

El ciclo de mercurio y filtrar por los árboles cerca de la Cuenca en  
Las Juntas de Abangares de Costa Rica.

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**Abstracto:**

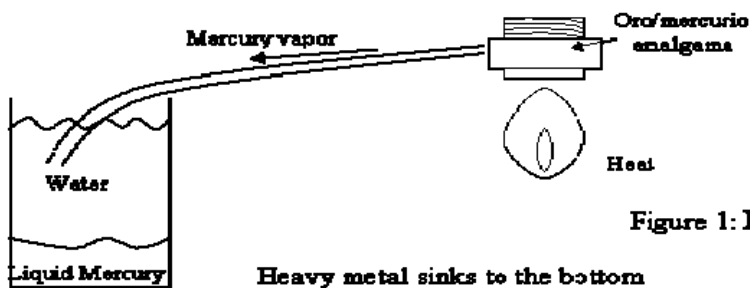
En el pueblo de Abangares de Costa Rica se llama Las Juntas, nueve lugares en la Cuenca estaban probando por la cualidad de agua y de la tierra. Los exámenes pasaron y el “Riparian buffer zone” se inspeccionó por decidir si “phytoremediation” era posible. “Phytoremediation” es necesario para limpiar el ambiente de mercurio. Por la industria de las minas, mercurio para refinar oro, ha entrada la cultural de Las Juntas y los tradiciones. Según de los exámenes de la Cuenca, “phytoremediation” no sirviera como una técnica efectiva por limpiar el mercurio porque hay alta pH y competición de los elementos. Pero, si el pH del agua no cambie y no se aumente el agua con más carbono orgánico, el mercurio no cambiará al mercurio – methyl, la forma más peligrosa.

## Introduction:

In Costa Rica, mercury is a fairly common metal found naturally in the soil due to volcanic activity. Volcanoes are also the source of most of the naturally occurring airborne mercury in the world (US Geological Survey 2000). The mining industry, in its methods of extracting gold with mercury, has caused the level of mercury in the environment to increase to unnatural harmful quantities. The Costa Rican government banned the use of mercury in attempts to curb this method, but the miners turned to buying mercury off the black market and the processors were moved from community plants to backyards of homes, increasing the potential harm on mothers and children (Castillo 2005).

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In the mining process, gold ore is broken down into smaller and smaller pieces using large machines called “rastras”. A rastra consists of a large metal tub and several heavy boulders strapped to the device in the center that turns them around the way an ox turns a mill stone. The boulders break down the pieces by grinding them for hours. The ore goes through a second rastra and then washed with water and added to the third rastra with mercury. When the rastra mixes mercury with the ore, which is now very fine silt, an amalgam (“amalgama”) forms with the mercury and gold. They take out these round pieces of amalgam and get rid of excess mercury by twisting it. Then it is placed within a pipe apparatus to be melted down.



**Figure 1: Pipe Apparatus**

Once melted down, the mercury goes through the pipe in vapor and condenses in a bucket of water. Gold is left within the chamber. This method of recycling the mercury has been used for the past 20 years (Andres 2005). Mercury is extremely volatile, however, even with this method of purification, mercury in the open air is evaporating into the atmosphere and being breathed in by the workers.

Mercury emission is the same type of problem faced with the energy industry burning coal. Mercury released returns to the earth with rainfall and is washed into the rivers, streams, which lead to the ocean (Associated Press, 2003). According to the Clean Air Act Amendments (CAAA), “[mercury has] significant threats to human health, wildlife and the environmental integrity of the aquatic food chain” which is a result of the bioaccumulation of high concentrations of mercury in fish (Penn Well Publishing Co 1992). Two toxic forms of mercury are found naturally, metallic mercury, Hg (II), and methylmercury, CH<sub>3</sub>Hg<sup>+</sup>. Methylmercury is more toxic because of its organic form and can be found highly concentrated in fish and aquatic organisms. It increases in concentration and toxicity as it climbs the food chain. Prolonged exposure to mercury may cause birth defects, child mortality, permanent damage to the nervous system, and infertility (California Department of Health Services, 1989). In a report to the US Congress, the Environmental Protection Agency (EPA) cited mercury as a carcinogen and to be more dangerous to the unborn child than to the mother. Mercury vapors cause a number of nervous disruptions and in high exposures, can induce kidney problems, lung failure, and death, especially in warm or poorly ventilated areas (EPA, 2005). The miners who directly work with the mercury on a daily basis are exposed to dangerous mercury vapors and the rest of the community is exposed through the water and the aquatic food sources due to the deposition of mercury with precipitation. Once it rains, mercury washes into the streams and rivers along with

