the sampling distribution within each stratum for every sampling criterion (LANDUSE, GEOLOGY and EDAPHOLOGY). For example, for the LANDUSE Criterion (Banana farms, Hilly areas and Pasture areas; Shrimp farms do not receive any sampling weight), the standard deviation for the organic matter content is 0.51% (Table 3.26). If we consider the Banana Farm Sector in the LANDUSE criterion, it can be seen that around 73% of the 15 samples in that sector fall within the region S1, around 27% fall in region S2, and no samples in region S3. We observe that the distribution of samples fulfils the criteria specified above and that therefore the sampling locations are representative for the type of assessment this study is aimed for, i.e. pesticides in banana plantations.

Table 3.27. Sampling distribution within standard deviation regions for three sampling criteria

SAMPLING CRITERIA			Organic Matter	Water Content	Bulk Density	% Sand	% Silt	% Clay
					SOIL PARAMETERS			
LANDUSE	Banana Farms (15 Samples)	S1	73.3%	73.3%	66.7%	86.7%	86.7%	93.3%
		S2	26.7%	20.0%	33.3%	13.3%	13.3%	0.0%
		S3	0.0%	6.7%	0.0%	0.0%	0.0%	6.7%
	Hilly Areas (8 Samples)	S1	62.5%	25.0%	62.5%	50.0%	50.0%	37.5%
		S2	37.5%	62.5%	25.0%	25.0%	50.0%	62.5%
		S3	0.0%	12.5%	12.5%	25.0%	0.0%	0.0%
	Pasture Areas (5 samples)	S1	60.0%	80.0%	40.0%	60.0%	60.0%	100.0%
		S2	20.0%	20.0%	60.0%	40.0%	40.0%	0.0%
		S3	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%
GEOLOGY	Alluvial Deposits (22 Samples)	S1	68.2%	72.7%	59.1%	77.3%	77.3%	90.9%
		S2	27.3%	22.7%	40.9%	22.7%	22.7%	0.0%
		S3	4.5%	4.5%	0.0%	0.0%	0.0%	9.1%
	Cretasic Formation (5 Samples)	S1	80.0%	20.0%	80.0%	40.0%	40.0%	20.0%
		S2	20.0%	60.0%	0.0%	20.0%	60.0%	80.0%
		S3	0.0%	20.0%	20.0%	40.0%	0.0%	0.0%
	Metamorphic Rock (1 samples)	S1	0.0%	0.0%	0.0%	100.0%	100.0%	100.0%
		S2	100.0%	100.0%	100.0%	0.0%	0.0%	0.0%
		S3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
EDAPHOLOGY	Tropofluvents (10 Samples)	S1	70.0%	70.0%	60.0%	90.0%	90.0%	100.0%
		S2	30.0%	20.0%	40.0%	10.0%	10.0%	0.0%
		S3	0.0%	10.0%	0.0%	0.0%	0.0%	0.0%
	Skeletal Haplustalfs (6 Samples)	S1	50.0%	50.0%	50.0%	50.0%	66.7%	83.3%
		S2	50.0%	50.0%	33.3%	33.3%	33.3%	16.7%
		S3	0.0%	0.0%	16.7%	16.7%	0.0%	0.0%
	Dystropepts (6 Samples)	S1	100.0%	66.7%	83.3%	50.0%	66.7%	33.3%
		S2	0.0%	16.7%	16.7%	33.3%	33.3%	50.0%
		S3	0.0%	16.7%	0.0%	16.7%	0.0%	16.7%
	Tropaquepts (3 Samples)	S1	66.7%	66.7%	33.3%	100.0%	66.7%	100.0%
		S2	0.0%	33.3%	66.7%	0.0%	33.3%	0.0%
		S3	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%
	Haplustalfs (2 Samples)	S1	0.0%	50.0%	50.0%	50.0%	50.0%	100.0%
		S2	100.0%	50.0%	50.0%	50.0%	50.0%	0.0%
		S3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Typic Ustifluvents (1 samples)	S1	100.0%	0.0%	100.0%	100.0%	0.0%	0.0%
		S2	0.0%	100.0%	0.0%	0.0%	100.0%	100.0%
		S3	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

3.7.3. SOIL MAPS (DIGITAL DATA) GENERATION

As written before, the purpose of sampling several soil sites was to obtain enough information to develop spatially distributed soil data as raster maps (Figure 3.15). Two methods were used to produce the raster maps depending on the case:

1.   Interpolation of soil point data to generate primary soil data maps, and
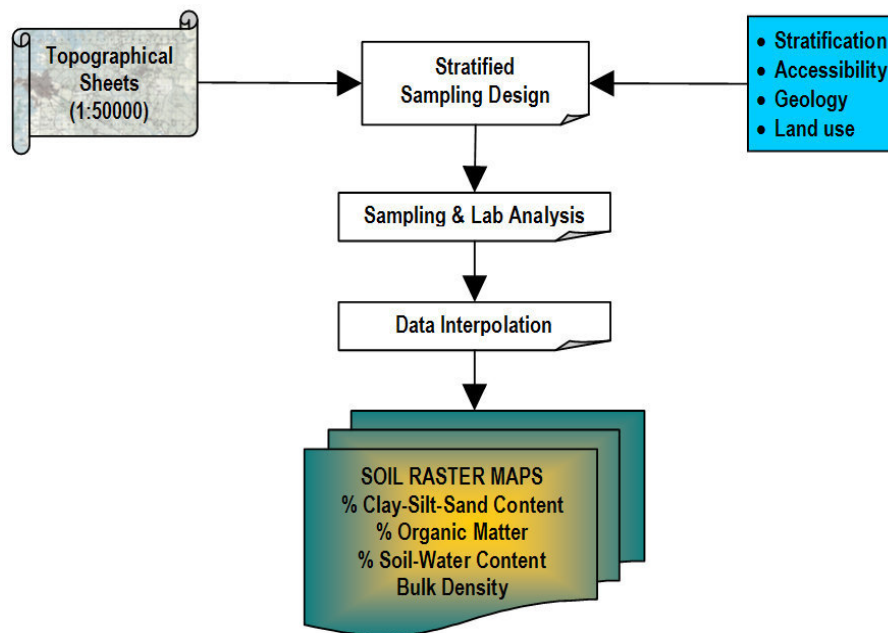2.   Usage of the Map Calculator macro in ArcView to generate secondary soil information by applying standard equations.

Figure 3.15. Schematic procedure to generate soil maps

<u>Primary soil data:</u>   This type of information is related directly to the parameters obtained from lab analysis such as soil texture content (*SAND*, *SILT*, and *CLAY*), organic matter (*ORGMAT*) and water content (*WATCONT*). The soil maps were generated by applying Kriging interpolation, as shown in Figure 3.16. Soil texture maps were corrected in order to have a value of 100% in their arithmetic addition[22]. Each of three texture maps was adjusted by adding or subtracting the mean error value (MEV) to the original texture value.

$$MEV = \frac{100 - (SAND + SILT + CLAY)}{3} \qquad [3.13]$$

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[22] Only sand, silt and clay are considered here size fractions of the soil mass.
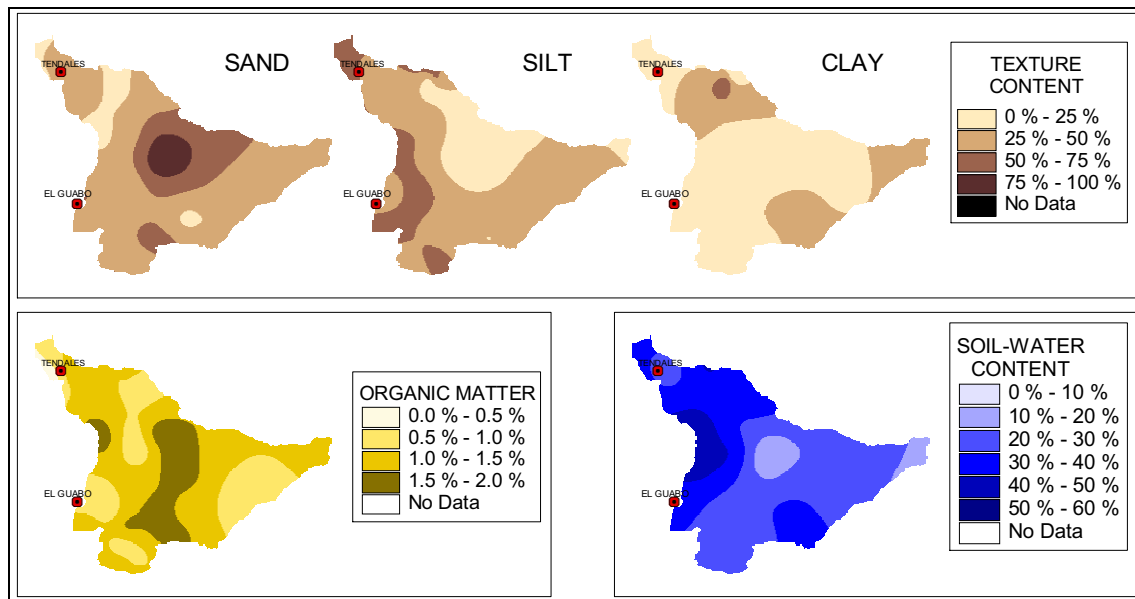
Figure 3.16. Soil primary data maps as a result of sampling interpolation

Regarding the soil water content, this soil property only reflects values obtained during an event (i.e. the sampling campaign). For that reason the generated map cannot be used for other hydrological events. In the present research, this map was used only to show the moisture pattern of the catchment: clayed and fine soils exhibit more water content than sandy soils. In addition, this information is going to be shown as a research by-product to local farmers in irrigation management issues. By showing this information, farmers can see the benefit of having and generating such data.

Regarding the bulk density map, the interpolation procedure did not consider the tillage practices. However, the majority of the crops in the basin are perennial (banana, cocoa and citrics), so tillage practices are almost not a common farming practice in the basin. The soil bulk density is required as an input data in both evaluated pesticide models.

Secondary soil data: Data such as soil albedo, permeability, wilting point, field capacity, and soil classification can be generated with equations or Boolean algebra in the ArcView Map Calculator, as seen in table 3.28. Soil maps are shown in figures 3.17 and 3.18.

In the current research, the soil albedo was determined by using an equation that only considers soil organic matter content. This equation is not completely accurate because the albedo is also function of vegetation cover. The best way to determine soil albedo is by using remote sensing techniques, but these could not be applied in the current research because:

- The basin area is covered by clouds during almost the whole year. This climatic condition makes it impossible to have good satellite images to perform albedo estimations.

