Analysis of the impacts of land-cover changes on soil erosion in watershed of Río Antón, Province of Coclé

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Table of Contents

I. Introduction and Background Information

In 1992, Panama was among 178 countries to ratify Agenda 21 at the United Nations Conference on Environment and Development in Río de Janeiro. Chapter thirteen of Agenda 21 calls upon nation states to take immediate action towards implementing proper management strategies for mountain resources. On a global scale, nearly 10% of the world's population depends on mountain resources – needless to say, scientific inquiry on the sustainable management of these regions is imperative. Despite ratification of Agenda 21 there appear to be very few studies focusing on Panama's mountainous corridors. For this reason, we felt it was important to have a preliminary assessment of the conditions of mountain resources within a specific location of Panama.

Tourism is burgeoning countrywide in Panama, including within the cooler mountainous regions. For the sake of our study, our definition of tourism goes beyond the description of vacationers in order to include residential developments which are marketed to international buyers. For instance, in El Valle de Antón, tourism could be considered new homes intended mainly for international retirees or for wealthy Panamanians as secondary residences. With this broader definition in mind, the effects of increased tourism on resources in El Valle de Antón have not been studied heretofore. Nevertheless, in other areas of the world studies have shown that there exist negative impacts of tourism particularly on mountainous areas. These include changes in land

cover, loss of biodiversity, decreased water quality, trampling of vegetation, littering, and most importantly deforestation (Pickering & Buckley 2003 ; Gössling 2002).

The link between deforestation and tourism in El Valle de Antón is not immediately obvious and therefore should be put into context. According to a World Bank report, 60 percent of recent deforestation within developing countries can be attributed to the expansion of the agricultural frontier (World Bank 1991). In Latin America, studies have shown that rural-to-rural migration leads to increased forest clearing and the advancement of the agricultural frontier (Bilsborrow 2002). Should the rural-to-rural migration trend hold true for El Valle de Anton, the resulting damage would be caused to the Río Antón watershed which extends to the Pacific Ocean. Migrant colonists tend to be underprivileged therefore they migrate onto low potential marginal lands, often on steep slopes. As will be shown later, the ensuing deforestation greatly exacerbates erosion and by extension, soil degradation. Furthermore, the increase in erosion and sedimentation, in addition to the loss in water retention, causes damage to watersheds.

Once soils are degraded, poor *campesinos* migrate onto other marginal lands where the deforestation process is repeated (Repetto 1986). What causes the poor to move onto marginal lands varies across space and time. In El Valle de Antón, however, we suspected that the driving force of this phenomenon was increased population due to a large influx of international tourists (see table I). An additional driving factor may be increasing land inequality due to large estates being built on the low-land fertile soils of El Valle. Given these two drivers of change, we expected that increased tourism in El

Valle would drive poor peasants onto steep marginal lands thereby increasing erosion and sedimentation in the surrounding watershed.

It has therefore been the main goal of our research to determine which areas, within the entire Río Antón watershed, are most susceptible to erosion and sedimentation. Although a socioeconomic study of the region was impossible given the timeframe of our research, it was our objective to make preliminary links between our scientific findings and socioeconomic changes within the region studied. Furthermore, it is our hope that our results may help launch management strategies to reduce damage to the Río Antón watershed. To fully comprehend the potential damage to the Río Antón watershed, it is essential to first understand how land use changes negatively affect watersheds. Deforestation and vegetation clearance are among the main factors responsible for soil erosion. The removal of top-layer vegetation is required to convert forests into pastureland or crop land. This change in land use exacerbates risks of soil erosion as intense harvesting and overgrazing cause the soil to be more vulnerable to the erosive forces of rainfall and wind. De Ploey estimated in 1989 that areas covered with permanent vegetation are associated with soil erosion rates 100-1000 times lower than on unprotected fields (Thomas 2009). Furthermore, tillage practices, if too frequent, will reduce the stability of the soil structure due to lower amounts of soil organic matter. Indeed, it has been shown that traditional agriculture tillage practices negatively impact the topsoil. In industrialized agricultural fields, the use of heavy machinery will compact the soil and affect the filtration capacity of soils which increases water runoff and surface erosion. The process of soil erosion affects the landscape and water systems in many

ways. The main impacts include a reduction in the land's fertility as the topsoil layer is washed away and the siltation of rivers and reservoirs (Van Rompaey et al. 2001).

The impacts of land cover changes and crop rotation on soil erosion are usually determined using erosion models such as the Revised Universal Soil Loss Equation (RUSLE). This equation predicts the average annual soil loss and is composed of the following elements: rainfall erosivity factor (R-factor), soil erodibility factor (K-factor), slope length and steepness, types of land cover and management practices (Coastal Services Center National Oceanic and Atmospheric Administration 2004). The rainfall erosivity factor, which consists in the erosive potential of rainfall, quantifies the effects of raindrop impacts and reflects the amount and rate of runoff associated with precipitation (Thomas 2009). Hence, a rainstorm of higher and longer intensity will be associated with a greater erosion potential. The soil erodibility factor is a measure of the resistance of soil particles to the impact of raindrops on the soil surface. Factors such as soil permeability, structure and texture as well as organic composition are likely to affect erodibility values.

Empirical models like RUSLE are widely used tools for decision-making in soil and water conservation. For example, erosion risks in the Cuyaguateje watershed in Cuba were evaluated using the RUSLE model (Schiettecatte et al. 2008). Results revealed that areas of highest erosion risk were located in agricultural valleys. Furthermore, it was found that the regions of very high erosion risk increased by 12% between 1985 and 2000 due to the conversion of 14 square kilometers of forest into arable lands. Another study looked at the influences of land cover and crop rotation changes on the intensity of soil erosion in Slovakia by means of the RUSLE model (Cebecauer & Hofierka 2008). The results indicated that deforestation for timber production and agricultural intensification

in mountainous regions was responsible for the increase in erosion rates. Similarly, risks of erosion increased in the northern and central parts of the country as clear-cutting augmented. On the other hand, the conversion of arable lands into forested land lowered erosion rates in the eastern portion of the country.

From the RUSLE model, we can conclude that changes in land use practices may have a greater impact on soil degradation in tropical regions where heavy rainfalls increase rates of erosion. However, soil loss can be significantly reduced if conservation practices are in place to protect portions of the vegetation cover. For example, the Agriculture Policy of the European Union (EU-CAP) introduced in 1992, established regulations for European farmers to set aside portions of their arable land out of production for conservation purposes (Giordano et al. 1991). As vegetation cover protects the soil from the impact of raindrops, it is likely that such regulations will efficiently lower soil erosion rates at these agricultural sites. Interestingly, it was found that under this agricultural policy, a majority of European farmers preferred leaving aside steeper and more erodible fields out of production. These decisions contributed to lowering significantly the total erosion rate as steep and unprotected areas are usually more at risk of soil loss due to higher vulnerability to rainfall erosivity.

Another way of mitigating the negative effects of changing land use practices is to address the underlying forces leading to land use change. For El Valle de Antón we suspect that the root cause of deforestation may be linked to the changing demographics caused by tourism. Consequently, it would be important to implement growth management strategies. Growth management strategies are formulated to encourage the expansion of tourism in a way that mitigates the environmental consequences of tourist

developments. Furthermore, the aim of growth management is to promote tourism without comprising the needs of the surrounding communities (Gill & Williams 1994).We consider this concept to be of utmost importance and we hope that our preliminary research in El Valle de Antón may serve as a catalyst for eventual growth management strategies within other mountainous regions of Panama.

