DEVELOPMENT AND VALIDATION OF THE WATERSHED SUSTAINABILITY INDEX (WSI) FOR THE WATERSHED OF THE REVENTAZÓN RIVER

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Abstract

This report, prepared for COMCURE, the Commission for the Preservation and Management of the Watershed of the Reventazón River, of Cartago, Costa Rica, examines the deterioration of the health of the Reventazón River watershed by means of the Watershed Sustainability Index. The watershed was divided into three regions based on altitude and environmental aspects, and the index was applied to the three regions individually. With the final results of the index for each region in mind, the report contains recommendations on ways to improve the sustainability of the watershed.

Executive Summary

Watersheds are vital for both the inhabitants and the wildlife within the region, though this important fact tends to be misunderstood or overlooked. The Reventazón River watershed, situated in the Costa Rican provinces of Cartago and Limón, is the area of land in which all of the water within its boundaries flows into the Reventazón River and eventually into the Caribbean Sea. As with any major river, the surrounding population relies heavily on the resources that are associated with the river. Over 400,000 inhabitants live within the boundaries of the Reventazón River watershed. They all rely on the river for a source of drinking water, as a means to feed and grow crops, and for a way to make money and support their families. Families outside of the watershed also rely on the river because, as the second largest river in the country, the Reventazón River and its surrounding land plays an important economic and agricultural role for the country; it provides 38 percent of the nation's hydroelectricity and a quarter of San Jose's drinking water. However, according to the 2007 Report on the State of the Nation, this river is the second most polluted river in the country, caused by a deficiency in waste management as well as the intensive use of agrochemicals from over farming activities. Erosion and sedimentation are also a serious problem due to geomorphologic features added to inadequate agriculture practices.

Located in Cartago, Costa Rica, COMCURE, the Commission for the Preservation and Management of the Watershed of the Reventazón River, analyzes all aspects of watershed management, works at reversing the damage that has been done to the Reventazón River basin and looks for means to make it more sustainable for future use. One approach is to apply the Watershed Sustainability Index (WSI) to the basin to analyze its overall health and critical issues that need most improvement. In July of 2009, COMCURE calculated the overall WSI for the watershed with the help of expert consultants from various Costa Rican organizations. However, COMCURE was unsatisfied with the end results, fearing that the overall score was not an accurate representation of the condition of the watershed.

To generate a more accurate description of the health of this watershed, COMCURE decided to divide the watershed into three regions: the upper, middle and lower (which refer to the elevation grade), since different problems arise for different elevation grades. The flat plains that comprise the majority of the lower region are not seriously concerned with landslides, though this land can fall victim to over-farming and other human activities. The upper region is less suitable for flatland farming but the sudden and frequent changes in altitude are cause for natural phenomena such as mudslides, landslides, and erosion to occur. These natural phenomena, as well as human activities, are serious threats to the future health of the Reventazón River watershed.

The HELP index, developed by UNESCO and further consolidated into one single variable called the Watershed Sustainability Index (WSI), is a watershed specific index that takes into account cause-effect relationships and considers policy responses implemented in a given period as part of the basin's sustainability. The WSI integrates the Hydrology (H), Environment (E), Life (L) and Policy (P) aspects of a watershed under three parameters: Pressure, State and Response. Pressure addresses the human activities exerted on the watershed, State assesses the quality of the watershed in the base year of study, as well as the quality and quantity of natural resources and Response examines the society's level of desire to address ecological problems in the watershed. The Pressure-State-Response structure incorporates cause-effect relationships and thus provides a more comprehensive understanding of the watershed than an index that only examines the State, for example. Granting equal weight to each indicator, the simplest linear form of the WSI is:

$$WSI = \frac{H + E + L + P}{4}$$

Operating on a scale of 0 (very poor) to 1.00 (excellent), the WSI uses the most basic parameters that are generally available for all basins, such as the Human Development Index, the Biochemical Oxygen Demand over a five-day period (BOD5), and the Environment Pressure Index. In order to facilitate the estimation of the parameter levels by the users, both quantitative and qualitative parameters are divided into five scores (0, 0.25, 0.50, 0.75 and 1.00). The parameters can be easily assigned a score according to the full description of the levels and scores of all WSI parameters by Chaves and Alipaz. After assigning a score to the aforementioned Pressure-State-Response parameters of each indicator, one averages the scores to obtain the indicator value. Then, following the same averaging method, one is able to obtain the overall WSI value that represents the integration of Hydrology, Environment, Life and Policy aspects of the target basin in the period studied.

After calculating all the parameters and indicators of the Watershed Sustainability Index, we investigated the parameters that had the lowest scores and thus need the most improvement. These parameters are: the Life indicator in general for the whole watershed, the Hydrology Quality Response parameter for the whole watershed, the Hydrology Quantity Pressure parameter for the lower region, and the Environment Pressure parameter for the middle region.

For the Life indicator, the evaluation of the Human Development Index for the three regions and the lack of high scores in the Response parameter indicate that the quality of life for the residents of the basin is not improving at the rate that is optimal. For the Hydrology Quality Response parameter, the lowest score indicates that the sewage treatment and disposal is inadequate and may be leading to pollution of the watershed. With regard to the Hydrology Quantity Pressure parameter for the lower region, the low score means there is a decrease in Water Availability in the period studied. Even though this low number indicates a problem area, the Water Availability rankings for all three regions are greatly above the value required for a score of 1.00 (indicated by the Hydrology Quantity State parameter). Therefore, the decrease in Water Availability in the lower region is not currently a major issue but should be reevaluated every five years for long-term trends. The final parameter that received an inadequate score was the modified Environment Pressure in the middle region. Since we used forest area instead of agriculture area in calculating this parameter, the low score implies an increase in population and a decrease in forest coverage in the region in the period studied. The inadequate score of this parameter would indicate that too much pressure is exerted on the environment due to intensive farming activities.

Based on the calculation process, we recommend that COMCURE conduct the following activities to improve the scores of the WSI results:

1) Add more sewage treatment and disposal systems to urban and rural wastewater sources, especially to agricultural areas, to work towards reducing agrochemical contamination.
2) Continue its effort with local farmers to develop sustainable farming projects in the basin area, and implement this effort in the WSI as a new parameter averaged with the EPI to create a new Environment Pressure parameter, to encourage sustainable farming.

Since the WSI cannot cover every aspect of the watershed's health, there are some issues that were not revealed by the aforementioned results, such as the inadequate level of waste management in the lower region. Large amounts of litter are collected by storm water and transported down the river system, at which point it flows into the sea and washes onto the beach. The large amount of uncollected and untreated solid waste is causing contamination problems and is ultimately impacting public health. Therefore, COMCURE should take this problem into consideration along with the other problems revealed by the WSI results.

This is a critical time to begin making significant and exceptional efforts towards restoration of the watershed, as our results indicate not only the largest problem areas but those that show no future signs of improvement without intervention. We hope that for the future, COMCURE take our recommendations seriously and that a positive change is brought about in improving the condition of the Reventazón River watershed.

Acknowledgements

We would like to thank Executive Director Guillermo Flores Marchena and Nimia Rivera Peña from COMCURE, Gustavo Calvo Domingo from ICE, and Arnulfo Díaz from MINAET for their collaboration for the input of data and information needed for the preparation of this proposal. We also thank advisors Dr. Ingrid Shockey and Dr. Isa Bar-On for their coordination of the project.

Authorship

Everyone in our group contributed equally to achieve the goal of our project. Each member performed 25 percent of the writing as well as 25 percent of the editing. Nick Catano, Yao Wang, and Simone Staley performed the calculations while Mark Marchand created all of the charts and maps.

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List of Acronyms

AyA - Instituto Costarricense de Acueductos y Alcantarillados

BOD5 – Biochemical Oxygen Demand over a five-day period

CATIE – Centro Agronómico Tropical de Investigación y Enseñanza

COMCURE - Commission for the Preservation and Management of the Watershed of the Reventazón River

EPI – Environmental Pressure Index

GIS – Geographical Information System

HDI – Human Development Index

HELP – Hydrology for the Environment, Life, and Policy

ICE - Costa Rican Institute of Electricity

IWRM – Integrated Water Resources Management

MAG – El Ministerio de Agricultura y Ganadería

MINAET - the Environment, Energy & Telecommunications Ministry

UNESCO – United Nations Educational, Scientific and Cultural Organization

W_A – Water Availability

WSI – Watershed Sustainability Index

1. Introduction

Watersheds are vital for both the inhabitants and the wildlife within the region, though this important fact tends to be misunderstood or overlooked. The Reventazón River watershed, situated in the Costa Rican provinces of Cartago and Limón, is the area of land in which all of the water within its boundaries flows into the Reventazón River and eventually into the Caribbean Sea. As with any major river, the surrounding population relies heavily on the resources that are associated with the river. Over 400,000 inhabitants live within the boundaries of the Reventazón River watershed. They all rely on the river for a source of drinking water, as a means to feed and grow crops, and for a way to make money and support their families. Families outside of the watershed also rely on the river because, as the second largest river in the country, the Reventazón River and its surrounding land plays an important economic and agricultural role for the country; it provides 38 percent of the nation's hydroelectricity and a quarter of San Jose's drinking water. Additionally, farms within the Reventazón River watershed yield 11 percent of the nation's agricultural exports (COMCURE, 2009). However, according to the 2007 Report on the State of the Nation, this river is the second most polluted river in the country, caused by a deficiency in waste management as well as the intensive use of agrochemicals from over farming activities. Erosion and sedimentation are also a serious problem due to geomorphologic features added to inadequate agriculture practices. Lack of proper environmental management leads to poor wastewater treatment and ineffective garbage removal (Information about Reventazón-Parismina, 2007).

The primary organizations that are involved with managing the health of the Reventazón River are AyA (Instituto Costarricense de Acueductos y Alcantarillados), ICE (Costa Rican Institute of Electricity), MAG (El Ministerio de Agricultura y Ganadería) and MINAET. MINAET, the Environment, Energy & Telecommunications Ministry, has been charged with the general task of managing water use and ensuring that it is conserved. In its efforts to specifically improve the Reventazón River watershed, MINAET formed COMCURE, the Commission for the Preservation and Management of the Watershed of the Reventazón River (Law 8023, 2000). Located in Cartago, Costa Rica, COMCURE analyzes all aspects of watershed management, works at reversing the damage that has been done to the Reventazón River basin and looks for means to make it more sustainable for future use. One approach is to apply the Watershed Sustainability Index (WSI) to the basin to analyze its overall health and critical issues that need most improvement.

