Utilizing Industrial Wastewater For Irrigation at The Cerrito School of Agriculture

By: Brendan Halloran, Nathan Smith, Jennifer Chaves, and Matthew Biando

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**An Interactive Qualifying Project submitted to the Faculty of
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Bachelor of Science**

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Submitted to:
Escuela Agrícola San Francisco, Cerrito
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Abstract

The Escuela Agrícola Cerrito, located in Benjamín Aceval, Paraguay, is an agricultural boarding school. Dry spells have become increasingly common, leading to stress on the crops. The purpose of our project was to utilize the treated wastewater from the cheese factory on campus to irrigate a maralfalfa pasture, a plant used to feed the cows on campus. We began by researching different irrigation systems, holding meetings, observing the crop field, constructing a list of materials, and creating a budget. We settled on a design that pumped the treated effluent along a chicken coop to an underground water tank. Finally, a pump in the tank moved water out from storage underground and through drip tape running between each row of maralfalfa.

Acknowledgements

We appreciate the collaboration and support of Eng. Amalio Enciso, Eng. Walter Medina, and Mr. Ricardo Negrete throughout our project and for all their valuable contributions to develop the project and offer us learning opportunities.Working with them and with the students of Cerrito was a very enriching experience that allowed us to put into practice and learn even more about the technical concepts for developing an irrigation system, as well as learning about the cultural and agricultural context of Cerrito School. We hope that our project can contribute to the sustainability of the school.

Executive Summary

Purpose and Goals:

The Cerrito Agricultural School (Cerrito) is a small boarding school in rural Paraguay owned by Fundación Paraguaya, the sponsors of this project, that serves students who are unable to pay the full cost of tuition. As a result, Cerrito relies on revenue from the professors and students practicing the trades taught at the school (Self Sufficient Schools, n.d.). The recently opened cheese factory, inaugurated in March 2024, on the Cerrito School grounds, provides one such revenue stream. The factory uses a large amount of water to clean its machinery and to produce dairy products. The resulting wastewater drains into a collection system and is treated through a sequential batch reactor before being stored in a tank on site. Cerrito built a water treatment plant to make the wastewater available for irrigation. Making the treated wastewater available for irrigation will ensure adequate water supply for a parcel of maralfalfa (Pennisetum sp) near the cheese factory during dry periods.

The challenge, and goal, of our project was to design and install a low-cost, easily maintained, and durable irrigation system to utilize the treated water from the cheese factory. This meant designing the best irrigation system for the Cerrito School, considering all technical and social factors such as the potential effect the system may have on the school and its profits, as well as building an irrigation system that makes the most efficient use of the water available. Within this goal we had two sub-goals, the first was a technical goal: we wanted to build an irrigation system that most efficiently increases cattle feed production. This increase in cattle feed due to the irrigation of the mar alfalfa then sends the school into a positive feedback loop. That is, increased maralfalfa causes more food for cattle, this results in an increase of dairy, the increased dairy means the cheese factory has an increase in production, the increase of production requires more cleaning of the machinery which results in more water for irrigation. The second was a social goal: we want to create a system that both integrates with and enhances the school’s culture and practices by promoting the reuse of water within the school.

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Methods:

To first settle on the type of irrigation system to use in our project, our group conducted preliminary research into the benefits and drawbacks of different irrigation systems, such as the different initial installation costs and the maintenance requirement. Our group considered this when researching the water available, the soil texture, and local material availability. In addition to this, local climate patterns were also researched to determine the best kind of irrigation system.

To settle on a design, we did field observations to obtain field measurements to then draw up our design. These measurements were then used again to know how much drip tape and pipe we would need for our system when calculating the budget. The semi-structured interviews with Ing. Amalio Enciso, Ing. Walter Medina, and Sr. Negrete provided us with valuable information about what their vision for our project was and which design would help to best achieve that. In addition to this, their insight gave us numbers to calculate a return on investment and generate a final design drawing using an overhead picture from Google Earth edited on GoodNote.

This system required various calculations that helped decide what pump should be used, starting with the required power of vertical pressure. However, friction loss also had to be factored in from the main pipe and sub pipes, which was calculated using distances of pipes and tables. Then the drip tape friction loss and filter loss had to be calculated. Once the total pressure for the system was solved, it needed to be converted from psi to total head then from total head to horsepower. After we multiplied the efficiency coefficient to the required horsepower, we got a solution that that the design that utilized the aljibe would be able to sufficiently irrigate the pasture with a 2 HP pump, making it the least power and financially intensive option. With assistance from our sponsors, this third design was chosen as the system to implement. This design required a weaker pump and made the most efficient use of the reservoir.

Deliverables:

Our first deliverable was the design of the irrigation system. Drip irrigation was decided as the mode of water delivery with input from our counterparts and field observations. The slow pace of drip irrigation was the best fit when considering the water available for irrigation along with the soil type of the pasture. Through our design we were able to show our counterparts where specifically different pumps and valves were going through our design, the distribution of PVC pipes and the drip tape, then we could walk outside and point out these areas in person as well. To see the design in full, refer to Figure 1.

Our second deliverable was the presentation of the materials budget for Fundacion Paraguaya which included a brief description of the purpose of the project, price estimates for the materials required, the final design of the irrigation system, and a financial analysis of the recovery time to recoup the investment in the proposed irrigation system (payback period). To estimate the impact of our project on the school's milk production, and in turn profits, our group collaborated with our counterparts, Professors Amalio Enciso and Walter Medina, to conduct a return-on-investment analysis. This return-on-investment analysis found that if the new irrigation system eliminated the normal reduction in maralfalfa crop production, in the winter and summer, so that it would match the normal spring and fall maralfalfa production, total yearly production would increase by just under 18%. This will pay back the cost of the new irrigation system in 1.08 years or 13 months.

The installation of the irrigation system was our third deliverable. This irrigation system pumps the treated water from the wastewater treatment center of the cheese factory to an aljibe, or underground water tank, which is 56 meters from the water treatment center, and at an elevation of roughly 4 meters higher than the water treatment center. From the aljibe the water is then pumped by a second pump to the maralfalfa field and through the drip tape lines in each row (See Figure 1). In the case of a burst pipe or the aljibe overflowing, there is an emergency release valve that sends water to a tajamar, which is roughly 56 meters south of the water treatment tanks. Figure 1 can be seen for added irrigation system detail.

Figure 1: Finalized design of our irrigation system.

The Operational Manual was our fourth deliverable. The thinking behind our operation manual was not only to create a document explaining how to correctly use and maintain our implemented irrigation system, but to also provide an abridged version as to what our group's thinking and process was for our design. This way anyone would be able to pick it up, read it, and be able to know not only how to run and maintain our system but use our reasoning and thinking to then apply it to a new irrigation system. This means, the manual explains our design process and reasoning, regarding why we made certain design choices. This will ease the process of determining power requirements for any future irrigation systems.

The Cerrito Agricultural School held a science fair-esque event that allowed all the WPI project groups in Paraguay to give a brief presentation on their project. For our group specifically we chose to focus on the broader idea behind our project and how it could potentially boost the school's finances.

We chose to emphasize this aspect of our project since Cerrito is an agricultural school, and the students were presumably familiar with irrigation and its benefits already. Opting to explain the “why” behind our project and its potential benefit for Cerrito allows us to explain to the students why Fundacion Paraguaya found this project worthwhile to put money and effort into.

Major Conclusions and Recommendations:

The major conclusion that came from our project is that our implemented irrigation system using the industrial wastewater from the cheese factory on campus will increase the maralfalfa yield from the pasture by about 18% annually. This in turn starts the positive feedback loop in which more maralfalfa means more feed, and thus more dairy production from the school's cows, which allows more dairy products to be processed, calling for more water to be used in cleaning the factory, resulting in more wastewater to be treated and reused for irrigation. The increased dairy production will yield an increase of profit for Cerrito, reducing the need for purchasing milk from outside sources, while increasing the amount of cheese and other dairy products produced and sold. We also concluded that the investment in the new irrigation system will pay for itself in 13 months.

Our team’s recommendations include abiding by the Operations Manual to properly maintain the irrigation system and to refer to it to effectively install additional irrigation systems around campus. As another source of water collection, our group also recommends investigating the restoration of the rainwater collection system from the roof of the chicken coop adjacent to the aljibe. Due to the size and area of the chicken coop, the roof could add a significant amount of water from rainfall collection. In addition to this, the extremely close proximity of the chicken coop to the aljibe would ensure that the collected water would not have to be transported a long distance.

Resumen Ejecutivo

Propósito y Objetivos:

La Escuela Agrícola Cerrito se encuentra en la región rural del Chaco Bajo en Paraguay, propiedad de la Fundación Paraguaya, los patrocinadores de este proyecto. Esta escuela se guía por la idea de "aprender haciendo" y ofrece educación secundaria con especialización en Turismo y Agricultura a estudiantes de familias de bajos ingresos. Como resultado, la Escuela Cerrito depende de los ingresos generados por los profesores y estudiantes que practican los oficios enseñados en la escuela (Escuelas Autosuficientes, s.f.). La fábrica de queso recientemente inaugurada, en marzo de 2024, en el terreno de la Escuela Cerrito, proporciona una de esas fuentes de ingresos. La fábrica utiliza una gran cantidad de agua para limpiar sus máquinas y producir productos lácteos. Las aguas residuales resultantes se desaguan en un sistema de recolección y se tratan a través de un reactor secuencial antes de almacenarse en un tanque en el lugar. Durante la construcción de la fábrica de quesos también se construyó una planta de tratamiento de aguas para hacer que las aguas residuales estén disponibles para el riego. Hacer que las aguas residuales tratadas estén disponibles para el riego garantizará un suministro adecuado de agua para una parcela de maralfalfa (Pennisetum sp) cerca de la fábrica de queso durante los períodos de sequía.