II. Host Institution Information

Our project was conducted in concurrence with the Centro del Agua del Trópico Húmedo para América Latina y El Caribe (CATHALAC). CATHALAC is a non-governmental organization (NGO) that was founded in 1992 with an overall objective of enhancing sustainable development, namely for water resources, within Latin American countries. Since then, the institution has quickly expanded to include many other areas of study together with the sustainable management of water. For instance, more recent projects have dealt with climate change, renewable resources, biodiversity, terrestrial ecosystems to name a few. Recent publications and projects from CATHALAC have addressed the loss of mangrove forests, potential impacts of climate change on biodiversity and ways of adapting to climate change. All of these topics are particularly relevant to Panama.

The majority of CATHALAC's projects focus on large-scale problems using Geographic al Information Systems (GIS) as a tool for identifying environmental changes in Latin America. CATHALAC's research falls into the branch of applied investigative science. For many projects, CATHALAC works alongside other international

organizations. For example, for a recent project on risk management in Central America, CATHALAC collaborated with UNICEF, PNUMA, the Red Cross to name a few.

A) Contribution to CATHALAC

Our internship project will provide valuable information to the host institution in several ways. Firstly, our field work will help validate the 2008 vegetation land cover map that CATHALAC has been working on in cooperation with Panama's Autoridad Nacional del Ambiente (ANAM). Our devised methodology for the field validation will be replicable in other areas of Panama. Secondly, our project investigates the degradation to watersheds caused by erosion and sediment runoff - a topic that falls into the institution's original interest in sustainable management of water resources. Thirdly, our project relies on N-SPECT modeling, a GIS tool that is newly being used and with a potential that has yet to be untapped by CATHALAC. Fourthly, our project is focused on the local scale; a spatial scale that we hope will be introduced into future projects at the institution. Lastly, our project will help to link scientific findings from N-SPECT with socioeconomic conditions within Panama, a relationship that is seldom explored in CATHALAC's projects.

B) Project Director

Our project coordinator is Octavio Smith, a research scientist at CATHALAC whose interests include GIS, Remote Sensing and Land-use Planning. Mr. Smith works in the Applied Research and Scientific Development Division of CATHALAC. In addition, our project has been carefully guided by Eric Anderson, a former McGill

graduate, a past participant in the Panama Field Study Semester and an asset to our project. Jose Maria Guardia and Ariel Agrazal, two research scientists at CATHLAC, helped with our training using ArcGIS.

Number of days spent in the field: 7.5 days

Number of days spent in office CATHALAC: 23 days

III. Goals and Objectives

The goals of our research were two-fold, where both a broader assessment of the Río Antón watershed was conducted in tandem with a local assessment of El Valle de Antón. The overarching objective of our research was to identify the critical areas susceptible to erosion and sediment runoff within the Río Antón watershed. To achieve this goal, we used a non-point source pollution and erosion comparison tool (N-SPECT) to identify the zones most vulnerable to erosion within the entire Río Antón watershed. We ran the model for both 2001 and 2008 in order to evaluate the level of change in recent years.

Our second objective, which is interrelated to the first, was to compare the changes in land cover for the Río Antón watershed over the last decade. According to several scientists, land cover change is seen as the single most important component of global environmental change affecting ecological systems (Sala et al. 2000; Gössling 2002). Land-cover changes cause the release of greenhouse gases, but more importantly for this study, it exacerbates erosion within surrounding watersheds. To identify land cover change, we compared the Autoridad Nacional del Ambiente (ANAM) vegetation

cover maps from 2001 and 2008. To account for the one year difference since the publication of the latest vegetation cover map, we validated the 2008 land-cover map using a Global Positioning System (GPS) to conduct field surveys.

At the more local scale, our analysis was focused on El Valle de Antón because of the growing pressures of tourism in this region. Indeed, although the mountain vistas of El Valle provide enjoyable sites for tourists, more importantly, the mountains surrounding the city center are home to an important watershed which provides humanity's most vital commodity - fresh water. Given El Valle's increasing demographic trends, alarms should perhaps be sounded about the future state of water quality and water availability in this region. Undeniably, in areas with extensive tourism, it has been shown that water consumption is greater since tourists tend to increase their consumption patterns while residing in hotels (Gössling 2002). Furthermore, tourism may lead to increased runoff due to clear-cutting for infrastructure. This in turn leads to nutrient pollution and siltation (UNDP/UNEP/World Bank/WRI 2000).

For the reasons enumerated above, it was our final objective to obtain a surface understanding the socioeconomic drivers that lead to damage of watersheds in El Valle de Antón. This was achieved by conducting informal interviews with local residents in order to determine how changes in land cover and water quality affect the lives inhabitants. In addition, socioeconomic data was obtained at Panama's national statistics bureau, the Contraloría General de la Republica de Panama. Although an in-depth socioeconomic study was not possible, ultimately it is hope that our findings may serve to develop sustainable management strategies for these surrounding communities. A more

in-depth discussion on the methodology constructed to obtain these objectives will be presented in the following section.

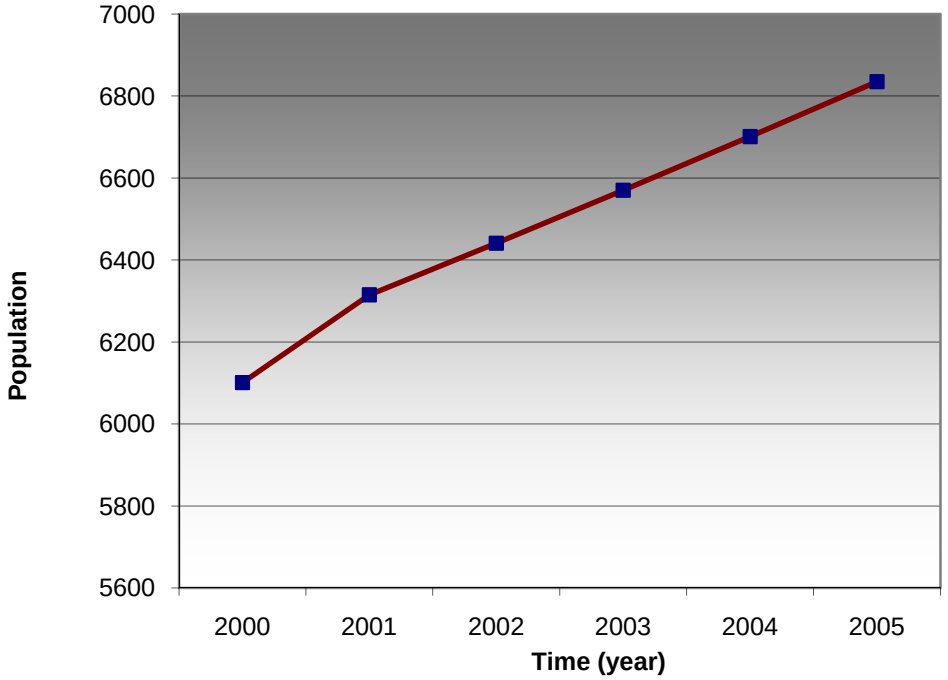
IV. Study Site

The study site for our research is the Río Antón watershed, located within the district of Antón, one of the 6 districts within the greater province of Coclé. Within this watershed, our study focuses on El Valle de Antón, one of ten corregimientos located in Antón district (see figure 1). The municipality of El Valle is huddled within a volcanic crater which forms part of the southern mountainous region, west of Panama City.

Figure 1: Map of the location of study, Río Antón watershed

The crater sits at an elevation of approximately 580 m about sea-level and most of the population is situated in the valley of 18. 3m^2 (Nato 1985). In recent years, El Valle has become a popular touristic destination and a site for development projects. Moreover, we find that there has been a large increase in population growth over the last several years, where based on the 2000 census we may estimate roughly 7,000 inhabitants in the region (see table 1).

