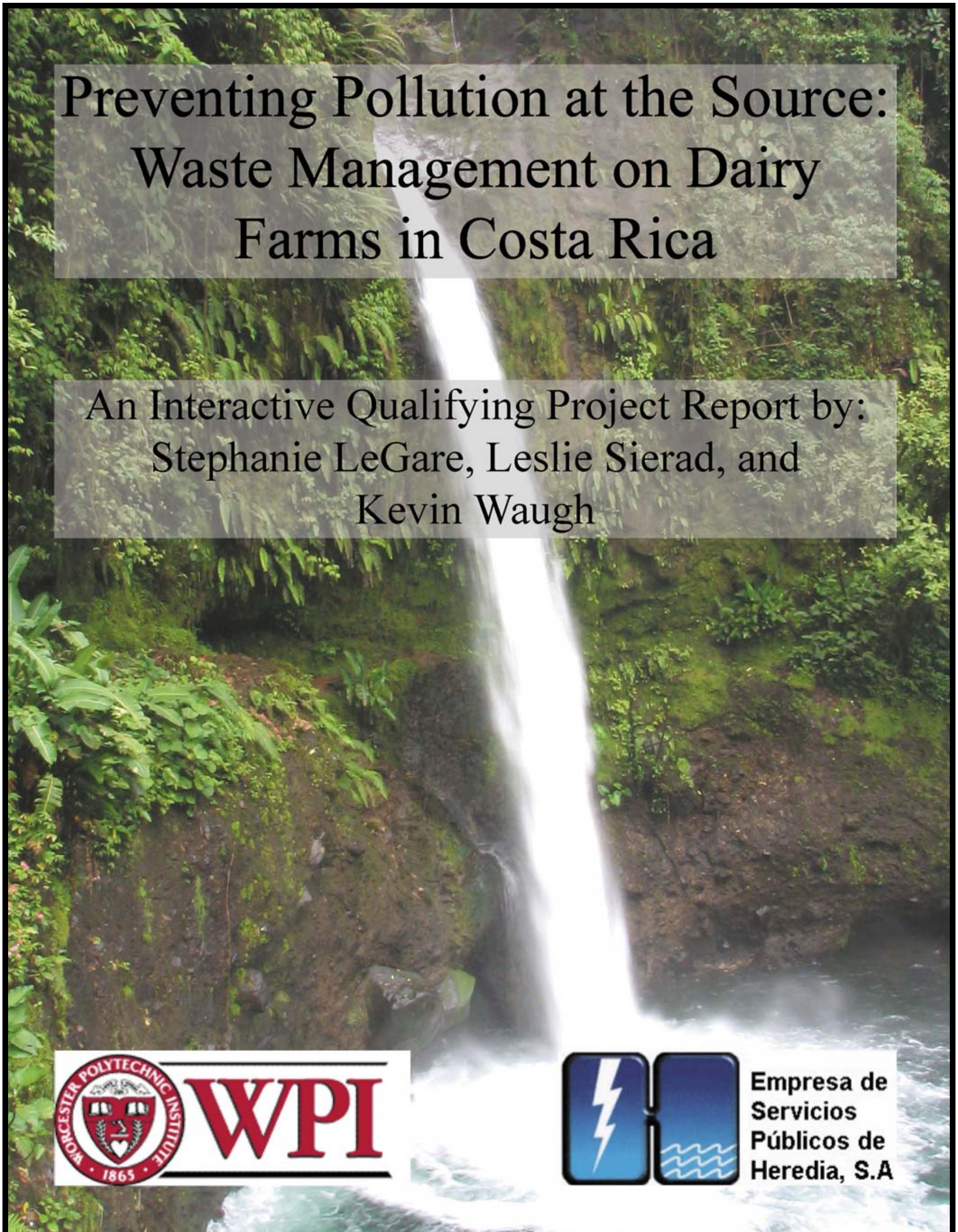
Preventing Pollution at the Source: Waste Management on Dairy Farms in Costa Rica

An Interactive Qualifying Project Report by:
Stephanie LeGare, Leslie Sierad, and
Kevin Waugh



WPI

Empresa de Servicios Públicos de Heredia, S.A

WPI/IGSD
100 Institute Rd
Worcester, MA 01609
U.S.A.

June 5, 2005,

Sr. Luis Gámez
Oficina regional ESPH
De la entrada principal de Iglesia, 50 metros sur
San Rafael de Heredia
Costa Rica

Dear Sr. Gámez:

Enclosed is our report entitled Preventing Pollution at the Source: Waste Management on Dairy Farms in Heredia, Costa Rica. Preliminary research for this report was completed in Worcester, MA, between March 15 and May 14, 2005. Data was collected, and field research, recommendations and conclusions were completed at the Empresa de Servicios Públicos de Heredia during the period of May 15 through July 5, 2005. Copies of this report are being submitted simultaneously to professors Susan Vernon-Gerstenfeld and Arthur Gerstenfeld for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We are grateful for the time and dedication you gave our project.

Sincerely,

Stephanie LeGare
Leslie Sierad
Kevin Waugh

Report Submitted to:

Susan Vernon-Gerstenfeld
Arthur Gerstenfeld

Costa Rica, Project Center

By

Stephanie LeGare	______________________
Leslie Sierad	______________________
Kevin Waugh	______________________

In Cooperation With

Sr. Luis Gámez, Head of the Department of Environmental Management
La Empresa de Servicios Públicos de Heredia
(Public Utilities Company of Heredia) [ESPH]

PREVENTING POLLUTION AT THE SOURCE: WASTE MANAGEMENT ON DAIRY FARMS IN COSTA RICA

July 5, 2005

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of La Empresa de Servicios Públicos de Heredia or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

ABSTRACT

This report, prepared for the Empresa de Servicios Públicos de Heredia (ESPH), investigates methods to prevent the pollution of water caused by wastewater discharge of dairy farms in Heredia, Costa Rica. The report describes how to determine the farming qualities necessary to implement the proposed waste management techniques. Also included are informational pamphlets describing the required farm qualities for each waste management practice. We recommend that dairy farms implement anaerobic digesters and best management practices such as fencing, buffer strips, water troughs, grassed waterways, and diversions to prevent the pollution of the water. Also described is how the ESPH can assist farmers to construct clean technologies by starting a pilot program and providing assistance through the Procuencas program.

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Chapter/Section	Primary Writer(s)	Primary Editor(s)
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We would also like to express our gratitude to Mr. Luis Allan Retana Calvo, our contact from the Instituto Costarricense de Electricidad, who was instrumental in helping us understand the importance of anaerobic digesters in Costa Rica. We greatly appreciated his patience, enthusiasm, and willingness to include us in projects to construct digesters on farms throughout the Sarapiquí region.

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EXECUTIVE SUMMARY

Agricultural pollution in nearly every part of the world is constantly increasing, destroying the quality of drinking water. In the central valley portion of the province of Heredia, Costa Rica, water pollution is mainly due to small dairy farms located on steep mountainsides that pollute water sources with manure. The contaminated wastewater seeps into ground and surface water, introducing nitrates and phosphates that support disease-carrying bacteria. Those bacteria travel with the water to the 47,000 families in the area and have the potential to cause sicknesses such as diarrhea and vomiting to each of the 188,000 people who drink the water daily.

The public utilities company that, among other functions, distributes the water to the population of greater Heredia is the Empresa de Servicios Públicos de Heredia (Public Utilities Company of Heredia) [ESPH]. In order to improve the quality of the drinking water and preserve the environment, the ESPH has developed a program called Procuencas, which is funded by a water tax charged to clients of the EPSH. Procuencas focuses on the prevention of pollution at its source rather than on the treatment of water after it is contaminated. The program pays landowners to protect valuable water sources through either land conservation or reforestation with native species.

Our group's goal was to assist the ESPH in expanding the Procuencas program to include the implementation of clean technologies, also known as waste management practices. Clean technologies are manufacturing processes or product technologies that reduce pollution, waste, energy use, or material in comparison to the technology they replace. The waste management practices we recommended include polyethylene

anaerobic digesters and best management practices. Best management practices are practical and affordable approaches to conserving a farm's soil and water resources without sacrificing productivity.

Clean technologies provide an additional means for the ESPH to improve water quality by preventing dairy farms from discharging waste into water used for human consumption. Those technologies also allow each farmer to take an active part in preventing pollution of the water in the community, allowing him to visualize the value of environmental protection on his farm.

To inform the ESPH and dairy farmers of the best uses of clean technologies and other waste management practices for farms in Heredia, we first spent seven weeks at Worcester Polytechnic Institute in Massachusetts researching waste management techniques that farmers use worldwide. For another seven weeks, we conducted research in Costa Rica, observing the current situations and identifying waste management methods that would be feasible to introduce in Costa Rica. We used propulsive sampling to choose eight sample farms for our field research. We collected information at each farm about terrain, bodies of water, livestock, farming practices, and pollution sources by filling out observation forms and taking pictures. We used our information to classify the farms by their size and the potential amount of waste they produced, which helped us determine which waste management strategies would be most appropriate for each farm.

We also interviewed the farmers to assess their willingness to participate in a program that would help them implement clean technologies such as anaerobic digesters and best management practices. In addition to farmers, we contacted four field experts in waste management practices from government and private organizations to determine the willingness of those parties to aid the farmers in implementing proper waste management strategies and to gain information about the techniques.

After collecting the data, we determined the viability of success of different waste management techniques in Costa Rica through cost benefit analyses, examinations of environmental impacts based on how much waste was prevented from entering the water sources, and return on investment evaluations. Using this data, we determined that the most viable clean technologies for Costa Rica include anaerobic digesters and best management practices including fencing, buffer strips, diversions, water troughs, and grassed waterways.

To understand more of how our project would help the families of Costa Rica, we assisted the Instituto Costarricense de Electricidad (Costa Rican Institute of Electricity) [ICE] to install anaerobic digesters for two of their customers. While constructing the digesters we were able to see first hand how our project will affect similar families in the service area of the ESPH.

While constructing the anaerobic digesters we discovered that most new technologies need a pilot program to create interest and that interest is spread by word of mouth. We used this understanding to help us develop our recommendations for the ESPH. First, we determined that the ESPH should create one or more pilot programs on farms in Heredia. Second, we provided pamphlets for the ESPH to help spread the word and interest in each of the recommended clean technologies.

Third, we recommended that the ESPH use the information we collected and the data from our cost analysis to develop a format for a clean technologies program to implement in conjunction with the current Procuencas program. The new addition to the program will make it easier for interested farmers to implement waste management practices and thereby improve their farms. The format of the new program includes the most efficient types of waste management techniques for farms in Costa Rica, suggestions for additional funding from the ESPH water tax, recommended contract length and terms, and materials that will help the ESPH promote the benefits of each clean technology. When implemented, the clean technologies program will allow the ESPH to fulfill its goal to provide quality drinking water to the population of Heredia. The program will also help farmers actively prevent water contamination and increase the community's value of environmental protection.

In addition to the recommendations for the ESPH, we made recommendations for farmers to change their management practices in order to improve production on their dairy farms and to assist them in efficiently implementing clean technologies. The recommendations will enable the farmers to increase their biogas production while using polyethylene anaerobic digesters and save money on their farms. These changes, in coordination with the clean technologies of the Procuencas program, will enable farmers to comply with Costa Rica's environmental laws and help them actively prevent pollution at its source.

CHAPTER ONE: INTRODUCTION

The number of people inhabiting this world is increasing and agricultural production is constantly expanding to compensate for the increase in food demand. As a result, agricultural waste is a growing problem in many countries because it causes groundwater contamination that leads to illness and disease (Madison, 1991). In order to decrease the deaths caused by water related illnesses, a community needs clean resources and a healthy surrounding environment (Kimball, 2004). Communities that do not implement measures to prevent the contamination of surface and groundwater by agricultural waste develop illnesses and diseases that affect local populations. If the contaminations spread, they can affect the health and cleanliness of the world population. Thus, the need is rising for clean technologies (see Glossary) and renewable energy options, such as anaerobic digesters, composting, and best management practices (see Glossary) that can safely control the waste and pollution created by agricultural production.

Researchers have conducted studies of groundwater contamination from agricultural practices worldwide. Farm studies in Canada show that the majority of contaminated groundwater comes from dairy farms, which deposit manure in places that are close to flowing surface water. There, the manure seeps into the groundwater supply (Crowe, McGregor, Ptacek, & Rudolph, 2002), introducing nitrogen, phosphorus, bacteria, and many other contaminants into the water (Agricultural Sources of Contamination, 1998).

Similarly, China has been having problems with agricultural groundwater contamination for years. There, the current irrigation systems are failing and the government plans to increase the food output of the country by fifty billion kilograms in the next few years (Guang-xin, Z. and We, D., 2002). Using approximately seventeen percent of the world's fresh water for agriculture (Guang-xin, Z. and We, D., 2002), China has a need for agricultural waste management practices (see Glossary) that prevent the contamination of drinking water.

Researchers from the Instituto Costarriense de Acueductos y Alcantarillados (Costa Rican Institute of Aqueducts and Sewers) [AyA] and the Universidad Nacional de Costa Rica (National University of Costa Rica) [UNA] have discovered results similar to the studies from Canada and China. Water is originating in the mountains, collecting contaminants while traveling through farmland, and becoming the main water source for many Costa Rican cities (Universidad Nacional de Costa Rica, n.d.; Bolaños, n.d.).

In 2000, the Empresa de Servicios Públicos de Heredia (Public Utilities Company of Heredia) [ESPH] (see Appendix A) in Costa Rica responded to the problem of groundwater contamination by starting a program called Procuencas. Procuencas pays landowners to either keep land undeveloped or to regenerate forests by planting native species in strategic areas of the watershed (see Glossary). The soil and root systems of the native vegetation help filter out some of the contaminants by absorbing the excessive nutrients that the water collects after running through farmland.

Maintaining undeveloped areas and encouraging regeneration to filter contaminants out of the groundwater helps, but it is not enough. Those methods are only partially effective because not all of the nutrients are absorbed as the water filters through the soil. The ESPH wants to develop a method to prevent surface and groundwater contamination before it occurs. This is necessary to provide cleaner water for the inhabitants of the country.

Our goal was to assist the ESPH in expanding the Procuencas program to include the implementation of clean technologies as an additional means of improving water quality by preventing the dairy farms from discharging waste into water used for human consumption. Our objectives were first to review worldwide waste management techniques and identify methods applicable in Costa Rica. Second, we determined the viability of management techniques through cost-benefit analyses and an examination of environmental impacts. Finally, we made recommendations to control wastewater and manure through clean technologies on dairy farms.

In most cases, waste management plans are highly tailored to individual farms. In Heredia, most dairy farms consist of less than one hundred cows and a few other animals. The farms are often located on the higher portions of the watersheds and have steep slopes and varying terrain (Umaña Román, 2000). Many of those farms are secluded and the disposal of their waste is not monitored or regulated. Although the pollution of one small farm may pass unnoticed, the combination of many small farms in the watershed can create a much larger problem of water contamination in Heredia (Umaña Román, 2000).

Our research about farms in Heredia included how much waste and manure is produced by each farm and how many farms contribute to the contamination. We also investigated how farmers currently use, store, or dispose of manure, and the willingness of farmers to change their practices to assist in water pollution prevention. Finally, we created a means to classify dairy farms in Heredia based on their size, location, terrain, and amount of waste produced. The classification criteria will aid the ESPH in determining which technologies are appropriate for each farm.

Our recommendations for the ESPH include projected costs and needed materials for implementing clean technologies, probable locations for clean technology projects, and a description of the necessary responsibilities for the ESPH and their clients within the program. Our recommendations for the farmers include methods of increasing the amount of collectable manure for the use of anaerobic digesters. We have also created pamphlets for each of our recommended clean technologies and a checklist for determining the viability of each clean technology on a farm. The pamphlets will help the ESPH and the dairy farm owners to decide which of the waste management strategies will be most appropriate for each farm. In addition to our recommendations, we included recommendations future projects that would help the ESPH expand on our research and continue to improve the quality of drinking water.

Our recommendations focus on alternative means of waste management, including different methods of collection, storage, and land application. The pertinent clean technologies include small-scale polyethylene anaerobic digesters and best management practices for dairy farm wastes. Anaerobic digesters produce a gas composed mostly of methane, which is commonly called biogas, through the decomposition of manure that farmers can collect and use as a clean energy source. Farmers can build digesters on individual farms, or entire communities can contribute wastes to a regional anaerobic digester. Each farm in Heredia can also implement best management practices to control and divert wastewater to prevent it from entering crucial water sources.

The proposed clean technology solutions provide benefits for their users beyond environmental quality. The farmers can use the biogas produced by anaerobic digesters in kitchens for cooking or on other parts of the farm for operating machinery. The biogas also saves the average farmer 7,000 colones ($15)[1] or more a month by eliminating propane costs. In addition, properly implemented best management practices, such as fencing and buffer strips, will ensure that farmers avoid the fines of up to 100,000 colones ($210) for discharging waste into the water supply.

By implementing a clean technologies branch of the Procuencas program, the ESPH will help farmers of Heredia do their own part in environmental conservation. The farmers will also reap the benefits of a renewable energy source. To start the widespread diffusion of these technologies, the ESPH needs a catalyst. Starting a pilot program in Heredia will help farmers visualize the monetary and environmental benefits of clean technologies. The initial implementation of these technologies in Heredia will immediately improve the water quality and overall health of the families around those farms, who drink directly from contaminated streams.