- The remote sensing techniques are very expensive and the research did not have enough budget to cover these costs.
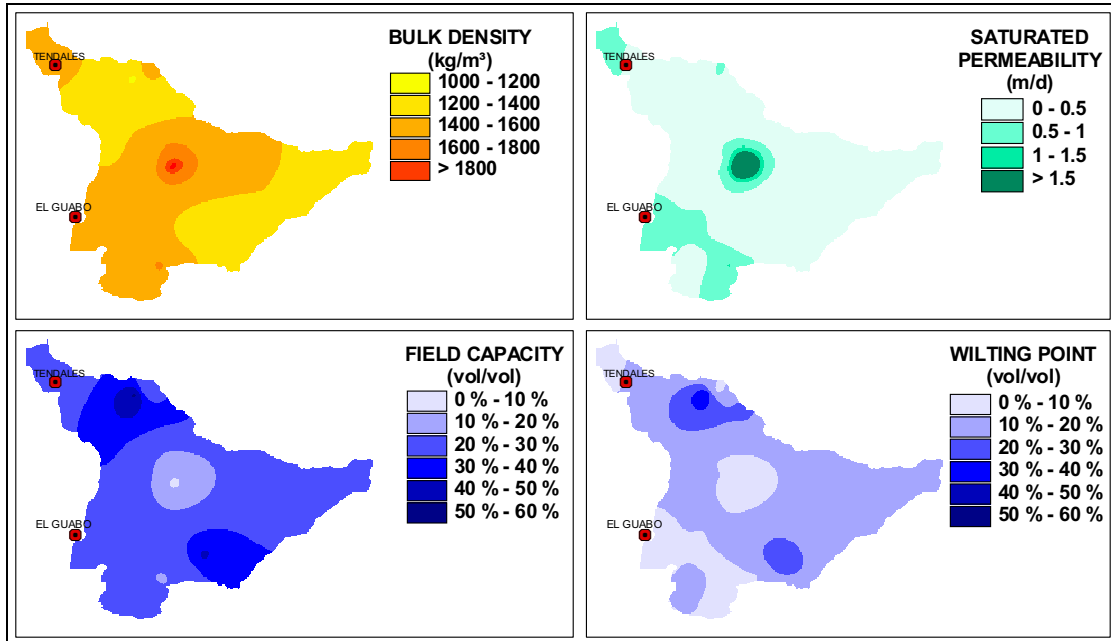

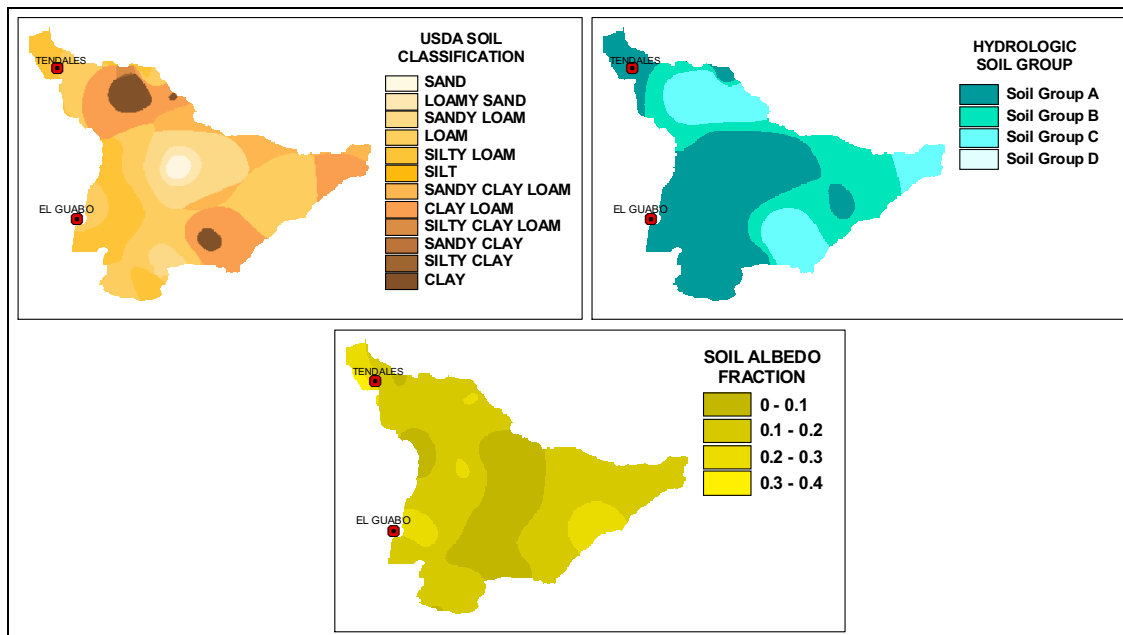**Figure 3.17. Soil properties generated with Saxton's equations**

Figure 3.18. Other soil parameters generated with Map Calculator in ArcView

Table 3.28. Secondary data generated with equations and boolean algebra

Data	Name of the map	Equation used
Soil Properties (Saxton *et al.* 1986**):** • **Permeability** • **Bulk Density** • **Wilting Point** • **Field Capacity**	*HYDCOND*	$\exp\left[12.012 - 0.0755\,Sand - \dfrac{3.895 - 0.03671\,Sand + 0.1103\,Clay - \left(8.7546\times10^{-4}\,Clay^{2}\right)}{0.332 - \left(7.25\times10^{-4}\,Sand\right) + 0.1276\log(Clay)}\right]$
	BULKDENS	$2.65\left(0.668 + 7.25\times10^{-4}\,SAND - 0.1276\log(CLAY)\right)$
	WILTPOINT	$\left[15.000\exp(4.396 + 0.0715\,CLAY + 4.88\times10^{-4}\,SAND^{2} + 4.285\times10^{-5}\,SAND^{2}\,CLAY)\right]^{B}$ *where* $B = 3.14 + 0.00222\,CLAY^{2} + 0.00003484\,SAND^{2}\,CLAY$
	FIELDCAPAC	$\left[0.3333\exp(4.396 + 0.0715\,CLAY + 4.88\times10^{-4}\,SAND^{2} + 4.285\times10^{-5}\,SAND^{2}\,CLAY)\right]^{B}$ *where* $B = 3.14 + 0.00222\,CLAY^{2} + 0.00003484\,SAND^{2}\,CLAY$
Soil Classification (Benham *et al.* 2001**)**	*USDAclass*	*Sand IF* $\left[(1.5\,CLAY + SILT) < 15\right]$ *Loamy Sand IF* $\left[(1.5\,CLAY + SILT) \geq 15\;and\;(2\,CLAY + SILT) < 30\right]$ *Sandy Loam IF* $\begin{cases}\left[(CLAY \geq 7)\;and\;(CLAY < 20)\;and\;(SAND > 52)\;and\;(2\,CLAY + SILT) \geq 30\right]\\ \left[(CLAY < 7)\;and\;(SILT < 50)\;and\;(2\,CLAY + SILT) \geq 30\right]\end{cases}$ *Loam IF* $\left[(CLAY \geq 7)\;and\;(CLAY < 27)\;and\;(SILT \geq 28)\;and\;(SILT < 50)\;and\;(SAND \leq 52)\right]$ *Silty Loam IF* $\begin{cases}\left[(SILT \geq 50)\;and\;(CLAY \geq 12)\;and\;(SAND < 27)\right]\\ \left[(SILT \geq 50)\;and\;(SILT < 80)\;and\;(CLAY < 12)\right]\end{cases}$ *Silt IF* $\left[(SILT \geq 80)\;and\;(CLAY < 12)\right]$ *Sandy Clay Loam IF* $\left[(CLAY \geq 20)\;and\;(CLAY < 35)\;and\;(SILT > 28)\;and\;(SAND > 45)\right]$ *Clay Loam IF* $\left[(CLAY \geq 27)\;and\;(CLAY < 40)\;and\;(SAND > 20)\;and\;(SAND \leq 45)\right]$ *Silty Clay Loam IF* $\left[(CLAY \geq 27)\;and\;(CLAY < 40)\;and\;(SAND \leq 20)\right]$ *Sandy Clay IF* $\left[(CLAY \geq 35)\;and\;(SAND > 45)\right]$ *Silty Clay IF* $\left[(CLAY \geq 40)\;and\;(SILT \geq 40)\right]$ *Clay IF* $\left[(CLAY \geq 40)\;and\;(SAND \leq 45)\;and\;(SILT < 40)\right]$
Soil Albedo (Baumer *et al.* 1994**)**	*ALBEDO*	$\left(0.7\,e^{-0.5596\,ORGMAT}\right)^{2}$
Hydrologic Soil Groups (USDA 1986**)**	*HSG*	Soil Type A if *HYDCOND* is greater than 0.18 m/day Soil Type B if *HYDCOND* is between 0.09 and 0.18 m/day Soil Type C if *HYDCOND* is between 0.03 and 0.09 m/day Soil Type D if *HYDCOND* is less than 0.03 m/day

3.8. LANDUSE DATA

3.8.1. EXISTING LAND USE INFORMATION

Land use data was gathered from the CLIRSEN[23] database. Information in this database is already in ArcView format (shapefiles). There are two types of information in the collected database:

- **Land Cover:** CLIRSEN compiled this data in 1994, and it was digitised from several sources of information such as aerial photographs, satellite information and printed maps at 1:250000 scale. By clipping the basin over the original landuse map, the Chaguana's land cover was obtained (Figure 3.19). Table 3.29 shows the percentage distribution of each activity in the basin. It can be seen that banana is the most important agricultural activity in the basin.
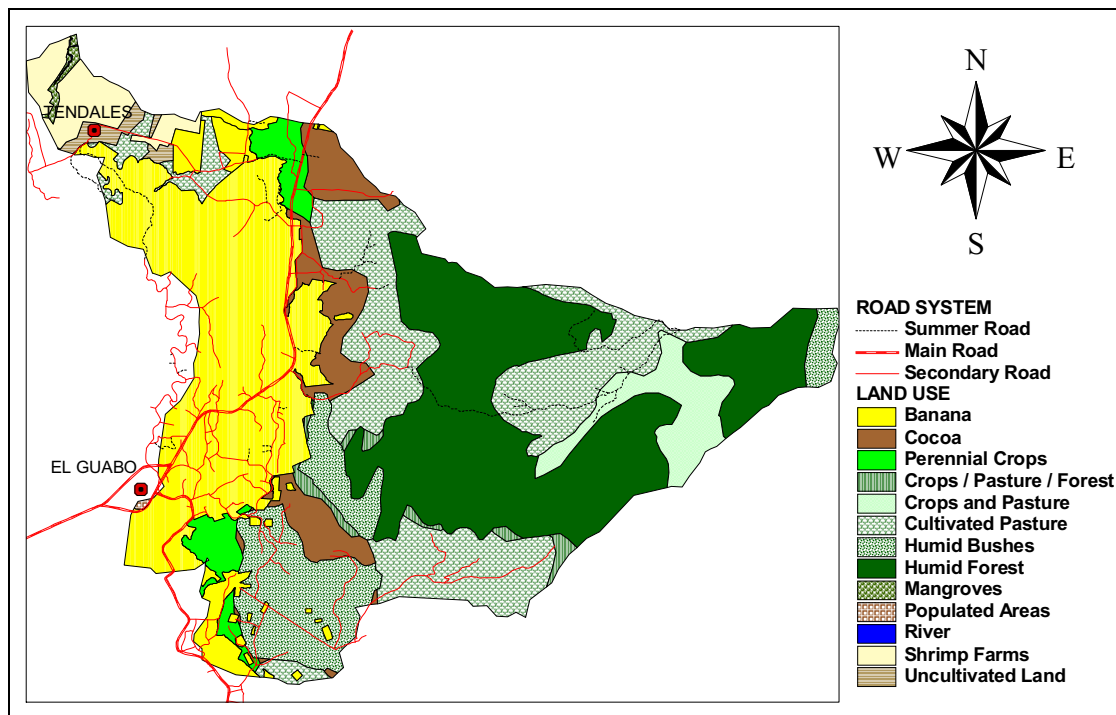

Figure 3.19. Existing land use in the Chaguana river basin

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[23] Centro de Levantamiento Integrado y Sensores Remotos (Ecuadorian Centre of Integrated Survey and Remote Sensing) is the official organism to manage land cover and land use data.

Table 3.29. Land use distribution in the Chaguana river basin

Type of Activity	Land Cover	Surface Area	Percentage
Agricultural	Banana crops	8182 Ha	26.21%
	Cultivated Pasture	6177 Ha	19.78%
	Cocoa crops	1927 Ha	6.17%
	Other perennial crops	934 Ha	2.99%
Rangeland	Humid Forest	8142 Ha	26.08%
	Humid Brushes	2950 Ha	9.45%
	Mangroves	86 Ha	0.28%
	Uncultivated lands	261 Ha	0.84%
Mixed Activities	Mixture of crops and pasture	1264 Ha	4.05%
	Mixture of crops, pasture and forest	323 Ha	1.03%
Non-Agricultural	Shrimp Farms	944 Ha	3.02%
	Water	18 Ha	0.06%
	Populated Areas	14 Ha	0.04%

Source: Ecuadorian Centre of Integrated Survey and Remote Sensing (1999)

- **Banana Farms:** There is also information regarding the location and extension of banana farms, and each owner's name. Although this detailed information was not used in the modelling process, it was possible to display a map showing the farms by their extension (Figure 3.20). However, the database is not complete as several banana farms in the southern part of the basin have not been included. The map also shows the river network related to farm locations. It is clear that banana activity mostly affects the lower part of the river basin where other productive activities coexist. This situation can start potential conflicts between users of a river basin as was exposed in the introductory chapter of this thesis.

