Feasibility Study for Land Use Options of the 6th Ring Curichi

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Executive Summary

The purpose of this report is to analyze various land use options for rehabilitating a degraded wetland (curichi). This project is for credit for the design team's senior design project that was based in Santa Cruz, Bolivia where the team traveled to gather the data necessary to evaluate the different options. The design options were analyzed based on seven criteria: economic feasibility, environmental and health impacts, social and political issues, appropriate technology and sustainability.

The 6th Ring Curichi is located in District 10 and in UVs 118, 118a, 124, and 125. This curichi was created about 50 years ago by the removal of clay for a brick making operation and is inundated with water almost 9 months of each year. Currently this curichi is used to dump a variety of residential and commercial wastes and there are several diseases and illnesses associated with the present state of this area. Regulations and laws that govern the disposal of wastes are not enforced.

The design team performed water quality tests and gathered data from site exploration and personal communications. This was done as preliminary research for feasible solution investigation. Based on the information gathered on location, the design team then proceeded to research the options presented by the client. Based on observations and input from local resident's and city officials, the design team feels that subsequent education programs should be incorporated with the implementation of all design options.

The land use options that were determined to be most feasible from the preliminary data were: cleaning the 6th Ring Curichi, developing the curichi into natural space and green space, constructing treatment wetlands, total and partial filling, constructing 6th Ring or walkways and taking no action. These options were then evaluated using a decision matrix. From the initial research and evaluation of each option it was determined that the most feasible and sustainable options were cleaning the curichi and developing natural and green space. Other options that are recommended include construction of treatment wetlands and building an elevated walkway. The options that did not meet the design team's criteria satisfactorily were total filing, constructing 6th Ring and taking no action.

In addition to the proposed larger land use options, there are many small-scale projects that could be implemented by local residents immediately. These include developing and implementing various educational programs, creating organized collection sites for waste, developing a community watch program to prevent unlawful dumping, developing individual and community based composting, initiating a recycling program, and developing a tire recycling or reuse program. A phase action plan was developed to assist residents and government officials with implementing the various options.

The design team recognizes the need for involving the community in cleaning and rehabilitating the curichi, because greater ownership is created within the community and can result in a greater level of innovation, creativity, participation, care and resourcing. Delegating responsibility to community groups and supporting their activities and decisions, can result in a high degree of initiative (Dunnett, 2002).

1. Introduction

1.1 International Senior Design

This report is one of two segments of an International Senior Design Project through Michigan Technological University's Civil and Environmental Engineering Department. The first portion of the class required students to travel to Santa Cruz, Bolivia for two weeks to gather data for their projects as well as help construct another room on the Walter Henry School (currently kindergarten through 10th grade). The second portion of the class is the design aspect that culminates in a report, presentation and poster.

The class is designed to mimic the work of a design/ build firm in industry, while also providing valuable class experience that integrates field construction with an engineering design project meant to benefit the people of Santa Cruz, Bolivia (Figure 1). This class encourages students to consider economic and health factors, social and societal impact, application of appropriate technology, constructability, and sustainability, safety, reliability, aesthetics, ethics, and environmental limitations of the developing world while applying engineering skills learned from their years at Michigan Tech (MTU CEE, 2005).

Figure 1: Map of Bolivia

This report will focus on a feasibility study for rehabilitating a curichi (wetland) located along the 6th Ring, and will serve as a model for rehabilitation of other curichis in the area. A map of Santa Cruz is shown below in Figure 2 with the 6th Ring highlighted.

Figure 2: Map of the city of Santa Cruz, Bolivia

1.2 Objectives

The purpose of this feasibility study is to determine the potential development options of the 6th Ring Curichi. Several options will be analyzed based the following criteria:

- Economic feasibility
- Environmental and health impacts
- Social and political issues
- Appropriate technology
- Sustainability

Appropriate technology is defined as "technology that can be made at an affordable price by ordinary people using local materials to do useful work in ways that do the least possible harm to both human society and the environment" (McGraw-Hill, 2005).

Sustainable development is defined as "the design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment" (Mihelcic et al., 2003).

1.3 Significance

Conducting an environmental evaluation and feasibility study is the necessary first step towards reclaiming this area. It is instrumental in building positive community growth. It is an effort to guide the residents affected by the curichi to a state of self empowerment, where they can, in effect, be the change they want to see. They can be involved in the decision making process and aid in the environmental improvement of the site. In having an involved role in the project they will see, first hand, the environmental improvement and experience the related improvements in their health and social standards.

2 Background

This feasibility study of the 6th Ring Curichi required a great deal of background information about the past and present history of the area and the curichis. This section covers the information that the design team was able to gather during the two week trip down in Santa Cruz, Bolivia. The following topics are discussed below: Santa Cruz, District 10, curichis, restored curichi, solid waste collection, health and environmental issues, social and political issues, education and recycling programs, and environmental regulations and zoning laws.

2.1 Santa Cruz

The city of Santa Cruz is located on the eastern plains of Bolivia. It is at an elevation of 415 m (1360 ft) with a sub-tropical climate. The average temperature is 23.8 degrees C (75 degrees F) and the average rainfall is 1540 mm (60 inches), based on a 21 year annual mean. The driest months are June through September, accounting for only 19% of annual total rainfall, and the wettest months are November through February, accounting for 49% of annual total (British Geological Survey Report (BGS et al., 1995). The Department of Santa Cruz is the regional center for the eastern lowlands and contains roughly 70% of Bolivia's population (BGS et al., 1995).

Santa Cruz is completely dependent on groundwater for their water supply. There are a number of water cooperatives that supply the city with water that typically is pumped from the deeper aquifer (BGS et al., 1995). Most of the private wells obtain their water from the upper aquifer. Groundwater flows from the southwestern corner of the city (beginning in the District 10 area) to the northeastern area of the city (BGS et al., 1997).

The Santa Cruz area has seen a period of rapid growth, with the population doubling in size between 1980 and 2001 to approximately 1,116,000 (The World Fact Book, 2005). This growth went largely unchecked and resulted in very little urban development planning. Many areas of the city are plagued with storm water drainage issues and improper rubbish disposal. 15-20% of the city's wastewater is removed for treatment using stabilization lagoons but the remaining wastewater is disposed by silage and storm water to the ground via soak ways, septic tanks and pit latrines (BGS et al., 1997). Due to this unplanned, high density development in Santa Cruz, contamination of surface and groundwater by domestic wastewater occurs through infiltration and surface run-off of improperly placed pit-latrines, especially during the rainy-season (Denny, 1997).

The city of Santa Cruz is set up in a radial pattern, subdivided into districts which are then further subdivided into grid-like blocks that represent neighborhoods (also known as UVs) as shown in Figure 3 below. There are a total of 12 districts and 330 UVs. A Mayor oversees the entire city and Sub-Mayors oversee each of the districts. This report will specifically analyze a curichi located in District 10 and UVs 118, 118A, 124 and 125. District 10 is one of two decentralized districts that have engineers, architects, etc who work exclusively in District 10.

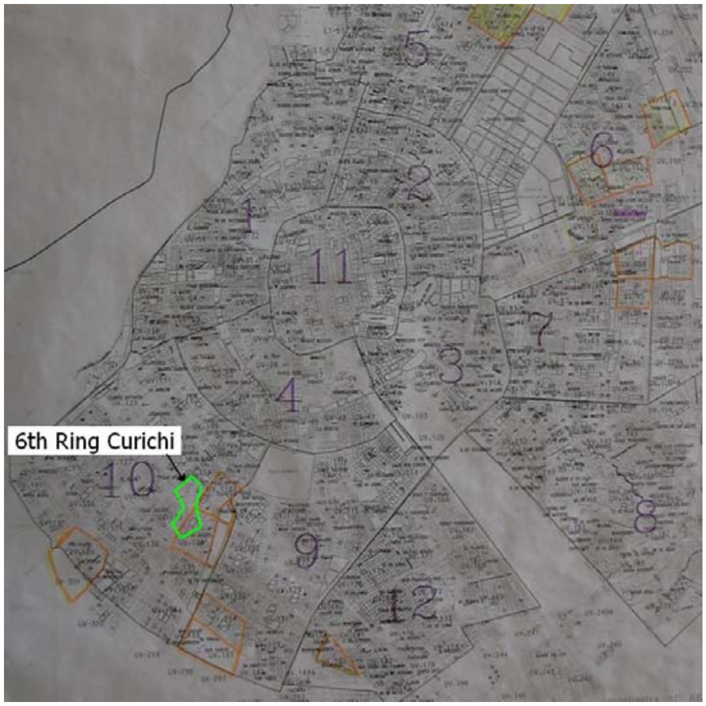

Figure 3: Map of the city of Santa Cruz with Districts marked

2.2 Barrio 30^0 de Agosto

The UVs are further divided up into barrios, which are the equivalent of large neighborhood blocks. Each barrio has a given name and these names are often celebrated days of the year (i.e. 26 de Septiembre or 26^{th} of September).

During the site investigation, a resident of the Barrio 30^0 de Agosto (30^{th} of August) was extremely interested in the rehabilitation of the 6^{th} Ring Curichi that is part of her neighborhood. The resident produced a report that had been conducted in the early months of 2005 (Avendaño, 2004). The report contained the following information that aided in the understanding of the socioeconomic status of the barrio, which is representative of the middle to lower class barrios of Santa Cruz as observed by the design team.

The 30^0 de Agosto sends 58% of children to area schools and the other 42% either attend school outside of the area or do not attend at all. The level of education included 43% completed primary education, 24% attended a public (non-paying) secondary education, 17% graduated from private (paying) secondary school, 11% had some University education, 4% technical skills and technical education (construction work, masonry, etc.), and 1% graduated from and received a University degree.

Other demographics were broken down by gender, where 53% of the population was male, and 47% were female. Breaking the population into age groups yielded the following results: 24% 0-10 yrs, 24% 10-18 yrs, and 52% 18 or older.

The report also contained a study on basic facilities and utilities. 27% of the population had no bathroom, 38% had the equivalent of pit toilets, and 38% had hygienic toilets. 19 % of the population had phones, while 81% either did not have a phone or did not have a need for one. 19% of the barrio did not benefit from street lights while 81% did. Only 7% of the population did not have access or the means of obtaining electricity. City water (supplied by the water cooperatives) was not available to 8% of the population, while 92% reported use of city water.

2.3 Solid Waste Collection

The current landfill used by the city of Santa Cruz is located 14 km (9 miles) outside of the city on the southeast side. It is 250 ha (620 acres) in size and about 30 years old. The only items not accepted at the landfill are vehicles, trees, building waste and biological waste. Currently private companies handle the biological waste disposal; however, the city has plans to build a site to handle this waste in the future (Villagrán, 2005). The city collects all the waste from the 5th ring out and private companies collect from the 5th ring into the center of the city.

Solid waste collection is billed with the municipal water, but the rate is charged based on the amount of electricity used by each home. Therefore, each residence that has electricity should have waste collection (Villagrán, 2005). Waste is collected in a bin as shown in Figure 4, that each household is required to supply themselves. The frequency of waste collection depends on the area of the city, but generally waste is collected several times a week in order to prevent additional waste from being discarded throughout the city. The system appears insufficient based on the amount of discarded waste seen throughout the city. From a survey of various income groups conducted in Jamaica, another developing country, it was determined that 10-20% of all household waste ends up as litter (Pendley, 2005). Many residents do not have a waste bin because they are nearby vacant land or a curichi where they dump their wastes. This uncontrolled disposal of waste can result in serious health threats for the residents as well as the environment (Zurbrugg et al., 2005).

Fires that are associated with uncontrolled disposal and accumulation of tires are detrimental to both human health and the environment (Reschner, 2004). The city has started to collect tires prior to the celebration of “the coldest day of the year” where hundreds of fires are started throughout the city. 2004 was the first year that any attempt was made to remove tires before they were used in these fires, and over 3,000 tires were collected in one day (Landivar, 2005).

Figure 4: Particular style of trash bin used in the Santa Cruz area

2.4 Curichis

The southern half of Santa Cruz has scattered patchy and thin coverage of clayey silt overlaying sediment (BGS et al., 1995). This clay has, and still is, being removed for brick-making (tejerias). This enterprise creates depressions in the landscape and over the years many of these areas have become wetland type habitats (curichis). Presently, there are many of these curichis around the city and they are generally associated with a negative connotation. Most locals do not assign much value to these curichis and do what they feel is a civic duty to help fill them in with construction material, household waste, and almost any other type of waste. Figure 5 and Figure 6 illustrate the different wastes and quantities discarded in curichis around District 10 (Ortiz et al., 2005). The amount of organic waste found in curichis was lower than the design team had expected (based on the findings from Ortiz et al., organic waste comprises less than 40% of the total waste in curichis). A study from a city in Jamaica (population < 600,000) found that 40-60% of the total waste is organic waste (Pendley, 2005). Several residents mentioned that discarding household waste in curichis or vacant land has been a common practice in this area; however, the current, often non-biodegradable, waste stream is different than the organic-based, decomposable waste thrown out 20 or 30 years ago.

Some of these non-biodegradable wastes are collected from the curichis and either reused or sold by local residents, beggars, homeless individuals, etc. Mostly re-salvageable items such as bricks, electric parts, and items that can be sold to recycling companies are removed (e.g. plastic, glass, paper and aluminum cans).