Word of the success of ESPH's Procuencas program will allow Heredia to become a model community for proper waste management in Costa Rica. The program will aid in increasing the widespread use of clean technologies and allow other farming communities throughout Costa Rica and the rest of Central America to use Heredia as an

[1] All USD to colones conversions calculated at a rate of 1 USD = 476.200 Colones on June 13, 2005 from the Universal Currency Converter at http://www.xe.com/ucc/convert.cgi

example of the benefits of environmental conservation. The use of the same technologies will soon begin to spread to every continent, thereby aiding in the prevention of the contamination of surface and groundwater all over the world, and improving the health and cleanliness of the world population.

CHAPTER TWO: BACKGROUND

Waste management is the processes involved in dealing with the refuse of humans and other organisms, including minimization, handling, processing, storage, recycling, transport, and final disposal of wastes (Webster's New Millennium Dictionary, 2004). Proper dairy farm waste management requires that minimal manure or other waste enter the ground or surface water of the area. This prevents nitrates and phosphates from contaminating the water and supporting bacteria that carry diseases and cause illness.

To improve the future applications of waste management in Costa Rica, it is important to understand the current background and methods of waste management. The background includes the history of dairy farming and waste management, its purpose and how it has changed today, the regulations regarding waste discharge, and the impacts of bad or good water quality. We discuss the methods through an investigation of waste management practices used worldwide. We also explain the clean technologies that are applicable on dairy farms including anaerobic digesters, composting, buffer strips, and other best management practices. We include the benefits and drawbacks for each of these types of waste management. We also provide the analysis that includes how we have eliminated certain types of waste management methods based on the ability to apply them on dairy farms in Costa Rica. Finally, we discuss the trend by which people adopt innovations.

PROCUENCAS: THE ESPH'S POLLUTION PREVENTION PROGRAM

In 2000, the ESPH responded to waste management and water pollution by creating a program called Procuencas. Procuencas encourages landowners to protect natural existing forests and open land located on the higher parts of the watersheds that provide drinking water to Heredia and surrounding towns (ESPH 2003; Bolaños, n.d.). As part of the program, landowners agree to preserve forests by not cutting down trees or building on protected land. As a second option, owners may opt to start regeneration of native species in the area (Empresa de Servicios Públicos de Heredia, 2003).

The Procuencas program is funded by the tarifa hidrica (see Glossary), a water tax paid by all water users that are clients of the ESPH. The tax, which is 3.8 colones per cubic meter ($0.008/m^3), provides money for the ESPH to compensate landowners who participate in the Procuencas program. Some financial assistance is also provided by the Ministerio del Ambiente y Energía de Costa Rica (Ministry of Environment and Energy of Costa Rica) [MINAE]. The use of a water tax allows the ESPH to internalize environmental protection costs and distribute that cost and its responsibility to all members of the community (Bolaños, n.d).

The compensation given to landowners who participate in the Procuencas program is equal to the cost of opportunity for land use determined by the ESPH (Bolaños, n.d). Landowners involved in the forest preservation program sign a contract for ten years and are compensated 47,720 colones per hectare ($100/ha) every year. Landowners who participate in the native species regeneration program sign a contract for twenty years and are compensated 450,000 colones per hectare ($950/ha) every five years (Gámez, 2005). The native-species planting program pays a larger amount to landowners because it requires more effort and a greater initial compensation to purchase materials and plants for reforestation.

Reforestation is the preferred method of environmental protection in the current Procuencas program because it regenerates the natural habitat of the area, prevents erosion and groundwater contamination, and allows landowners to take an active part in protecting the environment. Unfortunately, fewer than five percent of the 1190 hectares protected by Procuencas are contracts for reforestation. Luis Gámez, who is the head of the Department of Environmental Management for the ESPH, speculates that the landowners lack interest in the regeneration program is because native species that grow well in that area are not commercially valuable (Gámez, L., personal communication, June 22, 2005).

The ESPH is currently working on revising the Procuencas program to create more interest in native species regeneration. They are developing a plan that allows landowners who participate in regeneration program to switch contract types to a preservation program after seven or eight years. This is possible if the landowners' work has created enough rapid growth that the forest will continue to grow when the landowner switches to the preservation program (Gámez, L., personal communication, June 22, 2005). The ESPH believes that this change in the Procuencas program will create more interest in the regeneration program because the landowners would receive a yearly compensation for the trees they planted under the regeneration contract. It would also further the ESPH's goal by improving the environment and providing for a cleaner area of the watershed.

The objectives of the Procuencas program are also to conserve and recover sources for drinking water for the EPSH as well as to protect the surface and groundwater of the aquifers. Protecting the forest areas allows contaminants to filter out of the water while passing through the soil as well as prevent new contaminants from entering due to new developments (Empresa de Servicios Públicos de Heredia, 2003). In addition, the ESPH hopes that the Procuencas program will encourage landowners and the community of Heredia to place a higher value on protecting water resources as well as giver them an opportunity to take an active part in protecting the environment (Bolaños, n.d).

DAIRY FARMING IN HEREDIA

Heredia is located in the Central Valley area of Costa Rica. Forty years ago, the area of Heredia had a large concentration of dairy farms. Today, the number of active dairy farms in Heredia is decreasing due to increased costs of production and access to better farmland in other areas of the country (Umaña Román, 2000; Gámez, L., personal communication, May 16, 2005). Most of the remaining farms in Heredia are small and family-owned and only have the ability to take care of forty or fewer cows (50 Acre Dairy Farm, 2005).

Unlike in the United States, Costa Rican farmers rarely corral their cattle in barns. Instead, farmers allow cattle to roam on fenced pastures because the climate of Costa Rica is excellent for constant grazing (Ritchey, 2005). The farmers milk the cows twice a day, once every twelve hours. Milking time is often the only time when cows are kept in barns. Many of the farms only produce enough milk products for the family and do not sell any of what they produce to outside sources.

In Costa Rica, farms are smaller and have less revenue compared to those in the United States (Salary, 1998). Because dairy farming provides a limited income, a portion of the small farms in Heredia are now run as more of a hobby rather than as a primary source of income.

HISTORY OF WASTE MANAGEMENT

Before the 1970s, managing waste on farms was not a high priority (Umaña Román, 2000). The harmful effects of farm waste seeping into water were not known as they are today (Umaña Román, 2000). In the United States, when populations of fish and other aquatic life began dying in large quantities, researchers in Wisconsin discovered that excess amounts of sediments and nutrients, such as nitrates and phosphates, coming from agricultural practices were contaminating the ground and surface water that ran through farmland (Scanlan, 2005; DeVore, 2005). The disease-causing microorganisms present in the runoff water from livestock facilities were causing the fish deaths and creating hazards for human health (Scanlan, 2005). Similar discoveries have surfaced in Canada, China, Indonesia, Germany, and several other countries worldwide.

In response to the discovery of water contamination, researchers and farmers in affected countries started investigating ways to prevent contamination of the water. They discovered that both wind and water transport sediments. Contaminants can move into surface water when attached to eroding sediments, suspended in air, or dissolved in runoff water (Hilliard & Reedyk, 2000). Wind also moves odors, which environmentalists consider a special class of pollutant. Dissolved compounds can leach into groundwater supplies. All of these contaminates are present on farms, and they threaten the quality of the surrounding water (Hilliard & Reedyk, 2000).

As part of their investigations, the researchers have developed several techniques that successfully reduce the amount of waste entering the water supply. The challenge is now to apply the techniques worldwide. For example, researchers worldwide have been studying the use of anaerobic digesters on farms as a means to control waste and provide a renewable source of electricity for their users (Nelson & Lamb, 2002). Interest in anaerobic digesters has gained momentum over the last decade as the technology has become more reliable and farmers have proven it successful (Martin, 2003; Nelson and Lamb, 2002; Kramar, 2002). That technology, in hand with legislation and government funding that many countries implement for clean technologies, has caused the use of anaerobic digesters on farms to increase in Costa Rica by 200 percent in the last three years (Gámez, L., personal communication, June 22, 2005). In addition to anaerobic digesters, farmers have become more aware of types of vegetation that can filter contaminates, composting methods to create high quality fertilizer for agricultural use, as well as many more best management practices.

The Environmental Protection Agency [EPA] and the United Stated Department of Agriculture [USDA] has established guidelines for farmers to assist them in implementing proper waste management techniques. The Costa Rican government is also aware of the need for environmental conservation and protection of drinking water sources. Laws such as the Ley General de Salud [#5395] (General Health Law), the Ley de Conservación de la Vida Silvestre [#7788] (Wildlife Conservation Law) and several executive decrees strictly prohibit the dumping of wastewater in bodies of water and other “acts that can produce contamination or sanitary deterioration of water used as a drinking source” (La Gaceta, 2003). As a form of additional protection, the Ley Forestal (see Glossary) [#7575] (Forestry Law) declares specific areas of protection where farmers cannot cut trees or build structures along riverbanks and other permanent water sources (Fundes, n.d.)

In addition to those laws, the regulations for classification of land use state that land with a slope greater than thirty percent is not suitable for agriculture or pastures. Land with slopes between fifteen and thirty percent can only be used for agriculture and pastures if extreme soil conservation methods are in place (Umaña Román, 2000.) Despite these guidelines, it is extremely common to see cattle and agricultural crops in Costa Rica on slopes with grades much larger than thirty percent.

Due to a limited workforce, the majority of Costa Rica’s laws that regulate water pollution and land use are not enforced. Many of the farms are small, family run, and located in secluded areas that are not easily accessible. Farmers are often unaware of the environmental laws or disregard their mandates due to the lack of consequences. The penalties for breaking these environmental laws, which range from fines of 50,000 to 100,000 colones ($105-$210) or three months to three years in prison, are rarely assessed (Umaña Román, 2000; Gámez, L., personal communication). Rather than focus on the failure of legislation to protect water sources, the ESPH works to provide means for individual farms to properly dispose of waste and prevent water contamination at its source.

TYPES OF WASTE MANAGEMENT

Although waste management is described as the process of dealing with the waste of humans and organisms, not all waste management methods prevent pollution. Environmentally conscious waste management actively implements measures to prevent the contamination of air, water, and soil. Hilliard & Reedyk (2000) emphasize that prevention of pollution at its source is the most effective and widely implemented method of reducing contaminants. Farmers can combine several waste management techniques to create an effective program that prevents their farms from adding to ground and surface water pollution problems. In addition, a few of these waste management methods provide the opportunity to produce byproducts such as biogas, electricity, or fertilizer, which farmers can sell to make a profit or use to save money.

Anaerobic Digesters

An anaerobic digester uses bacteria in the absence of oxygen to break down organic material, converts decomposed matter to organic acids, and then turns the acids into biogas, which is composed of primarily methane and carbon dioxide (Energy Savers, 2003; Anaerobic Digestion, 2003). Farmers can then capture the biogas and use it as a source of renewable energy to minimize greenhouse gas emissions. For example, they can use biogas for heating, cooking, and operating an internal combustion engine for mechanical and electric power (Zhang, 2004).

Anaerobic digesters also have environmental benefits. They have the ability to reduce the pathogens such as E. Coli, cryptosporidium, and pfiesteria that are often present in manure (Moser, n.d.). Those pathogens are one cause of water pollution in bodies of water that run through farms. Digesters stabilize the nitrates and phosphates that support pathogens to levels that are not harmful to humans, but are still available to plants (Moser, n.d.). Thus, the digester byproduct becomes a very effective fertilizer. The fertilizer is more effective than raw manure because it contains high concentrations of ammonia and almost no pathogens (Nelson & Lamb, 2002). Finally, the digester reduces odor and the number of pests such as flies and mosquitoes. Some research shows that anaerobic digesters may also destroy the weed seeds in untreated manure (Nelson & Lamb, 2002).

Since the majority of cattle in Costa Rica do not stay in barns, they deposit their waste on the pastures and into the streams and other water sources (Ritchey, 2005). For this reason, the collection of manure for anaerobic digesters is often difficult and inconsistent. To maintain the bacteria necessary for anaerobic digestion, farmers must collect fresh manure year-round, with a relatively stable manure yield in all seasons. They must collect the manure within twenty-four hours, before it dries, and in most cases insert it into the digester twice daily. Therefore, the anaerobic digester may require additional attention or a change in management practices such as keeping the cattle in the barn for most of the day so that farmers can collect more manure. A designated technician that can troubleshoot problems and maintain the digester while it is in use may also be necessary, depending on the complexity of the system.

Most waste processed by digesters has a high content of water because farmers flush it through a plumbing system from their milking barns before it reaches the holding tank. Some waste, however, enters the digester with a higher concentration of solids because farmers add manure directly to the holding tank. When adding waste to the tank, farmers must be sure to regulate the amount of water they flush into the digester to ensure an appropriate concentration of solids.

In order to increase the amount of biogas generated by each digester, farmers can add other organic materials such as leaf litter or grasses, depending on the type of digester. Many of the systems will also digest portions of bedding, usually consisting of wood chips or newspaper shredding (Nelson & Lamb, 2002). Some types of livestock bedding are incompatible with the anaerobic digesters and cause clogging. Farmers who use bedding in their milking stalls may need to consider changing their bedding types to be more biodegradable when implementing anaerobic digester technology.

Farmers can implement an anaerobic digester for liquid, slurry, or semisolid manure. There are several types of anaerobic digesters that farmers can use for manure such as the plug flow, complete mix, and polyethylene digesters (Nelson & Lamb, 2002) (see Appendix C). Each type has unique qualities that provide for the different consistencies of manure, amount of manure available, amount of income available to implement a digester, and others.

In countries with tropical climates such as Cambodia, Thailand, Vietnam, and Costa Rica, as well as in many others, farmers use small-scale, continuous flow polyethylene anaerobic digesters (see Appendix C) (Rodriguez and Preston, n.d.). The polyethylene digester is the cheapest and simplest way to produce biogas for small-scale farms. The tropical climates of those countries provide the necessary heat for the decomposition of the waste. These digesters work very well in the rural communities of those countries because of their low installation costs, ease of installation in any terrain, and small size. Their lifespan is approximately five years, but they can last up to ten with proper maintenance.

In the United States, some farmers collect biogas and convert it into a renewable source of electricity through combustion. According to Nelson and Lamb (2002), one plug flow digester on the Haubenschild dairy farm in Minnesota produces enough electricity to power the entire farm and seventy-five average homes with the manure from 500 cows. The ability of these digesters to produce large amounts of electricity provides the opportunity for buyback programs from the electricity companies. With a buyback program, a digester on a large farm can pay for itself in as little as five years when working at optimum capacity (Nelson & Lamb, 2002). Unfortunately, investigations show that electricity generation is usually not effective for farms with less than 250 cows because there is not enough waste to continually fuel the digester (AgSTAR Handbook, 2004; Nelson & Lamb, 2002). In addition, the large digesters required for electricity generation, such as the plug flow digester, have high initial startup costs that the majority of farmers in Costa Rica cannot afford.

Some farmers in Europe and the United States have remedied the problems of high starting costs and lack of manure by building regional anaerobic digesters. This strategy reduces the cost of the digester to each individual by dispersing it among the participants. The regional digesters collect waste from small farms within a fifteen-mile radius (Moser, 2004; Cove Area Regional Digester, 2004). One community in Washington, USA even collects organic waste from high population facilities such as schools, jails, and food processing plants to add to the digester (Moser, 2004). Communities must use caution when using waste from public facilities and private septic systems because some cleaning supplies could kill the bacteria in the digester that breaks down the waste.

The limiting factor when running a regional digester is the high cost of collecting and transporting the waste from each individual location (Moser, 2004). Because Heredia is a very mountainous region and most dairy farms are located on steep hillsides, it may be possible to reduce transportation costs by allowing the waste to flow naturally through pipes or a drainage system down the steep hills and into a digester. This would avoid the necessity to transport the waste on the small, dirt, mountain roads on which many of the farms are located.

Determining whether farmers will be able to implement an anaerobic digester on a farm, or contribute to a regional digester is highly dependent on how manure is collected, the size of the farm, the location of the farm, the ability of the farmers to provide maintenance for the digesters, and available funds for implementing the project. All of these factors are very farm-specific and each farm must consider them when tailoring their own waste management program.

Composting and Covered Lagoons

Composting is the process of collecting organic waste in an area and allowing that waste to decay naturally (Manitoba Clean Water Guide, n.d.). It is necessary to line areas containing composting waste with impermeable materials, such as concrete, to prevent leaching into the groundwater. By allowing the waste to compost, bacteria consume most of the harmful contaminants as they break the waste down. When the waste is composted completely, it can be applied to agricultural crops or gardens as a fertilizer with no threat to the groundwater.

A variation of composting is to create a lagoon – a collection of manure, water, and other organic waste. Lagoons function best with a concentration of two percent or less solid waste (Nelson & Lamb, 2002). Impermeable covers capture biogas produced by the decomposition of the waste, which farmers can then use as a renewable energy resource. The covered lagoon system is similar to an anaerobic digester. Lagoons do not require an outside source of heat, but biogas production will vary with seasonal temperature changes (Zhang, 2004). Although the lagoon is simple and one of the least expensive methods of anaerobic digestion in the United States (Nelson & Lamb, 2002), it is much more expensive, requires much more space, and is less efficient for methane generation than the polyethylene anaerobic digesters used in tropical climates. Since a covered lagoon requires a large and flat area, there may not be adequate space to construct one on a small farm in Heredia.

Contour and Filter Strips

Contour and filter strips provide a natural method of reducing harmful runoff (United States Department of Agriculture, 1999). Contour buffer strips are the planting of trees, shrubs, or dense grasses along the contours of a slope or riverbank in several rows (United States Department of Agriculture, 1999). Thick strips of trees or shrubs that have dense root systems are able to capture and use sediments and nutrients that are flowing through them. As long as the roots grow fast and disperse widely, contour planting is partially effective at removing nutrients from runoff water along slopes

(United States Department of Agriculture, 1999). Filter strips are similar to contour strips, but are placed anywhere in a field instead of solely along slopes. In addition, when planting strips along streams and rivers, the roots from the plants hold the soil in place and reduce erosion of the banks (United States Department of Agriculture, 1999). The majority of farms in Costa Rica already have a riparian (see Glossary) buffer zone surrounding major water sources, which is ensured by the regulations of the Ley Forestal. Additional buffer strips can increase the effectiveness of those areas and can potentially replace traditional fencing without taking up more space.