Based on the map, a farm distribution can be obtained for the Chaguana Basin (Table 3.30). The distribution was arranged in agreement with the classification proposed by the Ecuadorian Ministry of Agriculture for small, medium and big farms (see Chapter 2, table 2.10). By comparing both tables, it can be seen that the farm distribution in the Chaguana basin reflects very well the current situation at national scale conforming this basin as case study. The majority of banana farming comprises small lots with heterogeneous management depending mostly on economics. This situation will be analysed in the next section.

Table 3.30. Banana farm distribution per size in the Chaguana basin

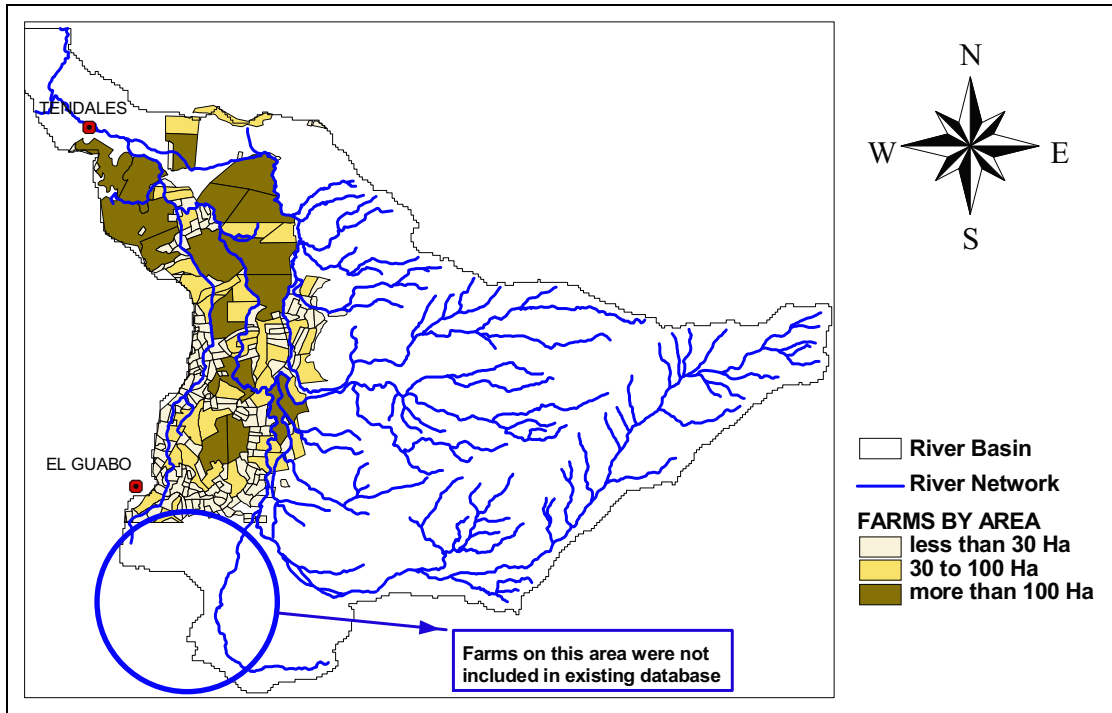| Farm Size	Percentage	Average Size
Less than 30 Ha	80.2 %	10.6 Ha
30 Ha – 100 Ha	13.8 %	52.2 Ha
More than 100 Ha	6.0 %	186.5 Ha

Figure 3.20. Distribution of banana farms by extension in the Chaguana river basin

3.8.2. PESTICIDE MANAGEMENT DATA

As quoted in the previous section, the majority of the banana farms in the basin can be classified as small farms which can strongly affect the way pesticides are being transported inside the basin. Although this problem analysis is out of the scope of the current research, a summary of several findings obtained during the research is presented here.

At the present time, there is a struggle between the banana farmers and the exporters about the in-situ price of a banana box. Farmers claim that prices should be increased because production costs have been increased since the change of the national currency[24]. Among the production costs, the use of agrichemicals represents the highest one after the management costs, as shown in Table 3.31.

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[24] In 1999, the Ecuadorian Government decided to use the U.S. dollar as national currency.

Table 3.31. Cost distribution to produce bananas in Ecuador

Cost type	Percentage
Management	40.50%
Pesticides and Fertilizers	24.60%
Transport	9.08%
Planting, Caring and Replanting	8.21%
Equipment and others	7.14%
Financial Costs	4.25%
Harvest	3.72%
Irrigation and Drainage	1.57%
Packaging	0.93%

Source: National Association of Banana Producers (1999)

Some small and medium farmers have readjusted their production costs in all items, including pesticide usage, to compensate for the low price of the banana box. On the other side, big farmers can still manage the production costs because sometimes they are also exporters. Therefore, small-medium farmers are forced to use less agrichemicals than the big ones. By using that scenario on the Chaguana basin, small-medium farms are mainly located upstream the river basin while the big farms are downstream. During sampling campaigns, the downstream section of the banana sector showed pesticide concentration values higher than the ones obtained in the upstream section of banana activity (see section 3.11.2).

Thus, the pesticide modelling assessment turns to be complex because pesticides are not used homogeneously in the entire basin, and there is no available information showing the complete pesticide application planning in the watershed. During the research, it was only possible to obtain detailed information regarding the pesticide management in two banana farms: one inside the basin and the other in a different location outside the basin. These data are used together with the general information obtained during the inspections performed on seven banana farms in Ecuador (see Section 2.5). A typical pesticide application planning was structured based on the collected information (Table 3.32).

Table 3.32. Typical application plan in an Ecuadorian banana farm

Application Date	Julian Day	Week	Type of pesticide	Typical pesticide	Application rate
January 02	2	1	Fungicide	Propiconazole	100 g.a.i. / Ha
January 06	6		Herbicide	Glyphosate	375 g.a.i. / Ha
January 26	26	4	Fungicide	Benomyl	15 g.a.i. / Ha
				Mancozeb	800 g.a.i. / Ha
January 29	29	5	Insecticide	Bacillus Thuringiensis	1 g.a.i. / Ha
February 06	37	6	Herbicide	Glyphosate	375 g.a.i. / Ha
February 15	46	7	Fungicide	Propiconazole	100 g.a.i. / Ha
March 06	65	10	Herbicide	Glyphosate	375 g.a.i. / Ha
March 26	85	13	Insecticide	Bacillus Thuringiensis	1 g.a.i. / Ha
March 28	87		Fungicide	Propiconazole	100 g.a.i. / Ha
April 06	96	14	Herbicide	Glyphosate	375 g.a.i. / Ha
April 08	98		Fungicide	Propiconazole	100 g.a.i. / Ha
April 18	108	16	Mixture	Mancozeb	800 g.a.i. / Ha
				Propiconazole	100 g.a.i. / Ha
May 03	123	18	Fungicide	Propiconazole	100 g.a.i. / Ha
May 29	149	22	Fungicide	Propiconazole	100 g.a.i. / Ha
June 25	176	26	Mixture	Benomyl	15 g.a.i. / Ha
				Mancozeb	800 g.a.i. / Ha
August 7	219	32	Mixture	Benomyl	15 g.a.i. / Ha
				Mancozeb	800 g.a.i. / Ha
August 24	236	34	Fungicide	Propiconazole	100 g.a.i. / Ha
September 15	258	37	Fungicide	Azoxystrobine	100 g.a.i. / Ha
October 04	277	40	Fungicide	Azoxystrobine	100 g.a.i. / Ha
October 25	298	43	Fungicide	Propiconazole	100 g.a.i. / Ha
November 06	310	45	Herbicide	Glyphosate	375 g.a.i. / Ha
November 18	322	46	Fungicide	Benomyl	18 g.a.i. / Ha
November 27	331	48	Fungicide	Propiconazole	100 g.a.i. / Ha
December 06	340	49	Herbicide	Glyphosate	375 g.a.i. / Ha
December 23	357	51	Fungicide	Bitertanol	150 g.a.i / Ha

Based on the table, it is concluded that pesticides are applied on a crop field around 29 times in a year (every 13 days on average). In addition, propiconazole is the most used pesticide in the year with 10 applications through the year (at least one application each month). In the packaging facilities, two pesticides are used after the fruit washing process: thiabendazole and imazalil. Both pesticides are mixed with water and alumina, and they are sprayed over the fruit at a specific location within the packaging facility. The mixture mist is collected in ditches which are connected to the farm channels and then discharged into the river with an average travel distance of 1 km. The pesticide concentration is between 1 and 10 mg of active ingredient per litre for both pesticides. This discharge is produced at least one day per week per farm.

3.9. EROSION DATA

Because pesticide modelling also involves the movement of a chemical attached to suspended particles resulting from erosion mechanisms, it is necessary to also have data related to erosion processes. The majority of pesticide models use the Revised / Universal Soil Loss Equation (RUSLE / USLE). In this equation the following characteristics must be provided:

- The length-slope factor (LS)
- The soil erodibility factor (K_S)
- The rainfall-runoff erosivity factor (R)
- The support practice factor (P)
- The cover management factor (C_M)

These characteristics are discussed below and applied to the current case study.

3.9.1. LENGTH-SLOPE FACTOR (LS)

Basically, the length-slope factor indicates how slope length and slope steepness influence land erosion. It actually measures the relationship between case study topographic conditions to a standard plot conditions (22.12 m of slope length and 9% of slope steepness). The basic L factor equation was first proposed by Wischmeier and Smith (1978), and the first S factor equation was proposed by McCool *et al.* (1987). Combination of these two factors produces the topographic LS factor used in the RUSLE and USLE equations.

The LS factor is usually either estimated or calculated from actual field measurements of length and steepness; however at regional scale, it can be difficult to estimate them because labour-intensive field measurements are obviously not always feasible (Van Remortel *et al.* 2001). For that reason, several authors have proposed methodologies to estimate the LS factor, such as Van Remortel et al. (2001), Desmet and Govers (1996) and Mitosova *et al.* (1996). Those authors recommend not only considering depositional and ridging areas, but also flow concentrated areas in the slope length estimation. Based on those methods, the Length-Slope factor map was obtained as follows by using the ArcView Map Calculator.

Depositional Areas Determination: It has been determined that depositional areas usually begin when the steepness of the evaluated cell is less or equal to a limiting steepness defined

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by the "concave" area[25]. In ArcView, the concave area can be obtained by using the avenue statement *Curvature*.

$$CURVATURE = FILLEDEM100.Curvature\ (Nil,\ Nil,\ Nil,\ Nil)$$

If the curvature is negative, the cell is concave related to its neighbours; otherwise, the cell is convex. Therefore, depositional areas are the ones where cells are concave. To create the depositional area map, the curvature map is reclassified by assigning a value of 0 to all cells with a negative curvature and a value of 1 to cells with positive curvature.

Concentrated Flow Areas Determination: Another restriction in the LS factor determination is the location of areas where the flow is concentrated (streams, channels, rivers). These areas should be determined by rasterizing the actual river network. However, as explained in section 3.5.3, there are small deviations between the actual river network and the generated river network by the *FlowAccumulation* statement which is the main input for other hydrological determinations. Then, the concentrated flow areas are determined by reclassifying the Flow Accumulation raster into two classes:

- All cells with a cumulative drainage area less than 12 Ha receives a value of 1 which indicates that no water is concentrated, so the cell is susceptible to runoff erosion[26].
- When the cumulative drainage area is greater or equal to 12 Ha, the water is concentrated in the cell, and the chance of deposition is greater than the chance of runoff erosion. Thus, the assigned value is 0.

Slope Length Determination: Once depositional and concentrated flow maps were obtained, a map (named *DEPO_FLOW*) showing all areas excluded for runoff erosion was produced by multiplying both raster maps. Then, the length of slope is determined by using the avenue statement *FlowLength* considering the flow direction raster map (*FLOWDIR*) and the constrained erosion map.

$$LENGTH\_SLOPE = FLOWDIR.FlowLength\ (DEPO\_FLOW,\ True)$$

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[25] It is the area surrounding the evaluated cell delimited by its eight neighbouring cells.