Figure 5: Typical material discarded in curichis around the Santa Cruz area (from front to back: motor oil cans, organic waste, and construction material)

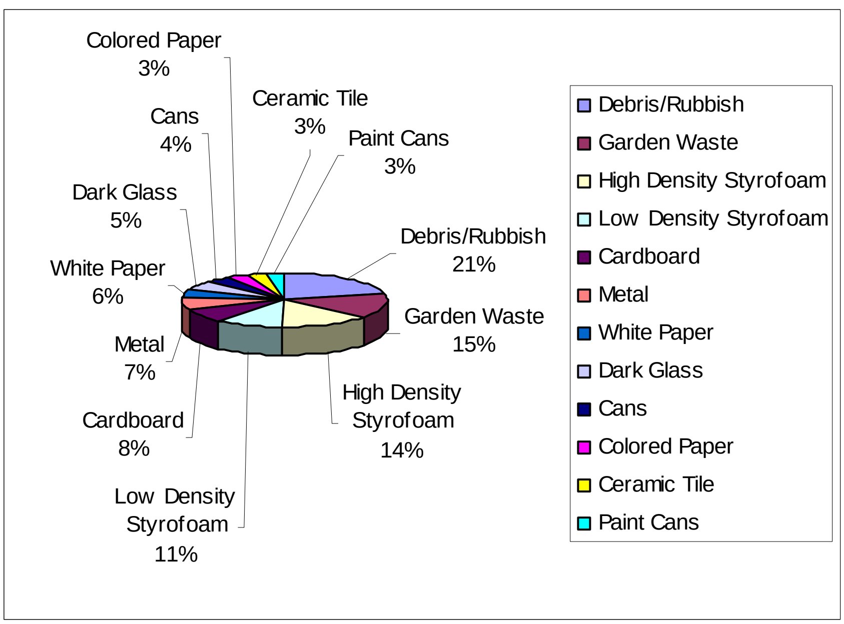

Figure 6: Breakdown of waste (by weight) components for a curichi in District 10 near the 26th of September barrio (Ortiz et al., 2005)

The curichi that is being analyzed for this study is located along the 6th Ring in District 10 and was formed about 50 years ago from these ex-tejerias (Marta, 2005). This curichi has a perimeter of about 42.6 m (26.5 miles), covers roughly an area of 20 ha (50 ac) and a depth between 2.0-2.2 m (6-8 ft). These dimensions were determined by actual measurement (depth) and by estimated measurements from scaled city maps. Based on information gathered from local residents, this curichi is either partially or fully inundated for roughly nine months each year (September through May). The surrounding land use is primarily residential with the bulk being private homes. Many of the homes surrounding the curichi share loose property boundaries with the curchi itself. In close proximity are schools, shops and other businesses, and recreational spaces.

The majority of vegetation found in the 6th Ring Curichi is invasive, non-native species (Carrasco, 2005). Table 6 located in Appendix 3 lists the current vegetation found in these curichis. In the present state of this curichi, no wildlife was observed and very few species of birds were seen. Several domestic animals were noted and those include cattle, pigs, dogs, cats, chickens, geese, and goats. There have been electric anguilas (eels) found in the curichi waters and some residents mentioned fishing in this curichi.

2.5 Restored Curichi

Located on the west side of Santa Cruz near the Rio Pirai River, there is a protected curichi/forest area that was restored because the nearby residents demanded that some action be taken to clean up the area. It was noted that initially not all of the residents wanted this curichi restored. Some were concerned about where they would discard their waste if they were no longer allowed to use the curichi (Villagrán, 2005). The Gabriel Mureno University assisted with the restoration process and still continues to conduct experiments and studies in this area (Carrasco, 2005). Table 7 located in Appendix 3 lists the vegetation recommended for restored areas. The topography of the restored curichi appeared to be similar to the 6th Ring, and it was also noted that controlled burns are still permitted. The biggest difference between the restored curichi and the rest of the curichis in the city was the vegetation and lack of rubbish everywhere.

2.6 Health and Environmental Issues

The continuous and rapid urban growth of developing countries, in this case Santa Cruz, has resulted in a lack of urban environmental management which is threatening the health of the citizens and overall environmental quality (Zurbrugg, 2002). Many of the illnesses and diseases experienced by the residents are associated with the curichis. Based on information given by the local residents the following diseases and illnesses were mentioned as being directly associated with the curichi:

- Dengue Fever
- Yellow Fever
- Malaria
- Skin diseases (caused by fungus and bacteria)
- Parasites
- Diarrhea
- Eye irritations (caused by dust and smoke from fires)

Other illnesses and diseases identified by the residents include:

- Problems with teeth
- Tuberculosis
- Bronchitis
- Rabies

- Allergies
- Asthma

It is also a common practice for residents to dump their waste into the curichis and then burn it, regardless of what might be in the waste. Often times the waste to be burned will contain plastics, metals, and rubber. Throughout the 6th Ring Curichi it was noted that on each site visit, there were fires burning; sometimes only one, but up to six fires were seen on one given occasion. Children were also seen playing in and around the fires, as shown in Figure 7 below. Many of the residents acknowledge that these fires are probably causing their asthma, eye problems, and allergies, but they do nothing to prevent the fires from being started.

Figure 7: Children playing near a tire fire in the 6th Ring Curichi

There is little or no attempt made to stop people from dumping any kind of waste in these curichis. The most disturbing discoveries made by residents living around the 6th Ring curichi included sacks of dead dogs, human fetuses, left over cow parts from a butcher (Figure 8), hypodermic needles, and large quantities of motor oil cans. Other than construction materials and garden wastes, none of the residents were pleased about the other types of waste that are dumped in these areas.

Figure 8: Cow hoofs discarded in 6th Ring Curichi by local butchers

The residents near the 6th Ring Curichi do organize “clean-up days.” However, based on observations and conversations with local residents, they “clean” the curichi by cutting down and burning the vegetation (Figure 9). The design team was informed that some actual removal of waste occurs, but the main point of the “cleaning” sessions is to eliminate hiding places for robbers that stay there at night. About 30% of the homes near curichis in Districts 5, 6, 7, 9, 10 and 12 have been broken into by these robbers (Ortiz, 2005).

Figure 9: A resident showing the design team how they ‘cleaned’ the tree to eliminate hiding spots for robbers

A majority of the residents that were spoken to saw very few benefits to living near the curichi. As previously mentioned, there are some serious health and safety issues associated with these areas. Many residents attributed the stagnant, polluted water in the 6th Ring curichi as a source for many of the diseases they suffer from (Barrio 30^0 de Agosto, 2005). A number of the diseases are transmitted by mosquitoes that find these waters to be a favorable place to breed. However, not all curichis or water bodies in Santa Cruz are breeding grounds for mosquitoes (refer to 'Controlling mosquitoes through healthy, functioning wetlands' located in Section 4.2, page 19). There is a retention pond/wetland area near the center of the city that does not facilitate the breeding of mosquitoes and there are also fewer instances of mosquito transmitted diseases (Villagrán, 2005).

2.7 Social and Political Issues

The political structure of Santa Cruz has a Mayor that oversees the entire city, and then Sub-Mayors oversee each of the 12 Districts. There are also engineers, architects, etc who work for the entire city, and those who work specifically in two districts of the city (District 10 being one of the decentralized districts). The Barrio's have their own executive branches and have a lot of participation by the residents. There are typically weekly or monthly meetings, depending on what is happening in each barrio. The Presidents of each barrio also meet to address issues that affect the entire district.

The current Sub-Mayor of District 10 is Lic. Janet Carmona. Her approach to dealing with problems within District 10 is to tackle them step-by-step, using community input at each step. This has not always been the approach and many promised projects in the past were either never started or once started, were never completed (Barrio 30^0 de Agosto, 2005).

Based on a community meeting attended for the Barrio 30^0 de Agosto, some of these unresolved issues include insufficient police and street lights, robbers in the curichis, the curichis themselves, and green spaces for children. While many of these issues need to be addressed by the government, some can and should be addressed by the residents. Residents near the 6th Ring Curichi have already begun addressing one of these issues involving the robbers and "cleaning" the curichi in order to remove their hiding places. It is encouraging to see residents from different barrios working together for a common cause.

Government officials and local residents have voiced their concern about the current state of the curichis and the health problems they pose. However, when the residents were asked why waste was dumped into the curichi they mentioned that it was people from outside the area that were doing the dumping (Barrio 30^0 de Agosto, 2005). It was difficult to find anyone who admitted to personally dumping or burning their waste in the curichi.

Residents of the Barrio 30^0 de Agosto did mention that once something was done with the 6th Ring Curichi they would then have a vested interest and would make an effort to stop others from illegally dumping their waste and burning it. An underlying feeling given by most residents was that the best way to deal with these areas was to fill them in and be rid of them. Quite the opposite view was given by government officials and President's from other barrios who expressed an interest in restoring these areas to natural or green spaces.

2.8 Education and Recycling Program

The city has begun implementing a recycling pilot program through the work of Ana Beatriz Landivar, a civil engineering student from the Santa Cruz area whose thesis is on recycling. The information presented on this program was gathered from a meeting with Ing. Landivar. This program is similar to a program currently in place in Brazil and Ing. Landivar received help from the individual responsible for creating the original community based recycling program. This program will be started in UV 30 and UV 101, located in Districts 1 and 8 respectively, and once these programs are successful and self-sustaining, the program will be expanded one UV at a time. UV 30 was chosen because it has all the amenities that could possibly be located in the other UVs (e.g. schools, markets, green spaces, etc) and is a medium-lower class area with an average waste generation rate. UV 101 was chosen because it is a lower class area and produces a below average amount of waste.

The program is based on developing a social network within each UV. The program coordinators have gone into each UV and met with the residents to discuss some of the details of the program. They handed out brochures and helped educate people on what is recyclable and how to separate these items from their trash. Each community was also given the opportunity to determine which day of the week would work best for them to have their recyclables collected. The city will provide 3 government trainers to each UV to train beggars, homeless individuals, and handicapped citizens to collect the community's recyclable items, which many already collect independently. These individuals are selected to help rehabilitate them back into society as well compensate them for services that they typically are already performing. The collectors are given training, uniforms and a collector cart while working, and all of this is free of charge to them. The collectors are paid a set amount for collecting these items and are offered higher wages if they pre-separate their items.

The neighbors are involved by sorting their recyclables for collection and they are also asked to monitor and evaluate the collectors to ensure that they are working and remaining sober. The biggest problem with the Brazil program was workers not showing up for work.

This direct contact and involvement within the community has helped integrate the program into the society. They require the residents to sign pacts stating that they will no longer dump their rubbish out into the community because that would take away work and money from the collectors. The program coordinators feel that a majority of households will participate, although some might decide to bring in their own recyclables for compensation. The progress of this program will be visually evaluated by observing whether there is a reduction of waste found in the streets, canals and other previously used dumping areas.

The timeline for the program is flexible and depends on how fast the collectors are able to work without supervision or assistance. The following items can be recycled at this time:

- Aluminum cans
- Plastic (#1-7)
- Newsprint
- Office paper
- Glass

Paper makes up the largest component of solid waste produced in the city (Landivar, 2005). Yet the current paper recycling company in Santa Cruz imports paper from Peru in order to make their process profitable. At present, Santa Cruz is collecting only a fraction of the paper that is used throughout the city. From this fact alone, there is potential for a successful recycling program (Landivar, 2005).

The amount of recyclable items will be expanded as more companies are willing or capable to recycle them. For items that currently cannot be recycled, other alternatives to disposal are being considered.

An example would be tires which are generally discarded throughout the city. However, in Brazil old tires are used to make roads and a couple artisans in Santa Cruz use tires for their art works (Landivar, 2005).

2.9 Environmental Regulations and Zoning Laws

The zoning laws for developed areas within Santa Cruz are based on the needs or wants of each barrio (Villagrán, 2005). Every so often, city officials will ask for a meeting with the barrios in their district and see what they are in need of (e.g. green space, housing, schools, etc). As long as the majority of the residents are in agreement and there is funding, the city will work to develop the area based on their requests (Villagrán, 2005).

The city of Santa Cruz has laws and regulations that direct the conduct of citizens in public places, green areas, and for waste collection. These regulations are based on the translation from Parada et al., 2001 and can be found in Table 8 located in Appendix 4. Some of these laws include no abandoning solid waste in green spaces; no burning in public areas without permission; no abandoning animals or animal waste; no dumping of items that would have a negative effect on workers or general human health (i.e. decomposable, infectious, toxic, corrosive or corrosive wastes); no dumping metal, wood or glass waste, no building or construction waste; and no dumping of garden waste.

3 Methods and Procedure

The data used for the feasibility study of the 6th Ring Curichi was gathered from field work (on site and off site) while in Santa Cruz. The work done on site involved performing water quality tests, photographing the area and vegetation, and measuring an average depth of the curichi. The off site work involved meetings with community members, city officials, and other government workers as well as performing water microbiology tests on the curichi water. Back in the United States the design portion of the study was completed using the information gathered from the field work.

3.1 Field Work

3.1.1 On Site

Water Quality

The onsite investigations centered upon scientific sampling and data gathering. Water quality tests were conducted to determine, from various locations within the Curichi, which of the following chemicals were present: pH, phosphate, nitrate and iron levels (Figure 10). These results are listed in Table 5 found in Appendix 2. These chemicals were tested using the following methods.

Figure 10: Design team collecting and testing 6th Ring Curichi water

Two samples of water were tested for *Escherichia coli* (*E. coli*) and total coliform using 3M™ Petrifilm™ *E. coli*/Coliform Count Plates. These tests were performed in a laboratory at Saguapac, a water cooperative in Santa Cruz. Using a pipette, one millimeter of sample water is transferred to the center of the plate and then the plastic cover is gently replaced on top, being careful not allow air pockets to form between the plate and the cover. The samples were then placed in an incubator set at 35 degrees C for 24 hours. Results listed in Figure 17 located in Appendix 2.