El objetivo principal de nuestro proyecto fue diseñar e instalar un sistema de riego de bajo costo, fácil de mantener y duradero para utilizar el agua tratada de la fábrica de queso. Esto significaba diseñar el mejor sistema de riego para la Escuela Cerrito, considerando todos los factores técnicos y sociales, como el efecto potencial que el sistema puede tener en la escuela y 4 sus ganancias, así como construir un sistema de riego que haga el uso más eficiente del agua disponible.

Dentro de este objetivo, teníamos dos subobjetivos: el primero era un objetivo técnico: queríamos construir un sistema de riego que aumentara de manera más eficiente la producción de alimento para el ganado. Este aumento en el alimento para el ganado debido al riego de la maralfalfa luego lleva a la escuela a un ciclo de retroalimentación positiva. Es decir, el aumento de la maralfalfa provoca más alimento para el ganado, esto resulta en un aumento de los productos lácteos, el aumento de los productos lácteos significa que la fábrica de queso tiene un aumento en la producción, el aumento de la producción requiere más limpieza de las máquinas, lo que resulta en más agua para el riego. El segundo era un objetivo social: queremos crear un sistema que se integre y mejore la cultura y las prácticas de la escuela promoviendo el reuso del agua dentro de la escuela.

Métodos:

Para establecer primero el tipo de sistema de riego a utilizar en nuestro proyecto, nuestro grupo realizó investigaciones preliminares sobre los beneficios y desventajas de diferentes sistemas de riego, como los diferentes costos de instalación inicial y los requisitos de mantenimiento. Nuestro grupo consideró esto al investigar el agua disponible, la textura del suelo y la disponibilidad local de materiales. Además de esto, también se investigaron los patrones climáticos locales para determinar el mejor tipo de sistema de riego.

Para establecer un diseño, realizamos observaciones de campo para obtener medidas del terreno y luego dibujamos nuestro diseño. Estas medidas se utilizaron nuevamente para calcular 5 cuánta cinta de goteo y tubería necesitaríamos para nuestro sistema al calcular el presupuesto. Las entrevistas semiestructuradas con el Ing. Amalio Enciso, el Ing. Walter Medina y el Sr. Negrete nos proporcionaron información valiosa sobre cuál era su visión para nuestro proyecto y qué diseño ayudaría mejor a lograrlo . Además de esto, su visión nos proporcionó números para calcular una recuperaciónde la inversión y generar un dibujo de diseño final utilizando una imagen aérea de Google Earth editada en GoodNote.

Este sistema requirió varios cálculos que ayudaron a decidir qué bomba debería usarse, comenzando con la potencia requerida de presión vertical. Sin embargo, también se tuvo en cuenta la pérdida de fricción de la tubería principal y las sub-tuberías, que se calculó utilizando distancias de tuberías y tablas. Luego se calculó la pérdida de fricción de la cinta de goteo y del filtro. Una vez resuelta la presión total para el sistema, esta necesitaba convertirse de psi a altura total y luego de altura total a caballos de fuerza. Después de multiplicar el coeficiente de eficiencia por los caballos de fuerza requeridos, obtuvimos una solución que indicaba que el diseño que utilizaba el aljibe sería capaz de regar suficientemente el pasto con una bomba de 2 HP, lo que lo convertía en la opción menos intensiva en energía y financieramente. Con la ayuda de nuestros patrocinadores, este tercer diseño fue elegido como el sistema a implementar. Este diseño requería una bomba con menos caballos de fuerza y hacía un uso más eficiente del depósito de agua

Productos finales:

Para cumplir con el objetivo de proporcionar a la Escuela Cerrito un sistema de riego eficiente para aumentar la producción de maralfalfa que utilice las aguas residuales tratadas, nuestro grupo produjo cinco entregables distintos. Estos entregables incluyeron el diseño del sistema de riego, un presupuesto para el costo de los materiales, la instalación del sistema de riego físico, un manual de operaciones que describiera clara y concisamente el propósito, diseño y requisitos de mantenimiento del sistema de riego, y una presentación para el cuerpo estudiantil que enfatizó la naturaleza cíclica de nuestro proyecto

Nuestro primer entregable fue el diseño de nuestro sistema. Se decidió la irrigación por goteo como el modo de entrega de agua con aportes de nuestros colaboradores y observaciones de campo. El ritmo lento de la irrigación por goteo fue el mejor ajuste al considerar el agua disponible para el riego junto con el tipo de suelo del pasto. A través de nuestro diseño pudimos mostrar a nuestros colaboradores dónde específicamente se encontraban las diferentes bombas y válvulas a través de nuestro diseño, la distribución de tuberías de PVC y la cinta de goteo, luego pudimos salir afuera y señalar estas áreas en persona también. Para ver el diseño completo, consulte la Figura 1.

Figura 1: Diseño finalizado de nuestro sistema de riego.

La presentación del presupuesto de materiales para la Fundación Paraguaya incluyó una breve descripción del propósito del proyecto, estimaciones de precios para los materiales requeridos, el diseño final del sistema de riego y un análisis financiero del tiempo de recuperación para recuperar la inversión en el sistema de riego propuesto (período de recuperación). Para estimar el impacto de nuestro proyecto en la producción de leche de la escuela y, a su vez, en las ganancias, nuestro grupo colaboró con nuestros colegas, los profesores Amalio Enciso y Walter Medina, para realizar un análisis de recuperación de la inversión. Este análisis de recuperación de la inversión encontró que si el nuevo sistema de riego eliminaba la reducción normal en la producción de maralfalfa, en invierno y verano, de manera que 8 coincidiera con la producción normal de maralfalfa en primavera y otoño, la producción total anual aumentaría en poco menos del 18%. Esto recuperaría el costo del nuevo sistema de riego en 1.08 años o 13 meses.

El sistema de riego bombea el agua tratada desde el centro de tratamiento de aguas residuales de la fábrica de queso hasta un aljibe, o tanque subterráneo de agua, que se encuentra a 56 metros del centro de tratamiento de agua y a una elevación aproximada de 4 metros más alta que el centro de tratamiento de agua. Desde el aljibe, el agua es luego bombeada por una segunda bomba al campo de maralfalfa y a través de las líneas de cinta de goteo en cada fila. (Ver Figura 1). En caso de una tubería rota o desbordamiento del aljibe, hay una válvula de liberación de emergencia que envía agua a un tajamar, que está aproximadamente a 56 metros al sur de los tanques de tratamiento de agua. La Figura 1 en la lista de figuras se puede ver para obtener detalles adicionales del sistema de riego.

El objetivo detrás de nuestro manual de operaciones no fue solo crear un documento que explicara cómo usar y mantener correctamente nuestro sistema de riego implementado, sino también proporcionar una versión abreviada de cuál fue nuestro razonamiento y el proceso de nuestro grupo para crear nuestro diseño. De esta manera, cualquier persona podría usarlo, leerlo y saber no solo cómo ejecutar y mantener nuestro sistema, sino también utilizar nuestro razonamiento y pensamiento para luego aplicarlo a un nuevo sistema de riego. Esto significa que el manual explica nuestro proceso de diseño y razonamiento, con respecto a por qué tomamos ciertas decisiones de diseño. Esto facilitará el proceso de determinar los requisitos para cualquier futuro sistema de riego.

Finalmente, la Escuela Agrícola Cerrito realizó una feria de ciencias que permitió a todos los grupos de proyectos de WPI en Paraguay dar una presentación sobre su proyecto. Para nuestro grupo específicamente, decidimos presentarles a los estudiantes el significado de la agricultura circular que enfatiza en la reutilización de recursos para obtener ganancias tanto económicas como ecológicas. Elegimos enfatizar este aspecto de nuestro proyecto ya que Cerrito es una escuela agrícola y los estudiantes probablemente estaban familiarizados con el riego y sus beneficios. Optar por explicar el "por qué" detrás de nuestro proyecto y su beneficio potencial para Cerrito nos permitió explicar a los estudiantes por qué la Fundación Paraguaya consideró que este proyecto valía la pena invertir dinero y esfuerzo.

Principales conclusiones y recomendaciones:

La principal conclusión que surgió de nuestro proyecto es que nuestro sistema de riego implementado utilizando las aguas residuales industriales de la fábrica de queso en el campus aumentará el rendimiento de maralfalfa del pasto en aproximadamente un 18% anualmente. Esto a su vez inicia el ciclo de retroalimentación positiva en el que más maralfalfa significa más alimento, y por lo tanto más producción láctea de las vacas de la escuela, lo que permite procesar más productos lácteos, lo que requiere más agua para limpiar la fábrica, lo que resulta en más aguas residuales para ser tratadas y reutilizadas para el riego. El aumento de la producción láctea generará un aumento de las ganancias para la Escuela Cerrito, reduciendo la necesidad de comprar leche de fuentes externas, al tiempo que aumenta la cantidad de queso y otros productos lácteos producidos y vendidos. También concluimos que la inversión en el nuevo sistema de riego se amortizará en 13 meses.

Las recomendaciones de nuestro equipo incluyen cumplir con el Manual de Operaciones para mantener adecuadamente el sistema de riego y consultarlo para instalar eficazmente sistemas de riego adicionales en el campus. Como otra fuente de recolección de agua, nuestro grupo también recomienda restaurar el sistema de recolección de agua de lluvia desde el techo del gallinero adyacente al aljibe. Debido al tamaño y área del gallinero, el techo podría agregar una cantidad significativa de agua recolectada de la lluvia para usarla como riego. Además de esto, la proximidad extremadamente cercana del gallinero al aljibe garantizaría que el agua recolectada no tenga que ser transportada a largas distancias.

