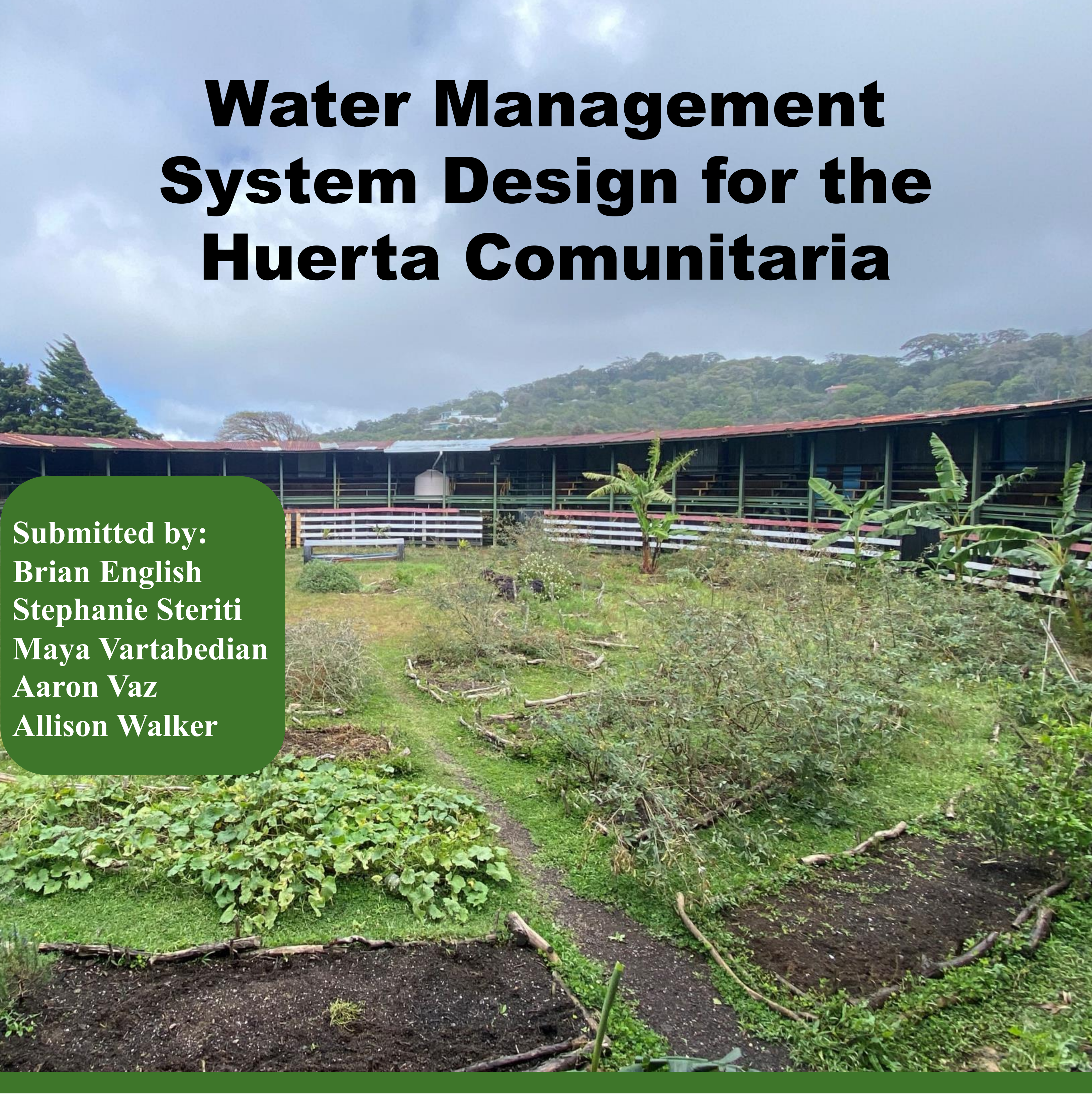
Water Management System Design for the Huerta Comunitaria



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Water Management System Design for the Huerta Comunitaria

An Interactive Qualifying Project
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
degree of Bachelor of Science

by
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Report Submitted to:

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Abstract

In Monteverde, Costa Rica, seasonal precipitation poses challenges in supplying a consistent source of produce to the local school year-round. We collaborated with CORCLIMA and Huerta Comunitaria to design a water management system to help stabilize crop production. Through extensive research, calculations, and design consultations, we designed a system that fits the garden's needs, capabilities, and constraints. Our proposed water management system is presented as a blueprint for the collection, irrigation, drainage, transportation, and storage systems for future implementation.

Acknowledgements

Our team is immensely grateful for everyone who contributed their time and effort to help us plan and begin the implementation of our designs. We would like to particularly thank Huerta Comunitaria and CORCLIMA for giving us the opportunity to collaborate in the design process of a water management system that will greatly benefit the local school. We are especially thankful to Paula Vargas and Katy VanDusen for their support, guidance, and knowledge throughout the completion of this project.

We would also like to thank all the local subject matter experts and volunteers who offered their experience and feedback to help strengthen our project. In addition, we would like to express our appreciation to our advisors Professor Carol Stimmel and Professor Robert Traver, of Worcester Polytechnic Institute, for all the guidance, experience, and knowledge throughout the preparation and completion of this project. Finally, we are also very grateful for the opportunity provided by Worcester Polytechnic Institute to be in Monteverde, Costa Rica, to work on such a meaningful project.

Our Team Working Alongside Paula Vargas

Authorship Table

Section	Author	Reviewer
Abstract	Aaron	Brian, Ally
Executive Summary	Maya, Ally	Steph
Acknowledgements	Aaron	Maya
1. Introduction	Steph	Ally
2. Background		
2. Logic Paragraph	Steph	Aaron
2.1.1 Food Insecurity and its Impacts	Steph	Ally, Brian
2.1.2 Causes and Conditions	Ally	Steph, Maya
2.1.3 Effects of Covid-19	Ally	Aaron, Maya
2.1.4 Costa Rica Specifically	Brian, Steph	Ally
2.2.1 Food Sovereignty & Local Resilience	Steph	Ally, Aaron
2.2.2 Policies	Ally	Steph
2.2.3 Monteverde's Response	Ally	Aaron, Brian
2.3.1 The Garden	Aaron, Brian, Ally	Steph, Ally
2.3.2 Climate Context	Brian	Ally, Steph
2.3.3 Agricultural Practices Intro	Steph	Maya, Aaron
2.3.3.1 Sprinkler and Center Pivot	Brian	Steph
2.3.3.2 Drip Irrigation	Brian, Ally	Steph, Maya
2.3.3.3 Rainwater Harvesting	Brian	Steph
2.3.4 Drainage Practices Intro	Steph	Maya
2.3.4.1 Water Relocation	Maya, Aaron	Brian
2.3.4.2 Rain Gardens	Ally	Steph, Brian
2.3.4.3 Retention and Detention Basins	Steph	Maya, Brian
2.4 Sponsor	Aaron, Ally	Maya
3. Methodology	Steph (visual)	Aaron
3.1 Obj. 1	Aaron	Steph, Ally
3.2 Obj. 2	Aaron	Ally, Steph

3.3 Obj. 3	Aaron	Steph, Ally, Maya
3.4 Obj. 4	Aaron	Steph, Maya
4. Results Intro Paragraph	Ally	Steph
4.1 Component Selection	Aaron	Steph, Ally
4.2 Location Selection	Steph	Maya, Ally
4.3 Validation Session	Maya, Ally	Aaron, Steph
4.4 Design Parameters	Maya, Ally	Aaron, Steph
5. Recommendations Intro	Steph	Ally
5.1 Components to be Implemented	Steph	Maya, Ally
5.2 Location for Components	Steph	Aaron, Ally, Maya
5.3 Improvements to Design	Steph	Aaron, Ally, Maya
5.4 Parameters for Building	Steph	Aaron, Ally, Maya
5.5 Order of Implementation	Steph	Aaron
6. Conclusion	Steph	Brian, Aaron, Ally

Meet the Team

From left to right: Stephanie Steriti, Maya Vartabedian, Allison Walker, Aaron Vaz, and Brian English

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Executive Summary

Background

Food insecurity has major negative impacts on individuals and societies worldwide. It is a challenging issue because it stems from a variety of complex conditions from household economic struggles on the individual scale to climatic and economic hardships on the national or global scale (*What Is Food Insecurity? | Feeding America*, n.d.). Most recently, the COVID-19 pandemic has had a devastating impact on food insecurity for many across the globe and has particularly challenged economies like Costa Rica.

As a result of the economic challenges posed by COVID-19, Monteverde focused on ways to supply their own food. CORCLIMA partnered with the Rafael Arguedas Herrera School to start a community garden in their abandoned bullring (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022). As small-scale farming and gardening expanded in Monteverde during the pandemic, the focus of the garden began to shift; it started to supply its crops directly to the school. This garden is a step towards controlling the production of food and allowing the community to be more resilient in the face of future challenges.

Huerta Comunitaria struggles to provide a consistent crop supply as Costa Rica experiences patterned rainfall. It experiences wet seasons with excessive precipitation, leading to flooding, and dry seasons with very little rainfall, causing the need for time-consuming manual watering (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022). Therefore, it is challenging to provide a consistent and balanced food supply from the garden.

Methodology

The goal of this project was to design a water management system to help promote year-round plant growth in the community garden in Monteverde, Costa Rica, to provide food for the local school. To obtain this goal, we pursued the following objectives:

Objective 1: Compile design components for the water management systems.

To discover the optimum water management solutions, it was crucial to research different components and consult a local subject expert about the specifics of Huerta Comunitaria.

Objective 2: Assess the topography, current water management system, and garden operations based on its operational requirements.

Through analysis of blueprints and 3D models, we split the property into zones and collected measurements of the structure and land to find the ideal locations of the systems.

Objective 3: Design validation to improve preliminary design.

To confirm the success of our design, we had a design validation session by which we held a semi-structured interview with Aníbal Torres of the Monteverde Institute.

Objective 4: Obtain design parameters to finalize design.

By conducting multiple soil and water tests and researching sizing standards, we were able to calculate and obtain dimensions of the management system.

Results

Water Management System Design Components

Our team discovered that the components for a water management system can be classified into five standard categories and are dependent on garden characteristics, including excess rain, land layout, and lack of operational funds. These categories helped us to comprehensively assess and address the rainwater harvesting, drip irrigation, French drains, trenching systems, and detention basin components of our five critical design categories, as shown in Table E1.

Table E1

Water Management System Categories with our Selected Subsystems

Water Management System Categories	
Water Collection	• Roof rainwater harvesting
Water Irrigation	• Drip irrigation
Water Drainage	• French drain
Water Transportation	• Trench system
Water Storage	• Detention basin

Note. This shows the categories that encapsulate the water management system and subsystems that were chosen. Authors' own work.

Topography, Management System, and Garden Operations

The design component locations were influenced by problematic flooding areas, garden layout, bullring structure, future construction plans, and land constraints.

An additional finding was that all components do not have to be installed at once and have an order of importance based on the garden's needs. This order is as follows transport, trenches; storage, detention basin; drainage, French drains; irrigation, drip irrigation; and collection, rainwater harvesting.

Design Improvements from Validation Session

By carrying out an interview with Mr. Torres, we discovered flaws and shortcomings in our preliminary designs. This helped us adjust our designs to address concerns such as the risk of children drowning in the detention basin. We were also concerned about implementing clogging prevention and improving percolation rate by planting specific plants in the basin.

Testing and Calculations

Conducting a variety of standard tests taken together with the literature allowed us to calculate and obtain design parameters. We were able to determine soil makeup, infiltration rates, water pressure, and water consumption through field testing. Using these variables, we concluded that the detention basin would be 1 m in depth, with an arch length of 55°, 24.5 m away from the center of the garden and a width of 7 m. Our water consumption test revealed that 1116 L of rainwater is used per day in the dry season and the three proposed rainwater harvesting barrels could supply water without being refilled for 6.7 days. To ensure that our drip irrigation design moves water efficiently, we found that the pressure from the water tank was 15.8 psi and the pressure from the municipality water hose was found to be 14.8 psi. As the necessary water pressure for drip irrigation is 8 to 20 psi, these were adequate for the irrigation system to run properly (Fathel, 2020). We found the proper size of the drip irrigation pipes to be ¾ in and the French drain to be four to eight in ("French Drains 101," 2020; *How to Make a Cheap Do-It-Yourself Drip Irrigation System Using PVC*, 2021). To combat the intense amount of rainfall experienced at the Huerta Comunitaria, we selected an 8 in diameter pipe.

Recommendations

After completing our methodology and analyzing our results, we were able to compile four recommendations for our sponsors to consider when building the water management system.

1. Implement Design Components in the Best Order

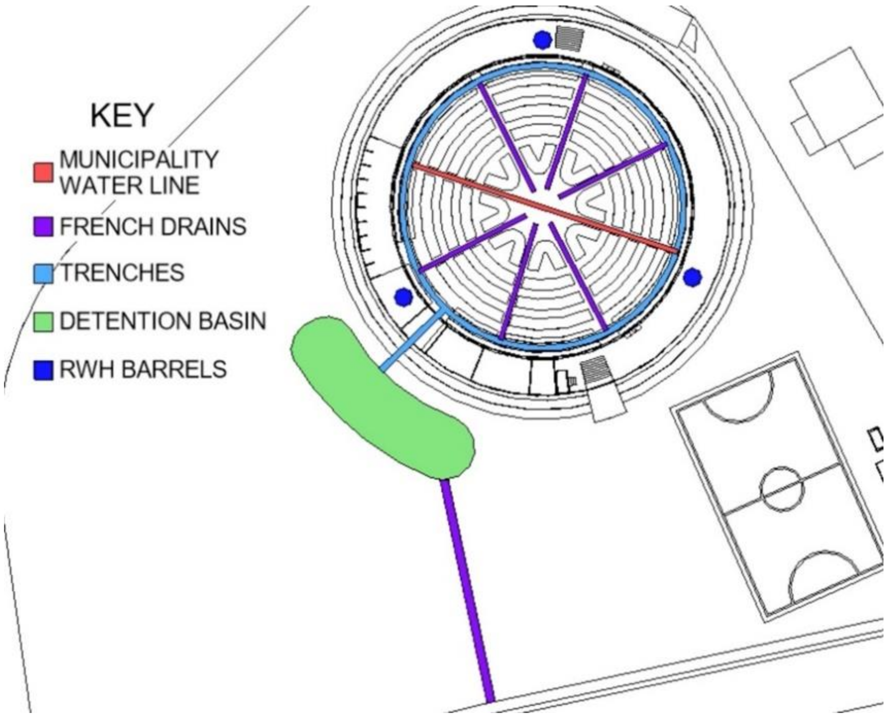
We recommend that Huerta Comunitaria implements the following subsystems for each respective category in the following order: transport, trenches; storage, detention basin; drainage, French drains; irrigation, drip irrigation; and collection, rainwater harvesting. It is best to install these components in an order rather than all at once for improved cost and efficiency. For irrigation, we recommend implementing a drip irrigation system because it is efficient, cheap, and easy to implement. For drainage, we recommend French drains because they are spatially efficient and can be disguised beneath walking paths. For transport, we recommend using trenches because they are already installed, simple, and affordable. For storage, we recommend using a detention basin because it has a good percolation rate and is spatially efficient.

2. Build in Recommended Locations

We recommend the drainage system be built as laid out in Figure E1. The French drains will evacuate excess water from the middle of the garden to the trench system on the outer rim of the garden. This will help relocate and transfer water into the detention basin. The detention basin will hold the water and slowly percolate it into the soil. The French drain will lead from the basin to the street to manage overflow.