Contour and filter strips are not an effective primary means of waste management. Instead, contour and filter strips are more efficient as a secondary method to filter contaminates that primary waste management techniques are unable to remove. According to the United States Department of Agriculture (1999), those strips should be used in combination with other waste management techniques because they are unable to absorb nitrates and phosphates fast enough to neutralize all the harmful effects of the pollution in the wastewater. This is particularly true in the area of Heredia, where steep slopes cause water to run downhill at high velocities. It is also difficult to plant enough strips of vegetation along the entire length of a stream or river that passes through farmland to create a sufficient change in pollutant concentration.

In Costa Rica, contour and filter strips may be useful in combination with other waste management techniques, particularly in areas with large slopes. Since it is difficult to implement them along entire lengths of water sources, it may be more logical to plant vegetation in key areas for removing pollution from water, such a areas where pollution sources are within one hundred meters of the water source.

Best Management Practices

Best management practices help prevent pollution by reducing the amount of waste introduced to water sources and minimizing risks to the environment without requiring high initial and maintenance costs (Hilliard & Reedyk, 2000). There are many different types of best management practices. Some require farmers to change the way they manage their livestock, such as setting up fencing and providing water troughs. Others involve removing contaminants from waste through composting, planting contour buffer or filter strips, providing for diversions of water run off, or creating grassed waterways (Animal Feeding Operations, 2004). All of those best management practices are easy to implement and are relatively inexpensive. They are also effective on small farms that do not have large volumes of waste and contaminants.

Fencing

Allowing cattle to wade in bodies of water, such as streams, directly introduces livestock waste into the water and causes erosion (Animal Feeding Operations, 2004). This rapidly increases the rate of pollution. Instead of allowing cows to drink directly from the water, farmers should set up fences that keep the cattle out of bodies of water, and introduce water troughs as a replacement water source (Animal Feeding Operations, 2004). Although it may be an inconvenience for farmers to fill water troughs daily, this practice is important to prevent waste from directly entering the water and reducing erosion.

In Costa Rica, a common form of fencing is the “live post” which uses trees and shrubs as a fence-like barrier. Those posts grow rapidly and do not need any additional attention to survive. Farmers frequently cut off the tops and placed them into the ground to grow roots and become more posts. Those live posts serve as a dual purpose – as fencing and as buffer strips to absorb excessive nutrients in crucial areas. Figure 1 shows an example of how farmers use live fence posts to separate pastures on many dairy farms in Costa Rica. To ensure that the cows cannot escape through gaps in the fence, barbed wire is connected to the live posts to create a fence-like structure similar to barbed wire fences with dead posts.

Figure 1: Live Fence Posts

Diversions

Diversions are physical barriers that divert runoff water from directly entering a water system. The physical barriers can include trenches or a dense planting of trees or shrubs (United States Department of Agriculture, 1999). Diversions can lead water to a natural nutrient filter such as a forest or to manmade lagoons or an anaerobic digester. A difficulty with diversions is keeping the water traveling in the desired path, especially with large amounts of runoff-water.

In Costa Rica, diversions are used to prevent rainwater from washing away roads, such as the diversion on Figure 2. Farmers can use similar diversions near their milkig barns or along the banks of streams to prevent wastewater from entering water sources.

Figure 2: Roadside Diversion

Grassed Waterways

The department of environmental quality of Michigan (Grassed Waterways, 1992) states that grassed waterways are areas that consist of thick vegetation and accommodate concentrated flows of water while preventing erosion. They can be either natural or manmade. Grassed waterways cover the soil with vegetation, thereby slowing the incoming water, and protecting the soil (Grassed Waterways, 1992). Because of this, they are capable of accepting water that has a high initial velocity, which is ideal for areas with large slopes such as in Heredia. Grassed waterways are also able to retain excess surface water coming from diversions and other natural drainage (Grassed Waterways, 1992). Planning grassed waterways carefully helps avoid flooding and waste overflow. If water and waste overwhelm those grassed waterways, their purpose will be defeated (Grassed Waterways, 1992).

All farmers can reduce the amount of pollution introduced to the environment by implementing best management practices. Which practices are implemented depend on the circumstances of each individual farm. Our field research helped us to identify which types of farms will be able to implement each type of best management practice.

DIFFUSION OF INNOVATION

Diffusion is the process by which an innovation, in most cases a new technology, is communicated through channels over time among the members of a social system (Rogers, 1995). Given that decisions are not authoritative or collective, each member of the social system faces their own innovation-decision that follows a 5-step process: knowledge, persuasion, decision, implementation, and confirmation. The knowledge step describes when a population becomes aware of an innovation and has some idea of how it functions. Persuasion occurs when the potential user forms a favorable or unfavorable attitude toward an innovation. The decision step describes when the user engages in activities that lead to a choice to adopt or reject the innovation. The implementation step occurs when the user puts an innovation into use. Confirmation describes the process by which the users evaluate the results of an innovation-decision already made (Rogers, 1995).

The most prominent feature of diffusion theory is that, for most members of a society, the innovation-decision depends mostly on the innovation-decisions of the other members of the society. Rogers (1976) shows that the successful spread of an innovation follows an S-shaped curve. There is, after about a quarter of society adopts an innovation, a relatively rapid adoption by the remaining members and then a period in which the people holding back finally adopt.

The innovation-decision is made through a cost-benefit analysis where the major obstacle is uncertainty. After considering every aspect, people will adopt an innovation if they believe that the benefits will enhance their convenience. They must believe that the innovation may yield some relative advantage to the idea it supersedes (Rogers, 1995; Xuan An, 2002). In addition to the downside of the costs, people also determine to what degree the innovation would disrupt other aspects of their daily life. They investigate the compatibility with existing habits and values. They want to know if the innovation is difficult to use or how other community members will view them if they make the drastic change of adapting the technology.

For a successful innovation, the adopter distributions follow a bell-shaped curve, which is the derivative of the S-shaped diffusion curve (Rogers, 1976). Diffusion scholars divide this bell-shaped curve (see Figure 3) to characterize five categories based on the innovativeness, where the scholars define innovativeness as the degree to which an individual is relatively earlier in adopting new ideas than other members of a system. These groups are innovators, early adopters, early majority, late majority, and laggards (Rogers, 1976).

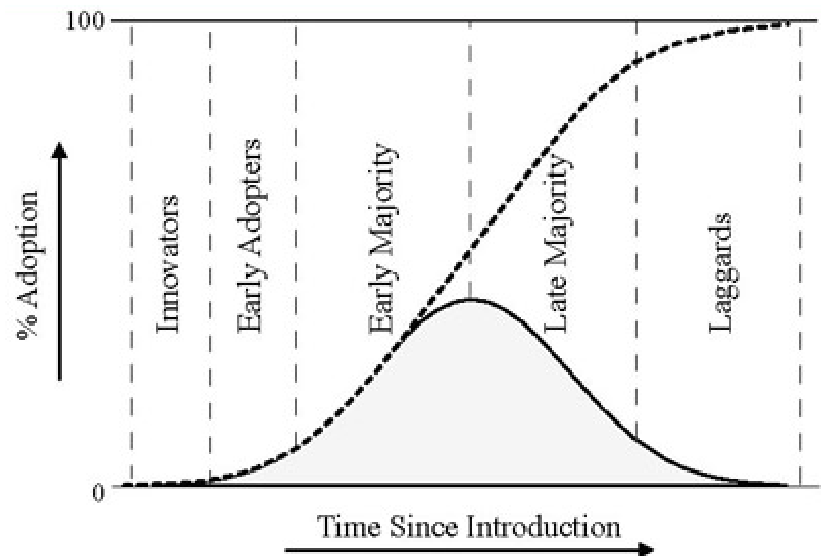


Figure 3: Adoption of Innovation Curve

Source: (Medscape, n.d.)

The innovators act as leaders that spread the word on how an innovation works and do not need any convincing that the innovation will benefit them. Without an effective catalyst like the innovators, the process would never get past the uncertainty of adopting an innovation.

It is important to understand the diffusion and adoption of innovations and new technology in order to implement agricultural waste management strategies in Costa Rica. Many Costa Rican farmers face doubts and obstacles that prevent them from adopting a new technology, which mostly revolve around the implementation and operation costs. Therefore, if the technology is economically beneficial, farmers are more likely to adopt it and spread throughout society. There has to be an obvious advantage for the farmer to implement a new technology, and there has to be some guarantee that the technology will continue to work (Xuan An, 2002). Once a few dairy farmers that are able to implement the new technology, they will inform others about the advantages and ease of using it. By showing one farmer a new technology, they will be able to spread its value through word of mouth and by letting others see how the technology directly benefits the owner (Xuan An, 2002).

CHAPTER THREE: METHODOLOGY

The focus of our project was to determine which of the possible clean technologies for farms would most efficiently prevent the contamination and thereby improve the quality of drinking water in the central valley portion of Heredia.

After preliminarily researching many waste management strategies we determined that the possible techniques include anaerobic digesters, methods of composting such as lagoons, buffer strips, and other best management practices such as fencing, diversions, and grassed waterways. While in Costa Rica, we further researched those waste management techniques and determined whether they would be efficient and cost effective for the varying qualities of farms in Costa Rica. This research included the farmers' perspectives on implementing those waste management techniques and ways to encourage farmers to use them.

To complete this project, we collaborated with dairy farmers, experts in fields relating to manure management, and government and private run public utilities companies such as the Instituto Costarricense de Electricidad (Costa Rican Institute of Electricity) [ICE] and the ESPH. Due to a time constraint of seven and one-half weeks, a lack of reliable transportation, and because our sponsor, the ESPH, provides services only to that area, we limited our research area to the central valley portion of Heredia.

While in Costa Rica, we completed field research, unstructured interviews, cost-benefit analyses, and provided the ESPH with material they could use for making individualized recommendations for waste management improvements on each farm.

FIELD RESEARCH

Upon arriving in Costa Rica, we chose our sample of farms to visit and farmers to interview through a type of non-probability sampling called purposive sampling. Purposive sampling is a method of purposefully selecting samples with a desired characteristic in order to represent a wider population. Researchers commonly use purposive sampling in qualitative research when they seek individuals who fit into one or more specific, predefined group (Trochim, 2002). In most cases, researchers use this type of sampling when they must reach a target population quickly or the when the researchers cannot easily access the population. This aspect was crucial to our project because our onsite research time was limited to seven and one-half weeks.

We predefined our sampling group as small dairy farms with less than 150 livestock animals, including cattle, pigs, and horses. Because of his familiarity with the farms in Heredia, our liaison from the ESPH, Luis Gámez, recommended the farms that we included in our sample. Unfortunately, this created an unavoidable sampling bias because we were only able to visit farms that are open to visits from the ESPH.

We classified the eight farms we visited into two types. Five farms currently implement few or no proper waste management techniques. We also conducted observations at three farms that were using one or more of the techniques that we had previously investigated, such as fencing and pasture rotation. By visiting these two types of farms, we were able to establish what types of waste management farms are currently using in the central valley portion of Heredia.

In order to maximize the size of our original sample in a short amount of time, our group also used a variation of snowball sampling. Snowball sampling occurs when a researcher identifies one member of the target group and then asks that member if he knows anyone else who would fit the same criteria (Trochim, 2002). In our sampling, Luis Gámez introduced us to a representative from ICE, L. Allan Retana, who brought us to farms that had previously implemented anaerobic digesters. We also collected information from other researchers in the area who had worked closely with farmers in Heredia and surrounding areas.

In our research, visiting a substantial proportion of farms was not a primary concern because we were investigating the willingness of individual farmers to implement proposed waste management strategies. The questions we used during our interviews and field research were to determine common problems and current methods of waste management on farms. We intended the field research and interview data we gathered to serve as supplemental general information rather than to serve as specific numerical data that represents farmers in Heredia, thereby being qualitative rather than quantitative research.

While on the farms, we observed aspects of the land, farmhouses and barns, bodies of water, livestock, and pollution sources by filling out observation and interview forms and taking pictures. The land aspect included the topography of the farm, how the land is used, areas of erosion, and available space on the farm. The farmhouses and barns aspect included the management of the farm, the amount of water and electricity used, and other specific information about the individual farm. The aspect of bodies of water included the quantity and quality of water and who uses the water. Our livestock aspect includes the number of animals on the farm and other information relating to the livestock like the milking practices and feeding habits. The pollution section includes where the pollution comes from and where it goes, how much manure there is and how it enters the water system.

Knowledge of those aspects was necessary to determine which methods of waste management were best for farms with specific qualities. Each group member recorded the information on our previously developed observation and interview forms. The forms prompted us to gather information about those five crucial aspects of dairy farms. We filled out some of the information on the forms by observation, but we also asked the farmers specific questions to answer the criteria on our forms.

By having each group member fill out the form individually, our group was able to ensure that we recorded accurate information for each aspect of the farm. On the day following a visit, our group discussed each question on the forms and completed a master Dairy Farm Observation Form (see Appendix D) for each farm. If we recorded information inconsistently among the three of us, we contacted the farmers to verify our data.

UNSTRUCTURED INTERVIEWS

We also conducted unstructured interviews with five owners of the farms we visited, four field experts in waste management and related areas, and three representatives from government and private organizations to determine the willingness of those parties to implement new waste management techniques through direct participation and funding. We also asked farmers what types of questions they have about the possible waste management techniques and if they anticipated any problems that would arise while implementing those techniques.

Three of the farms we visited were already using proper waste management techniques. Instead of determining those farmers' willingness to change their practices, we asked what changes they made on their farms to implement the new waste management practices and their problems and successes during the transition. We also inquired about their family's feelings and thoughts while transitioning to proper waste management practices. Finally, we asked how the process changed their views of preservation of the environment.

We conducted interviews with four experts in waste management techniques and representatives from government and private companies. We chose the interviewees based on suggestions from our liaison and research our group conducted. When choosing the interviewees, we investigated their organizations' history of contributing to other environmental protection programs.

We administered all the interviews with at least two of the group members as interviewers. One person posed questions and the other transcribed responses. When possible, we audio recorded all interviews to insure that our translations correctly reflected the opinions of the interviewee.

COST-BENEFIT ANALYSES

Using the information we collected about each farm and the research we completed about waste management strategies, we then prepared cost-benefit analyses to determine whether each type was viable for farms in Costa Rica and to establish the payback time, the return on investment (ROI) and monetary benefits. In the analyses, we also included sections that elaborated on environmental benefits that do not have measurable monetary value. We measured those benefits by how much waste the practices prevented from entering the water sources.

Using this information, we established criteria that the ESPH and farmers would use to determine which waste management practices are best for each specific farm (see Chapter Four). The criteria allows the ESPH to compare the plans' benefits and drawbacks to determine which methods the farmers could easily implement and will help the ESPH identify the most feasible and affordable plan for each dairy farm. We also made these criteria available to farmers in the form of pamphlets, which we will explain in the next section. Based on the criteria, we could immediately exclude some waste management solutions as options for farms or communities because of requirements that farms could not meet at that time.

SPREADING THE WORD: COMMUNITY INVOLVEMENT

To convince farmers that our new waste management strategies are important to public and environmental health as well as to show the farmers how they can easily implement the strategies, we created prototype pamphlets for each proper waste management technique. We also initiated the start of a pilot program on a dairy farm in Heredia.

The main purpose of the pamphlets was to enable the ESPH and individual farmers to determine which type of proper waste management and clean technologies would be most appropriate for each farm. In the pamphlets, we described the benefitsthat each technique provides for farmers, water users, and the environment. We included the changes that farmers must make, the farm qualities necessary to start the programs, and the funds required to implement each program. The pamphlets also included information about ESPH's Procuencas program, which will be a source of financial aid for the farmers. The information in the pamphlets also answered frequently asked questions that farmers may have before implementing those technologies.

We gave the prototype pamphlets to the ESPH so they could translate them, print them, and distribute them to the farmers in Heredia. The pamphlets will aid in convincing farmers that our recommended waste management strategies are important to public and environmental health and will show the farmers how they can easily implement the strategies. We also hope that the pamphlets, along with word of mouth, will help promote clean technologies.

In addition to creating pamphlets, we began to help one farm in Heredia become a leading example to others in Heredia by prompting the farm to implement an anaerobic digester and improve several waste management techniques. Using the knowledge and understanding we acquired while helping the ICE install two anaerobic digesters on farms in their area of service, we helped plan for the installation of a polyethylene anaerobic digester in Heredia. Unfortunately, due to time constraints, we unable to install the digester ourselves while in Costa Rica. The owner of this farm plans to install a polyethylene digester after we leave Costa Rica and will provide the funding for the implementation of the digester because he knows the benefits that it will bring to his farm and the community. That implementation of the first anaerobic digester in Heredia will create interest in the new branch of the Procuencas program by showing other farmers that proper waste management can be easily installed and very beneficial.

CHAPTER FOUR: DATA AND ANALYSIS

In order to fulfill our objectives, we gathered information on eight dairy farms in Heredia and surrounding areas, and classified those farms using observations from field research and interviews. We also analyzed common waste management strategies, determining what the necessary criteria would be to implement each on a small farm in Costa Rica. We compiled our information in pamphlets, to assist the ESPH in matching the classified farm data with the appropriate waste management technique. Finally, we explored the implications and benefits of a pilot program for waste management strategies in Costa Rica.