Authorship

Abstract, Acknowledgements, and Executive Summary	**Jennifer Chaves, Brendan Halloran, Matthew Biando**
1: Introduction	**Nathan Smith**
2: Preliminary Research	**Nathan Smith**
2.1 Environmental considerations of Low Chaco Paraguayo	**Jennifer Chaves**
2.2 Alfalfa	**Jennifer Chaves**
2.3: Wastewater from the Cheese Factory at Cerrito School	**Brendan Halloran**
2.4: Wastewater for Irrigation	**Brendan Halloran**
2.4.1 Wastewater at Cerrito Agricultural School	**Brendan Halloran**
2.5: Irrigation	**Brendan Halloran**
2.5.1 Drip Irrigation System for Cerrito Agricultural School	**Brendan Halloran**
2.5.2 Water Storage for the Irrigation System	**Brendan Halloran**
2.6 Irrigation of Alfalfa fields	**Jennifer Chaves**
2.6.1: Alfalfa Promotes Soil Health	**Jennifer Chaves**
2.6.2: Benefits of Alfalfa production to Cerrito Agricultural School	**Jennifer Chaves**
3: Methodology:	**Brendan Halloran**

3.1: Field Observation:	**Brendan Halloran, Matthew Biando**
3.2 Semi-structured Interviews	**Brendan Halloran, Matthew Biando**
3.3 Co-design of the Irrigation System and Mathematical Analysis	**Jennifer Chaves, Matthew Biando**
3.4 Budgeting	**Brendan Halloran**
3.4.1: Design Three's Budget	**Brendan Halloran**
3.5 Estimated Payback Period:	**Brendan Halloran, Matthew Biando, Nathan Smith**
3.6 Pedagogic Fair Presentation	**Brendan Halloran**
Insights and Outcomes	
4.0: Finding and Deliverables:	**Jennifer Chaves**
4.1 Design of the Irrigation System:	**Jennifer Chaves**
4.2 Budget Presentation	**Brendan Halloran**
4.3 Installation of the Irrigation System:	**Jennifer Chaves, Brendan Halloran**
4.4 Operations Manual:	**Brendan Halloran**
4.5 Pedagogic Fair Presentation:	**Brendan Halloran, Matthew Biando**
5: Conclusions	**Jennifer Chaves**

Each member had an equal part in editing all the sections mentioned above. The authorship indicates the students that worked on the preliminary draft of the sections mentioned.

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1. Introduction

Cattle farming is a long tradition in Paraguay and throughout Latin America (Reber, 1995). During Paraguay's largely authoritarian and isolationist history it has been a key part of the country's economic self-sufficiency and economic independence (Reber, 1995). Small farmers, like the Cerrito Agricultural School have been the largest contributors to this culture of economic self-sufficiency and independence by being able to effectively utilize the plentiful and cheap small plots of land that have been available (Reber, 1995).

The Cerrito Agricultural School is a small boarding school located in the Low Chaco in rural Paraguay that serves students who are unable to pay full tuition, as a consequence Cerrito relies on the revenue created from the students practicing the trades they are taught at the school (Self Sufficient Schools, n.d.). The cheese factory located on the grounds of the Cerrito School uses a large amount of water to clean its machinery, before our project the resulting wastewater then drained into the sewer system which was then filtered before being stored in a tank on site. When we started there was no plan for the reuse of the resulting wastewater, however considering the history and cultural importance of self-sufficiency and economic independence an irrigation system was created that uses the wastewater to increase cattle feed production.

The Cerrito Agricultural School realized that the large amount of water that is going to waste could be utilized within the campus instead. Along with Fundacion Paraguaya the Cerrito School constructed a wastewater treatment plant to filter the factory's effluence, making it usable for irrigation. Effective and environmentally friendly use of water is especially important in the Chaco region as droughts are increasing (Benitez & Domecq, 2014) and cattle farming causes widespread deforestation (J.E. Correia, 2022).

The unused water from the cheese factory presented an important opportunity to align the cultural principle of self-sufficiency with environmentally friendly farming practices as it is a good source for usable irrigation water that would have otherwise gone to waste.

Our goal was to create the best irrigation system for the Cerrito School, considering all technical and social factors. Within this goal we had two sub-goals, the first was a technical goal: we wanted to find the irrigation system that most efficiently increases cattle feed production. The second was a social goal: we wanted to create a system that improves the quality of life at the Cerrito School the most.

In this project we began by researching irrigation systems and maralfalfa before determining the basic outline of our project. When we arrived in Cerrito, we then held meetings, created budget and funding proposals, surveyed the land, and designed the irrigation system. Finally, we installed and tested the system before creating a manual with our recommendations on how to operate the installed system and potentially build another similar system. This report will take you through our research, methods, final products, and our conclusions surrounding the project.

2. Preliminary Research

The need for a reliable source of water in the Chaco is increasing due to more frequent and severe drought periods within the region (Benitez & Domecq, 2014). The more intense periods of drought were found to put families in the Paraguayan Chaco at an increased risk for food and water insecurity, due to the lack of both potable water and water usable for irrigation (Jiménez et al., 2017). The Cerrito Agricultural School has semi-treated effluent that comes from cleaning and production processes in the cheese factory that is not currently being utilized. This means that usable water for irrigation is not being taken advantage of, our group aims to fix this with our previously stated goals. In the next section we highlight the different considerations we are taking into account to complete our goals including wastewater itself, irrigation and its effects on alfalfa, and how these things would specifically apply to the Cerrito School.

2.1 Environmental considerations of Paraguayan Low Chaco

In the Paraguayan Chaco the weather conditions are characterized by a subtropical climate with distinct wet and dry seasons. The region experiences hot and humid summers with temperatures often exceeding 40° C (104°F), while winters are relatively mild with temperatures around 20-25°C (68-77°F) (The World Bank Group, 2021). The rainy season typically occurs from October to April, bringing heavy rainfall and occasional thunderstorms. However, the dry season from May to September is marked by reduced precipitation and higher evaporation rates, leading to water scarcity and drought conditions.

The soil in Paraguayan Chaco varies but is predominantly composed of sandy and loamy soil with low organic matter content (MID Lezcano, 2020). These soil types are generally well-draining but can also be prone to water retention issues during prolonged dry periods. Additionally, the region's topography features flat to gently rolling plains, which can affect water distribution and availability for agricultural activities.

Given these environmental factors, including the hot climate, seasonal rainfall patterns, soil characteristics, the need for an irrigation system at Cerrito School becomes crucial. The system will help mitigate the effects of drought during the dry season, ensuring consistent water supply for crop cultivation and livestock feed production. This understanding of local weather and soil conditions demonstrates thorough research and a strategic approach to addressing agricultural challenges in the region.

2.2 Alfalfa

Alfalfa is a versatile and highly nutritious continuing legume family crop that holds significant agricultural importance globally. Known for its adaptability to various climates and soil types, alfalfa is cultivated in regions across the world, with Latin America being a notable contributor.

This deep-rooted crop is particularly valued for its ability to fix atmospheric nitrogen through symbiosis with rhizobia bacteria, enhancing soil fertility naturally (Jiangjjao Qi, 2023). Alfalfa's resilience to drought conditions, due to its deep taproots, makes it well-suited for arid regions. It is a major forage crop, providing high-quality fodder for livestock due to its rich protein content. Usually, it contains about 25% to 30% percent of protein in the leaves of the alfalfa (Dan Undersander , 2021). In our case, we improv ed the pastureland of alfalfa for the cows to produce more milk for the cheese factory. Beyond its role in animal farm management, alfalfa has diverse applications, ranging from soil erosion control to its use as a cover crop. Additionally, its multifaceted nature extends to human consumption, as alfalfa sprouts are recognized as nutritious in modern cuisine.

2.3 Wastewater from the Cheese Factory at Cerrito School

Wastewater is any water used in a home, business, or industrial process and is no longer considered drinkable. The practice of using treated wastewater for the irrigation of crops is becoming increasingly popular. Treated wastewater helps to mitigate the water needs involved with irrigation by providing a sustainable and consistent solution for irrigation's demands. The water treatment system, designed by Fabripar Ingeniería (see Figure 1) and installed during the construction of the Cheese Factory, serves the primary purpose of ensuring the efficient and sustainable reuse of water resources within the facility. Its advanced filtration and purification capabilities aim to reduce environmental impact and support the factory's operations with clean water. The effluents first pass through a solids filter, then to a pool where the fat is retained (see Figure 2). From the pool, it goes to two other pools where added bacteria are responsible for cleaning the water. In these two pools, there is an automatic recirculation system to generate oxygen for aerobic bacteria (see Figure 3). The water then passes to a chlorination compartment where small doses of chlorine are added (see Figure 4). Finally, it passes to a tank where two pumps expel the water into exit pipes and into our irrigation system (see Figure 5).