Figure E1

Recommended Design Component Locations for Drainage System

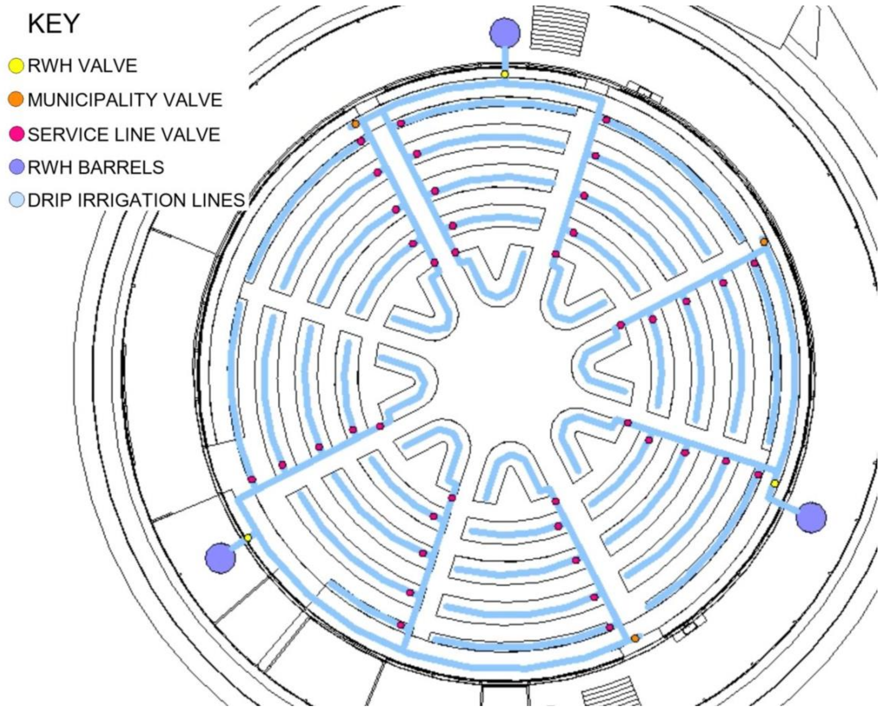


Note. Authors' own work overlaid on the blueprints from Paula Vargas.

We designed an irrigation system to be built as laid out in Figure E2. It is comprised of three rainwater harvesting barrels, drip irrigation lines, and valves at each bed, the connections to the rainwater harvesting barrels, and the connections to the municipality water.

Figure E2

Recommended Design Component Locations for Irrigation System



Note. Authors' own work overlaid on the blueprints from Paula Vargas.

3. Perform Regular System Maintenance

We recommend including clogging prevention to the rainwater harvesting system and French drains, as well as including plants in the detention basin. Installing mesh on roof gutters, barrel downspout, barrel spigot, and the inlets and outlets of the French drains will help prevent debris from clogging the system. Planting heliconia, spiral ginger, and ferns in the detention basin will aid in water drainage and the visual appeal of the basin.

4. Adhere to Calculated Parameters for Best Production Results

We recommend the water management system be built according to the parameters to function properly. We recommend that the French drains be installed at 3.5 m away from the center of the garden. The pipe will run 0.1 m down before meeting a 13.5 m pipe that is at about a 1° angle of depression to allow for the water to flow. The obtained sizes for the irrigation piping were found to be ¾ in and for the French drains, the sizing was found to be 8 in. The detention basin size was found in our calculations be 1 m in depth, with a width of 7 m, and arc spanning 55° around the perimeter, at 24.5 m away from the center of the garden. In order to avoid overflow, the outflow pipe in the French drain should be at 0.2 m deep into the detention basin.

The aim of this project was to design a water management system in the Huerta Comunitaria to take advantage of the rainfall during the wet season in Monteverde, Costa Rica while also mitigating the effects of the increased rainfall. At the completion of our project, we delivered blueprints of our design and guidance for implementing each component of the system.

Table of Contents

List of Figures

List of Tables

1. Introduction

Food insecurity, the condition of insufficient food to meet one's basic needs, has major negative impacts on individuals and societies worldwide. The condition contributes to significant physical and mental health issues for people of all ages. For children, it can lead to serious lifelong eating disorders and weight gain which brings about a variety of other health issues. In adults, insufficient food security can also lead to weight gain which contributes to chronic illnesses such as diabetes. Additionally, the lack of a balanced diet increases stress, anxiety, and depression. Yet, food insecurity is a challenging issue to solve because it stems from a variety of complex conditions. These conditions include household economic struggles on the individual scale to climatic challenges and widespread economic hardships on the national or global scale. Most recently, the COVID-19 pandemic has had a devastating impact on the problem of food insecurity for many across the globe and has particularly challenged developing economies such as Costa Rica.

Costa Rica struggles with food supply difficulties due to its pattern of rainfall as well as the residual economic effects of the pandemic. As a tropical country, Costa Rica has rainy wet seasons and dry seasons with very little rainfall. This leads to flooding in the wet season and insufficient natural water supplies in the dry season. Therefore, growing crops throughout the year to produce a consistent and balanced food supply can be challenging. Costa Rica also continues to suffer economically because of the pandemic. The country faced a large increase in unemployment and poverty during the pandemic and has not yet fully recovered. Monteverde, a small mountainous province in Costa Rica of just over 6,000 members with a primarily tourist-based economy, was majorly impacted. The shock of COVID-19 decreased economic stability and increased food insecurity in the community. The impacts of the pandemic highlighted the Monteverde community's need for improved resilience in terms of food security.

To address these systemic effects and support families experiencing food insecurity, the Monteverde community began to develop ways to supply their own food, rather than relying on external food sourcing as an expression of "food sovereignty," the right to choose where food comes from. CORCLIMA, the Commission for Resilience to Climate Change in Monteverde, partnered with the Rafael Arguedas Herrera School to start a community garden in the long-abandoned bullring that the school owns. Since the project began in 2021, the garden, named Huerta Comunitaria, has provided fresh produce as well as educational opportunities for many students and families. It currently supplies most of its produce to Rafael Arguedas Herrera school and hopes to be a large contributor to the school's overall food supply as the garden improves. The garden is a step for the community toward achieving food sovereignty, in which they control the production of food and, thus, will be more resilient when faced with future challenges.

The main issue facing the garden is the variability in its water source. Since the garden cannot rely on rainfall to supply its water needs year-round, due to the patterned rainfall in Monteverde, the volunteers must manually water the garden during the dry season. Also, the garden experiences flooding during the rainy season as the water does not seep into the soil. The gardeners have generally accommodated for this by planting different crops in the wet season than in the dry season. However, this means that for several months of the year, certain desirable crops are unavailable to the local school unless imported. To stabilize food production from the Huerta Comunitaria Garden, it is important to address the rainfall challenges that are inhibiting successful local food production.

The aim of this project was to design a water management system in the Huerta Comunitaria to take advantage of the rainfall during the wet season in Monteverde, Costa Rica yet also mitigating its detrimental effects. The captured water will be distributed throughout the garden with the use of the drip irrigation system that we designed to aid plant growth and produce food for the school in Cerro Plano. We also helped design a drainage system to aid in decreasing the flooding that is experienced in the garden. To successfully create this, we investigated a variety of irrigation and drainage systems and capture methods, garden layouts, soil properties, and performed average yearly rainfall calculations based on local data. To gather this information, our team utilized local resources and collaborated with local experts, carried out tests in the garden, and completed the relevant calculations. With the completion of our project, we created blueprints of our design as well as guidance for implementing each component of the irrigation and drainage systems.

2. Background

In this section, we start by explaining food insecurity, its causes, and its impacts on communities. We highlight the causes of climate change and inclement weather and the system shock caused by the COVID-19 pandemic, first on the global level, and then specifically in Costa Rica, which experienced an intensified food insecurity problem. Next, we talk about how this increase in food insecurity along with Costa Rica's environmental policies led Monteverde to start a community garden to help the town become more resilient to future disruptions. Then, we discuss the garden itself and the challenges that it faces, mainly pertaining to water management, and possible solutions for these challenges. Lastly, we share information about our sponsors and the full context of our project's impact on the community.

2.1 Global and Local Impacts of Food Insecurity

Food insecurity is caused by multiple contributing factors and is a significant cause of physical and mental health issues across the globe. The causes and effects of food insecurity are addressed here, particularly how they have impacted Costa Rica and the region of Monteverde.

2.1.1 Food Insecurity and Its Impacts

When people in a community do not have enough to eat to meet their nutritional needs, families and communities suffer. Feeding America defines food insecurity as "a lack of consistent access to enough food for every person in a household to live an active, healthy life" (*What Is Food Insecurity? | Feeding America*, n.d.). There are 345 million people in the world facing food insecurity today which largely impacts people's physical and mental health (*A Global Food Crisis | World Food Programme*, n.d.).

When children experience a lack of proper nutrition it leads to impaired growth and development, yet other physical and emotional conditions may occur (Paslakis et al., 2021).

Food insecurity can cause parents and caregivers to change feeding patterns that causes them to overfeed their children when they have access to food and underfeed them in hopes of conserving food when they do not have access (Paslakis et al., 2021). Paradoxically, underfeeding babies can lead to obesity, and restrictive feeding and food supply in childhood can lead to future eating disorders (Paslakis et al., 2021).

In 2016, a study conducted in Madrid with data collected on 1,938 children ages two to 14 years old showed that the condition of being overweight or obese was found to be directly related to household food insecurity (Ortiz-Marrón et al., 2022, p. 1). The study concludes in part, "A higher prevalence of overweight (33.1%) and obesity (28.4%) was observed in children from families with HFI (household food insecurity), who presented a lower quality diet and longer screen time compared to those from food-secure households (21.0% and 11.5%, respectively)" (Ortiz-Marrón et al., 2022, p. 1). Along with children and adolescents, adults also experience the health impacts of food insecurity.

Adults experience health issues resulting from a lack of access to adequate food for a healthy life. An increase or decrease in access to food can lead to weight gain which plays a large role in the development of chronic illnesses (Lee et al., 2012). For example, being overweight puts people at a higher risk of developing type 2 diabetes. Diabetics must follow a well-balanced, diabetic-friendly diet; those who experience food insecurity may struggle to manage their illness because they have insufficient resources to manage their diets properly (Lee et al., 2012). Food insecurity impacts all ages of people, not just developing children.

2.1.2 Causes and Conditions of Food Insecurity

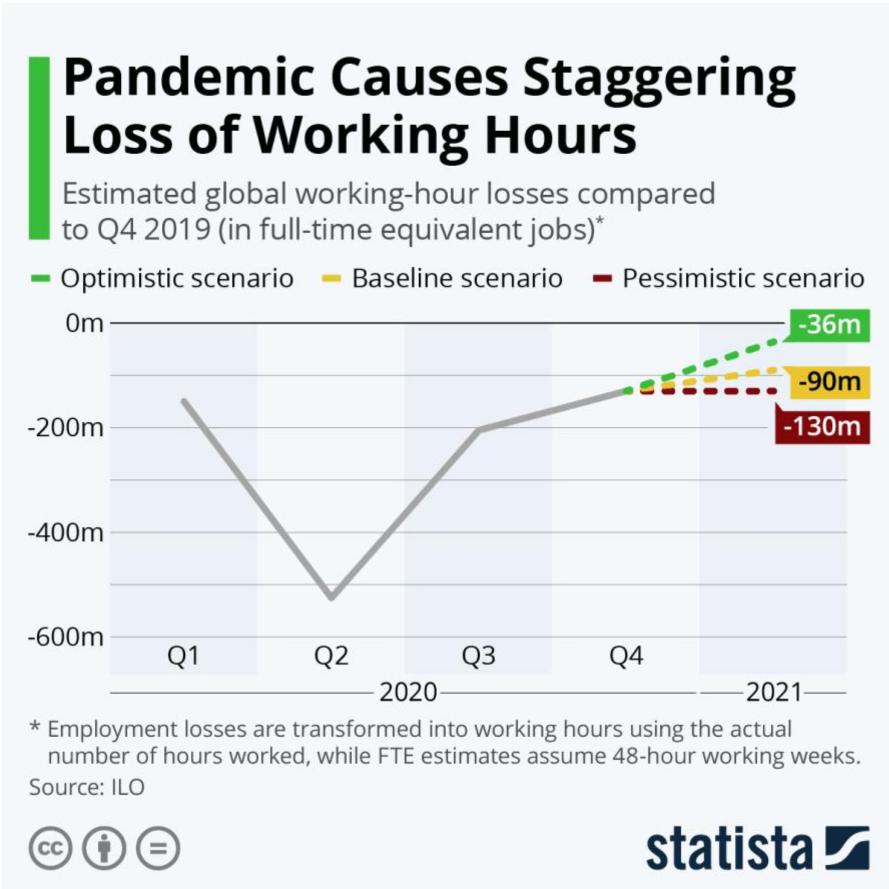
Food insecurity can be caused by household-level economic problems such as low income, unemployment, or increases in food prices. It may also be the result of environmental shocks such as drought, lack of farming land, and widespread illness that damages the food supply chain. Food insecurity can have a sizeable impact depending on one's circumstances and altered food access can cause health problems and financial instability since disruptions occur without enough forewarning to alter immediate impacts (Hunger in America, 2022). Economic system shocks caused by events such as drought, tropical storms, oil supply changes, war, disease, among other factors, have increased over the past 40 years as a result of climate change (NOAA, 2022). Any of these conditions can drastically alter a community's ability to afford or acquire food, which results in food insecurity.

2.1.3 Effects of the COVID-19 Pandemic

The COVID-19 pandemic caused widespread panic, social isolation, and shutdowns of schools and businesses beginning in March 2020 and has since surpassed 6.81 million fatalities (World Health Organization, 2022). COVID-19 is an infectious disease caused by the SARS-CoV-2 virus that causes respiratory distress. Worldwide, many countries are still recovering from its impacts nearly three years later, after its effects eliminated over 114 million jobs worldwide in 2020 alone (Ferrari & Nilsson, 2020). In developing or stressed economies, food is a significant portion of family expenditures. With severely depressed or eliminated income, it became increasingly difficult for individuals and families to acquire enough food for proper nourishment, leading to a rise in food insecurity (Feeding America, n.d.). As shown in Figure 1, the second quarter of the 2020 pandemic saw the largest labor market disruption, when the most job hours were lost (Ferrari, et al. 2020).

Figure 1

Pandemic Causes Loss of Working Hours, 2020-2021



Note. From "COVID Crisis Results in Staggering Loss of Working Hours" by Felix Richter is licensed under CC BY-ND 2.0.