soil and can either continue in the cycle through methylation, or sit in the streambed for years until another source pulls it out and sends it through the cycle. Mercury has sat and built up over time in this community since the first mining companies came and acquired mercury for the production of gold. Halting the use of mercury would stop the accumulation, but not solve the problem of its excess in the local environment.

Phytoremediation is a new method of using plants to absorb pollutants and heavy metals and then harvesting the plants and disposing properly of the wastes. Natural phytoremediation occurs with a riparian buffer zone set up along rivers, especially between a water source and agricultural fields. The trees, in addition to protecting the rivers from eroding away the banks and producing oxygen, filter out chemicals such as pesticides, fertilizers, ammonia, and other pollutants and often change the chemicals into less harmful compounds. Trees also are effective in shading the riverbed which helps keep the temperature and pH fairly constant, which in turn affects the oxygen level in the water required for the aquatic organisms to survive (Delaware Riverkeeper). Bishaw *et. al.* describes the purpose of the buffer zones this way, “Riparian buffers are established by planting trees along streams where trees and streamside vegetation have been removed for agricultural and grazing purposes” which is important because without that buffer zone, the soil and nutrients would be washed away by the stream.

It is well known in the scientific community that metal ions are easily taken up by plants because of their ionic form, charge and ability to diffuse across a membrane. Mercury in its metallic form and its organic form are both absorbed by plants, nevertheless, various factors affect this absorption. It can be taken up through the roots and possibly through the stomata in the leaves. According to Griffith, in his experiment comparing uptake from artificial soils to uptake from natural soil, “Many metals tend to be more mobile in soils under low pH conditions”

(Griffith, 2001). Dr. Kelsey of Muhlenberg College brought up the subject and encouraged the exploration of the soil pH and how that may affect the filtering of mercury.

This paper explores the possibility for phytoremediation as a solution to the mercury levels in Las Juntas and the indicators for effective uptake of mercury by the buffer zones in place. The significance of this topic is found in the broader spectrum of health in Las Juntas. This information is necessary for future decisions to be made about the environmental situation of the Avangares river as well for a general understanding of the balance of nature and how different factors disrupt this balance.

## Methods:

The main data collection was performed through range of tests and observations of La Cuenca de Las Juntas in order to determine the possible uses for phytoremediation in the area. Seven different sites were visited and observed, all different in location, geographical features, and riparian buffer zone. The first site is located at a bridge and below the town and is called “High School Bridge” because the local high school is nearby. The second site is at Aguas Calientes, which means “hot waters” for the hot springs that empties into this creek. The third site is called Gloria for its neighborhood which is a poorer side of town. The fourth site is next to the Ecomuseo and is called “El Puente” for the rope bridge that spans it at that point. This site is higher up in La Cuenca (watershed) so it has more shade unlike the first three locations that are within the town itself. Second Crossing is the fifth site, upstream from the Ecomuseo. The sixth site is actually six and seven combined. La Toma is where the Aguas Claras and the Boston meet. I tested both rivers upstream from their merge. Further up the Aguas Claras, water is taken from the stream and purified for drinking water in Las Juntas. The Boston runs down from the Tres Hermanos mine and therefore, contains runoff from the mine.

