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Permaculture Design to Address Coffee Leaf Rust and Climate Change on a Panamanian Coffee Farm

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Abstract

Coffee is an important crop to both producers and consumers. Unfortunately, the current epidemic of the *Hemileia vastatrix* or Coffee Leaf Rust, has been devastating coffee farms throughout Latin America. A highly argued explanation for the recent outbreak of the disease has been placed on the transition of coffee farms from traditional shaded systems to sun-grown monocultures, allowing for faster and easier spread of the disease. Climate Change also encourages increased incidence of pests and diseases while stressing the growing conditions for coffee. Farmers, for a myriad of economic and ecological reasons, have practiced alternative methods for coffee management systems such as, shade grown, organic, bird-friendly, and fair trade management. Permaculture is another alternative practice that promotes holistic agricultural systems that are ecologically regenerative, economically viable, and socially just. This thesis project uses permaculture theory and practice to redesign a coffee management system for a 1.5 ha plot located in Palmira, Boquete, Panama. The goals of the final design are to mitigate and contain the effects of coffee leaf rust. Strategies incorporated in the design include, an increase of shade trees and vegetative windbreaks; intercropping systems; vermicompost; the addition of a hostel; water and soil management technologies and understanding; and the use of farmer input.

Key Words: Coffee, Permaculture, *Hemileia vastatrix,* Ecologically-Regenerative, Shade-Grown, Coffee Management System, Climate Change Adaptation

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Introduction

Coffee is the second most important export commodity in the world following petroleum (Albertin, 2004). Unfortunately, coffee farms stretching from Brazil to Mexico are being abandoned by farmers due to the devastating effects of *Hemileia vastatrix* or Coffee Leaf Rust (Vandermeer, 2014a;Vandermeer, 2014b; Avelino, 2004; Samnegard, 2014; Martinati, 2008; Lopez, 2013). The main cause of this outbreak is due to shifts in coffee management systems that occurred in the decade 1970 to 1980. In line with the Green Revolution, the U.S. Agency for International Development encouraged and supported coffee farmers in transitioning from traditional shade grown management systems to sun grown monocultures in hopes of increasing yield (Global Exchange, 2011).

Due to the ecology of the leaf rust fungus, sun-grown monocultures have beomce a haven for the spread of this species (Avelino, 2004; Samnegard, 2014). The shade trees that once acted as a barrier to this wind-spread fungus were removed and replaced by high yielding varieties grown closely together, allowing for the rust to spread quickly from tree to tree and farm to farm. Current agrochemical methods to prevent and mitigate this disease have been insufficient and are known to have harmful environmental effects (Martinati, 2008). Additionally, it is difficult to replant shade trees once the rust has reached the region because the trees create a humid environment that encourages the rust further by providing it with its optimal growing conditions. As a result, this limits the option of shade grown coffee to be used as a management technique (Avelino, 2004; Samnegard, 2014).

Climate change is another threat to coffee associated with pest/disease. *Coffea arabica* is very sensitive to climate change due to its perennial nature (Coffee/Climate, 2015; Rahn). Currently, coffee relies on regular rainfall for berry production and a dry season for harvesting and drying. Unfortunately, climate change is altering these conditions drastically, increasing temperatures, wind, storms, and irregular rainfall throughout the year. The initiative for coffee & climate defines these events as *climate hazards.* They explain that these climate hazards cause *climate impacts,* which include stress to flowers, fruits, and an increased incidence of pest and disease (Coffee/Climate, 2015).

With devastated coffee farms come devastated farmer livelihoods. Small-scale farmers produce 70% of the world's coffee and rely on its income for survival (Toledo, 2012). Not only do these farmers rely on the income coffee production brings, but they often have a deep connection with the land itself. Many coffee farms are family owned, allowing farming knowledge to be passed down through generations (Blank, 2008). The retailer, roaster, and consumer also feel the economic stress of coffee production. A decrease in production due to unproductive, devastated crops will increase prices dramatically, possibly changing the entire coffee culture and international trade of this commodity crop. Environmentally, sun-grown monocultures have negative effects such as loss of wildlife habitat, decrease in biodiversity, pollution from chemical fertilizers and pesticides, and more (Global Exchange, 2011).

Current alternative models such as shade grown, bird-friendly, organic, agroforestry, and fair trade are some of the most prominent and alterative methods of coffee growing (Eakin, 2006). However, many of these methods of production have faults, mainly in that they do not work together to include each other's mission statements and goals (Global Exhange, 2011). Permaculture is an alternative practice that promotes holistic systems that are ecologically regenerative, economically viable, and socially just. Unfortunately, Permaculture design application in coffee systems is lacking. In response to this, this thesis project goes beyond a final permaculture design for a coffee farm, and also acts as a guide for other coffee farmers to implement their own permaculture designs.

This thesis project follows the theoretical and ethical framework of Permaculture to design a coffee management system that defends against coffee leaf rust and climate change in a systematic, precise, and economically beneficial. The design was created for a 1.5 ha plot in Palmira, Boquete, Panama owned by Maria Ruiz. Maria Ruiz currently shares ownership of the family run farm, Casa Ruiz, with her brother. After helping me with an independent research project I conducted while I was studying abroad, I asked her to partake in this thesis project. She agreed to the task and was the lead contact throughout this project.

During the first week of March 2015, the site analysis of the plot occurred on the site after an initial orientation meeting with Maria. It was evident through the site analysis that leaf rust was present on farm as well as additional challenges related to soil, water, wind, and vegetative management challenges. Once the site analysis was complete, a first draft of the design was created back in the United States with help from the site analysis and specific practices studied from the literature. The first draft was sent back to the farmer to allow for the farmer’s critique and input. A revised draft of the design, which is the final product of the thesis, was created after strong consideration of the issues present on farm and with the incorporation of the farmer’s critique. Lastly, the finalized design was sent back to the farmer for review and potential implementation.

Literature Review

This literature review is a comprehensive report on coffee ecology, coffee leaf rust, shade grown coffee, and permaculture design. The review is separated into these four sections with each section further divided into sub-sections. It begins with a review of coffee as a commodity crop, briefly describing its ecology, history, the industry, the coffee crisis, and its specific role in Panama. This is followed by a review of the coffee leaf rust epidemic and a review of permaculture design, with sections on the theory, ethical and design principles, and design process. Lastly, the review discusses shade-grown management, providing an overview of the practice, how it is used as a conservation tool, and the benefits and challenges of the practice for the farmer.

Overview of Coffee

Figure 1: Depicts the worldwide region in which coffee is grown (Ciperski,2012) has been omitted in this online version. The full version is available only in the UVM Environmental Program office.

Coffee Ecology

There are two main coffee varieties that are grown, Robusta and Arabica (ICO, 2014). Robusta can be grown at sea level while Arabica needs to be grown at higher altitudes. *Coffea Arabica* is grown in the high-elevated tropics of the "coffee belt" which is located 23.5 degrees Celsius north and south the equator. This tropical belt provides coffee with its optimal conditions, those being 1200-1700m in elevation, 17-23 degrees Celsius mean temperature, and 1500 to 2800mm average rainfall per year (Albertin, 2004). The coffee tree takes between three to four years until it starts producing fruit and will continue to produce for 50-60 years. The fruit or berry is harvested when it reaches a deep red color, which indicates its maturity. After processing, the two beans within the cherry are removed from the cherry, then dried, stored, and shipped to a roaster to be roasted, ground, and brewed for a cup of coffee (ICO, 2014).

Coffee History

Ethiopia is the origin country of coffee. From Ethiopia, coffee was introduced to Arabian countries in the 15^{th} century, to the Dutch in 1616 who brought it to Europe in 1615, North America in 1668, and Indonesia in 1699 (NCA). The Dutch brought the actual coffee seed to Central America in 1718, beginning one of the most important commodity crops of the region. There is also a famous legend surrounding the discovery of the bean. It is said that one day a shepherd boy in Ethiopia noticed that his goats had more energy than usual. The next day he followed his goats to the bush they were eating and tried one of the bright red cherries. Like his goats, he was became filled with energy and immediately ran back to tell his village about the discovery of the coffee tree (NCA).