In July of 2009, COMCURE worked with a group of consultants from various organizations, including ICE, to calculate the WSI for the watershed. However, COMCURE was unsatisfied with the results that indicated that the watershed was in better condition than it appears according to their experience is in reality. To generate a more accurate description of the health of this watershed, COMCURE decided to divide the watershed into three regions: the upper, middle and lower (which refer to the elevation grade), since different problems arise for different elevation grades. The flat plains that comprise the majority of the lower region are not seriously concerned with landslides, though this land can fall victim to over-farming and other human activities. The upper region is less suitable for flatland farming but the sudden and frequent changes in altitude are cause for natural phenomena such as mudslides and erosion to occur. These natural phenomena, as well as human activities, are serious threats to the future health of the Reventazón River watershed (HELP, 2009).

In September 2009, COMCURE commissioned a team of students from Worcester Polytechnic Institute, an engineering school in the US, to calculate the WSI for the three regions of the Reventazón River basin separately. The purpose was to confirm that the health of the different regions varies, and to find the critical issues within each region. In this proposal, the results of these calculations are presented and discussed. Additionally, recommendations on ways to improve the health of each region are presented.

2. Background

In order to best evaluate the health of a watershed, we need to understand the quantitative and qualitative indicators that determine a watershed's level of sustainability. We will begin with our understanding of the WSI, and how it pertains to the various aspects of a watershed. The majority of information that determines the scores of these indicators is selected based on their quantifiable nature, but there are a few indicators that are qualitative and therefore based on the subjectivity of individuals involved with the watershed. These qualitative indicators are converted to a numerical scale so that they can be used with the quantitative indicators and final numerical values can be calculated for the index. Although the index cannot cover all aspects of the watershed, particularly the intangible qualities that cannot necessarily be measured, such as social awareness of environmental issues, local and regional cleanup efforts and waste management practices, it will provide a first order assessment as to which areas of the watershed need more work and where it is needed.

2.1 Watershed Sustainability Index (WSI)

An "index" is a quantitative collection of many indicators that can provide a simplified, coherent, multidimensional view of a system (Mayer 2007). To achieve and maintain watershed sustainability, policy-makers require timely information on the condition of the watershed system and on specific characteristics that require the most improvement. Sets of sustainability indicators and aggregation of these indicators into overlying indices are increasingly used to make policy decisions, and it is critical to understand index strengths, weaknesses, biases, and scale-dependence when using them. However, there is always additional information unique to each watershed that can be obtained by examining factors of the watershed not included in the index (Oras, 2005; Hezri & Dovers, 2006; Parris and Kates, 2003; Morse and Fraser, 2005; Ness et al., 2007).

The HELP index, developed by UNESCO and further consolidated into one single variable called the Watershed Sustainability Index (WSI), is a watershed specific index that takes into account cause-effect relationships and considers policy responses implemented in a given period as part of the basin's sustainability (Chaves & Alipaz, 2006).

The WSI integrates the Hydrology (H), Environment (E), Life (L) and Policy (P) aspects of a basin under three parameters: Pressure, State and Response (see Table 1).

				Parameters	
	INDICATORS		PRESSURE	STATE	RESPONSE
WATERSHED SUSTAINABILITY INDEX	Hydrology (H)	Quantity	Δ1 - variation in the basin per capita water availability in the period studied, relative to the long-term average (m3/person year)	Basin per capita water availability (m3/person year), considering both surface and groundwater sources	Improvement in water-use efficiency in the basin, in the period studied
		Quality	Δ2 - variation in the basin BOD5 in the period studied, relative to the long-term average	Basin averaged long term BOD5 (mg/l)	Improvement in adequate sewage treatment/disposal in the basin, in the period studied
	Environment (E)		Basin EPI (rural and urban) in the period studied	Percent of basin area under natural vegetation (Av)	Evolution in basin conservation areas (Protected areas and BMPs) in the basin, in the period studied
	Life (L)		Variation in the basin per capita HDI-Income in the period studied, relative to the previous period	Basin HDI (weighted by population)	Evolution in the basin HDI, in the period studied
	Policy (P)		Variation in the basin HDI-Education in the period studied, relative to the previous period	Basin institutional capacity in IWRM (legal and organizational)	Evolution in the basin's IWRM expenditures, in the period studied

Table 1: Summary of the Four Indicators and Three Parameters of the Watershed Sustainability Index.

Pressure addresses the human activities exerted on the watershed, State assesses the quality of the watershed in the base year of study, as well as the quality and quantity of natural resources and Response examines the society's level of desire to address ecological problems in the watershed. The Pressure-State-Response structure incorporates cause-effect relationships and thus provides a more comprehensive understanding of the watershed than an index that only examines the State, for example. Granting equal weight to each indicator, the simplest linear form of the WSI is:

$$WSI = \frac{H + E + L + P}{4}$$

Operating on a scale of 0 (very poor) to 1.00 (excellent), the WSI uses the most basic parameters that are generally available for all basins, such as the Human Development Index, the Biochemical Oxygen Demand over a five-day period (BOD5), and the Environment Pressure

Index. In order to facilitate the estimation of the parameter levels by the users, both quantitative and qualitative parameters are divided into five scores (0, 0.25, 0.50, 0.75 and 1.00). The parameters can be easily assigned a score according to the full description of the levels and scores of all WSI parameters by Chaves and Alipaz (see Appendix A).

2.2 Hydrology Indicator (H)

The Hydrology indicator is the primary indicator of WSI since it evaluates the physical and chemical characteristics of the water body of the target basin. It contains two sets of sub-indicators: water quantity and water quality. These two sub-indicators are averaged together to find the overall Hydrology indicator.

2.2.1 Water Quantity Sub-Indicator

In the case of water quantity, the parameter is the per capita Water Availability per year per person (W_A), including both surface and ground water. Since water stress occurs when Water Availability falls below 1700 m^3/person/year (Falkenmark & Widstrand, 1992), the five levels of W_A selected by Chaves and Alipaz are multiples of the minimum requirement, corresponding to very poor, poor, medium, good and excellent. An excellent condition requires the W_A value to be greater than 6800 m^3/person/year, which is four times the base value (Chaves & Alipaz 2007). The W_A value for the base year is the State parameter, and the percent variation of W_A from the base year to the end year of the period studied is the Pressure parameter. The Response parameter is the only qualitative parameter of this sub-indicator. It evaluates the improvement in water-use efficiency during the period studied, meaning that a large improvement in drinking water treatment plants in the target basin may receive a score of 1.00.

2.2.2 Water Quality Sub-Indicator

In the case of water quality, the Biochemical Oxygen Demand over a five-day period (BOD5) is chosen as the parameter since it contains the basic information of hydrological studies and is therefore generally available in watersheds. BOD5 is also correlated with other important water quality parameters such as dissolved oxygen, turbidity and pollutant concentrations. A low BOD5 represents less organic waste and more dissolved oxygen in the water body and thus is desired. (Reible, 2005). The State parameter is basin BOD5 in the base year, the excellent condition attained in a BOD5 of less than 1.00. The Pressure parameter is the percent variation of BOD5 from the base year to the final year in the period studied. If BOD5 increases by more than 20 percent, the parameter will receive a score of 0 (Chaves & Alipaz, 2007). The Response parameter is chosen to be the improvement in adequate sewage treatment or disposal in the basin in the period studied. As another qualitative parameter, it is also evaluated with five ranges: very poor, poor, medium, good and excellent.

2.3 Environment Indicator (E)

The environment indicator focuses on environmental pressure as well as the area of vegetation and protected regions in the watershed. To define the Pressure parameter, the Environmental Pressure Index (EPI), which evaluates the pressure of human agricultural activities exerted on the environment, is applied. The EPI is an effective way of evaluating the balance between urban populations and agricultural regions. The task of balancing the two is directly related to maintaining the health of the environment due to human activities. To achieve a good score for the Pressure parameter, the basin would have needed to develop additional agricultural land with a reduced population. The State parameter addresses how much of the current vegetation is natural. This gives the stakeholders an understanding of how the environment has been affected over the years. The best score for this parameter would be a basin with over 40 percent of its total area covered in natural vegetation (Chaves & Alipaz 2007). The Response parameter assesses the improvement in basin conservation activities including new or expanded national forest reserves, national parks, and the best ways to evaluate them. The best possible score would be given to those basins with a 20 percent or greater improvement in basin conservation areas (Chaves & Alipaz 2007).

2.4 Life Indicator (L)

The human Life parameter assesses the standard of living and the Human Development Index in the watershed. The Pressure parameter is characterized by the per capita income variation in the period studied. This parameter gives the stakeholders a sense of whether or not the quality of life has improved. According to the WSI scoring table, for an optimum score in the

Pressure parameter, the basin would have to have a positive improvement of equal to or greater than ten percent in per capita income over the period studied since this shows significant economic growth (Chaves & Alipaz 2007). The State parameter utilizes the Human Development Index (HDI) and the Response parameter evaluates the change in HDI over the period studied. The reason for using the HDI is that it has been calculated throughout the world and is easily comparable to other basins of the same quality. The top possible score for the State and Response parameters are a HDI score of over 0.90 and a positive change of greater than 20 percent in HDI in the period studied, respectively (Chaves & Alipaz 2007).

2.5 Policy Indicator (P)

The policy indicator evaluates the levels of education, legal frameworks, and Integrated Water Resources Management (IWRM) institutional involvement in the basin. The HDI's sub-indicator of education is used to calculate the Pressure parameter. This sub-indicator takes into account the adult literacy rate as well as the gross enrollment rate in primary, secondary, and tertiary education programs of the population within each canton (HDR 2009). This sub-indicator is used due to its correlation with the population's willingness to support the sustainability of the watershed and place pressure on government officials and stakeholders (The World Bank 2003). The State parameter is determined by the basin's ability to incorporate the objectives of IWRM, among the various institutions or organizations present. The IWRM Organization aims to strengthen land and resource sharing, build social awareness of environmental issues and encourage collaboration among institutions (IWRM 2004). The qualitative State parameter assesses the comprehensiveness of institutional and legal systems within the watershed and determines if it is very poor, poor, average, good, or excellent. A very poor score would be given if no current systems exist, whereas an excellent score would be given for implemented and currently enforced systems (Chaves & Alipaz 2007). The Response parameter uses the IWRM expenditures in the period of analysis to determine the extent to which the government and institutions have attempted to financially address issues in the watershed. The higher the budget and expenditures allocated to watershed resources management, the greater the odds that the proposed goals for the watershed will be met (Chaves & Alipaz 2007).

2.6 Overall WSI Evaluation

After assigning a score to the aforementioned Pressure-State-Response parameters of each indicator, one averages the scores to obtain the indicator value. Then, following the same averaging method, one is able to obtain the overall WSI value that represents the integration of Hydrology, Environment, Life and Policy aspects of the target basin in the period studied.

3. Methodology

Based on the quantitative and qualitative information required for the WSI computation, our team applied several strategies to analyze different data.