[26] Based on a digitized river network from topographical maps, it was estimated that an average drainage area of 12 Ha initiates a river stream.

Length Factor (L): The slope length factor is calculated by applying equations developed by Wischmeier and Smith (1978), Foster et al. (1977) and McCool *et al.* (1989).

$$L = \left(\frac{L_{SLOPE}}{22.12848} \right)^{\frac{\beta}{1+\beta}} \qquad\qquad [3.14]$$

$$\beta = \frac{Sin\delta}{0.2688 \left(Sin\delta \right)^{0.8} + 1.68} \qquad\qquad [3.15]$$

Where

L_{SLOPE} Length of the maximum downhill slope

δ Slope angle

Steepness Factor (S): The slope steepness factor is evaluated with the equation proposed by McCool *et al.* (1987).

$$S = \begin{cases} 10.8\ Sin\delta + 0.03 & \rightarrow \quad Slope < 9\% \\ 16.8\ Sin\delta - 0.50 & \rightarrow \quad Slope \geq 9\% \end{cases} \qquad\qquad [3.16]$$

Equations 3.14, 3.15 and 3.16 were used in the Map Calculator to produce the raster maps L_FACTOR and S_FACTOR, which were multiplied to obtain the LS_FACTOR map (Figure 3.21a). Table 3.33 shows the range of results obtained from the previous calculations.

Table 3.33. LS factor values for the Chaguana basin

	Length of Slope (m)	*Slope (%)*	*Length Factor*	*Steepness Factor*	*LS Factor*
Maximum value	1228	172	11.64	14.02	111.99
Minimum value	0	0	0	0.03	0.00
Mean	175	20	1.65	2.76	6.21
Standard Deviation	232	22	1.86	3.00	12.45

3.9.2. SOIL ERODIBILITY FACTOR (K_S)

The soil erodibility factor represents the soil loss due to rainfall impact on a unit plot. It is an integrated average annual value which is mainly related to the soil properties. Although it is advisable to measure this value on the field, reliable field data are not always available. However, there are several methods to estimate this value mainly based on soil properties. Based on 225 soils around the world, Shirazi and Boersma (1984) related this value to the mean geometric particle diameter.

$$K_S = 0.0034 + 0.0405 \exp\left[-\frac{1}{2}\left(\frac{1.659 + \log Dg}{0.7101}\right)^2\right]$$ [3.17]

$$Dg = \exp\left[0.01\left(Cl \ln\Phi_C + St \ln\Phi_{St} + Sn \ln\Phi_S\right)\right]$$ [3.18]

Where

K_S Soil erodibility factor

Dg Geometric mean particle diameter for a specific soil

Cl, St, Sn Clay, Silt and Sand fraction respectively

Φ_C Arithmetic mean diameter of clay size limits (0.001 mm)

Φ_{St} Arithmetic mean diameter of silt size limits (0.00425 mm)

Φ_S Arithmetic mean diameter of sand size limits (1.00325 mm)

By applying those equations in map calculator, the K_FACTOR raster map was obtained (Figure 3.21b). Table 3.34 shows the range of obtained values.

Table 3.34. K factor values for the Chaguana basin

	Clay (%)	Silt (%)	Sand (%)	K factor (Ton.Ha.h.Ha^{-1}.MJ^{-1}.mm^{-1})
Maximum value	66.5	76.2	94.3	0.043900
Minimum value	0.4	4.3	8.7	0.007484
Mean	21.6	39.2	39.2	0.038658
Standard Deviation	8.6	12.8	12.1	0.007900

3.9.3. RAINFALL – RUNOFF EROSIVITY FACTOR (R)

The erosivity factor represents the soil loss produced by the influence of the energy of raindrop impacts and a 30-min rainfall intensity. Although this factor can be calculated for a single storm, it is advisable to account for all significant storms occurring through the year. Equations proposed by Brown and Foster (1987) are used in the calculation of the erosivity factor

$$E = 0.29\left(1 - 0.72\, e^{-0.05\, i}\right)$$ [3.19]

$$R_I = E\, I_{30}$$ [3.20]

Where

E Energy produced by the impact of a typical raindrop

i Intensity of the rain

I_{30} Maximum 30-min intensity for a specific storm

R_I Rainfall erosivity factor for a specific storm

In the Chaguana basin, there is no information regarding this erosivity factor or 30-min rainfall information. Therefore, it was necessary to estimate the factor based on the maximum 24-h precipitation for the basin during a "normal" year (or 2-year return period as explained in Section 3.6.2). The estimated 2-year maximum precipitations were processed to obtain the annual rainfall erosivity factors for each station (Pagua, Pasaje and Machala). The TR-20[27] methodology was followed to convert the 24-h precipitation into 30-min precipitation, and to estimate the corresponding erosivity factors for each station. The rainfall erosivity map was generated by *SPLINE* Interpolation (Figure 3.21c). In table 3.35, a summary of the generated data is given.

Table 3.35. R factor values for the Chaguana basin

	Annual R factor (MJ.mm.Ha⁻¹.h⁻¹.year⁻¹)
Maximum value	2115.80
Minimum value	1067.50
Mean	1384.30
Standard Deviation	249.60

3.9.4.   SUPPORT PRACTICE FACTOR (P)

The support practice factor represents the soil loss of a specific crop management practice related to the loss produced by upslope and downslope tillage. It is a dimensionless value ranging between 0 and 1. It is necessary to have very detailed information regarding the crop practice (contouring, stripping, tillage and so on) to estimate this factor.

In the Chaguana basin, the only information available is that bananas are cultivated in lots surrounded by drainage channels resembling terraces. Normally, when the banana plant is harvested, the plant is cut and the plant suckers are allowed to grow. Because banana plantations are permanent crops, no mechanical process affects the soil in the farm. To estimate the P factor values in the basin, equations proposed by Foster and Ferreira (1981) and Foster *et al.* (1997) can be used. Those equations are based on the terrace slope and the terrace length. In banana farms, the terrace length is normally less than 50 meters, and the slope grade is similar to the surface slope.

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[27] Technical Release No.20: Computer Program for Project Formulation Hydrology, USDA (1992)

$$P = 1 - B\,(1 - P_Y)$$
[3.21]

$$P_Y = \begin{cases} 0.1\exp(2.4\,s) \rightarrow s < 0.9\% \\ 1 \qquad\qquad \rightarrow s \geq 0.9\% \end{cases}$$
[3.22]

Where

s   Terrace slope grade or ground slope

B   Benefit factor. It is an indicator of the probability to have deposition within the terrace. It varies from 0.5 to 1, and it depends on the terrace length. In the banana farms, this value is assumed to be 0.5.

For the non-crop areas of the basin, the same equation was applied, by considering that there are no terraces in all mountainous and rangeland areas. However, there is still a chance of deposition, so the ground slope is considered for the estimations. Table 3.36 and Figure 3.21 show the generated results for the P factor in the study area.

Table 3.36. P factor values for the Chaguana basin

	P factor
Maximum value	1.00
Minimum value	0.55
Mean	0.87
Standard Deviation	0.19

3.9.5.   COVER MANAGEMENT FACTOR (C_M)

The cover management factor is also a dimensionless value ranging between 0 and 1. It represents the soil loss produced by all management activities within a period of time (usually one year). In the RUSLE estimation, this value varies every 15 days in order to cover all management activities within a farm (crop rotation, management schemes, plant growth, etc.). In the USLE estimation, on the other hand, this value is taken as a single average value representing the entire year. For areas such as rangelands or perennial crops, a single value is more appropriate to represent the soil loss rate because the actual cover changes very slowly with time.

In the Chaguana basin, this value will later be a variable to be changed in the model runs to calibrate suspended solids measurements in the river with the sediment loadings produced by the C_M factor (see Chapter 5). However, the initial values, assumed for the basin, depend on the existing land use / land cover conditions. Based on the AGNPS database, Table 3.37

shows recommended C_M factor values for the land cover conditions in the Chaguana basin. However, those values were mainly developed for USA land and crop cover. Therefore, some trial-and- error estimations should be done for banana plantations. Figure 3.21e shows the C_FACTOR map for the Chaguana basin.

Table 3.37. Recommended initial C_M factor values for the Chaguana basin

Land Cover	Recommended C_M Factor	
	Average	Minimum
Forest	0.03876	0.001
Pasture and brushes	0.06590	0.003
Crops	0.28575	0.170
Mixture of Crops and Pasture	0.17582	0.087
Mixture of Crops, Pasture and Forest	0.13014	0.058
Non crop and barren land	0.60000	0.230

Source: AGNPS model database
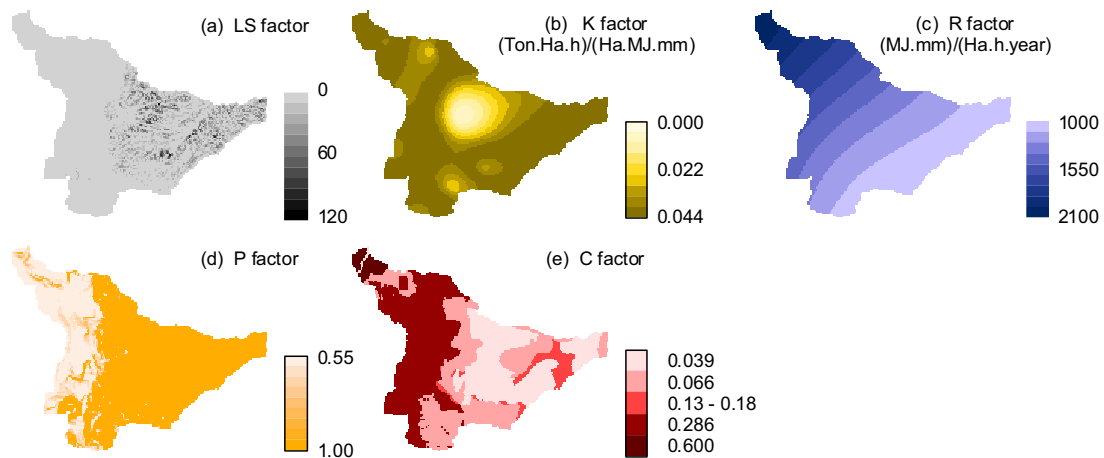
Figure 3.21. RUSLE / USLE factor raster maps for the Chaguana river basin

3.10. CROP DATA

In several pesticide models such as AGNPS and SWAT, it is also necessary to provide information regarding crops to which the pesticides are applied because plants can also affect the way pesticide is transferred to the environment. Time-changing parameters such as canopy cover, crop height and root mass are important for pesticide interception and soil detachment by erosion. Some models such as AGNPS require this information on a 15-day basis. Current models normally have a complete database showing properties of crops mostly

cultivated at places where the models were developed. Unfortunately, that is not the case for banana crops.

Data from farmers

In Ecuador, farmers are usually not interested in getting this information on a continuous basis. However, some data which can be used in the evaluated models could be gathered from them:

- The average population density in a banana farm is 1478 plants per hectare which represents around 7 m^2 per plant (diameter of 3 m.)
- The average yield of a banana farm is 27 Tons per Ha.
- The final height of a banana plant differs depending on the plant variety, but the typical height observed during field visits is 3.60 meters.
- The harvest time also depends on cultivated variety ranging from 12 to 15 months. In the current research, it will be assumed that full height and harvesting is reached at the end of 12th month. Once the plant is harvested, it is half-cut so the sucker can feed on it. The farmer can distribute the planting phase in the farm to harvest bananas every week.
- The growing pattern of banana is only available as normalized height values at four growth stages: planting, development, flowering and harvesting (Table 3.38). Normal curves of plant growth show a typical sigmoid shape starting at the origin and tending to a horizontal asymptote. To obtain the height on a 15-day basis, interpolation was done to obtain the curve that fits the data best. In the current research, straight lines were used to fit the data because the height is actually not significantly affecting results in the runoff model. Banana is a perennial crop and farmers do not plant it frequently. Therefore, the plants in banana farms can be considered to be fully developed in the analysis.