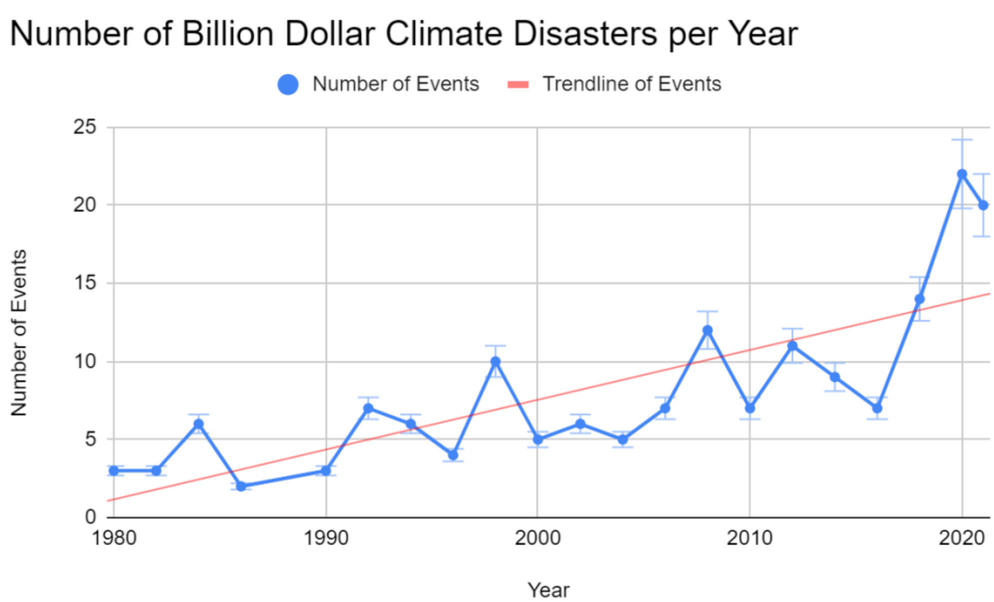
2.1.4 External Shocks Cause Food Insecurity in Costa Rica

Like many countries around the world, Costa Rica's weather patterns have measured significant shifts due to the impacts of climate change. CORCLIMA, The Commission for Resilience to Climate Change in Monteverde, has been monitoring these changes as part of their goal to promote Costa Rica's Climate Change Strategy. CORCLIMA has found that since the early 1970s, the average number of dry days has increased from approximately 25 to more than

110 per year. Simultaneously, the average annual rainfall has increased from approximately 2.5 m to more than 3 m (Corclima, 2019). This indicates that dry periods last longer and intense downpours are more common, which can lead to erosion and landslides. As seen in Figure 2, climate disasters have taken a global toll, specifically on Costa Rica, who has the seventh highest risk of natural disasters worldwide including severe floods, droughts, and rising temperatures (Boucher, 2014). All these impacts can disrupt the supply chain and result in limited access to food for many. The COVID-19 pandemic has amplified this concern, causing further and more extensive disruption to the food supply chain.

Figure 2

Number of Billion Dollar Climate Disasters per Year, 1980-2021



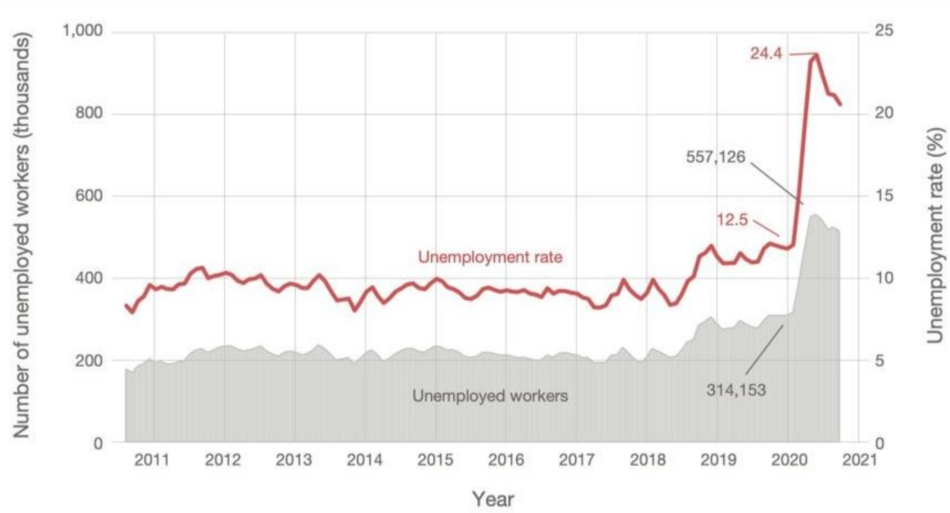
Note. The graph shows overall increasing climate disasters worldwide from 1980 to 2021. Authors' own work, with data from NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2022). https://ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73.

Latin American and Caribbean countries, including Costa Rica, saw a large increase in food insecurity during the COVID-19 pandemic. The rate of food insecurity in these countries rose from 31.7% in 2019 to 40.9% in 2020 as a result of the pandemic (Hernández-Vásquez et al., 2022). Compared to high-income countries, citizens of these countries have a larger portion of their income allocated to food. When income is reduced, affording food becomes more difficult, particularly when food prices simultaneously increase. A study on food insecurity in Latin America found that 45.4% of the 787 houses surveyed in Costa Rica had experienced price increases in food as a direct result of the pandemic (Hernández-Vásquez et al., 2022).

Despite its 25 years of steady economic expansion, Costa Rica saw its economy suffer considerably during the COVID-19 pandemic. As a result of the global lockdowns which shutdown world travel and consequently tourism, the percent of people in ecotourist Costa Rica who were living below the World Bank's poverty line reached 19.8% in 2020, or roughly one in five. Contrasted with the prior years between 2010 and 2019, poverty had decreased from 15.6% to 13.7%. This shows that the impact of the pandemic is clear (*The World Bank in Costa Rica, Overview*, 2022). Costa Rican families suffered greatly and experienced many changes to their incomes and financial stability. During the initial stages of the pandemic, 63.7% of the 787 households surveyed in Costa Rica had experienced a reduction in family income, and 42.7% had a family member lose their job (Hernández-Vásquez et al., 2022). The unemployment rate nearly doubled because of the pandemic with an increase from 12.5% in 2019 to 24.4% in 2020, as can be seen in Figure 3 (Groves et al., 2022). These economic effects thus amplified food insecurity in areas where the economy predominantly relies upon tourism and have not been easy to correct.

Figure 3

Monthly Change in Unemployed Workers and Unemployment Rate, 2010–2020



Note. From A green Costa Rican COVID-19 recovery: Aligning Costa Rica's decarbonization investments with economic recovery., by Groves, D. G., Molina-Perez, E., Syme, J., Alvarado, G., De León Denegri, F., Acuña Román, J. D., & Rojas, A. J., 2022, Rand Corporation, (https://www.rand.org/pubs/research_reports/RRA1381-1.html). Copyright 2022 by United Nations Development Program (UNDP-Costa Rica). Reprinted with permission.

2.1.5 The COVID-19 Pandemic's Effects on Monteverde

Like much of Costa Rica, the community of Monteverde relies heavily on ecotourism for its revenues, but during the pandemic the flow of travelers was depleted, leaving the community in a difficult state. In 2019, Monteverde had 250,000 visitors mostly from the United States, Canada, and Europe, but in March 2020 travel restrictions were put in place banning any travelers from other countries, bringing tourism to a halt. This total ban, which was in place until August 2020, left many families in Monteverde with very little income even as tourism started to slowly return (Shah, 2020). In Monteverde, for many whose jobs were not lost, income was substantially impacted through lowered wages, fewer working hours, or fewer total incomes within a household (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022). These impacts underscore the importance of the community in developing further forms of resilience from economic shocks, particularly in terms of food security.

2.2 Community Push for Resilience in the Food Supply Chain

Resilience in terms of food security means having a structured food supply (Menconi et al., 2022). The system shock caused by the COVID-19 pandemic started the push for this resilience in communities, which led to deliberating about how to navigate Costa Rica's environmental policies and bring about a way to grow locally together.

2.2.1 Food Sovereignty's Role in Resilience at the Local Level

Food sovereignty plays a large role in the drive for food security. Food sovereignty is the right to choose how one's food is obtained, and food security refers to having access to adequate food for a healthy lifestyle (Menconi et al., 2022). As the concept of food sovereignty is being further explored in terms of food security, so is the idea of food self-sufficiency, locally providing one's own food. Food self-sufficiency, when properly planned and executed, could go far to mitigate economic and climatic causes of food insecurity. With increased food sovereignty, communities are more self-reliant. Further, when self-sufficient food sources are planned to factor in climate changes, the climatic effects are mitigated (Menconi et al., 2022). Monteverde is also very focused on sustainability, so by achieving food sovereignty, they can control how their food supply affects the environment.

Monteverde, as a community, is very focused on the conservation of the environment. Described an "epicenter for biodiversity, international communities, and scientific discovery," Monteverde established the Monteverde Cloud Forest Reserve in 1972 to protect the animals and plant life that reside there (Looby, 2017). This drive for conservation and wildlife protection is still strong today. Local farmers push for the use of organic fertilizers and sustainable practices when growing food. By being able to supply one’s own food, Monteverde specifically can make sure that its food supply is environmentally friendly while protecting against food insecurity (Looby, 2017). Costa Rica’s agricultural and environmental policies are synchronized with the idea of staying local for food supply and achieving food self-sufficiency while being environmentally conscious.

2.2.2 Policy Challenges in Costa Rica Constrain Local Food Production

Costa Rica has a long-standing history of farming that has begun to change due to several environmental policies that provide agricultural restraints. For example, Costa Rica’s first commercial crop of coffee was produced in the 1820s, which has since evolved into producing 82 M kilograms (roughly 180.6 M pounds) of coffee in 2020 as well as commercial crops of bananas, pineapples, corn, and more being farmed in similarly high volumes (U.S. Department of Agriculture, 2022). This can be compared to the United States' 2020 coffee production, amounting to about 2 M kilograms (roughly 4.3 M pounds); Costa Rica produces more coffee per month than the United States produces in one year (Knoema, n.d.). Such high production rates have yielded harsh repercussions on the Costa Rican environment, including high carbon emissions caused by the release of significant amounts of methane and nitrous oxide – two of the most potent greenhouse gases. Since 2009, this has prompted their government to consider how to implement sustainable agricultural practices (European Environment Agency, 2015).

Costa Rica began drastically improving their sustainable practices by participating in the Multi-Stakeholder Advisory Committee of the United Nations 10YFP Sustainable Food Systems Program which arose in 2012 as a global initiative to help countries shift towards more sustainable food systems (Olsen, 1996). With the help of the Nationally Appropriate Mitigation Actions (NAMAs) and the National Strategy for Low-Carbon Livestock, Costa Rica was able to implement several adaptations to their farming practices to move towards a more sustainable farming approach (Patiño, 2020). These environmental policies led Costa Rica to reconsider its methods of farming and food production.

Since 2009, Costa Rica has established several programs to aid in its goal to reach carbon neutrality by 2085 (Groves et.al, 2022). Carbon neutrality is the idea of achieving net-zero carbon emissions by making the amount of carbon emitted into the environment less than or equal to the amount of carbon removed from the environment (Zuo, 2012). Some of the net-zero programs in Costa Rica include the Green Trademark, the Payments for Environmental Services (PES) program, and the Green Growth Program which monitor the large amounts of fertilizer and pesticides being used on Costa Rica's major exports which contribute to soil depletion, freshwater contamination, and deforestation, and work to eliminate these practices (Brennan, 2018). The programs laid out in the country's Decarbonization Plan have proved successful thus far, putting Costa Rica on track to achieve carbon neutrality 35 years earlier than planned – by 2050.

Propelled by Costa Rica's environmental policies, farmers began to explore more eco-friendly options such as small-scale farming and gardening that included crop rotation, permaculture, agroecology, and natural fertilizers. Small-scale agriculture also is more financially and economically stable than large-industry farming (Brennan, 2018). Since one of the first lawful motions towards environmental improvement in 1997, Costa Rica is 98% free of deforestation, has increased its recycling rate by 469% from 2015 to 2017, and generates 99% of its electricity from renewable sources, all of which minimizes the country's carbon footprint (Ibarcena, 2022). Because of decarbonization policies small-scale, community-based farming is an important option in introducing food security, and a culture of eco-friendly pride has formed around these projects (Stamm, 2020).

2.2.3 Benefits of Community Gardening

Community gardens not only help to mitigate food insecurity, but they have a positive social impact as gardening can provide mental health benefits. The act of gardening and being around natural systems can support mental health through “green care”, a form of exposure therapy that encourages gardening and plant care (Thompson, 2018). Several research trials performed in Japan have shown that subjects display improved cardiovascular health by reducing blood pressure, pulse rate, and muscle tension, as well as improved mental health which includes reduced stress, fear, and sadness which can be seen in the altered EEG readings (Thompson, 2018). Therapeutic horticulture has been utilized in several countries around the world for thousands of years and results in general mental and physical health improvement all around. CORCLIMA recognized the benefit of improving community connections while providing locally sourced food, particularly considering the isolation during the COVID-19 pandemic (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022).

2.2.4 Monteverde’s Approach to Community Gardening

During the peak of the pandemic, Monteverde individuals, organizations, and governments alike knew they needed a way to provide community-level food relief. Due to Costa Rica’s broad environmental protection laws, however, large-scale farming enterprises were prohibited. In August 2020, just five months after the COVID-19 pandemic began, the tight-knit community of Monteverde, Costa Rica came together to brainstorm ways to combat the many issues that arose at the inception of the pandemic. Economic collapse, food insecurity, and mental health concerns had become widespread, and the community hoped to find long-term solutions. COVID-19 severely impacted many families by terminating jobs and lowering income, making it difficult to afford food.

CORCLIMA, whose main mission is to minimize Monteverde's climate impact and help the region adapt to climate change, conceived the idea to create a community garden for families in need. A garden would allow families to grow their own food for free, while also bringing the community together through a meaningful project during a time of distancing (Elise Harris, 2009). The social interaction opportunities of community gardening have been especially important during the pandemic when social distancing has been an important measure of public health. Environmental protection laws combined with the shock of the COVID-19 pandemic have compelled citizens in Monteverde to think creatively and cohesively to come together through community gardening.

2.3 Creating the Community Garden

There were not many public spaces available to build the community garden, so CORCLIMA approached the Rafael Arguedas Herrera school to discuss utilizing an abandoned bullring on their property (see Figure 4

Bullring Aerial Photograph

). The two entities formed an agreement by which CORCLIMA could turn the bullring into a community garden if they would also provide classes to the school children about garden growing, maintenance, and environmental care. Along with this, CORCLIMA offered free workshops to anyone in the community who wanted to learn how to grow their own food (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022). Additionally, local farmers and gardeners came together to create a WhatsApp group of over 150 people where they taught and provided advice to those just starting their own home gardens (Wilkins, 2021).

Figure 4

Bullring Aerial Photograph

Note. This is an aerial photograph of the bullring and the surrounding area. The bullring garden is indicated by the red arrow. *(Used with the permission of the Huerta Comunitaria, 2022)*

As the community emerged from the worst of the pandemic in mid-2021, the focus of the bullring garden began to shift. Because small-scale farming and gardening efforts expanded in Monteverde during the pandemic, the bullring garden was able to supply food directly to the Rafael Arguedas Herrera School. Today, the WhatsApp gardening group remains in use to share information and the community garden now provides much of the school's produce. Whatever is not needed by the school is contributed to the local farmer's market that occurs every first and third Saturday of each month, where the garden food is sold for VERDES – a local currency used in the Monteverde community (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022).

2.3.1 How the Garden Operates

The total plot of land encompassing the bullring is approximately 6,800 m^2, while the land area within the bullring itself is around 960 m^2 (Paula Vargas, personal communication, January 27, 2022). This means there is a diameter of 35 m. The bullring has a large metal roof above its seating area which slopes downward toward the garden. This roof shades areas of the garden during certain hours of the day and directs the flow of rainwater into the garden as can be seen in **Error! Reference source not found.**. The garden's soil is composed largely of clay, which can make it difficult for the plants to properly uptake water. One way to amend soil with high clay content is by adding composted organic matter (Wagner et al., 2015).

Figure 5

Roof Slant and Garden Shading of the Bullring

Note. Authors' own work.

To help amend the soil, the garden began spreading compost that is provided by a local program in Monteverde, which collects food scraps around the area. Crops within the bullring are turned over depending on what will flourish during the given season as certain crops do not grow well in water-saturated soil such as tomatoes, zucchini, and Swiss chard. The layout of the garden is also intentional in that the plant types are mixed as a form of pest control. Rather than dividing garden sections by plant type, they combine them within the beds such as planting a mixture of lettuce with celery and peppers. There are also many trees and bushes within the garden because their root systems hold and utilize water longer in a way that makes them more resilient to drought and flood.