3.1 Quantitative Analysis

The quantitative data required for the calculation of the WSI is available in censuses and atlases, and includes information such as the district populations, HDI values, and the amount of natural vegetation areas for our study period, 2000 to 2005. To obtain the populations broken down by canton and district for both years, we accessed the Costa Rican National Institute of Statistics and Censuses. The final numbers for HDI and its sub-indicators (HDI-Income and HDI-Education) were acquired from the Atlas del Desarrollo Humano Cantonal de Costa Rica2007. For the percentage values of the watershed forest coverage, we collected GIS data from Arnulfo Díaz of MINAET, who used ArcView, a GIS analysis software product. Finally, Water Availability (W_A) and BOD5 were located in ICE reports that included data regarding various gagging stations throughout the watershed from the year 2000 to 2008.

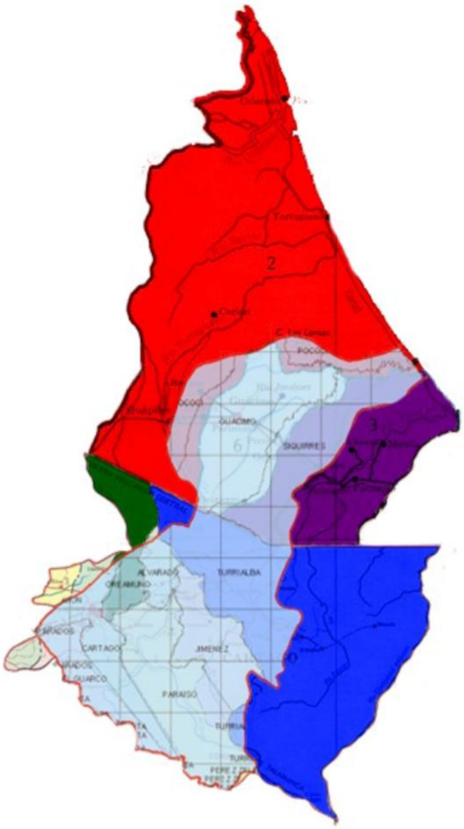
3.2 Population Breakdown

The parameters that use HDI and its sub-indicators need to be weighted by population for more accurate results; therefore the population of each canton as well as of each region was needed. To calculate this, we created a map (see Figure 1) that displayed the boundaries of the upper, middle, and lower regions. The boundaries that separate the three regions were defined by political cantonal boundaries, so each canton is uniquely considered part of only one of the three regions.

Legend	
Lower Region	Guácimo
	Pococí
	Siquirres
Middle Region	Turrialba
Upper Region	Alvarado
	Cartago
	El Guarco
	Jiménez
	Oreamuno
	Paraíso

Figure 1: The Reventazón River Watershed divided into upper, middle and lower regions based on altitude and political cantonal divisions.

To better understand how the cantons were contained in the watershed, we used a map of the watershed boundary and superimposed it over complete maps of the cantons (see Figure 2). From this map, it is clear that the cantons of Pococí, Siquirres, Turrialba and Oreamuno cannot be considered completely inside the watershed, and that using data that suggests that they are would be inaccurate.



Complete Cantons	Partial Cantons
Alvarado	Oreamuno (Green)
Cartago	Pococí (Red)
El Guarco	Siquirres (Purple)
Guácimo	Turrialba (Blue)
Jiménez	
Paraíso	
Watershed Boundary	

Figure 2: Map of the ten cantons of the watershed in their entirety with a boundary of the watershed (in light blue) placed as an overlay. The four partially contained cantons are colored.

For a closer look at the four partial cantons that are considered part of the watershed, a third map was created to determine the districts that lie within each partial canton and within the watershed boundaries. This map is available in Appendix B. Figures 3 and 4 show these four cantons and their districts in detail. Districts are smaller political divisions within each canton. It is understood that all of the districts of the Oreamuno canton (Figure 3) except Santa Rosa are completely contained. As for the Siquirres canton (Figure 4), the map shows that the district of Pacuarito is not in the watershed, the Siquirres district is partially contained and all of the other districts are fully inside the basin. In the Pococí canton (Figure 3), the district of Jiménez is the only district that is completely contained while the Roxana district is partially contained inside the watershed. It was also determined that the sparsely populated district of Colorado is so marginally within the watershed that it is considered negligible and therefore not part of the watershed. In the Turrialba canton (Figure 4), four districts (Santa Cruz, Peralta, La Suiza and

Tuis) are partially contained, while the district of Tayutic lies completely outside of the basin and the other five districts are fully inside the watershed.

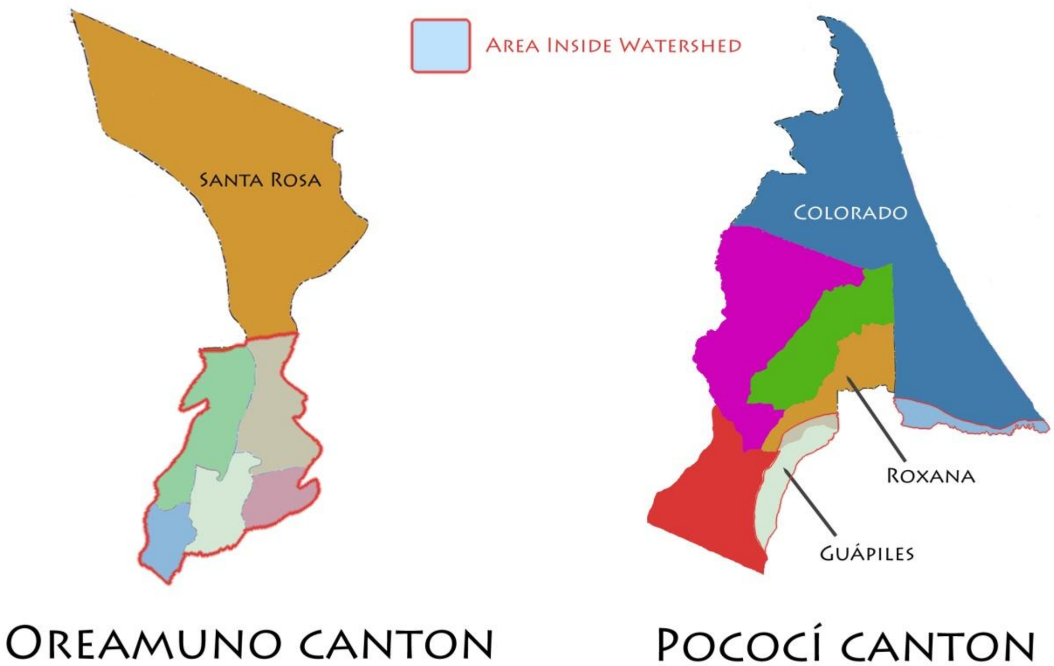


Figure 3: The cantons of Oreamuno and Pococí with individually colored districts. The area of each canton inside the watershed is denoted with a light blue fill color and a red boundary.

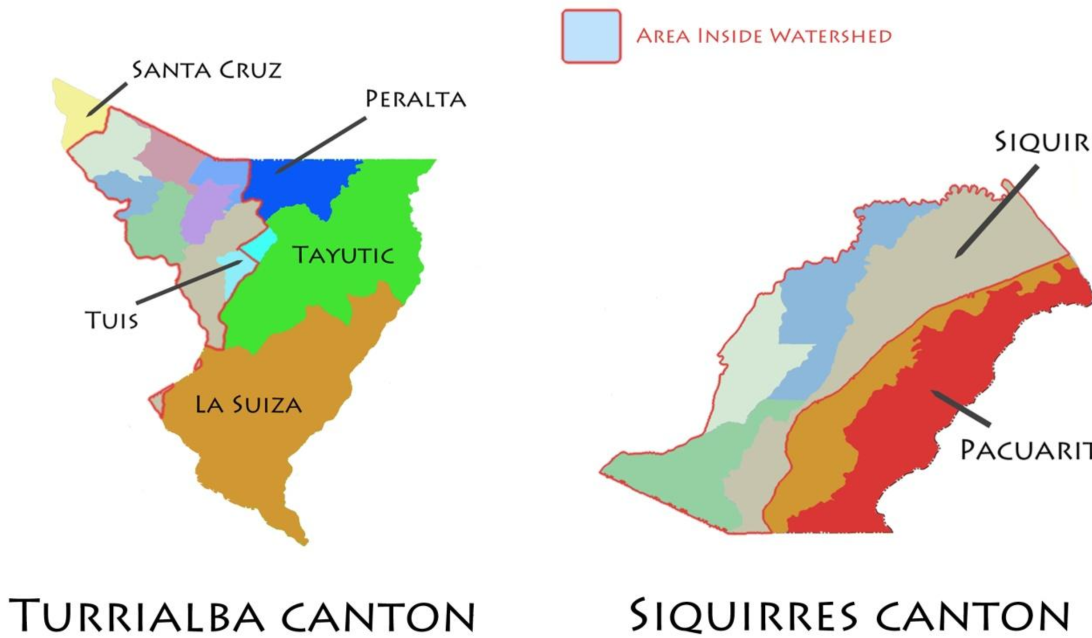


Figure 4: The cantons of Turrialba and Siquirres with individually colored districts. The area of each canton inside the watershed is denoted with a light blue fill color and a red boundary.

For the seven districts that were only partially in the watershed, a list of the primary cities (twelve in total) that fell within the boundaries was prepared and their population numbers were acquired from the Costa Rican National Institute of Statistics and Censuses. We checked the census to see if these cities were considered urban or rural. This is important because if the largest city in the district is considered rural, then the entire district will be considered rural, so it is much more likely that the population is evenly distributed in this case. Nearly all of the cities were considered rural, so the districts were also considered rural with evenly distributed populations. Therefore, the district population within the watershed was estimated as the percentage of land area within the watershed. Percent land area of each of these districts was determined using a pixel count tool in Adobe Photoshop Creative Suite 4 on the detailed cantonal map (see Appendix B). Only one of the twelve cities was considered to be urban by the census. This is the community of La Suiza in the La Suiza District. For this district, the population within the watershed was estimated as the population of the district inhabitants living in the city, which is justifiable because only a small section of the district was contained in the watershed, and, although small, included the largest city in the district (Figure 5). The results of these calculations yielded a much more accurate estimate of the population residing in each of the partial cantons of the watershed, which is essential in calculating certain parameters of the WSI. Appendix C presents the pixel counts and land area of each of these districts.

Figure 5: The district of La Suiza (green and blue color fill). The area of La Suiza within the watershed, denoted by the blue color fill, is the area includes the district's largest city, La Suiza.

3.3 Pixel Count of Protected Area Maps

To calculate the percentage of each region of the watershed that is designated as a protected area, we utilized maps of protected areas for the whole basin for 2000 and 2005 from the Areas Silvestres Protegidas Document. In order to obtain numerical values from the maps, we first overlaid the aforementioned maps with Figure 1 in order to separate the three regions.