The Coffee Industry

After petroleum, coffee is the largest export commodity in the world (Albertin, 2004). According to data from 2012, the top three producers in the coffee industry are Brazil, Vietnam, and Indonesia (Statistica, 2014). The world's top five consumers from 2006 data are, the USA, Germany, Japan, Italy, and France (Wikia, 2006). As mentioned above, the two main coffee varieties are *Coffea arabica* and *Coffea canephora* also know as *Robusta*. *Coffea arabica* makes up 70% of the world's production and has varieties that are sold as specialty coffees. *Robusta* makes up 30% of the world's production and contributes to bulk coffees such as Folgers (Coffee Research Institute, 2006). More than

70% of coffee is produced by small-scale farmers who rely on its income for survival (Toledo, 2012). Due to the high dependence these small-scale farmers have on coffee, any fluctuation in price has drastic livelihood effects on the farmer and his/her family.

During the coffee crisis of 1999-2002 coffee prices dropped almost in half, with historic lows recorded in the year 2001 (Albertin, 2004; Bacon, 2008; Eakin, 2006). The crisis was caused by the fall of the International Coffee Association (ICA), which led to unregulated markets and unequal market power distribution. In addition, there was a devastating frost in Brazil and increases in the quality of the higher yielding coffee variety, *Robusta.* Drastic measures were taken to adapt to this change in market prices and to adapt to the power shift that became focused in the hands of a few multinational producers. Actions by small-scale farmers included abandonment of farms, migration, diversification of crops, Organic/Shade Grown/Fair Trade practices to raise the value of their crops, and increasing land devoted to coffee production (Eakin, 2006).

Panamanian Coffee

Panamanian coffee, the most important agricultural product of the Panamanian highlands, is grown in the Western part of the country near the border of Costa Rica (SCAP Panama, 2014). Panama's highlands are created by the Cordillera de Talamanca mountain range, which extends from Eastern Costa Rica to Western Panama. These highlands provide the perfect conditions in regards to average rainfall, altitude, moisture, and cloud cover for rare and unique varieties of coffee. The town of Boquete, Chiriqui, Panama, is where a majority of Panama's coffee farms exist. Due to the fertile soils, the overall culture of this small community is very much devoted to coffee farming. Farming is not only a part of their economic viability but also family and community connection and involvement.

As mentioned above, Panama is home to prime growing conditions, which results in the growth and production of special coffee varieties. What makes these varieties "special" is their unique, full-body flavors that a farmer can only achieve from growing high quality coffee beans in their optimal conditions. Alerted by the low coffee prices in 1996, Panamanian farmers have taken advantage of this opportunity and entered the specialty coffee world (SCAP Panama, 2014). Though most of their specialty coffee is exported to the US, Europe, and Japan and in total exports only 250,000 quintales (one quintal equals 46 Kg) annually, Panama is home to some of the best quality coffees in the world (Blank, 2008).

Boquete is known for its century old tradition of coffee production (SCAP Panama, 2014). The coffee varieties used on these farms are Geisha, Typica, Bourbon, Caturra, and Catuai. These varieties are difficult in that, in order for the beans to achieve their greatest tastes, aromas, and overall quality they have to be grown at exactly the right conditions. A good example of this is done by Boquete's world-renowned farm, Hacienda La Esmeralda. The farmer of Hacienda La Esmeralda's grows the unique geisha coffee variety. The climatic and nutrient requirements of this variety are so specific that many farmers have failed to grow to its fullest potential. However, one of Hacienda la Esmeralda's farm plots had just the right conditions and as a result won first place in the Specialty Coffee Association of America Roasters Guild Cupping Pavilion for its Esmeralda Special Geisha three years in a row from 2005 to 2007 (SCAP Panama, 2014; Hacienda La Esmeralda, 2011).

Unfortunately and in correspondence to the rest of Central American coffee growing countries, coffee management systems have been largely converted from traditional shade grown systems to full sun monocultures (Global Exchange, 2011). This shift occurred during the 1970s – 1980s and was largely due to the Green Revolution. The overall goal of this shift was to increase yields. The U.S. Agency for International Development had $80 million dollars that they used to aid farmers during the transition period (Global Exchange, 2011). As a result, many farms in Panama are partially shaded to full sun monoculture crops. With this transition and the spread of leaf rust throughout Central America, there are cases of leaf rust within Boquete farms, some worse then others (Temple, 2013; Josephs, 2013). Along with the spread of the leaf rust disease, climate change is affecting this highland region of Panama. Researchers predict higher winds, increased incidence of pest and disease, increase temperatures and storm severity, and irregular rainfall patterns (CoffeeClimate, 2015). These changes will drastically affect coffee physiology and the management of this crop.

Leaf Rust Disease

Brief History

Currently, one of the most devastating pests to *Coffea arabica* is the fungal disease named coffee leaf rust or la roya or *Hemileia vastatrix* (Vandermeer, 2014a; Vandermeer, 2014b; Avelino, 2004; Samnegard, 2014; Martinati, 2008; Lopez, 2013). The first disease outbreak occurred in Ceylon (now Sri Lanka) during 1868. A fast spreading disease, it was found across the island within 5 years and continued to make its way to southern India and Java. Due to the severity of this disease, coffee farming within these areas was abandoned. More recently, an outbreak was recorded in 1966 in Angola. From here it was dispersed across seas to Bahia, Brazil. Understanding the nature of this pest, warning of its ability to quickly spread was given the northern countries of Latin America. Unfortunately, these warnings were dismissed and the disease hit Latin America with full force (Vandermeer, 2014a, Vandermeer, 2014b).

The drivers of this disease are a mystery to scientific researchers and farmers across the world (Vandermeer, 2014a). However, as mentioned the effects of this epidemic are well felt amongst past and present farmers. Presently, coffee farmers from Colombia to Mexico are experiencing massive infestation and as a result, big losses inyield. Recorded yield losses from the Latin American region alone were 25% in the year 2013 (Vandermeer, 2014a). From Mexico to Peru farmers experienced 40-50% reduction yield (Vandermeer, 2014b; Martinati, 2008).

Basic characteristics

Hemileia vastatrix is a fungal disease that attaches to the underside of coffee leaves. When leaf rust infects a coffee tree it causes defoliation, death of branches, and ultimately death of the tree (Lopes, 2014). These powdery yellow-orange spores are easily transported by wind, human clothes, and/or touch from one leaf to another (Avelino, 2004; Samnegard, 2014). Variables that effect leaf rust are wind, rainfall, leaf area, leaf wetness, light, temperature, fruit-load, soil moisture, and stomatal density (Avelino, 2004). To provide a few examples of how these variables influence the rust, Avelino (2014), goes into further detail. For example, wind provides transport of spores from leaf to leaf, rainfall distributes spores through splash dispersal, temperature (22 degrees C) allows for spore germination, and similar to other fungi it prefers shade and humidity. (Avelino, 2004). Other researchers have emphasized humidity as a positive variable for the rust. It gains such attention due to the use of shade trees in crop management and the idea that with more shade trees there is a greater occurrence of fungus (Avelino, 2004; Samnegard, 2014).

Effects of Shifts in Crop Management Systems

Though the immediate drivers of this disease are unknown, some scientists hypothesize that the rapid spread of disease through Latin America is attributed to changes in management techniques (Samnegard, 2014;Vandermeer, 2014a; Vandermeer, 2014b). *Coffea arabica* is originally an understory crop, grown under many layers of canopy (Cerdan, 2012). However, recent interest in producing higher yields has emphasized a transition to high yielding varieties that are grown under full sun. The loss of shade trees for protection against spore dispersal and as a host for natural enemies is thought to have aided the fungus in its advance through the coffee farms of the northern regions (Samnegard, 2014; Vandermeer, 2014a; Vandermeer, 2014b).

