Relationships between Land Uses and Water Quality in Costa Rica: An Analysis of the San Gerardo de Rivas Watershed and the Chirripo River

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SUMMARY

A dataset was compiled of the distribution of land uses in the municipal watershed of San Gerardo de Rivas, a small mountain town in southwestern Costa Rica. Water quality was also tested at six points along the Chirripo, a turbulent mountain river which runs through the San Gerardo valley. **The hypothesis of the study was that significant correlations could be established between the concentrations of different land uses in the San Gerardo de Rivas watershed and levels of contaminants in the Chirripo River**. The goal was to look for relationships between the town's land uses and the water quality of the Chirripo River as it travels through areas of changing land use and increasing population density. This study was completed for Cloudbridge Nature Reserve, a private reforestation project located in San Gerardo, and the *Comite Bandera Azul de San Gerardo de Rivas*, a local group that works to protect the town's natural resources.

Land uses in the ~11.5km^2 watershed were divided up into ten classes. The five most prevalent land uses in San Gerardo, in order, are forests, pastures, natural regeneration, agricultural lands, and forestry plantations. The other categories include residential, commercial, and institutional areas and roads. House locations were also mapped as points to be included in the analysis.

The water quality data for the Chirripo River that was used for this analysis is from a study conducted by Cloudbridge volunteers in 2004. In that study, the first eight kilometers of the river were tested for phosphorus, ammonia, nitrates/nitrites, pH levels, dissolved oxygen, temperature, and E. coli bacteria. Six of the nine points fell within the San Gerardo watershed study area and the data from those points were used.

Using linear regression analyses, a number of statistically significant relationships were established between the percentages of land uses draining cumulatively to each test point and the tested water quality variables at those points. **Of greatest interest, strong positive relationships were shown between phosphate concentrations in the river and increasing numbers of houses per hectare and increasing amounts of agricultural area; these relationships tested as being significant at the 99% confidence level. There was also a negative relationship between the amount of forested area and the concentration of E. coli bacteria; this relationship tested significant at the 95% confidence level.** It is important to note that this can only serve as a preliminary analysis since the water quality data was nearly three years old at the time this report was completed. Ideally this type of analysis would be conducted with a number of datasets taken over time and averaged together.

INTRODUCTION

Land uses and water quality are directly related. Wastes and pollutants from different land uses are transported in dissolved forms across watersheds by both overland flow and groundwater percolation to enter local streams and rivers. This study was developed to determine how the water quality of the Chirripo River is impacted by the land uses of the town of San Gerardo de Rivas in southwestern Costa Rica. The specific goal was ascertain what relationships exist between the concentration of different types of land uses in the watershed and inputs of contaminants to local surface waters.

HYPOTHESIS

A significant correlation can be established between the concentrations of different land uses in the San Gerardo de Rivas watershed and the levels of contaminants in that section of the Chirripo River.

BACKGROUND

Cloudbridge Nature Reserve, at an elevation of 5,000-7,000 ft, is located along the eastern edge of San Gerardo de Rivas. Cloudbridge and the town border Chirripo National Park, and Chirripo Park connects to the La Amistad Conservation Area, which extends into the northern part of Panama. It is one of the largest conservation areas in Central America. Cloudbridge is a private reforestation effort with the direct goal of bridging a gap in the forest between the Chirripo park line and the Chirripo River, and the greater goal of helping to protect to study the biodiversity of the region (Cloudbridge website). San Gerardo de Rivas, a small town of approximately 300 residents, was founded in the 1950s. The primary industries are tourism, agriculture and livestock (source: Report of Bandera Azul de San Gerardo de Rivas, 2006).

Since 2002, San Gerardo has been awarded each year the *Bandera Azul Ecologica* (Ecological Blue Flag) and the *Bandera Blanca*, an extra award for excellent water quality. The *Bandera Azul* is a prestigious government award that is given to communities that take certain steps to protect their local environment and natural resources, especially water. It is fundamentally aimed at helping rapidly developing communities establish environmentally friendly infrastructure early in their development so as to promote greater sustainability in the future (Programa Bandera Azul Ecological, pamphlet).

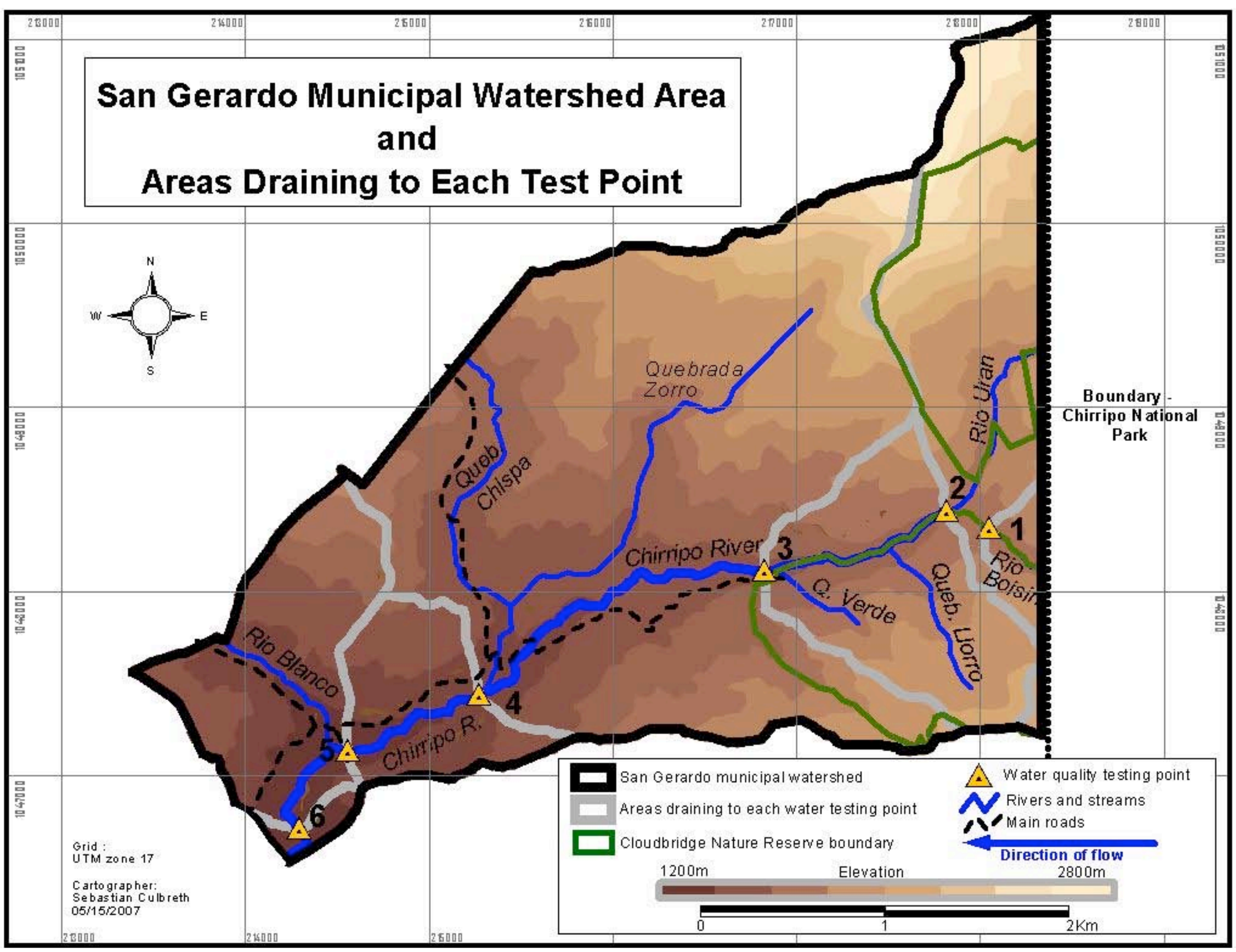
Because of the joint interest in the subject of this investigation, Cloudbridge and the *Comite de Bandera Azul de San Gerardo de Rivas* teamed up to complete the analysis.