Filling part or all of the curichi was a possible development option, so it was necessary to get a general idea of the average depth. A survey of the area was not performed due to the large area that the curichi spanned and time constraints. Thus a surveying tape, a plumb bob, a prism pole and tape measure were used to find an average depth over a series of several points of measurement. The process of measurement was performed several times at several different locations in the Curichi to obtain a number for the average depth. The style of measurement was unorthodox and truly engineered to obtain the required results.

Digital photographs were taken of the curichi to document the layout and topography, vegetation, types of waste and general quantities, activities taking place within and around the curichi, and water source. It was important to document the vegetation in the curichi in order to determine if the area was in fact a functioning wetland. The photographs were taken in order to have botanists at either Michigan Technological University or Gabriel Mureno University in Santa Cruz, identify the different vegetation at a later date.

The final scientific data gathering performed was consulting and working with a biologist from Santa Cruz. This biologist was able to aide in the identification, classification and categorization of some of the species of vegetation that resides in the Curichi by visual identification and the help of a list of plants from another report.

3.1.2 Off Site

A large portion of the data gathering came from meetings, which it learned early on that this was the fastest and best way to gather reports and set up other meetings. It was crucial to gather information from community members, city officials, engineers, and university students about the curichis, social and political issues, health issues, environmental laws and regulations, and any other pertinent information that would be valuable for this report. The yield from a single meeting can be monumental with only time spent discussing pressing issues of the Curichi. Table 1 listed below is an organized summary of the meetings that were attended while in Bolivia.

Table 1: Description of meetings, detailing the people present, the purpose and the information gathered

Meeting Schedule and Comments			
Person/Group	Group/ Personal Description	Purpose	Information Obtained
Martha Peréz	Resident of 30th of Agosto who is concerned about the state of the Curichi and a contact for further meetings	Preliminary meeting to investigate her enthusiasm and concern for the 6th Ring Curichi.	Obtained a social study of her barrio (neighborhood) and a meeting with the Dirigente of District 10
Dirigente	Elected leaders of each neighborhood in charge of meeting with the Sub Alcaldeza and serving their constituents	Meeting with the leaders of the neighborhoods in District 10 to discuss problems and possible solutions to the Curichi problem	Awareness of the diseases and general concerns of the people living around the Curichi as well as some ideas of what people would like done
Martha Peréz/ Neighbors	Neighbors of Martha and people concerned with the 6th Ring Curichi	Discuss problems of the 6th Ring Curichi	Awareness of the diseases and general concerns of the people living around the 6th Ring Curichi, as well as some ideas of what people would like done with the curichi
Martha Peréz/ Neighbors/ Sub Alcaldeza	Neighbors of the entire Barrio 30th de Agosto and the Sub Mayor (Sub Alcaldeza), Lic. Janet Carmona, who is a direct link to the Mayor of Santa Cruz	Barrio meeting where problems were identified to Sub Alcaldeza, and discussion on how the 6th Ring Curichi report could potentially help or assist them with the curichi problems	Sub Alcaldeza recognized desire of the residents to assist in a changing on the Curichi
Ing. Rufino Arano	Ex-Sub Alcalde of District 10 and a Civil Engineer	Discuss direction of project and history of area and curichis	Ing. Rufino provided contact information of M.Sc. Mariflor Aguilar and Martha Peréz as well helped gather background information about the area and the curichis
M.Sc. Mariflor Aguilar	M.Sc. Aguilar helped author a scientific study of Curichis in District 10	Discuss information regarding curichis in District 10 and what was covered in the report	Report was obtained as well as other significant information about the 6th Ring Curichi
Ing. Ana Beatriz Landivar	Civil Engineering student running a recycling pilot program in Santa Cruz	To investigate her program and its objectives	Found out about her program and got her contact information for further contact as well as obtained her help with our program
Lic. David Carrasco	Biologist working for the city of Santa Cruz	Assist in plant identification for existing species in the 6th Ring Curichi	Identified several species of plants, and their status regarding invasive or noninvasive species
Carmelo Villágran	Soild Waste Director for Santa Cruz	Discuss status of solid waste collection and management in the city as well as ideas for Curichi improvement	Gave information about solid waste management and access to photographs of maps of the city as well as ideas for Curichi improvement and management

3.2 Design Work

The final aspect of the data gathering and report writing comes from the two months following the trip down to Santa Cruz. Mark Anderson, a professional civil engineer, with the U.S. Army Corps of Engineers assisted during the design portion of the project as well as the report writing process with his professional advice and assistance.

4 Options and Analysis of Land Use

A number of options for land use for the 6th Ring Curichi were studied. These options were chosen based on information gathered while in Santa Cruz and include the following viable uses:

- Cleaning the 6th Ring Curichi
- Natural Space
- Green Space
- Treatment/Constructed Wetland
- Total or Partial Fill of 6th Ring Curichi
- Road/Walkway Options for the 6th Ring Curichi
- No Action Alternative
- Summary of Land Use Options

Before any of these options can be analyzed for future use, the design team believes that the 6th Ring Curichi must have all of the waste removed from it. Information regarding cleaning or reclaiming the curichi can be found in Section 4.1 below.

These land use options were analyzed using several criteria. These include how each option impacts the area socially, politically, environmentally, the economic and health factors, the application of appropriate technology, constructability and sustainability, and aesthetics.

4.1 Cleaning the 6th Ring Curichi

Before beginning any rehabilitation of the curichi or surrounding areas, cleaning must be performed. The first step is identifying the status of the area including:

- Water Quality assessment/Water table/ level depth
- Amount of trash
- Classification of trash

Water Quality assessment/Water table/ level depth

Presence of chemicals in water quality tests can signify presence of contaminating substances. If certain chemicals and bacteria are found, further water testing may be required before the removal process (Hydra 2004).

Determining the water level depth in a land area, especially in wetlands, is important in understanding where existing water comes from and why it is retained. In determining the water table depth, it is easier to pinpoint where water contaminating substances are (Heise, 2001 ROUGE RIVER).

The goal of performing these studies is to determine the presence of unseen contamination in the curichi. The cleaning process needs to include removing all contaminants contributing to the current state of the curichi.

The water of the curichi was tested for various chemicals and bacteria. Specifically, tests were conducted to detect the presence of phosphates, nitrates, iron and pH. In general, the chemical tests showed that the water had normal levels for all tests except phosphate which was slightly higher than the acceptable value (results can be found in Table 5 located in Appendix 2). The bacterial tests, performed at Saguapac, revealed the presence of numerous colonies of both total coliform and *E. coli* and more information can be found in Appendix 2. The design team believes that if the curichi is cleaned and maintained, water quality will improve.

Measurements were taken to determine curichi depth. The design team gathered data in a deeper area that was mentioned by local residents to be filled with water during the rainy period of the year. The average curichi depth was measured to be between 2.0 - 2.2 m (6.5 - 7.2 ft).

Amount of Waste

Determining the quantity and type of waste present in a reclaimable wetland can be difficult. If it is impossible to determine a volume of waste, a basic waste classification must be done (Heise, 2001). Although determining waste volumes in the curichi would be possible it would be very time consuming for the benefits it would yield. This arises from the large amount of waste that exists over the entire area of the curichi. Thus, classification is important because when clean up begins, the classification will determine the intensiveness of the clean up effort. This classification can help identify what materials can be collected for reuse or recycling by residents and what wastes will require machinery and government assistance. Collecting recyclable materials and selling them to recycling companies may help offset the financial costs of clean up.

Because cleanup can be a labor intensive process, cleanup drives should be organized by the community which includes determining areas to focus clean up efforts on each clean up session. Residents should lead the clean up effort, and machinery could be used to remove old cars and other larger objects. By uniting communities to clean up and maintain the curichi the community can take ownership of the project and be proud of what they accomplish.

The large size of the curichi will make this task more difficult, but with some planning and participation by the surrounding communities it should be a feasible project. Also, there may be larger and more problematic items that will need to be disposed of by private waste collection companies.

Putting fences or blockades in areas that are easily accessible by vehicles could help prevent additional materials from being dumped. Signs could also be put up at these areas to inform unlawful dumpers about the laws against unlawful dumping and a list of collection sites where they can take their waste.

Cleaning the curichi is the first phase in rehabilitation regardless of which design option or options are chosen. It is essential to combine clean up efforts will education programs to ensure that clean up efforts are maintained and waste is disposed of properly. The design team believes that if the recommended clean up steps are followed, which can be found in Section 6 (pages 36-38), the curichi will not only be cleaned but a recycling program may be started, diseases will be less likely to be transmitted from the curichi, and quality of life can be increased. Involving the residents surrounding the curichi may empower them to take more ownership of the project.

4.2 Natural Space

Topics discussed in this section:

- Description of Natural Space and Wetlands
- Functions and Values of Wetland
- Importance of Hydrology in Wetlands
- Curichi Restoration
- Controlling Mosquitoes through Healthy, Functioning Wetlands
- Steps for Protecting Residents and Communities from Mosquitoes

Description of Natural Space and Wetlands

In the context of this report, natural space refers to undeveloped land that supports native vegetation, provides wildlife habitat, as well as recreational use for humans. The particular type of natural space that will be discussed in this section is a wetland. There are many kinds of wetlands (bogs, floodplains, marshes, peatlands, swamps, wet prairies, etc), and there classification partially depends on where they are located in the landscape (Gopal, 1999). Many of the curichis in Santa Cruz can be described as palustrine wetlands (i.e. marshes and swamps) which are located in shallow depressions.

Functions and Values of Wetlands

The value of wetlands can be described in terms of worth and usefulness to humans as well as their ecological importance (Richardson, 1995). These perceived values come directly from the ecological functions found within the wetlands and in terms of human standards, they include (Mitsch, 2000):

- Natural or open spaces
- Recreational areas
- Erosion control
- Crop and food production
- Education and research opportunities
- Water supply, improved water quality

Values and functions of wetlands in terms of ecological importance include (Mitsch, 2000):

- Aquifer recharge
- Water quality
- Intercept storm runoff and water storage
- Nutrient cycling and storage (nutrient transformation)
- Highly productive

- Wildlife habitat (especially for threatened or endangered species)
- Global carbon storage

It is important to recognize that wetlands are not all similar in their function (Gopal, 1999). When restoring or creating wetland habitat it is important to remember that all wetlands cannot perform the same functions and the functions to be preformed by the wetland need to be identified early on in the design phase.

Importance of Hydrology in Wetlands

Hydrology (how water interacts with the earth's surface, the soil, and the atmosphere) is a major regulator for each wetland's structure and function. The hydrological pattern of a wetland is defined by the frequency, timing, depth and duration of flooding as well as the seasonal amplitude of the water level (Gopal, 1999). In natural wetlands, especially in tropical regions, there are typically large water level changes and the vegetation within these systems is adapted to these hydrologic regimes (Gopal, 1999).

Curichi Restoration

There are three main goals to achieving restoration of an ecosystem: structural/compositional replication, functional success, and durability (Higgs, 1997). A restored ecosystem must resemble the structure and composition of the desired natural ecosystem. This replication will not be a fast process, but these ecosystems did not get into their degraded state over night, therefore, the process of restoring an ecosystem can often time-consuming.

Functional success is directly linked to compositional and structural replication and is usually dependent on management (Higgs, 1997). The restored ecosystem must mimic the functions of the system is designed to reproduce. Biogeochemical processes must operate normally according to the expectations of the specific ecosystem (e.g. flushing rates, ion exchanges, decomposition).

The durability of restored ecosystems is an issue of growing importance for those involved in the restoration process (Higgs, 997). This is because a higher than expected number of restored sites have either not met the restoration goals or have required more management than was initially expected. For a restoration to be successful, it must hold up over a significant period of time, significant is defined relative to the type of ecosystem. Ecosystems are dynamic complicated living systems and notoriously difficult to predict and regulate effectively.

Based on the design team's brief assessment of the 6th Ring Curichi it did not appear to be a functional wetland due to the types of vegetation and soil and the quantities of waste present. It would be important to find and analyze a natural or functional wetland in the Santa Cruz area and use it as a model for restoration.

Controlling Mosquitoes through Healthy, Functioning Wetlands

Contrary to popular belief, healthy, functioning wetlands can actually reduce mosquito populations (IDNR, 2005). Wetland restoration decreases mosquito populations in two ways. The first is by providing proper habitat for the natural predators of mosquitoes and the other is by preventing or reducing flooding in areas that are not normally wet and support mosquitoes, but not their predators.

Mosquitoes have a very short life cycle (average of 4-30 days), but their eggs can remain dormant for more than a year, and will hatch when flooded with water. Therefore, if a wetland is drained, after a rain event there may still be enough water to breed mosquitoes. And the drained area may actually produce more mosquitoes than it did when it was a wetland because the standing water does not support beneficial predators that feed on mosquitoes (IDNR, 2005). Most any kind of standing water makes a good breeding site for mosquitoes (e.g. old tires, containers that catch rainfall, low spots where water pools). A healthy wetland however, does provide habitat for many animals and insects that are natural predators of mosquitoes and these predators keep mosquito populations low. Certain birds, frogs, fish, bats and insects live in healthy wetlands and feed on mosquito larvae and/or adults. Certain bird and bat species can be encouraged to live in the area by constructing nesting boxes (Mitsch, 2000).

Steps for Protecting Residents and Communities from Mosquitoes (U.S. EPA, 2004):

1. Eliminate stagnant water

   Limit the number of places available for mosquitoes to lay their eggs by eliminating standing water sources from around your home (e.g., tires, garden pots and bird baths).