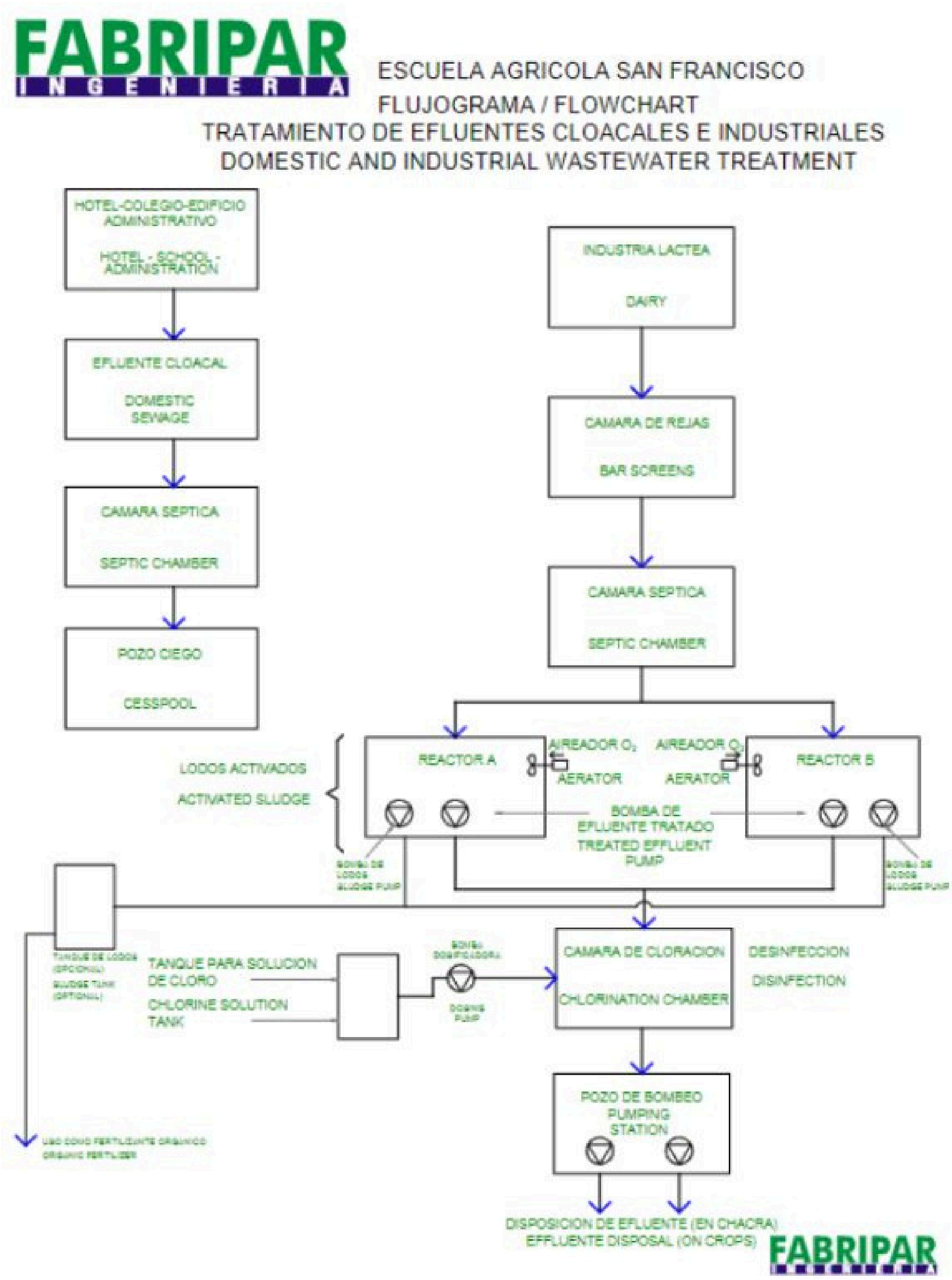

Figure 1: The blueprints of the water treatment systems

Figure 2: The first pool where the fat is retained from the water.

Figure 3: There are two pools that have "good" bacteria, which is responsible for cleaning the water.

Figure 4: The tank where the chlorination occurs to finalize the cleaning process.

Figure 5: The two pumps that move the treated water to the aljibe(cistern).

2.4 Wastewater for Irrigation

Wastewater used for irrigation is held to a lower standard compared to wastewater used for consumption (World Health Organization, 2006). However, the United Nations does have strict water quality levels that must be met so that the water does not damage the soil or plants that are being irrigated. Irrigating soil with water that is either too acidic or alkaline has immediate negative consequences as well as damaging the soil in the long term by greatly reducing the soil quality for future crop growth (Sou/Dakouré, Mermoud, Yacouba, & Boivin, 2013). Ensuring that the treated wastewater abides by the current guidelines to promote beneficial irrigation is paramount for our project. The effluence created by the cheese factory is treated and usable for irrigation according to the UN standards.

We are aware that, because the effluent wastewater is from a dairy factory, there is expected to be a high amount of organic matter in the effluence. However, organic matter levels within the range of 140 to 400 mg/L will help plant growth, as it provides more organic matter for the crops to utilize (World Health Organization, 2006). If the levels of organic matter in the treated wastewater do not exceed these levels , the increased amount in the effluent water will be beneficial to the crops.

2.4.1 Wastewater at Cerrito Agricultural School

The endpoint for the industrial effluent from the cheese factory before instillation of the water treatment system was draining into the school’s sewer system. However, upon the wastewater treatment center's completion at the Cerrito School, water that used to drain into the sewers is being cleaned in the wastewater treatment center and is now usable for irrigation. This increases the amount of water the Cerrito School has access to, to increase irrigation efforts on campus, especially as water in the Chaco is becoming an increasingly scarce resource (Correia, 2022). In addition to this, the effluent is no longer going into the sewer system on campus, which reduces the amount of material entering the sewer. Currently, the Cerrito cheese factory outputs 42,000 liters a month, with a maximum production estimation of 210,000 liters a month. With this amount of water, the implementation of an irrigation system benefits crop production on campus. .

2.5 Irrigation

Irrigation is the process of supplementing crops or plants with additional water to benefit their growth, providing evaporative cooling and reducing crops' heat stress (Li et al., 2020). In the alfalfa field at the Cerrito School, two types of irrigation systems could be installed: drip irrigation and spray irrigation. Both systems have their advantages, but drip irrigation stands out for its efficiency (Bhavsar et al., 2023).

Drip irrigation offers several benefits over spray irrigation. Firstly, it minimizes water wastage by delivering water directly to the plant roots, reducing evaporation and runoff. This targeted approach also helps in conserving water resources, which is crucial in regions prone to water scarcity like the Paraguayan Chaco. D rip irrigation also promotes healthier plant growth as it prevents water from contacting foliage, reducing the risk of fungal diseases.

On the other hand, spray irrigation, while effective in covering large areas quickly, is not the best option for this project due to its high-water consumption and potential for water loss through evaporation and wind drift. Given that the cheese factory may not produce effluent water at a high enough rate to consistently fully irrigate the entire pasture, drip irrigation emerged as a practical and sustainable choice to maximize the available water resources for our group's objectives at Cerrito School.

2.5.1 Drip Irrigation System for Cerrito Agricultural School

The implementation of a drip irrigation system at Cerrito School was strategically chosen due to the optimal match between the effluent water output and the required irrigation volume for alfalfa cultivation. Drip irrigation precisely delivers water to the soil above the plant roots, maximizing water efficiency. Unlike spray irrigation, drip systems are characterized by lower installation and maintenance labor, as well as reduced upkeep expenses (van der Kooij et al., 2013). These attributes are particularly advantageous for a rural setting like the Cerrito School in Paraguay, where access to replacement parts may be limited and costly. The cost-effective maintenance of drip irrigation minimizes the system's demand on the students' time, ensuring that the implementation remains seamless and does not impose a financial or operational burden on the school.

2.5.2 Water Storage for the Irrigation System

Once the wastewater from the Cheese Factory is ready to use in the irrigation system, it will be stored in an underground water tank (aljibe) that is located in close proximity to the alfalfa field. This tank can be seen below in figure 6. The underground water tank was part of a rainwater collection system built in a chicken coop that is abandoned now. The approximate size of the aljibe is 5 meters 20 centimeters long by 4 meters 60 centimeters wide by 2 meters tall. This means that there is roughly 47,840 liters of water storage available in the aljibe. Water will be pumped to this storage as it is uphill from the other storage options, meaning that irrigation in the field will be gravity aided, as the field itself has a slight grade, once it is pumped over a small rise in between the aljibe and the field. Gravity aided irrigation allows for the pump to not have to run at its maximum capacity, thus extending its lifespan. Due to the varying level of irrigation needs and treated water output from the factory, emergency water storage was necessary for our project. Near the maralfalfa pasture there is a natural reservoir, or tajamar, that we felt was appropriate to use as an emergency release in the case of the aljibe being filled up or another system emergency occurring. This way the treated water would not have to sit in the treatment tanks, the risk of flooding the aljibe was nullified, and an issue with the irrigation system would not affect the ability of the cheese factory to output water.

Figure 6: An image of aljibe (underground tank).

2.6 Irrigation of Alfalfa fields

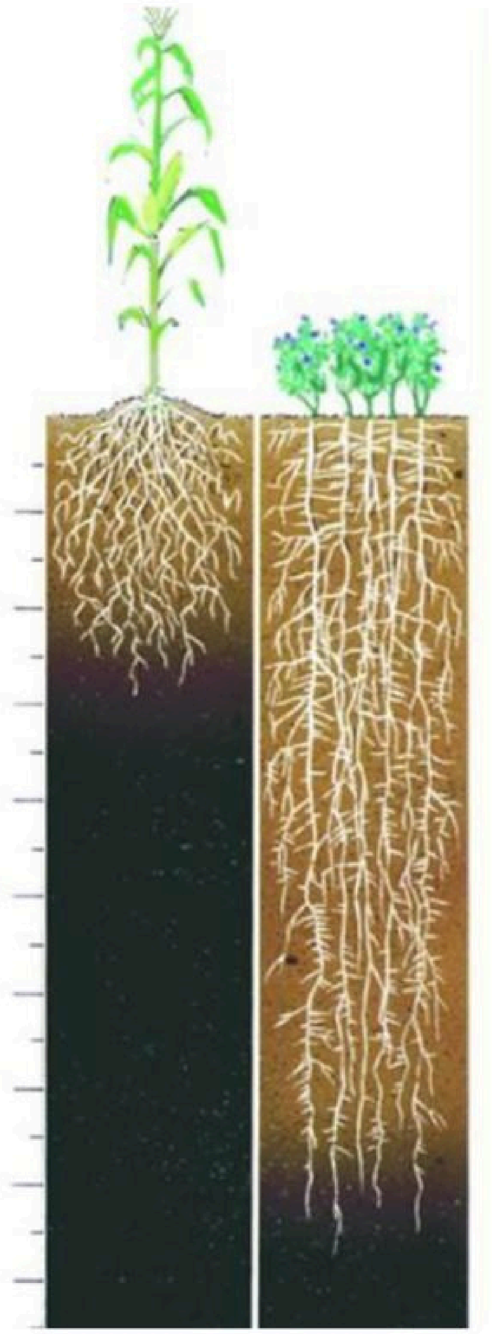

Figure 7: An illustration of the depth of alfalfa root systems in comparison to corn roots.