Table I: Estimated Population for EL Valle 2000-2005



In terms of forest ecology, the region surrounding El Valle is characterized by a mosaic of forest types while the city center consists of disturbed forest ecosystems. To the north of the town of El Valle, is located the cloud forest reserve of Cerro El Gaital, the highest point of the Río Antón watershed with an elevation of 1,185m above sea-level

(Nato 1985). This protected area serves as a source of freshwater for the community of El Valle.

The watershed of Río Antón, located in the southeastern portion of the province of Coclé, drains an area of approximately 298 squared kilometers (ANAM 2005). With a mean elevation above sea-level of 80m, the area of the watershed receives a mean annual precipitation of 2,290mm. Precipitation is distributed heterogeneously throughout the region with the center of the watershed receiving as much as 3,000mm of rainfall as opposed to the Pacific coast with an average of 1,500mm of rainfall (ANAM 2005). The bulk of precipitation (92%) occurs between the months of May and November.

With a length of 53km, Río Antón runs through the towns of El Valle and Antón and is affected by non-point source pollution, agricultural and industrial runoff of contaminants and household-generated pollutants associated with these urban centers (ANAM 2005). Table 2 summarizes measures of water parameters and indicators of water quality collected at three stations (El Valle, Antón and Finca La Paila) operated by the *Autoridad Nacional del Ambiente* (ANAM) of Panama.

Table 2: Water quality indicators of Rio Antón measured at three stations (El Valle, Antón and Finca La Paila) within the watershed

	Station 1 (El Valle)		Station 2 (Antón)		Station 3 (Finca La Paila)	
Coordinates	952712 N / 598210 E		928353 N / 581615 E		924313 N / 583014 E	
Year	2004	2005	2004	2005	2004	2005
Season	Dry (January)	Wet (June)	Dry (January)	Wet (June)	Dry (January)	Wet (June)
pH	7,90	7,32	7,60	6,47	7,40	6,87
Temperature (°C)	22,90	22,00	26,20	25,70	27,40	26,70
Turb. (NTU)	S/A	0,80	S/A	37,60	S/A	27,10
Suspended Sediments	9,20	4,00	4,40	37,00	13,30	7,00

(mg/L)						
Dissolved solids (mg/L)	167,10	136,00	156,65	167,00	167,70	155,00
NO3 (mg/L)	0,67	2,80	0,39	3,44	0,41	2,70
PO4 (mg/L)	0,52	0,14	0,40	0,15	0,60	0,20
E.Coli (NMP/100 mL)	S/A	410	S/A	630	S/A	<100

During the month of June in 2005, turbidity levels of 0.80, 37.6 and 27.10 NTU (Nephelometric Turbidity Units) were recorded for the respective stations of El Valle, Antón and Finca La Paila. Moreover, in January 2004, ANAM recorded values of 9.20 mg/L of suspended sediments and 167.10 mg/L of dissolved solids at the El Valle station and values of 13.3 mg/L of suspended sediments and 167.70 mg/L of dissolved solids at the Finca La Paila station. Measures of suspended sediments and dissolved solids for the station in Antón were greater in June 2005 with respective values of 37.00 and 167.00 mg/L.

Nitrate (NO_3) concentrations of 2.80, 3.44 and 2.70 mg/L for June 2005 and phosphate (PO_4) concentrations of 0.52, 0.40 and 0.60mg/L for January 2004 were measured at the respective stations of El Valle, Antón and Finca la Paila. Nitrate and phosphate contaminations of aquatic system are primarily caused by surface runoff from industrial areas as well as agricultural lands where inorganic fertilizers have been applied. Moreover, fecal contamination, expressed in E.Coli concentrations, was assessed at each of the three stations in June 2005. The Finca La Paila station recorded a concentration lower than 100 NMP/mL while the El Valle and Antón stations respectively showed values of 410 and 630 NMP/mL.

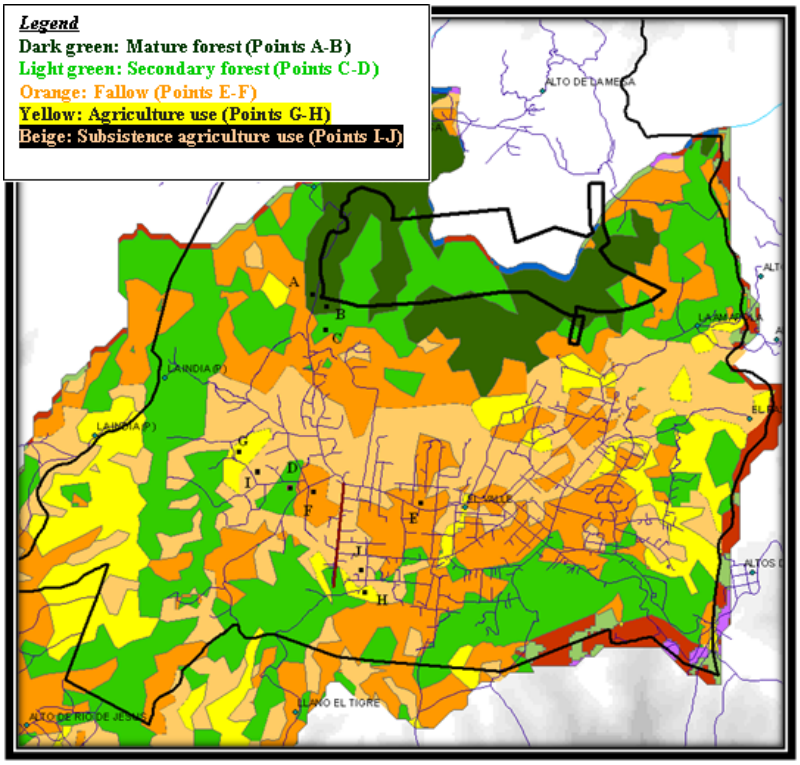
V. Methodology

A) *Land Validation*

A surface understanding of the impacts from tourism was obtained through informal interviews with workers involved in these activities (eg. Restaurants, hotels) as well as local residents of El Valle. These interviews provided us with a better sense of the main environmental and social changes resulting from the increasing local economic activity on the water quality, the vegetation cover, the local community and the current situation of the land use in El Valle.

The first component of our project consisted of field validation of ANAM's 2008 land cover map for the different land cover types particular to the region of El Valle de Antón. This validation is important given that the most recent vegetation map for the area of Coclé dates back to 2008 and thus, potential changes in land cover since 2008 need to be visually assessed on the field since no land cover maps are available for 2009. The validation will be conducted as follows. To validate the 2008 model, we derived a field survey methodology that allowed us to compare the land classifications found on the 2008 map with field observations. The land validation methodology was inspired by a vegetation validation methodology produced in June 2007 by biologist and director of Belize Tropical Forest Studies (BTFS), Jan Meerman.

Figure 2: Pre-selected points for land validation: El Valle



Prior to leaving for the field observations in El Valle de Antón, we pre-selected two points for each land classification present in the corregimiento. Since there were five forest cover types present in El Valle, this totaled ten points. On the map, each point was chosen at the center of polygons showing forest types, that is away from boundaries, because it is important that each transect lies within the same forest subtype (see Figure 2).

The coordinates for each of these points were recorded within a GPS. Once on location, we went to each GPS point and at times this required asking permission to local landowners to walk on their land. From the point we proceeded to a land classification system. Using a tape measurer, we measured a straight line of 25m and using flagging tape, tagged the start and end of the transect. Using a meter stick, 5m in width was measured along the transect to obtain a 25m x 5 m area in which to evaluate. For certain

forest types, such as mature forest, measuring the transect was impossible due to the dense vegetation therefore for these cases a visual estimation was used.