2. Protect wetlands from pollution

   Contaminated water attracts mosquitoes. Implement ways to prevent the runoff from human and animal waste, agriculture, and roads into wetlands. Mosquito populations are held in check in healthy wetlands.

3. Maintain Stormwater Systems

   Ensure that stormwater catchments and constructed wetlands are properly designed and maintained.

4. Install Screens

   Install or repair screens on doors and windows so that mosquitoes cannot get indoors.

4.3 Green Space

Topics covered in this section include:

- Description and Types of Green Spaces
- Community Involvement and Values of Green Space
- Technical Considerations
- Local Concerns

Description and Types of Green Spaces

Green spaces are areas of undeveloped land that are separated or surrounded by residential or industrial areas and are used for recreational enjoyment (Dictionary.com, 2005). Urban green spaces play a key role in improving the liveability of towns and cities (Levent, 2004). The quality of green spaces helps to define the identity of towns and cities, and can enhance their attractiveness for living, working, and tourism.

Dunnett et al. performed a study on green spaces and found that people wanted a variety of land uses (i.e. natural areas, open spaces, parks, etc), activities (for younger children, teenagers and adults), and upkeep of facilities. In regards to natural and open areas, people enjoyed trails, diverse vegetation, wildlife, birds, and water (i.e. ponds, streams, etc).

Community Involvement and Values of Green Space

Community involvement in urban parks and green spaces can lead to greater ownership in the project, increased use, enhancement of quality and richness of experience and ensuring that facilities are suited to local needs. It is also important to identify opportunities for both building and supporting partnerships for managing open space, especially where businesses and local communities are involved (Dunnett, 2002). Along with the social contributions they also have many contributions to economic life, to the ecological and planning system, and as a whole to the urban quality of life (Levent, 2004).

Social Contribution
Particular types of green space can offer a larger diversity of land uses. They enhance cultural life by providing venues for local festivals, civic celebrations and theatrical performances. Urban green spaces provide safe play space for children, contribute to children's physical, mental and social development, and play an important role in the basic education of school children with regard to the environment and nature.

City Planning
Well-designed networks of green spaces help to encourage people to travel safely by foot or by bicycle for recreation or commuting and well-designed urban green spaces provide a barrier to noise and can function as a visual screen.

Economics
Their presence can create an increase in the economic value of an area and provide new jobs.

Ecological Contribution
Urban green spaces moderate the impact of human activities (e.g. absorbing pollutants from vehicles and industry as well as releasing oxygen), contribute to the maintenance of a healthy urban environment by providing clean air, water and soil, preserve local natural and cultural heritage by providing habitats for a diversity of urban wildlife and conserve a diversity of urban resources.

Technical Considerations

Among the needs for planning and managing urban green spaces the following factors are important (Levent, 2004):

- Urban green and open space planning policies need to be determined locally in order to satisfy local needs and to assist in meeting community and city objectives.
- More integrated approaches and the active involvement of the community for the development and management of green spaces are necessary.

- Planning authorities should develop their own local standards for green spaces not only in new developments but also in non-housing developments, such as industry and business.
- Quantity, quality and accessibility of green spaces are important to improving the quality of life in cities.

Funding green and open space developments can be a major barrier to their creation and management. Self-management by local communities is a valuable means to overcoming some of the financial barriers. There is a reduced financial and administration cost to the local authority in the long-term involved in transfer of a park to a self-managing group or organization (Dunnett, 2002). The main advantages come from the benefits associated with a high degree of community involvement. There is also potential for creating a city-wide partnership for parks and green space, not just increase use and activity in a single park or green space, but also to raise the level and quality of open space and parks in the entire city, through neighborhood organizations and park partnerships.

Local Concerns

Based on conversations with local residents, several did not see many benefits in having or preserving green spaces because they were not maintained by the city or by the community. Maintaining the upkeep of green spaces, natural spaces and in general, public areas, can be achieved by educating residents and business owners about proper waste disposal and integrating local communities in these projects. Giving residents and local businesses some ownership of these projects will help in achieving some of these goals.

Some residents also objected to spending limited funds on creating more green spaces because they did not have children and felt these areas were of no use to them. As mentioned above, there are many different types of green space and by creating and maintaining a variety of different green spaces throughout the city, the needs of the majority of residents can be better met.

4.4 Treatment/Constructed Wetland

Topics discussed in this section:

- Introduction to Treatment Wetlands
- Uses and Considerations
- Differences between Natural and Constructed Wetlands
- Design Considerations and Types of Constructed Wetlands
- Economic and Technical Considerations for Treatment Wetlands

Introduction to Treatment Wetlands

Treatment or constructed wetlands are used for water quality improvement world-wide due to their ability to act as sinks for many chemicals, particularly nutrients. Therefore their uses as treatment wetlands are quite varied and range from treating domestic wastewater to landfill leachate (Mitsch, 2000). With that said, the rate of adoption of constructed wetlands for wastewater treatment has been slow in the tropics (Kivaisi, 2001).

Uses and Considerations

These systems can be very suitable technologies for use in developing countries because they utilize natural processes, simpler construction, and lower operation costs than conventional wastewater treatment systems. The design of treatment wetlands requires knowledge of the hydrology, chemical loading, soil physics and chemistry, source and quality of water to be treated, and wetland vegetation (Mitsch, 2000). Once construction completed and wastewater is applied, management can involve harvesting plants, wildlife habitat, mosquito and pathogen control, water-level management, and sediment dredging (Mitsch, 2000).

These systems also create interest and public awareness of water pollution sources and treatment. The wetland treatment processes and wildlife present in wetlands provides an opportunity for environmental education in the community (Shutes, 2001).

Differences between Natural and Constructed Wetlands

There are limitations to the use of either natural or constructed wetlands for treating wastewater. The input of wastewaters to natural wetlands alters the hydrology within the system and brings in organic matter, nutrients and toxic substances. Hydrological changes alter the species composition of plant communities and can promote the dominance of invasive, non-native species that are better suited to handle different hydrologic regimes and excess nutrients (Gopal, 1999).

As mentioned above, natural wetlands support a large biodiversity of vegetation, and not all of that vegetation is suitable for treating wastewater. Constructed wetlands however, tend to promote single species stands that are selected for their ability to treat wastewater and are better adapted to the specific hydrologic regimes in these systems. Although diversity may increase over the years of operation, periodic harvesting of the macrophytes (large aquatic plants) to maintain the system, keeps the diversity low (Gopal, 1999). It is also important to select species of plants that will not out-compete the native vegetation, if non-native species are selected. An example of this comes from Lake Victoria where the water hyacinth (*Eichhornia crassipes*), a free-floating macrophyte, is spreading fast, choking out the biota (plants and animals), and providing breeding habitats for mosquitoes and vector snails (Kivaisi, 2001).

Design Considerations and Types of Constructed Wetlands

The average lifespan of constructed wetlands has been found to be approximately 20 years with organic waste treatment (Shutes, 2001). There are several factors that influence the performance of these systems such as area, length to width ratio, water depth, rate of wastewater loading, and the residence time (the time for the water to pass through the wetland) (Shutes, 2001). Constructed wetlands used in combination with stabilization ponds can achieve better removal of nutrients and pathogens from the wastewater (Kivaisi, 2001).

Other factors influencing water quality in wetlands are the hydrology of the system, vegetation and soil (Kivaisi, 2001). The water level in these systems is usually uniformly maintained throughout the year except for the variation in the amount of influent of wastewater (Gopal, 1999). The hydrological regime is the main factor because it influences the type of vegetation, microbial activity, and biogeochemical cycling (storage, transformation, and cycling) of nutrients in the soil (Kivaisi, 2001). Microorganisms are essential in biogeochemical transformation of nutrients as well as their ability to remove toxic organic compounds (Kivaisi, 2001).

Prior to the design or development stage, it is important to consider the objectives of the system (i.e. what values or functions are desired) (Kivaisi, 2001). Considering the objectives of the system, there are two ways of designing constructed wetlands (Figure 11, bottom two diagrams). These include surface and subsurface flow systems (Shutes, 2001).

Surface Flow Wetlands

This type of design of constructed wetlands is similar to natural marshes and can be a better habitat for certain wetland species because of standing water throughout most of the year (Mitsch, 2000). They tend to be used in shallow channels and basins in which water flows at low velocities above and within the substrate (Shutes, 2001). The basins are usually made up of a combination of gravel, clay or peat based soils and crushed rock. Natural filtration occurs in the soil and helps to remove many pollutants and pathogenic microorganisms. The vegetation is made up of macrophytes which are able to assist in the breakdown of human and animal wastewater, remove disease-causing microorganisms and pollutants as well as effectively utilize excess nutrients found in many wastewaters (Shutes, 2001).

Sub-surface Flow Wetlands

In sub-surface flow constructed wetlands, wastewater flows horizontally or vertically through the substrate. The substrate is composed of soil, sand, rock or artificial media and the water is purified through its contact with the surface of the media and plant rhizospheres (thin zone around the roots) (Shutes, 2001). This design is more similar to wastewater treatment plants than wetlands because there is no standing water (Mitsch, 2000). They are also more effective at removing pollutants at higher application rates than surface flow systems, but overloading, surface flooding and media clogging can cause reduced efficiency (Shutes, 2001).

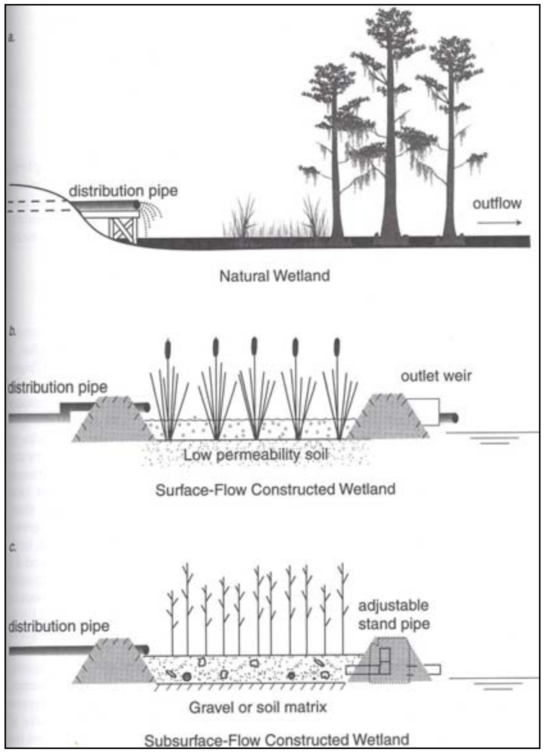

Figure 11: Types of wetland treatment systems (top to bottom): Natural wetland, Surface-flow constructed wetland, and Subsurface-flow constructed wetland

Economic and Technical Considerations for Constructed Wetlands

Construction Costs

In general, treatment wetlands are less expensive to build and maintain than conventional wastewater treatment systems; however, cost comparisons should be carefully made before investing in these systems (Mitsch, 2000). Wetland construction costs vary widely and depend on location, type, size and objectives of the wetland.

The costs of construction are greatly reduced by using existing land structures or features. Some data has also suggested that there is an economy of scale involved in wetland construction; the larger the wetland to be constructed, the less it costs per unit area (Mitsch, 2000).

Technical and Other Considerations

There are many considerations besides construction and maintenance costs that need to be taken into account when designing and building treatment wetlands (Mitsch, 2000).

Technical Considerations

- Acceptable pollutant and hydrologic loadings must be determined and these loadings will also determine the size of the wetland to be constructed. It should be noted that overloading a constructed wetland is worse than not building it at all.

- All existing characteristics of local wetlands, including vegetation, geomorphology, hydrology, and water quality, should be well understood so that natural wetlands can be “copied” in the construction of treatment wetlands.
- The wetland design should address mosquito control and protection of groundwater resources.
- Values of the wetlands (i.e. wildlife habitat) should be considered in the development of any constructed wetlands.

Other Considerations

- Potential conflicts over the protection and use of wetlands may arise among local groups, residents or government agencies.
- Wastewater treatment using constructed wetlands can serve many purposes including habitat development, wastewater treatment and water recycling.

4.5 Total or Partial Fill of the 6th Ring Curichi

One proposed solution, favored by many of the community residents, is the filling of the curichi. Before developing a plan to fill any portion of the curichi, the following topics must be discussed:

- Environmental Considerations
- Hydrologic Concerns
- Geotechnical Requirements

It is first important to assess the feasibility of filling the entire curichi. The major drawback to filling the curichi is its size. The area of the curichi is 20.24 hectares (50 acres), which converts to 20,234 m^2 (2,178,000 ft^2). The relative size may be better understood by converting to standard soccer fields. Filling the entire 6th Ring Curichi would be equivalent to filling an area slightly larger than 50 standard soccer fields, filling to a depth of approximately 2.2 m (7.2 ft) in some places. Basic calculations have shown that given a standard 3.82 m^3 dump truck, 11,653 truck loads of fill would be needed to fill the entire curichi. At a cost of nearly 20 Bolivianos per 1 m^3 of fill, the total cost of just the fill is nearly 890,000 Bolivianos. A cost will also be incurred for rental of trucks, loading of fill, and placement. The estimated cost simply reflects the fill itself. The availability of the substantial amount of fill is another factor that may contributes to the difficulty in filling part or all of the curichi.

Environmental Considerations

Fill brought in from outside the area should be checked to ensure that additional pollutants will not be transferred into the curichi. This is especially important because Santa Cruz gets their drinking water from ground water that flows southwest to northeast and originates in District 10 (BGS et al., 1997). Preventing additional pollutants from entering the groundwater is in the best interest for the city and the residents.