A fundamental consideration in managing alfalfa irrigation is its extended growing season which enables it to utilize more water annually than many other crops. Evapotranspiration comprises water transpired by the crop and water evaporating directly from soil and plant surfaces. Key climatic factors, such as air temperature, solar radiation, and wind speed significantly influence alfalfa's water consumption while soil water availability plays a direct and important role (Mendoza-Grimon, 2015). Alfalfa's water use commences in early to mid-April with the initialization of spring growth, exhibiting slow initial growth and limited water use. In Paraguay the rainfall seasons are March to May and October to November, leaving the intervening months with less rainfall and irrigation. As temperature rises and growth accelerates, daily water use intensifies.

Notably, alfalfa experiences a decline in water use during harvest due to minimal transpiration when most leaf area is removed. Post -harvest re-growth initiates a cyclical water use pattern that repeats each cutting, typically every 30 to 40 days. Alfalfa's robust root system, penetrating 8 to 12 feet in well - drained soils, plays a key role in water uptake , as seen in figure 7 . Despite this deep root system, the majority, 75% to 90%, of its moisture is obtained from the upper four fee t of soil. Effective irrigation of alfalfa therefore generally targets the upper soil profile during the growing season. Soil characteristics may limit the effective root zone depth due to the presence of a restrictive layer, necessitating tailored irrigation strategies.

2.6.1 Alfalfa Promotes Soil Health

Alfalfa has gained attention for its potential in promoting soil health and ecological restoration in various environments. The unique characteristics of alfalfa, such as its developed root system and strong regeneration, contribute to its ability to thrive in challenging conditions and make it an asset for soil improvement. Alfalfa demonstrated a substantially higher root biomass density compared to sweet clover and natural abandonment, underscoring its ability to establish a robust root system that contributes significantly to soil structure and nutrient dynamics (Song et al, 2021). Moreover, the introduction of alfalfa resulted in elevated levels of organic matter, total nitrogen, total phosphorus, available phosphorus, and nitrate-nitrogen in soil when compared to sweet clover and natural abandonment. This indicates that alfalfa positively influences soil health by fostering organic matter accumulation and enhancing nutrient availability (Song et al, 2021).

It was shown that microbial biomass carbon and nitrogen increased in soils where alfalfa was introduced, suggesting a stimulation of microbial activity. This microbial enhancement is critical for nutrient cycling and overall soil health (Song et al, 2021). Corroborating these positive effects, research identified positive correlations between alfalfa root biomass density and soil nutrients, and microbial biomass. Conversely, a negative correlation was observed between soil ammonia-nitrogen (NH4+-N) concentration and alfalfa root biomass density, emphasizing the intricate relationships between root systems and soil parameters (Song et al, 2021).

2.6.2 Benefits of Alfalfa Production to Cerrito Agricultural School

Increasing alfalfa production with our irrigation system has the potential to significantly enhance the dairy industry's productivity in Cerrito. As a key component of many cattle diets, alfalfa serves as a nutritious forage that can directly impact the overall well-being of cows. If there is a rise in alfalfa cultivation, it would result in a more abundant and affordable source of feed for dairy cattle. This, in turn, would contribute to high milk production, subsequently benefiting the Cerrito cheese factory.

Cattle that are well-nourished with well irrigated alfalfa are likely to yield greater quantities of high-quality milk, providing the Cerrito cheese factory with a sustainable and reliable source of dairy products.

Moreover, a boost in alfalfa production can have broader economic benefits for the local community. With increased demand for alfalfa as feed source, local farmers may find new opportunities for growth and income generation. This can stimulate agricultural activity and contribute to economic development for Cerrito and surrounding areas. Additionally, by utilizing wastewater for irrigation, the project aligns with sustainable practices and promotes environmental conservation and resource efficiency. We called this economic cycle "Agricultural circle" (See Appendix I).

In conclusion, the synergy between alfalfa cultivation, efficient irrigation, and sustainable agricultural practices is a promising opportunity to enhance the cheese factory's production and Cerrito's overall sustainability and economic independence.

3. Methodology

The purpose of our project was to develop an irrigation system for a maralfalfa pasture that utilized the wastewater from the cheese factory in a way that not only enhanced crop production, but also integrated and enhanced school culture and practices. To meet these goals our group needed to understand the problem in terms of the irrigation system's water needs and the physical properties of the maralfalfa pasture. We also created the object to design our irrigation system and develop the budget for that design to get approval for funding from Fundación Paraguaya. To meet these objectives, we adopted the methods of field observations, semi-structured interviews, mathematical analysis, and co-design of the irrigation system.

3.1 Field Observation

Field observation was a crucial method for our project, as it allowed us to physically measure and assess the areas we were focused on. Our primary objective was to determine the dimensions of the field relevant to irrigation. To accomplish this we conducted manual measurements to obtain precise specifications regarding the field's size. The results of our field dimension measurements are detailed below in figure 8.

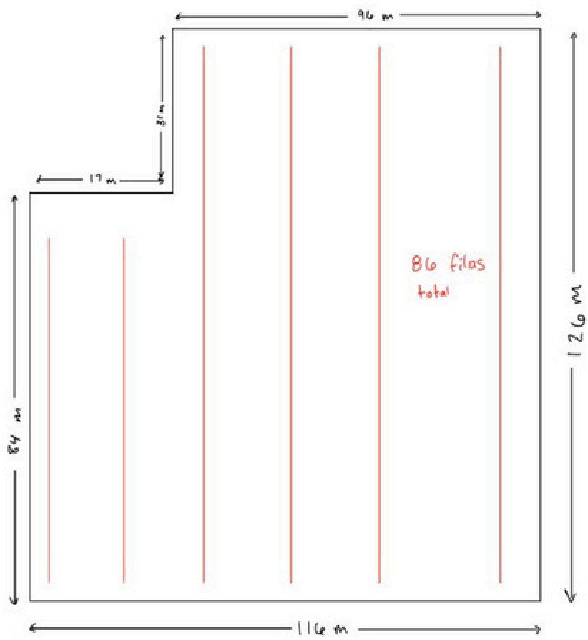

Figure 8: Drawing of the maralfalfa pasture with dimensions.

As shown in figure eight, the maralfalfa field measured 116 meters long by 126 meters wide at its longest points. However, in the upper left corner 13 rows of maralfalfa were cut short due to the presence of an abandoned building. With 73 rows of maralfalfa at 126 meters in length and 13 rows at 84 meters in length, the total amount of drip tape needed for irrigation was 10,356 meters. Figure 9 can be seen below for a picture of the work area.

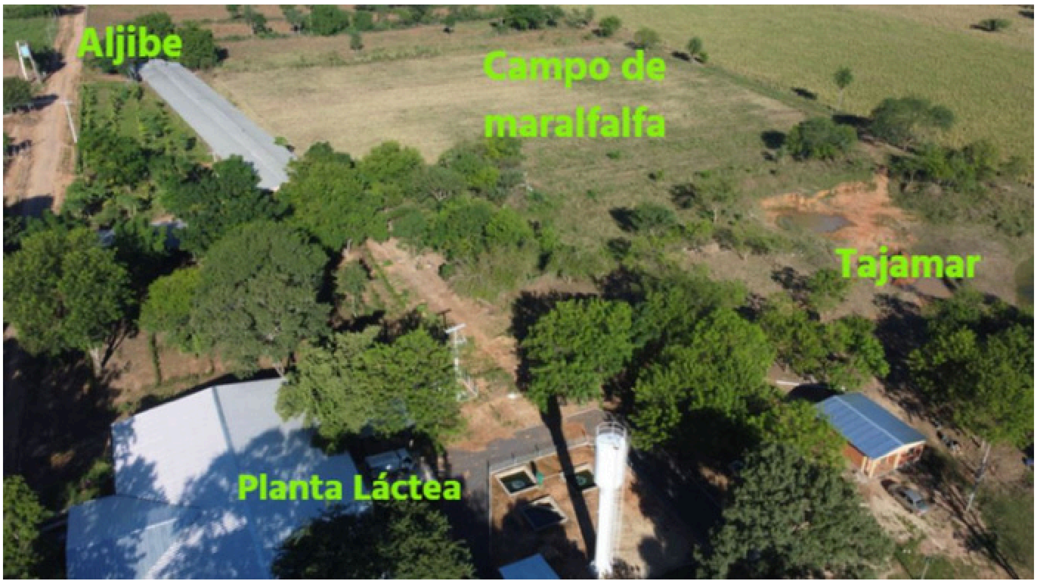

Figure 9: Annotated aerial view of the irrigation system's setting

In addition to measuring the pasture dimensions, we also measured the distance from Cerrito's cheese factory to the aljibe and the tajamar (see Figure 11) to accurately plan the piping from the factory. The distances were measured manually, resulting in measurements of 56 meters to the tajamar and 180 meters to the alijbe. To assess the elevation difference across the pasture, our group utilized Google Earth, indicating a four-meter difference in elevation from the upper right corner to the bottom left corner of the field.