Then, by using Adobe Photoshop Creative Suite 4, we performed a pixel count on the protected area in each region as well as a pixel count on the total region to calculate the percent of protected area in the region.

3.4 Analyzing WSI Results

After calculating all the parameters and indicators of the Watershed Sustainability Index, we investigated the parameters that had the lowest scores and thus need the most improvement. We took observational field trips to justify our technical results and conducted research on how to improve the critical conditions indicated by both our calculations and observations.

4. WSI Calculation Findings and Results

This section presents the results of our calculation of the Watershed Sustainability Index separated into the upper, middle and lower regions of the Reventazón River watershed. To facilitate the presentation of the results, the compiled and systemized information is divided according to each indicator, namely: Hydrology, Environment, Life and Policy. The qualitative information necessary to complete the index could not be obtained, therefore the scores and values used in the preliminary study (Hydrology Presentation, 2009) were used as placeholders in order to calculate final average values. These values, however, were calculated on the entire watershed so we had to apply the same score to each region. The placeholder text is denoted in the tables with blue font.

4.1 Hydrology Indicator (H)

The Hydrology indicator encompasses all aspects of water management. To fully evaluate the Hydrology Indicator, it is necessary to divide the indicator into two sub-indicators, water quality and water quantity.

4.1.1 Water Quality

The Water Availability calculated at all of the major gagging stations within the watershed constitutes the data for the Pressure and State parameters. In the upper region, three gagging stations were considered: La Troya, Palomo and Angostura. In the middle region, there was only the Guayabo Gagging Station and for the lower region, the Pascua and Hamburgo Gagging Stations were considered. Table 2 summarizes the average Water Availability per person per year for the three regions for both long-term (1954-2005) and short-term (2000-2005), considering the population of the three regions in 2005 as the base population.

Region	Population (2005)	Gagging Stations	Long-Term (1954-2005) Water Flow Rate (m^3/s)	Long-Term (1954-2005) Regional W_A (m^3/person*year)	Short-Term (2000-2005) Water Flow Rate (m^3/s)	Short-Term (2000-2005) Regional W_A (m^3/person*year)
Upper	311,436	La Troya	9.39	15,136	11.40	19,801
		Palomo	37.29		41.85	
		Angostura	102.80		142.30	
Middle	49,854	Guayabo	111.24	58,140	115.00	60,105
Lower	85,789	Pascua	149.75	132,427	162.50	120,094
		Hamburgo	210.50		164.20	

Table 2: Average Water Availability (m^3/s) of Gagging Stations in the Three Regions.

We calculated the percent variation between long-term and short-term Water Availability, which is the Pressure parameter, as shown in the equation below (Chaves & Alipaz, 2006):

$$\Delta 1 = \frac{SW_A - LW_A}{LW_A} \times 100\%$$

SW_A = Short-Term Average Water Availability

LW_A = Long-Term Average Water Availability

$\Delta 1$= Percent Variation of the Long-Term and Short-Term Water Availability

The resulting values for $\Delta 1$ were assigned a score based on Chaves & Alipaz's ranges of scores in Appendix A. The upper region scored a 1.00 while the middle region received a 0.75 and lastly the lower region received the lowest score of 0.50.

The State parameter of this indicator is the long-term regional listed in Table 2. The three regions' long term Water Availability values are all greater than the 6,800 m^3/year/person, the standard to receive the most optimal score, which means a score of 1.00 can be assigned to all three regions (see Appendix A). See Appendix E for the complete calculations. For the Response parameter, qualitative information on water-use efficiency could not be obtained due to insufficient feedback, so placeholder values from the preliminary study were used, which was a score of 1.00 (Hydrology Group, 2009). Overall the upper region scored highest with a perfect score of 1.00, followed by the middle region with 0.92, and lastly the lower region attained a score of 0.83.

HYDROLOGY QUANTITY RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
Upper	34.1%	1.00	15,179	1.00	Excellent	1.00	1.00
Middle	4.3%	0.75	69,714	1.00	Excellent	1.00	0.92
Lower	-6.5%	0.50	127,204	1.00	Excellent	1.00	0.83
Total							0.92

Table 3: Calculated & Placeholder Values for Hydrology Quantity.

4.1.2 Water Quantity

In this sub-indicator, the five-day Biochemical Oxygen Demand (BOD5) data from 2000 to 2005 for the entire basin was the only data available. Thus instead of using variation of the short-term average relative to the long-term average, we used the variation of BOD5 of 2005 relative to that of 2000 in calculating the Pressure parameter. Also, the result of this calculation was equally applied to the three regions of the basin.

The BOD5 is 1.87 mg/L for 2000 and 1.42 mg/L for 2005, so the variation, Δ2, was calculated to be -24.3 percent, yielding a score of 1.00, according to Chaves & Alipaz'sranges of scores (Appendix A).

$$\Delta 2 = \frac{(1.42 - 1.87)}{1.87} \times 100 = -24.3\%$$

Δ2= Percent Variation of BOD5 from 2000 to 2005

For the State parameter, we used the BOD5 for the year 2000 and applied it equally to the three regions. According to Chaves & Alipaz's ranges of scores (Appendix A), the value of 1.87mg/L yields a score of 0.75. As for Hydrology Quality Response, this qualitative parameter was obtained from the July, 2009 report (Hydrology Presentation, 2009), in which they determined a score of 0.50 for the watershed's improvement level in sewage treatment and disposal (Hydrology Group, 2009). Since this parameter was the same for each region, every region attained the same score of 0.75. Table 4 presents the results of Hydrology Quality results.

HYDROLOGY QUALITY RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
Upper	24.3%	1.00	1.87	0.75	Regular	0.50	0.75
Middle					Regular	0.50	0.75
Lower					Regular	0.50	0.75
Total							0.75

Table 4: Calculated & Placeholder Values for Hydrology Quality.

4.2 Environment Indicator (E)

For the Pressure parameter, the upper and lower regions received a score a 0.75 for having very good values for the EPI. The middle region's value turned out to be lower, yielding a score of 0.50. Due to the lack of available data, we created the following equation, which is a modified version of EPI, substituting forest coverage for agriculture coverage and population for urban population:

$$EPI^* = \frac{V_F - V_P}{2}$$

V_F = Percent Variation of Regional Forest Area

V_P = Percent Variation of Regional Population

The State indicator, evaluating the percentage of area of natural vegetation in each region in 2000, resulted in very high scores. The upper and lower regions both have about 28 percent of their natural vegetation, earning them a score of 0.75, while the middle region excelled with almost 60 percent of its land being natural vegetation resulting in a score of 1.00, much above the 40 percent needed. The final parameter, Response, turned out to be the best of the three environmental parameters, yielding the highest scores overall. Evaluating the evolution in basin conservation, the percent variation in protected land from the year 2000 to 2005 gave the upper region a value of 18.9 percent, giving the region a score of 0.75. The other two regions surpassed the requirement of having a 20 percent or greater increase in protected areas to receive a score of

1.00. After averaging the scores of the three parameters for each of the three regions, a final WSI value was determined for each region. The final averages show that the middle and lower regions scored highly with a score of 0.83, while the upper region was slightly lower with 0.75. Table 5 summarizes the results for this indicator. The full calculations for the Environment indicator are in Appendix D.

ENVIRONMENT RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
Upper	2.81	0.75	29.73%	0.75	18.9%	0.75	0.75
Middle	9.63	0.50	59.17%	1.00	20.8%	1.00	0.83
Lower	4.76	0.75	27.28%	0.75	35.8%	1.00	0.83
Total							0.81

Table 5: Calculated Values for the Environment indicator.

4.3 Life Indicator (L)

To calculate the Life Pressure parameter, we calculated the percent variation of the HDI-Income population weighted by canton over the five-year period. The upper and middle regions both scored a 0.50 while the lower region obtained a score of 0.75. The State parameter is the HDI of the cantons for 2000, the base year, weighted by population. For this parameter, the middle and lower regions received a score of 0.50 and the upper region attained a score of 0.75. As for the Response parameter, which is the percent variation in the overall HDI, all three regions attained relatively poor values of 0.50. The final average scores for the upper and middle regions were 0.58 while the middle region was the lowest with 0.50. For full calculations of the Life indicator, see Appendix E.

LIFE RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
Upper	-0.6	0.50	0.77	0.75	3.77	0.50	0.58
Middle	-2.3	0.50	0.67	0.50	3.88	0.50	0.50
Lower	5.9	0.75	0.63	0.50	9.24	0.50	0.58
Total							0.56

Table 6: Calculated Values for the Life indicator.

4.4 Policy Indicator (P)

Policy Pressure, which is the variation in HDI-Education between 2000 and 2005, shows that all of the regions are faring equally well, each receiving a score of 0.75. The Policy State results are based on surveys that were conducted regarding legal and institutional frameworks. However, insufficient data was gathered from organizations for this report. No results could be obtained for the Policy Response from these organizations. Under these circumstances, placeholder values were used in order to calculate average scores. For the scores of State and Response, values of 0.75 were assigned. This yielded final average scores of 0.75 for each region (Policy Group, 2009). For full calculations for Policy Response see Appendix E.

POLICY RESULTS							
Region	Pressure		State		Response		WSI Average Score
	Value	Score	Value	Score	Value	Score	
Upper	4.25	0.75	Good	0.75	N/A	0.75	0.75
Middle	4.27	0.75	Good	0.75	N/A	0.75	0.75
Lower	6.70	0.75	Good	0.75	N/A	0.75	0.75
Total							0.75

Table 7: Calculated & Placeholder Values for the Policy indicator.

4.5 Overall WSI

Table 8 shows the average scores grouped by region, as well as the average parameter scores for each region and for the entire watershed. It can be seen that the final averages of each region are similar (0.74, 0.73 and 0.74 for the upper, middle and lower, respectively). Therefore, in order to understand what areas require improvement, it is important to look past the average scores and observe where scores were the lowest. Across all of the indicators, the lowest relative score for this watershed was 0.50. As seen in Table 8, Life was the lowest scoring indicator. Ignoring the Life indicator's scores, the upper region fared well in every other indicator, whereas the middle region needs improvement in the Environment Pressure parameter, and the lower region has a problem with the Hydrology Quantity Pressure parameter. These different problem areas need to be treated individually and, without dividing the watershed into three regions, may have gone unnoticed.