Current Methods for Disease Control

In compliance with modernized crop management systems, the current conventional way to handle coffee leaf rust is by using a fungicide spray on the coffee leaves (Vandermeer, 2104a; Martinati, 2008). Martinati (2008) expresses the concerns regarding the use of fungicides, claiming that there are possible harmful environmental effects and the potential for resistant strains. Another researcher suggests that spraying fungicides results in killing natural fungal enemies such as *L. lecanii* (Vandermeer, 2104a). Contrastingly, some authorities such as the USDA (United States Department of Agriculture) argue that a fungal epidemic should be, "vanquished with pesticides, not stewarded by environmentalists" (Vandermeer, 2104a). This argument stems from the other proposed options of how to deal with this devastating crop such as silicon and triadimenol treatments, microclimate monitoring, and managing semi-forested coffee systems (Avelino, 2004; Martinati, 2008; Lopez, 2013; Samnegard, 2014).

Due to the recent spread of the coffee leaf rust epidemic, scientific research on alternative methods to defeat this disease are just being discovered. Some of these methods include silicon and triadimenol treatments, microclimate monitoring, and semi-forest management systems (Avelino, 2004; Martinati, 2008; Lopez, 2013; Samnegard, 2014). Silicon acts as an enhancer of the host plant's defense mechanisms. The silicon sends the plant signals, which results in induced resistance that is faster and more extensive (Martinati, 2008). Triadimenol is impactful when considering yield. In Martinati's study, there was a 117% increase in yield for plants that were treated with triadimenol (2008). Microclimate management is an effective mechanism due to the influence that abiotic factors such as, rainfall and leaf area have on the survival of leaf rust (Avelino, 2004). The idea behind semi-forested coffee systems is that this method takes into account the humidity caused by too much shade but also the ability for shade trees to act as wind breaks, breaks in the coffee canopy, and habitat for natural enemies (Samnegard, 2014).

Design Focus: Incorporation of Shade Trees and Coffee Leaf Rust

Overview of Practice

Management practices used in coffee production vary amongst farmers. These practices range from full shade to full sun. On one end of the scale is the *rustic* model, which entails 71-100% shade coverage. The other end of the spectrum includes full sun monoculture, which entails 0% shade coverage beyond the coffee plants themselves (Toledo, 2014). Both practices are in use. However, recent management shifts during the 1970's and 80's have led toward intensive full-sun monocultures with high-yielding crop varieties (Philpott, 2012; Borkhataria, 2012). These management changes are occurring mostly in larger scale coffee production systems in countries like Brazil and Vietnam, the top two leading producers in the coffee industry (Bacon, 2008; Jha, S.et. al, 2014). Alternatively, many smallholders and micro-producers continue to use shaded systems. With an increase in smallholders and micro-producers since the 1999 crisis, it is safe to say that shade-grown coffee is still a relatively abundant practice even though it is done at smaller scales (Jha, S. et al, 2014).

Shade as a Conservation Tool

Shaded coffee systems are viewed by scientists as conservation tools due to their ability to foster and maintain biodiversity of flora and fauna species (Borkhataria, 2012; Philpott, 2012; Jha, S. et al, 2014; Perfecto et al, 1996). Coffee's growing region, located within the tropical belt, places it in one of Earth's greatest biodiversity *hotspots* (Jha, S. et al, 2014; Toledo, 2012). Unfortunately, this tropical environment, which is home to a majority of the world's species, is under serious threat due to increased deforestation rates (Jha, S. et al, 2014; Perfecto et al, 1996; Philpott, 2012). Shaded coffee farms are viewed by scientists as biological pathways connecting forest fragments and degraded or deforested landscapes with semi-forested animal and plant refuges (Jha, S. et al, 2014).

Benefits to farmers

In addition to the role shade-grown coffee plays in the maintenance of biodiversity, this system provides many ecosystem services such as nutrient-rich food, clean water, timber for shelter, clean air, carbon sequestration, income diversification, pest management, shade-grown certifications, and more that humans depend on for survival (Albertin, 2004; Cerdan, 2012; Jha, S. et al, 2014). Much attention has been given to the effects of shaded farms on bird species abundance, richness, and diversity. Most of the results conclude that migratory and local bird abundance and richness increase in shaded systems versus cut or sun grown (Philpott, 2012; Borkhataria, 2012;Perfecto, 1996; Cerdan, 2012, Jha, 2014). Additionally, arthropods, bees, bats, amphibians, and small mammals have greater abundance and richness in shaded systems (Philpott, 2012; Perfecto, 1996, Samnegard, U., et al., 2014). The presence of such life translates to biologically controlled pest management for farmers.

Challenges

Though these benefits do increase farmer livelihoods, there are challenges to maintaining shaded systems. Many farmers believe that shaded systems will decrease yields, increase maintenance via pruning, and increase humidity, which increases incidence of crop devastating fungal diseases such as, the coffee leaf rust (Samnegard, 2014; Martinati, 2008). There are studies that have contradicted this idea that shade produces less yield arguing that shade is not directly responsible for yield and that shade can have a greater effect on quality of beans (Jha, 2014). As for an increased incidence of fungal disease due to increased humidity, other methods such as windbreaks and biological sprays can be used in combination with shade trees in order to, decrease the impact of humidity. Regarding an increase in maintenance, the prunings can be sold as firewood or used by the workers, which make up for the added work.

Permaculture Design

Definition, Vision, and Theory

Permaculture is slowly becoming more recognizable to the public eye despite its deep roots in Australian aboriginal culture (Morris, 2014). First defined in-depth by Bill Mollison and David Holmgren in the 1970's, permaculture is, "an integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man" (Holmgren, 2002). More modern definitions expand on the design piece defining permaculture as, "consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre, and energy for provision of local needs" (Holmgren, 2002). Dave Jacke (1999), includes the social and economic side of permaculture defining the term as, "the conscious design and co-creative evolution of agriculturally productive ecosystems and, cooperative and just social and economic systems that have the diversity, stability and, resilience of "nature."

Ben Falk (2013), highlights the ecological piece describing the term as, "any system in which the whole function of each part is fully realized."

Permaculture provides a solution-based framework and philosophical model that a culture can follow so that the people reorganize their lives to provide the essentials for human life while adhering to and respecting ecological limits (Holmgren, 2013; Morris, 2014). The term Permaculture stands as a combination of "permanent culture" and "permanent agriculture" (Holmgren, 2002; Jacke, 1999). The combination of culture and agriculture is due in part because it is impossible to sustain human beings without managing a sustainable food system (Jacke, 1999). Many who believe and follow Permaculture do so because they recognize the responsibility people have to the resources they depend on (Morris, 2014). Permaculture allows those to take responsibility for their lives by redesigning and reorganizing their ways of living and playing so that they maintain the potential for life of future generations (Jacke, 1999). As a result they transition from acting solely as dependent consumers to productive citizens that maintain mutualistic relationships with each other and the environment (Holmgren, 2002).

Lastly, permaculture is becoming a worldwide movement that consists of networks of rich and poor individuals and groups (Holmgren, 2002). These networks currently create Permaculture designs that are small in scale resulting in small and localized change. Much of the reason behind why Permaculture is mostly a grassroots movement is due to, the lack of interest and attention from large-scale government and business (Holmgren, 2002).

Ethics and design principles

Permaculture is a holistic approach that creates socioeconomic structures and belief systems that support sustainable uses of resources and appropriate technologies as well as, the engagement and enlightenment of human beings (Jacke, 1999). Ecologically speaking, Permaculture encourages maintenance of biodiversity, healthy ecosystems, and the reduction of mechanical energy and off-site inputs. Most importantly it aims to design agricultural systems that allow and better enable the ecosystem to perform its own functions (Falk, 2013). Design principles created by Mollison, act as a guideline for Permaculture-based design systems. These principles allow us to look at a landscape in a holistic way. There are many principles and many different versions adapted by permaculturalists. However, some of the main and most consistent principles defined by Morris (2014), Mollison (1998), and Falk (2013) are paraphrased below;

Relative location*:* Design *elements* or the physical things you are using such as, a tomato, a herb, a chicken, a garden, etc., are appropriately placed in areas that make the most sense for their function. For example, if someone wants to grow herbs for culinary purposes, the herb garden is planted by the kitchen for easy access.