3.2 Semi-structured Interviews

ur group conducted semi-structured interviews with our sponsors to obtain data they would have intimate knowledge of. Since our project is specific to Cerrito, we relied on our sponsors to obtain information on factors already in place. For example, when discussing irrigation with Ing. Walter Medina we were informed of the planned irrigation schedule that the maralfalfa would receive during the summer months.

Ing. Medina explained that the maralfalfa would follow the same irrigation cycle of the other crops on campus three times per week, for roughly two hours.

These interviews were conducted primarily during our weekly meetings. Our group along with our advisors would meet with our counterparts then we would go into the field to conduct the interviews. We opted to do these out in our work area so that way there would be clear communication on what their ideas for our project were. These interviews provided us with key knowledge of background information and provided insight as to what our sponsors' vision for this project was, helping us to create a design that met their goals for the project. Due to the results of these interviews in the third design we decided to not utilize the tajamar , as the water treatment facility had a pump that could be utilized to transport water uphill. This cut out the tajamar as a " middleman " and allowed for a more efficient route of transportation for the water.

In addition to these semi-structured interviews providing context to our irrigation system's scope, they were used to construct our return on investment. The numbers used in our calculations were provided by the sponsors in response to our questions regarding the requirements for the return-on-investment calculations. These numbers include the alfalfa yield during the summer and winter compared to the fall and spring, the yearly production of milk by the cows on campus, the estimated percent increase in yield during the summer and winter from irrigation, and the going price of milk per liter. With this information, we calculated the rough timeframe in which our project would be paid back.

3.3 Co-design of the Irrigation System and Mathematical Analysis

At the request of our sponsors, we developed three different designs for our irrigation system to compare their effectiveness and prices. The three designs are outlined below in figures 1 0 , 1 1 , and 1 2 . In all three designs we chose to utilize drip tape as the method for irrigating the field.

This decision was based on the clay-like soil in the Chaco region, particularly at Cerrito, where water absorption is slow due to the soil's high density (Green et al., 1981). Drip irrigation was selected to avoid flooding the field, which could lead to soil erosion and inefficient absorption. D rip irrigation is also more water-efficient than spray irrigation for crop cultivation (Laycock, 2007). Given the considerable size of the maralfalfa pasture it requires a substantial amount of water for full irrigation, depending on the production rate at the cheese factory water from the factory alone may not suffice for fully irrigating the field. Drip irrigation mitigates this by optimizing the available water resources, contributing to a more efficient overall system (Tayyab Sohail et al., 2021).

Figure 10: Design One

Figure 11: Design Two

Figure 12: Design Three

Design one and two both involved pumping water from the tajamar located near the cheese factory, to the bottom of the maralfalfa field. The tajamar was chosen as the first option for storing water due to its downhill and close location to both the cheese factory (56 meters) and the maralfalfa field (68 meters). In design one, the water was pumped around the edge of the field and into drip tape laid perpendicular to the incline. In design two, the pipe was laid down the center of the field, with two lines of drip tape extending from each side of the pipe perpendicular to the slope . Design three, on the other hand, pumped water directly from the cheese factory to the aljibe but used the same irrigation delivery system as design one, entering from the other end at the top of the field.

The calculations for design one and two involved first determining the total flow through the field in gallons per minute using the total length of drip tape multiplied by the flow rate per 100 feet. Once this was found we determined the total pressure required by the system by adding six parts together: the vertical pressure required, the operating pressure requirements, friction loss from the main line (the line from the tajamar to field), the sub main friction pressure loss (the line through or around the field), the friction pressure loss from the drip tape, and the pressure loss from the filter.

The vertical pressure required was calculated by dividing the vertical distance from the top to the bottom in feet by 2.31, the number of feet of water over a square inch required to create one psi of pressure. The operating pressure is given on the drip tape itself, we opted to lower this pressure slightly as the clay soil of the field is not conducive to high absorption. Both the friction loss from the main and sub main lines were calculated by multiplying the length divided by 100 by the friction loss from the pipe per 100 feet; this was found by using the tables for friction loss by flow rate and pipe width for standard schedule 40 PVC pipe (PVC Pipes Schedule 40 - Friction Loss vs. Water Flow , n.d.). Drip tape pressure loss was estimated by dividing the sub main pressure loss by three; this shorthand is common in irrigation system analysis. Filter loss was calculated by assuming the average of about ten psi. Once the total pressure required for the system was found using the previous calculations it was multiplied by 2.31 to convert it from psi to the total head and multiplied by the total flow rate in gallons per minute and then divided by 3960 to convert from total head in feet times gallons per minute to horsepower; finally we multiplied by the generic pump efficiency coefficient of .6, or that 60 percent of effort output by the pump will be converted to actual pressure in the system, to get the required horsepower of the pump (Rowell, n.d.).

The math for the third design was largely the same except for the calculation of the vertical pressure loss because the only vertical pressure required is the pressure for pumping water out of the aljibe. It also includes the added pressure from gravity. To calculate this, we added .1 bar per meter of vertical distance to get the total pressure assistance gravity provides. One bar is 14.5 psi so .1 bar is 1.45 psi.

With the input from our sponsors, design three was selected as the most suitable option for the school. This decision was based on factors such as the potential variability of water levels in the tajamar and the efficiency of the delivery route. There was an uncertainty that the t ajamar would be full year-round. Pumping water to a potentially empty area then back uphill to the maralfalfa pasture would require too many unnecessary steps and a stronger, more expensive pump to achieve.

It would lead to increased energy requirements, cost, and overall inefficiency of the irrigation system. The third design ensures that no water will be wasted and, despite needing more materials, it makes more efficient use of energy by requiring a lower powered pump. The gravitational aid from the field's slope in design three allowed for a lower horsepower pump, resulting in cost savings both in terms of initial investment and in ongoing power consumption.

3.4 Budgeting

The next step in the process was to contact local hardware stores and agricultural material suppliers in and around Benjamín Aceval. Our group needed three different budgets for Fundacion Paraguay's funding approval. We contacted three different agricultural suppliers and three different hardware stores for drip tape and associated accessories, such as attachments and end caps, and obtained quotes for PVC pipe from each. After presenting the proposed budgets to the sponsors, they made decisions regarding the procurement of the materials.

We created three different designs for the irrigation system with dimensions, lengths of pipes, and quantity of each material being used and got one approved by our sponsors. Before the approval of the final design, we created a list of materials for each design specifying the exact amount of each material, the prices of each, and provided a drawing that detailed where each material would be used. The pump was provided by Ing. Walter Medina, as he already had a working one on hand, removing the cost from our budget.

For design one, the materials needed were 85 meters of mainline tubing from the cheese factory to the tajamar, then 144 meters of irrigation tubing from the tajamar to the field, along with a five-horsepower pump, four one-way valves, a Y coupling joint, and two 90-degree elbow joints. Design two required 76 meters of mainline tubing, 116 meters of irrigation tubing, a Y coupling joint, and only one 90-degree elbow joint.

Design three required the most materials with 180 meters of mainline tubing and 161 meters of irrigation tubing. This design also required a Y coupling, a T valve, three one-way valves, and two 90-degree elbow joints. All three designs needed the same amount of drip tape at 10,356 meters. To secure funding for our project, we contacted three suppliers, including several recommended by our sponsors, for the drip tape and its accessories, as well as three suppliers for the PVC tubing.

Before receiving pricing from every supplier, our group decided to focus solely on the specific budget for design three as it had been unanimously decided upon as the best design by our whole team, our advisors, and our sponsors. A 50cm deep trench was excavated from the cheese factory's treatment center leading directly to the aljibe, an inactive underground water storage unit. Before utilizing the aljibe it underwent cleaning. The school's pump was utilized for irrigating the maralfalfa field, complemented by an emergency release pipe from the cheese factory to the tajamar to prevent aljibe overflow. Subsequently, following manual labor, we compiled a detailed report of completed tasks and created a maintenance manual outlining necessary maintenance and operation protocols.

Insights and Outcomes

4.0 Finding and Deliverables

To meet the goal of providing the Cerrito School with an efficient irrigation system to increase maralfalfa production, while reutilizing the effluent from the new cheese factory, our group produced four distinct deliverables: the design of the irrigation system, the preparation of a budget proposal to buy the parts of the irrigation system that was presented to Fundacion Paraguaya for funding approval, the installation of the actual irrigation system, the Operations Manual for the system, and a presentation for the students during the Feria Científica.

4.1 Design of the Irrigation System

The water treatment and irrigation system operate through a well-structured design that efficiently utilizes wastewater and distributes treated water to the maralfalfa plants. The water treatment process ensures thorough cleaning of the effluent, making it suitable for agricultural use. Once treated, the clean effluent is pumped using a 1 horsepower pump, lifting it 4 meters in elevation and spanning 164 meters through a pipe to reach the aljibe, serving as the central water storage cistern. This setup allows efficient storage and distribution of clean water across the maralfalfa field. Once in the aljibe, a second pipe with a 1.5 horsepower pump is employed to transfer water from the aljibe to the field, approximately 10 to 15 meters away.