METHODS

Creating the watershed study area:

The Chirripo River watershed that falls within San Gerardo de Rivas was delineated using ten-meter interval topographic line data, and the method described by S. Lawrence Dingman in his text <u>Physical Hydrology</u>. The watershed is 11.5 km² (1,147.37 ha) in total (See **Figure 1**). The Chirripo River and the eight main tributaries that are shown on government topographic maps were included, although there are countless smaller streams that feed into the river along the length of the study area as well. Of the tributaries mapped, five of the eight are relatively small and their entire watershed is contained within the San Gerardo boundaries. The Chirripo, Blanco and Uran Rivers, and the Chispa Stream, are larger waterways that originate well outside town boundaries. For the purposes of this project, the watersheds for these rivers are cut off at the municipal boundary. The Chirripo and Uran Rivers originate within the national park and travel through undisturbed forest until they enter the Cloudbridge Nature Reserve. The Chispa Stream originates in a largely forested area with low population densities. The Blanco River comes from Herradura de Rivas, another town similar to San Gerardo, where more focus is placed on agricultural activity rather than tourism.

FIGURE 1: All of the map elements were drawn from Costa Rican government topographic maps and aerial photographs. See **Appendix 1** for a larger print of this map.



Creating the land use dataset:

The base data for the land use map dataset came from two geo-referenced two-meter resolution aerial photographs of the study area. These were obtained from the *Centro Nacional de Alta Technologia de Costa Rica*, the organization that coordinates information sharing and maintenance between the country's four public universities. This resolution is clear enough to delineate the difference between large areas of pasture and forest, but not sufficient clear to accurately tell the difference between an agricultural field and other types of vegetation. For this reason, agricultural fields, forestry plantations, and other difficult to discern areas in the study area were measured with global positioning systems (GPS). The collected data was compiled into a polygon map dataset (See **Figure 2.1**). The following system was used to classify the polygons:

- **Forest –** Closed canopy primary or secondary forest
- **Natural Regrowth –** Previously deforested area that is being allowed to regenerate naturally
- **Forestry Plantation –** Replanted forest trees, commercial or reforestation
- **Pasture –** Most pasture areas are grazed by cattle, horses, or other livestock, but at relatively low densities
- **Perennial Agriculture –** Perennial crops such as coffee or fruit trees
- **Seasonal Agriculture –** Seasonal crops, primarily tomatoes, peppers, beans, and other vegetables
- **Roads –** The majority of the roads in San Gerardo are not paved
- **Residential –** Inhabited area with two or more houses in close proximity, with no other land uses in between
- **Institutional –** Areas and buildings such as schools, churches, government buildings
- **Commercial –** Businesses such as stores, restaurants, and hotels
- **House Density –** House locations were also mapped to have their density by watershed (houses/Ha) included in the analysis

FIGURE 2.1: To compile the land use dataset, large portions of forest and pasture were drawn from aerial photographs, whereas agricultural fields, houses, and forestry plantations were mapped on foot using GPS, or a combination of both. See **Appendix 1** for a larger print of this map.

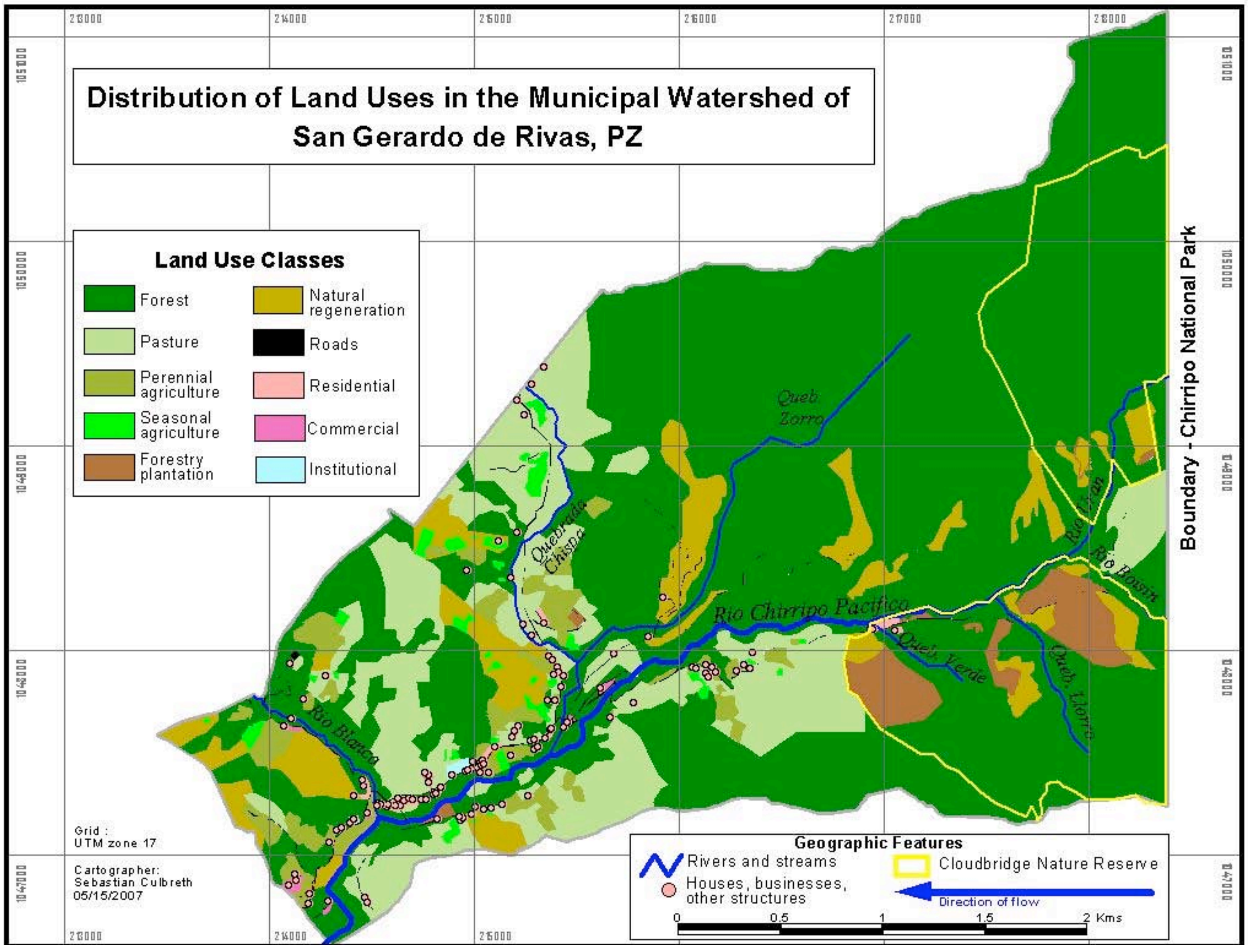
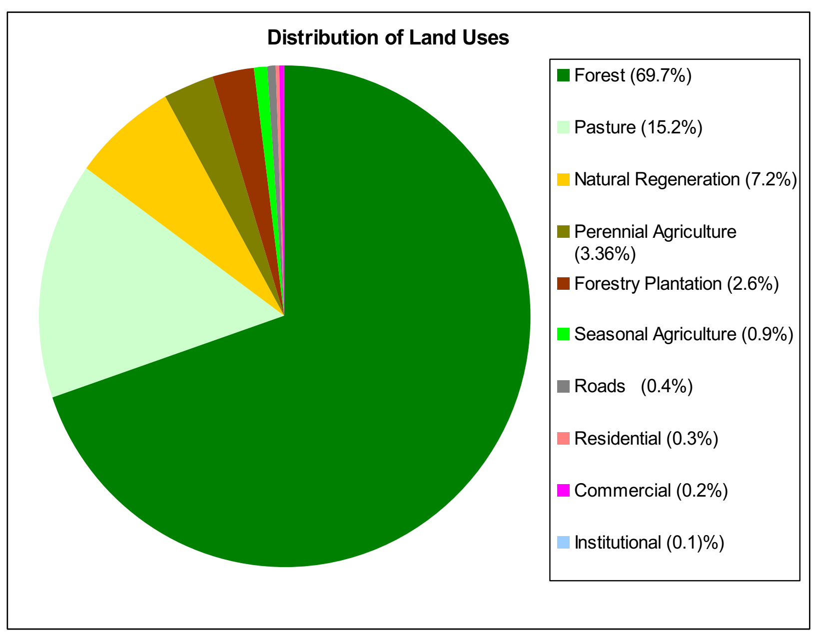