One of the more difficult problems in maintaining the garden is watering. The garden is currently being supplied with water from the municipality as well as a 2500L water collection tank (see Figure 6) that is used when the garden has not received sufficient rain. Watering the garden is also extremely time-consuming, taking up to 1.5 hours twice a day during the dry season's hot temperatures. However, the dry season only makes up four months of each year, and the other time the garden is at constant risk of being flooded, with no drainage or cover system to help control the water levels. The wet and dry seasons in Monteverde have made it difficult to maintain the garden.

Figure 6

Rainwater Capture System at the Huerta Comunitaria

Note. Authors' own work.

2.3.2 The Impact of Climate in Managing the Garden's Operations

Monteverde has a tropical climate and therefore experiences only two seasons: wet and dry. These two seasons differ most significantly in rainfall amount. The discrepancy in rainfall between these two seasons is why there is often either too much water or not enough. Excessive rainfall during the wet season floods the garden and inhibits the growth of certain crops. The clay soil in the garden further amplifies this problem by limiting the ability for water to drain. Utah State University states that irrigation water penetrates clay slowly (0.0254 to 1.27 cm of water per hour), so water should be applied to the soil surface at a slow rate over a long period or it will run off (Wagner et al., 2015). The Huerta Comunitaria is largely built upon clay, thus, without proper drainage, water sits idle and causes bad germination and diseased plants. During the dry season, the volunteers for the Huerta Comunitaria must water the garden by hand, which takes up valuable time that should be used for other maintenance such as weeding and harvesting.

Over time, local gardeners have adapted their gardening practices to account for Costa Rica's variable climate. The Huerta Comunitaria has adopted some common solutions such as planting in raised garden beds and beginning plant seedling in a small greenhouse to shield them from heavy rains. They have also been alternating the plants that they grow depending on the season, but this means that certain crops, such as lettuce, are unavailable to the schoolchildren for significant portions of the year unless imported from another source. To ensure the garden's year-round success, it is crucial that water management methods are implemented that can help the garden adapt to seasonality and supply a consistent local food source.

2.3.3 Irrigation Practices

Installing a large-scale irrigation system in the community garden would greatly cut down the amount of time that volunteers spend watering plants in the dry season and grant them more time to plant, weed, and harvest. However, irrigation systems appear in many different forms and have different advantages and disadvantages.

2.3.3.1 Sprinkler and Center-Pivot Irrigation Systems

Sprinkler irrigation is one of the most common types of irrigation seen on small farms and in grassy backyards around the world. For the bullring, this could be as simple as a single, rotating sprayer connected to the water source at the center of the garden. But another technique often used by farmers for circular plots is center-pivot irrigation (see Figure 7). The U.S. Geological Survey (USGS) Walter Science School describes center-pivot irrigation as a long arm that rotates about a pivot in the center with a sprayer or dripper system that releases water on top of the plants (Walter Science School, 2018). While sprinkler and center-pivot systems are viable options for many farms, they do not meet the garden's goal of efficient water usage. According to USGS, sprinkler systems can lose up to 35% of the water through evaporation into the air (Walter Science School, 2018). Therefore, more efficient systems, such as drip irrigation, should be investigated.

Figure 7

Center Pivot Irrigation (Water Science School, 2009)

Note. The figure above shows a center pivot irrigation system using sprayers to water crops. From Water Science School licensed under Public Domain.

2.3.3.2 Drip Irrigation

For a garden that is focused on water conservation and sustainable agriculture, drip irrigation would be a reasonable option. Drip irrigation is one of the most efficient irrigation techniques because it loses little water through evaporation. As seen in Figure , water is applied directly to the root zone of plants through emitters or perforated pipes, either on or below the surface of the ground (Walter Science School, 2018). The pipes branch out from a large water source which can be pumped out to the plant beds. Since water is meant to trickle out of the emitters over a long period of time, this type of system can be operated at a lower pressure, whether pumped or gravity-fed. An article from Pennsylvania State University's College of Agricultural Sciences notes that drip irrigation uses water pressures between 8 psi and 20 psi, which is less than half the 45-70 psi required to pump alternative irrigation systems such as sprinklers (Fathel, 2020). This directly translates to lower operating costs because less energy can be used for pumping water into the garden. Compared to high-pressure irrigation systems, drip irrigation can reduce energy costs by as much as 50% and increase water efficiency by up to 40-70%, according to the Natural Resources Conservation Service (NRSC) Irrigation Guide (Fathel, 2020).

Figure 8

Drip Irrigation System (MIT, 2017)

Note. The figure above demonstrates how a drip irrigation system delivers water directly to the root zone of the plant, via a perforated pipe. From Massachusetts Institute of Technology licensed under CC-BY-NC-ND.

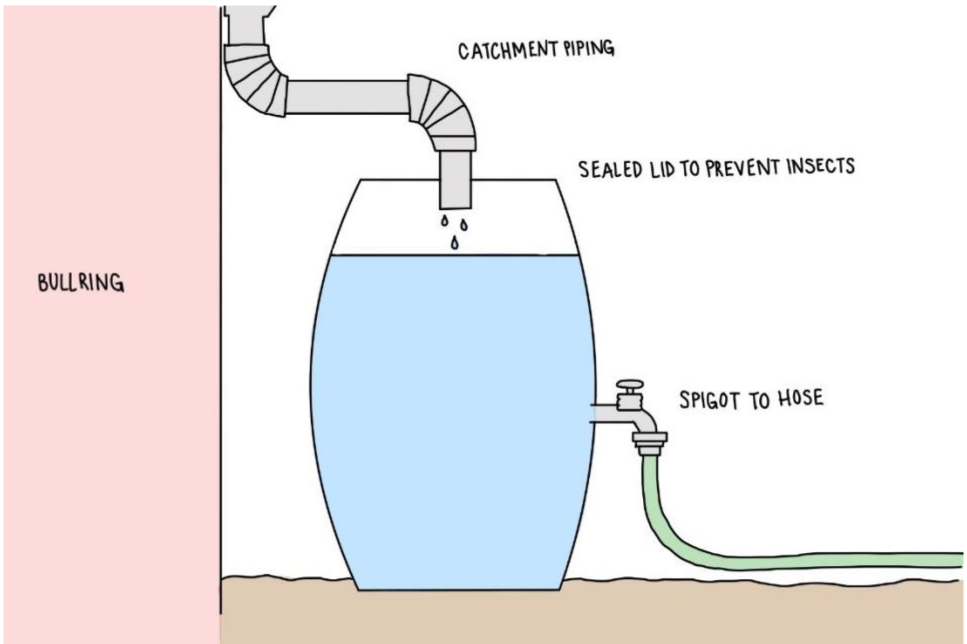
Drip irrigation systems can be simple to implement because they are often sold as inexpensive kits through many local home improvement and gardening stores. They can also be easily constructed by hand using PVC piping. This type of system is more common for rectangular gardens but can also be constructed in a series of concentric circles to cater to the bullring garden's layout. However, drip irrigation faces the issue of clogging due to ground sediment if positioned either underground or directly above the top layer of soil. Potential clogging issues and other maintenance requirements must be considered prior to installation.

2.3.3.3 Rainwater Harvesting

Rainwater harvesting (RWH) is one way to supply irrigation water during the dry season. By capturing and storing rainfall, the garden would be more self-sufficient, as they would not need to rely on town water to support their crops. A typical RWH system consists of three parts: the catchment surface, the conveyance system, and the storage barrel (Abdulla et al., 2021). The catchment surface is the surface on which precipitation lands, such as the bullring's roof. The conveyance system consists of gutters or pipes that transport the water from the catchment surface to a storage barrel where it will be stored, as shown in Figure 9. Currently, the garden has one barrel for water collection which may be modified or supplemented to meet their water requirements.

Figure 9

Rainwater Harvesting System



Note. Authors' own work

Some considerations must be made when building a rain capture system. To prevent possible harmful contaminants, the New Jersey Agricultural Experiment Station recommends cleaning the barrel with a 3% bleach solution before collecting water to irrigate a vegetable garden (Bakacs et al., 2013). Additionally, the storage barrel should be covered to minimize evaporation, mosquito breeding, and algae growth due to sunlight exposure (Abdulla et al., 2021). Inlet pipes should have a screen at the entrance to keep large debris out of the system and minimize clogging. But even then, sediment can build up over time. Thus, it is recommended that a tank be flushed at least once a year to remove all silt accumulation from the previous year (Abdulla et al., 2021). Lastly, keeping the storage barrels at a higher elevation than the garden would allow gravity to aid in water distribution and possibly eliminate the need for a pump.

In addition to providing water for later use, RWH systems also help reduce flooding during big rainstorms. A simulation performed for a residential area in Sicily, Italy, found that supplying 408 single-family houses with a 5 m^3 storage barrel each would have reduced the area's floodwater volume by an average of 71.1% between 2002 and 2008 (Freni, 2019). Utilizing rain capture in the Huerta Comunitaria could be especially beneficial since the bullring's roof is slanted inward toward the garden. Rather than letting the water pour into the garden and flood the crops, a portion of the roof runoff would be intercepted by a catchment system.

The potential volume of rainwater collected from an RWH system can be estimated given the annual rainfall, catchment surface area, and catchment surface material. The formula found in Figure 10 shows how to calculate this volume. For a metal sheet surface, such as the bullring's roof, a runoff coefficient between 0.7 and 0.9 is used to account for water losses in the system (Abdulla et al., 2021). But in a place like Monteverde that receives an excessive amount of rain in the wet season, it is not feasible to store the entire volume of water for several months. It would take up too much space and be far too costly for the community garden. Thus, any barrels used for RWH purposes should have an outlet at the top to divert the overflow when the barrel has reached full capacity. Ideally, the overflow water can be relocated somewhere outside of the garden where it poses fewer issues.

Figure 10

Water Collection Equation

$$\boldsymbol{V} = \boldsymbol{R} \times \boldsymbol{A} \times \boldsymbol{C}$$

V = Volume of water collected (L)

R = Annual rainfall in location (mm/year)

A = Roof surface area (m^2)

C = Runoff coefficient (non-dimensional)

Note. Authors' own work derived from (Abdulla et al., 2021).

2.3.4 Drainage Practices

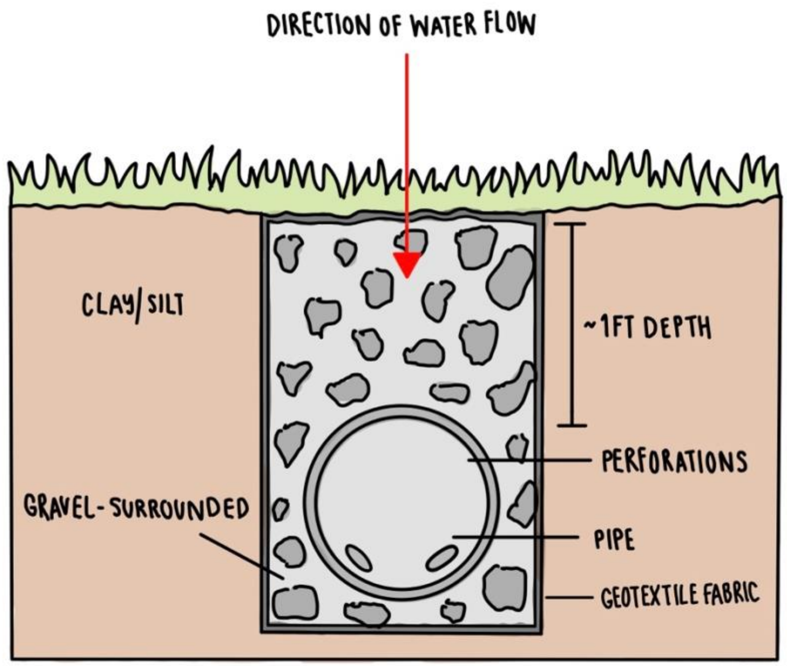
There are several other agricultural practices to prevent flooding in gardens, such as relocating water using French drains to rain gardens, retention ponds, or detention ponds.

2.3.4.1 Use of Trenches and French Drains as Means of Water Relocation

French drains are a form of water drainage systems that help with the relocation of excess water through operations underground. French drains utilize trenches which are filled with gravel and stones and lined with a geotextile fabric with a pipe located at the bottom. The pipe located at the bottom of the trench is perforated, allowing water to seep through but prevents roots and sediment from clogging the pipe (Dale, 2022). This drainage system uses gravity to collect rainwater as it runs down the trench through the gaps in the gravel and stone where it is led into a piping system. This piping system collects the water and directs it away from the plot of land that experiences the flooding. An additional benefit of French drains is its ability to be installed seamlessly into an area without interrupting the previous layout, making it spatially efficient for the relatively small garden. The piping systems may differ from one another, with some of the pipes being perforated and percolating water throughout the soil until it reaches the final location, as shown in Figure 11. While others are solid pipes that direct water out into one location (BDS, 2018).

Figure 11

French Drain System



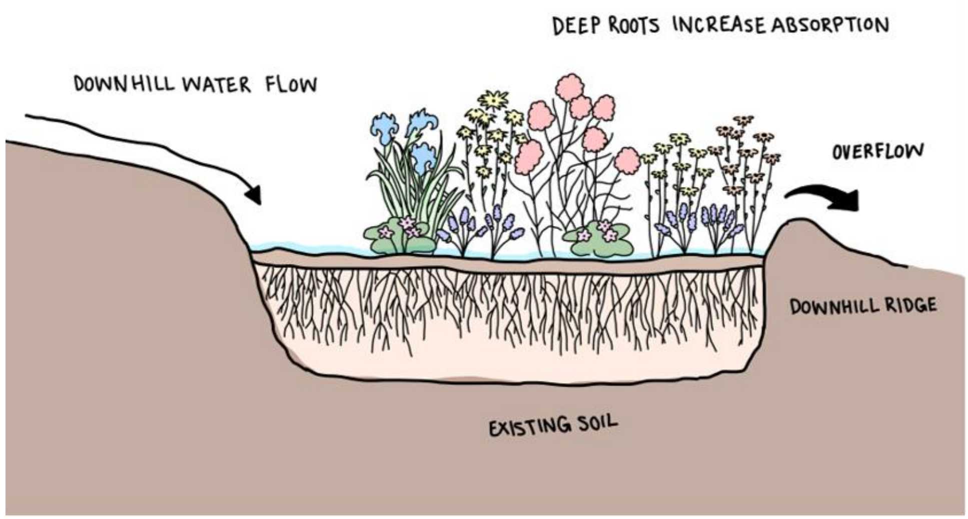
Note. Authors’ own work.

2.3.4.2 Rain Gardens

Implementing rain gardens around areas of high rainfall is another way to decrease flooding. A typical rain garden consists of a plant bed of compost and sand to increase water filtration, and contains shrubs, perennials, and flowers planted on a natural slope to soak up water runoff (Groundwater Foundation, 2022). Figure 12 shows an example of the flow of water through a rain garden. Compared to a typical lawn, rain gardens can soak up to 30% more water into the ground, which could aid in Monteverde's flood management (Groundwater Foundation, 2022). They also drain within 12-48 hours of rainfall, so they prevent water buildup and mosquito breeding (Groundwater Foundation, 2022). Maintenance of these gardens is also quite minimal, especially because they utilize native vegetation. When considering the size of a rain garden, it should be around 20% of the area draining into it. They are typically longer than they are wide and are perpendicular to the land slope to maximize runoff catchment (Groundwater Foundation, 2022). They are also able to be built and installed independently, which makes them a great option for Monteverde.

Figure 12

An Example Rain Garden and How it Functions



Note. Authors' own work.