Hydrologic Concerns

One basic problem with filling any active water system is to redesign and recalculate contributing rainfall run off, stream flow, ground water and drainage patterns (RCCA, 2000). It is necessary to consider the effect of rainwater and its drainage. The 6th Ring Curichi is filled with water nearly nine months of the year and filling or altering any part of the curichi may cause flooding problems for residents living around the curichi. Filling the curichi could potentially cause the water to flow to another location and cause flooding elsewhere. A topographical survey and watershed model should be prepared to predict water flow and flooding.

Geotechnical Requirements

If even partial filling would take place, special care must be taken to assure soil stability. Careful placement and compaction of fill is required. Otherwise any facility or road built could result in foundational and structural problems.

Another concern with filling wetlands is the soils are usually saturated and thus large amounts of fill and compaction are needed to accommodate and prevent excessive settling, shear, and degradation. To have the land surface be stable enough to make the it useful, often concrete walls must be installed to guard against soil erosion and improve stability which is due to lack of soil bearing strength (RCCA, 2000) (Heise, 2001).

Practicality and functionality of filling the curichi is an issue because the amount of fill required and the extra precautions which are necessary to making the fill successful. It is recommended that motivation for filling be vital to human advancement. This stems from the belief that altering a wetland alters an entire ecologic and hydrologic system (RCCA, 2000). These problems should be taken into account in filling of any wetland.

Some advantages to filling the curichi would be the possibility of increased community activity and interaction if the land were used as a green space and it could also provide land for further residential or agricultural development. There is a restored curichi that exists in the west part of the city near the Pirai River. This area was partially filled and may serve as a model for the 6th Ring Curichi if there is interest from the community or the government.

4.6 Road/Walkway Options for the 6th Ring Curichi

Roadways are necessary for transit around Santa Cruz and the 6th Ring Curichi is currently fragmenting the 6th Ring. There are many footpaths that exist in the curichi, and therefore it is necessary to discuss this option of designing a road or permanent walkways. Before either design options can be formed, the following considerations must be discussed:

- Civil Engineering Transportation
- Environmental Concerns

Civil Engineering Transportation

Placing a road over a wetland poses a unique engineering scenario. There is the discussion of the environmental impacts of filling a wetland, as well as the consideration of how to place the fill into the curichi using support layers of aggregate base. Then the load from vehicles and pedestrian traffic would need to be supported by the paved surface.

Environmental Concerns

Another problem with placing a road over a wetland is that a paved surface is relatively impermeable, and any runoff from vehicle emissions and rain or drainage runoff will seep into the wetland unless an adequate design is provided. In order to reduce further contamination or pollution of the curichi, it is suggested that traffic go around the curichi to minimize environmental impacts of runoff (CETS, 2002).

Walkway

Many residents were very interested in having a road/walkway across the curichi. One of the largest problems with the curichi is the waste, contamination and resulting health impacts. Many residents living near the curichi walk through it to get to their destination and continuous exposure from walking through the curichi, especially during the wet season promote transmittal of disease and illness.

The benefits of designing an elevated walkway through the curichi would allow for safer passage where disease transmittal could possibly be reduced due to reduction of contact with the curichi's contents. The most advantageous aspect of this design is that it promotes community involvement because the design requires their input for determining a widely used location for implementing the walkway. However, extensive studies are still required before design and implementation are possible.

One of the drawbacks of the walkway system is that it will not support vehicle traffic. However, subsequent designs could include a road system; however, the design team feels that the immediate need involves pedestrian traffic.

4.7 No Action Alternative

The no action alternative means that the curichi will be left in its current state and no efforts will be made to either clean it up or rehabilitate it. This would result in continual dumping and burning of waste in the curichi, more health problems for the residents living near the curichi as it becomes more polluted and contaminated, constant threat of robbers, and an eyesore for the residents and the city.

4.8 Summary of Land Use Options

The design team used the research provided in Section 4 along with a decision matrix to further analyze the land use options. A decision matrix is a table that assists in the analysis of various options by systematically identifying and rating the strengths of each option using assigned criteria. The criteria will be given a weighting and each option will be rated for the separate criteria. This allows the design team to score each option based on the established criteria.

The seven criteria used in the decision matrix were given a weighting based on what the design team considered to be the most crucial to the success of the various options. The use of appropriate technology was determined to be the most crucial criteria because improper technology could result in failure of the project and this governs the outcomes of the other criteria. The next important criteria were positive impacts to community health and the sustainability of the options. Improving the health of the curichi means improving the health of the surrounding communities and without a sustainable design option the curichi will regress into a degraded state. Following those criteria are the costs and social impact of the options. The design team felt that a successful design option must be within the communities' economic means as well as fulfill the wants and needs of the community. The last two options, political approval and environmental impacts, were not considered the least important, but rather were weighted lower because the design team felt that every option had political backing and was an improvement to the current environmental state of the curichi. These opinions are based upon the input and information gathered while in Santa Cruz as well as the research conducted while in the United States.

Using the seven previously established criteria, the potential land use options were evaluated by comparing the criteria of each option to the no action alternative as shown in Table 2. The ratings are based on a 0-5 scale, with 5 being considered the top score. The total score tallies the weighted scores for each option (e.g. the overall score for cost of cleaning the curichi would be 4 x 3 = 12).

Cleaning the curichi ranked the highest for total score because it will help improve the health of the communities surrounding the curichi, is appropriate and within the means of the residents and the government to fund. If recycling and composting are incorporated with the clean up it reduces the environmental impact, and residents would have to take ownership of the project for it to be maintained. It is also a necessary for the waste to be removed from the curichi before any other option can be implemented.

The options that were the next highest ranking include **green space** that does not require any filling and **natural space**. Both of these options are sustainable and have a minimal environmental impact, provide habitat for wildlife, offer recreational and educational opportunities, and use appropriate technology. The costs vary for each option and both options could offer benefits in water quality improvement.

Constructed wetlands, **green space** that requires partial filling and **elevated walkways** are also feasible options that also provide recreational and educational opportunities for learning about natural ecosystems and wildlife, and use appropriate technology that benefits society. They do require more funding and maintenance, but offer a variety for residents depending on which option and some of those include wastewater treatment/water quality improvements, an area for social gatherings, or a way to get through the curichi in the rainy season.

Partial filling is feasible depending on the area that would be filled and a benefit from this option includes utilizing the partially filled area for **green space** or a **constructed wetland**. Possible disadvantages include the effect on water storage or flow in the curichi, the costs, and the potential environmental impacts. Some assumptions were made when evaluating the partial fill option. The design team considered only a partial fill to indicate a fraction of the curichi would be filled and filling would be kept to a minimum to reduce financial costs and impacts to the environment.

Connecting the 6th Ring through the curichi has the benefit of allowing traffic through the curichi which might be necessary for emergencies, but the benefits should be reviewed to justify the cost and the impacts to the environment and water flow. This option is more sustainable than a total fill of the curichi, but the level of sustainability depends on the amount of fill necessary to ensure the road is elevated enough to avoid flooding and washouts in the rainy season. This option was given a lower rating for health based on the negative impacts to human health and the environment caused by motor vehicles. Some of those impacts include vehicle emissions and leakage of vehicle fluids such as oil.

Filling the entire curichi and **taking no action** were the lowest ranked and not recommended by the design team. The costs of filling are prohibitive as is the reduced water storage ability of the area and potential flooding that would mostly result. These options are not sustainable and would have significant impacts on the environment and the design team did not feel that either used appropriate technology.

Table 2: Decision matrix for 6th Ring Curichi land use options

Option	**Costs**	x Wt.	**Env. Impact**	x Wt.	**Sustainability**	x Wt.	**Health**	x Wt.	**Social**	x Wt.	**Political**	x Wt.	**Appropriate Technology**	x Wt.	**Total**
No action	5	3	0	2	1	4	0	4	0	3	0	2	0	5	19
Cleaned	4	3	4	2	5	4	5	4	5	3	5	2	5	5	110
Green Space (no filling)	3	3	4	2	4	4	5	4	4	3	5	2	5	5	100
Natural Space	3	3	5	2	4	4	5	4	4	3	4	2	4	5	95
Constructed Wetland	1	3	3	2	4	4	4	4	4	3	4	2	4	5	81
Green Space (filling required)	1	3	2	2	2	4	5	4	5	3	5	2	4	5	80
Walkway	2	3	4	2	3	4	4	4	4	3	3	2	3	5	75
Partial Fill	2	3	1	2	2	4	3	4	3	3	3	2	3	5	58
6th Ring Construction	1	3	1	2	2	4	2	4	3	3	3	2	3	5	51
Total Fill	0	3	0	2	1	4	2	4	2	3	2	2	0	5	22

5 Additional Land Use Options and Recommendations

The land use options discussed in the previous section can be thought of as end products for the curichi. However, there are many other options available that can help with the transition from the curichis' current state to the desirable end product. These options can be implemented at anytime during the transition period by the community or by the government. These include the following options and recommendations:

- Education Programs
- Composting
- Open Burning Recommendations
- Creating Designated Collection Sites
- Alternative Tire Disposal
- Considerations for Partnerships with Foreign Aid

5.1 Education Programs

In general, to ensure the success of any rehabilitation project, public re-education is vitally important and must be utilized in conjunction with the land rehabilitation. The design team feels that many of the land use options need concurrent education programs in order to sustain any progress made. Some recommendations for programs are:

- Disease education (causes and preventions)
- Science of wetlands (importance in water quality, aquifer recharge, natural spaces, etc)
- Environmental (awareness, knowledge, appreciation and stewardship)
- Health issues (hygiene, waste handling and management)

5.2 Creating Designated Collection Sites

The idea of creating designated collection sites came from talking with several residents and city workers. These sites could be an intermediate step in rehabilitating the curichi by diverting waste that would otherwise be dumped into the curichi. These areas would work by building basic structures, such as wire fenced enclosures, to temporarily store different types of waste. An example is shown in Figure 12 below. They should be located in areas that currently receive larger quantities of waste or in areas that are convenient for a majority of users. Areas where collection sites are not built but residents or business owners use to dump waste should have fences or simple blockades put up to prevent vehicles or individuals from easily accessing and unlawfully dump their wastes.

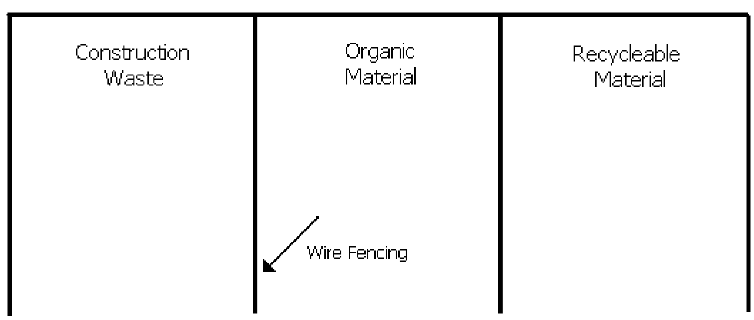

Figure 12: Plan view of an example layout of a collection site

There would need to be education and publicity about these sites to inform residents and business owners of their existence, their location and how to use them. Each collection site should be clearly marked with the types of waste that are to be collected and in which area they are to be placed in. This approach would allow residents to visually see action being taken to prevent further waste accumulation in the curichi and could also act as an education tool by making residents aware of waste generation and disposal practices.

Construction Waste

Clean and uncontaminated construction waste can be collected, sorted and usable materials gathered such as bricks to be used in other construction sites (Carroll, 2004). These organized collection areas would allow residents or business owners whom wish to reuse, recycle or re-sell these materials to come and gather them from designated areas around the city.

Other Waste

Creating designated collection sites for other materials such as garden and yard wastes, recyclable material, and tires could help reduce the amount of waste discarded throughout the city and allow for more reuse and recycling. This would reduce the disposal costs for the city if these wastes were reused (i.e. finding new uses for old tires), recycled, or composted (organic material).

5.3 Composting

Composting, as defined by the U.S. EPA, involves the aerobic biological decomposition of organic materials to produce a stable humus-like product. In District 10, organic material accounts for less than 40% of the total waste generated (Ortiz et al., 2004). District 10 has a lower amount of organic waste material than other developing countries which average about 50% (Zurbrugg, 2002). There are many benefits to composting and some of those include reducing the costs of the disposal facilities, extending the landfill's life span and also reducing the environmental impact of the landfill because it reduces the amount of organic waste that generally produce contamination. By increasing recycling and reuse of organic wastes, valuable nutrients and organic matter can be returned to the soil and used for agricultural, community and individual gardens, or for green space vegetation (Zurbrugg et al., 2005). Residents can compost their organic household wastes for use in their personal gardens or plantings.

While composting has many benefits, in the past there have been some problems with composting efforts. Some reasons for past composting projects to fail include (Zurbrugg, 2002):

- Lack of support and cooperation from the public and municipal governments
- Poor marketing plans for the end product
- Poor quality feedstock waste
- Inappropriate technology resulting in high operating costs and frequent mechanical breakdowns through poor maintenance
- Lack of understanding of the composting process and training in operational procedures, often resulting in offensive odors

Small scale and decentralized approaches are more successful but they often struggle with marketing the compost product (Zurbrugg et al., 2005). Before initiating a composting program, a feasibility study should be done to analyze the technical and financial issues in addition to the available or potential markets for the final product (Zurbrugg, 2002).