CLASSIFICATION OF DAIRY FARMS

In order to determine the ability of each individual farm to implement clean technologies, it was necessary to use our field research to examine their size, location, terrain, and amount of waste produced. We also observed what waste management practices farmers were using on their farms. Using the information collected on our Dairy Farm Observation Forms, we created a brief profile for each dairy farm we visited. We then matched profile of each farm with the clean technologies criteria that we have established in the following section.

We classified the farms by the number of cows on the farm, by their location in Heredia, their proximity to crucial water sources, the terrain, and amount of waste produced. For quantification purposes, we assumed that the average cow in Costa Rica produces 1.0-1.3 kilograms of waste per hour (Cañas, personal communication). The

ESPH will be able to use this type of classification for each farm in order to match each farm with appropriate waste management strategies.

Farm 1: Mario Arguedas

The Arguedas farm is a small, family owned operation of thirty-eight hectares that has existed for nearly fifty years. It is located on the Río Segundo watershed and is approximately one hundred meters north of San Miguel de San Jose de la Montaña. The access road for this farm is paved. It is considered a two-lane road, but sometimes only has room for one vehicle to pass.

The barn and farmhouse on the Arguedas property are located next to each other approximately twenty meters from the road. Twenty-five meters up the road is a water source that supplies water to the community. One hundred fifty meters down the road is another farm with approximately sixty cows.

Caring for fifty-five cows and one goat, the Arguedas farm has the potential to produce a minimum of 265 kilograms of waste per day. The farmer keeps the cows in the barn only for milking twice per day. Most of this farm's waste goes directly onto the fields while the cows graze for their food. The waste that is not absorbed into the ground runs down steep fields when it rains. One-third of the fields have a slope of greater than thirty percent and therefore should not be used for agricultural purposes (Umaña Román, 2000).

When visiting this farm, we noted that the farmer was washing the milking barn waste with a hose, letting the waste flow directly into the drainage ditch on the side of the road. The water in that small ditch consisted entirely of the waste from the barn. There were many flies and mosquitoes around the 0.25-meter wide ditch. Before the wastewater reached the road, it eroded the banks of the drainage ditch and collected sediments. At the top of those banks were sparse small bushes and grass. Leading into the same drainage ditch is a stream that runs through the center of the farm and is located one meter from the milking barn. Once the wastewater ran along the road, there was no vegetation on the banks. Our liaison, Luis Gámez, confirmed that this drainage dish leads directly to a branch of the Porrosatí River, which is one of the primary water sources for the city of Heredia. In his research, Róger Umaña Román (2000) observed that the branch of the Porrosatí River that borders this farm turns a greenish color two hours after milking the cows from farms in the river watershed.

This farm is not concerned about the environmental impacts of their methods of waste disposal, but was slightly interested in an anaerobic digester because of the monetary benefits. There are feeding and water troughs in the barns and fences, but the farm does not appear to use any other proper waste management techniques. As a further sign that the owner of this farm is not very concerned about the current waste disposal problems, the owner of this farm is considering renting or selling the farm. We do not anticipate that he will make any investments for proper waste management techniques before selling or renting the farm.

Farm 2: Jorge Steinvorth

The Steinvorth farm is one of the few large farms left in Heredia and is over one hundred years old. A wealthy dentist who works in San Jose owns the 270-hectare farm. Farming is not the main source of income for the owner, but is for the supervisor and many of the workers on the farm. It is located on the Río Segundo watershed and is five hundred meters north of San Miguel de San Jose de La Montaña on the same road as the Arguedas farm. The single-lane road between those barns is impassible by cars and is more suitable for the four wheelers or tractors on the farm. The surface of the access road is made of large rocks packed closely together. When crossing rivers, the vehicles drive on concrete slabs so they do not mix up the bottom of the riverbed.

The Steinworth farm separates its ninety-three milking cows into three groups of twenty-three, forty, and thirty. Each group goes to its own milking barn, which is located about two kilometers from each of the others. There is one house under five hundred meters from each of the milking barns. There are other houses in the immediate area of the entrance to the farm and other farms further up and down the road.

Twenty percent of the farm has a slope of greater than thirty percent, but the Steinvorth farm does not use that land for agricultural purposes. Most of the farm is mountainside forest and pasture, where twenty-five percent is protected through the Procuencas program. There are many pastures, which are rotated for grazing. They are fenced with either electric or barbed wire fencing and have dead fence posts.

Three rivers originate in this farm and all are main water sources for the ESPH. There is also at least one swampy area on the farm. The rivers are the Segundo, the Mancarrón, and the Porrosatí. The cows do not have direct access to any of those water sources, but nutrients may enter the river next to the last milking barn on the road that is only twenty meters from the river. The bottoms of the rivers are comprised of dirt and rocks of all sizes. On the steep banks are trees and shrubs that extend many meters from the rivers. The rivers vary in size, but on average are two to three meters wide and up to one-half meter deep. The main water source for the house and barns is the Porrosatí River.

In addition to the 93 milking cows are 15 pregnant cows, some calves, and many other cows, brining the total number of cows to 189. The workers milk the cows twice per day at 2:00 PM and 3:00 AM. Twenty-three of the cows are in the barn for 1 to 1½ hours, forty of the cows are in the barn for four hours, and thirty of the cows are in the barn for three hours. The all the cows graze to get their food and drink from water troughs in the barn and on the fields. The farmers also feed vitamins to the cows.

After the cows leave the barns, the farmers wash the barns with a hose and drain the wastewater to the fields for fertilizer. The Steinvorth farm stopped buying fertilizer for their fields two years ago. In place of buying fertilizers, they leave manure on the fields from the grazing cows. There is no bedding in the milking barns.

Minimal pollutants enter the water sources on this farm because of the farmers' care to keep the water clean. There are many proper waste management techniques already in place on this farm, including contour buffer strips, filter strips, fencing, feeding troughs for vitamins, water troughs, diversions, grassed waterways, and a unique type of cow path comprised of sand-filled tires that prevent erosion of the cow paths.

To accommodate the planned growth of the farm to 130 milking cows, the Steinvorth farm is willing to participate in conservation programs if the programs lower the production costs for the farm. One waste management program that we started on the Steinvorth farm is the implementation a polyethylene anaerobic digester, thus making the farm the first in ESPH's protected watershed to begin to implement such a digester. With this biogas produced from this digester, the farm plans to heat and cool the milk as necessary and eventually produce electricity. The owner is enthusiastic about producing electricity, but the supervisor understands the necessity to start with a small project, then increase the size of the reactor before being able to produce electricity.

Farm 3: Eliécer Solano

The Solano farm is a 1.2 hectare family farm, where farming is the main source of income for the family. It is located near Cariblanco, which is approximately seven kilometers south of San Miguel. This farm is not part of the ESPH's jurisdiction but was important to visit because it is an example of a farm with many proper waste management techniques, including a polyethylene anaerobic digester. The access road for this farm is dirt and leads to route 126. Route 126 has two paved lanes with a moderate amount of traffic. The house, which uses a septic tank for waste, is about twenty meters from the road and the barn is about twenty meters from the house. There are five other houses in the immediate area.

From the edge of the barn to the small river at the bottom of the hill, one hundred meters away, the slope of the land increases greatly. On the edge of the river is vegetation varying from grass to trees. A pasture for five full-sized cows, an anaerobic digester, and two fields of tall grass cover the hill. The pasture covers about half of the area of the farm and the grass covers another half of the farm area. To contain the large cows in the pasture, the farmer uses barbed wire with dead fence posts. Some manure and dirt enters the river from the pasture after going through the natural buffer strip of trees lining the river. The amount of waste that enters the water from this farm is minimal because there are less than fifteen cows on the pasture.

The grass grown in one of the pastures on this farm is very nutritious because the farmer fertilizes it with the effluent from the digester, once per day, through a series of diversions and grassed waterways, thus preventing any effluent from entering the stream. The farmer routinely cuts and feeds the fertilized grass to the cows in the barn. The nutrition in the grass prevents the need for vitamins for the cows. By feeding the cows the grass that was fertilized by their own processed waste, the farmers have successfully created a closed system. This closed system, shown in Figure 4, is very important because as it continues to improve the quality of the cows and grass, it also prevents any waste from entering the water through this source.

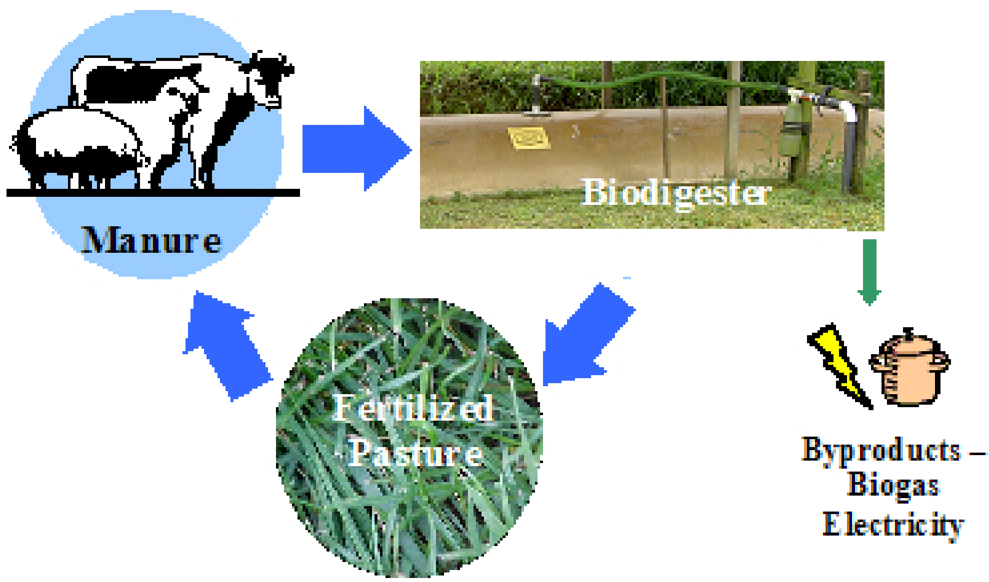


Figure 4: Closed System for Recycling Manure

In the barn are approximately ten calves and three pigs. The numbers of these animals vary with time because this farm sells the calves and pigs once they reach maturity. While on that farm, the family uses the cows' milk for drinking and making cheese. The young cows and pigs are in the barn all day, but the large cows remain on the pasture unless they are being milked.

Either Eliécer Solano or his son washes the barn once per day with a limited amount of water. He captures all of the waste from the barn and mixes it well in a small concrete holding tank (see Figure 5) before allowing it to enter the anaerobic digester, maintaining the required concentration of solids entering the digester. Many times, the children of the farm complete the cleaning chores so they learn how to operate the digester. Completing these tasks also allows the children on the farm to learn the value of keeping the environment and water sources clean.

Figure 5: Manure Mixing Tank

The owner of this farm currently uses the biogas produced from the anaerobic digester for stovetop cooking. The family is also considering buying an oven that will cook with biogas. On this farm, there is enough gas to cook for twelve hours straight, thus eliminating the need for propane cooking. This saves the family from 7,000 to 10,000 colones ($15-$20) every month that would be normally be spent on the propane tank and gas required to drive to the city to buy the propane tank. In addition to money, the biogas saves the time spent driving to the city, improves the safety of the house by keeping the gas storage outside, and eliminates almost all of the smell of the manure in the barn.

At the time of the visit, the anaerobic digester on the Solano farm was eight years old. Although the average lifespan of the polyethylene digester is approximately five years, the Solano digester lasted longer due to a metal roof the farm built to protect the plastic from the sun (see Figure 6).

Figure 6: Solano Farm Polyethylene Anaerobic Digester

The family first learned about anaerobic digesters from the Instituto Costarricense de Electricidad (Costa Rican Institute of Electricity) [ICE], which provides electricity in their area. After understanding the system with help from ICE, the only thing that family had to adjust to was an extra ten minutes of cleanup in the barn everyday as well as to learn how to adjust the flame to a size appropriate for each pot and pan used for cooking. In order to adapt their stove to cook with biogas, Sr. Solano constructed a stovetop adaptation (see Figure 7) that he connected to the biogas pipes from the anaerobic digester. Cooking with biogas is similar to cooking with propane.

Figure 7: Biogas Adapted Stove

Farm 4: Roberto Morera

The Morera farm is a medium sized, family owned operation of two hundred acres that has existed for nearly hundred years as their main source of income. It is located near Cariblanco, which is approximately seven kilometers south of San Miguel. This farm is not part of the ESPH's jurisdiction but was important to visit because it is an example of a farm with many proper waste management techniques, including an anaerobic digester. The access road for this farm is gravel and shortly leads to route 126. Route 126 has two-lanes and is paved, and sustains a moderate amount of traffic. The milking barn is approximately twenty-five meters from the road and is easily accessible.

Caring for fifty dairy cows, thirty meat cows, two pigs, several dogs, one horse, and a water buffalo, this farm has the potential to produce more than 800 kilograms of waste per day. The farm has a large potential to collect waste because the farmer keeps the cows in the barn for approximately twelve hours a day for milking, between 2:00 AM and 2:00 PM, so half of the waste produced by the cows enters directly into their anaerobic digester. The remainder of the waste goes directly onto the fields while the cows graze for their food.

The milking barn is located on a gentle slope around the barn, with steep hill nearby. A river that crosses approximately thirty to fifty meters from the barn divides the property in half. The farmhouse is located at the top of a hill overlooking the barn from three hundred and fifty meters away. The farm milks their dairy cows twice a day, at four in the morning and two in the afternoon, and produces four hundred liters of milk per day. The owner hopes to expand his operation to seventy-five milking cows and to remodel the barn to make room for the additional cows. The farm is optimistic to become meet the standards for organic production in order to sell their milk to an organic cocoa farm.

The Morera farm currently uses a combination of management practices including a twenty-one meter polyethylene plug-flow digester. The owners were reluctant to consider proper waste management techniques at first because of the initial investment.

However, after a few years of using techniques such as the anaerobic digester they are very enthusiastic about increasing the size of their operation.

Because the cows are in the milking barn for twelve hours at a time, the farm needs to feed the cows and provide them with water. The farmers do this by cutting the grass from the fields that the cows graze on and transporting it using a tractor. The farmers feed the cows a combination of grasses, vitamins and minerals, and oranges mixed with ground corn and molasses. The grassland is fenced with live fence post and barbed wire. The farmers currently use the biogas produced from the waste to heat water used to clean their milking equipment and wash the barn waste into the digester. The farm also uses the effluent from the digester to feed a worm composting pile behind the barn. This composing pile serves as an additional source of fertilizer for the fields.

The farm plans to install an additional bioreactor to accommodate the additional cows they plan to buy in the near future. Their first priority with the second bioreactor is to generate enough electricity from the biogas to run the milking machines. They also hope to pipe the extra biogas to their restaurant located 150 meters up the hill.

Farm 5: Roger Corrales

Two friends, Rafael Mena and Roger Corrales, own the fifth and sixth farms we visited. On both of these farms, we helped ICE install anaerobic digesters. The farms are not located in the area of ESPH's service, but the data collected is still relevant because it represents two families' feelings' and purpose of implementing an anaerobic digester.

Sr. Corrales' farm is located on a one-lane dirt road about twenty minutes from the soccer field in San Ramón de La Virgen. It is small, without electricity, and provides for the entire income of the five-person family. Barbed wire fencing and dead posts surround the property and house. Sr. Corrales allows most of the fifteen cows, ten chickens, and two dogs to roam in any of the areas within the fencing. The farmer keeps the young cows in the barn and the five pigs in a pen. There is also a small tilapia pond in a section not accessible to the other animals.

The farmland is mostly hills and has some rocks in the soil. Around the barn, there is a heavily trodden area composed of mud and manure. The other places on the farm consist of an even mix of grass, shrubs, and trees. There are no other houses near the farm.

There is a stream running through the property about ten meters from the barn and twenty meters from the house, which is about fifty meters from the barn. The stream is 0.15 meters deep, one-meter wide, and has a mud bottom with scattered rocks of up to one-third meter in size. The steep slope moves the water quickly, which contributes to the eroded banks consisting of patches of grass. The cows, chickens, and dogs have easy access to that stream and often wade in it.

Also contributing to the water in this stream was the wastewater from the barn. The farmer currently cleans his barn with a hose and allows the runoff to enter the stream. By helping install an anaerobic digester on this farm, we have directly contributed to the improvement of the water quality for the people of Sarapiquí. With the digester, the farmer will begin to wash his barn waste into the digester to make methane gas instead of directly into the stream that runs through his farm.

Though this farm does not plan to increase in size, Sr. Corrales will use the biogas produced from the cattle he does have for cooking and hopes he can use it for biogas lighting as well. Along with the plastic feeding troughs in the barn, the anaerobic digester is the start to another farm with proper waste management techniques. After seeing the great benefits the gas creates for his family, we suspect that Sr. Corrales will further improve his farm by keeping the cows in the barn for a longer part of the day to collect more manure and installing.

Farm 6: Rafael Mena

Sr. Corrales's friend, Rafael Mena, also has a small, isolated family owned farm that provides for his family. On it, there are at least two pigs, five chickens, and an undetermined number of cows. The isolated farm is located approximately five kilometers from San Ramón de La Virgen. The access road is a one-lane, dirt road with almost no traffic. One side of the farm is steep with varying vegetation from grass to a few trees. At the bottom of that slope is a stream that has a small buffer of grass, shrubs, and trees. On the top of the slope, about 150-250 meters from the stream, are the barns. 100-200 meters from the barns, on the top of the same hill, is the farmhouse with a tank collecting water that is the water source for the house. On the top of the hill and on the opposite side of the house and barns as the slope is a field fenced in with barbed wire and dead fence posts.