We looked at the vegetation within each transect and recorded what we saw. In addition, we took photos of surrounding vegetation from four different sides of each transect. The photos gave us a broader overview of the surrounding vegetation. In instances where it was impossible to make it to the pre-selected point due to private property infringements, we made it to the nearest possible point and recorded the new GPS coordinates. These points were then recorded into ArcGIS to see where they were located on the land cover map. Finally, we carefully analyzed the vegetation and land use for each field point and compared this with the classification found on the map.

B) *Field Work and GIS-Analysis*

The second component of our project consists of calculating the changes in the distribution of the land cover types between 2001 and 2008, using Geographical Information System (GIS) and ANAM's vegetation maps for 2001 and 2008. These calculations were based on the values of area covered by each land cover type within the boundaries of the watershed of Río Antón for both 2001 and 2008. Based on this data, we were able to estimate the ramifications caused by changes in land cover and identify regions affected by land use changes. Furthermore, since land cover changes affect water quality through sedimentation and erosion, this information was necessary for assessing impacts on the watershed of Río Antón.

The relationship between land cover and watersheds gives way to the final component of our research. The analysis of interactions between land cover changes and erosion in the watershed of Río Antón was performed using the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) developed by the NOAA Coastal Services. This tool allowed us to identify areas of the watershed most susceptible to sediment accumulation and erosion. The N-SPECT program requires data of the biophysical environment such as land cover classes, elevation (or topography), soil types and precipitation levels specific to the area of study. We used these landscape parameters to estimate sediment loads and accumulation across the river system within the watershed of Río Antón and to examine water quality in a larger spatial scale. Each N-SPECT trial requires as a first step the delineation of the watershed of interest.

In order to estimate annual rates of erosion, N-SPECT uses the Revised Universal Soil Loss Equation (RUSLE) which calculates average soil loss based on a series of parameters. The RUSLE model has been used as an important tool for conservation planning as well as soil protection.

The use of RUSLE to measure soil erosion as well as sediment yields requires a series of important input data sets including the following: a digital elevation model (DEM), a land cover grid, a rasterized soil data set, a rainfall grid, slope values, and an erosivity (R-factor) grid (Coastal Services Center National Oceanic and Atmospheric Administration 2004). The erosivity factor is calculated using the precipitation and the elevation values. The digital elevation model represents ground surface topography and allows for the generation of a flow direction grid from which a stream network can be derived. As the analysis is performed on an annual basis, the annual rainfall grid was

created by adding the twelve monthly precipitation maps of Panama. The land cover grid is based on the land cover classification of the N-SPECT program. Hence, the land cover data from the 2001 and 2008 maps of the Río Antón watershed, which uses a classification system established by ANAM, needed to be converted to the classification system of N-SPECT. The conversion of the land cover types from one classification system to the other is summarized in Table 2.

Table 2: Conversion of land cover types from the classification system of ANAM to the classification system of N-SPECT

Land cover type classification systems	
ANAM	***N-SPECT***
Water	Water
Primary forest	Evergreen forest
Secondary forest	
Forest plantations	
Fallow	Scrub/Shrub
Agricultural use	Cultivated land
Subsistence agricultural use	Low intensity development
Lowland flooded forest	Palustrine forested wetland
Mangrove forest	

The two main output data sets generated by an N-SPECT model are the accumulated sediment (kg) and the sediment concentration (kg/L). The accumulated sediment data set refers to the sediment yields and their area of accumulation while the sediment concentration data set shows the location of sediment source areas and their associated estimated values of suspended sediment concentration.

Given this, two analyses were run, one for the 2001 data and another for the 2008 data. Input parameters like elevation, precipitation, soil types and erosivity remained constant between each trial. The only factor that was subject to change between 2001 and 2008 was the land cover grid. These two analyses allowed for a comparison of accumulated sediment and sediment concentration and for the identification of regions within the watershed that were most affected by erosion during the time period. With the N-SPECT program results, it was also possible to highlight connections between areas subjected to increase erosive processes and land use changes peculiar to these areas.

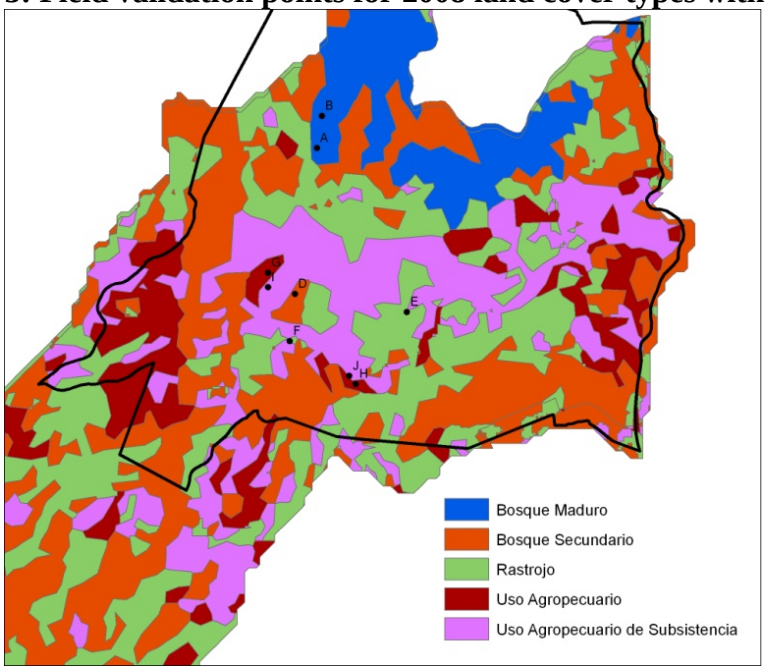
In order to identify the contribution of each factor to average annual soil loss, a comparison was performed between different sites within the watershed for the same time period. This was necessary because each area, associated with specific values for topography, rainfall, slope and land cover types, were impacted by erosive processes and contribute to sedimentation differently from other areas.

VI. Results

A) Land validation

The results from the field validation conducted in El Valle (refer to Figure 3) showed that for certain areas, land use classifications and field observations were incongruent.

Figure 3: Field validation points for 2008 land cover types within El Valle de Anton



For instance Point D was found to be a community of small households instead of secondary forest as was shown on the 2008 land-cover map. Points J and H were thought to be agriculture/subsistence agriculture however we found only very large estates in this area. Nevertheless, within the classification system adopted by CATHALAC, when an estate has a garden of sorts, such as fruit trees, it will be considered subsistence agriculture therefore these points were in fact well classified. Within this subsistence

agriculture classification, an entire road called *Calle de Millionarios* was categorized as subsistence agriculture despite the presence of only very large domains. Point G was believed to be agriculture but appeared to be subsistence agriculture whereas Point I was classified as subsistence agriculture however we found no evidence of crops. Point F was classified as fallow however there was a large-scale grain crop being managed in this area. Lastly, it was found that Points A and B, both of which were marked as primary forest, were indeed well classified.

B) Land cover change

The area covered by each land cover type and the calculated changes during the 2001-2008 period are summarized in Table 3.