At each site I collected soil samples to test for nitrogen, potassium (potash), phosphorous, and pH. I used the Rapitest © Soil Test Kit for this analysis. I also tested the water with an YSI Multimeter with an electronic probe for a number of readings: temperature, conductivity, salinity, dissolved oxygen, pH, and oxidation-reduction potential. I used the Streams Field Operations Manual put out by the EPA, to analyze the riparian buffer zone health of each site. Each zone was ranked, 1-20, 20 being the healthiest, based upon the thickness of the zone and the amount of human activity in the area. In order to get a comparison for the water conditions, two other sites were tested with the Multimeter; a small local hot spring along the road to Tres Hermanos and direct runoff mostly pumped out of the mine itself which ran down into the Boston. These gave comparisons for metal content and temperature and the factors influenced by these two elements.

In addition to tests and observations, interviews and conversations with the people of Las Juntas greatly increased my knowledge of the issues surrounding mining and the use of mercury within the town. Joaquin, a local conservationist and retired science professor, gave me his thoughts on the environmental issues faced by the town because of mercury. I toured the mines and a refining plant in the town where mercury was being used. Don Romain gave a tour of the mine ruins that were in use when the companies were still in control of production. He was also a good source of information. Three other sources of information and opinions were Don Oscar Castillo, head of the MINAE (Abangares Ministry of the Environment), Dee, our tour guide, and Jose Francisco Bogaltes (also goes by Kiko), a local special education teacher in the public high school.

**Results/Discussion:**

The first test I performed in the field was more of an observation, how healthy the stream was based on the thickness of the buffer zone and the amount of human activity affecting the stream. The EPA gave good standards for a healthy buffer zone and a ranking system of 1 through 20, 20 being the healthiest. As the sites were located further into the Cuenca, the buffer zone improved from a 3, at the High School Bridge, to 18 at Aguas Claras. Each time I measured the buffer zone in meters and judged the human activity from its proximity to a residential area or a series of roads and how much trash was seen in the vicinity. These two factors determined the health of the buffer zone (See Page for specifics).

High School Bridge, based on its location, was supposed to be the worst site as far as quality of the water, simply because it was below the town and would contain all of the runoff and the trash from there. The way they keep their streets clean is by redirecting water from the river through the gutters of the town and back into the river at the far end. This site would show the affects from that. The flow was a 2 (out of 5 which is fast), but as the tests were ending, it began to rain, so it would have picked up the flow slightly, possibly to a 3. Nevertheless, the turbidity was still greater than the rest of the sites at 3 (out of 5 being the cloudiest), reflecting the soil erosion from the town due to poor buffer zones. As the buffer zone rating gets higher, the turbidity lowers all the way to 0 (see Figure 3). The temperature, averaged in the sun and the shade, was 28.55°C. At this slightly elevated average, the dissolved oxygen reading was a slight surprise because the higher the temperature, the less likely the oxygen will remain dissolved in the water. It varied as well and averaged to 94.10% and 7.29 mg/L. The salinity was a little higher than the rest at 0.17 and the ORP was the highest at 170.3, but the pH was surprisingly basic at 7.80. The location below the town was reflected by low buffer health, the warmer temperature, higher conductivity which also reflects the buffer health because of erosion of metal

ions, the higher salinity, and the higher ORP. The buffer impact is very visible in the turbidity level, the salinity, the conductivity and the ORP, and all of these factors varied from the healthy buffer results at the Second Crossing, Aguas Claras, and the Boston.

Aguas Calientes was unique in its results because its source was a hot spring. The temperature of the water was slightly higher at the site, but it was averaged between sunlight and shade, just like the High School Bridge. As seen in Figure 1, the conductivity and salinity are high at 1.55 and 0.77 because the temperature is higher allowing for more dissolved substance in the water. The buffer zone is not much better than High School Bridge, so erosion is another factor. The dissolved oxygen, as a result of the temperature, is low in percentage, but close to average in mg/L.