2.3.4.3 Retention and Detention Basins

Retention and detention basins are methods that utilize natural land layout and minimal materials to aid in stormwater storage and ground percolation. These systems can be arranged to support specific water management situations. Detention basins are designed to temporarily store water runoff and gradually release it through soil percolation and steady drainage. Conversely, retention basins are designed with no outlet source and aim to permanently store water. Both systems are easily constructed and require little maintenance, making them ideal for low-budget preferences (Sustainable Stormwater Management, 2009). As the Huerta Comunitaria seeks an efficient method of diverting excess rainwater away from crops to be drained in a safe and effective manner, and given the unique requirements of the garden, detention basins are a promising option for managing flooding during the wet season in Monteverde.

2.4 Garden Project Sponsors

Our sponsors are the Monteverde Community Garden, or Huerta Comunitaria, and CORCLIMA, which work alongside the Rafael Arguedas H. School. The Huerta Comunitaria program works in conjunction with the Planting Sustainability Program of the Monteverde Institute which provides temporary work in sustainability for unemployed people in the area. CORCLIMA is an organization in Monteverde that aims to unite the community in adopting more carbon negative behavior and serving as a model for climate resilience. The Rafael Arguedas H. School owns the bullring in which the Huerta Comunitaria is housed. It was founded in 1957 as the first school in Cerro Plano. The school currently has 64 enrolled students and is built on the foundation of educating the child as a whole – body, mind, and heart. Their studies consist of building characters and natural inclinations through the enforcement of love, justice, and equality both in school and at home (*Rafael Arguedas Herrera School*, 2019).

Our main point of contact with the Monteverde Community Garden is Paula Vargas, who is actively involved in managing the Huerta Comunitaria. She was born and raised in Monteverde where she attended the Monteverde Friends School (Escuela de Los Amigos) from kindergarten through 12th grade. She continued her education at the University of Costa Rica where she studied architecture and wrote her undergraduate thesis on permaculture to unify her love for architecture and the environment (Paula Vargas and Katy VanDusen, personal communication, November 30, 2022).

Our main point of contact with CORCLIMA is Katy VanDusen. Katy is the coordinator of CORCLIMA. She is a native of the United States who decided to visit in 1990 with no intentions to stay but met her husband and they have remained there together for over 30 years (Class of '79 Newsletter, 2007).

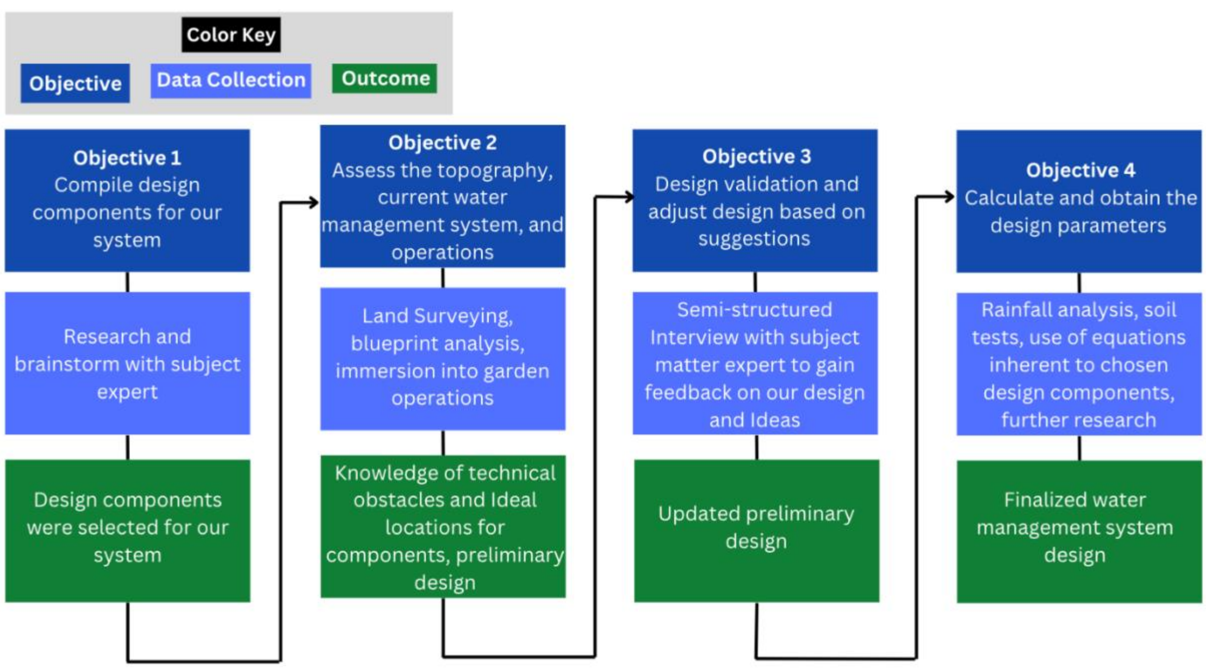
3. Methodology

The goal of this project was to design a water management system to help promote year-round plant growth in the community garden in Monteverde, Costa Rica, to provide food for the local school. As described in Figure 13, we pursued the following objectives:

1. Compile design components for the water management systems.
2. Assess the topography, current water management system, and garden operations based on its operational requirements.
3. Design validation to improve preliminary design.
4. Obtain design parameters to finalize design.

Figure 13

Visual Methodology



Note. Authors' own work.

3.1 Objective 1: Compile Design Components for the Water Management System

Background research was crucial for forming the foundation of our project. Becoming more knowledgeable about many different water management systems allowed our group to explore potential designs. Monteverde, Costa Rica has seasonal weather, influencing our group to think creatively by considering a combination of potential systems that would balance water complications depending on the season. Also, it was crucial to consult a subject matter expert on the specifics of the Huerta Comunitaria because we were not very familiar with the conditions of the garden.

3.1.1 Data Collection

Our team reviewed many water management systems through our research to understand the variety of approaches. One of the systems we researched was water capture systems. The focus was on rain barrel water catchment due to the fact the Huerta Comunitaria already had one in operation. Another system we investigated was different systems of irrigation. We looked at sprinkler systems, center pivot systems, and drip irrigation systems. Furthermore, we explored different drainage systems. We analyzed trenches, French drains, rain gardens, retention basins, and detention basins. The information gathered and assessed was important to improving our understanding and design abilities, due to having a wide range of potential candidates and being able to choose the most efficient and effective system for the Huerta Comunitaria.

3.1.2 Analysis

Upon completion of compiling background information on potential design components for a water management system, we worked directly with our sponsor's subject matter expert, Paula Vargas. Through consultation with Ms. Vargas, we were able to understand how a particular design component might serve the needs and capabilities of the Huerta Comunitaria given its conditions. Using ongoing discussion, we were able to directly explore, in-depth, the systems with capabilities that correlated to the factors at play with the Huerta Comunitaria.

3.1.3 Research Limitations

The main limitation we encountered with this objective was the lack of available information around regional methods of water management systems. We were able to compile multiple methods of water management systems but none of which were Costa Rica specific. Costa Rica has very diverse climates and soil composition which made it difficult to do secondary research on systems that would be best in the Costa Rican environment.

3.2 Objective 2: Assess the Topography, Current Water Management System, and Garden Operations Based on Its Operational Requirements

It was vital to the overall success of our project to carry out an engineering assessment of the land in and around the garden, including measuring the performance of the current water management system, and clarifying garden conditions. This gave us a better understanding of the constraints of our design, as well as clarifying how current solutions were working in day-to-day operations.

3.2.1 Data Collection

Through the analysis of blueprints and 3D models of the bullring, provided by Ms. Vargas of the Huerta Comunitaria, we collected measurements of the structure and land. With this information, we were able to make predictions on how much water would be captured by our water management system. Along with this, we collected the dimensions for available land found within and around the bullring. The land surrounding the bullring is important for the planning of implementing detention basins, one technique under consideration. In total, our dimensions are vital in garden designs, including installing an irrigation system, along with planning the implementation of water management systems, such as detention basins to collect the excess runoff produced during the rainy months.

Additionally, through hands-on immersion we learned firsthand about the maintenance operations of the garden. We contributed to the garden upkeep throughout the research term with weeding, tilling the soil, and planting new crops. As shown in Figure 14, another form of garden maintenance at the site was the extension of the current trench system. This system was installed to combat flooding within the garden but needed to be expanded and better developed to be more successful.

Figure 14

Continuation of the Trench System

Note. Authors' own work.

3.2.2 Analysis

Through land surveying, we mapped out the available land within and surrounding the bullring. This is important because it allowed us to plan the layout of the drip irrigation system, rainwater harvesting system, French drains, trenches, and the detention basins found around the surrounding available land outside the bullring. This was done by working directly with Vargas, an architect, to analyze the blueprints and 3D models of the bullring's structure and available land. Supported by our immersion approach, we were able to focus on the ideal locations for trench digging and the installation of a detention basin by taking into consideration potential future construction on the land by the Cerro Plano School as well as what structures and land are surrounding the property.

3.2.3 Research Limitations

Our work in carrying out this objective encountered a couple of limitations. The first limitation of this objective was regarding the season. We were in Monteverde during the dry season, which didn't allow us to access a full rainy season in full effect. The second limitation was regarding the school calendar of the Cerro Plano School. They were on their two-month vacation and as a result the garden was left aside, meaning it was not operating at full capacity, because it didn't need to provide any food for the school, so our observations were limited.

3.3 Objective 3: Design Validation to Improve Preliminary Water Management System Design

It was vital for the success of our project to hold a validation session with a local subject matter expert in addition to our work with the sponsoring organization, to help confirm that our design will be successful. Although research and iterative design are very beneficial in objective completion, having a design validation session with a local subject matter expert who has experience is highly beneficial to the success of our water management system as they were well positioned to provide a system-level overview in a local context.

3.3.1 Data Collection

We conducted a semi-structured interview with Aníbal Torres of the Monteverde Institute to finalize the design of our group's water management system. Torres is Coordinator of the Sustainable Future Program at the institute and a student of land planning (*Our Team*, n.d.). To prepare for this session, we finalized our preliminary drafts of the designs to be validated during our interview with Torres, and we prepared questions to ask, which can be found in Appendix B.

3.3.2 Analysis

Using interview transcripts, our team categorized the feedback given by Aníbal Torres. We categorized the responses into a code book of multiple categories, shown in Appendix C. Selective coding is the analysis of interview transcripts using a code book that is a shorthand interpretation of information offered by the participant. This was important because we were able to visualize in what ways our designs are successful, in what ways they could be changed, and other aspects we must take into consideration. With Aníbal's knowledge and experience with land planning and sustainable futures, we received valuable feedback to create our final design and start its implementation.

3.3.3 Research Limitations

A limitation we encountered was that our subject matter expert did not aid in the design of every water management system at Monteverde Institute, so he was not able to assist us specifically from experience. Along with this limitation was the breadth of ideas Torres raised being implemented in the short term. The Huerta Comunitaria does not have a budget and works more on donations from community members. Depending on the ideas he brought up, we had to consider what might have been out of scope of the immediate project scope, but also how it might be integrated later.

3.4 Objective 4: Calculate Conditionally Dependent Design Parameters and Obtain Standardized Parameters to Finalize Blueprints

To design the most successful and efficient form of a water management system for the local conditions it is important to obtain comprehensive field measurements. Through various testing procedures of soil and analysis of rainfall data, supported by further secondary research, we were able to compute conditionally dependent measurements and obtain standard measures for the water management system components.

3.4.1 Data Collection

Through various soil and water tests we collected vital information regarding some of the properties found in and around the bullring. The first test conducted was the soil texture test. We followed the procedure shown in **Error! Reference source not found.** to analyze the composition of the soil.

Table 1

Soil Texture Test

Test Locations	• One sample from outside the bull corral • One sample from the center of the bullring • One sample from a raised garden bed
Materials	• Jars or clear containers • Measuring tape or ruler
Method	1. Dig down about 2-5 cm to collect your sample 2. Fill jar about halfway with soil. 3. Fill the jar with water. Equal parts water and soil. 4. Place lid on jar and shake well for a couple of minutes until soil is suspended. 5. Leave the jar on a flat surface and let it sit for at least 24 hours. 6. After 24 hours, measure the levels of sand, silt, and clay using the ruler.

Note. This table explains the process in which the soil texture test was carried out and what was needed to conduct the test. The methods of this test were replicated from (Revival, 2020).

The second test conducted was the soil percolation test, with procedures shown in **Error! Reference source not found.**.

Table 2

Soil Percolation Test

Test Locations	• Outside the bull corral
Materials	• Shovel • Stick • Measuring Tape/Ruler • Marker
Method	1. Dig a hole roughly 1ft by 1ft. 2. Fill the hole with water and let it absorb fully. 3. Place a stick in the bottom of the hole. 4. Fill the hole almost completely with water again. 5. Mark the stick where the initial water level is. 6. Check every hour and mark the water level on the stick. 7. Calculate the water drainage per hour.

Note. This table explains the process in which the soil percolation test was carried out and what was needed to conduct the test. The methods of this test were replicated from (Revival, 2020).

The final tests we conducted were a water pressure test and a water consumption test, with procedures shown in Table 3.

Table 3

Water Pressure and Consumption Test

Test Locations	• Collection tank • Municipality water tap
Materials	• Measuring tape • Flow rate meter
Method	1. Attach flow rate meter to location of water output. 2. Allow water to run for a limited amount of time to measure flow rate. 3. Separately measure pipe diameter and hose diameter using measuring tape. 4. Separately measure water tank height and water output heights using tape measure. 5. Calculate pressure per square inch (psi) via the Bernoulli's equation: $$P_{pipe} = P_{atm} + (h_{tank} - h_{pipe}) g \rho_{water} - \frac{{Vel_{water\ in\ pipe}}^2}{2}$$ $$P_{hose} = P_{atm} - \frac{{Vel_{water\ in\ hose}}^2}{2}$$ Where: P = pressure P_{atm} = atmospheric pressure h_{tank} = height of water in the tank h_{pipe} = height of pipe coming of the tank Vel = velocity g = acceleration due to gravity ρ = density 6. Calculate water consumption during dry season with the following equation: $$WC = FR\left(\frac{L}{min}\right) \cdot WSL\left(\frac{min}{day}\right) \cdot DSL\left(\frac{days}{dry\ season}\right)$$ Where: WC = water consumption FR = flow rate WST = watering session length DSL = dry season length

Note. This table explains the process in which the pressure and water consumption tests were carried out and what was needed to conduct the tests. These methods were self-designed. Bernoulli's equation was adapted from (Cengel & Cimbala, 2018).

Through further background research, we found standard sizing measures for the drip irrigation and French drain pipe components we included in our design (*How to Make a Cheap Do-It-Yourself Drip Irrigation System Using PVC*, 2021; "French Drains 101," 2020).

3.4.2 Analysis

Through multiple soil tests conducted by the group, we were able to identify soil composition and other properties that will impact dimensions on the water management system. The first test we conducted was the soil texture test, with its process in Table 1. This was important to understand the composition of the soil in crucial parts of the bullring, understanding the percentage composition of the soil between sand, silt, and clay. The second test we conducted was the soil drainage test, with its process in Table 2. This test allowed us to understand the drainage rate of the soil in the area where the detention basin would be installed. This information allowed us to finalize the dimensions of our detention basin design. Utilizing a system of equations, we were able to create a relationship between the volume and drainage rate of the percolation test with the volume and drainage rate of the ideal detention basin. This can be seen below in Figure 15.