Within the maralfalfa field, precise water distribution is managed through 86 drip tapes, each equipped with its own valve for control. This level of control enables us to tailor water distribution according to specific areas' needs, ensuring optimal hydration for the plants. Originally the pump used to power the drip tape was supposed to be a 2-horsepower pump, a decision backed by detailed mathematical calculations considering factors such as distance, elevation changes, pipe friction losses, and required flow rates. This analysis ensured the pumps have enough capacity to efficiently pump water through the system, maintaining consistent performance and efficiency throughout the irrigation process. However, facts discussed further down changed this to a 1.5 horsepower pump

Our irrigation system's design was created by editing a screenshot in Google Earth of the area where the system was to be installed, to provide a clear picture of where our system was going. The design was developed not only for our counterparts at the Cerrito School but was also presented by Prof. Amalio Enciso to Fundación Paraguaya along with the request for approval of the budget. The design was developed to clearly outline the specifications of the chosen design in a clear and effective way to viewers, as well as to demonstrate what components would comprise the system. Our budget presentation, combined with this detailed explanation of the system's components and their placement, demonstrated strategic allocation of resources and ensured that our budget excluded any unnecessary materials, thereby maintaining cost efficiency.

4.2 Budget Presentation

Our sponsors settled on Hortipro and Wal y Yol for the proposed budget of 9,641,780 Gs, the table containing all 9 possible budgets can be found in Appendix A. With the budget and design approved by the Cerrito School and Fundación Paraguaya, we were able to commence construction on the irrigation system.

The total budget approved by Fundación Paraguaya was 10,000,000 Gs and the itemized budgets for purchase can be found in Appendices B, C, D, E, F, and G. After our group consolidated the budgets submitted by the six separate companies, a final budget was presented to Fundacion Paraguaya for approval. The budget presentation request included a brief description of the irrigation system we designed, lists of system part prices from each company, our proposed design, as well as an estimation of the payback period to recover the investment in the system. Calculating the payback period to recover the investment was important to ensure that our project was useful to Cerrito and would not be a financial burden on the school. Our group's finding from the payback period analysis suggests that if the irrigation system makes summer and winter maralfalfa crop yields match those of spring and fall yields, then the extra yield would produce roughly 8,800,000 Gs a year in additional revenue. This extra income is the result of the extra milk production in liters, being sold at 2,800 Gs per liter. The price is per liter of milk because the animal production center of Cerrito sells the milk to Cerrito's cheese factory. This is a very conservative estimate as it does not account for the profit margins of the products from the cheese factory or savings on feed, but rather the sale price of the milk itself .

The first step in calculating this was finding out how many liters of milk a year the cows at Cerrito produce. Our sponsors provided us with a production estimate of about 18,000 liters of milk a year. The next step was to find out how many liters of milk were produced each month, while our sponsors did not have this exact information, they said milk yields decreased by roughly 30% for half the year during the winter and summer months. With this information we developed the following equation:

$$6x+6(0.70x) = 18{,}000 \text{ liters of milk.}$$

X in the equation represents a normal month of milk production, "6x" being the six normal months and "6(0.75x)" representing the six months of decreased yields. When the math is completed out x equals 1,765 liters per month.

So, to calculate the estimated increase in milk production you would multiply 1,714 liters by 12 months yielding 21,176 liters per year, a 3,176-liter increase. Using the average price of 2,800 Gs per liter of milk given to us by our counterparts, the extra 3,176-liter increase would result in 8,894,256 Gs per year for the school. With our project costing 9,641,780 Gs we can then divide 9,641,780 Gs by 8,894,256 Gs per year to get 1.08 years or roughly 13 months for our project to be paid off. Due to the rapid payback period of our project, Fundacion Paraguaya approved funding for our irrigation system (See the summary of calculations for the payback period in Appendix H).

4.3 Installation of the Irrigation System

The first step of construction began before our budget was approved, we started by cleaning out the aljibe in order to ensure no contaminants would be in the water stored there. The aljibe was initially extremely cluttered with old materials from the adjacent chicken coop. Cleaning the aljibe was also needed to confirm that there were no leaks in the tank, as it had been unused for many years up until our project. To check for leaks we filled the aljibe with water after it had been cleaned then marked the water level and checked again after 24 hours. The difference in heights was compared to the evaporation rate from a bucket to see if there was a noticeable difference between the two. Using this process, we found very limited leaks and determined the aljibe was suitable for use.

Once the parts for the irrigation system were acquired, our team, together with students from the Cerrito School, and under the guidance of Ing. Amalio Enciso, Sr. Venancio Franco, and Ing. Walter Medina installed the system following the design as described below in Figure 13.

Figure 13: Final approved design.

The selected design provided the most straightforward route for the water to be pumped uphill from the wastewater treatment plant to the aljibe (as seen in Figure 13). This is important as bends or curves would require more power to force the water through them, making the design more power intensive. While there was already temporary tubing for the wastewater treatment plant in place, our group along with our sponsors decided the best course of action was to not use these tubes and to completely replace them during construction.

The final version of our design included automatically triggered pumps to pump water from the effluent treatment center to the aljibe that are “float activated”. This means that there is a floating buoy attached physically to a trigger that will turn on the pump if the water level is too high and turn off the pump if the water level goes below its threshold. The pump that distributes the stored water from the aljibe to the pasture is manually operated, although an automatic timing system was proposed, involving a floater system similar to the one installed on the pumps at the treatment center. For now, the pump will continue to be activated manually. This will allow for irrigation that can be based on local weather patterns.

For example, if the school experiences a very wet period it can hold off on irrigating to save water for a dry period. Manual operation of the irrigation system allows for the most efficient use of water. In the case of the aljibe filling up or the pumps in the water treatment system breaking, an emergency release was added to the design of the system. This release was made at a slight decline into a nearby tajamar (manmade reservoir) to allow the water to drain away without the need for power. Having a backup system to drain the water in case of an emergency ensures that the irrigation or water treatment system will not be potentially damaged when repairs are being made.

While all drip tape valves can be opened at once to ensure the most efficient use of water and that the pasture receives roughly equivalent watering throughout all rows only a third of the field should be opened at a time. This is because the pump at the aljibe ended up being a 1.5 HP pump as the cost of repairs to the 2 HP pump were deemed too expensive. In total if the system is used as outlined in the manual described below and each parcel is watered for 1.5 hours then each parcel should receive 7773.66 liters of water per irrigation session.

4.4 Operations Manual

Another deliverable our group compiled was an Operations Manual for the new irrigation system. Our team thought this would be valuable for any new staff member needing to understand the design of the new watering system and/or how to operate and maintain it. The guide is also a helpful learning aid to teach how to operate irrigation systems in general. The manual describes how to operate the new irrigation system and is a quick review of the different considerations our group took into account when designing the system and why we settled on the design we did.

The manual includes a section detailing how to care for the irrigation system, including information on how often to check the filters, how long to run the pump in the aljibe for, and how to do routine checks and repairs to the tubing.

The manual also briefly details the math behind our calculations, including the math we used to determine how powerful a pump the drip tape requires to act as a guide on how to apply the math for new systems in the future. Our goal with the operations manual was to make it so that someone with no prior knowledge of our project could read it and not only understand how to use and maintain our irrigation system, but also know what to consider when building one of their own. This way, once our group left our project site, there was a written document explaining our reasoning and how to operate and maintain the system.

4.5 Feria Cientifica Presentation

The Cerrito Agricultural School held a science fair-type event while we were developing this project that allowed all the WPI project groups in Paraguay to give a brief presentation on their project. Our group chose to focus on the broader idea behind our project and how it could potentially boost the school's finances, as described in appendix I of this report. We emphasized this aspect of our project rather than focusing on the importance of irrigation because Cerrito is an agricultural school, and the students are familiar with irrigation and its benefits already. Opting to explain the "why" behind our project, and its potential benefit for Cerrito, allowed us to explain to the students why Fundacion Paraguaya found this project worthwhile to put both money and effort into .

In order to effectively communicate this idea, we focused on demonstrating the positive feedback loop that will result from our project: increased maralfalfa production will lead to more food for the cattle, allowing for increased milk production for the cheese factory to process, thereby creating more effluent, which is then treated and used for more irrigation of the maralfalfa. The increased dairy product production then allows the school to increase its sales, bringing in more money for the school. The poster our group presented to the students at the Feria Científica, demonstrating this cycle, can be seen below in figure 15.

Figure 14: The Feria Científica presentation.

In addition to focusing on self-reinforcing cycle consisting of increased maralfalfa production leading to increased effluent to use for irrigation, our presentation also included a brief description of the sequential batch reactor effluent treatment process at the cheese factory as seen in figure 15. This information was included because the sequential batch reactor treatment system is the first of its kind on the Cerrito campus, so it is a novel idea for its students. By providing an explanation of how the cheese factory effluent is cleaned and treated we were able to provide the student body with more knowledge than just “the effluent is treated”, opening the door to a better comprehension of the process behind the treatment.

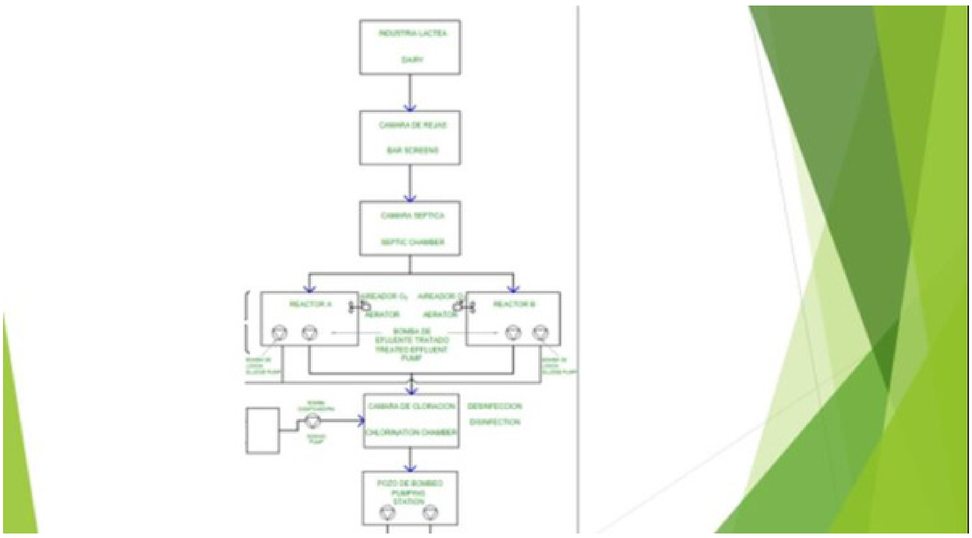

Figure 16: A description of the sequential batch reactor process in Spanish, as used in the presentation.