The rest of the sites follow pretty close to the average without many defining traits besides improving buffer zone and healthy water conditions – lots of oxygen, steady temperature, very low turbidity and dissolved substance, and neutral pH. Hot spring and Tres Hermanos mine runoff have defining characteristics to be compared with the rest of the sites. Hot Spring has a very high temperature of 38.36°C and has no flow, so the oxygen is very low at 3.30% and the conductivity and salinity are very high at 6.09 and 3.24, showing the amount of dissolved particles in the water. The pH is also slightly lower. The Tres Hermanos mine data is a very good control for pH because it is very acidic, 3.03. As a result, the ORP is very high at 460 along with the conductivity, 1.277, and the turbidity was at 5. When this data was taken, it had been raining very hard and the runoff flow was pretty fast at 4. Both extra pieces of data are good for seeing relationships between tests and conditions.

On average, the soil tests remained pretty constant. The average pH of the soil was slightly basic at 7.75 (see Figure 2) and almost no nitrogen was found to be present. Phosphorous

varied from location to location. It seems to decrease as the buffer zone gets thicker and healthier and may reflect the use of the element by the flora; however, it is not consistent enough to judge for certain. Potash, or potassium, was in excess at almost every site.

The people that I had the pleasure of interviewing had the same general opinion about the mining and the mercury. The miners and those that ran the rastras had different opinions. Those I interviewed had seen the negative effects of mining and the mercury on the town. Joaquin talked about the acceleration of the extraction process now that the rastras have been put to use for the last 10 years. As a result, more mercury is being leached into the air and the contamination rate is sped up. He also explained what happened with the miner that died while we were there. They use machines to pump water out of the tunnels in the mine, but it's dangerous because it breaks down gasoline into carbon monoxide (CO). The deadly gas sinks to the bottom of the tunnels. This miner must have leaned down to fix something or to check the machine and he breathed in the gas. Those in the mining industry refuse to believe that it was carbon monoxide poisoning. They think it was heart failure since the miner was older in age and had problems before.

Don Castillo mentioned the law that made mercury illegal and sent the refining operations into family homes and backyards where the presence of the mercury was around the mother and the children of the family. It seems that the law only made the situation worse. Some tried to start a private cooperative that tried to put all the rastras in one place outside of the home, but the town did not react well to the privately owned company and it fell through.

According to Kiko, the people are very stubborn and the mining traditions are very strong in the town and in Abangares. As a teacher, he believes that the secret to the problem is educating the children before they can grow up and want to become miners like their fathers. Another big issue would be finding work for these miners in place of their present condition.

Normally, they pull their children from school after they learn to read, write, and do arithmetic because that is all they need to know to mine gold. Since he teaches Special Education, he has seen first hand some of the effects of mercury on the next generation of Las Juntas. He said (translated), “These kids can think, one can raise his hand, but he can’t write or use his fingers. The mercury blocks that pathway to reading and writing” (Kiko, 2005).

Returning to the problem at hand, is phytoremediation possible in this area and is it already in motion based on the conditions surrounding the riparian buffer zone. According to the results (see Figure 1), the conditions necessary for phytoremediation to be effective do not exist in Las Juntas. In order for the tree buffer to properly take up and store mercury, the soil needs to be acidic (Griffith, 2001), the nutrient amount needs to be low to avoid competition with the metal ions (Agneta, 2004), and there must be a higher concentration of metal ions present. The conditions are almost the opposite. The soil is on average alkaline basic (see Figure 2), there is a very high concentration of potash and a fairly good amount of phosphorous in the soil. There are probably more nutrients available because it is volcanic soil and rich enough to support the rainforest that grows in it.

The health of the tree buffers in the Cuenca is encouraging. The policy concerning tree buffers is strict, requiring 200 meters of trees along the river in the watershed and at least 50 meters thick within the town limits. In Las Juntas, the same law applies; however, the municipalidad decided that no tree buffer could be cut down within the town limits, whether it’s within 50 meters or not. Not all tree buffer zones are that healthy within the town, but the watershed and their source of water is very good quality and rather impressive. The health of the Cuenca buffer zones reduces erosion dramatically and keeps the metals in the soil from washing into the water.