Figure 15

Equation Used for Drainage Rate of Detention Basin

$$\frac{V_{P.T.}}{V_{D.B.}} = \frac{\Delta_{P.T.}}{\Delta_{D.B.}}$$

$$V_{P.T.} = Volume\ of\ Percolation\ Test\ (m^3)$$

$$V_{D.B.} = Volume\ of\ Detention\ Basin\ (m^3)$$

$$\Delta_{P.T.} = Drainage\ Rate\ of\ Percolation\ Test\ \left(\frac{m^3}{hr}\right)$$

$$\Delta_{D.B.} = Drainage\ Rate\ of\ Detention\ Basin\ \left(\frac{m^3}{hr}\right)$$

Note. Authors' own work.

To help in this decision making we also utilized the rainfall data from the Monteverde Institute. This formed the basis of many of our calculations, including how big the detention basin needed to be to drain the excess water in rainy season, along with how much water would be captured and stored through the catchment system. For rainfall data, we relied on that provided by the Monteverde Institute and shown in Table 4.

Table 4

Monthly Rainfall Data

Monthly Rainfall in Monteverde				
Month	**Rainfall (mm)**			
	2020	**2021**	**2022**	**Average**
Jan	81	122	28	77
Feb	49	34	25	36
Mar	14	48	55	39
Apr	39	208	142	130
May	197	181	424	267
Jun	501	308	739	516
Jul	163	305	231	233
Aug	352	502	396	416
Sep	438	410	782	543
Oct	569	274	283	375
Nov	804	190	399	464
Dec	110	148	34	98
Total	3316	2730	3539	3195
Dry Season Avg./Month	46	103	63	70
Dry Season Total	183	412	251	282
Wet Season Avg./Month	392	290	411	364
Wet Season Total	3133	2318	3289	2913

Note. This table shows rainfall data in Monteverde over the past three years. Authors' own work compiled from (*Reportes Estación Climática*, 2022).

After completing the water pressure and consumption tests (whose processes are seen in Table 3), we were able to calculate the pressure supplied by the water tank and the municipality water line, as well as how much water is used during a watering session and during the whole dry season. The pressure calculations were necessary to ensure that the drip irrigation system would be able to operate with water being supplied by either method, RWH tank or municipality water line. The water consumption calculations were useful in understanding how much water needs to be supplied for a single watering session as well as understanding the impact of the use of RWH tanks.

Combined with the information obtained from the further research on standard sizing for our components, we selected the pipe sizes that would best suit the Huerta Comunitaria. For drip irrigation made with PVC piping, there was one standard size recommended, but the French drain pipe sizing standards included a range that varied depending on the amount of rainfall experienced in the area.

3.4.3 Research Limitations:

With the completion of this objective, we ran into multiple limitations. The tests conducted by our group were all done in the dry season in Monteverde. The results of the drainage test could fluctuate depending on the season and how saturated the soil is with water. Another limitation we ran into is the unpredictability of the rainfall rates. Monteverde is receiving more rain every year but the number of rainy days every year is decreasing. Due to this, making a reasonable prediction based on years prior is difficult. Also, the standardized sizing recommendations of pipes for French drains are not Costa Rica specific, meaning it did not take into the account the amount of rainfall here.

4. Results & Analysis

By identifying and improving our understanding of water management systems and land topography, our team was able to receive comprehensive design validation from subject matter experts and calculate meaningful blueprint parameters for the drainage and irrigation systems at the Huerta Comunitaria. Our findings, obtained from the various forms of data collection in our methodology, allowed us to analyze and design a fitting system for the garden's needs.

4.1 Design Components for the Water Management System

4.1.1 Results

The components for a water management system can be classified into five standard categories, and are dependent on garden characteristics, including excess rain, land layout, and lack of operational funds.

Through the completion of Objective 1, our team gathered and organized a considerable amount of information regarding systems that encapsulate a water management system. We found that a water management system is created through many sub-systems that work together to create stability. Through our background research, we found that these smaller systems can be divided into water collection, irrigation, drainage, transportation, and storage systems as seen in Table 5. Each system plays a vital role in the overall functionality of the water management system.

Table 5

Water Management System Categories

Water Management System Categories	
Water Collection	• Roof rainwater harvesting
Water Irrigation	• Drip irrigation • Center pivot irrigation • Sprinkler irrigation
Water Drainage	• French drain
Water Transportation	• Trench system
Water Storage	• Detention basin • Retention basin • Rain gardens

Note. This shows the categories that encapsulate the water management system and potential sub systems that were considered. Authors' own work.

Additionally, we identified constraining factors about the garden's operation that impacted our system selection because of lack of a budget and operational funding. The garden operates off community donations limiting it from making investment in more expensive operational systems. Another factor found was the shear amount of excess rainfall taken into the garden because of the slanted roof. This leads to there being even more water directed into the garden which needs to be drained out. Finally, the property is frequently visited by children, so the designed system must take that into consideration. Huerta Comunitaria, as it is a project run by CORCLIMA, is focused on being environmentally friendly. This includes being efficient with water consumption and conserving that resource as much as possible.

With our results, these factors taken with each system category led us to select rainwater harvesting for collection, drip irrigation for irrigation, French drains for drainage, trenching systems for transportation, and a detention basin for storage and percolation.

4.1.2 Discussion

The identification of system categories enabled a repeatable decision-making process as we designed our system. Through the understanding of the different factors that impact the community garden we were able to isolate each system, weighing out the possibilities and choose the optimal system. Based on the results in Objective 1, a drip irrigation system was selected as the most realistic method to be implemented into the Huerta Comunitaria due to its efficiency, low start-up costs, and ease of implementation. During dry season, water is scarce and must be used in the most efficient form. Designs such as a center pivot system loses a high percentage of water into the air. Also, the waste of water using a system like center pivot does not support the garden being environmentally friendly.

The Huerta Comunitaria has no regular source of funding, which further solidified the decision of choosing a system as drip irrigation is less expensive to install. With no tangible budget to invest in the garden, most of its garden innovations and investments are made by community members and with the help of donations. The inexpensive cost of drip irrigation systems makes this design a more feasible possibility. While we initially considered a center pivot system due to the shape of the garden, this design was not feasible because of the inefficiency of the system. Center pivot systems are commonly implemented in large scale farms where a large surface area is watered at a single time and allows for ease of use where most of it is controlled through a monitor system. The Huerta Comunitaria is relatively small compared to the large-scale farms that use center pivot systems. Ultimately, the center pivot irrigation system was not recommended for the Huerta Comunitaria project due to the relative efficiency of the system, startup costs, and garden layout.

In considering drainage systems, our dedicated expert, Paula Vargas, recommended a network of multiple systems that could work together in mitigating the excess amount of water taken into the garden. During our research, we determined that detention basins were a very appealing form of water storage, because they work to capture, store, and percolate water into the surrounding soil in short periods of time. If water could be redirected to a detention pond, this would assist in the rainy season by preventing garden flooding, providing stability in the production of crops. The use of trench systems and French drains provided the means of conveyance of excess water away from the garden, along with storing water when the detention basin is at capacity.

Vargas discouraged the use of retention basins and rain gardens because both systems focus solely on the capture and storage of excess water; Retention basins do not promote soil percolation and rain gardens have very slow percolation. Since retention basins do not allow for percolation, they must be larger than a detention basin for the same area. As the property is subject to young children visiting, a smaller basin would be a safer option.

4.2 Topography, Current Water Management System, and Garden Operations

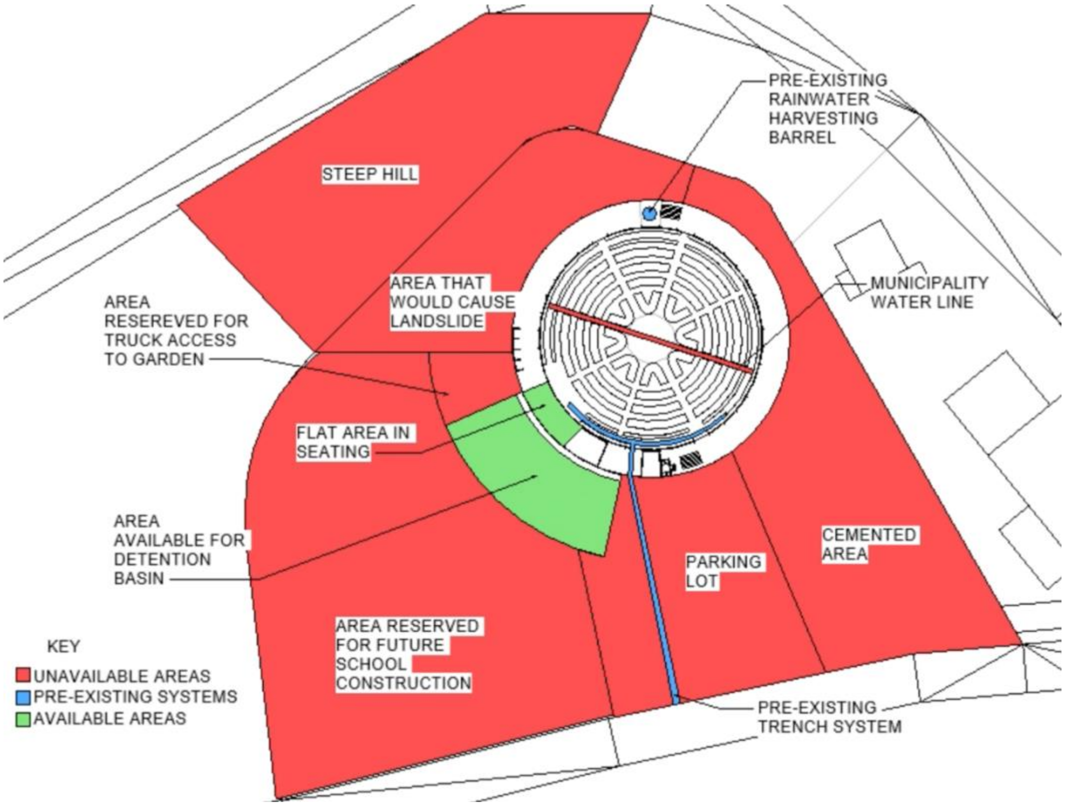
4.2.1 Results

The main flooding areas, garden layout, bullring structure, future construction plans, and surrounding land conditions and usage constrain the location of preferred design components.

By assessing the topography of the garden as well as the current water management system and garden operations, we were able to separate the property into zones, seen in Figure 16, that would help us better understand the ideal locations for our systems.

Figure 16

Land Availability of Bullring Property



Note: This figure will be used to discuss the available locations to implement the design components we selected. Authors' own work modeled over blueprints provided by Paula Vargas.

Additionally, upon assessing the garden's operations and needs, the order of importance of the systems became apparent. Because there is no garden operation to address the flooding in the garden, the need for a drainage system was found to be most prominent over the irrigation system as the volunteers can manually supply water to the beds. The order for the drainage system is as follows: trench system, detention basin, and then French drains. The order for the irrigation system is as follows: drip irrigation and then rainwater harvesting barrels.

4.2.2 Discussion

When planning the ideal locations of the drainage system components, there were several constraints to consider. The parking lot layout, future school construction area, the area reserved for truck access to the garden for compost deliveries, and the area that could cause landslides because of the steep hill behind the bullring (shown in red in Figure 16) all contributed to the location considerations for the detention basin, suggesting that the area where the bull corral currently is would be the most ideal location (shown in green in Figure 16). The previous implementation of a partial trench system that ran around a portion of the perimeter of the garden and out to the street (shown in blue in Figure 16) also influenced the layout of additional trenches, which will allow excess water to relocate to the detention basin. The fact that the garden center experiences the heaviest floods, the layout of walking paths between plant beds that lead outward to the perimeter, and the municipality waterline (shown in red in Figure 16) influenced the French drain placement, which will allow for the water to be drained into the trench system.

The pre-existing location of the rainwater harvesting barrel (shown in blue in Figure 16) and bullring structure with a flat area in the seating (shown in green in Figure 16) guided the placement of two additional rainwater harvesting barrels. To make the rainwater supply equally distributed throughout the garden, the barrels should be placed as equidistant as possible. Water source location also influenced arrangement of the irrigation mains.

The garden beds are arranged in concentric circles with walking paths separating them into sectors. The location of the drip irrigation piping cannot obstruct the walking paths, but the system needs to provide water to each bed.

As the system will be comprised of components that can operate alone but provide the greatest overall impact when they work together, all components do not have to be installed at once and have an order of importance based on the garden's needs. The trench system would be first because by itself, it is able to hold water for some time, and it is needed to transport the water to the storage system, the detention basin. This is why the detention basin follows. The French drains are last in the drainage system because they are additional help in draining the garden, mainly the center, but they are not crucial because there are not crops growing in the middle, therefore flooding there does not pose a large threat to crop production. The order for the irrigation system was found because the drip irrigation system does not have to be run by rainwater harvesting barrels and can be run by other water supplies. Therefore, rainwater harvesting is the least important. It is not crucial to the garden but will help to utilize rainwater and decrease the use of the municipal water.

4.3 Design Validation Session

4.3.1 Results

Clogging prevention and the need for the implementation of plants in the detention basin for a more effective drainage rate and aesthetics were identified as key constraints for the design.

After gathering consent and carrying out a roughly 30-minute interview with Aníbal Torres, we were able to discover possible flaws or things we were missing in our preliminary design. During the design validation session, we presented our designs and data to which Torres offered constructive criticism, ideas, and possible problems, as shown in Table 6. This was done by recording the interview and taking notes during it, then utilizing the table to organize what Torres had to say.

Table 6

Selective Coding Table for Design Validation Session with Aníbal Torres

Approved	• Detention basin design • Drip irrigation system • Piping materials
Improvements	• Rain gardens are not good for large volumes of water • Attaching a filter to prevent large sediment from clogging pipe system • Prevent basin and trench sediment from caving in by adding a liner
Further Considerations	• How will pipe pressure be controlled • How deep and wide the detention basin will be due to safety concerns • Trench distance from the building • Potential of multiple small basins rather than one large one • Putting water-loving plants to improve water absorption such as heliconia, spiral ginger, and ferns

Note. This table demonstrates the selective coding of the interview with Anibal Torres of the Monteverde Institute, in a design validation consolation of our preliminary designs. Authors' own work.

4.3.2 Discussion

Through the design validation session with Aníbal Torres, the irrigation and drainage designs were properly adjusted to address concerns and validated. Torres brought up a potential issue concerning how deep and wide the detention basin should be due to addressed safety concerns, including the risk of having an open body of water near an area heavily populated by young children. Due to this concern, the detention basin design was designed to only hold a few weeks of rain instead of the whole year.

An additional concern of our initial design was clogging prevention. Sediment such as leaves, rocks, and other large organic matter can easily clog irrigation and drainage piping. A solution to this problem was proposed during the interview addressed in Table 6, suggesting that we implement mesh filters to piping for easy cleanup and minimizing obstruction.

At the Monteverde Institute, the detention basins present contain multiple water-loving plants throughout to improve water absorption into the soil. Torres recommended including species such as heliconia, spiral ginger, and ferns in our final design to allow for optimal soil percolation and water filtration as well as improved aesthetics.

4.4 Standardized and Calculated Design Parameters

4.4.1 Results

Various testing approaches were required to confirm garden soil compositions and construction calculations required to move forward with a sound design.

Through a variety of tests, we determined the soil makeup, infiltration rates, water pressure, and water consumption at the garden which provided us with the necessary variables to move forward with construction calculations.

To assess the composition of the garden space soil, we conducted composition testing by obtaining dirt samples from three different areas: the bull corral, garden center, and garden bed. After completing this 36-hour test, we were able to measure the percentages of sand, silt, and clay in each area as seen in Table 7. To further explore the drainage capabilities, we administered additional testing in our areas of interest.