FIGURE 2.2: Forest covers more area than all of the other land uses combined. See **Appendix 1** for detailed tables of the data for land use distributions in the areas draining to each test point.



Water quality data and test points:
The water quality data used for the analysis was compiled by Cloudbridge researcher Tom Newman in 2004. Water quality was tested at nine points along the first eight kilometers of the Chirripo River. The points were located at irregular intervals, with focus placed more on ease of access to the river rather than obtaining equal lengths of river study area. Test points 1-6 fell within the San Gerardo watershed and their data was used for this project. The locations are shown on the watershed and elevation map shown in **Figure 1**. The water quality study measured levels of nitrates/nitrites, ammonia, phosphorus, E. coli bacteria, dissolved oxygen, and temperature. Variables that changed significantly over the course of the study area were phosphorus, E. coli, and nitrate/nitrite (NOx) concentrations. Total phosphorus levels rose steadily along the length of the study area, while E. coli and NOx levels fluctuated. See **Appendix 2** for all raw water quality data with a brief explanation.

Cumulative watershed areas and percentages of total area per land use:
To put the land use data in a format appropriate for comparison with the available water quality data, it had to be divided into watersheds that corresponded to each test point. This was done by dividing the San Gerardo municipal watershed into 6 watersheds, one for each test point. Cumulative test point watersheds are defined as the total area from the Chirripo park boundary that drains to each water quality test point; the cumulative watershed area for any given test point includes all of the watersheds for any previous upstream test points.

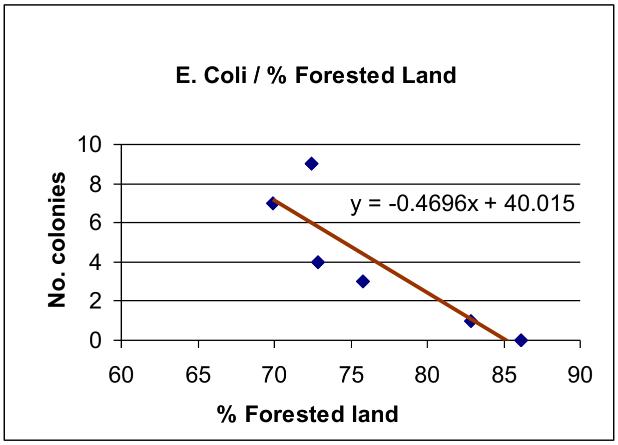
For each test point, the sum of areas for each land use was divided by the total area of the cumulative watershed to obtain the percentage of each type of land use in each watershed. These percentages could then be compared with the water quality data at each respective test point. See **Appendix 2** for a table of this data for each cumulative watershed.

DATA ANALYSIS AND RESULTS

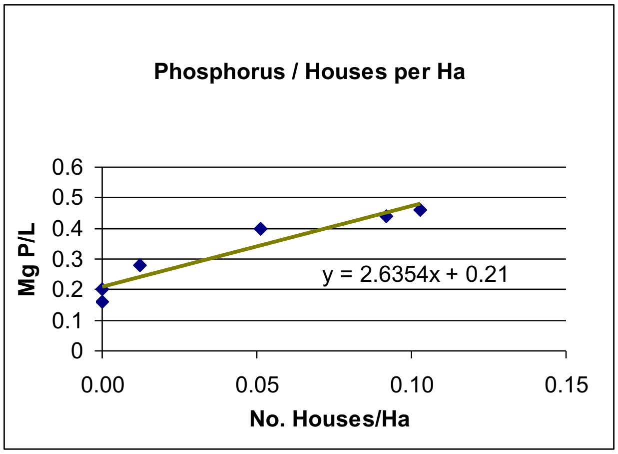
To compare the land use and water quality datasets, the first step was to calculate the Pearson correlation coefficient (*r*) value between the percentages of each land use class (as the independent variable) and each water quality variable (as the dependent variable). Pearson's *r* is a measure of association between an independent and dependent variable that can range from ± 1, with a value of ± 1 meaning a perfect liner positive or negative relationship (Healey 379). Sets of variables with values of *r* closer to ± 1 were graphed using a linear regression, and then tested for significance using the *t* distribution. See **Appendix 3** for a table of values of *r*, regression graphs, and completed statistical tests.

Of some interest, there was a negative relationship between the abundance of E. coli and increasing amounts forested areas that tested significant at the 95% confidence level (See **Figure 3.1**). While it is entirely to be expected that water coming from less developed and more forested areas would have lower levels of E. coli bacterium, it is encouraging to see that this obvious relationship is supported by the methodology used for this watershed analysis.

FIGURE 3.1: As the percentage of forested land increased, the amount of E. coli bacteria decreased.



Of more notable interest were the strong positive relationships between phosphorus concentrations and density of houses, as well as with the amount of agricultural land (See **Figure 3.2**). Phosphorus is an important plant nutrient, too much of which can cause rampant algae growth in aquatic ecosystems. These excessive amounts of algae eventually begin to die off, and as they decompose, the bacterium that eats the rotting vegetation consumes all of the dissolved oxygen available in the water and, in addition, poisons the water with their wastes. This process of nutrient pollution, known as eutrophication, can eventually make the stream unable to support diverse aquatic life (Stiling 246).