5.4 Alternative Tire Disposal

Tires are a difficult waste to landfill because they have low densities and are bulky and incinerating tires can be a major health and environmental hazard. Santa Cruz has an excess of tires that offer enormous potential for reclamation and reuse of rubber. Reclaiming or recycling rubber can be a difficult process, but there are many reasons for doing it, and these include (ITDG, 2005):

- Recovered rubber can cost half that of natural or synthetic rubber.
- Recovered rubber has some properties that are better than those of virgin rubber.

- Rubber produced from reclaimed rubber requires less energy in the total production process than does virgin material.
- Excellent way to dispose of unwanted rubber products, which is often difficult.
- Conserves non-renewable petroleum products, which are used to produce synthetic rubbers.
- Recycling activities can generate work.
- Many useful products are derived from reused tires and other rubber products.
- If tires are incinerated to reclaim embodied energy then they can yield substantial quantities of useful power.

By reusing, reprocessing or hand crafting new products from tires the end result is less waste and less environmental degradation. Some products that can be made from reprocessing waste are often impressive and require high levels of skill and ingenuity as shown in Figure 13 (ITDG, 2005). Examples of reused tire products include using the sidewalls for shoe soles, slippers, washers and the tread for wheels of vendor carts (ITDG, 2005). Tire chips (1 inch tire pieces) are also used to replace conventional construction material such as road fill, gravel, crushed rock or sand (Reschner, 2005). Some of the benefits of using tire chips versus conventional construction material are reduced density, improved drainage properties and better thermal insulation (Reschner, 2005).

Figure 13: Garbage containers made from truck tires in the Philippines (ITDG, 2005).

5.5 Open Burning Recommendations

Health Effects

In many areas of the world, household waste is burned in the open when cost, convenience or local custom/social acceptability make it an attractive option for citizens or governments. However, open burning is an environmentally harmful process which can generate toxic or persistent pollutants from the incomplete combustion (Carroll, 2004). Open burning poses health concerns for the local population near burning sites as well as the regional population. The local population is exposed primarily through inhalation of airborne emissions; whereas the regional population is effected through food contamination resulting from the release of the persistent and bioaccumulative pollutants (Hammond, 2000). Burning sites should be located away from the population, areas of plant or animal production and forage areas (Carroll, 2004).

Fires that are associated with uncontrolled disposal and accumulation of tires are detrimental to both human health and the environment. However, it has been determined that air and soil pollution are worse when attempts are made to extinguish tire fires with water or foam (Reschner, 2004). For this reason it is safer to allow tire fires to burn out in a controlled manner until the entire pile is exhausted.

Safer methods to reduce health risks of open burning

Good incineration requires a combination of adequate residence time in the flame zone, combustion gases reaching temperatures of at least 800º C (~1450-1500º F), and sufficient turbulence to ensure all material is burned (Carroll, 2004). Some practice process modifications that can immediately help reduce unintentional pollutant formation include (Carroll, 2004):

- Reduce the amount of material discarded by open burning
- Remove non-combustibles (i.e. glass, bulk metals, and materials of low fuel value)
- Avoid burning high chloride content waste (i.e. organic chloride, PVC)
- Avoid burning waste that contains metals (i.e. copper and iron), even in small amounts
- Supply of sufficient air
- Burn in piles rather than confined in burners
- Steady burning/rate of mass loss
- Minimize smoldering (possibly with direct extinguishment)

For materials to be burned, the following wastes should be used (Carroll, 2004):

- Dry waste combustibles of high fuel value (avoid wet materials)
- Well-blended or homogeneous combustibles
- Non-compacted or low density waste

Ways to reduce open burning

In order to reduce or eliminate open burning there needs to be reasonable alternatives and public education regarding these alternatives and the harm caused by open burning. Municipalities must be able to mandate an end to open burning by citizens and then accept the responsibility to enforce those laws (Carroll, 2004). Education about ways to reduce, reuse, recycle or compose waste will help in decreasing the amount of waste that needs to be burned or landfilled. Open burning should be a last resort and should always exclude materials that do not burn well or at all (Carroll, 2004).

5.6 Recommendations for Problems with Robbers in Curichi

The problem of robbers living and hiding in the curichis is a serious problem that should be dealt with as the curichi is being rehabilitated. The design team recommends increasing foot patrols by police officers in the curichis and other vacant land. It is also suggested that residents who have incidents with robbers notify the police or appropriate authorities so that more action can be taken.

The Sub-Mayor mentioned that sometime in the future 4,000 new streetlights would be added around the city. The design team recommends that some of these lights be placed around the curichis with robber problems. While this is not sustainable in the long-term, there are already plans to add these lights and it would be beneficial for residents living around the curichi that have to deal with the threat of robbers.

5.7 Considerations for Partnerships with Foreign Aid

There are considerations that should be made when partnering with foreign organizations or companies. Developed countries tend to favor more widely used technologies that have financial opportunities for the donors (Kivaisi, 2001). Appropriate solutions and technologies for northern regions and developed countries can not always be applied to tropical, sub-tropical regions or developing countries which have different materials, skills, knowledge and climates.

Some essential pre-conditions for success of developing solutions include (Haberl, 1999):

- Government officials and residents have to define and formulate their needs
- Coordination and cooperation between officials and residents
- Education of local experts that will be able to communicate and spread new technologies
- Sustainability of all aspects of the project
- Ownership of facilities by local communities or organizations (i.e. decentralization)

To fulfill these pre-conditions, other supporting measures must be considered (Haberl, 1999):

- Awareness of environmental problems
- Use of designs, materials, skills and knowledge from local area and culture
- Dialogue between government officials, residents and other supporting partners involved in project
- Ensuring funding will be available throughout project's lifespan
- Improvement of the future project control
- Providing a scientific solution, within the means of the country, for social problems

6 Final Recommendations and Conclusion

Due to the size of the 6th Ring Curichi (roughly 20 ha or 50 ac), a combination of options may be best suited for specific areas within the curichi. A map outlining potential areas within curichi can be seen below in Figure 14; however, it is important to consider that this map is based on the design team's research and limited knowledge of the layout of the curichi. The map should act as an example for how the curichi could be divided for multiple land use options.

The map is color coordinated for each land use option with darker green indicating green space, blue for natural space, fluorescent for constructed wetlands, gray for collection sites and red indicates roads. Green space was placed in the upper portion of the curichi because the design team felt this area was shallower and depending on the type of green space preferred, less filling would be required in this area. Natural space was determined to be best suited in the lower portion of the curichi based on information gathered from locals that this area is typically saturated or inundated with water for the majority of the year and it would be more costly to fill this area for other uses. Constructed wetlands were placed in areas that were near two schools that could potentially use them for treating their wastewater. The collection sites were placed in areas that either already contained large quantities of waste (and appear to be favorable areas to dump waste) or they were located near roads to allow for easy access to the sites. The design team recommends a more thorough analysis of their placement using local knowledge of the area possibly by performing a survey. There is already an existing road that goes through the curichi and the broader red line labeled 6th Ring indicates where the road connects the 6th Ring.

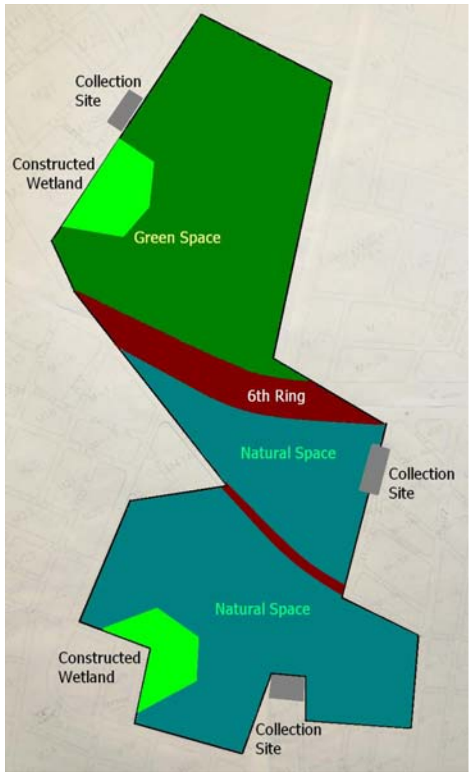

Figure 14: Map of potential land use for 6th Ring Curichi

Cleaning the curichi is the first step for any land use option, and is necessary to improve the health of the residents. The following recommendations and plans will be discussed in this section:

- Community Involvement
- Recommended Steps for Cleaning the Curichi
- Recommendations for Smaller Projects
- Recommendations for Land Use Options
- Phased Action Plan
- Future Projects

6.1 Community Involvement

By involving the public in cleaning and rehabilitating the curichi, greater ownership is created within the community and can result in a greater level of innovation, creativity, participation, care and resourcing.

Delegating responsibility to community groups and supporting their activities and decisions, can result in a high degree of initiative (Dunnett, 2002).

6.2 Recommended Steps for Cleaning the Curichi

After a site's waste quantity and location has been determined the cleaning process can begin. Visible waste removal is often among one of the first tasks performed. In the case of larger or problematic materials that may be more difficult to dispose of, specialists are often hired for removal (Hydra, 2004). After the trash has been removed and it has been determined that the land is ready for development, an approved construction design or process can be built.

The cleaning process for the curichi will be labor intensive, will require multiple cleaning sessions and may require assistance in determining waste quantity and classification. To ensure that the clean up is done in a manner that promotes sustained cleanliness beyond initial cleaning, the following steps are suggested:

1. Develop an objective statement and document to achieve an agreement by the surrounding communities to collect and remove waste from the curichi, without permitting any burning of waste or destroying vegetation, which results in a decrease in the curichis function of water storage and cycling.

2. Choose a resident or community group to lead the cleaning program. It is important that a local community member or members are chosen, which we will refer to as the clean up committee, because the clean up will be a continual process and extend beyond the initial cleaning. Also, having a person or committee to head the cleaning effort will promote unity among the residents and may encourage community involvement in the process. This established committee should begin contacting and working with the appropriate government offices, especially the City of Santa Cruz Solid Waste Department.

3. Develop public reeducation program. This should include training on waste collection and separation, reuse and disposal. This education program should be based on the same principles as the aforementioned reeducation program, but should include more extensive training in waste identification, collection and placing of waste in the designated collection sites. A method of educating the residents should be developed that will be effective in the areas surrounding the curichi.

4. Have the clean up committee implement the reeducation program and inform the residents of the general purpose of the project and solicit help. The reeducation program may be done door-to-door; however, because community meetings are successful ways to reach community members and generate community synergy, group reeducation may be an easier and more productive method. Again, the community must be studied to determine the best method of implementation.

5. Determine the types of waste that exist in the curichi and classify them by location in the curichi. Label all areas that contain waste that may not be suitable for residents to remove themselves, including larger more problematic items. This step could be done simultaneously with steps 2 and 3.

6. Design a segregated waste disposal program that includes a design of a facility for waste.

7. Before the residents begin removing waste from the curichi, it will be vital to contact the appropriate parties to remove any larger or problematic materials that are detrimental to public health and the environment. Waste removal companies should also be contacted to establish the types of waste that each will remove from the collection sites and frequency of collection. This can be done by community members as they may know prospective waste collectors or re-users. This may promote and spur the possibility of a simultaneous recycling program. The collection agencies may be specialized in the area of recycling of rubber materials, papers, metals, and glasses. There is a potential that agencies would be willing to provide monetary compensation for the materials collected by the residents. The potential funds could be used to initiate a recycling program.

8. Choose locations for collected waste to be stored in collection sites before clean up begins and waste is accumulated. These locations should be strategically positioned around the edges of the curichi and piles should be divided by waste type to allow for easier reuse or disposal of waste (as mentioned in Section 5.2 Creating Designated Collection Sites). This process of managed waste disposal may also spur interest in a continual public recycling or composting program. The waste is collected from the curichi and placed in specified locations by residents. The clean up committee should be responsible for coordinating residential efforts and oversee the cleaning process.

9. Contract private waste removal companies to collect the waste and dispose or reuse it as scheduled. It is important to note the cleaning process will take many separate clean up sessions. Thus a schedule of cleaning times and dates should not only be coordinated between residents, but also with the waste removal companies to assure adequate space is available in designated collection sites.

10. Increased vigilance will be necessary to sustaining a waste-free curichi. It is advised that regulations are drafted by the surrounding community to promote vigilance and compliance. A draft should be sent to each household in proximity to the curichi. The community regulations as well as city laws and regulations should be imposed and enforced by community members and leaders.

6.3 Recommendations for Smaller Projects

There are smaller projects that can be initiated which require community and or government support, but minimal funding, these include:

- Each resident in Santa Cruz properly disposing their wastes in trash bins that the city collects. May take some education within the communities, but other residents can help by stopping and educating those who continue to use the curichis, vacant land, canals or the streets to dump their waste.
- Initiate community watch programs for unlawful dumping and burning to help create a sense of community pride as well as protect public health and the environment.

- Enforce laws and regulations that govern dumping and burning waste in Santa Cruz as given by Parada et al., 2001. This reinforces the importance of public education and awareness and the design team believes that it is essential to maintaining any improvements in the curichi.

Other projects that require more organization and funding include:

- Creating designated collection sites throughout the city
- Initiating educational programs (at both the school and community level)
- Developing community or individual composting programs (larger programs will require more planning and involvement)
- Initiating recycling programs.

These all work toward the same goal of keeping waste out of the curichi and will make it easier to clean the curichi and keep it free of waste in the future. For the success of these projects there must be community support, participation and education.