According to the EPA's report on mercury to Congress, low pH and low levels of Dissolved Organic Carbon increase methylation of mercury and increase the amount of methylmercury in the aquatic environment (USGS, 2000). Therefore, if the people of Las Juntas hold to their high quality of water and keep the pH and organic carbon levels high, it is possible that the mercury levels will decrease overtime. It is also extremely important that they halt the use of mercury and turn to another method of production. Otherwise, mercury contamination will continue to build up and will turn into a greater problem and pose more threats to health than ever before. Unfortunately, mercury use will not end until the tradition ends, when it is forgotten.

Back in the 1930's, cyanide was ended because of the uprising of citizens who saw the problem with its use. They experienced the damaging health effects and knew they had to stop the contamination. Hopefully something similar can be found in the future of Las Juntas and a solution can be found not only for the miner's but for the ecosystem in its entirety.

Figure 3 The Cycle of Mercury in an Ecosystem

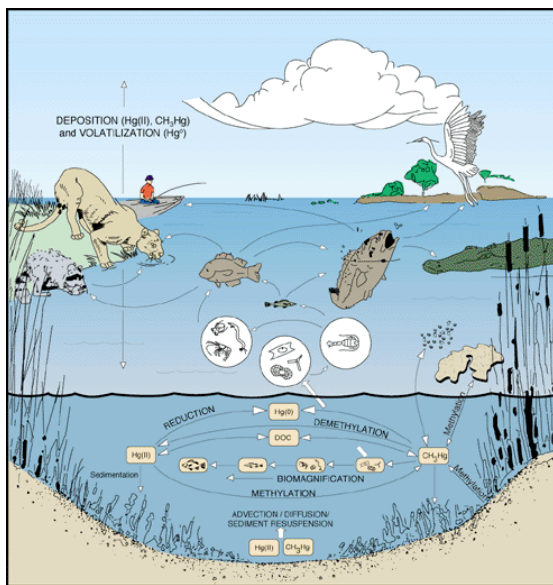


Figure 1 Field Tests of Nine Sites

Site Name		High School Bridge	Aguas Calientes	Gloria	El Puente	Second Crossing	Aguas Claras	Boston	Hot Spring	Tres Hermanos mine runoff
Buffer Health		3	4	8	10	18	18	18		
Water Tests	Flow (1 to 5 fast)	2	1.5	2	2	3	3	3	0	4
	pH	7.8	7.26	8.22	7.91	7.6	7.76	7.89	6.13	3.03
	Temperature °C	28.55°	30.98°	26.55°	24.48°	24.05°	24.48°	23.86°	38.36°	27.04°
	Conductivity	0.362	1.55	0.249	0.232	0.228	0.253	0.224	6.09	1.277
	ORP	170.3	93*	120.7	123.5	132.3	153.3	139.1	34	460
	Turb (1-5 cloudiest)	3	2	2	1	0	0	0	no flow	5
	DO %	94.10%	86.40%	99.50%	85.00%	97.80%	91.00%	97.30%	3.30%	93.10%
	oxygen mg/L	7.29 mg/L	6.43mg/L	7.98 mg/L	3.03 mg/L	8.22 mg/L	7.59 mg/L	8.19 mg/L	2.83 mg/L	7.37 mg/L
Salinity	0.17	0.77	0.12	0.11	0.11	0.12	0.11	3.24	0.63	
Soil Tests (0 to 4 surplus)	pH	7.5+	6.5 - 7	7.5++	6.5	7.5++	7.5+	7.5+		
	Nitrogen	0	0	0	0	0	0	2		
	Phosphorous	4	3 to 4	2	1 to 2	1	3 to 4	2		
	Potash (potassium)	4	4	4	4	3	4	4		

Figure 2 Averages of Field Tests

Type	Test Name	Test Average
Water	pH	7.78
	Temperature	26.24°
	Conductivity	0.443
	ORP	133.2
	Turbidity	1
	DO%	93.01%
	O2	6.96 mg/L
Soil	Salinity	0.22
	pH	7.75
	N	0
	P	2.5
	K	4

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