Multiple functions*:* Every element that is added to the design must attribute to more then one desired result. For example, a chicken provides eggs, meat, controls pests, fertilizes land, and provides entertainment. By having chickens one will be yielding more then one product and function.

Redundancy: This principle refers to having many back up systems for one function. For example, when one is looking to provide water to his/her home he/she can have many different kinds of water catchment mechanisms. Water can be gathered from a well, spring pumps, rain water barrels off the side of the house, ponds, roof cisterns, etc. If a homeowner has more than one of these systems then he/she is guaranteed a water source at almost all times.

Zones of Use: Zones of Use represent the pieces of the land that are most often visited and attended to, to those that are rarely ever visited and require little attention. The zones can range from 0-5 with 0 being most often interacted with and 5 being the area that is least interacted with. Zone 0 generally entails the home, zone 1 could be the herb garden just outside the door, zone 2 is the garden of veggies that requires frequent attention, zone 3 could be the pumpkin patch that doesn't need as much attention, zone 4 could be the pasture used for grazing horses, and zone 5 could be the wild and unmanaged forest at the edge of the yard. The purpose of these zones is to allow the designer to make sense of the choices he/she has to make and appropriately place his/her designs so that they can adhere to the other design principles.

Attitudal Principles: This refers to the power of the "mental frame" or an individual's mindset toward the system and how this affects the overall success of the design's functions and elements. Famous lines such as, "The problem is the solution" and

“The only limits to the system is the lack of imagination and knowledge” are often referred to when thinking about this principle.

Cycling of energy*:* Refers to moving things in entropy. A lot of work when managing a farm comes from the actual physical labor of planting, harvesting, maintenance of crops, transporting vegetables and tools, and other farm hand tasks. This principle emphasizes the act of moving things around a farm in the most passive way possible, by always questioning what element you’re moving, why you are moving it, and if there is a way to reduce the need to move it.

Nutrient resources*:* This principle refers to building up nutrients in soils to increase soil fertility through the application of organic matter (dead plant material). It also teaches one to take advantage of certain plants that supply nutrients. For example, planting beans next to corn provides the corn with a good source of nitrogen because beans are a leguminous species that capture nitrogen and make it accessible to neighboring plants.

Small-scale intensive systems*:* This principle refers to how the overall production of vegetables or livestock is done. Permaculture emphasizes using less land to get the same amount of yield if not more in comparison to growing food in large-scale monocultures. This does not mean that 300 heads of cattle will be crammed into one barn but rather that by following the other design principles such as multiple function and relative location, the design will organize its elements and functions in ways that allows for less land.

Beyond the design principles are the ethical principles that make Permaculture so unique as a food system model. Permaculture’s holistic approach means that it looks at food systems and our culture as interacting parts of a whole. As a result, it considers ethical issues as the center of the human crisis (Holmgren, 2002). To address this, Permaculture promotes and follows three different ethical statements those being, “Earth Care,” “People Care,” “Fair share.” With these ethical considerations in mind, Permaculture designs are ultimately ecologically regenerative, economically viable, and socially just (Morris, 2014; Holmgren 2002).

These ethics translate to a design that accounts for and includes gathering areas or individual spaces such as meditative spots, tree circles with seating, etc. These spaces help the individual achieve mental clarity and positive social interaction, which isn't always achieved when designing for just the production of food. This ethic is also a place where workers rights are addressed. In addition to "people care" is "Fair Share", where all people are treated equally and the food that is produced is distributed to as many people it can feed and without discrimination. "Earth Care" emphasizes the need for the people involved to become stewards of the land. The design aims to take care of the Earth and its resources versus the exploitation and degradation of them. Therefore, the design has to account for the maintenance and regeneration of the ecosystem functions of the land being used. Permaculture design not only eliminates harm to the landscape but makes it better then it was before.

Design Process

Design is described as a hands-on way to bring an individual's vision into the real world (Morris, 2014). The design piece of Permaculture is the part where an individual can bring to life these visions of say a community where people interact with each other and the environment. Keeping in mind the design principles mentioned above, there are three parts to the actual design process. The goals articulation piece is important and unique to Permaculture in the sense that the goals are written in an active voice (Morris, 20140. The designer is to write down his/her goals with present tense action words such as "I build" or "I create." This is to avoid goals that are vague or unachievable. Phrases like, "I will do this" or "I am going to build," often lead to a misunderstood, unrealistic, or a romanticized idea of the task at hand.

The second portion of the design process is performing site analysis on the area the designer is working in. Permaculture's approach requires many different aspects of analysis that go beyond the base map. These include zones of use, climate, land forms, water, legal issues, access and circulation, vegetation/wildlife, microclimate, buildings/infrastructure, soil and even aesthetics/experience of place (Morris, 2014; Mollison, 1998; Holmgren 2002). These aspects of a landscape are first observed as individual sections that are then overlaid onto each other for a greater understanding of the landscape. Generally, Permaculture designers will use trace paper and draw each section on a piece of trace that is easily overlaid and readable over the base map.

What comes out of the site analysis is what is called an A&A synthesis, which provides the "what" and the "so what" part of the analysis (Mollison, 1998). For example, the way water flows through the landscape is going to affect where the farmer can place his/her retention pond. In this case, the A&A synthesis would include a bulleted point that says, *water flows and stays here* (the "what") and another that states, *potential for retention pond* (the "so what"). Therefore, the designer understands the characteristics of the site and already begins designing according to these characteristics.

Once a designer has fully assessed the land he/she can begin designing the landscape while keeping in mind the design principles and ethics. After a few design concepts, the final design shows the overall function of the design and how the specific elements are interacting and influencing each other as well as the greater landscape. From here, specific design features can be explained in further detail to show exactly how it works.

Lack of Permaculture in Coffee Management Systems

In coffee management systems farmers have used alternative forms of management such as Certified Organic, Fair Trade, Shade Grown, and Agroecological initiatives. The farmers adapt these alternative management techniques in order to increase their coffee bean prices and in turn their income. Much of this is possible because of large-scale business involvement through the creation and sale of certified products that are valued higher. Though permaculture has been applied to agroecosystems involving vegetable and livestock production, it has yet to become a mainstream practice accepted by coffee producers. Although there are practices and techniques used by farmers that are similar to permaculture theory and practice, permaculture in itself has not been yet been widely or intentionally applied to coffee systems.

Methods

The goals of this section are to provide a detailed overview of the methods done for this project. It explains the methods in the order in which each they were done. It begins with an overview of the preliminary research process and continues with the site analysis, design, and soil sampling processes. Each section is broken down into sections to provide greater detail to the reader.

Preliminary Research

Preliminary research beyond the literature review was done in order to better understand coffee ecology, climate change effects on coffee, coffee leaf rust, permaculture principles and technologies, and any additional ecological practices and techniques. Research was done mainly by reviewing peer reviewed articles, journals, scientific research papers, manuals, and reports. Additional sources included informational videos, websites, UVM classes, books, and in person exchanges of information between professors, the coffee farmer Maria Ruiz, my assistant, experts, and myself. These sources provided basic background information on the problems I came across as well as possible solutions and ways of addressing the issues present on site.