6.4 Recommendations for Land Use Options

While the scope of this feasibility study is not to determine the best suited option for specific areas within the curichi, the design team has recommendations based on research and the brief time spent meeting with the local population involved with this project. The feasible land use options include:

- Building a constructed/treatment wetland
- Restoring a functional wetland
- Creating green space

These projects will take planning, designing and funding for them to be successful.

Constructed Wetland

We recommend using constructed wetlands for treating the wastewater of two local schools in portions of UV 118 and 125 (La Base and La Calama, respectively). The constructed wetlands should be used in conjunction with septic tanks that will be used for primary treatment of the wastewater. This option has been analyzed by two other design teams from Michigan Technological University whose projects involved working with these schools. For more specific design information please refer to the following reports:

LSS Engineering: Mary Anderson, Kasey Cornwell, Melissa Trahan, 2005. *Septic Design and Master Site Plan of Polifuncional Calama*. Michigan Technological University.

Functional Wetland

It is also recommended that a further investigation be made into restoring the curichi to a functioning, natural wetland in order to improve water quality and storage, provide open space for residents, and habitat for wildlife and birds. Some principles of restoration of wetlands include (Mitsch, 2000):

- Design for minimum maintenance by developing a system of plants, animals, microbes, substrate and water flow that is self-sufficient. This can be accomplished by selecting species of vegetation that are adapted to the conditions of the desired wetland (climate, hydrology, soils, etc). If existing plant species are to be used, then other factors can be manipulated such as the hydrology of the system.
- Design the system to fulfill multiple goals, but identify at least one major objective and several secondary objectives (i.e. water storage/flood control, water quality improvement, wildlife habitat, etc).
- Design a system that utilizes natural energies such as rain events. The desired functions of the system should be selected based on natural occurrences on the site. This includes analyzing the topography, soils, and vegetation to determine how the site will handle natural weather events.
- Design the system with the hydrologic and ecologic landscape as well as the climate. Natural ecosystems should be able to recover from natural disturbances such as floods, droughts and storms to which they are adapted to.
- Be patient with the system as it will take time before plant establishment, nutrient retention, and wildlife enhancement can become optimal and mature soils systems may take much longer. Beware of short-cutting ecological succession or over managing the system, because all these can lead to failure of the system.
- Design the ecosystem for function, not form. It is important to monitor the system to ensure that it is fulfilling the desired functions even though initial plantings or animal introductions may fail. The outbreak of plant diseases and the invasion of non-native species are often symptomatic of other stresses and may indicate false expectations rather than ecosystem failures.
- Avoid over-engineering wetland design with rigid structures or channels, instead natural systems should be mimicked accommodate biological systems.

Without additional input from residents and city officials it is difficult to establish a step-by-step approach to restoring a wetland or natural area. There has been a lot literature and research on this topic and it is suggested that whoever undertakes this project reviews this data before proceeding.

Green Space

The possibility of developing green space within the curichi depends entirely on the type of green space desired by the residents. One very feasible option is leaving the curichi how it is once the waste is removed. The curichi will be an open and natural space that residents may enjoy in its new form and this option only requires the initial clean up costs and continual maintenance. This may also be the only option available until funding, support or a proper design can be obtained.

Certain types of green space such as parks or recreational areas may not be feasible with the topography of the curichi and the level of water during wet periods. If a community park or play area is desired by the community, it would be necessary to look into partially filling the appropriate area within the curichi. This will increase costs and require more analysis and engineering design.

Other types of green space are available that do not require any filling and instead use the current topography. Those include creating natural areas for educational purposes, developing the current walking paths into marked nature trails, planting community gardens, or creating a pond for recreational activities. These options may require less financial investment because they do not require the additional step of filling an area. With that said, additional studies should be performed before any type of green space is implemented to assess whether funding, support and appropriate designs are available.

Curichi Filling Options

Given that some residents prefer that the 6th Ring Curichi be at least partially filled for future use as a green space or roadway, the design team would recommend the following steps:

1. Conduct a planned development study of where a fill or partial fill is most needed for useful community development.

2. Conduct a topographical survey of the selected fill area(s) to determine the amount of fill needed to achieve proposed land use.

3. Conduct soil borings and testing during the wet season to determine soil type and what degree of soil strength can be expected during the worst conditions. Thus any extra fill needed for strengthening due to saturation can be assessed.

4. Design fill areas to include compensation for excess compaction. Also, during the design phase of the fill, an adequate amount and standard of quality level should be established. Locating viable fill may prove difficult, thus it is important to find an adequate location to purchase or remove material for the filling.

5. A hydrologic study/model should be performed/developed to determine how filling of the curichi will affect water flow. A study of the current drainage of the curichi must be conducted to understand where the water, displaced because of the proposed fill, will flow. Within the hydrologic study there should be designs included that prevent erosion and degradation of the proposed fill.

If the preceding conditions are satisfied the fill may be placed and used as determined by the client. Due to cost the design team recommends that if a fill is to be conducted, it be partial in nature and only where necessary.

Walkway Options

The design team recommends that the most immediate need for an avenue of transportation through the curichi is an elevated walkway. A corresponding design must be developed to provide a walkway for the residents and should include the following:

1. A public survey should be complied that includes the potential demand for an elevated walkway. From this, daily traffic volumes should be established and an appropriate design of the walkway can be determined. An extensive study should be performed to determine the best locations for walkway placement that would support pedestrian traffic across the curichi. A cost benefit study should be considered to minimize the length of the crossing or bridge and therefore cost while still maintaining functionality.

2. During the dry season, a survey of the proposed elevated walkway location should be performed to determine the exact length of the walkway. Then data should be gathered during the wet season to determine the highest level of water in the curichi so that the walkways can be designed for year round use.

3. The design of a crossing or bridge should include a soil or foundation analysis. Within the design, accommodations should be made for the situation where the foundations would be submerged.

4. Ensure that the walkway design is feasible for the conditions that it must fulfill and can serve as a model for additional walkways.

After the walkway has been in service another traffic volume study should be performed. The demand for additional walkways should be investigated as well as the demand for a paved roadway provided that funding and support for these projects are available.

6.5 Phased Action Plan

The curichi rehabilitation should occur in several phases to make it a more manageable task. This will also allow residents and city officials to evaluate each phase of the rehabilitation process and make changes as necessary. Refer to Figure 15 for a chart detailing the progression of actions for rehabilitating the curichi.

Phase I: Education and Community Watch Programs Initiated

- Develop and implement educational programs about trash separation and proper waste disposal practices and the health impacts of open burning of waste.
- Organize community watch programs within each barrio to stop unlawful dumping by residents or businesses.
- Draft a community pact outlining an agreement that each resident will not dump or burn their waste in the curichi or other vacant land.

Phase II: Collection Sites Created

- Create collection sites in strategic areas to assist with the transition from using the curichi as a dumping area to a non-dumping zone.
- Coordinate projects with Solid Waste Department and private collectors to obtain city participation, arrange the frequency of pick-up, and sort through the logistics of funding and trucks. This partnership is essential to the success of these collection areas.
- Determine what will be collected, the appropriate size of each collection site (based on quantity of waste and frequency of pick-up), location of collection sites, frequency of pick-up, and which companies will collect each type of waste.
- Maintain community agreements to only dump waste in these collection areas.
- Initiate community or individual based composting programs using the organic materials that are collected (see Section 5.3 Composting).

- Implement a recycling program by selling recyclable materials that are collected to help offset the costs of the clean up effort (see Section 2.8 Education and Recycling Program). This should be further investigated and for more information about starting a recycling program Ing. Landivar should be contacted.

Phase III: Full Curichi Clean Up

- Evaluate progress of education and recycling programs, collection sites and community watch programs to make sure that unlawful dumping has ceased or been greatly reduced. The success of Phases I and II are important to ensure that future work will not be undone.
- Refer to Recommended Steps for Cleaning the Curichi for information on how to proceed with cleaning up the curichi.

Phase IV: Implementing Land Use Options

- Land use options should be evaluated and prioritized once the waste has been removed from the curichi.
- Options with the highest priority should have funding secured, a developed plan and engineering design, and the support and participation by residents and city officials.
- Refer to Recommendations for Land Use Options for information regarding how to proceed with implementing the land use options.
- Project managers or committees should be selected or formed for each chosen option. This will help ensure continuity in each project, community input, and a decision making body that will help maintain forward momentum in the project.

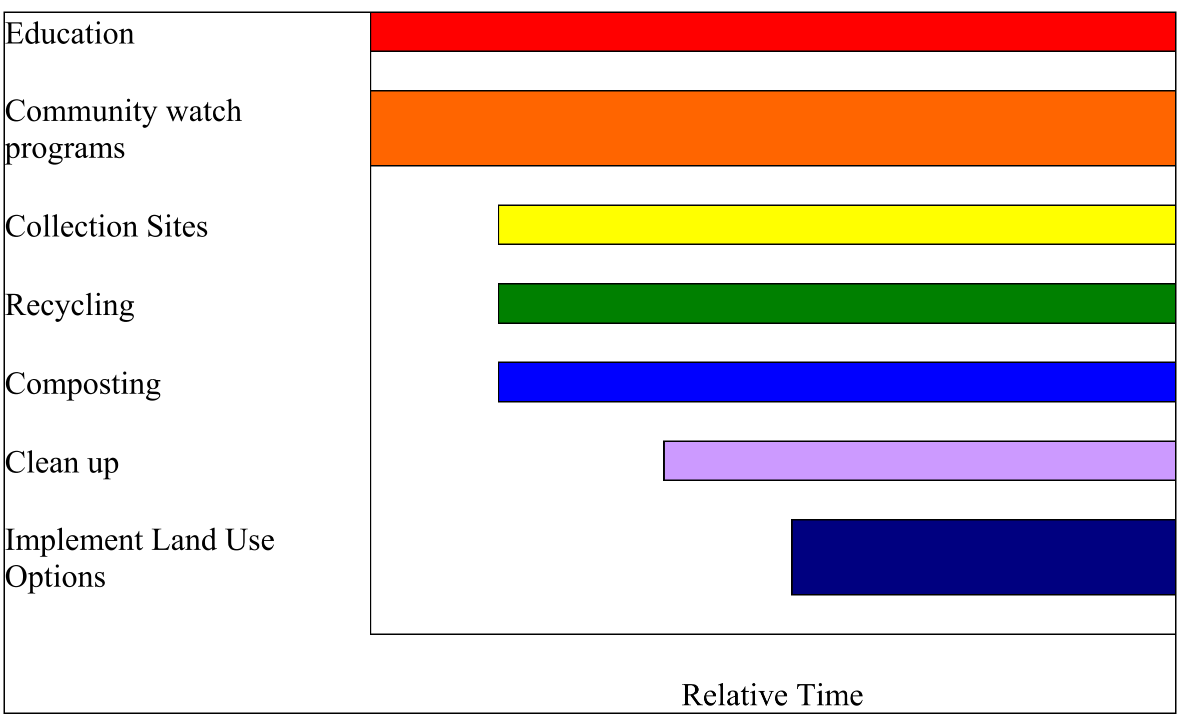

Figure 15: 6th Ring Curichi suggested progression of rehabilitation

6.6 Future Projects

The goal of this report was to analyze the rehabilitation options for the 6th Ring Curichi. After completing this analysis the design team believes that there are future projects that could be further studied and implemented by residents, government officials or university students. The recommended projects or programs include:

- Development and implementation of various education programs
- Determine strategic locations for collections sites and construct
- Organize and implement waste removal from 6th Ring Curichi
- Analyze potential recycling programs in surrounding communities
- Development of community based composting project
- Assess wetland functions and appropriate restoration options
- Perform study and evaluate potential green space options
- Investigate alternative tire reuse and recycling options
- Analyze areas in need of partial fill
- Assess the cost-benefits of connecting 6th Ring through curichi
- Study the demand and location options of an elevated pedestrian walkway

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Appendix 1: Waste Stream Composition in District 10 curichis

Table 3: Type and quantity of waste discarded into a curichi in District 10 near the San Martin barrio (Ortiz et al., 2005)

Material	Mass (kg)	% of Waste
Debris/Rubbish	10.4	20.8
Garden Waste	7.6	15.2
High Density Styrofoam	7.2	14.4
Low Density Styrofoam	5.4	10.8
Cardboard	3.8	7.6
Metal	3.6	7.2
White Paper	2.9	5.8
Dark Glass	2.5	5.0
Cans	2.0	4.0
Colored Paper	1.7	3.4
Ceramic Tile	1.5	3.0
Paint Cans	1.4	2.8
Total	50	100

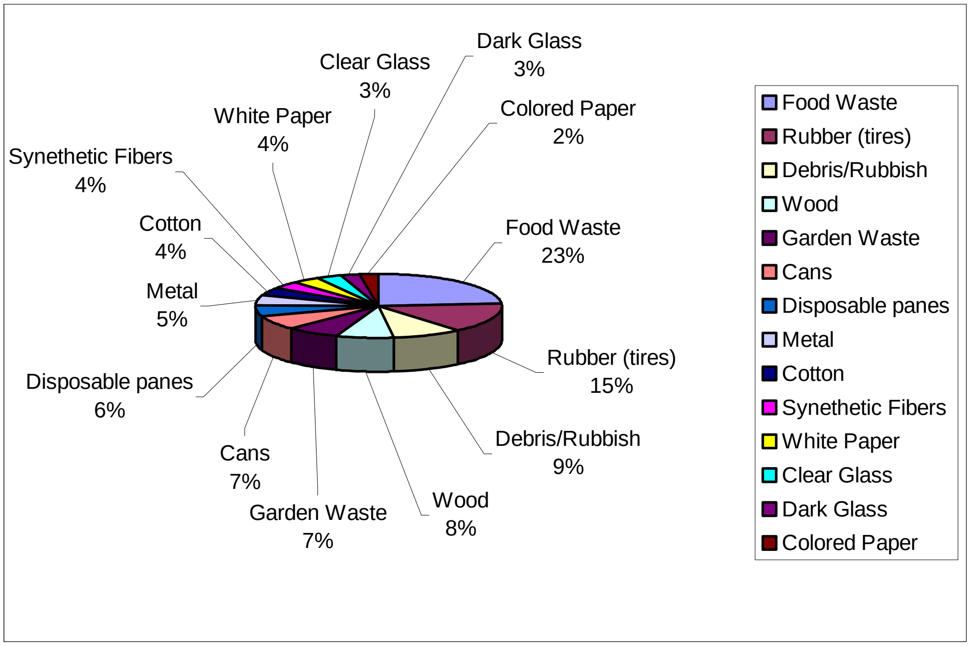


Figure 16: Breakdown of waste (by weight) components for a curichi in District 10 near the San Martin barrio (Ortiz et al., 2005)