Region	Indicator	Pressure Score	State Score	Response Score	Indicator Score		FINAL REGION SCORE
Upper	Hydrology Quantity	1.00	1.00	1.00	1.00	0.88	0.74
	Hydrology Quality	1.00	0.75	0.50	0.75		
	Environment	0.75	0.75	0.75	0.75		
	Life	0.50	0.75	0.50	0.58		
	Policy	0.75	0.75	0.75	0.75		
	PARAMETER SCORE	0.80	0.80	0.70			
Middle	Hydrology Quantity	0.75	1.00	1.00	0.92	0.83	0.73
	Hydrology Quality	1.00	0.75	0.50	0.75		
	Environment	0.50	1.00	1.00	0.83		
	Life	0.50	0.50	0.50	0.50		
	Policy	0.75	0.75	0.75	0.75		
	PARAMETER SCORE	0.70	0.80	0.75			
Lower	Hydrology Quantity	0.50	1.00	1.00	0.83	0.79	0.74
	Hydrology Quality	1.00	0.75	0.50	0.75		
	Environment	0.75	0.75	1.00	0.83		
	Life	0.75	0.50	0.50	0.58		
	Policy	0.75	0.75	0.75	0.75		
	PARAMETER SCORE	0.75	0.75	0.75			
TOTAL PARAMETER SCORE		0.75	0.78	0.73			

Table 8: Summary Table of the Watershed Sustainability Index.

5. Results Analysis

We compared the results presented above with the July, 2009 report and with similar watersheds to best understand the meaning behind the numbers.

5.1 Results Comparison with the Preliminary Study in July, 2009

Table 9 shows the overall WSI results for the whole watershed that our group calculated, compared with the results of the July, 2009 report. Due to the implementation of placeholders, the two sets of values are similar. Looking at each indicator, the biggest difference occurs within the Life section, where our findings are significantly lower than previous findings. We expect that taking into consideration the percent cantons and population actually contained in the watershed, has adjusted this value from the previous work. Both sets of results, the previous work and our work, indicate that the watershed is in good condition in terms of sustainability, which conflicts with our research and observation.

<table>
<tr><th rowspan="2">Indicator</th><th colspan="4">Total Scores</th></tr>
<tr><th colspan="2">Previous</th><th colspan="2">Ours</th></tr>
<tr><td>Hydrology Quantity</td><td>0.83</td><td rowspan="2">0.79</td><td>0.92</td><td rowspan="2">0.83</td></tr>
<tr><td>Hydrology Quality</td><td>0.75</td><td>0.75</td></tr>
<tr><td>Environment</td><td colspan="2">0.75</td><td colspan="2">0.80</td></tr>
<tr><td>Life</td><td colspan="2">0.67</td><td colspan="2">0.55</td></tr>
<tr><td>Policy</td><td colspan="2">0.75</td><td colspan="2">0.75</td></tr>
<tr><td>WSI</td><td colspan="2">0.74</td><td colspan="2">0.74</td></tr>
</table>

Table 9: Our Results Compared with the July, 2009 Report.

5.2 Results Comparison with Similar Watersheds

In comparison to the major watersheds located in the Central America Region, the Reventazón River watershed's overall WSI value of 0.74, found through the averaging of the final scores of the three regions, indicates that the watershed fares better than others with respect to sustainability. The only other watershed that scored higher than the Reventazón was the Panama Canal watershed, calculated by Professor Chaves (Chaves, 2009). This also means that the Reventazón River watershed scored higher than the San Francisco Verdadeiro in Brazil

(0.65), the Tacuarembó in Uruguay (0.62) and Lake Poopo in Bolivia, which attained the lowest score of 0.45 as seen below in Table 10.

Watershed	Country	Period	WSI
Panama Canal	Panama	2003-2007	0.76
Reventazón River	Costa Rica	2000-2005	0.74
San Francisco Verdadeiro	Brazil	1996-2000	0.65
Tacuarembó	Uruguay	1996-2000	0.62
Lake Poopo	Bolivia	2000-2004	0.43

Table 10: Results Comparison with Similar Watersheds.

Similar to the Reventazón River watershed, the Panama Canal watershed had its largest problem with the Life indicator. Evaluating each of the indicator scores of the Panama Canal watershed showed a similarity to the Reventazón River's indicator scores. This means that many of the recommendations for improving the Panama Canal can also be applied to the Reventazón River, including ongoing data collection and re-evaluation when needed. Meanwhile, the Lake Poopo Watershed WSI was almost opposite to the Reventazón River Watershed in terms of the final WSI and indicator values. Lake Poopo's Life indicator generated the best WSI value for the watershed, while they lacked severely in the Policy indicator value. This means that there are other watersheds that could use the Reventazón River watershed as an example.

5.3 Parameters with the Lowest Score

Looking past the average scores of the upper, middle and lower regions of the watershed, we discovered different problem areas in different regions denoted by the parameters with the lowest score of 0.50. These parameters are: Life indicator in general for the whole watershed, Hydrology Quality Response parameter for the whole watershed, Hydrology Quantity Pressure parameter for the lower region, and Environment Pressure parameter for the middle region.

For the Life indicator, the evaluation of the Human Development Index for the three regions and the lack of high scores in the Response parameter indicate that the quality of life for the residents of the basin is not improving at the rate that it should be. For improved watershed sustainability, it is important that the inhabitants participate in and support the effort, which they are less likely to do if they do not have the resources to do so (Chaves & Alipaz, 2006). The low Pressure score in the upper and middle regions indicate that the inhabitants of the regions are actually becoming poorer as time goes on. For the watershed, this means that there are fewer resources available to use in order to improve its sustainability.

For the Hydrology Quality Response parameter, the lowest score indicates that the sewage treatment and disposal is inadequate and may be leading to pollution of the watershed. This issue has proven to be a major problem in the watershed. Research shows that 79 percent of waste-water around the river is contained in septic tanks, and 12 percent flows into the sanitary sewage system. Cartago is the only city in the basin with an operational sanitary sewage system consisting of a network that covers the central sector, and other isolated networks operating in various peripheral city sectors and connected to non-operational treatment plants (Information about Reventazón-Parismina, 2007)

With regard to the Hydrology Quantity Pressure parameter for the lower region, the low score means there is a decrease in Water Availability in the period studied. Even though this low number indicates a problem area, the Water Availability rankings for all three regions are greatly above the value required for a score of 1.00 (indicated by the Hydrology Quantity State parameter). Therefore, the decrease in Water Availability in the lower region is not currently a major issue but should be reevaluated every five years for long-term trends.

The final parameter that received an inadequate score was the modified Environment Pressure in the middle region. Since we used forest area instead of agriculture area in calculating this parameter, the low score implies an increase in population and a decrease in forest coverage in the region in the period studied. If the agriculture area information is used, then the inadequate score of this parameter would indicate that too much pressure is exerted on the environment due to intensive farming activities. Over-farming is hazardous to the health of the watershed because it increases erosion and therefore sedimentation in rivers, and it also increases the amount of pesticides in the water. Sedimentation can increase the water level of the rivers as well as decrease the power generation in dams, and its removal is very costly (Information about Reventazón-Parismina, 2007). These changes would ultimately reduce the river’s capacity for life.

Since the WSI cannot cover every aspect of the watershed’s health, there are some issues that were not revealed by the aforementioned results, such as the inadequate level of waste management in the lower region. This issue was originally brought to our attention during our observational field trip to the small coastal village of Parismina in the lower region, where the Reventazón River feeds into the Caribbean Sea. Large amounts of litter are collected by storm water and transported down the river system, at which point it flows into the sea and washes onto the beach. Research shows that the river contains ten metric tons of solid waste per square kilometer per year that is not collected. Additionally, the watershed produces about 94 thousand metric tons of solid waste, 26 percent of which is not collected (Information about Reventazón-Parismina, 2007). Large amount of uncollected and untreated solid waste is causing contamination problems and is ultimately impacting public health. Therefore, COMCURE should take this problem into consideration along with the other problems revealed by the WSI results.

6. Recommendations

Based on the calculation process, we recommend that COMCURE conduct the following activities to improve the **accuracy** of the WSI results:

1) Continue to collect BOD5 data in various parts of the watershed to be able to continue to calculate the Hydrology Quality parameters separately for the three regions.
2) Use ArcView and GIS data to obtain and log agriculture information for future years, so the EPI values can be correctly calculated.
3) Collect water flow information for all of the sub-watersheds and rivers within the watershed. For groundwater availability, collecting data on domestic and municipal wells is suggested. By doing this, COMCURE will be able to obtain more accurate results for the Hydrology Quantity parameters.
4) For the three qualitative parameters:
   A. Interview the Instituto Costarricense de Acueductos y Alcantarillados (AyA) for a professional opinion on the improvement in sewage treatment and disposal for the Hydrology Quality Response parameter.
   B. Interview MINAET for improvement in water-use efficiency for the Hydrology Quantity Response parameter.
   C. Conduct surveys on the adequacy and effectiveness of the laws and institutions in the basin for the Policy State parameter.

Additionally, we recommend that COMCURE conduct the following activities to improve the **scores** of the WSI results:

3) Add more sewage treatment and disposal systems to urban and rural wastewater sources, especially to agricultural areas, to work towards reducing agrochemical contamination.
4) Continue its effort with local farmers to develop sustainable farming projects in the basin area, and implement this effort into WSI as a new parameter that can be averaged with EPI. Therefore, COMCURE can evaluate this parameter more accurately and more sustainable farming projects will be encouraged.

5) Add more solid waste collection systems and improve solid waste treatment technologies. It would also be beneficial to educate the inhabitants of the watershed about proper waste management and recycling practices.

These activities will raise the accuracy of the calculation process and improve the problem areas indicated by the results.

7. Conclusion

We followed the Chaves and Alipaz's WSI computation process and calculated the four indicators (Hydrology, Environment, Life, and Policy) of the WSI for each of the three regions of the Reventazón River watershed. The results point to concerns in each region and these concerns are validated by our research and observation. The general low scores of the Life indicator show the relatively poor living conditions within the whole basin. The low value of the Hydrology Quality Response parameter indicates a need to improve the sewage treatment and disposal plants in the basin. The result of the Hydrology Quantity Pressure parameter suggests that the lower region may need to, in the future, increase its water availability. The score of the Environment Pressure parameter implies that the middle region suffers from human agricultural activities. However, some other issues revealed by our observation were not indicated in the results. These issues include erosion and inadequate solid waste treatment. Therefore, several strategies were recommended to solve the problems, including adding more sewage treatment plants and solid waste treatment plants, and developing more sustainable farming projects.

In sum, the Reventazón River watershed could benefit greatly from being a part of the UNESCO H.E.L.P. program since the H.E.L.P. program will provide resources that otherwise would not be available to COMCURE. This is a critical time to begin making significant and unprecedented efforts towards restoration of the watershed, as our results indicate not only the largest problem areas but those that show no future signs of improvement without intervention. We hope that for the future, COMCURE and UNESCO take our recommendations seriously and that a positive change is brought about in standardizing H.E.L.P. basins and improving the condition of more than just the Reventazón River watershed.

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Appendix A: The full description of levels and scores for the Watershed Sustainability Index (WSI). Source: Chaves and Alipaz, 2006.