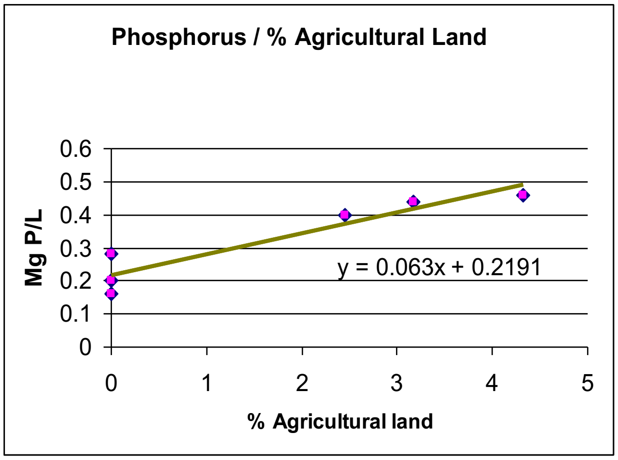


FIGURE 3.2: As the number of houses per hectare increased, so did the amount of phosphorus. As the amount of agricultural land increased, so did the amount of phosphorus. Phosphorus is found in many household soaps and agricultural fertilizers.

Household soaps and agricultural fertilizers are both common sources of excess phosphorus to the environment (Allan 323). It stands to reason that the Chirripo River is overloaded with phosphorus from these sources. Many households in San Gerardo do not have constructed grey water drains, and in many cases waste water from sinks, showers and laundry machines simply washes out onto the ground next to a house. There is also nearly 50 hectares of active agricultural land in the study area, and with very few exceptions it all receives chemical fertilizers several times per year.

The fact that the Chirripo River is overloaded with phosphorus means that there is very likely an enormous demand by algae for nitrogen in absorbable forms (NOx included). That is why phosphorus levels ramp up steadily during the entire length of the study area while NOx levels fluctuate, as there is probably fierce competition among algae for any fresh inputs of it. Refer to **Appendix 2** for a further explanation of the relationship between the amounts of available nitrogen and phosphorus.

Despite the high demand for nitrogen by algae because of the excess phosphorus, there is still NOx present in the water. As such, it can be concluded that there are also large inputs of NOx to the river, most likely from agricultural fertilizers. Please refer to **Appendix 2** for further explanation of how these conclusions were reached.

It is doubtful that any of the eutrophic conditions listed above will ever become a problem in the San Gerardo stretch of the Chirripo River. Although local accounts state a visible increase in algae growth over the last few years, the upper stretch the Chirripo is such a fast flowing, turbulent mountain stream that dissolved oxygen levels remain near saturation levels and any pieces of dead algae are immediately washed away. High levels of nutrient inputs upstream are more likely to cause problems downstream in the lowlands where flow velocity drops dramatically. Here, in the slow moving water, nutrients and vegetation have a chance to accumulate and interact, causing eutrophication (Stiling 246).

CONCLUSIONS FROM THIS STUDY

The relationships that were found between land use and indicators of water quality indicate that the practices of farmers and inhabitants of San Gerardo have an effect on local aquatic ecosystems. These effects illustrate the negative impacts of human habitation and agricultural activity on the environment and potentially on the health of communities. The implications of this are twofold. First education and dissemination of this kind of knowledge is essential for inhabitants of rural and urbanizing communities. To this end, community organizations like the local Bandera Azul committee must assume a leadership role. Second, to preserve the health of these communities and of their environment, further studies must be undertaken and alternatives must be found.

This preliminary watershed analysis, especially if combined with the following suggestions for further studies could provide an in-depth look at the structure and function of tropical mountain watersheds and how the land uses within change the aquatic processes. This information could then be disseminated to those who live in the Chirripo River watershed in San Gerardo de Rivas, which would allow them to make informed decisions about their land while considering the health of their watershed.

SUGGESTIONS FOR FUTURE RESEARCH

For this study:

The conclusions suggested by this preliminary analysis are interesting, but there is still much more work to be done. The data used is not comprehensive enough to draw any solid conclusions. In order to get a better idea of the real nature of cause and effect relationships between land uses and river water quality, it would be best to have several sets of both the water quality data and the land use data taken over time and then averaged for the most accurate values.

Land uses tend to shift around and change over time for a variety of reasons. Seasonal crops can be planted in different places every season, or different crops can be planted in the same place season after season. New houses get built in one place while others become uninhabited. At the time of the writing of this report, some coffee farmers in San Gerardo were thinking of clearing their land for pasture and going back to raising livestock because it is becoming a better market than coffee. In San Gerardo, and especially in the Cloudbridge Nature Reserve, large areas of previous pasture are being allowed to regenerate naturally while others are being actively reforested. All of these changes in land use should be recorded and factored in to any analysis with water quality.

Water quality data can fluctuate very easily due to any number of factors. Recent rainfall patterns, one time events such as random spills of contaminants in the watershed, and seasonal changes in flora, fauna, agrochemical application, and land uses are some examples of factors that can cause spikes or other misrepresentations in water data. It is important to test water regularly several times per year, in different seasons, over the course of several years to get a clear picture of an aquatic ecosystem's actual health.

To summarize, the land use dataset should be kept updated, water quality should be tested several times per year at regular intervals, and a similar analysis can be performed again after sufficient data has been gathered to generate better, more accurate results with more accurate values.

Additions to this study:

While solidifying the current data in the manner described above, it would also be good to include a few extra variables that should be examined in future water quality testing. Since San Gerardo has such an active agricultural industry, further testing should include screens for pesticides, fungicides and herbicides. These chemicals have the same effect in aquatic ecosystems as on a farm field, each poisoning their respective types of targeted organisms (Allan 322). Such chemicals are widely used in the San Gerardo watershed and it would be very easy to monitor their levels while testing for the other variables to see if they are having any negative effects and where their specific sources are.

The sediment load of the river is another variable that should be examined. Excess sediment clouds the water column, inhibiting photosynthesis and primary production in aquatic ecosystems (Allan 106). It clogs benthic habitat (on the stream bottom, in leaf litter and rocks), where many insects live that serve as food for fish and other large predators. Sediment can fill in the bottom of streams, causing the channel width to widen and affecting streamside conditions and changing the habitats (Hauer & Lamberti 127). Additionally, depending on where they are washed from, sediments can carry other organic and chemical contaminants to water, a phenomenon known as “piggybacking”.

Monitoring the sediment load is more involved than simply adding another strip to the test kit. Both the suspended and bed (washing along the bottom) loads have to be physically sampled, which involves wading out to the middle of the river with special sampling tools. Ideally, sediment sampling would also rotate around rainfall events, which would be very inconvenient (Hauer & Lamberti 123-42). However, this extra effort should be made as a dramatic increase in sediment load is clearly apparent in the river every time it rains and the water level rises. There are many obvious sources for excess sediment in the San Gerardo watershed; bare earth, such as dirt roads, cleared agricultural fields, and construction sites, can all be major contributors.