Table 4: Type and quantity of waste discarded into a curichi in District 10 near the 26th of September barrio (Ortiz et al., 2005)

Material	% of Waste	Mass (kg)
Food Waste	12.0	24.0
Rubber (tires)	7.5	15.0
Debris/Rubbish	4.5	9.0
Wood	3.8	7.6
Garden Waste	3.5	7.0
Cans	3.5	7.0
Disposable panes	2.9	5.8
Metal	2.5	5.0
Cotton	2.0	4.0
Synethetic Fibers	1.8	3.6
White Paper	1.8	3.6
Clear Glass	1.7	3.4
Dark Glass	1.3	2.6
Colored Paper	1.2	2.4
Total	50	100

Appendix 2: Water Quality and Microbiology Test Results

Water Quality Tests

Water chemistry tests were performed to analyze the water quality of the 6th Ring Curichi. By Measuring the water chemistry allows the level of pollution to be determined as well as the source(s) of the pollution. The water chemistry tests performed included pH, phosphates, nitrates and iron. These tests were performed on site at the 6th Ring Curichi using test kits donated by the Michigan Tech Center for Science and Environmental Outreach. The test results can be seen in Table 5 and the interpretation of the test results can be found below.

Water microbial levels were also tested using 3M™ Petrifilm™ *E. coli*/Coliform Count Plates donated by Dr. Susan Bagley of the Michigan Tech Biology Department. These tests were performed in a laboratory at Saguapac, a water cooperative in Santa Cruz.

pH

The pH is the measure of the acidity of water and the pH affects what types of organism can survive in a water body (Tech Alive, 2005). The pH can change when water is polluted and this can occur from runoff from agriculture, domestic or industrial areas. Most aquatic life can tolerate a pH of 5 to 8.5, with pH of 7.0 being neutral, pH < 7.0 is acidic, and pH > 7.0 is alkaline or basic (Tech Alive, 2005).

The health effects to humans are a result of low pH that can corrode water distribution pipes which may release heavy metals such as copper, lead, zinc and cadmium into the drinking water (NCSU, 2005). The environmental effects from low pH include the release of toxic metals that would normally be absorbed into the sediment and removed from the system, are then available for uptake by organisms. Acidification of aquatic systems reduces decomposition and nutrient cycling which can ultimately lead to a shift in community structure (NCSU, 2005). While an increase in pH causes organisms to experience ammonia toxicity more readily.

Phosphates and Nitrates

Aquatic plants and animals require both nitrogen and phosphorus to grow. Aquatic systems generally have no more than 0.1 ppm phosphate or nitrate unless the water has become polluted (Tech Alive, 2005). Sources of phosphates in water include human waste discharged from septic systems, animal wastes and agricultural runoff. Different sources of nitrogen include runoff from human or animal wastes and industrial discharges (Tech Alive, 2005).

Excessive amounts of either of these nutrients can accelerate plant and algae growth (i.e. algal blooms), potentially causing the eutrophication of the receiving water body. This accelerated growth of plants and algae will cause a reduction in the dissolved oxygen level, leading to unsuitable conditions for many organisms (NCSU, 2005).

Iron

Heavy metals can be found in the environment because of different natural processes; however, there are also human activities that can cause heavy metal pollution. Different sources of contamination are leachate from landfills and waste from manufacturing processes (Tech Alive, 2005).

Table 5: Water Chemistry Analysis Results for 6th Ring Curichi

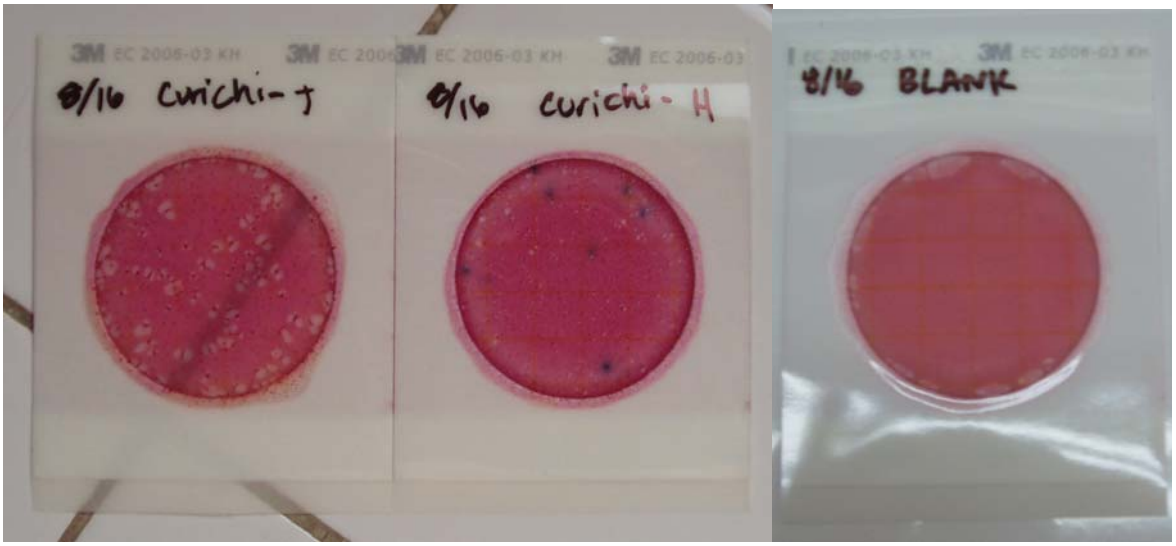
	Results	**Acceptable Levels**
pH	6.5	5-8.5
Nitrates (ppm)	0-0.2	Should not exceed 10 ppm, but any nitrate is cause for concern
Phosphates (ppm)	0.3-0.4	≤0.1 ppm
Iron	0-0.05	0-0.5

***E. coli* and Total Coliform**

Total coliforms are mostly harmless bacteria that live in soil, water and the gut of animals. The amount of total coliforms present in water can indicate the general quality of water as well as the likelihood that the water is fecally contaminated (U.S. EPA, 2002). Total coliform is comprised of fecal coliform and *E. coli*.

These bacteria are found in the feces of humans and other warm-blooded animals may be found in the environment from livestock, birds and other animals, sewage, or in agricultural or stormwater runoff (Tech Alive, 2005). By themselves, these bacteria are not pathogenic, yet they are associated with other pathogenic organisms including bacteria, viruses and parasites that may cause diseases and illnesses. These organisms can be picked up by ingesting water containing disease-causing organisms, or may enter the skin through a cut, or nose and ears. Diseases and illnesses such as typhoid fever, hepatitis, gastroenteritis, dysentery and ear infections are possible in waters with high fecal coliform (Tech Alive, 2005).

There were two samples taken from the 6th Ring Curichi water located in UV 124. Figure 17 below shows the test results. The plate with Curichi sample J has an estimated total coliform count of 15, which is the lower range for the total population on Petrifilm plates (counting range is 15-150). This is an underestimate of the number of total coliform on the plate. The other plate with Curichi sample H has a much higher total coliform count of around ~10^8 because the plate is overgrown with organisms and the colonies are too numerous to count. This was caused by using undiluted water samples that have so many organisms that the colonies do not form proper sizes because they are competing for nutrients (Bagley, 2005). Sample H also has 6 or 7 *E. coli* colonies that did not form gas. This is not unusual because when high levels of coliforms are present, some strains of *E. coli* may produce less gas and blue colonies may be less definitive. The blank sample used distilled water from Saguapac and there was no growth on that plate.



NOTE: Blue colonies with gas indicate *E. coli*;
Red and blue colonies with gas indicate Total Coliform

Figure 17: Results for 6th Ring Curichi water and Blank using 3M™ Petrifilm™ *E. coli*/Coliform Count Plates

Appendix 3: Vegetation identified in curichis located in Districts 9 and 10

Table 6: Vegetation species identified from curichis located in Districts 9 and 10 (Ortiz et al., 2004)

Scientific Name	Family	Form
Cecropia concolor	Cecropiaceae	Tree
Aristoloquia burelae	Aristoloquiaceae	Woody vine (rattan)
Leucaena leucocephala	Mimosaceae	Shrub
Partenium sp.	Asteraceae	Herbaceous
Croton gracilype	Euphorbiaceae	Herbaceous
Acacia aroma	Mimosaceae	Shrub
Prosopis chilensis	Mimosaceae	Tree
Acacia albicorticata	Mimosaceae	Shrub
Hibiscus rosasinensis	Malvaceae	Herbaceous
Jacaranda cuspidifolia	Bignoniaceae	Tree
Lantana camara	Verbenaceae	Herbaceous
Albizia niopides	Mimosaceae	Tree
Juncus sp.	Juncaceae	Herbaceous
Ricinus communis	Euphorbiaceae	Shrub
Abutilon sp.	Malvaceae	Herbaceous
Sida sp.	Malvaceae	Herbaceous
Athalea phalerata	Arecaceae	Palmoide (spanish term)
Passiflora coccinea	Passifloraceae	Woody vine (rattan)
Andropogon sp.	Poaceae	Grass
Melia azederach	Meliaceae	Tree
Tessaria inegrifolia	Asteraceae	Shrub
Phitecellobium saman	Mimosaceae	Shrub
Cordia alliodora	Boraginaceae	Tree
Salix humboldtiana	Salicaceae	Tree
Gomphrena albicans	Amaranthaceae	Rastrera (spanish term)
Annona muricata	Annonaceae	Shrub
Ipomoea sp.	Solanaceae	Aquatic
Eichhornia crassipes	Pontederiaceae	Aquatic
Typha sp.	Typhaceae	Aquatic
Enterolobium contortisiliquum	Mimosaceae	Tree
Tecoma stans	Bignoniaceae	Shrub
Solanum urticans	Solanaceae	Herbaceous
Acrocomia aculeata	Arecaceae	Palmoide (spanish term)

Table 7: Recommended tree/arboreal species for the reforestation projects in Santa Cruz area (Ortiz et al., 2004)

Scientific Name	Family	Form
Cecropia spp.	Cecropiaceae	Tree
Acacia aroma	Mimosaceae	Shrub
Genipa americana	Rubiaceae	Tree
Senna coimbrae	Caesalpinaceae	Shrub
Prosopis chilensis	Mimosaceae	Tree
Erythrina spp.	Fabaceae	Tree
Jacaranda cuspidifolia	Bignoniaceae	Tree
Albizia niopides	Mimosaceae	Tree
Swartzia jorori	Caesalpinaceae	Tree
Solanum mirianthum	Solanaceae	Shrub
Tessaria inegrifolia	Asteraceae	Shrub
Pithecellobium saman	Mimosaceae	Shrub
Cordia alliodora	Boraginaceae	Tree
Salix humboldtiana	Salicaceae	Tree
Annona muricata	Annonaceae	Tree
Enterolobium contortisiliquum	Mimosaceae	Tree
Tecoma stans	Bignoniaceae	Shrub
Melicocca lepidopetala	Sapindaceae	Tree
Pithecellobium angustifoliun	Mimosaceae	Tree
Tabebuia spp.	Bignoniaceae	Tree
Chorisia spp.	Bombacaceae	Tree
Swietenia macrohpylla	Meliaceae	Tree

Appendix 4: Environmental Regulations for Santa Cruz, Bolivia

Table 8: Municipal environmental regulations for Santa Cruz (Parada et al., 2001)

Title	Chapter	Article	Regulation
4	1	19	Municipal jurisdiction in Santa Cruz makes it the legal obligation of all habitants and residents to keep all public areas clean and conduct themselves in a clean way while they are using the areas.
4	1	20	If you have trash collection, it must be bagged and tied, or else it will not be picked up.
4	1	21	Commercial merchants must do the same as in Article 20. They must also provide their own collection bin.
5	1	44	There is to be no abandoning of solid waste in green spaces. Also there is to be no burning in areas of public domain or any other places without permission from the city. There will be no dumping of oils and fuels. There will be no abandoning of any deceased animals or animal waste. There will be no collection of or dumping of the following in bags: explosives, corrosives, toxics, decomposable, infectious, or anything that could have a negative effect on workers or general human health. There is no dumping of metal, wood or glass waste. No building rubbish including, sand, rock, brick, earth, and other debris in public or city owned areas. No dumping of vegetative or garden wastes.
5	2	46	The following describe sanctions and punishments of the preceding violations. Fines and subsequent punishments are increasingly progressive.
5	2	47	If you are guilty of any infraction, you are subject to detainment until you can be charged by the legislative branch of the city of Santa Cruz.

Municipal Decree No. 030/2001