Table II Description of WSI pressure parameters, levels, and scores

Indicator	Pressure parameters	Level	Score
Hydrology	Δ1-variation in the basin per capita water availability in the period studied, relative to the long-term average (m^3/person year)	$\Delta 1 < -20\%$	0.00
		$-20\% < \Delta 1 < -10\%$	0.25
		$-10\% < \Delta 1 < 0\%$	0.50
		$0 < \Delta 1 < +10\%$	0.75
		$\Delta 1 > +10\%$	1.00
	Δ2-variation in the basin BOD_5 in the period studied, relative to the long-term average	$\Delta 2 > 20\%$	0.00
		$20\% > \Delta 2 > 10\%$	0.25
		$0 < \Delta 2 < 10\%$	0.50
		$-10\% < \Delta 2 < 0\%$	0.75
		$\Delta 2 < -10\%$	1.00
Environment	Basin E.P.I. (rural and urban) in the period studied	EPI>20%	0.00
		20%<EPI>10%	0.25
		10%<EPI<5%	0.50
		5%<EPI<0%	0.75
		EPI<0%	1.00
Life	Variation in the basin per capita HDI-Income in the period studied, relative to the previous period.	$\Delta < -20\%$	0.00
		$-20\% < \Delta < -10\%$	0.25
		$-10\% < \Delta < 0\%$	0.50
		$0 < \Delta < +10\%$	0.75
		$\Delta > +10\%$	1.00
Policy	Variation in the basin HDI-Education in the period studied, relative to the previous period	$\Delta < -20\%$	0.00
		$-20\% < \Delta < -10\%$	0.25
		$-10\% < \Delta < 0\%$	0.50
		$0 < \Delta < +10\%$	0.75
		$\Delta > +10\%$	1.00

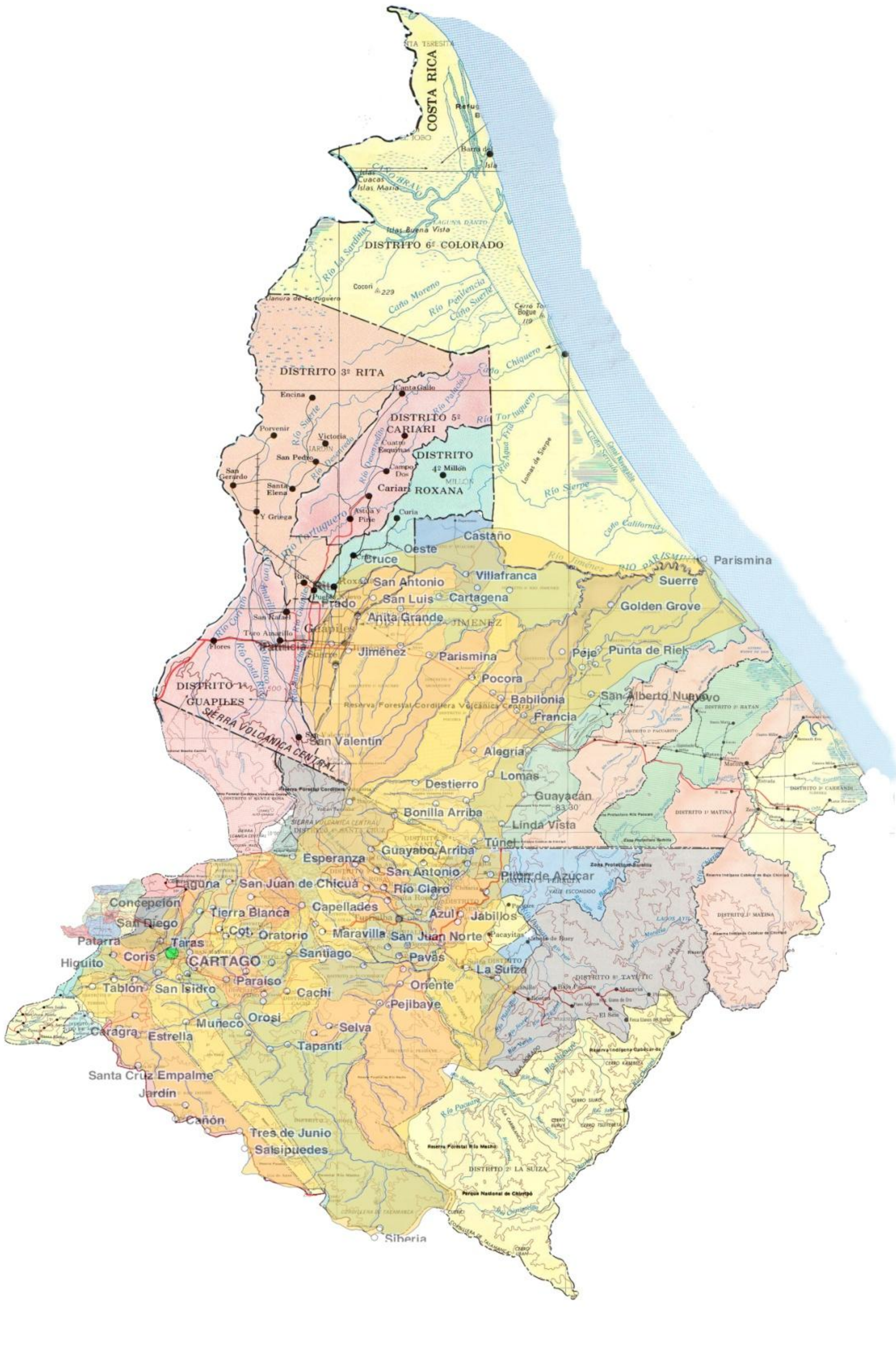
Table III Description of WSI state parameters, levels, and scores

Indicator	State parameters	Level	Score
Hydrology	Basin per capita water availability (m^3/person year), considering both surface and groundwater sources	Wa<1,700	0.00
		1,700<Wa<3,400	0.25
		3,400<Wa<5,100	0.50
		5,100<Wa<6,800	0.75
		Wa>6,800	1.00
	Basin averaged long term BOD_5 (mg/l)	BOD>10	0.00
		10<BOD<5	0.25
		5<BOD<3	0.50
		3<BOD<1	0.75
		BOD<1	1.00
Environment	Percent of basin area under natural vegetation (Av)	Av<5	0.00
		5<Av<10	0.25
		10<Av<25	0.50
		25<Av<40	0.75
		Av>40	1.00
Life	Basin HDI (weighed by county population)	HDI<0.5	0.00
		0.5<HDI<0,6	0.25
		0.6<HDI<0.75	0.50
		0.75<HDI<0.9	0.75
		HDI>0.9	1.00
Policy	Basin institutional capacity in IWRM (legal and organizational)	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00

Table IV Description of WSI response parameters, levels, and scores

Indicator	Response parameters	Level	Score
Hydrology	Improvement in water-use efficiency in the basin, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
	Improvement in adequate sewage treatment/disposal in the basin, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
Environment	Evolution in basin conservation areas (Protected areas and BMPs) in the basin, in the period studied	$\Delta < -10\%$	0.00
		$-10\% < \Delta < 0\%$	0.25
		$0 < \Delta < +10\%$	0.50
		$+10\% > \Delta > +20\%$	0.75
		$\Delta > 20\%$	1.00
Life	Evolution in the basin HDI in the basin, in the period studied	$\Delta < -10\%$	0.00
		$-10\% < \Delta < 0\%$	0.25
		$0 < \Delta < +10\%$	0.50
		$+10\% > \Delta > +20\%$	0.75
		$\Delta > 20\%$	1.00
Policy	Evolution in the basin's WRM expenditures in the basin, in the period studied	$\Delta < -10\%$	0.00
		$-10\% < \Delta < 0\%$	0.25
		$0 < \Delta < +10\%$	0.50
		$+10\% > \Delta > +20\%$	0.75
		$\Delta > 20\%$	1.00

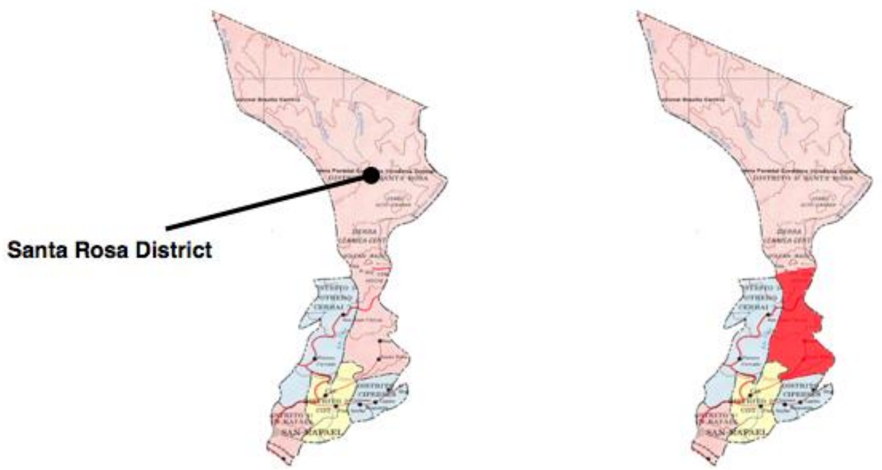
Appendix B: Detailed cantonal map with an overlay of the watershed boundary. Sources:.Atlas Cantonal de Costa Rica (Cantonal Maps) & Resumen Diagnóstico Cuenca Reventazón, 2004 (Overlay). Maps were merged and overlayed in Adobe Photoshop Creative Suite 4.



Appendix C: Detailed Population Data. Source: Instituto Nacional de Estadística y Censos (for District Populations in 2000 and 2005). Percent Land Area within the watershed was determined by using a pixel count tool (Adobe Photoshop Creative Suite 4) on the map in Appendix B.