Table 7

Soil Composition of the Huerta Comunitaria

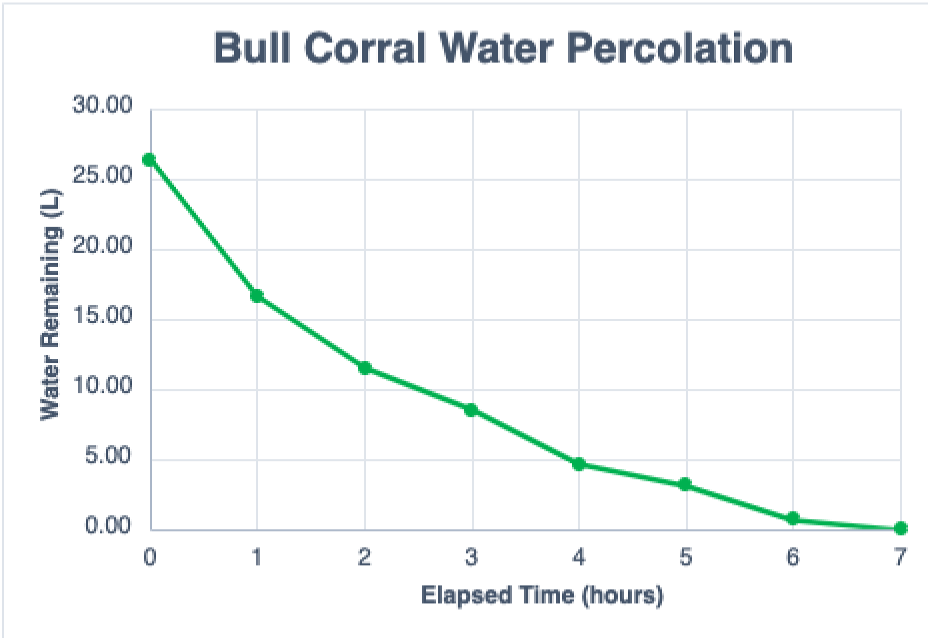
	Sand	Silt	Clay
Garden Center	58%	39%	3%
Bull Corral	0%	0%	100%
Garden Bed	50%	33%	17%
Ideal for Growing	40%	40%	20%
Ideal for Drainage	100%	0%	0%

Note. This shows the optimal soil composition for planting and drainage compared to the Huerta Comunitaria. Authors' own work with information from (Revival, 2020).

Another assessment we conducted was the percolation test to determine the infiltration, or percolation, rate of the bull coral. As shown in Figure 17, the percolation rate slows down as the soil becomes more saturated, creating exponential decay. We began our test with 26 L of water inside of the hole that we dug with the dimensions of 52 cm in diameter and 21 cm deep, with calculations shown in Appendix D. After seven hours of allowing the water to percolate into the soil, checking the level every hour, there was no water remaining in the test site. The ideal soil composition for water drainage is 100% sand, shown in Table 7, however the soil composition was 100% clay in the bull coral, as proven by the soil composition test. The average percolation rate was found to be 3.76 $\frac{L}{hr}$ (see Appendix D).

Figure 17

Soil Percolation Test Data

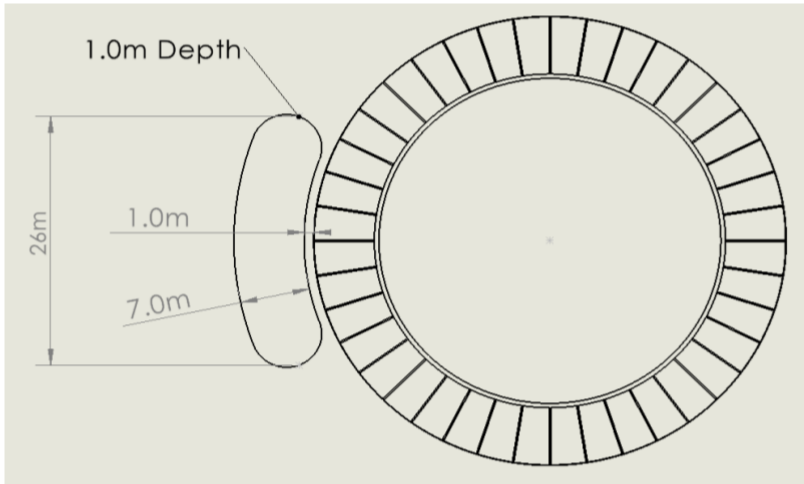


Note. This shows the soil percolation rates at the desired detention basin build site. Authors' own work.

To ensure the detention basin and trench system would be able to retain a week's worth of rainfall in the rainy season, we calculated the detention basin size through volume calculations of both systems (see Appendix E). The sizing of the basin can be seen in Figure 18. Using the percolation test calculations, we were also able to create a relationship using systems of equations as seen in Appendix E to estimate the drainage rate of the detention basin. This estimated drainage rate was found to be about 25.7 $\frac{m^3}{hr}$.

Figure 18

Detention Basin Size Representation



Note. This diagram shows, side-by-side with the bullring, the size of the detention basin used for storage volume and drainage calculations. Authors' own work.

To fully understand the impact of the rainwater harvesting barrels, we conducted a water consumption test and calculations. As seen in Appendix F, the amount of water used per day in the dry season was found to be 1116 L and the number of days for which the three RWH barrels could supply water without being refilled would be about 6.7 days.

To ensure that our drip irrigation design moves water efficiently throughout the garden, we conducted a pressure test and water flow test using a flow rate meter. We found these variables by taking the water consumption as noted on the water meter, as well as taking measurements and dimensions of the pipes, hoses, and height of the water tank and utilizing Bernoulli's equation and a self-designed equation, respectively. The pressure from the water tank was found to be 15.8 psi and the pressure from the municipality water hose was found to be 14.8 psi (see Appendix G).

Through further background research, we were able to find the standardized pipe sizing for PVC drip irrigation and French drains. A ¾ in diameter PVC piping is standard for drip irrigation and a 4–8-in diameter is standard for French Drain ("French Drains 101," 2020; *How to Make a Cheap Do-It-Yourself Drip Irrigation System Using PVC*, 2021).

4.4.2 Discussion

The bull coral area is not ideal for a detention basin, but due to land constraints such as upcoming construction on the garden land by the local school and safety considerations, we were limited in the building area. With the estimated drainage rate of the detention basin, through Appendix E, we can assume that due to storage size of the basin and percolation rates this system will prove to be effective during the rainy season with excess rainfall. Through the water consumption test, we observed that the RWH barrels would be enough to supply water for just under a week of watering in the dry season. At first glance, this might seem insufficient, but that accounts for no rainfall happening in those days. Also, to be able to use the rainwater that would otherwise be runoff helps to save and use the Earth's resources of water more efficiently. By using the pressure calculations performed in this objective and looking at the required water pressure for drip irrigation, 8 to 20 psi, we found that the water supplies that were in place supplied sufficient water pressure and therefore a pump would not be needed (Fathel, 2020). By looking into standard pipe sizing, we determined the necessary materials to effectively irrigate the garden is ¾ in diameter PVC piping. Due to Monteverde's heavy annual rainfall, we decided to select the higher end of the average diameters for French drains, 8 in, to account for excess water.

5. Recommendations

After completing our methodology and analyzing our results, our team was able to generate four recommendations for our sponsors to consider when building the water management system.

5.1 Implement the Selected Design Components in Best Order

During our design process, our team was able to select the design components for the water management system as well as develop an order of implementation. We recommend that Huerta Comunitaria implements the following subsystems for their respective categories in the following order: transport, trenches; storage, detention basin; drainage, French drains; irrigation, drip irrigation; and collection, rainwater harvesting (see Table 8). As it is not feasible to implement all these components at once because of cost and lack of efficiency, it is important to have an order in which they should be implemented.

Table 8

Water Management System Categories in Order of Implementation

Water Management System Categories	
1. Water Transportation	• Trench system
2. Water Storage	• Detention basin
3. Water Drainage	• French drain
4. Water Irrigation	• Drip irrigation
5. Water Collection	• Roof rainwater harvesting

Note. This shows the categories that constitute the water management system and the sub-systems that were chosen arranged in the recommended order of implementation. Authors' own work.

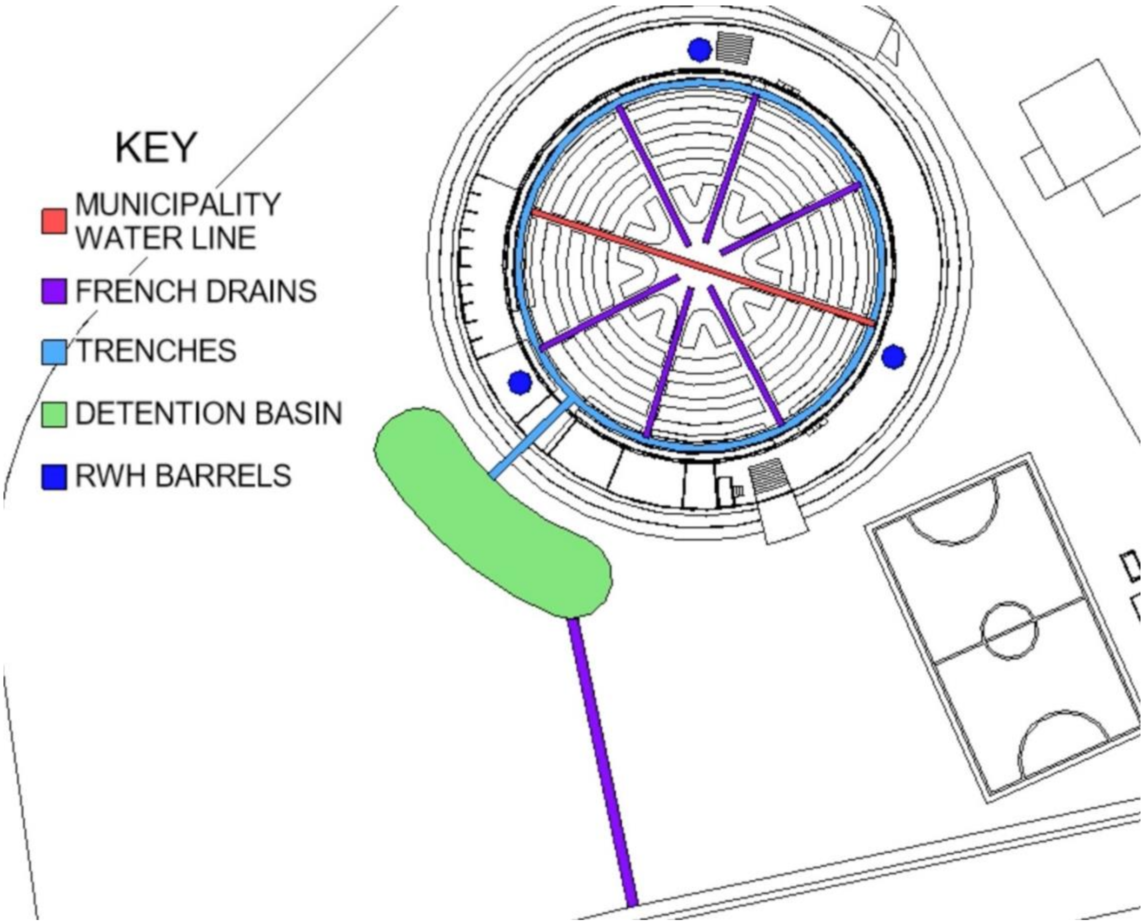
For collection, it is reasonable to continue with the use of rainwater harvesting because it is already in place, and it utilizes the rain that would otherwise runoff. For irrigation, drip is the most water efficient, cheapest, and easiest to implement. For drainage, French drains are the best option because they are spatially efficient and would not interrupt the location of the beds or walking paths. For transport, it is feasible to use trenches because they were already installed in the garden and the continuation of the current trenches would be simple and affordable. For storage, the use of a detention basin is logical since it will have a percolation rate that is better than the other options, making it more spatially efficient.

5.2 Build the Systems in the Recommended Locations

We recommend that the drainage system be built as it is laid out in Figure 19. The French drains will evacuate the excess water that puddles in the middle of the garden to the trench system on the outer rim of the garden. In addition to relocating this water, it will transfer the water that naturally flows into the trenches to the detention basin. The detention basin will hold the water and slowly percolate it into the soil. The French drain leading to the street from the detention basin will manage the overflow from the basin when there are severe storms.

Figure 19

Recommended Design Component Locations for Drainage System



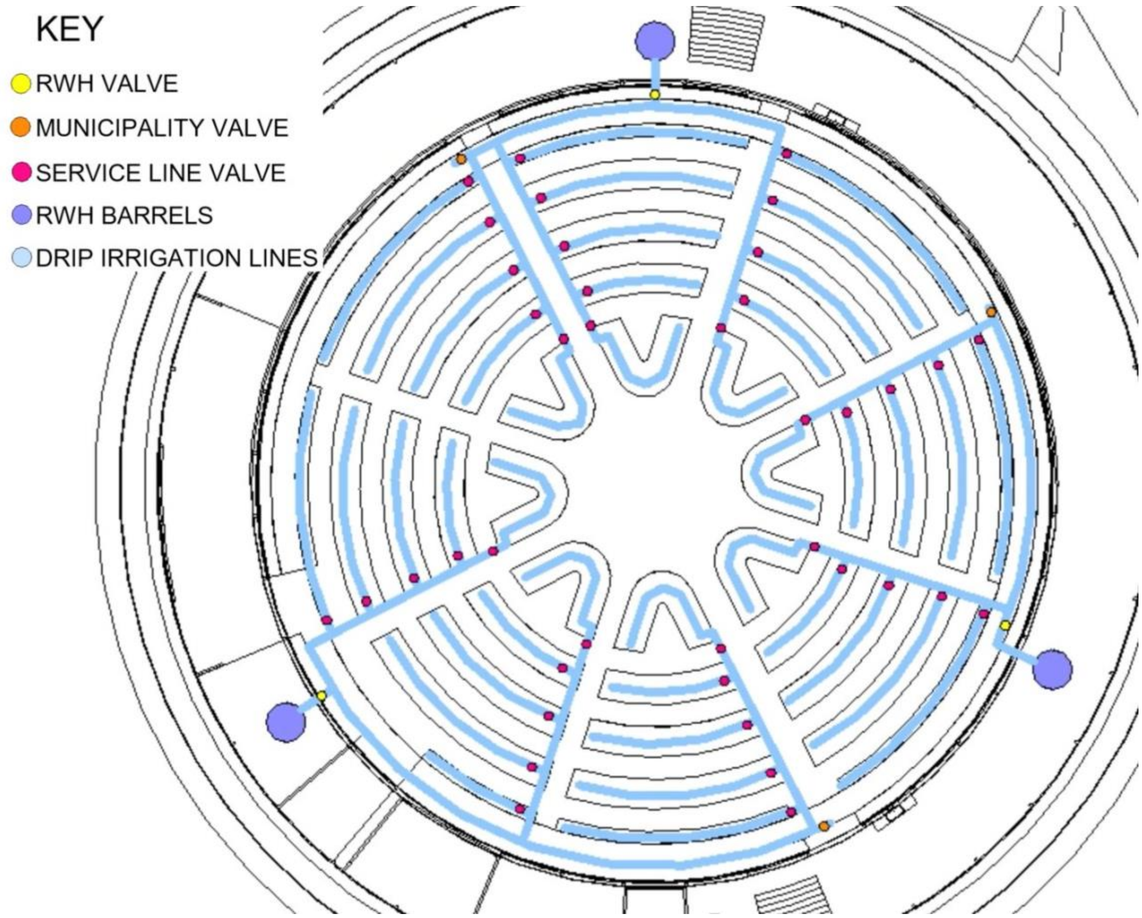
Note. Authors' own work overlaid on the blueprints from Paula Vargas.