Related studies:

Another tangential study that intuitively follows this watershed study would be to examine what changes in the flow responses of the river to rainfall events occur as previously cleared areas are allowed to grow. A hydrograph is a graph of stream discharge over time that shows the spike in stream flow that can be expected around a rainfall event of a specific magnitude and duration (Dingman 390). Land cover affects the rate at which rainfall washes into waterways in a watershed (Dingman). The land cover of the natural regrowth and reforestation areas will change as scrubby regrowth becomes secondary forest. It would be assumed that the shape of the hydrograph will change in response to the land uses changes. It would be interesting to examine this, as changes in stream flow responses to rainfall can have significant impacts on the physical characteristics and ecology of a waterway.

A final note:

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Residents of San Gerardo de Rivas

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Hauer, F. Richard, and Gary Lamberti (ed). *Methods in Stream Ecology*. Academic Press, San Diego, CA, 1996.

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APPENDIX 1 – Full Size Maps and Detailed Watershed Statistics

Cumulative test point watershed land use distribution data:

The following table shows the total area distribution of land uses for each test point:

LAND USE AREAS PER CUMULATIVE WATERSHED

Test Point	Cum. W.S. Area (Ha)	Perennial Agriculture	Seasonal Agriculture	Total Agriculture	Commercial	Forest	Forestry Plantation
1	20.21	0.00	0.00	0.00	0.00	146453.30	8006.09
2	196.73	0.00	0.00	0.00	0.00	1694485.32	49996.33
3	330.92	0.00	0.00	0.00	0.00	2742878.57	221185.83
4	938.19	156415.85	73256.07	229671.92	4622.60	7113686.02	293836.03
5	1011.09	226533.16	93493.52	320026.68	9179.62	7370444.14	302161.64
6	1138.59	382810.92	108620.33	491431.25	19183.04	7961170.26	302161.64

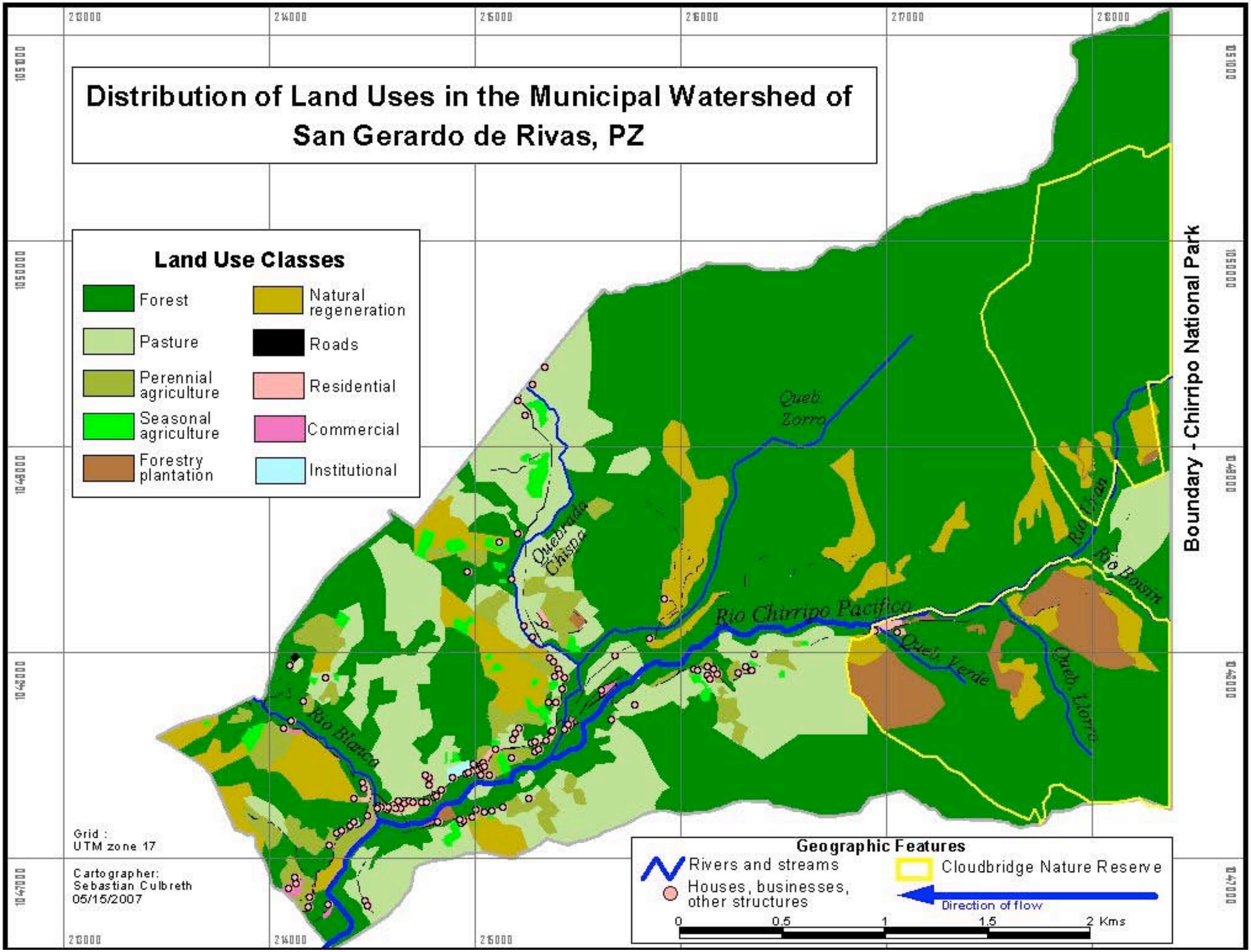
Test Point (continued from above)	Institutional	Natural Regeneration	Pasture	Roads	Residential	Number of Houses
1	0.00	32866.96	14407.81	356.99	0.00	0.00
2	0.00	116341.80	105179.66	1290.09	0.00	0.00
3	0.00	227391.60	105179.66	3790.74	8744.69	4.00
4	0.00	574250.28	1119215.53	30386.97	16198.18	48.00
5	8778.76	653188.83	1382658.07	36378.07	28092.62	93.00
6	10640.33	821671.65	1695896.09	48781.24	34927.28	117.00

The following table shows the percentage distribution of land uses found in each cumulative watershed:

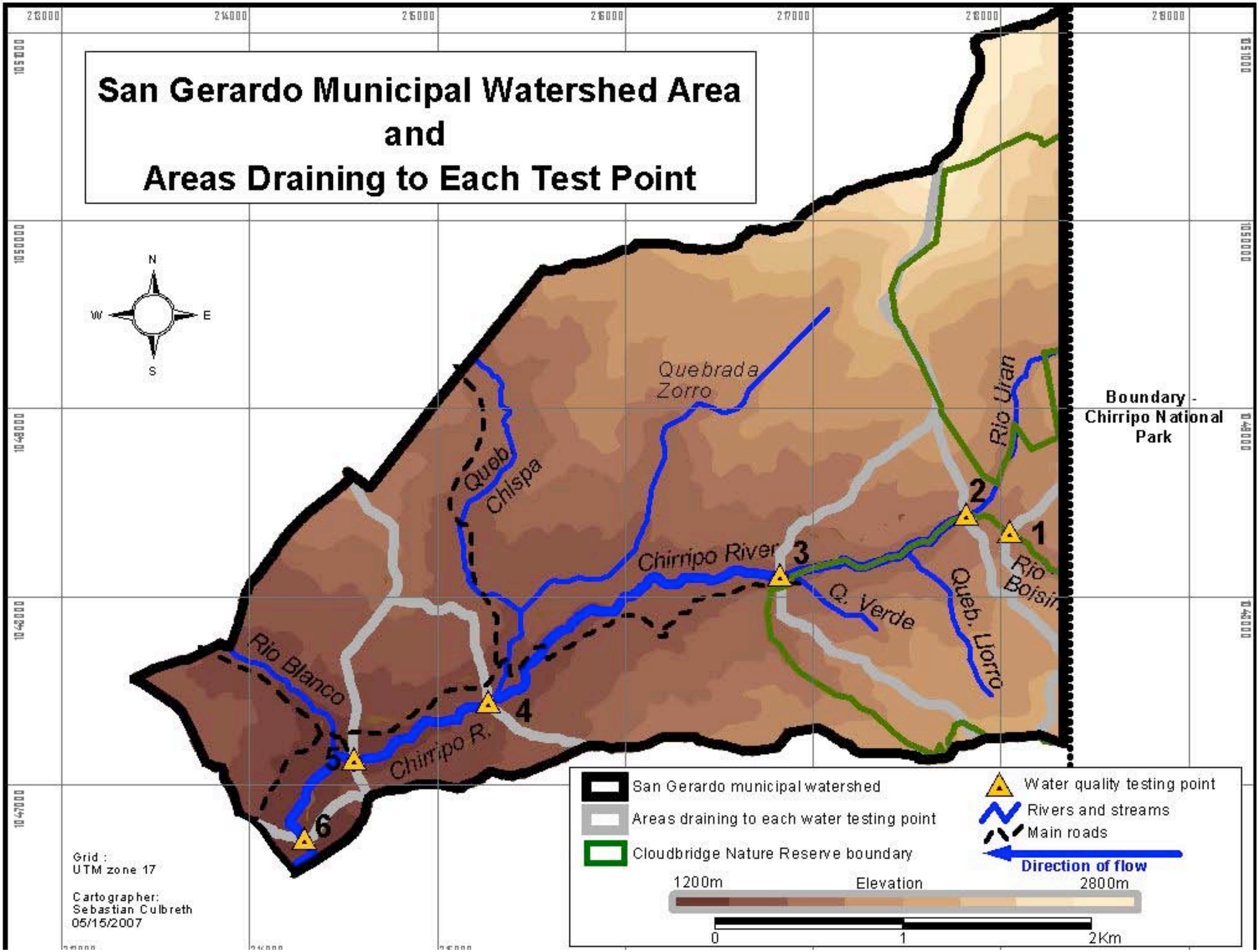
LAND USE AREA % DISTRIBUTION PER CUMULATIVE WATERSHED

Testpoint	Cum. W.S. Area (Ha)	% Perennial Agriculture	% Seasonal Agriculture	% Total Agriculture	% Commercial	% Forest	% Forestry Plantation
1	20.21	0.00	0.00	0.00	0.00	72.47	3.96
2	196.73	0.00	0.00	0.00	0.00	86.13	2.54
3	330.92	0.00	0.00	0.00	0.00	82.89	6.68
4	938.19	1.67	0.78	2.45	0.05	75.82	3.13
5	1011.09	2.24	0.92	3.17	0.09	72.90	2.99
6	1138.59	3.36	0.95	4.32	0.17	69.92	2.65

Testpoint (continued)	% Institutional	% Natural Regeneration	% Pasture	% Roads	% Residential	Houses per Hectare
1	0.00	16.26	7.13	0.18	0.00	0.00
2	0.00	5.91	5.35	0.07	0.00	0.00
3	0.00	6.87	3.18	0.11	0.26	0.01
4	0.00	6.12	11.93	0.32	0.17	0.05
5	0.09	6.46	13.67	0.36	0.28	0.09
6	0.09	7.22	14.89	0.43	0.31	0.10



Distribution of Land Uses in the Municipal Watershed of San Gerardo de Rivas, PZ
Land Use Classes
Forest
Pasture
Perennial agriculture
Seasonal agriculture
Forestry plantation
Natural regeneration
Roads
Residential
Commercial
Institutional
Boundary - Chirripo National Park
Queb Zorro
Quebrada Chispa
Rio Chirripo Pacifico
Rio Blanco
Queb. Verde
Queb. Llorro
Rio Uran
Rio Bonsin
Grid : UTM zone 17
Cartographer: Sebastian Culbreth 05/15/2007
Geographic Features
Rivers and streams
Houses, businesses, other structures
Cloudbridge Nature Reserve
Direction of flow
0 0.5 1 1.5 2 Kms


San Gerardo Municipal Watershed Area
and
Areas Draining to Each Test Point
N
W
E
S
Quebrada Zorro
Queb. Chispa
Rio Urian
Boundary - Chirripo National Park
Chirripo River
Q. Verde
Queb. Llorro
Rio Boisin
Rio Blanco
Chirripo R.
1
2
3
4
5
6
San Gerardo municipal watershed
Areas draining to each water testing point
Cloudbridge Nature Reserve boundary
Water quality testing point
Rivers and streams
Main roads
Direction of flow
1200m
Elevation
2800m
0
1
2Km
Grid :
UTM zone 17
Cartographer:
Sebastian Culbreth
05/15/2007

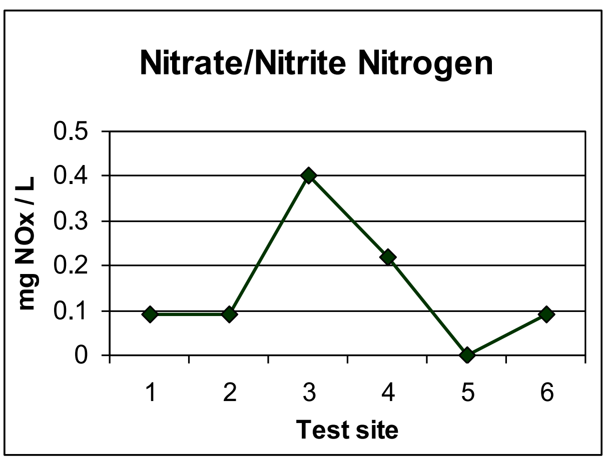
APPENDIX 2 – Summary of water quality data

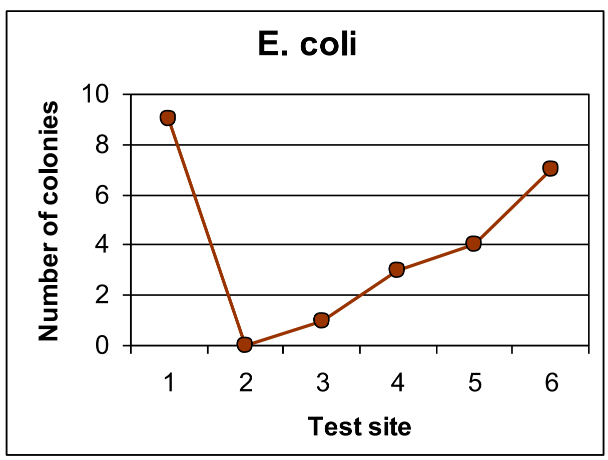
A note about this water quality dataset and the placement of testing points:
There are two issues with the water quality data used for this analysis that make any conclusions that come from this study indicators of general trends at best. First, there is only one set of six one-time observations. For this type of study, more solid conclusions can be drawn by using several datasets taken over regular intervals of time and averaged together. Second, the points where water quality was tested in 2004 were located at irregular intervals, with focus placed more on ease of access to the river rather than obtaining equal lengths of river study area.