Appendix C1: Population Calculation of Oreamuno Canton

Population Data of Oreamuno Canton					
District	2000	2005	% Land Area Contained in Watershed	2000	2005
	District Population			District Population Contained in Watershed Based on % Land Area	
San Rafael	24,586	26,013	100	24,586	26,013
Cot	8,125	8,771	100	8,125	8,771
Potrero Cerrado	2,103	2,213	100	2,103	2,213
Cipreses	3,012	3,219	100	3,012	3,219
Santa Rosa	2,701	2,855	14	378	400
	Total Canton Population			Canton Population Contained in Watershed	
	40,527	43,071		**38,204**	**40,616**



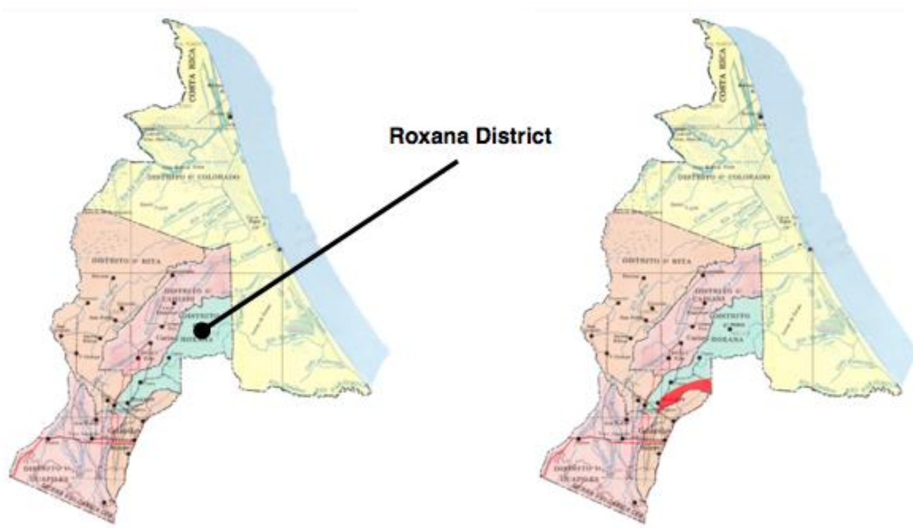
Entire Oreamuno Canton

Portion of Santa Rosa District Contained Inside Watershed

Santa Rosa District (Oreamuno Canton)		
Land Area	Pixel Count	% Land Area Contained in Watershed
Inside Watershed	13,292 pixels	$\frac{13292}{94553} = 14\%$
Total	94,553 pixels	

Appendix C2: Population Calculation of Pococí Canton

Population Data of Pococí Canton					
District	2000	2005	% Land Area Contained in Watershed	2000	2005
	District Population			District Population Contained in Watershed Based on % Land Area	
Guápiles	28,523	31,429	0	0	0
Jiménez	6,904	7,429	100	6,904	7,429
Rita	22,729	24,463	0	0	0
Roxana	16,350	17,582	12	1,962	2,110
Cariari	29,292	32,157	0	0	0
Colorado	3,607	3,835	0	0	0
	Total Canton Population			Canton Population Contained in Watershed	
	107,405	116,895		8,866	9,539



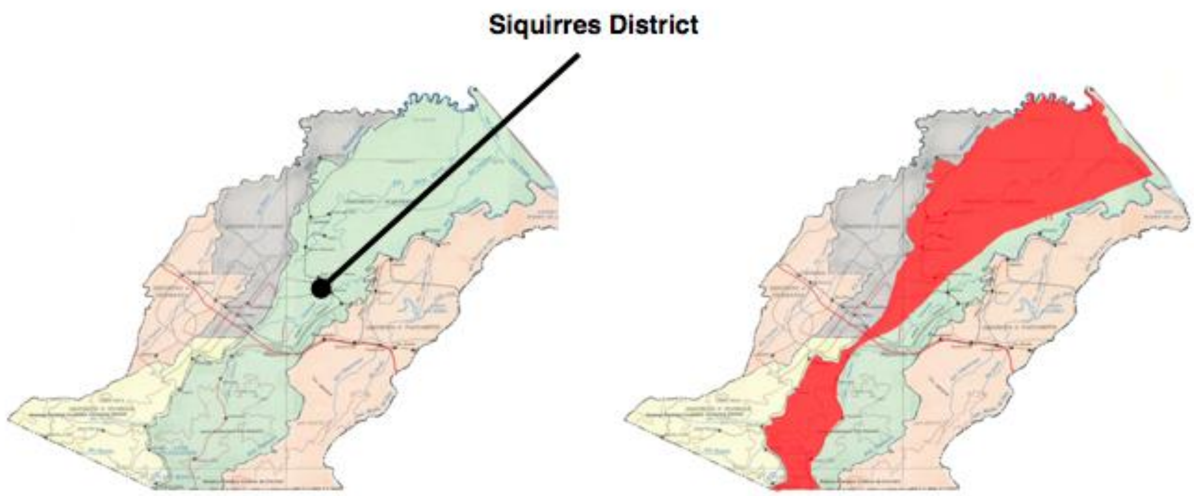
Entire Pococí Canton

Portion of Roxana District Contained Inside Watershed

Roxana District (Pococí Canton)		
Land Area	Pixel Count	% Land Area Contained in Watershed
Inside Watershed	11,204 pixels	$\frac{11204}{95250} = 12\%$
Total	95,250 pixels	

Appendix C3: Population Calculation of Siquirres Canton

Population Data of Siquirres Canton					
District	2000	2005	% Land Area Contained in Watershed	2000	2005
	District Population			District Population Contained in Watershed Based on % Land Area	
Siquirres	32,675	35,450	65	21,239	23,043
Pacuarito	9,042	9,700	0	0	0
Florida	2,042	2,155	100	2,042	2,155
Germania	2,520	2,650	100	2,520	2,650
Cairo	4,521	4,891	100	4,521	4,891
Alegría	3,729	3,967	100	3,729	3,967
	Total Canton Population			Canton Population Contained in Watershed	
	54,529	58,813		**34,051**	**36,706**



Entire Siquirres Canton

Portion of Siquirres District Contained Inside Watershed

Siquirres District (Siquirres Canton)		
Land Area	Pixel Count	% Land Area Contained in Watershed
Inside Watershed	34,275 pixels	$\frac{34275}{52693} = 65\%$
Total	52,693 pixels	

Note that there exists a Siquirres District within the Siquirres Canton

Appendix C4: Population Calculation of Turrialba Canton

Population Data of Turrialba Canton					
District	2000	2005	% Land Area Contained in Watershed	2000	2005
	District Population			District Population Contained in Watershed Based on % Land Area	
Turrialba	33,201	25,246	100	33,201	25,246
La Suiza	9,548	10,227	*	2,387*	2,557*
Peralta	597	617	25	149	154
Santa Cruz	3,564	3,799	62	2,210	2,355
Santa Teresita	5,285	5,551	100	5,285	5,551
Pavones	4,606	4,877	100	4,606	4,877
Tuis	2,726	2,871	62	1,690	1,780
Tayutic	4,647	5,044	0	0	0
Santa Rosa	4,927	5,128	100	4,927	5,128
Tres Equis	2,025	2,205	100	2,025	2,205
La Isabel	0	5,434	100	0	5,434
Chirripo	0	5,051	100	0	5,051
	Total Canton Population		*Calculated by City Population	Canton Population Contained in Watershed	
	71,126	76,050		**56,480**	**60,338**

Peralta District

Entire Turrialba Canton

Portion of Peralta District Contained Inside Watershed

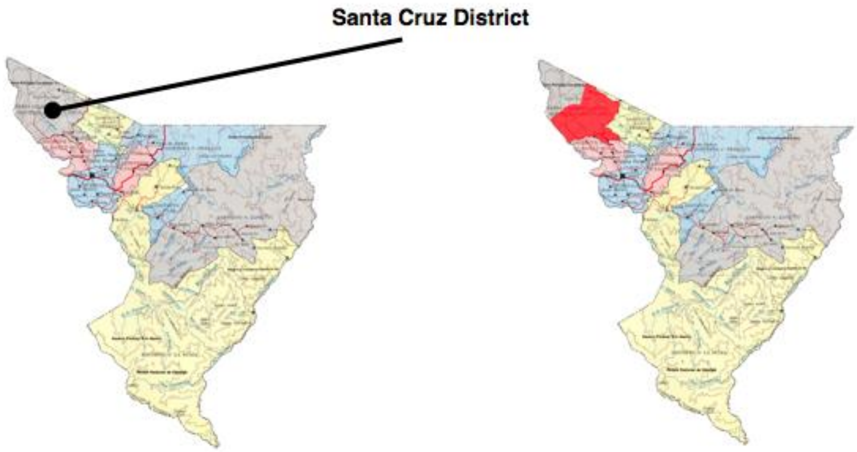
Peralta District (Turrialba Canton)		
Land Area	Pixel Count	% Land Area Contained in Watershed
Inside Watershed	18447 pixels	$\frac{18447}{74603} = 25\%$
Total	74603 pixels	

Tuis District

Entire Turrialba Canton

Portion of Tuis District Contained Inside Watershed

Tuis District (Turrialba Canton)		
Land Area	Pixel Count	% Land Area Contained in Watershed
Inside Watershed	11994 pixels	$\frac{11994}{19335} = 62\%$
Total	19335 pixels	

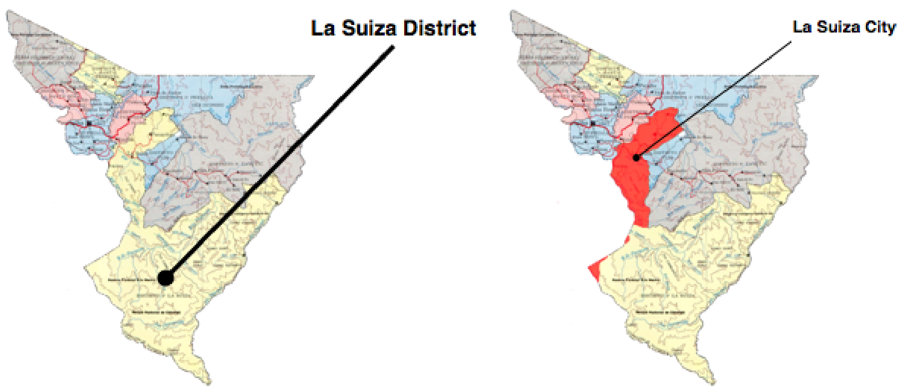


Entire Turrialba Canton

Portion of Santa Cruz District Contained Inside Watershed

Santa Cruz District (Turrialba Canton)		
Land Area	**Pixel Count**	**% Land Area Contained in Watershed**
Inside Watershed	41420 pixels	$\frac{41420}{67341} = 62\%$
Total	67341 pixels	

Of the thirteen cities that were analyzed, La Suiza City (contained inside the watershed in the La Suiza District) is the only city considered urban by the Costa Rican Census. Additionally, only 17% of the La Suiza District is within the watershed and the city of La Suiza is the largest city in the district, so we felt that a more accurate population count would be made by calculating the percentage of inhabitants living in urban areas (versus rural) in the district.



Entire Turrialba Canton

Portion of La Suiza District Contained Inside Watershed (17% land area)

La Suiza District (Turrialba Canton)		
Population Type	**Population Count**	**% Population Contained in Watershed**
Urban	2,168 people	$\frac{2168}{9202} = 25\%$
Rural	7,034 people	
Total	9,202 people	

Appendix D: Protected Area information. Source: Instituto Nacional de Estadística y Censos.