Table 3.38. Average growth of banana for the main crop stages

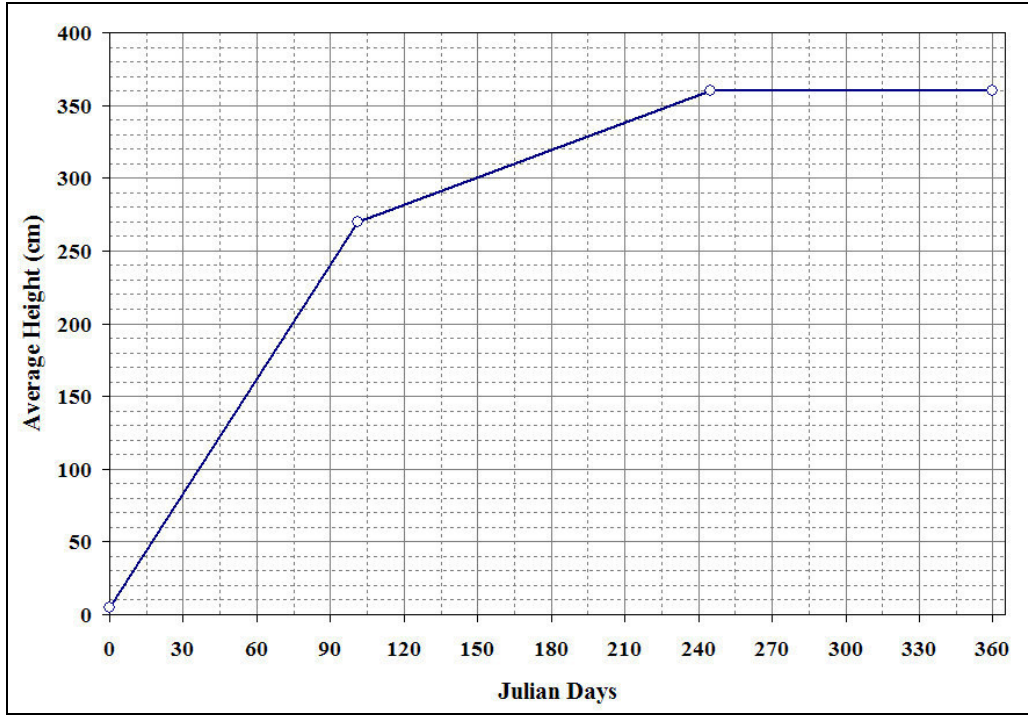| Growth Stage	Average Julian Day	Normalized Height	Average Height
Planting	0	0.01 %	0.05 m
Development	101	75 %	2.70 m
Flowering	245	100 %	3.60 m
Harvesting	365	100 %	3.60 m

Source: Farmer records

Figure 3.22. Estimated growth of a banana plant

Fresh root mass

The root mass development on a year was estimated based on the research done by Blomme *et al.* (2001a). This study states that root mass can be obtained by using the leaf area, the pseudostem circumference and the tallest sucker length of the banana plant, as shown in equation [3.23]. After searching the literature and some farmer records, values shown in table 3.39 were used to estimate the fresh root mass per hectare of harvested banana plants. For the root development on a 15-day basis, it is assumed that root mass will increase linearly up to the value obtained in the equation.

$$AM_{ROOT}=\left(\frac{0.002066\,A_{LEAF}+0.42659\,\phi_{PSEUDO}+0.171415\,H_{SUCKER}}{1-w}\right)\left(\frac{Den}{1000}\right)$$ [3.23]

where

AM_{ROOT} Estimated unitary root mass

A_{LEAF} Mean leaf area of the plant

Φ_{PSEUDO} Pseudostem circumference

H_{SUCKER} Height of the tallest sucker

w   Mean water content of the root system

Den   Plant population density in the farm

Table 3.39. Values used for root mass estimation for banana crops

Parameter	Mean Value	Source
Leaf Area	9900 cm^2	Kumar *et al.* (2002)
Pseudostem Circumference	130 cm	Krauss *et al.* (2001); Blomme *et al.* (2001b)
Height of tallest sucker	85 cm	Blomme *et al.* (2001b)
Root water content	75 %	Several sources

Carbon to Nitrogen Ratio

Another input parameter needed in the AGNPS model is the Carbon to Nitrogen ratio for the banana crop. A study conducted by CEMA[28] (1998), evaluated this ratio in several banana farms at two coastal provinces in Ecuador (Table 3.40). In the current research, the value from the El Oro province is used because that site is the nearest to the study area.

Table 3.40. C:N ratios for banana crops in Ecuador

Province	Farm Site	Mean C:N ratio
	Quevedo 1	11.75
Los Ríos	Quevedo 2	15.62
	La Mana	13.20
El Oro	Pasaje	17.25

Source: CEMA (1998)

3.11. CHEMICAL DATA

3.11.1. WATER AND SEDIMENT SAMPLING CAMPAIGNS

The Chaguana system has two main rivers: the Zapote and the Chaguana. The Zapote river joins the Chaguana river 5 km before the basin outlet. This basin is not discharging to the sea, but to a bigger basin named the Pagua river basin. In the assessment, the Colorado river, a tributary of the Zapote, is also considered. However, for the purposes of this analysis, it is combined with the Zapote river evaluation as "Colorado & Zapote rivers."

The Chaguana river basin has no historical water quality records, so it was necessary to design and implement a sampling campaign to develop water quality data along the main streams in the catchment. Pesticide concentrations, BOD, TOC, pH, solids content,

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[28] Centre of Environmental Studies at ESPOL, Guayaquil, Ecuador

temperature, and dissolved oxygen were measured in the samples, so the existing water conditions were established.

Four measurement campaigns were conducted between November 2001 and November 2002. Each sampling campaign was three days long in order to cover all sampling points. Only one water sample was taken in each sampling point at a certain date and time during the sampling period. Water samples were taken consecutively by following the downstream path of the river once during every sampling campaign. In addition, every certain number of sampling points, a sediment sample was taken for pesticide analysis. The sampling periods were devised in such a way that the climate of a whole year was covered:

1. Transition between dry and rainy season (November 2001)
2. Rainy season (February 2002)
3. Transition between rainy and dry season (June 2002)
4. Dry season (November 2002)

It is important to note that the fourth sampling campaign was influenced by the presence of an extreme climate event (El Niño) which began at the end of 2002 according to INAMHI, the official meteorological organism in Ecuador.

Sampling Methodology

In order to prepare the sampling campaigns optimally, an exploratory field trip was conducted to get direct data from the river system at the moment of the trip. This trip was done in June 2001 which was on the transition between the rainy and dry season. Although most of the observations done during this trip are only representative for the time of the trip (Table 3.41), other non-time dependent information was obtained to improve the future sampling campaigns such as location of banana farms, other land use activities, water discharges and so on. Figure 3.23 shows the travelled path by boat (**thicker line**) during the exploratory trip, and the location of the uppermost place where both rivers are influenced by the tidal effect **(dotted line)**. It was impossible to travel by boat further upstream in both rivers because of the low river depth and river barriers[29] (Photo 3.3). Thus, the exploration was continued by following accessible roads adjacent to both rivers (**bold line**).

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[29] To pump water into farms, farmers build rock barriers at the downstream side of the pump uptake

Table 3.41. Physical conditions of rivers in June 2001

River	Average mid-stream depth	Average river width	Average water velocity
Chaguana	0.5 m (upstream)	10 m (upstream)	0.2 – 0.6 m/s
	2.0 m (downstream)	30 m (downstream)	
Zapote	0.3 m (upstream)	6 m (upstream)	0.2 – 0.6 m/s
	1.5 m (downstream)	10 m (downstream	

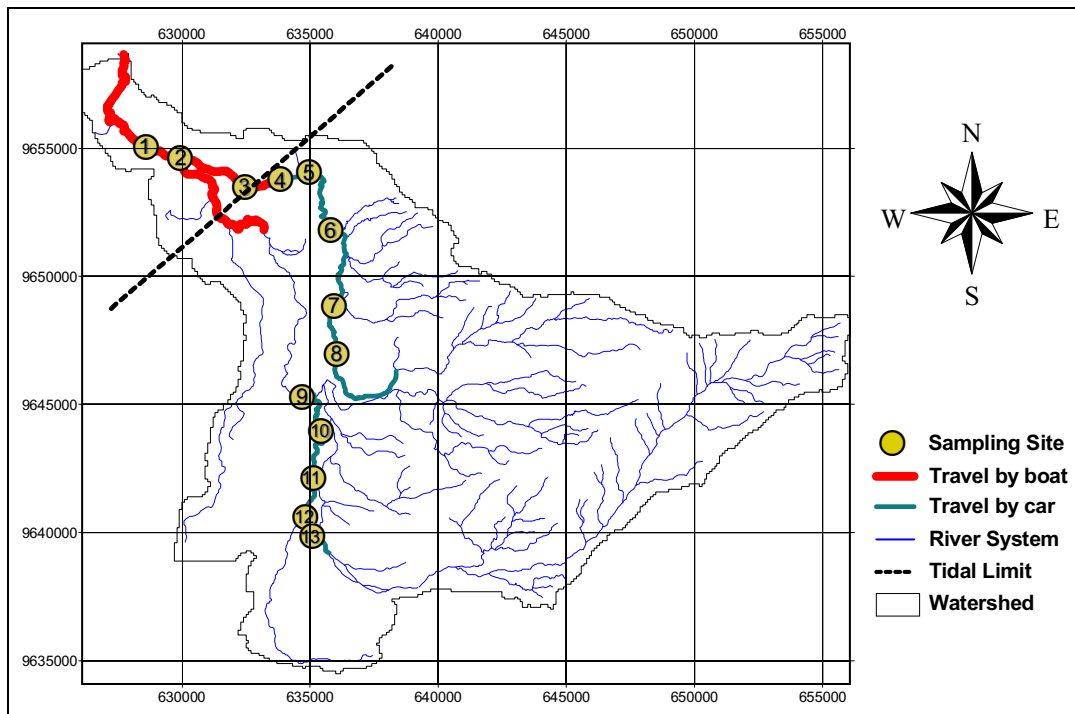**Photo 3.3. Barrier built by a banana farmer to protect a pump uptake**

Figure 3.23. Travelling path of the survey done in June 2001 and selected sampling sites

Before the exploratory trip, a sampling procedure called follow-the-plug method[30] was opted for. However, due to the problems mentioned previously, another sampling method was selected: to sample only accessible sampling sites from the most upstream to the most downstream location.

Sampling Sites

Thirteen places which can be accessed at any time of the year were selected to take water samples and eventually sediment samples from each sampling period. From here on, these places will be known as the *Sampling Stations*. However, some other samples were taken at places only accessible by boat during the rainy season or when the river depth allowed to travel by boat. Those places will be called *Reference Sampling Sites* for river stretches not sampled during the whole campaign periods. Table 3.42 shows the location coordinates and a brief description of the sampling stations, which can be seen in Figure 3.23.

Table 3.42. Location of sampling stations in the Chaguana River Basin

Sampling Station	UTM Coordinates		Monitored River	Site Description
	E	*N*		
1	628475	9655363	Main River	Tendales Town near the outlet of the basin
2	629818	9654923		Confluence of both rivers
3	632343	9653798	Zapote	Pump Station at Zapote river
4	633719	9654101		Entrance to "Quirola" farm in the Zapote river
5	634849	9654362		Entrance to "Agricola Leticia" farm in the Zapote river
6	635692	9652118		Main highway bridge over Zapote river
7	635812	9649161		Service road of "Pennsylvania" farm
8	635916	9647300		The most upstream sampling point in the Zapote river
9	634582	9645601	Chaguana	Main highway bridge over the Chaguana river
10	635313	9644289		"La Flores" farm in the Chaguana river
11	635030	9642430		"Juana Fernandez" farm in the Chaguana river
12	634709	9640917		Road bridge to "Chaguana" farm
13	634963	9640170		The most upstream sampling point in the Chaguana river

Measurement Methodology

During sampling, some environmental parameters such as temperature, conductivity and salinity were measured with a YSI-30 instrument. The apparatus probe was introduced up to

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[30] It considers sampling the same mass of water while travelling downstream the river.

one third of the river depth at several places across the sampling section. The average value of the measurements is reported for each sampling place.