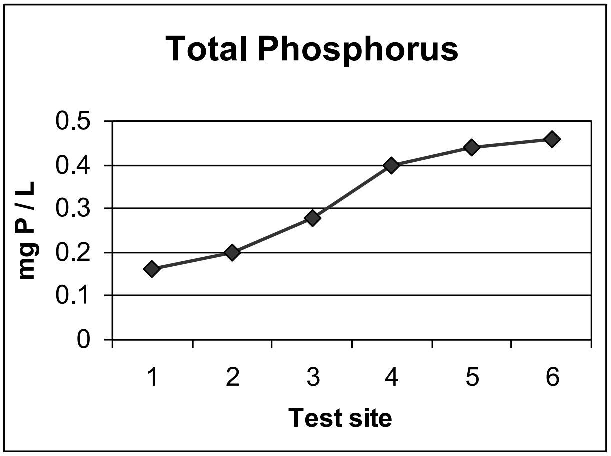
Had the water quality testing points been chosen with a later study such as this in mind, point 1 could have been located right at the Chirripo National Park boundary, which would be more appropriate for this study in two ways. First, the park boundary marks the eastern limit of municipal San Gerardo. Second, since the river would be flowing from a 100% protected forest watershed, water quality measurements from that location could be treated as a control standard for cleanliness. At present, no such assumption can be made.

This dataset is satisfactory for preliminary analysis to point future research in the correct direction. However, because of the issues mentioned above it is important to remember to be careful with any conclusions drawn from this data. Please refer back to the "Suggestions for Future Research" section at the end of the main report for steps that can be taken to solidify conclusions from a future iteration of this study.

Raw water quality data from 2004:







Other water quality Variables tested that showed no significant variation:

Test Point	NH4	Temp. (°C)	Dissolved Oxygen	pH
1	0	16	9	8
2	0	15	8	7.7
3	0	16	9	7.7
4	0	17	9	7.7
5	0	18	9	7.8
6	0	17	8	7.7

Variables with significant variation:
Three of the tested variables, E. coli, NOx, and phosphorus, showed significant changes along the length of the study area. E. coli levels rose steadily from test points 2-6, which stands to reason as there are more sources for sewage effluent and livestock runoff further downstream in the watershed. However, point 1 tested higher than all the other sites. This is likely because test point 1 was across the stream from a large, moderately grazed pasture that is shaped like a chute going straight up and down the side of the mountain. It is shaped perfectly to funnel it’s runoff through a narrow section of riparian zone, and straight out to test point 1. As it is now, the E. coli data shows no significant relationship with any land use, except for a negative relationship with forested area. If the first test point were to be excluded from the statistic analysis, as is often the practice with such outliers, some other more solid-appearing relationships could test as significant. However, this analysis is already tenuous enough due to the small number of observations and further manipulation of the data to look for relationships could lead to contrived conclusions

NOx levels ranged from 0.0-0.4 Mg/l. The levels followed no apparent pattern and showed no significant correlations with any land use, except for forestry plantations, which is not supported by what is known about sources of nutrients and other contaminants. This anomaly is most easily explained by changes in land use between 2004, when the water quality was tested and 2007, when the land use data for this study was collected. In 2004 there were still some active agricultural fields in areas that are now Cloudbridge forest plantations where chemicals are not used. These fields could have provided enough sources of fertilizer runoff to change the data in this manner. This is another good example of why it is so important to keep all data as current and uniform as possible, so as to avoid comparing apples to oranges, figuratively speaking.

Total phosphorus rose steadily for the entire length of the study area, starting at 1.8 Mg/l and finishing at 4.6 Mg/l. it is clear that phosphorus inputs exceed biological demand by organisms in the stream. This will be discussed further in the following section on nutrient limitation and ratios.

Variables without significant variation:
Other variables that were tested but showed no significant variation attributable to land uses were ammonia (NH4), temperature, dissolved oxygen, and pH level. Ammonia levels remained at zero for all test sites, which can be interpreted in one of two ways. Either the test was defective or damaged, or, since ammonia is the most popular form of nitrogen for aquatic plants (Allan 288), any inputs could be consumed immediately by vegetation and algae as soon as it becomes available.

Temperature, for the most part, rose steadily across the study area, which was probably caused by decreasing altitude and increasing channel width exposed to sunlight. The two test points where temperature dropped slightly from the previous point (2 & 6), are both located directly after where smaller mountain rivers (Uran River and Blanco River) flow in. These smaller rivers have narrower channel widths that not exposed to as much warming sunlight as the Chirripo, therefore they are likely colder and caused the slight drops in temperature.

Dissolved oxygen remained at or near saturation levels due to the fact that the Chirripo is such a turbulent mountain river, constantly mixing in fresh oxygen (Allan 24). pH values fluctuated slightly between 7.7 - 8, staying for the most part at 7.7. This amount of variation is not enough to cause any changes in the ecosystem; negative effects to biota due to changes in pH are only felt when it drops below 5.0 (Allan 39).

A Brief explanation of nutrient levels, limiting resources, and N:P ratios in aquatic ecosystems:
Dissolved nutrient levels are one of the greatest factors affecting algae growth in aquatic ecosystems. Algae are primary production in aquatic ecosystems and thus affect the health of the whole system. Too little nutrient availability can starve a stream food chain from the bottom up. Too much nutrient availability can lead to eutrophic, or nutrient overloaded conditions, causing algae to grow out of control. These excessive amounts of algae eventually begin to die off, and as they decompose, the bacterium that eats the rotting vegetation consumes all of the dissolved oxygen available in the water and, in addition, poisons the water with their wastes (Stiling 246).

Nutrients tested in the 2004 water quality study included ammonia (NH4), nitrates (NO3), nitrites (NO2); these are all ionic forms of nitrogen, the nutrient needed in the greatest quantities by plants. Levels of phosphorus, the nutrient needed in the second greatest quantities, were also tested (Stiling 352).

A limiting resource is the nutrient or resource in shortest supply in relation to an organism's demand for it (Stiling 377). In aquatic ecosystems, nitrogen and phosphorus get taken up by algae in specific ratios, most commonly at or close to 16:1, respectively. In situations where there are greater inputs of one nutrient relative to the other in the ratio, the lesser nutrient will become the limiting nutrient for algae growth. Usually, nitrogen is the more abundant nutrient and phosphorus is the limiting nutrient that gets taken up as soon as it becomes available. (Allan 292)

The fact that there are similar concentrations of NOx and phosphorus in the water, with measurements for both varying mostly between .1 and .5 mg/l, shows that the stream is overloaded with phosphorus. There is much more than 1 part phosphorus for each 16 parts NOx. That is why phosphorus levels ramp up steadily during the entire length of the study area while NOx levels fluctuate, as there is probably fierce competition among algae for fresh inputs of it. There is clearly a large input of NOx, as it still exists at all in dissolved form when there is such a high demand for it in this nitrogen limited system. These inputs can probably be attributed to fertilizer runoff.