Table 3: Area associated with each land cover type and changes (%) between 2001 and 2008

Category	Area (km^2) 2001	Proportion (%)	Area (km^2) 2008	Proportion (%)	2001-2008 change (%)
Forest plantations	0	0	0.02	0.01	100
Lowland flooded forest	3.57	1.19	3.44	1.16	-3.4
Mature forest	4.11	1.38	3.6	1.22	-12.43
Other uses	9.27	3.1	9.27	3.13	0
Mangrove forest	17.95	6	17.64	5.95	-1.72
Subsistence agricultural use	37.98	12.7	38.55	13.01	1.52
Secondary forest	67.73	22.66	42.7	14.41	-36.96
Succession/regrowth	57.04	19.08	73.92	24.95	29.59
Agricultural use	101.21	33.85	109.24	36.87	7.93

The landscape of the watershed of Río Antón in 2001 was dominated by agricultural lands (33.85%), secondary forest (22.66%) and zones of fallow (19.08%).

The regions covered by primary forest represented a small portion (1.38%) of the total area of the watershed. Similarly, the landscape of the watershed in 2008 is characterized by a predominance of agriculture areas (36.87%), zones of fallow (24.95%) and secondary forest (14.41%). Primary forest remained fairly insignificant with an approximate area of 3.60 km^2 representing a proportion of 1.22% for the watershed of Río Antón.

The most significant losses in vegetation are related to the mature and secondary forests as their area decreased by 36.96% and 12.43% respectively between 2001 and 2008. Other natural ecosystems were also characterized by losses in surface area during this time period. Indeed, the lowland flooded forest and mangrove forest coverage decreased by 3.40% and 1.72% respectively. Forest plantations which were absent in 2001 covered an area of approximately 0.02 km^2 in 2008. Moreover, the largest increase during the 2001-2008 period is attributed to zones of fallow with a change of approximately 30%. Arable lands also witnessed an increase in coverage with 7.93% gains in agricultural lands and 1.52% gains in areas used for subsistence agriculture.

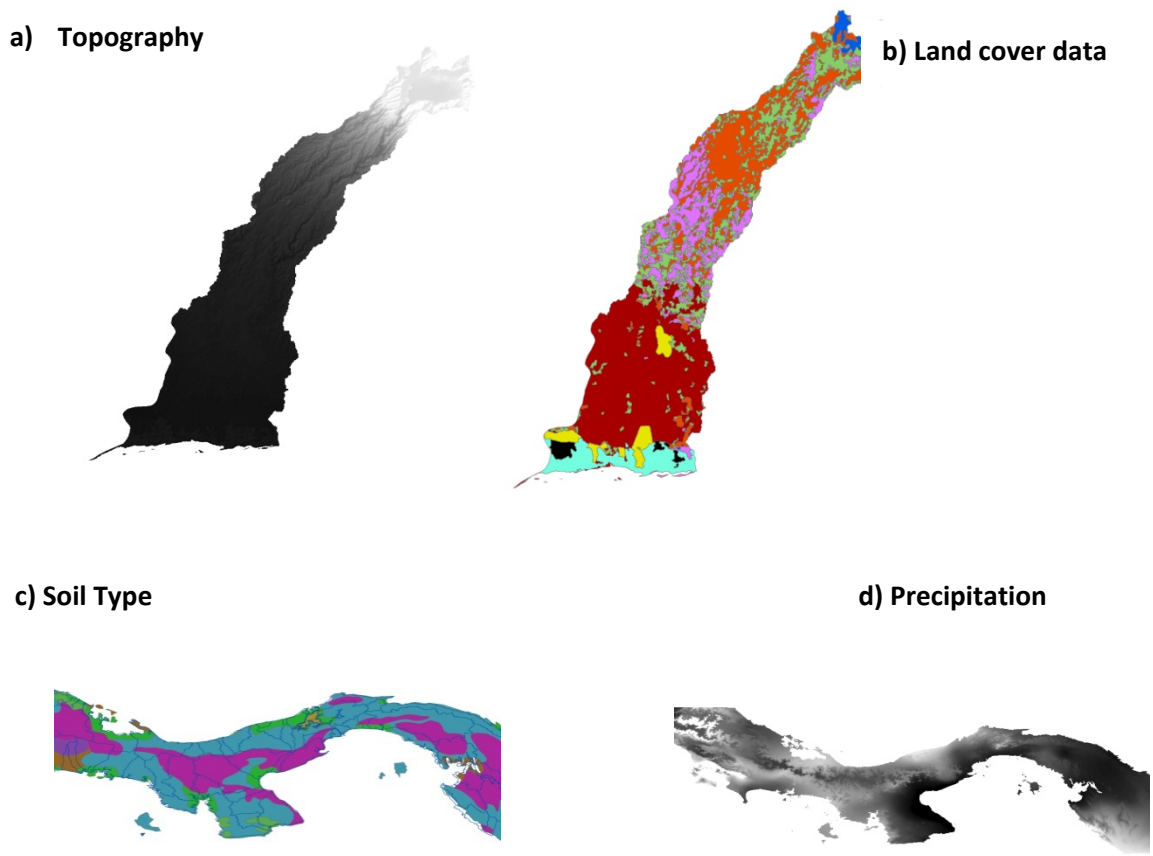
C) N-SPECT Model

The results from the N-SPECT model can be divided into four sections. The first section consists of the four initial inputs that were produced in order to run the model. The second, similarly to the first, are the intermediate inputs that were calculated for the N-SPECT model. Thirdly, and most importantly, are the overall results produced by N-

SPECT for the Río Antón watershed in its entirety. Lastly will be presented results from three case studies of specific areas within the watershed using N-SPECT modeling.

1) The four main outputs required to run the model were topography, land cover, soil type and precipitation (refer to Figure 4). Since land cover data has changed from 2001 to 2008, two trial runs of the model were run in order to identify changes in erosion and sedimentation.

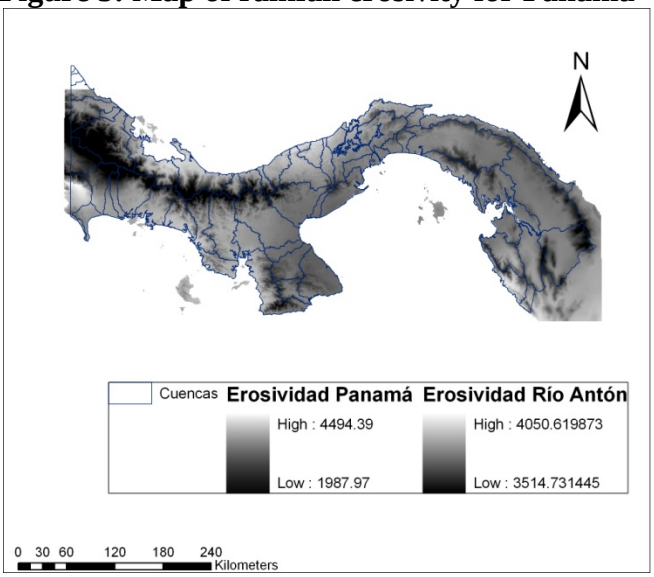
Figure 4: Four initial inputs put into the N-SPECT model



2) The intermediate inputs required for the model were slope and the rainfall erosivity (R-factor). The R-factor was obtained through annual rainfall data and the digital elevation