Protected Areas in Watershed 2005	Total Area (ha)	% in watershed	area in watershed (ha)	region	% in region	Lower (ha)	Middle (ha)	Upper (ha)
2b - Cordillera Volcan Central	61,063	16%	9,770	Middle/Lower	2% Middle/14%lower	8,549	1,221	-
10 - Río Macho/Tapantí	80,823	60%	48,494	Upper	60% Upper	-	-	48,494
1 - Acuíferos Guácimo-Pococí	4,258	47%	2,001	Lower	47% Lower	2,001	-	-
7 - Cerros de La Carpintera	2,390	64%	1,530	Upper	64% Upper	-	-	1,530
10 - Cuenca del Río Tuis	4,113	89%	3,661	Middle	89% Middle	-	3,661	-
19 - Río Navarro/Río Sombrero	6,463	100%	6,463	Upper	100% Upper	-	-	6,463
Monumento Nacional Guayabo	232	100%	232	Middle/Lower	55% Middle/45%Lower	-	128	104
Refugion Nacional De Fauna Silvestre La Marta	1,291	100%	1,291	Upper	100% Upper	-	-	1,291
			73,441			10,550	5,010	57,882
Protected Areas in Watershed 2000	**Total Area (ha)**	**% in watershed**	**area in watershed (ha)**	**region**	**% in region**	**Lower (ha)**	**Middle (ha)**	**Upper (ha)**
2b - Cordillera Volcan Central	48,035	16%	7,686	Middle/Lower	2% Middle/14%lower	6,725	961	-
10 - Río Macho/Tapantí	77,632	60%	46,579	Upper	60% Upper	-	-	46,579
1 - Acuíferos Guácimo-Pococí	4,270	47%	2,007	Lower	47% Lower	2,007	-	-
7 - Cerros de La Carpintera	2,000	64%	1,280	Upper	64% Upper	-	-	1,280
10 - Cuenca del Río Tuis	4,095	89%	3,645	Middle	89% Middle	-	3,645	-
19 - Río Navarro/Río Sombrero	6,440	100%	6,440	Upper	100% Upper	-	-	6,440
Monumento Nacional Guayabo	233	100%	233	Middle/Lower	55% Middle/45%Lower	-	128	105
Refugion Nacional De Fauna Silvestre La Marta	1,298	100%	1,298	Upper	100% Upper	-	-	1,298
			69,168			8,732	4,734	55,702
Reservas Forestales								
Zonas Protectoras								
Other								

Appendix E: Full Calculations for the Hydrology, Life and Policy Indicators. Sources: Population: Instituto Nacional de Estadística y Censos; HDI: Atlas del Desarrollo Humano Cantonal de Costa Rica 2007; Flow Rate: Copy of Caudales Río Reventazón.

Life Pressure Parameter									
Region	Canton	Population		HDI Income		Population weighted HDI		Percent Variation	WSI Value
		2000	2005	2000	2005	2000	2005		
Lower	Pococí	8 866	9 539	0.394	0.398	0.0440822	0.044254182		0.75
	Siquirres	34 051	36706	0.359	0.411	0.1542636	0.175851986		
	Guácimo	36 326	39 544	0.381	0.393	0.1746553	0.181151336		
	Total	79 243	85 789			0.373001	0.401257504	7.575447143	
Middle	Turrialba			0.436	0.426				0.5
	Total							-2.293577982	
Upper	Cartago	137 095	145 748	0.726	0.723	0.3405423	0.338354603		0.5
	Paraíso	54 426	58 201	0.609	0.613	0.1134061	0.114557126		
	Jiménez	14 599	15 497	0.389	0.392	0.0194306	0.01950585		
	Alvarado	12 758	13 482	0.695	0.681	0.0303375	0.029480349		
	Oreamuno	38 240	40 616	0.761	0.753	0.099567	0.098202674		
	El Guarco	35 154	37 892	0.67	0.651	0.0805865	0.079206296		
	Total	292 272	311 436			0.68387	0.679306898	-0.667243235	

Life State Parameter					
Region	**Canton**	**Population**	**HDI**	**Population weighted HDI**	**WSI Value**
Lower	**Pococí**	8 866	0.621	0.069479777	**0.5**
	Siquirres	34 051	0.635	0.272861767	
	Guácimo	36 326	0.632	0.289716846	
	Total	79 243		0.63205839	
Middle	**Turrialba**		0.67		**0.5**
Upper	**Cartago**	137 095	0.786	0.368686258	**0.75**
	Paraíso	54 426	0.744	0.13854541	
	Jiménez	14 599	0.672	0.033566431	
	Alvarado	12 758	0.772	0.033698664	
	Oreamuno	38 240	0.778	0.101791208	
	El Guarco	35 154	0.76	0.091411562	
	Total	292 272		0.767699533	

Life Response									
Region	Canton	Population		HDI		population weighted HDI		percent variation	WSI Value
		2000	2005	2000	2005	2000	2005		
Lower	Pococí	8 866	9 539	0.621	0.667	0.069479777	0.074164671		0.5
	Siquirres	34 051	36706	0.635	0.699	0.272861767	0.299076735		
	Guácimo	36 326	39 544	0.632	0.691	0.289716846	0.31851291		
	Total	79 243	85 789			0.63205839	0.691754316	9.444685293	
Middle	Turrialba			0.67	0.696				0.5
	Total							3.880597015	
Upper	Cartago	137 095	145 748	0.786	0.813	0.368686258	0.380473433		0.5
	Paraíso	54 426	58 201	0.744	0.767	0.13854541	0.143336567		
	Jiménez	14 599	15 497	0.672	0.728	0.033566431	0.036225151		
	Alvarado	12 758	13 482	0.772	0.806	0.033698664	0.034891573		
	Oreamuno	38 240	40 616	0.778	0.811	0.101791208	0.105766758		
	El Guarco	35 154	37 892	0.76	0.789	0.091411562	0.095996571		
	Total	292 272	311 436			0.767699533	0.796690052	3.776284512	

Policy Pressure Parameter									
Region	**Canton**	**Population**		**HDI-Education**		**Population Weighted HDI-Education**		**Percent Variation**	**WSI Value**
		2000	**2005**	**2000**	**2005**	**2000**	**2005**		
Lower	**Pococí**	8 866	9 539	0.731	0.773	0.09721812	0.102238526		**0.75**
	Siquirres	34 051	36706	0.757	0.809	0.386658771	0.411735032		
	Guácimo	36 326	39 544	0.714	0.771	0.389061187	0.422734034		
	Total	79 243	85 789			0.872938078	0.936707593	6.807835736	
Middle	**Turrialba**			0.739	0.772				**0.75**
	Total							4.274611399	
Upper	**Cartago**	137 095	145 748	0.847	0.873	0.397336019	0.408515925		**0.75**
	Paraíso	54 426	58 201	0.803	0.825	0.149546025	0.154161717		
	Jiménez	14 599	15 497	0.775	0.837	0.038714863	0.041645227		
	Alvarado	12 758	13 482	0.755	0.815	0.03295964	0.03527801		
	Oreamuno	38 213	40 644	0.759	0.84	0.099244357	0.109614466		
	El Guarco	35 154	37 892	0.84	0.874	0.101043166	0.106328847		
	Total	292245	311464			0.818844069	0.855544191	4.289681642	

Hydrology Quantity State					
Region	**Gagging Stations**	**Long Term Flow Rate**	**Population (2005)**	**Water Availability**	**WSI**
Lower	**Hamburgo**	210.5			1
	Pascua	149.75			
	Total	360.25	85789	132427.7471	
Middle	**Guayabo**	111.24			1
	Total	111.24	60338	58140.22076	
Upper	**La Troya**	9.39			1
	Palomo	37.29			
	Angostura	102.8			
	Total	149.48	311436	15136.34031	

Hydrology Quantity Pressure					
	Gagging Stations	Long Term Flow Rate	Short Term Flow Rate	Percent Variation Water Availability	WSI
Lower	Hamburgo	210.5	164.2		0.5
	Pascua	149.75	162.5		
	Total	360.25	326.7	-9.312977099	
Middle	Guayabo	111.24	115	3.380079108	0.75
Upper	Troya	9.39	11.4		1
	Palomo	37.29	41.85		
	Angostura	102.8	142.3		
	Total	149.48	195.55	30.82017661	

Appendix F: Population Calculations. Source: Instituto Nacional de Estadística y Censos.

Upper Region			**Lower Region**			**Middle Region**		
	Population Contained			**Population Contained**			**Population Contained**	
Canton	**2000**	**2005**	**Canton**	**2000**	**2005**	**Canton**	**2000**	**2005**
Cartago	137 095	145 748	Pococí	8866	9539	Turrialba	56480	60338
Paraíso	54 426	58 201	Siquirres	34051	36706			
Jiménez	14 599	15 497	Guácimo	36 326	39 544			
Alvarado	12 758	13 482						
Oreamuno	38204	40616						
El Guarco	35 154	37 892						
Totals	292 236	311 436		79243	85789		56480	60338

Oreamuno						
District	Population		% Contained	way found	Population Contained	
	2000	2005			2000	2005
San Rafael	24 586	26 013	100		24586	26013
Cot	8 125	8 771	100		8125	8771
Potrero Cerrado	2 103	2 213	100		2103	2213
Cipreses	3 012	3 219	100		3012	3219
Santa Rosa	2 701	2 855	14	Land	378.14	399.7
Total Pop.	40,527	43,071			38204.14	40615.7

Pococí						
District	Population		% Contained	Process	Population Contained	
	2000	2005			2000	2005
Guápiles	28 523	31 429	0		0	0
Jiménez	6 904	7 429	100		6904	7429
Rita	22 729	24 463	0		0	0
Roxana	16 350	17 582	12	Land	1962	2109.84
Cariari	29 292	32 157	0		0	0
Colorado	3 607	3 835	0		0	0
Total	107,405	116,895			8866	9538.84

Siquirres						
District	Population		% contained	Process	Population Contained	
	2000	2005			2000	2005
Siquirres	32 675	35 450	65	Land	21238.75	23042.5
Pacuarito	9 042	9 700	0		0	0
Florida	2 042	2 155	100		2042	2155
Germania	2 520	2 650	100		2520	2650
Cairo	4 521	4 891	100		4521	4891
Alegría	3 729	3 967	100		3729	3967
Total	54,529	58,813			34050.75	36705.5

Turrialba						
District	Population		% Contained	Way Found	Population Contained	
	2000	2005			2000	2005
Turrialba	33 201	35 731	100		33201	35731
La Suiza	9 548	10 227	25	City	2387	2556.75
Peralta	597	617	25	Land	149.25	154.25
Santa Cruz	3 564	3 799	62	Land	2209.68	2355.38
Santa Teresita	5 285	5 551	100		5285	5551
Pavones	4 606	4 877	100		4606	4877
Tuis	2 726	2 871	62	Land	1690.12	1780.02
Tayutic	4 647	5 044	0		0	0
Santa Rosa	4 927	5 128	100		4927	5128
Tres Equis	2 025	2 205	100		2025	2205
Total	71,126	76,050			56480.05	60338.4