The idea that phosphorus overloading is throwing off the normal N:P ratio in the Chirripo River is further reinforced if one chooses to believe that the above- mentioned ammonia test was not defective, and that this most popular form of nitrogen is simply taken up too rapidly to register on any tests.

Please refer back to the main report for further interpretation of these results and other conclusions.

APPENDIX 3 – Statistical comparisons between land uses and water quality

Looking for relationships between land uses and water quality data:
The first step in looking for cause and effect relationships between the two datasets was to calculate the Pearson correlation coefficient (*r*). The percentage of land use concentrations was the independent variable and water quality was the dependent variable. Pearson's *r* is a measure of association between an independent and dependent variable that can range from ± 1, with a value of ± 1 meaning a perfect liner positive or negative relationship (Healey 379).

Equation 1 – Pearson Correlation Coefficient (*r*) (Healey 379)

$$r = \frac{\sum(X-mX)\sum(Y-mY)}{\sqrt{\left(\sum(X-mX)^2 \sum(Y-mY)^2\right)}}$$

The values of *r* between each set of variables are displayed in the following table:

Pearson's *r* values for study area cumulative watershed land use distributions correlated with water quality information at a site:

	Perennial Ag.	**Seasonal Ag.**	**Total Ag.**	**Commer.**	**Forest**	**Forestry Plantation**	**Institution**	**Natural Regeneration**	**Pasture**	**Road**	**Residential**	**Houses per ha**
E. Coli	0.34	0.25	0.32	0.39	**-0.87**	-0.21	0.35	0.76	0.45	0.49	-0.02	0.28
Phosphor.	0.92	0.95	**0.94**	0.86	-0.53	-0.30	0.77	-0.57	0.84	0.89	0.85	**0.95**
NOx	-0.40	-0.39	-0.40	-0.41	0.47	0.84	-0.55	-0.18	-0.58	-0.39	0.20	-0.39

Illustrating relationships between land use and water quality data:
A few sets of variables with values of *r* closer to ± 1 were then graphed on the following scatter plots with each graph's respective land use on the *x* axis and water quality variable on the *y* axis. A line of the function that approximates the relationship between the two variables was drawn to give an idea of the general nature of the relationship. This was done using the following two linear regression formulas that provide slope and y intercept to generate the standard equation of a line ($y=bx+a$). In this equation, *b* is slope and *a* is the y intercept.

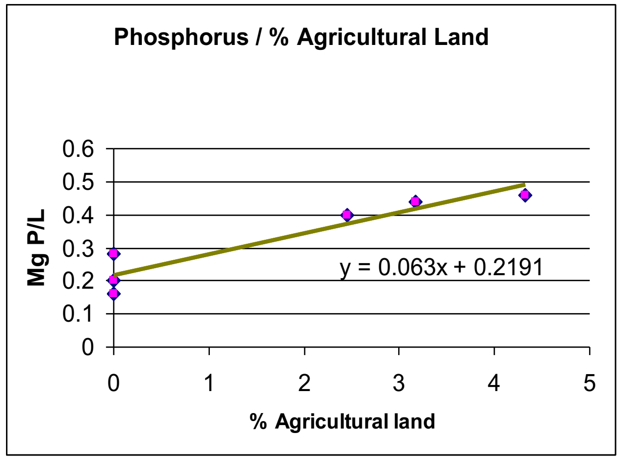
Equation 2 – Regression slope formula (Healey 377)

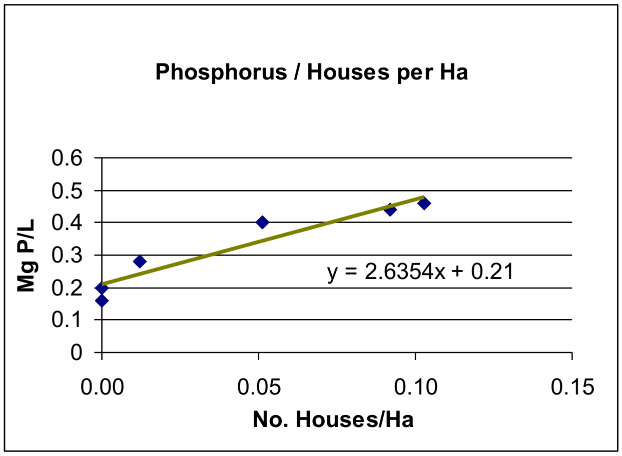
$$b = \frac{\sum(X-mX)(Y-mY)}{\sum(X-mX)^2}$$

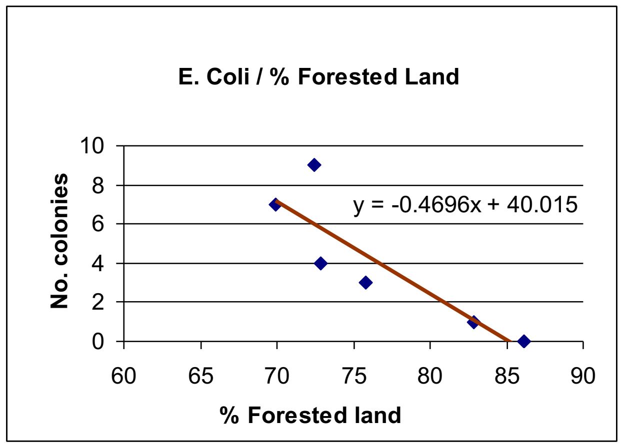
Equation 3 – Regression Y-intercept formula (Healey 378)

$$a = mY - b(mX)$$

Linear regression graphs of the relationship between the selected water quality variables and the percent distribution of different land uses in the San Gerardo cumulative watershed draining to each test site:







Testing land use - water quality relationships for significance:

These sets of variables were then tested for statistical significance using the following equation that calculates a value of *t* for sets of data that have been tested with Pearson's *r*. The *t* distribution is suitable to use in this case because the number of observations is small, and the distribution of all possible values of *r* is well approximated by the *t* distribution (Healey 205, 385)

Equation 4 – *t* (obtained) for sets of data tested with Pearson's *r* (Healey 386)

$$t = r\sqrt{((N-2)/(1-r^2))}$$

Null hypothesis - There is no significant correlation between the two sets of variables.

Alternative hypothesis – There is a significant correlation between the two sets of variables.

Calculated values of *t* for significance of the correlation between selected land uses and water quality variables:

Contaminant & land use	**Pearson's r**	**T – critical & (significance level)**	**T – obtained**
E. Coli & Forest	-0.87	±2.776 (95%)	-3.544
Phosphorus & Houses per ha	0.95	±4.604 (99%)	6.216
Phosphorus & Agriculture	0.94	±4.604 (99%)	5.457

The null hypothesis is rejected in all three cases and the alternative hypothesis is accepted. **There is a statistically significant relationship between the amount of the San Gerardo de Rivas land uses (forest, houses/Ha, agriculture) and the level of each tested water quality variable (E. coli, phosphorus) in the Chirripo River.** Please refer back to the "Results and Discussion" section of the main report for further interpretation of these findings.