Site Analysis

Farmer, Site, and Assistant Description

Farmer

The Ruiz family has been growing coffee in the highlands of Boquete, Panama for more than a century. Currently, Casa Ruiz produces, processes, roasts, packages, and exports their renowned specialty *Coffea arabica* varieties. Such coffees include, *Typica* (40%), *Catura* (30%), *Catuai* (20%), and *Mundo Novo/ Bourbon* (10%) (Casa Ruiz, 2014). *Geisha* is another high quality and internationally acclaimed variety that is present on site. For this thesis project, I worked closely with Maria Ruiz who currently co-owns the family farm with her brother. Our initial connection began during my study abroad experience in Panama, when I worked with Maria to complete an independent student research project. We continued to maintain a good relationship after the completion of the project, making her and her farm the perfect candidate for this thesis. Maria chose the plot and continued to be the lead contact throughout this project.

Site

The chosen plot for this design is 1.5 hectares in total and is where the growing and processing of specialty coffee occurs. Much of the site is devoted to the processing plant, fostering a place where the entire process of coffee, from bean to cup, occurs on site. In addition, this plot is where tours from Café Ruiz are brought to show where coffee is grown and how it is processed. This particular site is located in Palmira, a district of Boquete located ten minutes before the main center of town and at an altitude of 1200m (3,937 ft.). It is surrounded on three sides by coffee farms that are partially owned but not fully managed by Maria. The main road borders the remaining side where the two entrances of the plot are located. The main partially paved entrance leads to the office, dorms, and processing plant while the second unpaved road accesses the backside of the processing plant. Four separate plots were identified by my assistant and I (see figure 3).

Assistant

After collaborating on a permaculture design project for the Rock Point property in Burlington, VT. Quinn Wilcox (my assistant) and I expressed a common interest for ecologically-based agricultural systems and recognized our complimentary skillsets in the field of permaculture design. Both in the environmental program at the Rubenstein School, we have gained an understanding of the environment in terms of what it provides, how we affect it, and what we can do to make it better. I have focused my studies on agriculture's effects on the environment and how alternative types of farm management lead to a more positive and regenerative outcome. Quinn has focused on Ecological design and Sustainability studies, gaining much experience in site analysis and design in an effort to combat the current environmental issues. He brings a perspective of the built environment and the implementation of ecologically conscious infrastructure.

Combining our academic experiences and permaculture certifications, we worked together on the site analysis section of this thesis project. We walked the site, observed from vantage points, and spoke to Maria about the land. Our individual notes and discussion of specific details allowed for different perspectives, critical thinking, and further accuracy of what can be done regarding design. Quinn took detailed notes during discussions, helped with tree identification, asked questions regarding his thoughts and observations which helped me to notice different aspects of the landscape, and maintained organization of materials in and out of the field. Having two people with previous experience in site analysis allowed for a more accurate and comprehensive understanding of the intricacies of the site. One further benefit of working and traveling together that is worth mentioning is travel safety. Having a person you trust by your side and to look out for when traveling in foreign countries, is crucial to having a safe and productive research experience.

Overview of Site Analysis Process

The site analysis was a total of five days and occurred during the first week of March 2015. This time of year is the dry season and immediately follows the harvesting season. During the first day on site, my assistant and I had a preliminary meeting with Maria at Café Ruiz located in Boquete Central. Here we discussed what plot we would be working with and an overview of the project. The second day began with a walk around the plot with Maria in order to provide orientation and a general explanation. Once the basics were covered, my assistant and I were allowed to stay on the farm and continue our initial orientation. For the remaining three days, the in-depth site analysis occurred.

Site analysis included zones of use, circulation, water flow, resources, infrastructure, vegetation and wildlife, microclimates, wind, vibes and viewpoints, and the sun path. We assessed each of these elements separately by observing and walking the site. Components of the analyses are represented and explained on each base map using symbols and a descriptive legend. The symbols helped create a black and white visual representation of what was going on as well as created a distinction between two similar features. For example, if there was water flowing on buildings and water flowing on land, the same symbol was used (an arrow) but it was distinguished to show difference (natural had a double-lined arrow while industrial had a single line). Each final layer was finished with labels, a title block, a scale, and a legend.

The materials used were a camera, a base map, a notebook, and colored markers/pens. While on site we used an 8X11 printed copy of a base map that Maria provided us with. We printed out multiple copies for the multiple site analyses. When I returned to UVM, I traced over the 8X11 copy and scanned the traced version into the computer. My professor determined the scale and resent the final version back to me as a PDF. I then brought the PDF to Staples and made a 26X34 size base map. The site analyses were then retraced into the 26X34 size. Once site analyses were completed they were scanned into the computer.

Sit spots were also used throughout the five days. These sit spots were important for observing what goes on throughout the day without looking through the distinct lenses of the site analysis elements. These sit spots varied on time ranging anywhere from 20-40 minutes depending on various factors. During the sit spot my assistant and I would take notes on our observations, write down any questions for Maria, and discuss our observations, concerns, and ideas for the site. We had a total of four sit spot locations. Two of the spots were vantage points of the entire farm and were visited daily. The other two were visited once.

Detailed Description of Site Analysis

Vegetation and Wildlife

This element of the site analysis was done first. In addition to the materials listed above, we carried a tree identifier book for this analysis. We began by noting all of the shade trees existent on site. Shade trees were circled on the base map and color coated according to type. The trees that were unknown were circled and written with the number of the photo for future identification. Trees where the trunk was located outside the perimeter of the site were noted for their shade but identification of the tree was not included. Wildlife was determined through observation. Whenever we saw birds, insects, dogs, chickens, ducks, etc. we marked the location on the map.

Microclimates

Microclimates including shady, windy, hot, cold, moist, and dry places on site were noted on the base map. This was done last so that we had spent enough time on the site to figure out what places were shady, windy, hot, cold, wet, dry for the time we were there. Determining these spaces was done mainly using touch and sight. If we noticed wet areas we would physically touch the area to determine if was truly wet. For areas we felt were hot we would stand in them and then move to an area we noticed was cold and note the two locations.

Water Flow

Due to the high quantity of infrastructure we began assessing water flow by finding a vantage point (one of the sit spots). In addition to vantage points, observing and walking the site determined the following features. We were able to see what direction rainwater flowed off the roofs of the buildings. We noted where there were gutters, where the gutters were going, and if the gutters were going to a drainage ditch where the drainage ditch was going. We noted impervious and pervious road surfaces, natural drainages within the coffee rows and industrial drainages along the roadsides, the direction water flowed on the landscape, low and high points, natural springs and industrial spigots, and water usage around dorms.

Infrastructure

Infrastructure consisted of two parts. The first part noted what each building was currently used for. We learned what uses the buildings had by asking Maria during our first orientation walk. The second part was noting the built infrastructure beyond buildings. This included roads, fences, stones wall, etc. We noted these by walking and observing the site.

Resources

Resources were identified as anywhere on site that could provide something beneficial for the land and business. These resources were categorized under biological resources (plants, animals, insects), energy resources (wind, wood, water, sun), and social resources (access, markets, relationships, money). They were determined using observation and asking Maria questions.

Vibes and Viewpoints

This assessment was for determining good viewpoints and bad viewpoints. In addition, we noted areas that felt unsafe, dangerous, fearful, informative, inviting, inspiring, aesthetically pleasing, messy, stressful, and peaceful. We based our assessment on our own feelings and responses to the site's features and discussed them with each other. Since this assessment is personal, it may vary.

Zones of Use/Circulation

Circulation included the most commonly used paths taken by service vehicles, coffee harvesters, on-site residents, and the tour groups. Each group had its own symbol to differentiate their paths. Zones of Use, was done in four perspectives, the service employees, the coffee pickers, on-site residents, and tour groups. A scale (1-3) was used to distinguish the zones with zone 1 being the area most visited and zone 3 being the least visited place. Each one had its own color with different shades to mark the different zones. These circulation patterns and zones of use were determined mainly from the sit spot observations and our overall time spent and experience on the farm. We also asked Maria clarifying or reassuring questions about our observations.

Wind

Wind was identified using two methods. We noted where winds were strongest and weakest by analyzing our own experiences walking around the site. Not only did we physically feel where winds were strongest and weakest but we also observed what trees, both coffee and shade, looked windblown and which did not. Wind tunnels created by the infrastructure were also noted along with the weather probe data.