Sr. Mena's farm cooks with wood and generates electricity their own for their house. The main purpose for the anaerobic digester we helped install on this farm will be to save the money and time it takes to cut wood for the cooking stove. By installing the digester on the slope of the hill below the barns, Sr. Mena will divert the waste to the reactor rather than allow it to travel down the hill and into the stream. We predict that this is another example of a farm starting proper waste management techniques for the monetary benefits, but will soon realize the environmental benefits as well and pass on that knowledge to others in the area and to their own children.

Farm 7: Oscar Escríbel

The Escríbel farm is a small, family owned operation of seventy hectares that has existed for about sixty years. It is located outside Monte de la Cruz. The access road for this farm is dirt, but it is well packed. It is usually a two-lane road, but sometimes only has room for one vehicle to pass at a time. There is very little traffic and there are no feeding streets. The barn and the main farmhouse are located within twenty meters of each other, about twenty-five meters from the road. The farm consists of forty hectares of pasture, and approximately thirty hectares of forest.

The farm has thirty-eight cows, ten dogs, and chickens, and has the potential to produce approximately 230 kilograms of waste per day. Thirty years ago, the farm was much larger and more productive. The farmer keeps the cows in the barn only for milking twice per day for a total of five hours, so most of the cows' waste goes directly onto the fields, where they graze for their food. The waste that is not absorbed into the ground runs down the steep fields when it rains.

The barn is designed to be washed out with water and has two drainage trenches in the center of the milking stalls. The farmer washes the manure directly into the pastures that have a very gentle slope that lead to the driveway and eventually the main road.

One stream, which does not go dry at any point of the year, runs through the property. The stream originates from a spring on the property and eventually enters a canyon that follows the mountain. This water source is protected with a riparian buffer along the entire length of the property and has fencing to keep cows out of and in the pastures. The stream is the main source of water for the farmhouses on the property.

The Escríbel farm is concerned about the environmental impacts of their methods of waste disposal, but they only use minimal management methods such as fencing and riparian buffers. The farmers feed the cows grass from the pastures and some corn in feeding troughs while the cows are in the barn. The water for the barn is supplied by the same stream from which the houses get their water. The pastures are fenced with live fence posts that have grown into trees with barbed wire connecting them.

Sr. Escríbel, Oscar Escríbel's father, is the owner of the farm and is very reluctant to make changes in the management of the farm. Oscar Escríbel and his brothers, who manage the farm, would like to increase in size. They are interested in a polyethylene anaerobic digester, but they do not know much about it and would like to see how it works before investing in it. They would like to generate electricity with the digester for lighting for the barn and houses.

Farm 8: Fransisco Vindas

The Vindas farm is a small, family owned operation of seventy-six hectares that has existed for nearly seventy years. It is located outside Santa Elena. The two dairy barns and the farmhouse are located next to each other. The farm consists of forty hectares of pasture and approximately thirty hectares of forest. There are currently fifteen people living and working on the farm.

The farm has two-hundred twenty cows, four horses, several goats, dogs, and chickens, and has the potential to produce approximately 900 kilograms of waste per day. The farmers milk 126 of the cows. The farm has two barns, one housing 100 cows, twice a day, for a total of six hours, and another housing 26 cows, once a day, for approximately five hours. The amount of time that the cows are kept in the barns depends on how much time is needed to milk the cows. The farmer does not keep the cows in the milking barns longer than it takes to milk them. The waste from the barns is applied to the pasture that is specifically used for feeding the cows in the barns. The area is four and a half acres and contains two to three foot tall grasses that are easy to cut. The farmers feed the cows this grass in combination with ground grain and corn in troughs in the barns. The cows are also fed some vitamin supplements.

The farm currently has fourteen milking machines, water heaters, and milk coolers. The owner pays an average of 200,000 colones ($500) a month on electricity to operate this equipment. The owner also plans to increase the amount of milking cows on the farm to 150. This means that he would have to purchase additional equipment and increase the electricity usage. The owner expressed interest in an anaerobic digester to generate electricity to reduce his electricity bill. The farm is concerned about the environmental impacts of their methods of waste disposal, but they only use minimal management methods such as electric and barbed wire fencing.

The milking barns of this farm are located in one central area, with drainage ditches that lead to a central field, making this farm an ideal location for an anaerobic digester and other best management strategies.

WASTE PRODUCED PER DAY ON A DAIRY FARM

In order to determine whether some of the clean technologies would be possible on a particular farm, it is important to calculate the total amount of usable waste that a farm produces each day. Usable waste is defined as any organic waste that is produced in the barn or another contained area, and can be easily moved to a holding tank to be used for composting, anaerobic digesters, or other management purposes. The calculation for usable waste does not include the waste produced while cows are in the fields because the manure there is difficult to collect. The calculation for determining how much waste each farm produces per day takes into account the number of animals in a barn, how much waste the cows produce per hour, and how many hours the cows are in the barn.

The average dairy cow in Costa Rica produces 6.8 percent of its body weight in manure per day. The average weight of a dairy cow in Costa Rica is 350-400 kilograms per day. The dairy cows produce approximately 1.0-1.3 kilograms of waste per hour (Cañas, personal communication, July 1, 2005). If other animals are present in the barns, it is important to add their waste to the equation, provided it a farmer can easily collect it and use it for management purposes. If the farmer uses bedding in the barns, it must be organic so it can decompose easily. The amount of bedding excluded from the barn can be estimated and does not need to be an exact amount.

The following is an equation for determining the amount of usable waste produced per day in a dairy barn.

__ cows in barn * __ hours in barn per day * 1.2 kg waste produced per cow per hour
= __ kg waste produced by cows per day

__ kg waste produced by cows per day
+ __ kg waste produced by other animals in barn per day
+ __ kg bedding washed out from the barn per day
= __ kg waste produced by farm per day

PROJECTED COSTS OF CLEAN TECHNOLOGIES

For each type of clean technology that we have investigated, we included the costs of all the materials. Estimates for the costs of labor and technical assistance vary depending on whether the workers on the farm supply the labor or if it is supplied by an outside source. In addition, companies who promote the technologies often provide technical assistance free. For private enterprises, the cost of hiring an expert in technical assistance for management practices is between $100 and $150 per day.

For the clean technologies that produce a usable product, such as anaerobic digesters, we have included a cost benefit analyses and simple return on investment [ROI] calculations. In additional to the monetary comparisons, each clean technology provides environmental benefits that are difficult to quantify. We have included these benefits as an addition to the monetary calculation provided in this section.

According to the Central Intelligence Agency (CIA), the yearly per capita income in Costa Rica is $9,600. It is difficult, however, to determine the average yearly income of dairy farmers in Costa Rica. There is a drastic difference in sizes of farms and amount of land owned on each farm. Each farmer's income is determined by how many cows are milked, whether that milk is sold to an outside source, and whether the farmer produces any other products such as cheese or cream to sell. In addition, many farmers grow small crops for food and trade goods and crops with their neighbors, which are not counted as part of a yearly income.

For these reasons, the value of savings for each farmer when implementing clean technologies is significant on a different scale. For subsistence farmers, the money saved from implementing an anaerobic digester signifies a large savings each month because it reduces the amount of products that the farmers must purchase from an outside source. For farmers with larger operations, the savings results in lower production costs for milking cows that translates to better returns once the farmers sell their milk products.

Ultimately, despite whether the savings is large or incremental, the anaerobic digester provides the same environmental benefits of cleaner water and environment for all of its users. We were not able to evaluate numerically the environmental benefits of using clean technologies. Their benefit to the community is far greater than a savings on dollars and colones. A cleaner environment and quality water provides security for future generations to continue the work of their fathers. In addition, by preventing pollution at its source, money can be saved through less waste treatment at water treatment plants, fewer medical costs from illness related to contaminated water, and avoiding costly chemical cleanups for accidental waste spills.

Cost Analysis for Polyethylene Anaerobic Digesters

Included in the cost analysis for polyethylene anaerobic digesters are the estimated material costs to construct an eight meter anaerobic digester as estimated by the Ministerio de Agricultura y Ganaderia (Ministry of Agriculture and Livestock) [MAG] (see Table 1). The actual cost of an eight meter polyethylene digester may range between 50,000 and 70,000 colones ($100- $150) depending on the extra materials needed to run gas pipes from the digester to the barn or the house.

Table 1: Costs of a Polyethylene Anaerobic Digester

Materials	Projected Cost	
	Colones	**Dollars**
25 meters of tubular plastic, 8 caliber, 2.5 meters in radius	37,523.59	$79.00
2 concrete sewer tubes, 12 inches in diameter, 1 meter long	6,804.28	$14.32
1 PVC male adaptor, 1.25 inches	266.83	$0.56
1 PVC female adaptor, 1.25 inches	300.19	$0.63
3 meters of transparent hosing, 1.5 inches in diameter	3,044.77	$6.41
1 PVC T, 1.25 inches	528.90	$1.11
1 meter PVC tube, 1.25 inches	443.14	$0.93
1 PVC end cap, 1.25 inches	252.54	$0.53
1 PVC elbow, 1.25 inches	533.67	$1.12
3 meters of garden hosing	605.14	$1.27
8 plastic sacks	400.25	$0.84
3 used tire inner tubes	52.41	$0.11
PVC glue	1,134.05	$2.39
1 aluminum wire sponge	100.06	$0.21
2 hose clamps, 2 inches	409.78	$0.86
1 valve, 1.25 inches	1,601.01	$3.37
1 transparent plastic bottle, 2-3 liters	200.13	$0.42
2 stainless steel washers, 20 cm outside diameter, 1 inch inside diameter	4,750.00	$10.00
TOTAL	58,950.74	$124.11

(Source: Ministerio de Agricultura y Ganadería, personal communication, July 2005)

Return on Investment for Polyethylene Anaerobic Digesters

In order to asses the payback time and monetary benefits of the polyethylene anaerobic digester, we completed a simple return on investment (see Tables 2 and 3). The simple return on investment takes into account the total amount of gains for the project in comparison to the total investment. We calculated our return on investment for five years because five years is the average life span of a polyethylene digester.

Table 2: Return on Investment in Colones

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Total incremental inflows	77,000	84,000	84,000	84,000	84,000	413,000
Total incremental outflows	-70,000	-5,000	-5,000	-5,000	-5,000	-90,000
Simple ROI	10%	115%	206%	287%	359%	

Table 3: Return on Investment in US Dollars

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Total incremental inflows	162	177	177	177	177	870
Total incremental outflows	-147	-11	-11	-11	-11	-191
Simple ROI	10%	115%	206%	286%	357%	

Equation for a simple ROI:

(Total Gains – Total Investment) / (Total Investment)

We based our calculations for return on investment on an eight-meter polyethylene anaerobic digester, which has an average initial cost of 70,000 colones ($150), which accounts for materials only. The cost for constructing a stove unit that is compatible with biogas is not included. Yearly inflow is calculated with and an estimated savings of 7,000 ($15) colones per month, which is the estimated amount of replacing a propane tank monthly and the costs of transportation for buying the propane tank. The cost of maintaining the polyethylene anaerobic digester yearly is estimated 5,000 colones ($11). The estimation of the total cost of the reactor is high, and the estimation of monthly savings is low. The calculated values are conservative and many farmers spend less money on their reactors and save more each month. The return on investment calculation also does not include the savings if a farmer uses the effluent to fertilize fields as a replacement for purchasing commercial fertilizer.

Our data shows that the polyethylene anaerobic digester saves enough money to pay for itself in less than one year. For the first year, farmers receive an average of a 10 percent return on their original investment on the reactor. After five years, the reactor provides nearly 350 percent return on the original investment.

The expected lifespan of the polyethylene anaerobic digester is five years. Thus, monetary returns after five years are not calculated. In most cases, the digester continues to provide a monetary return after the first five years. However, after five years the cost to maintain the digester may increase as some of the materials from the original digester need to be replaced.

Costs of Best Management Practices

The costs of best management practices can be seen in Table 4 in United States Dollars. The costs of these practices in Costa Rica cannot be calculated accurately through a simple dollar to colon conversion. The costs of the materials and labor for these practices in Costa Rica is undetermined, but is likely to be considerably lower than the calculated amounts for implementing these practices in the United States.

Table 4: Costs of Other Clean Technologies

Clean Technology	Projected Costs	
	Dollars	Per Unit
Complete Mix Anaerobic Digester	$6,000.00	each
Regional Complete Mix Anaerobic Digester	$6,000.00	each
Electricity Generation	$10,000.00	facility
Grassed Waterways	$2,644.00	acre
Contour and Filter Strips	$27.11	foot
Fences	$1.54	foot
Diversions	$3.10	foot
Water Troughs	$905.00	trough
Composting	$8,409.00	facility
Keep Cows in Barns Longer	labor	
Pasture Rotation	fencing	
Feeding Troughs	$905.00	trough
Covered Lagoons	$20,777.00	lagoon

(Source: Animal Agriculture, 1999)

CLEAN TECHNOLOGIES CRITERIA

Based on our research, we have established the following criteria, which the ESPH can use to match farms with possible clean technologies. We have included classification criteria for four categories of waste management techniques – anaerobic digesters, composting, best management practices, and other waste management strategies. The criterion appears as a checklist for farmers to review. If the farms currently have all of required conditions, or if the farmers are willing to make the required additions or changes, the waste management technique will be appropriate for that farm if implemented correctly. An identical set of criteria, which the farmers can use to match their farms with clean technologies, is located in pamphlets we have designed.

More information about these pamphlets can be found in the section entitled “Pamphlets” of this chapter.

Anaerobic Digesters

There is not a particular number of cows that must be present on a farm for the farmer to implement an anaerobic digester. Instead, the important factor is how much potential usable waste a farm produces each day. A farm with a small amount of cows that are kept in barns for twenty-four hours has just as much potential to implement an anaerobic digester as a larger farm that only keeps cows in the barns for a few hours while milking.

It is important for farmers who use anaerobic digesters to use organic bedding if they use any bedding. In addition, organic cleaner or only hot water is recommended to clean the barn and the milking equipment on these farms. Non-organic cleansers kill the bacteria that decompose waste in a digester, making it ineffective for producing biogas. In addition, farms that use anaerobic digesters often need to regulate the amount of water they use to clean the barns to ensure the proper mix of manure and water within the digester.

Polyethylene Anaerobic Digester

Required Farm Conditions	*Required Additions or Changes*
☐ 75-100 kilograms of waste per day ☐ 10 X 3 meter area near barn ☐ Field for dispersing effluent ☐ Organic or no bedding in barn ☐ Organic or no cleaning supplies ☐ Able to clean barn in a contained Manner	☐ Labor for consistent and frequent manure collection ☐ Labor for running and maintaining digester ☐ Keep cows in barns longer ☐ Premixing tank to ensure 15% solids ☐ Biogas stove or heating and cooling

Complete Mix Anaerobic Digester

Required Farm Conditions	*Required Additions or Changes*
☐ 1000+ kilograms of waste per day ☐ Area available for digester near barn ☐ Field for dispersing effluent ☐ Organic or no bedding in barn ☐ Organic or no cleaning supplies ☐ Able to clean barn in a contained manner	☐ Labor for consistent and frequent manure collection ☐ Labor for running and maintaining digester ☐ Keep cows in barns longer ☐ Premixing tank to ensure 33% solids ☐ Biogas stove, heating and cooling, or generating electricity

Regional Complete Mix Anaerobic Digester

Required Farm Conditions	*Required Additions or Changes*
☐ 10,000+ kg of waste per day from all farms ☐ All farms in close proximity ☐ Large and centralized area within the community of farmers for a digester ☐ Field for dispersing effluent ☐ Organic or no bedding in barns ☐ Organic or no cleaning supplies ☐ Able to clean barns in a contained manner ☐ Roads passable by large trucks or downhill pipes	☐ Labor for consistent and frequent manure collection ☐ Labor for running and maintaining digester ☐ Keep cows in barns longer ☐ Premixing tank to ensure 33% solids ☐ Biogas stove, heating and cooling, or generating electricity ☐ Method of ensuring equal participation, cooperation, and distribution among the community

Generate Electricity with an Anaerobic Digester

Required Farm Conditions	*Required Additions or Changes*
☐ [n] m^3 of biogas per day	☐ Labor for running and maintaining generator
☐ Complete mix anaerobic digester	☐ Use for the electricity
☐ Area available for generator near digester	

Composting

There is not a particular number of cows that must be present on a farm for the farmer to implement composting. Instead, the important factor is how potential usable waste a farm produces each day. Covered lagoons require large amounts of water to be effective for producing biogas. Composting can be done with any amount of manure but requires a certain extra amount of labor for collecting the manure because it should be collected as a solid rather than just washing it out with water.

Similar to anaerobic digesters, it is important for farmers who use composting to use organic bedding, if any. Organic cleaners or hot water are recommended for cleaning the barns and equipment because non-organic cleansers kill the bacteria that decompose waste in the compost.

Covered Lagoons

Required Farm Conditions	*Required Additions or Changes*
☐ Barn waste entering a water source ☐ Large and flat space ☐ Large source of water ☐ Large amount of manure available ☐ Impermeable containment ☐ Impermeable cover ☐ Roads passable by large trucks	☐ Premixing tank to ensure 2% or less solids ☐ Biogas stove, heating and cooling, or generating electricity

Composting

Required Farm Conditions	*Required Additions or Changes*
☐ Solid waste entering a water source ☐ Space where organic waste can be piled and left ☐ Impermeable bottom lining ☐ Non-airtight cover	☐ Labor for applying fertilizer after composted

Best Management Practices

Best management practices are individually tailored to each farm; a practice that works on one farm may not work on another. Many farms in Heredia already use these practices. What makes them effective for controlling wastewater is ensuring that each farmer uses the practices strategically to prevent wastewater contamination. For example, a farm may use fencing to contain their livestock, but it may not prevent the animals from entering a water source. Farmers must use best management practices in places where they are going to be effective for controlling wastewater if they are going to make a difference in the water quality in Heredia.