For pesticide concentrations and other water quality parameters, a sample was obtained in each sampling point. The sample consisted of three 1000-ml bottles (1 glass bottle for pesticide analysis), which were preserved at 4ºC in coolers while they were transported to the lab. Because a sampling campaign was three days long, collected samples were sent to the lab on a daily basis.

Two bottles for each sampling place were analyzed at the Water Quality Lab of the Centre of Aquiculture Services (ESPOL) to obtain Biochemical Oxygen Demand, Total Organic Carbon and Solids Content. Samples in amber glass bottles and sediment samples were analysed in the Ecuadorian Commission of Atomic Energy to obtain pesticide concentration.

3.11.2. LAB ANALYSIS AND RESULTS

As said before, there were two groups of data measured during the sampling campaigns: digital data and data obtained from laboratory analysis. In this section, the results obtained will be evaluated and discussed. Results are displayed as colour maps on corresponding river stretches, in which the colour depends to the value assigned to each river stretch. As sampling places are points rather than lines, the following procedure was followed to assign a value to a river stretch:

- A river stretch is connected by two consecutive sampling stations.
- The value assigned to a river stretch corresponds to its upstream sampling station.
- If there are reference sampling sites in the evaluated stretch, these values will be used with the station value to obtain an average for the stretch. In case there is one reference sampling site significantly different from the others, the river stretch will be split at the location of the reference sampling site.

pH

Recorded values of pH during all sampling campaigns were between 6 and 7 which are typical for fresh water. Therefore, there is no significant discharge or no discharge at all of acids or bases that could affect the buffer capacity of the river. The Ecuadorian standard for pH in fresh water rivers is between 6 and 9.

Temperature

The behaviour of water temperature in the sampling points was a little different for all sampling periods. It is important to note that these temperatures are not measured at the same time for each point in both rivers, but they are measured consecutively with increasing time steps from point to point. Therefore, it is better to look at the temperature difference in the whole sampling period for the entire basin rather than interpreting the temperature in each sampling place.

In table 3.43, it can be seen that water temperature varies per sampling campaign. Compared with historical records for those months, the three first sampling campaigns show a normal behaviour. On the other hand, the fourth campaign exhibits a range of temperatures higher than the historical one. This could be explained due to the presence of the initial stages of the 2002 El Niño event. Figure 3.24 shows the measured temperature in the Chaguana river.

Table 3.43. Water temperature difference within the basin per sampling campaign.

Sampling Period	Temperature Range	ΔT spatial	Comment	Mean $T_{HISTORIC}$
November 2001	23.5 ºC – 24.6 ºC	1.1ºC	Abnormally dry month	23.4 ºC
March 2002	23.0 ºC – 25.8 ºC	2.8ºC	Rainy month	25.9 ºC
July 2002	22.7 ºC – 24.6 ºC	1.9ºC	Dry month	22.4 ºC
November 2002	24.4 ºC – 27.7 ºC	3.3ºC	Beginning of El Niño event	23.4 ºC

Electrical Conductivity

Conductivity measurements can help in aquatic assessments by providing an estimate of the dissolved ionic matter in the water. This value can be related to the existing environmental state of water bodies: oligotrophic, eutrophic and highly-polluted waters. The two last types of water bodies can exhibit very high values of conductivity. On the other hand, a pollution discharge can be reflected as a sudden change in conductivity. Studies of inland fresh waters indicate that streams supporting good mixed fisheries have a conductivity ranging between 150 and 500 μS/cm (EPA 1997). In the current research, conductivity was measured with digital equipment.
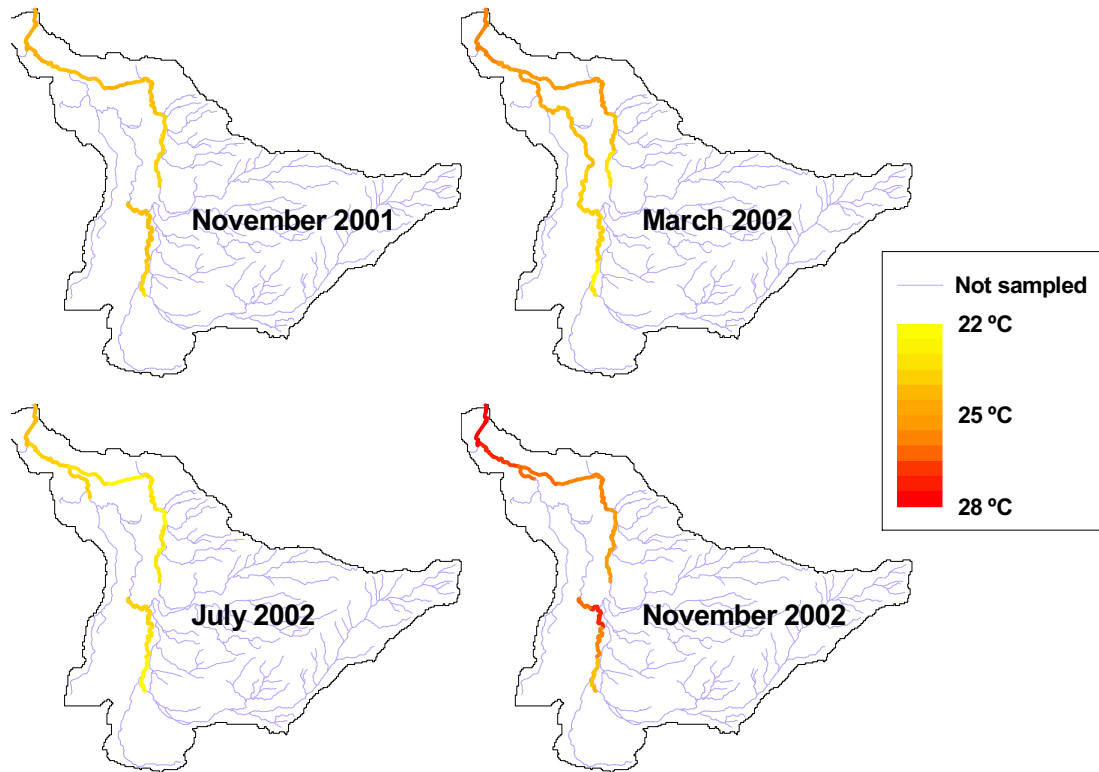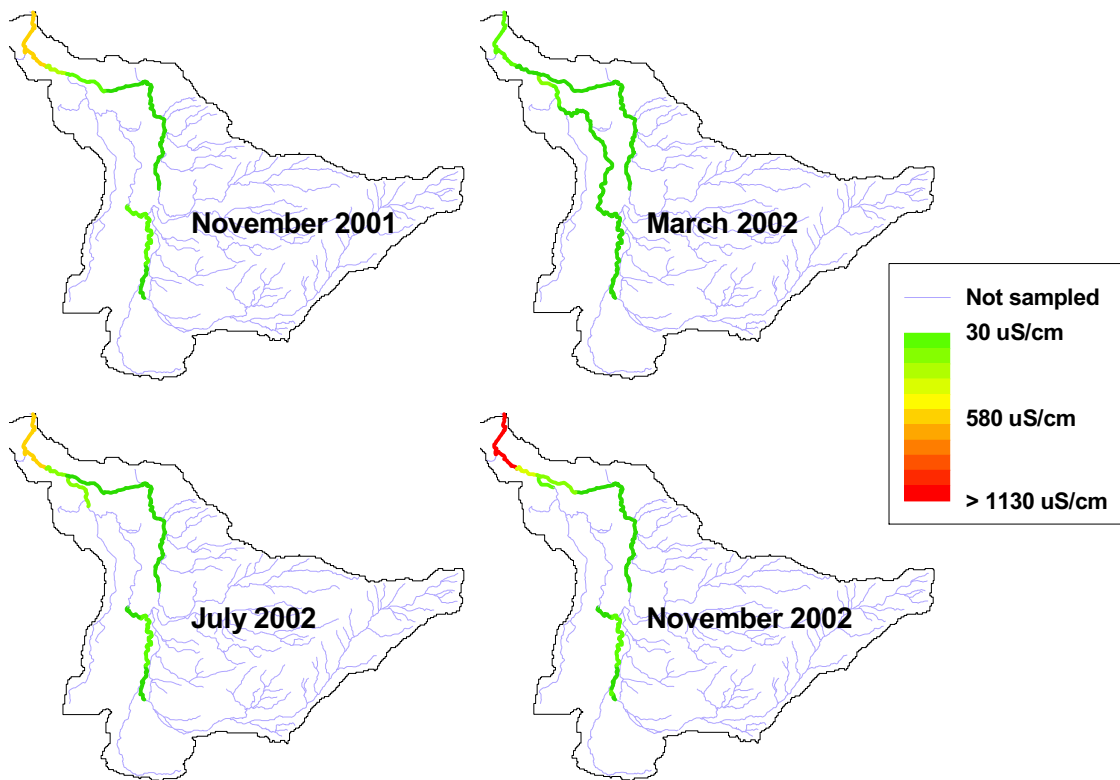
Figure 3.24. Monitored water temperature

Figure 3.25. Monitored electrical conductivity

In the Chaguana river basin, the majority of the measured conductivity values are below 500 μS/cm, which means that they do not indicate pollution at the sampling dates. However, conductivity values greater than 500 μS/cm were found near the outlet of the basin (Figure 3.25); and this is explained by the potential saline intrusion into the basin. In addition, a town called Tendales (less than 2000 people) is located 5 km upstream from the outlet, and it discharges its wastewater directly to the river.

Solids Content

Suspended and dissolved solids were measured in the laboratory by using STANDARD METHODS AWWA 2540. Results are given in figure 3.26 (Suspended solids) and figure 3.27 (dissolved solids).

The suspended solids content in a river is directly related to the resulting erosion through the basin. Although the Chaguana and the Zapote rivers run through erosive soils (sands and silts), the Chaguana river (left stream) showed more suspended sediments than the Zapote river (right stream) during sampling campaigns, mainly in November 2001 and March 2002. During that period, both river sides of the Chaguana River were under civil works maintenance done by the farms adjacent to the river. Thus, some resulting river erosion was produced at that time. Farmers perform these maintenance works at least once a year.

In river waters, dissolved solids content consist of calcium, chlorides, nitrate, phosphorus, and other ions particles that will pass through a filter with pores of around 2 microns (0.0002 cm) in size. There are many sources where those ions come from; however, pesticides and fertilizers are the main suppliers of dissolved solids in basins where agriculture is the main activity.