Sun Diagram

Sun paths were determined using the sun path charts from the Internet. Three dates were used, one representing the week the site analysis occurred, one for the winter solstice, and one for the summer solstice. The three different charts represented the range of sun the farm received.

Analysis and Assessment Summary

The A&A summary is the final layer of analysis. It is inclusive of the most important analyses and what these analyses indicate for the overall design. This layer was done in the same process as the individual analyses. However, the specific analyses and the "so what" of these findings was included in writing on the layer itself.

Climatological Summary Data Collection

Maria provided us with data from a weather probe and monitor that are located on site. We acquired copies of average wind speeds, temperature, rain, etc. There are six summary reports, a monthly summary of January 2014 and 2015, a monthly summary for February 2014 and 2015, a monthly summary for May 2014, and an annual summary for the year 2014. These reports were used to gauge differences in weather patterns of the dry and wet seasons as well as changes amongst temperatures, rainfall, and wind between the years 2014 and 2015.

Design Process

Goals Articulation

After completing the site analysis, the goals for the final design were created. Articulating goals is an on going process that changes throughout the project. However, the initial set of goals was used as a reference point during the design process. While designing, every proposed design idea was checked by the listed goals to make sure added elements adhered to the overall goals of the site. During the first meeting with Maria, she shared her personal goals for the overall site. After the site analysis, I created my own individual set of goals. My goals were written in an active voice using phrases such as, "This design prepares for climate change by…" and "This site remediates soil by…" Both Maria's and my personal goals were referenced throughout the design. In addition, anytime a new goal came up it was added to the list along with any edits made to previous goals.

Design Concept

Once the multiple layers of the site analysis, the A&A summary, and the goals articulation were complete, two design concepts were created. The design concept is its own layer of trace paper. On this trace, I drew large bubbles to indicate, in general, what design ideas would occur in the circled location. The bubbles were not to scale and did not provide a lot of detail. This part of the process allowed me to consider my different ideas and begin applying them to the landscape. I created two design concepts, one from a vegetation and wildlife perspective and one from a people and infrastructure perspective.

Final Design

With preliminary background information, site analysis, A&A summary, and two design concepts, a final design was created. The final design had its own layer of trace that was printed in 11X7 for an easier read. The final design brought the two concept designs together and included more detail. Numbers were placed in the locations of the proposed elements. A corresponding numbered detailed design further described the proposed element.

Detailed and Section drawings

Detailed drawings were done in order to provide further explanation of certain parts of the design. These were picked due to their importance, frequency, and need for greater explanation of this specific element. The detailed designs were accompanied with a written explanation. The section drawing shows further detail of a design element by displaying it in a way that allows the observer to see the element as though he/she were looking at it in front of them. This helps the observer to visualize the relationship between the various components that go into the design. The section line is drawn big and bold with additional features drawn with thinner line weights. Sections were done on areas where more information was needed in order to convey the idea better to the viewer. Accompanying written descriptions help to explain what is going on in each diagram.

Soil Sampling

Soil sampling was done on all four plots. On each plot my assistant and I followed a W formation, taking a sample at each point of the W. Samples were dug with an auger and put into a large coffee bag. Once all the samples for a plot were collected we shook the large coffee bag to mix the soil. We then poured soil into a zip lock sandwich bag and discarded the rest back onto the ground. This process was done for each plot, resulting in a total of four zip lock bags, each labeled "Plot 1, Plot 2…" for organization. These zip lock bags were brought back to the UVM Soil Sampling lab for testing.

Results

In this section, the results from the preliminary research, goals articulation, the soil tests, the weather probe data, the site analyses, the A&A summary, the design concepts, the final design, and the detailed and section drawings are ordered according to when they were completed throughout this process. The results are represented in the order they were completed in order to show each steps influence to the next. The preliminary research is incorporated throughout the results section where it's applicable.

Goals for the Site Design

Below are two sets of goals. Maria stated her goals for the site during our first meeting and I created my own after the completion of the site analysis. My goals were influenced by Maria's goals and by the problems and opportunities discovered during the site analysis. Both sets of goals are referenced throughout the design process and acknowledged within the final design.

Goals Defined by Maria Ruiz

1. Transform the area to a highly specialized, innovative, experimental plot.
2. Educate and excite tour groups on the alternative methods used on the farm in order to inspire a paradigm shift.
3. Surpass soil and water *management* to reach soil and water *understanding*.
4. Create a hostel, coffee laboratory for seed production, and educational center.
5. Plant high valued species.
6. Reference **Figure 2** below:

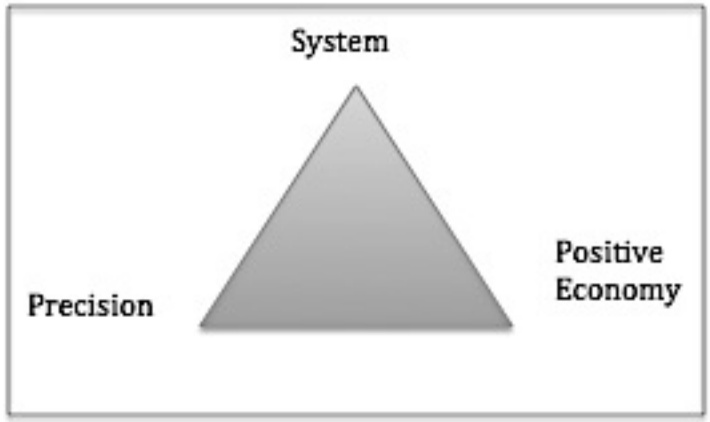

Figure 2. System: to think of each element (coffee, soil, etc.) of the farm as a whole, with each element working interdependently with each other. Precision: thoroughly researching each management decision in order to avoid costly and detrimental repercussions. Positively economic: create a system that is economically viable, one that adds to the economy of the farm versus takes away from it.

Goals Defined By The Researcher

1. The design addresses, mitigates, and contains the coffee leaf rust disease on site. It also prevents further infestation of the disease.
2. The farm is designed and managed using systems thinking and precision while maintaining a positive economy.
3. The project is representative of permaculture design and displays the process in a way that is replicable for other farmers.
4. The plot provides educational, experimental, and ecological technological opportunities for Maria, the indigenous peoples who harvest the coffee and live on site, and for the tourists.
5. Maria practices soil, wind, and water management and understanding.
6. The farm is a working ecological system inclusive of appropriately placed shade trees for habitat management of important wildlife such as birds, recycling of waste via vermicompost and organic matter collection, using natural biological control agents and windbreaks to combat pest and disease, and addressing wind, soil, and water issues by using natural systems and ecological technologies.
7. A section of the dorms are converted to a hostel and tree houses are built where guests are hosted and taught about the alternative practices done on the farm in

order to, encourage a paradigm shift in thinking about ecological management of coffee farms.

8. The design recognizes climate change and plans for a smaller margin of error by increasing the farms resilience to increasing temperatures, decreases in water supply, and increased incidence of pest and disease.
9. Maria understands the indicators of the farm in a systemic and interdisciplinary manner.

Soils Test Summary and Recommendations

The soil tests of all four plots were relatively similar in organic matter percentage, nutrient levels, and pH. In general organic matter (OM) was around 16%, which is especially high for tropical soils. Magnesium and Potassium was high to excessive while Phosphorus was medium to optimum. In tropical soils, P is bound to the iron/aluminum oxides in acidic tropical soils (RCF, 2015). This could be a reason for the tested lower levels of phosphorus. High OM causes high CEC attributing to the high levels of Mg and K due to the ability of the OM to soak up and hold onto these nutrients. Overall the pH was acidic to neutral ranging on a scale 5.7-6.3. These acidity levels just reach the perfect range (6-7pH), which makes soil nutrients readily available to the plant. One reasons for the acidic levels could be attributed to the leeching of basic irons from rainwater runoff, which is a recognized problem on site (ESF, 2015). The plot specific soil test results can be referenced in the appendices.