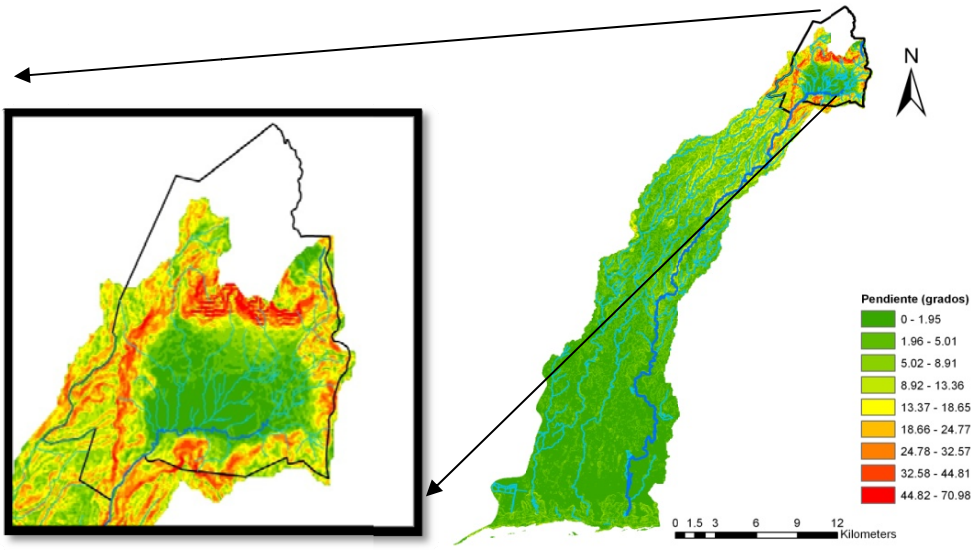
model (DEM). It can be seen from Figure 5 that erosivity does not change significantly for the Antón district when compared with the differences in greater Panama. For instance there is a 13.2% change in the Anton district versus a 55.8% change for the whole of Panama. This indicates that the erosivity factor will have little influence on the N-SPECT model for the Antón watershed. As a result, other factors, such as slope, may have a greater impact on the results for both 2001 and 2008.

Figure 5: Map of rainfall erosivity for Panama



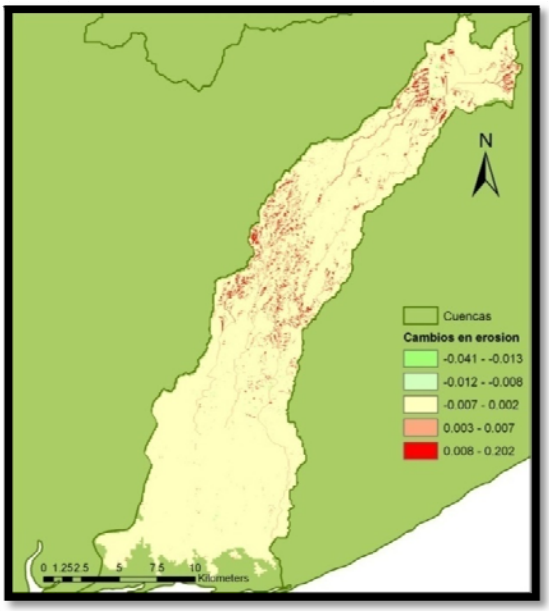
The second intermediate input required for the model was slope values for the area of the watershed, as shown in Figure 6. It can be seen that the lower portion of the watershed is characterized by smaller slope values, ranging between 0 and 8 degrees. Steeper regions associated with slope values between 9 and 45 degrees appear in the portion south of El Valle de Anton. The position of El Valle in the center of a volcanic crater is well highlighted by Figure 6 as the steepest mountainsides with slope values reaching a maximum value of approximately 71 degrees surround the town.

Figure 6: Map of slope for watershed of Rio Anton, zoom-in on El Valle de Anton



3) It was found that both erosion and sedimentation have increased in different locations within the watershed of Río Antón from 2001 to 2008. The change in erosion was calculated and can be seen on Figure 7 where areas in red indicate the greatest change.

Figure 7: Map of erosion change between 2001 and 2008 for the watershed of Rio Anton

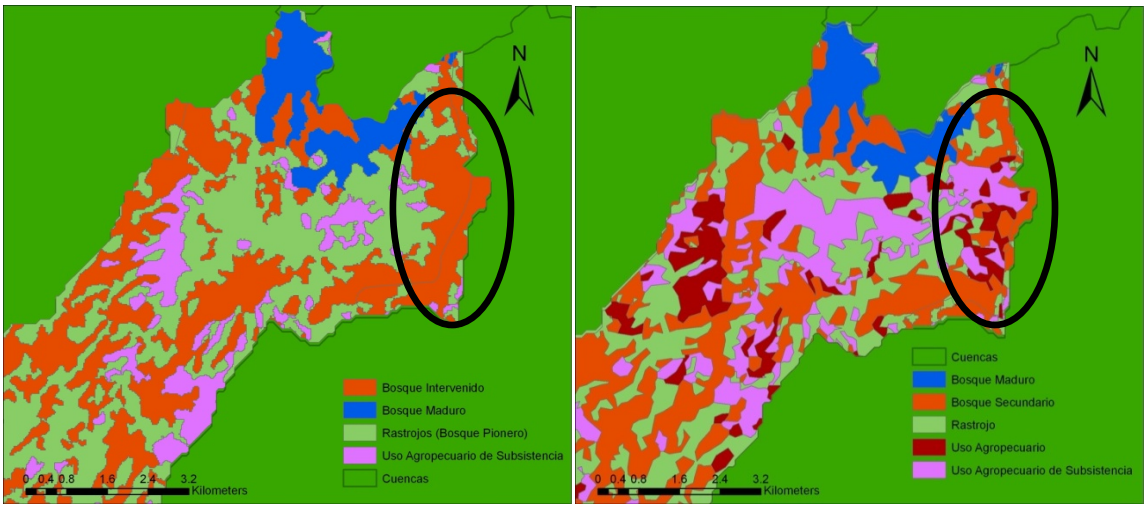


At first glance, the critical areas appear sporadically distributed. It was found, however, that the areas experiencing the greatest erosion and sedimentation are those that have steeper slopes. Nevertheless, this is an anomaly because the only input factor that changes in the N-SPECT model from both the 2001 and 2008 trials is land cover.

Case-Study 1:

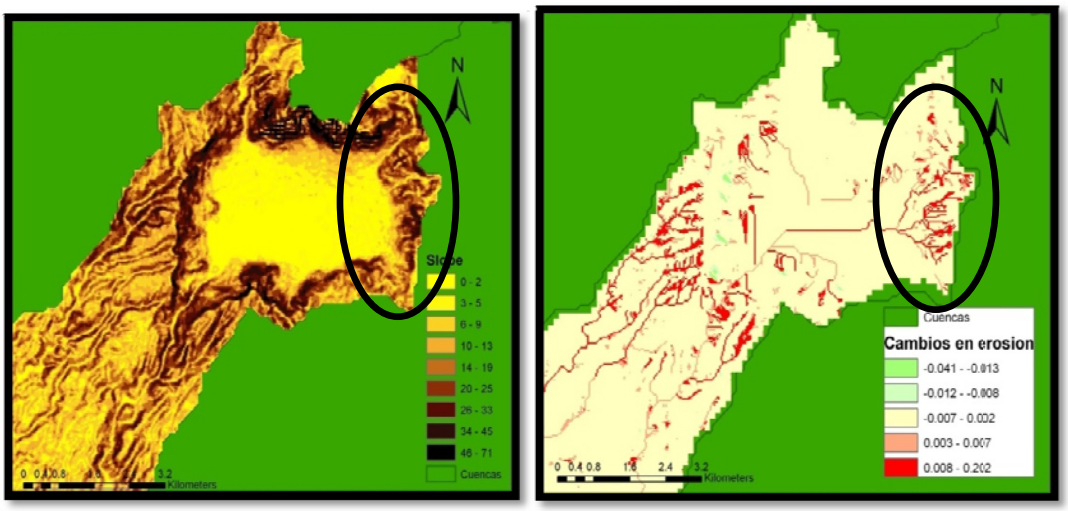
4) Three cases studies, two in El Valle and one in the central portion of the watershed will help demonstrate the overall trend of our results. The first case study is on the Eastern side of El Valle, in a mountainous area that we visited for both informal interviews and observation purposes. We see from the Figure 8 that for the area delineated, land cover went from a dominance of secondary forest in 2001 to a mix of agricultural and subsistence agricultural land-uses, fallow and fragments of secondary forest. It follows from these results that in recent years, there has been increased deforestation and land degradation caused by land use changes.