Contour and Filter Strips

Required Farm Conditions	*Required Additions or Changes*
☐ Runoff entering a water source ☐ Time to let roots grow ☐ Area to plant trees, shrubs, or living fence posts	None

Grassed Waterways

Required Farm Conditions	*Required Additions or Changes*
☐ Runoff entering a water source ☐ Large field or area of vegetation ☐ Stable soil	None

Fences

Required Farm Conditions	*Required Additions or Changes*
☐ Livestock entering a water source ☐ A need of pasture rotation	☐ Water troughs

Diversions

Required Farm Conditions	*Required Additions or Changes*
☐ Runoff entering a water source ☐ Able to divert water to an area of dense vegetation	☐ Labor to keep diversions directing water in desired path

Water troughs

Required Farm Conditions	*Required Additions or Changes*
☐ Livestock entering a water source ☐ Space in the barn and/or pastures	None

Feeding troughs

Required Farm Conditions	*Required Additions or Changes*
☐ Need more manure in barn	☐ Labor for collecting grass
☐ Space in the barn	☐ Special field for growing nutritious Grass
	☐ Method of transporting the grass

Other Waste Management Improvements

Pasture rotation and keeping the livestock in the barns longer are two other waste management practices that farmers can use to improve the effectiveness of other waste management techniques. Pasture rotation allows the fields and grasses waterways to regenerate and stabilize the soil to prevent erosion. Farmers can increase the production of biogas from an anaerobic digester by having more manure, which they can do by keeping the cows in the barns longer. These practices are designed to be used in combination with other management techniques.

Pasture rotation

Required Farm Conditions	*Required Additions or Changes*
☐ Field is muddy	☐ Fencing
☐ Grass is not growing well or is thin	

Keep cows in barns longer

Required Farm Conditions	*Required Additions or Changes*
☐ Need more manure in barn	☐ Water troughs
☐ Space in barn	☐ Feeding troughs
☐ Able to clean barn in a contained manner	

CLEAN TECHNOLOGIES PAMPHLETS

To promote the use of clean technologies, we created prototype pamphlets for each proper waste management technique that we etermined to be viable in Costa Rica. These pamphlets will enable the ESPH and the farmers to determine which type of proper waste management and clean technology would be best for each farm.

In the pamphlets, we described the benefits for farmers, water users, and the environment that each technique provides. We included the changes that farmers must make, farm qualities necessary to start the programs, and the funds required to implement each program. The pamphlets also included information about ESPH's Procuencas program, which will be a source of financial aid for the farmers. The information in the pamphlets also answered frequently asked questions that farmers may have before implementing those technologies.

We gave the prototypes to the ESPH so they could print and distribute them to the farmers in Heredia. The pamphlets will aid in convincing farmers that our recommended waste management strategies are important to public and environmental health and will show the farmers how they can easily implement the strategies. We also hope that the pamphlets, along with word of mouth, will help promote clean technologies. The pamphlet prototypes can be found in Appendix E.

ELIMINATIONS OF PRELIMINARY WASTE MANAGEMENT STRATEGIES

After examining our data, we have eliminated covered lagoons and composting from our recommended clean technologies for Costa Rica. With a price of $20,777, covered lagoons are too expensive for farmers in the area. There is also not enough flat space or collectable manure on the small mountainside farms. Composting is possible, but the costs outweigh the benefits. Methods of cleaning barns would have to change drastically and we do not think many farms would be willing to undergo this change when there are better alternatives to composting, such as the polyethylene anaerobic digester.

The final waste management techniques that we have determined to be viable in Costa Rica include polyethylene digesters and best management practices. The best management practices that most applicable in Costa Rica include grassed waterways, diversions, buffer and filter strips, water and feeding troughs, and fencing.

BENEFITS OF A PILOT PROGRAM

A pilot program is a small-scale test project used to assess the viability of a concept prior to committing significant capital to a large-scale project (Devon Energy Corporation, 2004). Pilot programs can also be used as a teaching tool in an area where a certain technology has never been implemented before. The program allows the community to see the benefits of the program, and ask questions before they decide to make investments in the technology with their own money.

Pilot programs for waste management strategies, particularly the anaerobic digester, can easily be started on farms where farming is not the main source of income and the startup cost does not represent a significant investment for the owner. However, studies done in Vietnam and Thailand show that pilot programs are most effective on farms where farming is the primary source of income and the cost of the pilot program represents a significant portion of the farm's income (Xuan An, 2002). The large investment in these programs creates a reason for the family to make the program work, thereby insuring its success. Starting a pilot on a farm with a larger income is also a good idea because it allows more flexibility of funds with the program. In addition, pilot programs on a larger scale have more opportunities to expand if the pilot program is successful.

While in Costa Rica, our group saw the benefits of a pilot program when we helped install anaerobic digesters for two farms in the Sarapiquí region of Costa Rica. Those farmers had heard of the technology from friends, ICE, other farmers, and by seeing the digesters on other farms.

In addition to the technological implementation aspects of installing the digesters, we also saw the personal growth aspects. While installing the digester, the farmers' children were helping with the construction and watching the process of building the digester. As those children grow up operating this valuable tool on the farm, they will learn the benefits that come from protecting the environment and recycling waste.

Installing the digesters on those farms was made possible by a pilot project in that area. That pilot program began the spread of the technology. Interest spread as more and more people saw the digesters and talked about them. Farmers became able to visualize the benefits created by the digesters and could see first hand how clean technologies had improved the production of the farms. Those observations greatly decrease the time needed for a farmer to decide to implement clean technologies on their own farm (Rogers, 1976; Xuan An, 2002).

As was the case with Roger Corrales' farm, one of the farms on which we helped install a digester, deciding to make an investment for the anaerobic digester took more than a year. Roger Corrales wife, Maria Corrales, had first seen the anaerobic digester at a friend's farm while going to visit the doctor. Seeing how the family used the biogas from the digester for cooking, Sra. Corrales was intrigued. She came home and told her husband about what she had seen. The two discussed implementing a digester for nearly a year; they were undecided about whether they could afford to make the initial investment to have one of their own. It was not until Roger Corrales visited a neighbor's farm with an anaerobic digester while selling piglets that he saw the benefits and decide to make the investment for an anaerobic digester on his farm.

Implementing a pilot program in Heredia is an excellent way to spread the implementation of clean technologies. One possible location for a pilot program would be on the Steinvorth farm because the owner has shown a great deal of interest in the technology and his goals and funds for his farm can support an anaerobic digester. In addition, this farm is already using many best management practices and is willing to implement other best management practices as an example to other farmers. A digester on that farm could become the required catalyst that gets the rest of the community interested in the clean technologies.

Another ideal location for a pilot program using an anaerobic digester is on the farm owned by Fransisco Vindas, where several milking barns are in a central location. Sr. Vindas also keeps several of the cows on his farm in the barns for as long as twelve hours per day, meaning the farm has the potential to create enough usable waste for an anaerobic digester.

Without pilot programs as catalysts, the spread of clean technologies would never proceed past the uncertainty of adopting an innovation. While in Costa Rica, we started the planning of a pilot program on the Steinvorth farm, but were unable to install an anaerobic digester due to the time constraint of seven weeks. It is our hope that this planning will lead to the installation of a pilot digester so that the implementation of these technologies will begin to spread in Heredia.

Pilot programs will be ultimately responsible for the improvement of many farms in the area, creating interest in the anaerobic digesters, and improving farms and water quality in the area. After the technology spreads and more farms are involved in the program, the technology will become commonplace, and community members will be able to help each other implement the programs on each other's farms instead of relying on the assistance of an outside organization. Many people will also begin to appreciate the improvements to the environment that these digesters will create and be motivated to help spread the technology beyond their own community, starting new pilot programs in surrounding areas. Those pilot programs unite the community and teach them that environmental conservation is not only good for the environment, but it can help their farms too.

SOCIAL IMPLICATIONS OF CLEAN TECHNOLOGIES

In a time where many countries are suffering from economic crises and shortages of resources, the implementation of clean technologies goes beyond receiving a high return on investment. The use of clean technologies will enable Costa Rica to begin to recycle resources that farmers otherwise considered useless. By recycling resources and preventing pollution, there will be an improvement in the health of the people of Costa Rica and environment.

The use of an anaerobic digester is an excellent example of how a community can use waste to generate energy. Not only do these types of solutions create a renewable energy source for the community, but they also reduce the amount of waste polluting the natural resources. According to L. Allan Retana Calvo, a technician from ICE that helps farmers build polyethylene anaerobic digesters, the impacts of one digester on water quality is significant.

Retana estimates that each polyethylene anaerobic digester prevents a minimum of 150 kilograms of waste from entering water sources each month. According to Retana there are currently 125 polyethylene digesters that are operating in the Sarapiquí and other areas of Costa Rica (Retana, personal communication). Polyethylene anaerobic digesters in Costa Rica prevent approximately 20,000 kilograms of waste from polluting the water per month. Within one year, those digesters prevent approximately 225,000 kilograms of waste from polluting the drinking water every year.

This technology, if implemented on every eligible farm in Costa Rica, has the potential to prevent millions of kilograms of farm waste from contaminating drinking water each year.

In other countries where polluted water causes thousands of deaths daily (Gleick, 1999), the anaerobic digester could be used to help prevent waste from entering water, preventing deaths and improving daily living conditions. The polyethylene anaerobic digester is an excellent method for small farms to create a system of sustainable development, providing themselves with a means for cooking for food, electricity for homes, fertilizer for food crops, and an ability to take part in environmental conservation, all using the wastes from their own farms and homes.

A widespread use of this technology throughout the world has the potential to reduce deforestations by preventing wood burning for cooking and for heating water, to provide better crops through safe fertilizer that does not pollute water or kill endangered animals, and to reduce the energy crisis by providing an alternative form of fuel to power homes. In addition, the anaerobic digester technology can service as a miniature power plant, bringing energy to areas that traditional power plants do not reach. All these benefits serve to improve the quality of life of the population that implements them.

Farmers and communities can use the polyethylene anaerobic digester technology to recycle organic wastes in any warm climate, extending its potential to several countries in Central America, Asia, South America, and even Africa. Because farmers can and are using this technology globally, it has the potential to affect millions by proving energy and a cleaner environment that leads to a better way of life.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

Based on our research, we believe the ESPH should be able to begin expanding the Procuencas program to include the implementation of clean technologies as an additional means of preventing dairy farms from discharging waste into water. We have reviewed worldwide waste management techniques, identified methods applicable in Costa Rica, and determined the viability of those techniques through cost-benefit analyses and an examination of environmental impacts.

Our recommendations focus on two audiences. The first audience is the ESPH, for which we recommended starting a pilot program, spreading the technology through word of mouth and pamphlets, and developing a third branch of the Procuencas program. Our additional recommendations for farmers are several changes in management practices, such as keeping their cows in the barns longer, which will assist farmers in improving their production and help them take an active part in preventing wastewater pollution at its source.

RECOMMENDATIONS FOR THE ESPH

We recommend that the ESPH start a third branch in their Procuencas program, adding clean technologies to their forest protection and regeneration regimen. The strategies the ESPH should use in the clean technologies branch of Procuencas should include two major areas, anaerobic digesters, and best management practices.

The first section of the new program is the implementation of polyethylene anaerobic digesters. We recommend that the members of the ESPH promote the benefits of anaerobic digesters and the third branch of the Procuencas program using word of mouth and pamphlets. In addition, we highly recommend that the ESPH start a pilot program on one or more of the farms within their jurisdiction. The ESPH should construct at least one pilot program on a farm where dairy farming is the main source of income. For the program, the ESPH should construct an example of each of the clean technologies that will be included in the Procuencas program. We also recommend that the ESPH provide technical assistance to farmers to build these digesters to generate biogas and prevent wastewater runoff wherever possible in Heredia.

The second part of the clean technologies program will include the implementation of various best management practices, including grassed waterways, fences, diversions, water and feeding troughs, and contour and filter strips. Every farm can benefit from the addition of one or more of those techniques, including farms that have already constructed or plan to start an anaerobic digester.

To begin implementing clean technologies on farms in Heredia, the ESPH will need to start classifying farms that are interested in participating in the clean technologies branch of the Procuencas program. The ESPH will need to classify farms by size, terrain, location of water bodies, and the amount of usable waste produced in the milking barn daily. Every farm has the potential to implement waste management strategies, although not all farms will produce enough manure in the milking barns to implement an anaerobic digester. The ESPH can then work with the owners of the farms to match the most beneficial clean technologies for each farm and decide where to implement each technique.

The tarifa hidrica will absorb the majority of the costs for the clean technologies branch of the Procuencas program. We recommend that for the construction of anaerobic digesters, the farmers take full responsibility for the costs of materials where possible. For implementing best management practices, we recommend that the ESPH provide the full amount to construct each best management practice on a farm. The ESPH must individually calculate the amount of money paid to each farmer per year of contract by the tarifa hidrica for maintaining best management practices on each farm. That amount will depend on the cost of each practice in Costa Rica, which practices the farmers implement, how many practices are present on each farm, and how many hectares are protected.

The ESPH should provide technical assistance to farmers at the time of building as well as throughout the future use of the anaerobic digester and best management practices without charge. At the initiation of the clean technologies branch of Procuencas, entities other than the ESPH, such as ICE, may provide technical assistance for constructing the clean technologies. However, as the project expands, we recommend that the ESPH hire their own full time staff member trained to provide technical assistance for farmers using anaerobic digesters and other best management practices. The ESPH may absorb the cost of this technical assistance with funds from the tarifa hidrica or other areas of funding from the ESPH.

We recommend that the period of the contract for the clean technologies portion of Procuencas be five years. The funds for each best management practice implemented on a farm should be paid by the ESPH in the first year of contract, providing the means for each farm to implement the practices immediately.

The terms of contract should specify that the ESPH will provide technical assistance for anaerobic digesters and best management practices for five years, provided that the farm maintains the upkeep of the technologies in good condition to prevent waste from entering the water supply. A breach of contract should require that the farm reimburse the funds paid by the ESPH to build and maintain the technologies. The ESPH will need to monitor the upkeep of anaerobic digesters and clean technologies after the farmers implement them in order to ensure that the farmers are maintaining them at a working level that will prevent water pollution.

The ESPH should give farmers who implement the best management practices as part of the Procuencas program an option to renew their contract once it expires. For farmers who wish to renew their contract, the new contract will provide them with a small, predetermined amount of money paid each year designated to maintain the good upkeep of the best management practices. Good upkeep of best management practice may include replacing broken or old parts to keep the practices working effectively. By paying farmers a small amount of money to maintain their practices, farmers will be more likely to continue using their waste management techniques after they initially build them.

RECOMMENDATIONS FOR DAIRY FARMERS

We believe that the ESPH will discover that once they have begun the implementation of anaerobic digesters on farms, many farmers will be interested in increasing their biogas production to provide more energy for running equipment on the farm. For those farmers we are recommending management changes that will enable them to increase biogas production and save more money on their farms.

Farmers who do not currently produce enough manure to use an anaerobic digester or farmers who wish to increase their biogas production need to consider keeping the cows in barns for longer periods each day. By keeping cows in barns longer, farmers are able to collect more fresh manure to add to their bioreactors or compost piles, without having to collect manure from the fields. Farmers should use a strategy similar to Farm 4: Roberto Morera by keeping the cows in the barn for twelve hours in-between milking and leaving the cows on the pastures for the remaining twelve hours. By doing this, they will be able to increase their intake of manure for anaerobic digesters and still be able to benefit from using manure on pastures for fertilizers. Farmers should also use the effluent from the anaerobic digesters as fertilizer for a field. To substitute for feed, farmers should use grass cut from the fields to feed the cows.

In some cases, farmers may discover that they need to expand their barns in order to manage cows for longer periods. For farms with small amounts of livestock, this option may not be cost efficient and will restrict the farmer from producing more biogas.

FUTURE PROJECTS

Our report has included the costs to implement best management practices on farms in the United States; however, their cost in Costa Rica is unknown. Before the ESPH can truly implement a clean technologies branch for Procuencas, they will need to do an evaluation of the costs of best management practices in Costa Rica. For the ESPH to determine the amount they will need to increase the tarifa hidrica, they will need to account for the Costa Rican costs of best management practices in the Procuencas valuation equations. Once the actual costs and the amount of funding needed from the tarifa hidrica are determined, the ESPH can petition to add the third branch to the Procuencas program and begin implementing clean technologies on farms as part of the protection program for the watersheds of Heredia.

Due to the time limitations of our research, we were unable to do a complete study of the management changes that small farms would need to make to generate electricity for uses such as lighting, and running milking equipment or other electric appliances. We discovered that many farmers who currently use polyethylene anaerobic digesters for biogas are eager to expand their farms to generate electricity. We anticipate that farmers who wish to generate electricity on individual farms will need to make drastic changes in management practices, such as keeping the cows in barns for longer periods, centralizing their milking areas, carefully monitoring the mix of manure and water in their digesters, and on some cases, installing more advanced anaerobic digester systems. In the future, it would be beneficial for the ESPH to expand on our research to determine what costs, management changes, and other aspects need to be explored in order to generate electricity on small farms with limited amounts of manure.

Another area that would benefit the ESPH for future research is an in-depth study of a regional anaerobic digester. Since many of the farms of Heredia do not produce enough waste to sustain a biodigester of their own, it is possible that several of these smaller farms in a centralized location could contribute to a larger, regional anaerobic digester. Future research should determine whether this solution would be cost effective in Costa Rica, as well as explore the aspects of regional management, transportation of waste, probable locations for the digester, and allotment of the final product, whether it be compressed biogas for cooking or electricity.