Some ways to remediate the soils are through the addition of lime, gypsum, bio-char, rhizobium fungus, and introduction of beneficial bacteria and nematodes. Lime, which can be applied as ground limestone, provides the soil with calcium and magnesium, makes phosphorus more available, raises soil pH, and increases the speed of OM decomposition. Gypsum (calcium sulfate) has many benefits for soil such as introduction of calcium into soils, greater soil organic matter stability, pH increase, mitigates the toxic impact of excess magnesium, aids plants in the absorption of nutrients, improves water retention and penetration, helps prevent water logging, and helps slow water runoff, improves earthworm reproduction, enhances fruit quality, and stabilizes soil aggregates (Diamond, 2010). Bio char is carbonized organic matter (dead plant material that is burned in an environment absent of oxygen) that enhances soils functions, increases biodiversity of the soil, sequesters carbon by capturing and holding biomass emissions, and holds carbon within the soil (IBI, 2015). Inoculating root nodules with rhizobium and other beneficial fungi, bacteria, and nematodes helps aerate the soils, infiltrate water, promotes nutrient cycling, and absorbs and fixes nutrients such as nitrogen and phosphorous through the decomposition of organic matter and makes it available to the plant (RCF, 2015). Any of these methods could be a good option for increasing the pH, phosphorous availability, and improving soil function of the site's soils, however further soils research should be done in order to understand what methods are best for this site.

Climatological Summary Results

Overall results after studying the climatological reports indicated the highest winds and temperatures were recorded during the dry season. The rainy season (end of April-November) has the most rainfall throughout the year and also decreases in temperature. Average temperatures during the dry season were 78.8 degrees Farenheit (F) and during the rainy season 65.2 degrees F. The hottest time of the day during the dry season was between 1:00-3:00pm. During the rainy season the hottest times were 12-2:30pm. Differences in rainfall and wind speeds were compared between the February 2014 and May 2014 reports. In February, wind speeds averaged 6.1 mph and rainfall averaged 0.07in. In May, wind speeds averaged 1.5 and rainfall averaged 8.24 in. Lastly, there was a 1-degree increase in temperature from January 2014 (70.4 degrees F) to January 2015 (71.3 degrees F).

Site Analysis Results

Base Map

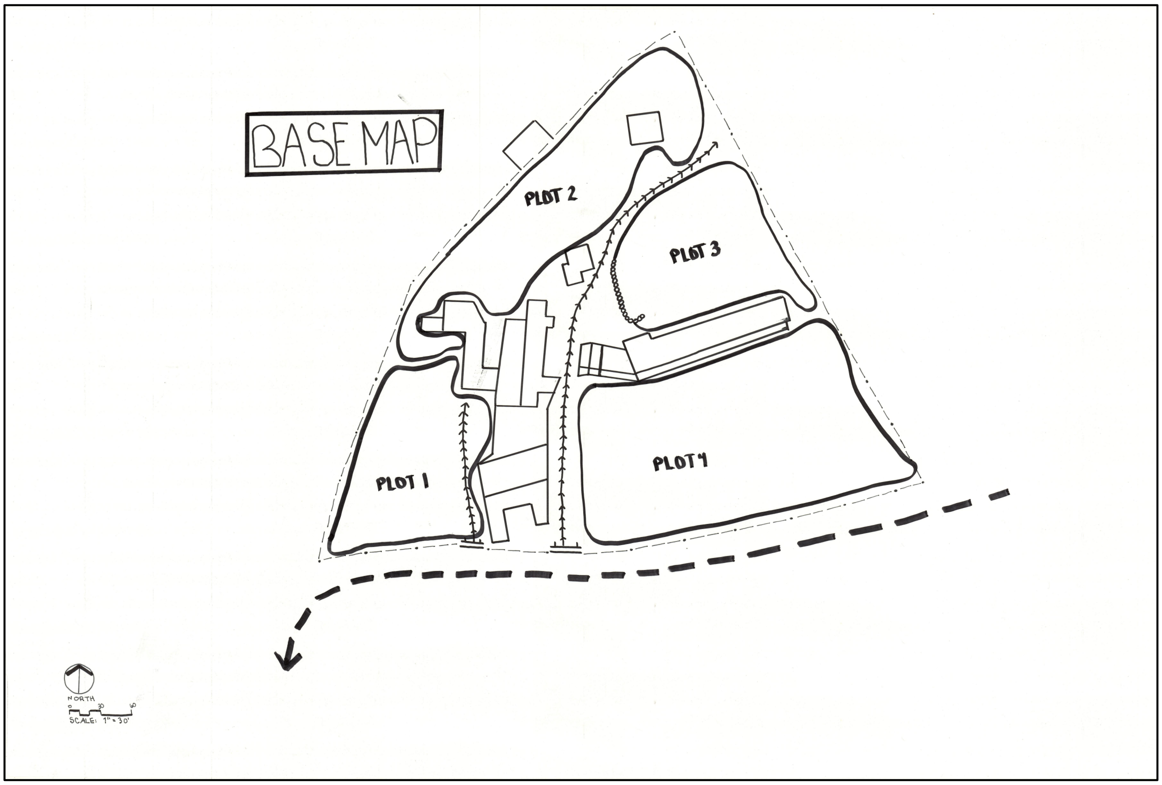

Figure 3: Base map of the property.

This base map is a representation of the main features of the site, including the main buildings, access roads, property lines, the four distinguished plots, a compass for orientation, and a scale. This map is a model that is replicated throughout the site analyses, design concepts, and final draft in order to maintain consistency.

Sun Chart Diagram

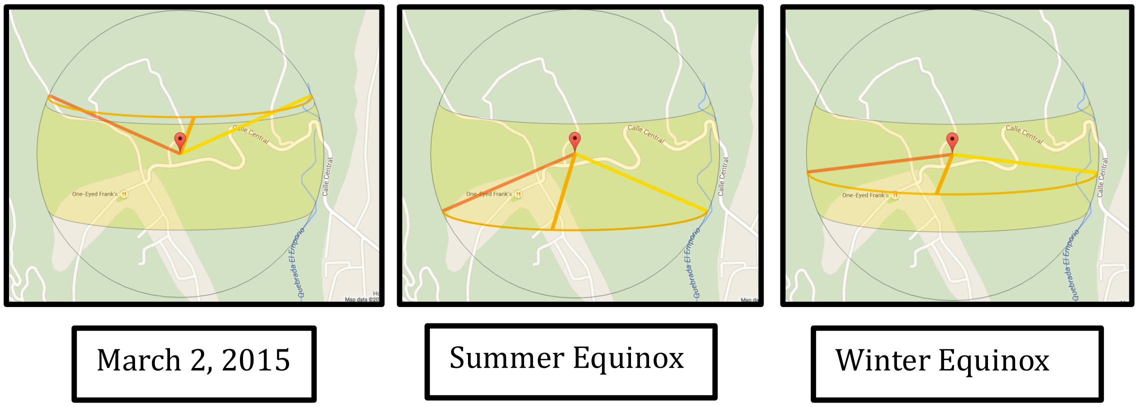

Figure 4: Shows three diagrams of the sun's path on the farm throughout the year.

These sun charts show the path of the sun over the site. The site is the orange bubble located in the center. Three different diagrams were taken to show where the sun was when we conducted the site analysis and the winter and summer solstices in order to represent the extremes. Due to Panama's close proximity to the equator there is not much difference in the sun's path throughout the year. These diagrams are useful when considering planting on the property and how much shade or sun certain areas of the farm receive.

Detailed Site Analyses

The following are scans of each layer of the site analysis. The analyses included below are, water flow, resources, infrastructure, microclimates, vegetation and wildlife, and vibes and views. The results of the site analysis are represented and explained on each map with symbols and a descriptive legend.