Figure 8: Distribution of land cover types for El Valle de Antón in 2001 (left) and 2008 (right)



The N-SPECT results for the changes in soil erosion between 2001 and 2008 show that there is significant increase in erosion for the delineated area (refer to figures 9-10). The greatest change in erosion can be found in an area where secondary forest has been most affected by the conversion to arable lands. This demonstrates that these areas are more susceptible to erosion and sedimentation. Interestingly, we also find that for the same area, there are zones of high slope (slope values higher than 26 degrees). We must bear in mind that slope is not a biophysical factor that changed between years 2001 and 2008.

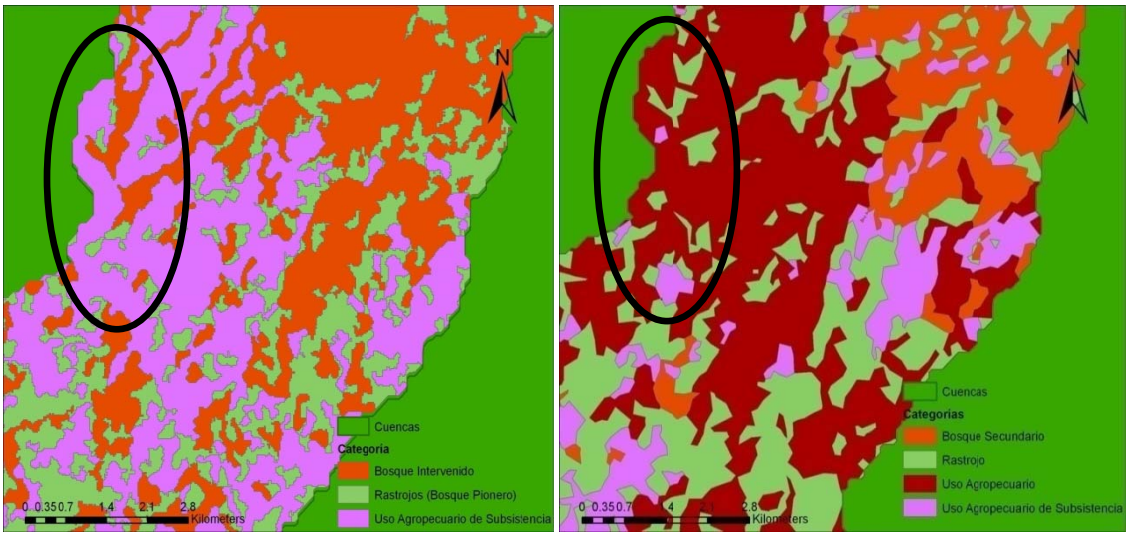
Figures 9-10: Maps for slope and erosion change for El Valle de Antón



CASE STUDY 2:

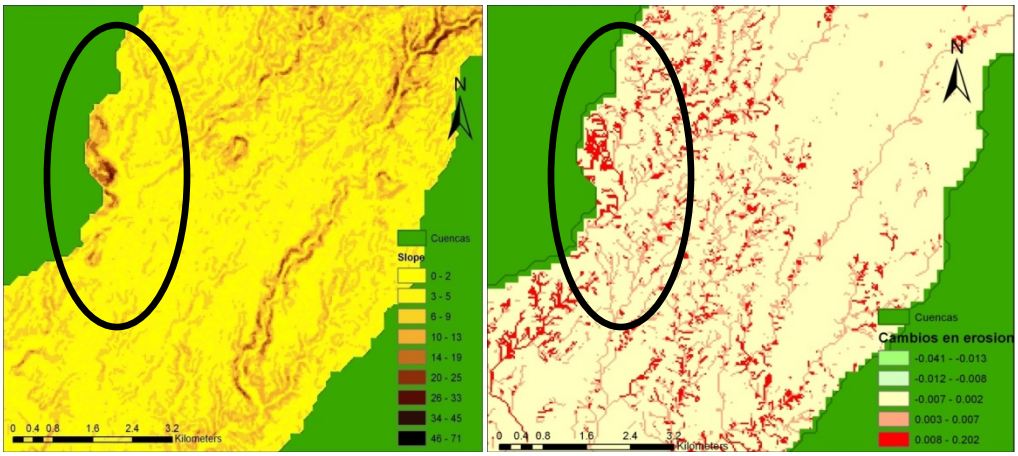
In the second case study located in the central portion of the watershed, we found that the delineated area went from subsistence agriculture and secondary forest to a mix of agricultural lands and fallow as observed in Figure 11. Once again, these changes in land use increase deforestation, albeit less significantly than the change in the first case study.

Figure 11: Distribution of land cover types for the central portion of the watershed in 2001 (left) and 2008 (right)



The N-SPECT model for the same area shows similar results as the first case study, that is, a high amount of change in erosion for the delineated area. Looking at figures 12 and 13, we may observe that once again, the largest increases in erosion occur on the steeper areas.

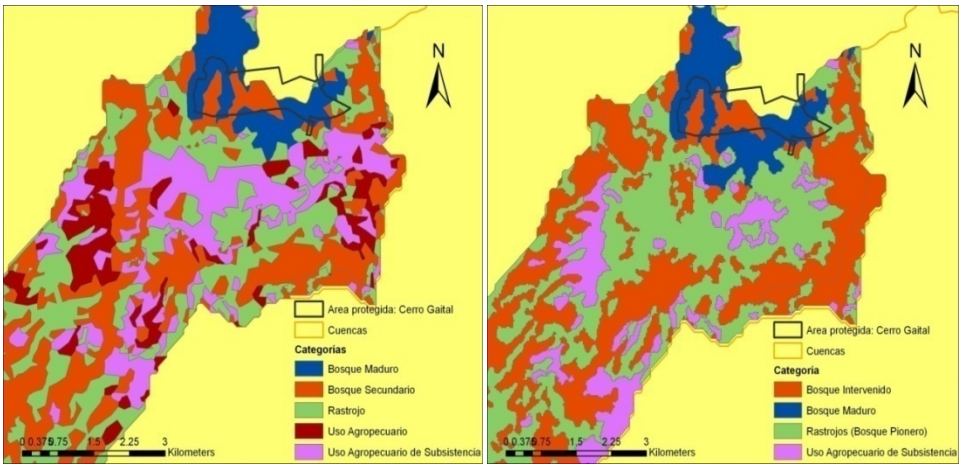
Figure 12-13: Maps of slope and erosion change for the central portion of the watershed