We believe that adding a program to assist farmers to build clean technologies, such as anaerobic digesters and best management practices, will advance the ESPH´s goal to provide quality drinking water to its clients, as well as to encourage the community to cherish the value of environmental protection. Farmers will be able to use the program to increase their production and comply with Costa Rica's environmental laws.

Exploring these options further will allow the Procuencas program to evolve to the next step of maintaining a clean environment in Costa Rica. If implemented, these ideas will enable the ESPH to unite the community through active waste management. Each farmer will be able to take part in the many benefits of clean technologies, proper waste management, and actively prevent water contamination at its source.

Preventing the contamination of drinking water does not have to stop in Heredia. Other farms in Costa Rica and other parts of the world with similar climates could easily implement these clean technologies. Cambodia, Thailand, China and Vietnam have already implemented anaerobic digesters. The influence of a similar program in Costa Rica could encourage other small farms in Nicaragua, Ecuador, rural areas in Africa, and countless other places throughout the world to reap the benefits of clean technologies and actively take part in improving the health of the world population by preventing the pollution of the drinking water at its source.

APPENDIX A: LA EMPRESA DE SERVICIOS PÚBLICOS DE HEREDIA

The Empresa de Servicios Públicos de Heredia (Public Services Company of Heredia) [ESPH] sponsored this report, which was prepared by members of the Worcester Polytechnic Institute Costa Rica Project Center in 2005. The liaison between Worcester Polytechnic Institute and the ESPH for this project was Luis Gámez, the Head of Departmental Management for the ESPH.

HISTORY AND DEVELOPMENT OF THE ESPH

When electricity services became necessary for Costa Rica in 1915**,** the State created a private enterprise called JASEMH (Joint Administration of Municipal Electrical Service of Heredia) to provide electricity to Heredia and its surrounding areas. JASEMH coordinated the construction of La Joya hydroelectric plant in 1915, and in 1926 expanded the plant to meet the needs of the country. In 1949, when the electricity demand exceeded the plant's capacity, the state authorized construction of the Carrillos hydroelectric plant (Empresa de Servicios Públicos de Heredia, 2003).

JASEMH continued to provide electric energy and public lighting to the community of Heredia until 1976. In this year, Law 5889 was passed to initiate the creation of the ESPH (The Public Service Company of Heredia) that took charge of the administration, maintenance, and development of the aqueduct, sewage services, and energy services. This new company replaced JASEMH and functioned under state control (ESPH 2003).

In 1998, the ESPH petitioned for independence from State control, stating that the State's rigid regulations restricted the development necessary to expand and meet growing demands for electricity. The State granted the ESPH its independence, recognized by Law 7789 (Law of Transformation of the Company of Public Services of Heredia). The law transformed the ESPH into a joint stock company (see Glossary) governed by the private sector. Upon gaining independence, the ESPH redefined its goals to satisfy increasing demands for electricity, public lighting, and sewer systems. Today, the ESPH commits to providing a continuous supply of high quality drinking water, electricity, and street lighting for the public (Empresa de Servicios Públicos de Heredia, 2003).

ESPH MISSION AND VISION

The ESPH website describes a vision "to be a company that is a leader in public service that improves the quality of life in the community, in harmony with the environment." In their mission statement, the ESPH states, "We are an innovative company with social and environmental responsibilities to offer excellent service, supported by the people and seeking the satisfaction of our clients and the community at large" (Empresa de Servicios Públicos de Heredia, 2003).

ESPH GOALS AND OBJECTIVES

The ESPH is also dedicated to promoting the development, education, and environmental conservation of Heredia's natural resources. The company has been researching and encouraging the implementation of clean technologies over the past few years (Empresa de Servicios Públicos de Heredia, 2003). Together with various other municipalities, such as the Central American Institute, the ESPH has also devoted itself to providing technological opportunities for rural areas (Empresa de Servicios Públicos de Heredia, 2003).

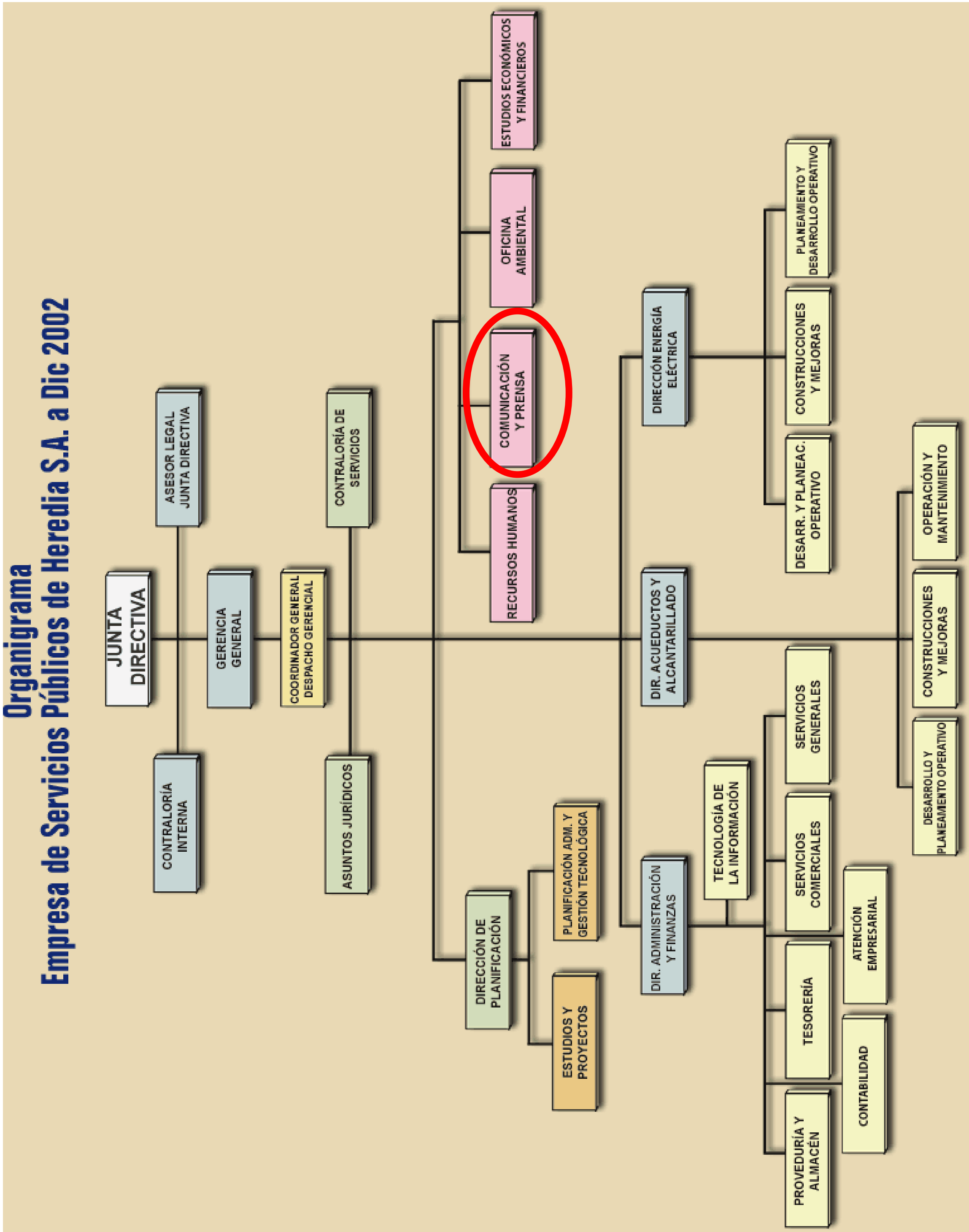
To have enough safe drinking water it is important for the people to prevent its contamination by protecting the forests from where the water originates (Empresa de Servicios Públicos de Heredia, 2003). The ESPH does this through a program called Procuencas. This program uses funds provided by donations of large corporations with similar interests in conservation as well as revenue from a water tax. In return, the Procuencas program pays landowners for their voluntary participation in either both the conservation and natural regeneration of forests or reforestation with native species (Empresa de Servicios Públicos de Heredia, 2003). The overall goal of the Procuencas program for the ESPH is to increase the value of environmental conservation and to promote environmental awareness.

The ESPH has several important objectives including, extending further the protection of the quality of surface and groundwater by reduction of the pollution risk posed by wastewater discharge, investigating clean technologies and renewable energy options to reduce energy consumption, and promoting environmental education throughout the community.

POSITION AND RESPONSIBILITIES OF LUIS GÁMEZ

The ESPH is a local public utilities company that provides electric power, street lighting, water, and sewage services. Figure 8 contains information regarding the organizational hierarchy within the ESPH. The circled box in the diagram indicates our sponsor's position in relation to the ESPH's other departments. Luis Gámez is the head of the Department of Environmental Management, and he directly deals with environmental quality control in Heredia. The Department of Environmental Management is one of the main departments of the ESPH, and it assures that the other departments abide by the environmental quality standards and laws. The responsibilities of Sr. Gámez include finding participants for the Procuencas program, determining the environmental impact of services such as power lines and dams for drinking water. He is also deals prevention of contamination of ground and surface water.

Figure 8: Organization of the ESPH



Source: La Empresa de Servicios Públicos de Heredia, 2003

APPENDIX B: BIOGAS

Biogas is a versatile product produced from the waste of animals, plants, and people. This gas is composed of methane and carbon dioxide, is the product of anaerobic decomposition, and is the byproduct of anaerobic digesters. Biogas has many uses, such as for cooking, lighting, heating and cooling, or for burning. It can be combusted and converted into electrical power, which can be used to sustain houses, milking equipment, or any other electrical appliance. Additionally, biogas can be purified, compressed, and sold as an alternative to propane. In Finland, researchers are investigating biogas as an alternative source of fuel for vehicles.

ANAEROBIC DECOMPOSITION

Anaerobic decomposition occurs in three basic stages as the result of the activity of a variety of naturally occurring microorganisms. Initially, a group of microorganisms converts organic material to a form that a second group of organisms utilizes to form organic acids. Methane-producing anaerobic bacteria utilize those acids and complete the decomposition process. As a result, manure is broken up into several base components by the degradation process (Wright, 2001).

BIOGAS PRODUCTION

Varieties of factors affect the rate of anaerobic digestion and biogas production. The most important is temperature. Anaerobic bacteria communities can endure temperatures ranging from below freezing to above 135 degrees Fahrenheit (57.2 degrees Celsius), but they thrive best at temperatures of about 98 degrees Fahrenheit (36.7

degrees Celsius) (mesophilic) and 130 degrees Fahrenheit (54.4 degrees Celsius) (thermophilic). Bacteria activity, and therefore biogas production, falls off significantly between about 103 and 125 degrees Fahrenheit (39.4 and 51.7 degrees Celsius) and gradually from 95 to 32 degrees Fahrenheit (35 to 0 degrees Celsius) (Energy Savers, 2003). To optimize the digestion process, the digester must be kept at a consistent temperature, as rapid changes will upset bacterial activity. As long as proper conditions are present, anaerobic bacteria will continuously produce biogas.

Biogas is odorless, colorless, and yields about one-thousand British Thermal Units (Btu) [252 kilocalories (kcal)] of heat energy per cubic foot (0.028 cubic meters) when burned (Energy Savers, 2003). Biogas produced in anaerobic digesters consists of methane (fifty to eighty percent), carbon dioxide (twenty to fifty percent), and trace levels of other gases such as hydrogen, carbon monoxide, nitrogen, oxygen, and hydrogen sulfide. The relative percentage of those gases in biogas depends on the feed material and management of the process. When burned, a cubic foot (0.028 cubic meters) of biogas yields about ten Btu (2.52 kcal) of heat energy per percentage of methane composition. For example, biogas composed of sixty-five percent methane yields 650 Btu per cubic foot (5,857 kcal/cubic meter) (Energy Savers, 2003).

APPENDIX C: ANAEROBIC DIGESTERS

Anaerobic digesters are made out of concrete, steel, brick, or plastic and are shaped like silos, troughs, basins, or ponds, and may be placed underground or on the surface. All designs incorporate the same basic components: a pre-mixing area or tank, a digester vessel(s), a system for using the biogas, and a system for distributing or spreading the remaining digested material, called effluent (Seale, n.d.).

There are two basic types of digesters: batch and continuous. Batch-type digesters are the simplest to build and are more feasible for smaller farming operations. Their operation consists of loading the digester with organic materials and allowing it to decompose. The retention time depends on temperature, size and type of the reactor, and amount of bacteria present. Once the digestion is complete, the effluent is removed and the process is repeated. In a continuous digester, organic material is constantly fed into the digester. The material moves through the digester either mechanically or by the force of the new feed pushing out digested material. Unlike batch-type digesters, continuous digesters produce biogas without the interruption of loading material and unloading effluent. Those digesters are better suited for large-scale operations (Seale, n.d.).

There are three main types of anaerobic digesters that are currently implemented on farms in the United States by the US Department of Agriculture's Natural Resource Conservation Service: Covered Lagoon, Complete Mix, and Plug Flow digesters. Each one of those anaerobic digesters has advantages and disadvantages depending on the size of the farm and the consistency of the waste produced (Nelson & Lamb, 2002).

COVERED LAGOONS

A covered lagoon digester consists of a manure treatment lagoon with an impermeable lining, usually concrete, that prevents waste from seeping into the soil. An impermeable top cover is also placed over the manure lagoon to capture the biogas produced by the decomposing manure that percolates through the water to the surface in the lagoon. The cover has built in channels that direct the captured biogas to a collection tank. This type of digester is very dependent on the ambient temperatures around the lagoon. If the temperature gets too low, the decomposing bacteria cannot function and there is a poor output of biogas. Of the three types of large anaerobic digesters, the covered lagoon is one of the least expensive, but also requires the most space (Nelson & Lamb, 2002). The covered lagoon requires an amount of 1000 cubic feet of water for every four pounds of manure.

POLYETHYLENE ANAEROBIC DIGESTERS

The polyethylene anaerobic digester is the cheapest and simplest way to produce biogas for small-scale farms. Polyethylene digesters are very similar to plug flow digesters, but on a much smaller scale. They are appealing to rural communities because of the low cost of the installation and monetary benefits they produce, while improving the environment at the same time.

The polyethylene anaerobic digester is composed of a double-layered tube of thick polyethylene that is resistant to ultraviolet light. This plastic resists degradation in the presence of weather elements, sun, and water. Other components of the polyethylene digester are PVC piping and connecters, and concrete cylinders. This type of anaerobic digester can be built with very few advanced tools.

The plastic anaerobic digester must be carefully maintained because it can be easily punctured by stones, branches, or livestock that fall into the digester area. If the digester bag is punctured, the entire system must be replaced before it can continue producing biogas.

The polyethylene digester is 1.5 meters wide, 1 meter deep, and ranges from eight to 21 meters in length. Polyethylene digesters with lengths longer than 21 meters tend to collect manure in the center of the digester and the manure does not pass through properly, hindering the production of biogas. For anaerobic digesters larger than 21 m, more advanced systems should be considered, such as the plug flow or complete mix anaerobic digesters.

COMPLETE MIX DIGESTER

The complete mix digester is primarily used with manure collected by a flush system, where the waste is brought to the digester by flowing water across an impermeable floor, and tends to have more solid waste, with a concentration of approximately thirty three percent. The flush waste is processed by heating it in a tank and a mechanical or gas mixer continually mixes the solids. This method of manure decomposition is highly effective, however, the system is very expensive and costs more to maintain and operate than any of the other common anaerobic digesters (Nelson & Lamb, 2002)

PLUG FLOW DIGESTER

The plug flow digester is designed to be used with a higher concentration of solid waste, approximately thirteen to fifteen percent, which needs to be scraped into the digester. This means that a flush system cannot be used, which increases the required amount of labor needed to input waste into the digester. The process of plug flow digesters starts with the pre-mixing of solids in a separate tank. The manure then enters one end of the plug flow digester and flows through the tank. New waste pushes the old waste through the tank and forms solid floating masses or "plugs." The plugs produce biogas that is captured by an impermeable cover, which directs the biogas to a place where it can be used for cooking or energy production. Hot water is circulated through the tank to heat it and circulate the waste (Nelson & Lamb, 2002).

Using a plug flow anaerobic digester on a dairy farm has many benefits. The first is its ability to collect biogas and convert it into a renewable source of electricity through combustion. A plug flow digester produces a greater amount of biogas per day than a covered lagoon would because there are higher concentrations of solid waste that are input into the system. The combustion process also produces a large amount of heat that the operators can then use in many other applications such as hot water and space heating (Nelson & Lamb, 2002). According to Nelson and Lamb (2002), a digester on the Haubenschild farm produces enough electricity to power their entire farm and seventy-five average homes. The ability of those digesters to produce large amounts of electricity provides the opportunity for buyback programs from the electricity companies. A digester on a large farm, larger than most farms in Heredia, can pay for itself in as little as five years when working at optimum capacity (Nelson & Lamb, 2002).

Although they have many benefits, there are also drawbacks to using plug flow digesters. Several investigations show that the plug flow digester is not effective for farms with less than 250 cows because there is not enough waste to continually fuel the digester (AgSTAR Handbook, 2004; Nelson & Lamb, 2002). A plug flow digester must have consistently large additions of manure to maintain the bacterial population necessary to decompose the waste.