Based on our findings, we designed the irrigation system to be built as laid out in Figure 20. The three rainwater harvesting barrels supply water for multiple sections of garden beds via water mains that run along each walking path and service lines running to each bed. The water mains can also be fed by a hose that is connected to the municipality's water supply located in the center of the garden. The placement of valves is at the connection points of the drip irrigation mains to the RWH barrels and the hose to allow for switching between water supplies when the

RWH barrels are empty. The service lines each have their own valve to control the water supply to each bed.

Figure 20

Recommended Design Component Locations for Irrigation System



Note. Authors' own work overlaid on the blueprints from Paula Vargas.

5.3 Perform Regular System Maintenance

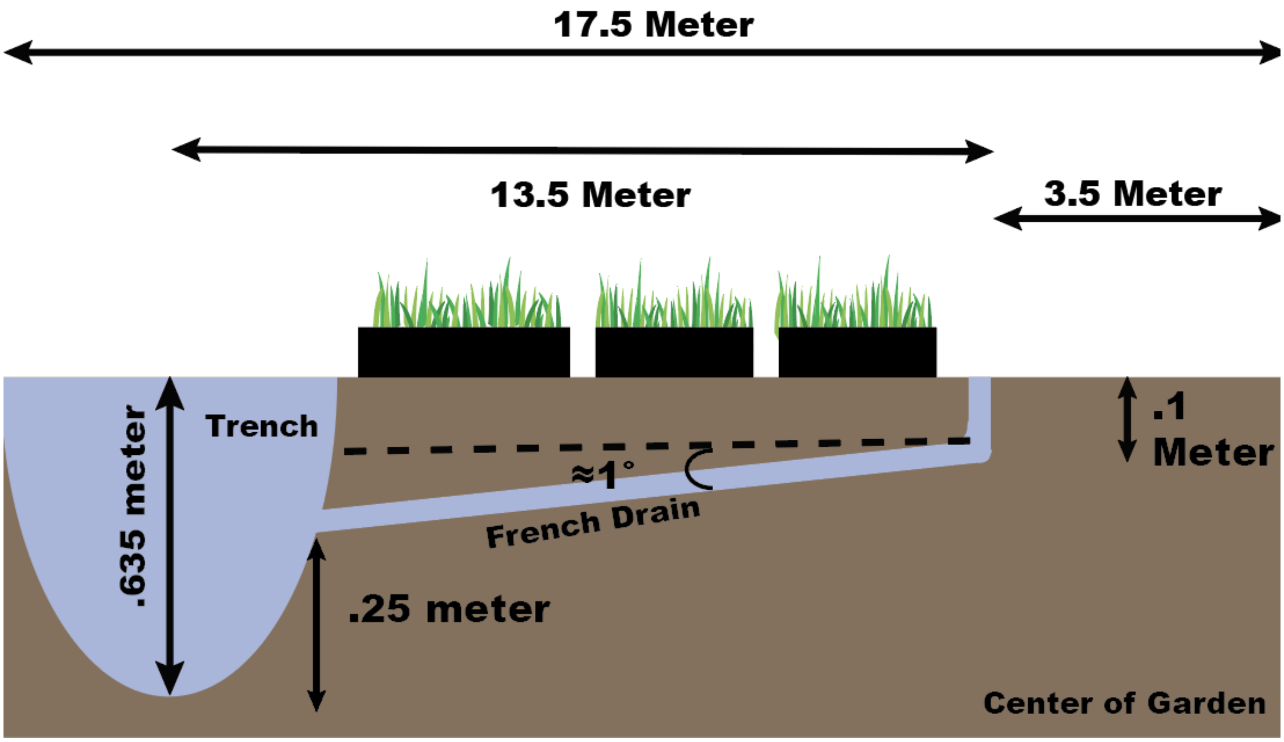
Seasonal maintenance is recommended to include clogging prevention for the rainwater harvesting system and French drains as well as include plants in the detention basin. By installing mesh on the gutters of the roof, it will prevent large debris, such as leaves, from entering the RWH barrel and blocking water flow. The installation of filters at the bottom of the downspout into the barrel and at the spigot out of the barrel will aid in removing smaller debris, such as dirt, to prevent clogging of the drip irrigation lines. Fine mesh should be placed on the inlets and outlets of the French drains to prevent clogging by large debris and the entrance of animals. The planting of heliconia, spiral ginger, and ferns in the detention basin will aid in water drainage, as the plants will uptake some of the water and add to the visual appeal of the basin.

5.4 Adhere to Calculated and Obtained Parameters for Best Production Results

We recommend the water management system be built according to the following parameters to create adequate systems that can manage the rainy season precipitation. The PVC piping should be ¾ in (1.905 cm) in diameter, and the pipes for the French drains should be 8 in (20.32 cm) in diameter according to the standardized sizing. The French drains should be installed at 3.5 m away from the center of the garden. The system should include a filter cap at the entrance of the pipe to prevent sediment from entering the pipe. The pipe will run 0.1 m down before entering a 13.5 m pipe that is down at about a 1° angle of depression as shown in Figure 21 to allow for the water to flow from the center of the garden outward to the trenches. Our calculations for the detention basin yielded a storage volume that would manage the rainfall experienced in the Huerta Comunitaria. The detention basin should reach 1 m in depth, span 7 m in width, maintain a gap of 1 m between the bullring exterior and the start of the basin, and extend to an angle of 55° from the garden center around the perimeter. With these dimensions, the detention basin will hold about 178 m^3 of rainfall assuming no percolation occurs. Also, to manage overflow from the detention basin, the outlet pipe that leads to the road should begin at a depth of 0.2 m.

Figure 21

Recommended French Drain Installation



Note. Authors' own work.

6. Conclusion

The COVID-19 pandemic led to serious food insecurity throughout the world and especially impacted areas whose economies relied heavily on tourism. Amidst the pandemic, the people of Monteverde, Costa Rica, banded together and started a community garden to address the rise in food insecurity in their community. Once the issue of food insecurity improved in Monteverde, the garden shifted its focus to supplying food for the local school. Yet the seasonal rainfall in Monteverde has posed challenges for the maintenance, operations, and production of the Huerta Comunitaria.

Heavy rain during the wet season in Monteverde causes flooding which prevents crops from flourishing, and the lack of rain in the dry season demands a significant time investment in watering the garden. This problem drove the need for an effective water management system in the garden for it to be most efficient in producing regular food for the school. Through the culmination of background research, subject matter expert consultations, topography assessments, soil analysis, water-usage testing, and calculations, our team was able to design a water management system for the Huerta Comunitaria. In the process of creating our design, we documented a more generalized approach for managing the identification and implementation of the subsystems, that allowed us to approach the project in a modular way and ultimately allowed us to provide a more flexible design. The full implementation of this system will allow for more consistent plant growth year-round and decreased maintenance by reducing the impacts of the area's variable rainfall.

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Appendix A

Interview Preamble

English Version:

We are students from Worcester Polytechnic Institute. We are working alongside CORCLIMA to research and design a sustainable water management system for a local community garden. We will be collaborating with the Cerro Plano Public School and CORCLIMA and are conducting interviews with local farmers to understand more about the topic of farming practices in Monteverde and conducting interviews with families involved with the garden to analyze how they have benefited from the project. Participation in the interview is voluntary, and you may withdraw at any moment. The interview will take approximately 15 minutes. Do you agree to partake in the interview? If so, may we record the interview for data collection purposes? Lastly, may we quote what is said in this interview for future publication and data collection purposes?

Spanish Version:

Nosotros somos estudiantes de Worcester Polytechnic Institute. Estamos trabajando junto con CORCLIMA para investigar y diseñar un sistema de gestión sostenible del agua para una huerta comunitaria local. Estaremos colaborando con la Escuela de Cerro Plano y CORCLIMA y estaremos realizando entrevistas con agricultores locales para entender más sobre el tema de las prácticas agrícolas en Monteverde y realizando entrevistas con las familias involucradas en el jardín para analizar cómo han beneficiado del proyecto. La participación en la entrevista es voluntaria y puede retirarse en cualquier momento. La entrevista tendrá aproximadamente 15 minutos. ¿Está de acuerdo en participar en la entrevista? ¿En caso afirmativo, podemos grabar la entrevista con fines de recopilación de datos? ¿Por último, podemos citar lo que se dice en esta entrevista para fines de publicación futura y recopilación de datos?

Appendix B

Subject Matter Expert Design Validation Session Questions

English:

We are students from Worcester Polytechnic Institute. We are working alongside CORCLIMA to research and design a sustainable water management system for the local community garden. We would like to talk to you about the water management system here and to run our preliminary design idea by you and see what your thoughts and feedback are on the designs. Participation in this interview is voluntary, and you may withdraw at any moment. The interview will take approximately 30 minutes. Do you agree to partake in the interview? If so, may we record the interview and take pictures and videos of the water management systems for data collection purposes? Lastly, may we quote what is said in this interview for future publication and data collection purposes?

Below are questions that our group would like to ask. Questions will flow in order of relevance and what is brought up.

Drainage:

- What components do you have in your water management system?
- What has worked well with your system?
- What would you change?
- How did you figure out the size of the detention basin?
    - Did you do a calculation for the detention basin size? What were they like
- Do you use French drains?

- How do you prevent clogging with them?
- Do you use geotextile fabric?
- What kind of piping do you use for French drains?
- Where did you buy them? How much for a certain amount?

Irrigation:

- How did you figure out the sizing for the drip irrigation system?
    - How do you prevent clogging with drip irrigation system?

Feedback:

- What are some things in the design that you think would work well?
- What are some flaws in the design?
    - What are some ways we could change that to make it work?
- What are some things we must consider in the implementation of this design?
- What do you think would be best to deal with the overflow from the detention basin?
    - We were thinking French drain or a pipe to run to the street
- What kind of pipping work best in Costa Rican water management systems:
    - For irrigation purposes
    - For drainage purposes
    - For percolation purposes

Spanish:

Nosotros somos estudiantes del Worcester Polytechnic Institute. Estamos trabajando junto con CORCLIMA para investigar y diseñar un sistema de gestión de agua sostenible para el jardín comunitario local. Nos gustaría hablar con usted sobre el sistema de gestión de agua aquí y presentarle nuestra idea de diseño preliminar y ver sus pensamientos y comentarios sobre los diseños. La participación en esta entrevista es voluntaria y puede retirarse en cualquier momento. La entrevista tomará aproximadamente 30 minutos. ¿Está de acuerdo en participar en la entrevista? Si es así, ¿podemos grabar la entrevista y sacar fotos y videos del sistema de gestión de agua con fines de recopilación de datos? Por último, ¿podemos citar lo que se dice en esta entrevista para su futura publicación y recopilación de datos?

Abajo se presentan preguntas que nuestro grupo quiere hacer. Las preguntas fluirán en orden de relevancia y lo que se mencione.

Drenaje:

- ¿Qué componentes tiene en su sistema de gestión de agua?
- ¿Qué ha funcionado bien con su sistema?
- ¿Qué cambiarías?
- ¿Cómo determinó el tamaño de la cuenca de detención?
    - ¿Realizó un cálculo para el tamaño de la cuenca de detención? ¿Cómo eran?
- ¿Usas drenes franceses?
    - ¿Cómo evitas el obstrucciona miento con ellos?
    - ¿Usas telas geotextiles?
    - ¿Qué tipo de tuberías usas para los drenes franceses?
    - ¿Dónde los compraste?
    - ¿Cuánto por cierta cantidad?

Riego de Agua:

- ¿Cómo determinó el tamaño del sistema de goteo?

        - ¿Cómo evitas el atasco con el sistema de riego por goteo?

Comentario:

- ¿Qué cosas en el diseño crees que funcionarían bien?
- ¿Cuáles son algunos defectos en el diseño?
    - Si sí, ¿cuáles son algunas formas en que podríamos cambiar eso para que funcione?
- ¿Qué cosas debemos considerar en la implementación de este diseño?
- ¿Qué tipo de tuberías funcionan mejor en los sistemas de gestión de agua de Costa Rica?
    - Para fines de riego
    - Para fines de drenaje
    - Para fines de percolación

Appendix C

Selective Coding Table for Design Validation Sessions

Approved	
Improvements	
Further Considerations	

Appendix D

Percolation Calculations

Bull Corral Water Percolation				
Water Level (cm)	**Depth Change (cm)**	**Volume Left (L)**	**Volume Lost (L)**	**Elapsed Time (hrs)**
21.0	0	26.32	0.00	0
16.0	5	16.62	9.70	1
13.0	3	11.50	5.12	2
11.0	2	8.49	3.01	3
8.0	3	4.69	3.80	4
6.5	1.5	3.16	1.53	5
3.0	3.5	0.71	2.46	6
0.0	3	0.00	0.71	7

$$\textit{Average Percolation Rate} = 3.76\ L/hr$$

Water Volume Equation:

$$V = \frac{\pi h^2(3R - h)}{3}$$

$V = \textit{volume of water remaining}\ (L)$

$h = \textit{water depth}\ (cm)$

$R = \textit{hole radius} = 26\ cm$

("Spherical Cap Volume Formula," 2022)

Appendix E

Detention Basin Calculations

Detention Basin Calculations			
Volume of Percolation Test (m^3)	**Drainage rate of Percolation Test ($\frac{L}{hr}$)**	**Volume of Detention Basin (m^3)**	**Drainage Rate of Detention Basin ($\frac{m^3}{hr}$)**
0.026	3.76	178	25.72

Rainfall Volumes - Trench & Detention Basin Volumes	
Volume of Detention Basin (m^3)	178
Volume of Trenching System (m^3)	29
Total Storage Volume (m^3)	207
Average Rainy Season Weekly Rain Fall (mm)	102.75
Collection Area (m^2)	1578
Volume of Collected Rain (m^3)	162.1395
Volume of Storage (m^3)	207
Remaining Space (m^3)	44.8605

Appendix F

Water Consumption Calculations

These calculations were done by unit conversion.

$$Total\ Water\ Used\ in\ Dry\ Season = \frac{Flow\ Rate}{Time\ Spent\ Watering\ per\ Day} * \frac{Days}{Dry\ Season}$$

$$Number\ of\ Days\ Supplied\ by\ Barrels = \frac{Volume\ of\ water\ held\ in\ tanks}{Volume\ of\ water\ needed\ per\ day}$$

Water Required for Dry Season			
Hose Flow Rate (L/min)	**Daily Water** (L/day)	**Total Water** (L)	**Number of Days Supplied by Barrels** (days)
12.4	1116	124992	6.72

Appendix G

Water Pressure Calculations

Calculation of Velocity for Use in Bernoulli's Equation for Water Tank

$$Velocity = \frac{Flow\ Rate}{Area}$$

(Cengel & Cimbala, 2018)

Flow Rate (m^3/s)	**Pipe Cross Sectional Area** (m^2)	**Velocity** (m/s)
0.00022667	0.000446003	0.508225063

Measurements for Use in Bernoulli's Equation for Water Tank

Tank Water Height (m)	**Pipe Height** (m)	**Atmospheric Pressure** (Pa)
2.855	2.16	101800

Atmospheric pressure from (*Monte Verde, Puntarenas, Costa Rica Current Weather | AccuWeather*, 2023).

Results of Bernoulli's Equation for Water Tank

Pressure from Water Tank (Pa)	**Pressure from Water Tank** (psi)
108597.367	15.8

Calculation of Velocity for Use in Bernoulli's Equation for Water Tank

Flow Rate (m^3/s)	**Pipe Cross Sectional Area** (m^2)	**Velocity** (m/s)
0.00022667	0.000446003	0.508225063

Results of Bernoulli's Equation for Municipality Water

Pressure of Municipality Water (Pa)	**Pressure of Municipality Water** (psi)
101799.8892	14.8