<u>Case Study 3:</u>

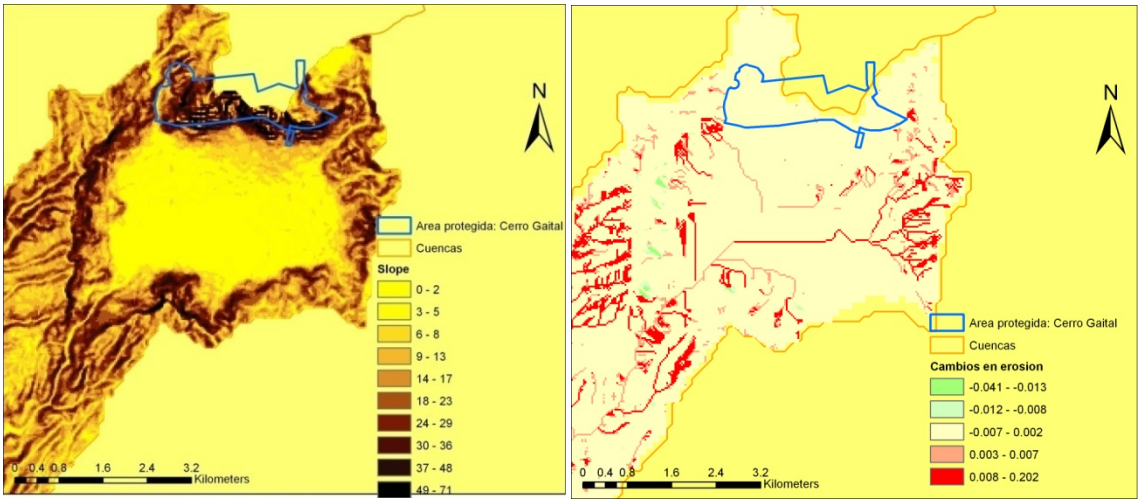
5) The third case study is on the Northern side of El Valle, in the mountainous area of the protected reserve of *El Cerro Gaital*. We see from the figure 14 below that for the area delineated, the land cover occupying the protected area, mainly mature and secondary forests, did not change significantly between 2001 and 2008. It follows from these results that conservation efforts during the 2001-2008 period prevented effectively further deforestation and land degradation since the vegetation coverage remained relatively constant.

Figure 14 : Distribution of land cover types for *Parque El Cerro Gaital* in 2001 (left) and 2008 (right)



Despite the steep hillsides found in the park as highlighted in Figure 15, which are usually more susceptible to soil erosion, the change in erosion calculated by the N-SPECT model between 2001 and 2008 shows that there is no increase in erosion within the area of the protected park (refer to Figure 16).

Figure 15-16 : Maps of slope and erosion change for the area of *Parque El Cerro Gaital*



VII. Discussion of Results

A) N-SPECT Results:

Despite certain limitations of relying on land cover maps, the N-SPECT findings showed significant results. As was previously stated, the N-SPECT results showed that there is a correlation between land cover and erosion. Indeed, as all parameters required for the model, except for the distribution of land cover types, remained constant between 2001 and 2008, increases in erosion rates can only be attributed to changes in land cover. We have found that as land use changes from forest cover to agricultural use, erosion and sediment runoff increase. For instance, it was shown that the greatest land use change between 2001 and 2008 for the Río Antón watershed consisted in the conversion from secondary forest to agricultural use. These areas were also home to the greatest erosion and sediment runoff. As predicted by scientific theory, the results therefore show that agricultural intensification is increasing rates of erosion due to the protective topsoil layer being washed away, rendering land more vulnerable to the impact of raindrops. In order to regulate for increased erosion, a policy should be implemented to conserve certain areas of forest cover, particularly mountainous areas.

A second correlation revealed by the N-SPECT model was between slope and erosion. Indeed, it was demonstrated that the areas of highest slope experienced the largest change in erosion and sediment runoff. A plausible explanation for this correlation is that rural migrants are settling on sloped marginal lands and deforesting these areas. Although it cannot be validated with absolute certainty, we feel that the likeliest push factor leading to the migration of *campesinos* onto mountainous areas is land inequality caused by the presence of tourism. As tourists buy fertile low-valley land, the

Picture 1: Subsistence Agriculture in mountainous region of El Valle

marginalized population is squeezed out and pushed onto marginal lands, for our study, onto the mountains surrounding El Valle (see picture 1).

Evidence for this trend is based on information gathered from informal interviews with local inhabitants. Growth management strategies should be implemented to attend to the needs of the local community of El Valle and to mitigate the damage to the Río Antón watershed. Our project has established a correlation between land cover change and erosion, and we hope that future studies will look more thoroughly into the sociological drivers of land cover change in El Valle.

The N-SPECT results further displayed the positive case of the *Cerro El Gaital* protected area where conservation strategies have been successful. Indeed, the zones occupied by mature and secondary forests within the park have remained approximately the same between 2001 and 2008, thanks to ANAM's conservation efforts. This prevented an increase in erosion rates and accumulation of sediments as vegetation cover reduces the vulnerability of soil to the impact of rainfall erosivity. Hence, the case of the *Cerro El Gaital* protected area illustrates how soil protection is interrelated to conservation strategies.

B) Land Validation

The classification system used for the land validation may be suitable for scientific inquiry, however, there are possible ramifications should data be used within social

sciences. For instance, ‘subsistence agriculture’ within social sciences implies certain land use practices as well as a certain level of income. Given this, when large estates are classified under ‘subsistence agriculture’ it may be misleading for social scientists using the land cover data. Moreover, there were no indications of any agricultural land used for the mass production of a particular crop or plant species in El Valle de Anton. The field observations indicated the presence of smaller agriculture plots used for subsistence. Since our study sought to make connections with the socioeconomic drivers of increased erosion, the classification system was a limitation to our analysis.

Furthermore, the satellite imagery did not appear to be capturing the disturbed areas, particularly the city center of El Valle. This was also observed for the city of Antón which was classified as ‘other uses’ (or higher intensity development) in the 2001 land cover map but not in the 2008 land cover map. Since Antón remained an urban center between 2001 and 2008, we manually changed the land cover type of the area using ArcGIS to ensure it remained classified as ‘other uses’. These cases show that relying solely on the map data proved to be insufficient for assessing the land-cover distribution within the watershed.

Several limitations to technology may explain why the land cover map and field observations differ. Firstly, the area surrounding El Valle is extremely fragmented where for instance, patches of fallow are scattered throughout the outskirts of the city. Perhaps the satellite is not sensitive to the local scale changes that fall within our visibility range therefore the imagery can only capture large sized polygons. Spatial scales were important in our analysis since our project focuses on microcosm while the ANAM land cover map is at the macrocosm therefore the data is meant to be generalized.

Since our N-SPECT model relies principally on land cover data, it should be underlined that the lack of local scale data is a significant limitation to the validity of our results.

Moreover, when conducting the N-SPECT analysis the land cover data needed to be transferred to the N-SPECT land classification system. This classification system was suboptimal as it was much less precise than the ANAM classification. Consequently, our analysis was not as accurate as it could have been using the original classification system. Similarly, the input for soil type was too broad, where only two soil types were identified for the entire watershed. Once again, this represents a limitation to the accuracy of the results derived from the N-SPECT model. Hence, large-scale classification systems can lead to misleading interpretations of a site's biophysical and socio-economic conditions.

The project's timeframe may also explain the discrepancies between field observations and the land cover map. Based on information gathered from local inhabitants, there has been a recent rural exodus of farmers from El Valle. As such, there is very little agriculture in the region and farmlands have been sold off for the creation of large estate homes, which from observation, appeared to be owned mainly by international retirees. Since the 2008 land cover map was based on input data from 2007, perhaps the information is outdated and therefore does not account for these recent land use changes.

The inconsistencies between the 2008 land cover map and field observations come as a caveat to using technology to conduct an analysis. These discrepancies demonstrate the need to validate computerized models. Moreover, it is a reminder that a model serves as a tool to understand trends therefore it can never be an exact

representation of reality. As such, a model should not replace field work. For example, our results showed that there exists a trend between land cover change and sediment runoff in the Río Antón watershed, however, we highly recommend that fieldwork be conducted in order to validate these findings. The validation could be achieved through water sampling to measure the sediment concentrations associated with the critical watershed areas identified by model.

VIII. Acknowelgments

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