Figure 3.27 shows the dissolved solids content measured during each sampling campaign. It is seen that both rivers exhibit very low dissolved solids content (less than 100 mg/l). However, high values (larger than 500 mg/l) were recorded near the basin's outlet. This behaviour correlates very well with the conductivity measurement done at the same places (figure 3.25). As explained before, this last river stretch is influenced by marine intrusion as flood tide enters the basin.
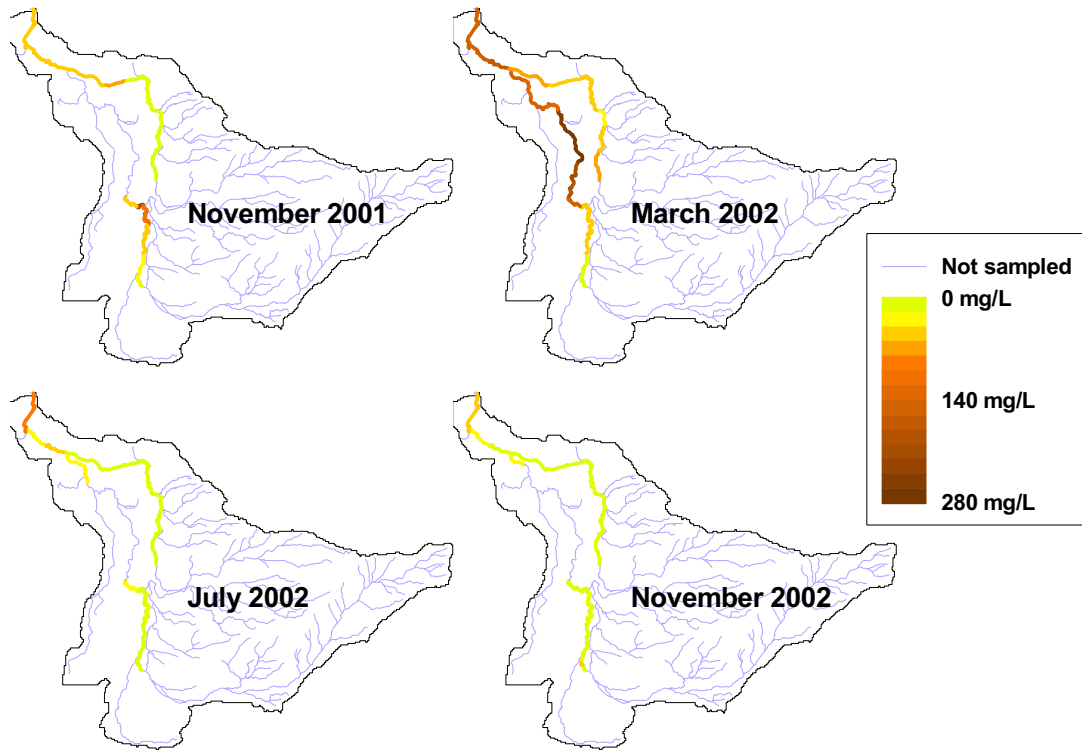
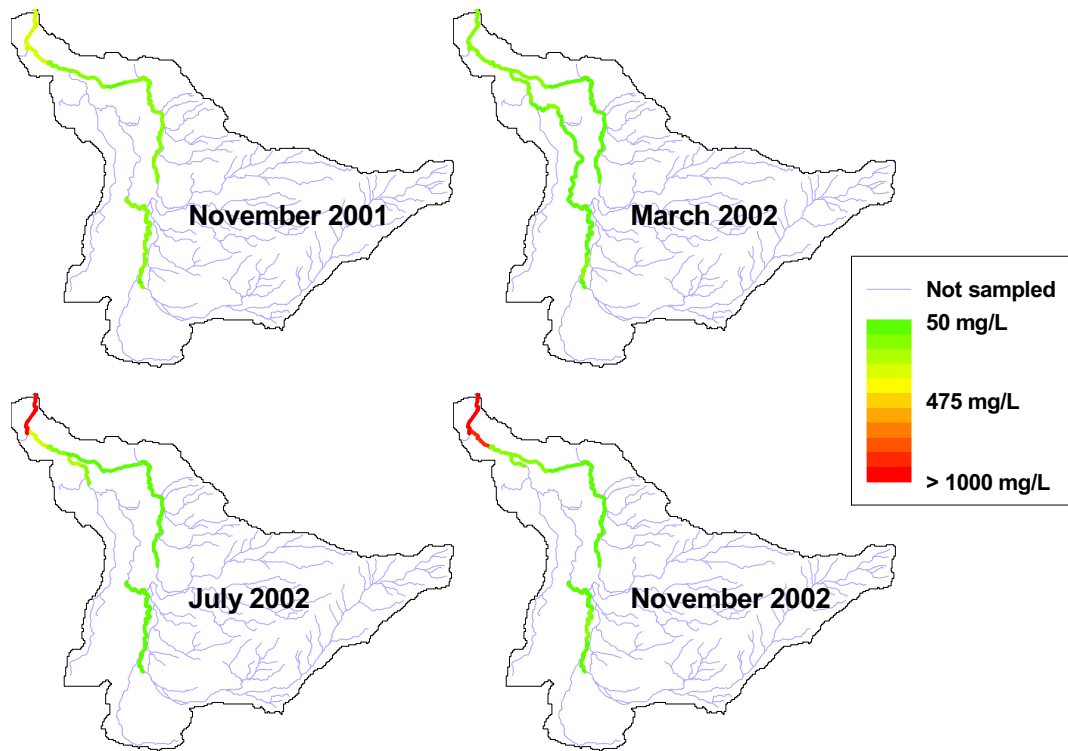**Figure 3.26. Monitored Suspended Solids**

Figure 3.27. Monitored Dissolved Solids

Biochemical Oxygen Demand

BOD measurements are indirect indicators of the amount of organic matter present in water bodies, mainly produced by domestic wastewater discharges. For the case of the Chaguana river basin, the recorded BOD values were between 1 to 4 mg/l which indicates that organic matter discharges into the river were not the main concern for the ecosystem at the moment of sampling. These values are within the acceptable range for fresh-water bodies.

In the evaluated watershed, there are only two main residential areas located at the most western parts of the basin: Tendales and El Guabo (Figure 3.19). In addition, there are some sparse settlements within the farms. Most of the residential areas do not have wastewater treatment systems.

The total amount of people living in the basin is less than 20000, which represents around 23 litres of wastewater per second; and a BOD loading of 500 kg/day or 10 kg BOD per day per kilometre of the monitored stream[31].

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[31] The equations used to calculate these values are

$$Q_{sewage} = \frac{N\, q_u}{86400} \qquad\qquad [3.24]$$

$$Load_{daily} = \frac{54}{625}\, BOD_{domestic}\, Q_{sewage} \qquad\qquad [3.25]$$

$$l_{daily} = \frac{Load_{daily}}{L_{river}} \qquad\qquad [3.26]$$

Where

Q_{sewage}	Domestic wastewater flow
q_u	Unitary sewage production which is assumed to be 100 l/p/day in Ecuadorian rural areas.
$BOD_{domestic}$	BOD concentration for domestic wastewater which has an average value of 250 mg/l in Ecuadorian rural areas
$Load_{daily}$	BOD loading on daily basis
l_{daily}	Average linear distribution of BOD loading along the river length
L_{river}	Length of monitored river stream, which in the current research is around 50 km.
N	Number of inhabitants

Pesticides

Water and sediment samples were analysed to obtain pesticide concentrations. As explained in previous sections, propiconazole, imazalil, thiabendazole, glyphosate and tridemorph are the pesticides most used in Ecuadorian banana farms. However, glyphosate and tridemorph could not be traced due to existing lab restrictions in Ecuador (see section 2.5.3); and the others were detected up to 0.01 ppb (minimum detection limit). As expected, a sampling campaign can only detect pesticide concentrations when the spraying is performed within a period of time before the campaign takes place. This is mainly because the river travel time in the basin is less than 24 hours.

Propiconazole is a pesticide applied by air spraying, and it is used mainly for Sigatoka control. During the sampling campaigns some river stretches showed propiconazole concentrations while others did not show any at all (Figure 3.29). From the figure, it is clear that most of the farmers in the basin sprayed their plantations during the March campaign because Sigatoka tends to be present on banana leaves during the rainy season (extreme humid conditions). During the other campaigns, propiconazole is only detected near the basin outlet which is mainly a shrimp area; however, this pesticide could have come from the most downstream banana farm which is located around 7 km upstream the outlet.

Imazalil and thiabendazole are pesticides used during the packaging process of banana mainly as a pesticide mixture. As explained in the *Pesticide Management Data* section 3.8.2, farmers harvest banana at least one day every week. However, the packaging process is performed independently, depending on each farm's operational plan. Detected concentrations of both pesticides can be seen in figures 3.30 and 3.31. The presence of both pesticides in the river is very similar, which is very logical in view of their similar application.
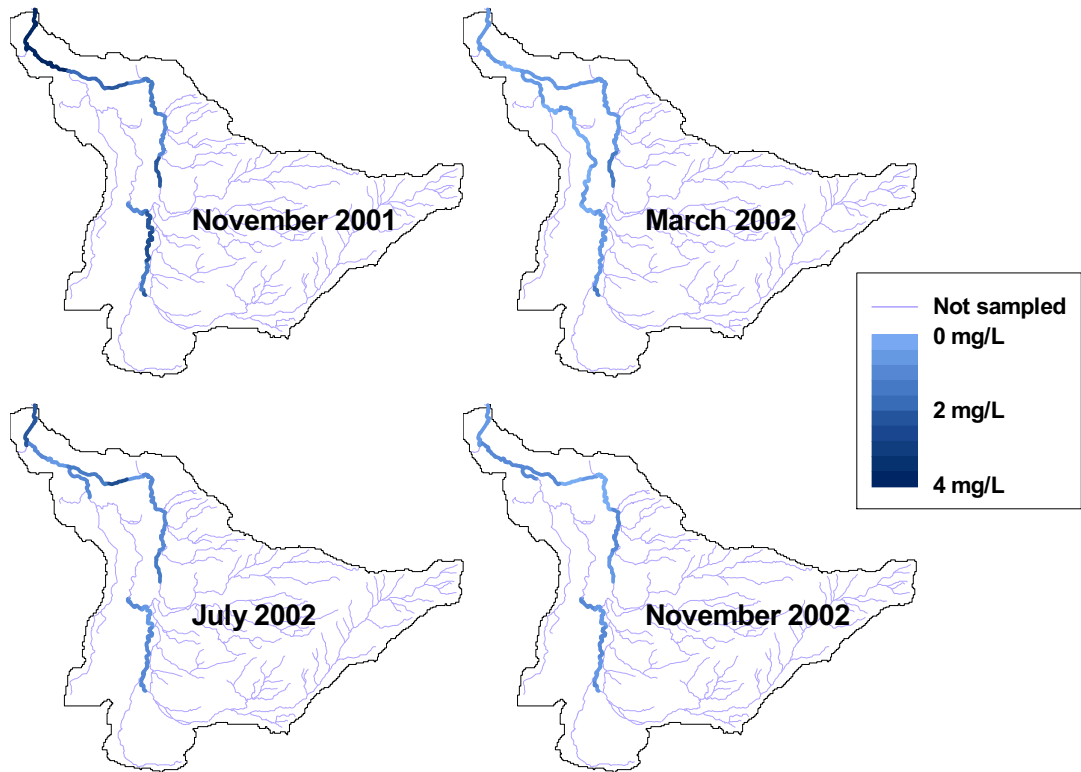
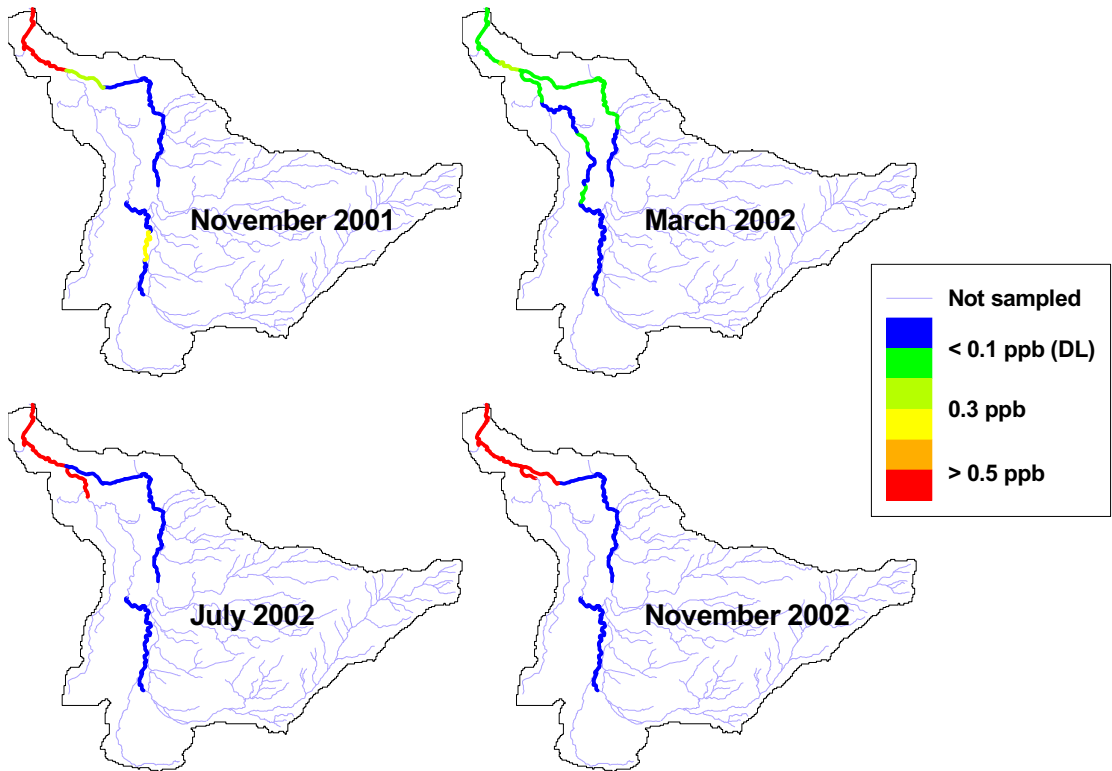**Figure 3.28. Monitored Biochemical Oxygen Demand**