ENVIRONMENTAL BENEFITS OF ANAEROBIC DIGESTERS

Anaerobic digesters have the ability to reduce the pathogens such as E. Coli, cryptosporidia, and pfiesteria that are often present in manure (Moser, n.d.). Those pathogens are one cause of water pollution in bodies of water that run through farms. Digesters stabilize the nitrates and phosphates that support pathogens to levels that are not harmful to humans, but are still available to plants (Moser, n.d.). Thus, the digester byproduct becomes a very effective fertilizer. The fertilizer is more effective than raw manure because it contains high concentrations of ammonia and almost no pathogens (Nelson & Lamb, 2002). Finally, anaerobic digesters reduce odor, the number of pests such as flies, and greenhouse gases such as carbon dioxide and nitrous oxide. They may also destroy some of the weed seeds in untreated manure (Nelson & Lamb, 2002).

APPENDIX D: DAIRY FARM OBSERVATION FORM

	Yes	No	N/A
Name of farm: ______________________________			☐
Owner of farm: ______________________________			☐
Location of farm: ______________________________			☐
Other identifying information: ______________________________			

Livestock

	Yes	No	N/A
Number of cows: ______________________________			☐
Number of other domestic animals: ______________________________	☐	☐	☐
Amount of waste produced by cows: ______________________________			☐
Regular milking methods: ______________________________			☐
Time cows are in the barn per day: ______________________________			☐
Diet of cows: ______________________________			☐
How fed to the cows: ______________________________			☐
Where does it come from: ______________________________			☐
Vitamins fed to cows: ______________________________	☐	☐	☐
The area of pasture cut and brought to barns: ______________________________	☐	☐	☐

Additional notes: ______________________________

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Land Yes No N/A

Size of farm: ____ ☐

Terrain: ____ ☐

Land use: ____ ☐

Percentage forest: ____ ☐

Percentage pasture: ____ ☐

Percentage protected: ______________________________________ ☐

Percentage other: ____ ☐

Types of vegetation: _______________________________________ ☐

Total number of pastures: ___________________________________ ☐

Period of rotation for the pastures: _____________________________ ☐ ☐ ☐

Types and ratio of fences: ___________________________________ ☐

Type of fence posts: ____ ☐

Additional notes: ____

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____

Sketch of property: ☐

Body of Water: ____ Yes No N/A

Times water source goes dry: ________________________________ ☐

Bugs in water: ______________________________________ ☐ ☐ ☐

Dead animals in or near water: ____________________________ ☐ ☐ ☐

Animal feces in or near water: ____________________________ ☐ ☐ ☐

Animals with access to water: _____________________________ ☐ ☐ ☐

Dirt in water: _______________________________________ ☐ ☐ ☐

Visible depth: _______________________________________ ☐ ☐ ☐

Surface of bottom: mud☐ rock☐ vegetation☐ other☐____________ ☐

Size of rocks (diameter): ________________________________ ☐

Description of bank: ___________________________________ ☐

Buffer width: _______________________________________ ☐

Slope of bank: ______________________________________ ☐

Speed of water: ______________________________________ ☐

Width: ____ ☐

Depth: ____ ☐

Temperature: _______________________________________ ☐

Comes from: ____ ☐

Goes to: ____ ☐

Used for drinking: ____________________________________ ☐ ☐ ☐

Distances between water source and animals, barns etc: ____________ ☐

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Other houses or farms on or using this body of water: ____________ ☐ ☐ ☐

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Additional notes: _____________________________________

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Main water source for house and barn: ______________________ ☐ ☐ ☐

Times water source goes dry: ________________________________ ☐

Secondary water sources: ________________________________ ☐ ☐ ☐

Springs or wells on farm: _________________________________ ☐ ☐ ☐

Depth of well: _______________________________________ ☐

Main aquifer on which this farm is located: ___________________ ☐

Additional notes: _____________________________________

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Pollution Sources	Yes	No	N/A
Kind of pesticides used: ____________________	☐	☐	☐
Quantity applied per hectre: ____________________			☐
How often applied: ____________________			☐
Kind of fertilizer used: ____________________	☐	☐	☐
Quantity applied per hectre: ____________________			☐
How often applied: ____________________			☐
Source and amount of manure put on pastures: ____________________ ____________________			☐
Wastewater from farmhouse goes to: ____________________			☐
Wastewater from barn goes to: ____________________			☐
Manure from barn goes to: ____________________			☐
Type of bedding in barn: ____________________	☐	☐	☐
Barn cleaning practices: ____________________ ____________________			☐
Distance from farmhouse to barn: ____________________			☐
Other buildings in area: ____________________ ____________________	☐	☐	☐
Distances from barn: ____________________ ____________________			☐

Additional notes: ____________________

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General Farm Information	Yes	No	N/A
Is farming the main source of income: ______________________________	☐	☐	☐
Increase, decrease, or constant size: ________________________________			☐
Plans for future changes in management practices: ____________________ ____	☐	☐	☐
Other plans for farm's future: _______________________________________ ____	☐	☐	☐
Government imposed regulations: ____________________________________ ____	☐	☐	☐
Residence of farm owner: ____			☐
Time under current ownership: ______________________________________			☐
Age of farm: ____			☐
Description and use of land thirty or more years ago: ___________________ ____ ____			☐
Farming equipment:____	☐	☐	☐
Other gas or electricity consuming equipment: _________________________ ____	☐	☐	☐

Additional notes: ____
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Access Road	
Name: ____	☐
Width: ____	☐
Surface: ____	☐
Amount of traffic: ____	☐
Feeding streets: ____	☐

Additional notes: ____
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Current Management Practices	Yes	No	N/A
Anaerobic digester: ______________________________	☐	☐	☐
Composting: ______________________________	☐	☐	☐
Lagoon: ______________________________	☐	☐	☐
Contour buffer strips: ______________________________	☐	☐	☐
Filter strips: ______________________________	☐	☐	☐
Fencing: ______________________________	☐	☐	☐
Feeding troughs: ______________________________	☐	☐	☐
Water troughs: ______________________________	☐	☐	☐
Diversions: ______________________________	☐	☐	☐
Grassed waterways: ______________________________	☐	☐	☐
Pasture rotation: ______________________________	☐	☐	☐
Other methods of managing waste: ______________________________	☐	☐	☐
Previous considerations of proper waste management techniques: ________	☐	☐	☐
Interest in implementing proper waste management techniques: ________	☐	☐	☐
Current methods of preventing waste from contaminating water supply: __	☐	☐	☐
Farmers' questions about possible waste management techniques: _______	☐	☐	☐
Anticipations of problems with these techniques: ______________________	☐	☐	☐
Changes made to farm to implement waste management techniques: _____	☐	☐	☐
Problems and successes during transition: ______________________			☐
Family's feelings and thoughts during transition: ______________________			☐
Workers' feelings and thoughts during transition: ______________________			☐
Most successful and worthwhile methods: ______________________			☐
Changes in views of preservation of environment: ______________________			☐
Would removing waste from farm decrease production: ________________	☐	☐	☐
Suggestions for promoting waste management techniques: _____________			☐

Additional notes: ____

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APPENDIX E: TEMPLATES FOR WASTE MANAGEMENT PAMPHLETS

Figures 9 through 16 are templates for pamphlets for four of our proposed clean technologies. Once translated into Spanish, the ESPH can pass them out to farmers so the farmers know more about the clean technologies.

Figure 9: Polyethylene Biodigester Page 1

Is a Polyethylene Biodigester Right For You?

Required Qualities

☐ A 10 X 3 meter area near the barn.

☐ **A field for dispersing** the processed manure.

☐ Organic or no bedding in barn.

☐ Organic or no cleaning supplies.

☐ Able to clean your barn in a controlled manner.

Frequently Asked Questions

How long does a digester take to start?

After the hole is dug, the installation takes only a few hours. Once the digester is installed, it will take about a month to start producing biogas.

How easy is a digester to run and maintain?

A biodigester is very easy to install and maintain, and it does not require any special tools to install.

How much money would a digester save my farm?

The biogas produced can be used to replace propane for cooking. By using biogas you can save up to 7000 colones a month.

Polyethylene Biodigester

Empresa de Servicios Públicos de Heredia, S.A

Figure 10: Polyethylene Biodigester Page 2

What's Involved

1. A technical director will need to assess the size and location of the biodigester on each farm. Then, you must purchase materials and install the biodigester.

2. The biodigester should be sheltered to prevent damage from the weather and the sun.

3. The cows must be in the barns long enough to generate enough waste to continuously fuel the biodigester.

4. The barn should be flushed directly into the biodigester with a high content of water.

Benefits

Odor and fly control
Anaerobic digesters consume odor-causing compounds in ma**nure and reduces fly propagation.**

Prevents water pollution
By digesting the manure, the amount of nitrates and phosphates **in the effluent is reduced and** therefore the amount of harmful bacteria entering water associated with those are also reduced.

Biogas production
Polyethylene biodigesters produce **Biogas, which is a flammable gas** that can be used for cooking or even electricity generation.

Costs

The overall cost of a plastic biodigester is approximately 70,000 Colones ($150)

A polyethylene biodigester has a life span of 5 to 10 years, which means that new materials must be purchased to maintain the production of biogas.

Funding

Funding for a polyethylene biodigester may be available through the Procuencas program to eligible participants.

procuencas

Figure 11: Contour and Filter Strips Page 1

Are Contour and Filter Strips Right For You?

Required Qualities

☐ Waste water runoff that enters a water source.

☐ Area to plant trees, shrubs, or living fence posts.

☐ Time to let roots of the buffers grow.

☐ Must be used with other proper waste management practices to be effective enough to remove all the problem nutrients.

Frequently Asked Questions

What are contour and filter strips?

Contour and filter strips are lines of vegetation located on hills or along bodies of water that absorb nutrients from run-off water before they can enter a water system.

What plants can be used as contour and filter strips?

Any vegetation that has a dense root system can be used for filter strips. You can even use crops like hay or tall grasses that can be used for feed.

How large do contour and filter strips need to be?

The necessary size of filter strips are different for every farm. It depends on the terrain, the proximity of water, and how much wastewater runoff there is.

Contour and Filter Strips

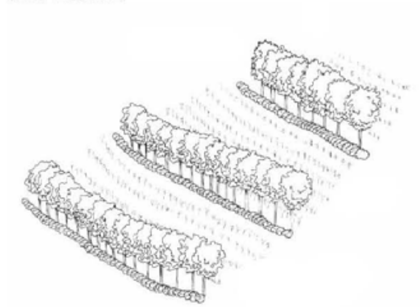
Empresa de Servicios Públicos de Heredia, S.A

Figure 12: Contour and Filter Strips Page 2

What's Involved

1. Must determine where there is wastewater runoff leading toward a water system on your property.

2. Purchasing and planting vegetation that will best absorb wastewater and possibly **provide economic benefits to** the farm.



3. It may be necessary to fertilize and maintain certain plants when they are **first starting so that they are** not washed away with the wastewater.

Benefits

Social benefits

The social benefits considered here are environmental, where the public downstream obtains **benefits through reduced sediment and nutrient flows that** could be harmful to the people who drink the water.

Farmer benefits

A contour or filter strip can be any type of vegetation such as hay or even trees that can be used for timber.

Costs

The average costs of contour **and filter strips are 12,877** colones per foot. Depending on the plants, fertilizers may have to applied when they **are first planted. Once the filter strips are in place, very** little maintenance is necessary.

Funding

Funding and incentives for **contour and filter strips can** be available through the Procuencas program to eligible participants.

Figure 13: Diversions to Prevent Water Pollution Page 1

Are Diversions Right For You?

Required Qualities

- ☐ Runoff entering a water source
- ☐ Able to divert water to an area of dense vegetation
- ☐ Labor to keep diversions directing water in desired path

Frequently Asked Questions

What is a diversion?

A diversion is a ditch or trench or even a dense row of vegetation that diverts runoff water from directly entering a water source.

How does a diversion help my farm?

A diversion prevents erosion and reduces the amount of harmful nutrients from entering a water source by allowing the nutrients to be absorbed by the vegetation as it passes through.

Which plants work best to absorb nutrients?

Any plants that have a dense root system will work to absorb nutrients from runoff water redirected from diversions.

Diversions to Prevent Water Pollution

Empresa de Servicios Públicos de Heredia. S.A

Figure 14: Diversions to Prevent Water Pollution Page 2

What's Involved

1. Determine where runoff water is causing a problem with erosion and where your barn waste goes.

2. Determine where the best place for the runoff water to go is. This involves having a location where the water can **disperse and infiltrate the soil.**

3. Dig small trenches directing the water to the predetermined location. Some maintenance may be needed in the future to make sure that the diverions are properly directing the water.

Benefits

Prevents the erosion of pasture land

By diverting runoff water to **pastures and fields where the** water can diffuse, the amount of erosion is reduced.

Prevents water pollution

By directing manure in runoff **water to field, the nitrates and** phosphates in the runoff are absorbed by the vegetation **in the fields. Therefore the** amount of harmful bacteria entering water associated with nitrates and phosphates are also reduced.

Costs

The overall cost of a diversion to prevent wastewater pollution is approximately 4,833 colones per meter.

Diversions may need additional labor to properly maintain.

Funding

Funding for diversions on dairy farms may be available through the Procuencas program to eligible participants.

Figure 15: Fencing to Protect Waterways Page 1

Is Fencing Right For You?

Required Qualities

- ☐ Livestock entering a water source
- ☐ Pastures are being overused, causing erosion.
- ☐ Grass in the pastures is not growing well or is thin.
- ☐ Space for troughs for an alternate source of water for livestock.

Frequently Asked Questions

Where do my livestock get water from if the water source is fenced off?

Fencing is best used in combination with water troughs. This keeps the animals from contaminating the water source while still providing water.

What should be used for a fence post?

Anything from branches to live trees can be used a fence post. If live fence posts are used, they can act as a filter strip to absorb nutrients as well.

How do the water troughs get filled?

The troughs can be filled by had or by pumps from a water source.

Fencing to Protect Waterways

Empresa de Servicios Públicos de Heredia, S.A

Figure 16: Fencing to Protect Waterways Page 2

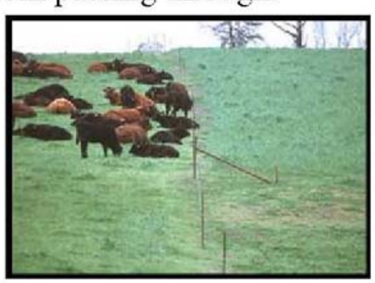
What's involved

1. Determining where your livestock is entering a water source.

2. Determining which of your pasture lands have a problem with erosion and which pastures can be divided and sectioned.

3. Plant live fence posts or dig holes for post and connect the posts with barbed wire.

4. Cut branches from the posts and plant more until they are dense enough to stop animals from passing through.



Benefits

Prevents Water Pollution

Fencing prevents pollution by keeping animals out of the water source to stop direct contamination of water. If live fence posts are used, the vegetation will help absorb harmful nutrients and help reduced erosion.

Pasture rotation

The separation of the pasture land allows the vegetation to fully regrow and reduce the **amount of erosion of the fields.**

Costs

The cost of fencing of pasture land is approximately 1200 colones per meter.

When implementing fencing, waster troughs must be supplied for the livestock. The average cost of a water trough is about 429,875 colones per trough.

Funding

Funding for fencing and water troughs may be available through the Procuencas program to eligible participants.

GLOSSARY

AyA:

Instituto Costarriense de Acueductos y Alcantarillados (Costa Rican Institute of Aqueducts and Sewers)

best management practice (BMP):

A practical, affordable approach to conserving a farm's soil and water resources without sacrificing productivity. The best management practices considered in our project include anaerobic digesters, composting, lagoons, contour buffer strips, filter strips, fencing, water troughs, diversions, and grassed waterways (OMAF Staff, 2003).

clean technology:

A manufacturing process or product technology that reduces pollution or waste, energy use, or material use in comparison to the technology that it replaces. This term will be used interchangeably throughout our report with the following terms: waste management technique, waste management practice, waste management plan, waste management strategy, and waste management method.

ESPH:

Empresa de Servícios Públicos de Heredia (Public Services Company of Heredia)

ICE:

Instituto Costarricense de Electricidad (Costa Rican Institute of Electricity)

joint stock company:

A company that has some features of a corporation and some features of a partnership. A corporation is chartered by a state and given many legal rights as an entity separate from its owners. Corporations are characterized by the limited liability of their owners, the issuance of shares of easily transferable stock, and existence as a going concern. A partnership is a relationship of two or more entities conducting business for mutual benefit (Joint Stock Company, 2000).

Ley Forestal:

Law #7353, Article thirty-three specifies declared areas of protection for water sources. Areas that border permanent water sources are not to have building developments or tree cutting within one hundred horizontal meters of the source. For riverbanks, protected areas extend fifteen meters measured horizontal from both sides in rural areas, and ten meters in urban zones. Article fifty-eight establishes a penalty of three months to three years in prison for whoever invades a protected zone.

MAG:

Ministerio de Agricultura y Ganadería (Ministry of Agriculture and Livestock)

MINAE:
Ministerio del Ambiente y Energía (Ministry of Environment and Energy)

riparian:
Of, on, or relating to the banks of a natural course of water (The American Heritage Dictionary, 2000).

tarifa hidrica:
A water tax of 3.8 colones per cubic meter ($0.008/$m^3$) of water charged to the customers of the ESPH. This tax helps preserve the watershed of Heredia by providing money for the ESPH to compensate landowners who participate in the Procuencas program.

UCR:
Universidad de Costa Rica (University of Costa Rica)

UNA:
Universidad Nacional de Costa Rica (National University of Costa Rica)

waste management:
The processes involved in dealing with the waste of humans and organisms, including minimization, handling, processing, storage, recycling, transport, and final disposal (Webster's New Millennium Dictionary, 2004).

waste management practice:
See "clean technology" in glossary.

watershed:
The region draining into a river, river system, or other body of water (The American Heritage Dictionary, 2000).

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