5. Conclusions and Recommendations

The utilization of treated wastewater involved repurposing treated water from the Cerrito School cheese factory's wastewater treatment process. This treated effluence, which meets safety and quality standards, was directed to a drip irrigation system to nourish maralfalfa crops. By reusing this treated wastewater, we not only conserve valuable water resources but also introduce more water back into the soil, promoting healthier soil and benefiting crop growth. This sustainable approach reduces the need for freshwater resources and minimizes wastewater discharge into the environment.

The implementation of our efficient drip irrigation system and the use of treated wastewater will directly contribute to a significant increase in maralfalfa yield at the Cerrito School. By providing a consistent and precise water supply to the maralfalfa , the watering system will help optimize growing conditions and promote healthier plant development, leading to higher yields during harvests. This boost in maralfalfa production has the potential to generate increased revenue for the school, which utilizes it for various on-campus needs, thereby enhancing the financial sustainability and success of the school's agricultural endeavors.

These ideas were shared with the student body through the presentation of our project at the school's project fair. By elaborating on and stressing the importance of the school using the agricultural circle to be able to be self-sufficient and how it would benefit the school, we may encourage the student body to identify more ways the school can become more efficient. In this case, the idea of self-sufficiency refers to the reuse of the effluent water to increase crop production through irrigation.

Our group effectively communicated our thought processes behind the design and implementation of the irrigation system by providing documents and design proposals to our counterpart professors during our stay on the Cerrito campus. For example, in the future, anyone can refer to our operations manual and irrigation system design and know why we chose the design that was implemented.

In addition, a person with no prior knowledge of our irrigation system will be able to learn how to operate and maintain the new irrigation system by referring to the operations manual. The operations manual will prevent reliance on word of mouth for information on how the system operates and is maintained , and will ensure that anyone, student or administrator, at Cerrito will be able to smoothly operate and maintain the irrigation system.

The successful implementation of treated wastewater in our irrigation system opens exciting opportunities for further exploration on campus. The school can now consider expanding the use of treated water to other agricultural areas, landscaping projects, or even non-agricultural applications like sanitation or cooling systems. This not only conserves freshwater resources but also promotes sustainable practices across the Cerrito School campus , fostering a culture of environmental responsibility and innovation. It should also be noted that exploring additional uses for treated water can lead to cost savings and increased operational efficiencies in various aspects of Cerrito campus management.

Our group's recommendations for the use and operation of the irrigation system are to irrigate a third of the field at a time, clean the pump in the aljibe's filter every week, and have a run time of 1.5 hours on and 1.5 hours rest. Our recommendations are designed to get the most use out of the system while maintaining efficiency and to have a long-lasting system.

One future recommendation for ease of use of our system is to install a floater switch in the aljibe to turn off the pump after the correct amount of time. Simply attaching a stiff arm to the floater and calculating the amount of water each degree of movement of the arm indicates has been pumped out of the aljibe should be sufficient to be able to design a switch that will turn the system off after 7773.66 liters have been used.

As another source of water collection our group recommends investigating the restoration of the rainwater collection system installed on the roof of the chicken coop adjacent to the aljibe . Due to the size and area of the chicken coop, the roof could add a significant amount of water from rainfall collection. In addition to this, the extreme proximity of the chicken coop to the aljibe would ensure that the collected water would not have to be transported a long

In addition to this, the extreme proximity of the chicken coop to the aljibe would ensure that the collected water would not have to be transported a long distance. Repairs to this system would involve putting the gutter system back onto the chicken coop and ensuring the brackets that hold them in place are secure. After the gutters are back up, attaching some sort of funnel from the end of the gutter down into the aljibe would allow the water to be used for irrigation. A similar system may also be implemented on any building with a suitably large roof, especially the cheese factory itself as a gutter system already exists and the only modifications required to the system are shifting the output of the gutter system to be the pipes that lead to the aljibe.

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Appendix

Appendix A: Table of the Proposed Budgets from Six Companies

Presupuestos Combinados	Agro Abasto : 6.652.000 Gs	Hortipro: 4.533.780 Gs	Agro Norte :5.260.000 Gs
Herrios Chaco: 5.246.000 Gs	11.898.000 Gs	9.779.780 Gs	10.506.000 Gs
Wal y Yol : 5.108.000 Gs	11.760.000 Gs	9.641.780 Gs	10.368.000 Gs
San Vicente: 5.402.000 Gs	12.054.000 Gs	9.935.780 Gs	10.662.000 Gs

Appendix B: Budget From Agricultural Company 1

AgroNorte			
Descripción	Cantidad solicitada	Precio unitario	Precio Total
Cinta de reigo 16 MM-Gotero C/20cm-200MIC	11 rollos	400.000 Gs	4.400.000 Gs
Conector inicial con anillo tipo	86 unid.	6.000 Gs	516.000 Gs
Conector final	86 unid.	4.000 Gs	344.000 Gs
Total:			5.260.000 Gs

Appendix C: Budget From Agricultural Company 2

HortiPro			
Descripción	Cantidad solicitada	Precio unitario	Precio Total
Cinta de reigo 16 MM-Gotero C/20cm-200MIC	11 rollos	346.180 Gs	4.005.980 Gs
Conector inicial con anillo tipo	86 unid.	2.870 Gs	516.000 Gs
8-0117] CAÑO CIEGO NEGRO DE 16mm X mts	10	4.920 Gs	49.200 Gs
[25-0005] CONECTOR INICIAL DE 16MM 14x16MM SUNSTREAM (C.700 P.50)	1	1.050 Gs	1.050 Gs

[38-0006] Microtubo de 8mm metro	2	1.300 Gs	2.600 Gs
[8-100] Nebulizador Completo de 4 boquillas con antigoteo NETAFIM	7	32.460 Gs	227.220 Gs
25-0057] Conector Final de caño ciego de 16mm MARIPOSA [25-0034] UNION PARA IDROP MICROTUBO de 7mm	1	480,000 Gs	480,000 Gs
[25-0034] UNION PARA IDROP MICROTUBO de 7mm	1	430,000 Gs	430,000 Gs
Total:			4.533.830 Gs

Appendix D: Budget From Agricultural Company 3

AgroAbasto			
Descripción	Cantidad solicitada	Precio unitario	Precio Total
Cinta de reigo 16 MM-Gotero C/20cm-200MIC	11 rollos	550.000 Gs	6.050.000 Gs
Conector inicial con anillo tipo	86 unid.	7.000 Gs	602.000 Gs
Conector final	86 unid.	4.500 Gs	387.000 Gs
Total:			7.039.000 Gs

Appendix E: Budget From Hardware Store 1

Herrios Chaco			
Caño negro de 1 1/2	400 m	11.500 Gs	4.600.000 Gs
Tee accompliement 1 1/2	2	10.000 Gs	20.000 Gs
Valvula de retancion con filtro de 1 1/2	4	150.000 Gs	600.000 Gs
Codo da 1 1/2	2	13.000 Gs	26.000 Gs
Total:			5.246.000 Gs

Appendix F: Budget From Hardware Store 2

Wal y Yol			
Caño negro de 1 1/2	400 m	11.500 Gs	4.600.000 Gs
Tee accompliement 1 1/2	2	20.000 Gs	40.000 Gs
Valvula de retancion con filtro de 1 1/2	4	112.000 Gs	448.000 Gs
Codo da 1 1/2	2	10.000 Gs	20.000 Gs
Total:			5.108.000 Gs

Appendix G: Budget From Hardware Store 3

San Vicente			
Caño negro de 1 1/2	400 m	13.000 Gs	5.200.00 Gs
Tee accomplement 1 1/2	2	18.000 Gs	36.000 Gs
Valvula de retancion con filtro de 1 1/2	4	35.000 Gs	140.000 Gs
Codo da 1 1/2	2	13.000 Gs	26.000 Gs
Total:			5.402.000 Gs

Appendix H: Calculations for Payback Period

6x+6(0.70x)=18,000 liters of milk

10.2x=18,000 liters of milk

x=1,764.705882 liters per month

Without the decrease in production, 12x=y

12(1,765)=21,176.47059 liters of milk per year

Sale price of milk is 2,800 Gs per liter

21,176-18,000=3,176 additional liters of milk per year

2,800 Gs x 3,176 liters per year=8,892,800 Gs per year

Cost of project is 9,641,780 Gs

Payback period is 9.641.780 Gs/8,892,800 Gs per year=1.08 years, roughly 13 months

Appendix I: Agricultural Circle

Description:

1. **Water is used to clean the cheese production equipment.**
2. **Industrial wastewater is collected after being used by the cheese factory.**
3. **Industrial wastewater goes through three stages of the cleaning process.**
4. **Water is used to irrigate the maralfalfa field.**
5. **This increases the growth and nutrient content of the maralfalfa.**
6. **Which results in more food for the livestock.**
7. **Leading to an increase in milk and cheese production.**
8. **Ultimately, this generates more income and sales for the school.**