Legend:
- Not sampled
- 0 mg/L
- 2 mg/L
- 4 mg/L

Figure 3.29. Monitored Propiconazole concentrations

Legend:
- Not sampled
- < 0.1 ppb (DL)
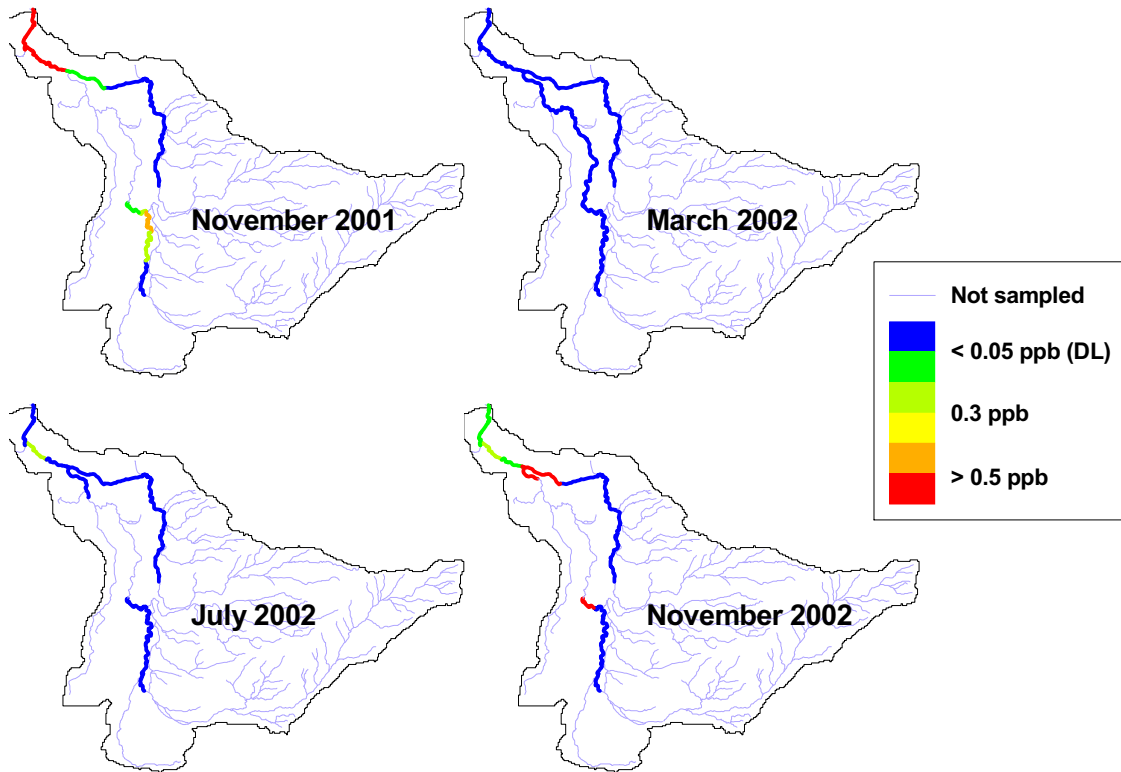- 0.3 ppb
- > 0.5 ppb

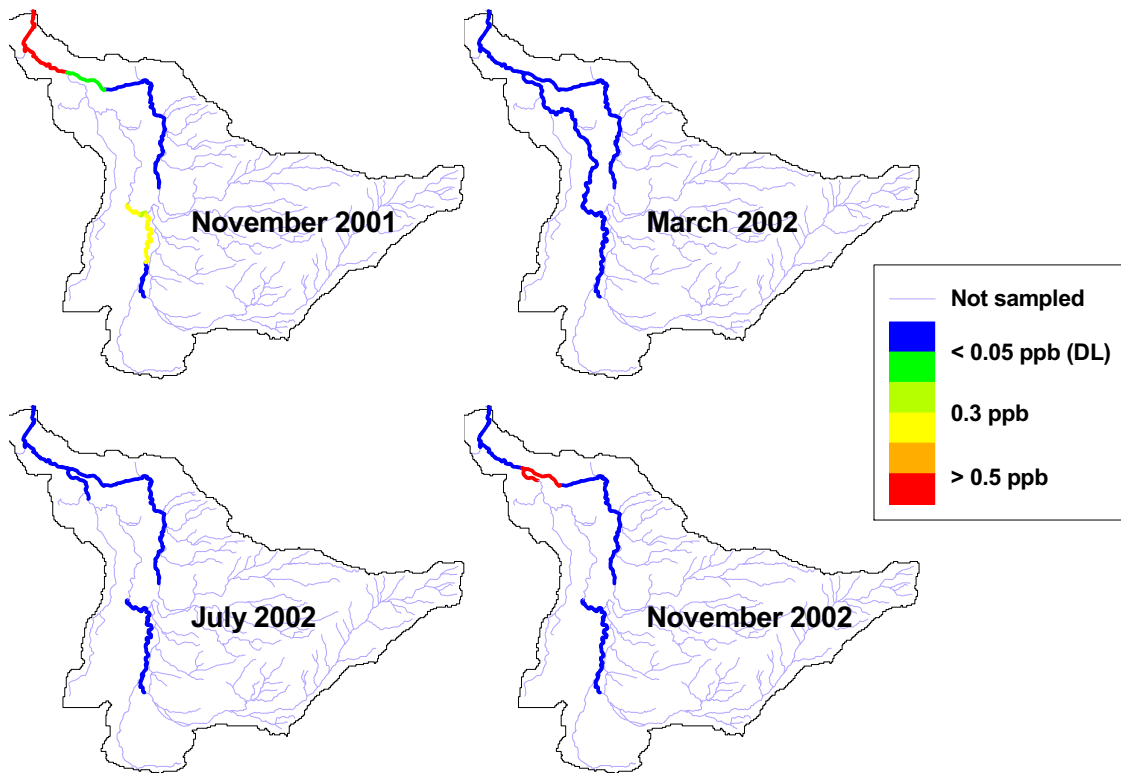**Figure 3.30. Monitored Imazalil concentrations**

Figure 3.31. Monitored Thiabendazole concentrations

The pesticide analysis performed by the laboratory could detect other pesticides than the requested ones. Organophosphorus and Organochlorine pesticides were also detected by the chromatography analysis. Those detected pesticides represent mostly insecticides, which seem to be used in the majority of the basin's farms throughout the year, as shown in figure 3.32. In the figure, the total amount of detected pesticide concentration in every sampled stretch is displayed.
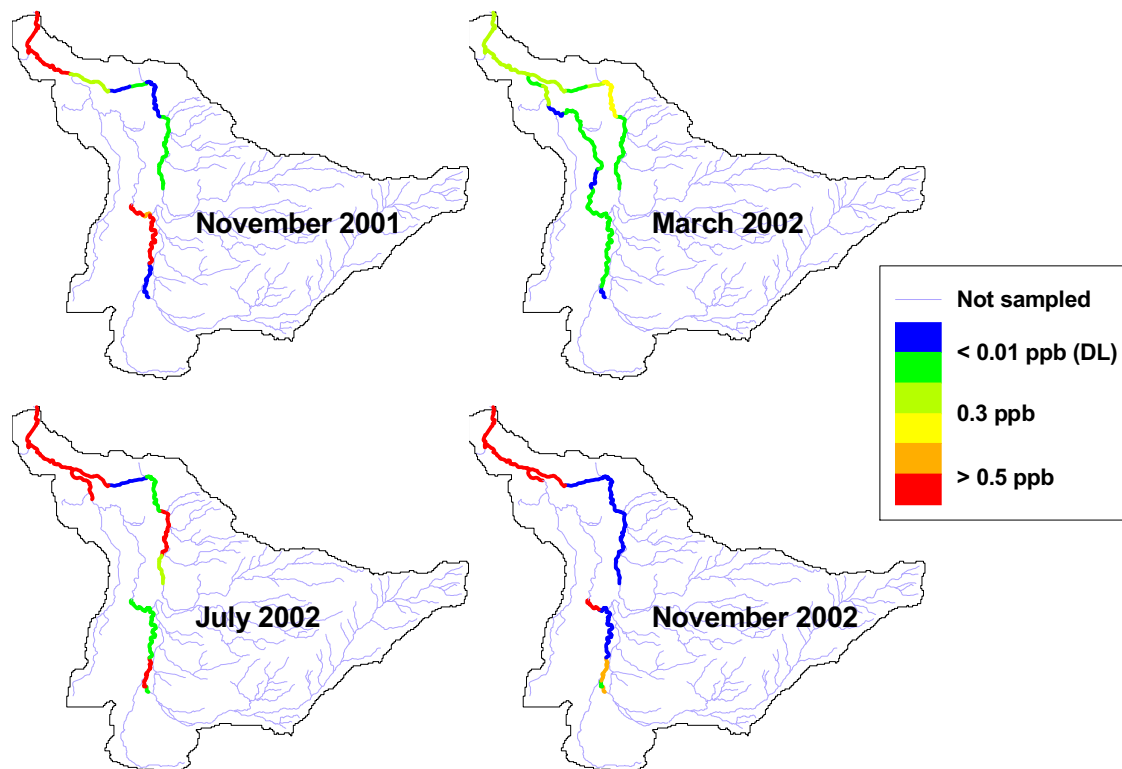

Figure 3.32. Total monitored pesticide concentrations

In the previous figure, maximum detected values were around 6 ppb (July and November 2002), which is significantly below the reported toxicity values for aquatic organisms. Based on that, the pesticide impact on the Chaguana basin on the aquatic biota is relatively low. However, detected pesticide values are exceeding the European maximum residue levels in water for human consumption (0.5 ppb for total amount of pesticides, and 0.1 ppb for one pesticide). Therefore, human health must be the main concern related to the pesticide usage in the Chaguana Basin.

3.12. CONCLUDING REMARKS

The data necessary to run a model sometimes is overwhelming, and are usually not so easily available. This chapter has gone through different methodologies to obtain reliable data to assess environmental problems in a case study: the Chaguana river basin. During the data evaluation, it was found that the existing state of the art in Ecuador regarding data housekeeping is still low. Although the procedures presented here can help to overcome that problem in other "data-poor" basins, they can not replace field measurements because uncertainties can be introduced in the model, and outcomes can differ from reality. All collected data has been organized and structured within a Geographical Information System. Thus, it can be available for future research or the basin stakeholders.

Another important finding in this chapter is the determination of the environmental baseline of the Chaguana river basin. There was no information regarding the environmental quality of the basin before this research began. Based on the sampling campaigns, it can be concluded that the basin is still not heavily polluted. However, data presented here should only be considered as a starting point to begin a monitoring programme on a frequent basis to develop a reliable historical data of several environmental parameters.

In the next chapter, a detailed description of the model evaluation is given. Selected models were executed with all data presented in Chapter 3. GIS was used to input some data into the models.