Water flow

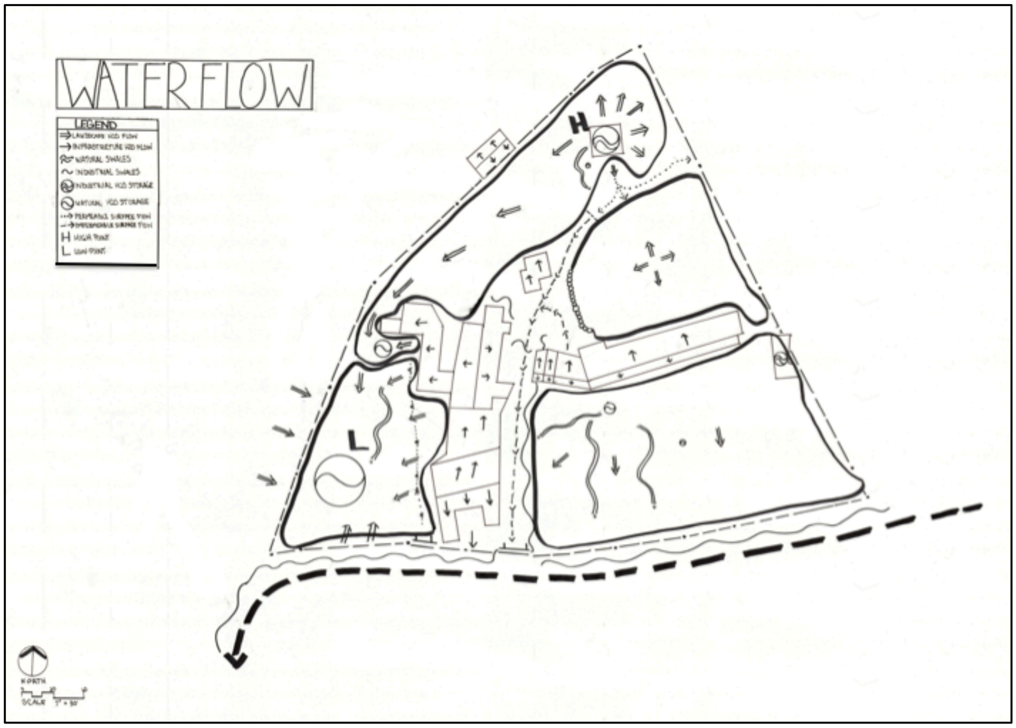

Figure 5. Water flow.

The key points taken away from this analysis were: areas where water can be collected on site, how the water can be distributed across the land and to the buildings, and where to keep excess water. Regarding where water can be collected, this map shows the way water flows off of the roofs and processing plant. Knowing where the rainwater drains off the roof allows for collection of that water via rain barrels. It also shows a marshy area at the lowest point where water off the backside of the processing plant flows to. This point is both a source and a sink, absorbing excess water while posing as a potential area for water collection if managed appropriately. Another point in which water can be collected or managed is the water coming from the sinks located outside the dorms. Water flows downhill from the source in a straight line through the coffee trees. Since the water naturally flows through the coffee, if better managed it could act as an irrigation system during the dry season. Existing water management features are also noted in order to understand if these are the best options or if there is room for improvement. For example, beside the retention pond is a water reclamation barrel. When we checked we determined the barrel was mostly if not completely empty. This barrel could be moved to another location where it can act as a water tank and collect excess water from the rain barrels.

Resources

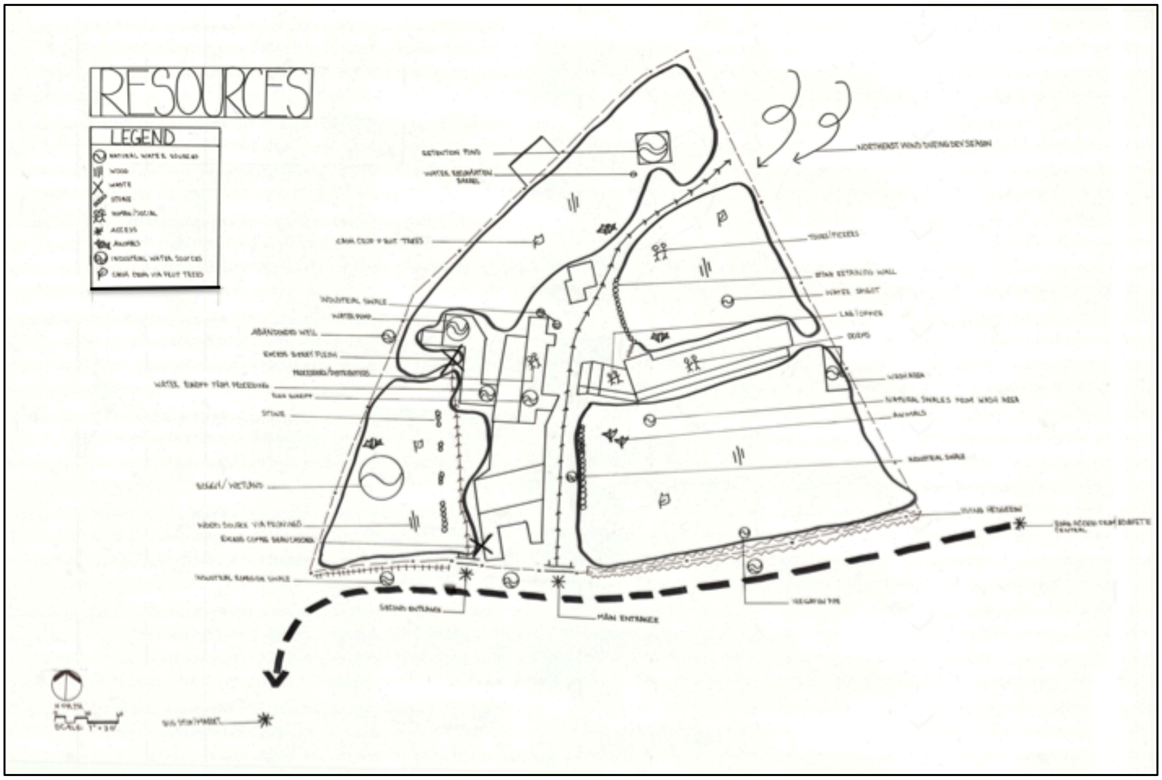

Figure 6. Resources.

On site resources represent the potential for a site to be self-sufficient. The resources represented in this layer fall under three main categories. There are biological resources (plants, animals, insects), energy resources (wind, wood, water, sun), and social resources (access, markets, relationships, money). Through this analysis, areas with recyclable waste were determined such as the excess berry skins as compost or the excess coffee parchment as a burning source. Energy sources, such as the high-speed dry season winds, sun, and wood from tree prunings were noted as ways to provide electricity to the processing plant. Biological resources such as animals and plants were noted for benefits they could provide. Such benefits include fertilization and tillage from ducks and chickens, biological pest control through insects, nitrogen fixation from leguminous plant species, mulch from shade tree prunings and leaf litter, shade and wind protection via fruit and wood trees, erosion control through vegetative hillsides, etc. Being aware of where these biological elements are located is important not only for there uses but for the enhancement of these resources. For examples, if birds are an important resource and birds are located where there are shade trees then planting more shade trees could potentially attract more birds and in turn more resources.

Social resources are also included in this analysis. The most important ones noted are workers and visitors. The workers provided their labor to keep the farm running while visitors bring in outside money and resources from other countries. Between all the members of the farm are relationships being made which can lead to more resources depending on the people. In addition to people are the access points in which people can get to and from the farm. This is important for the sale of the products generated on site, and any outside resources. The biggest access point is the main road that runs along one side of the farm. The two separate entrances are important access points for transfer of products to and from the farm. Lastly is a bus stop located 30 seconds up the road that goes to and from the main center of town. This is a transportation point for both workers and visitors.

Infrastructure

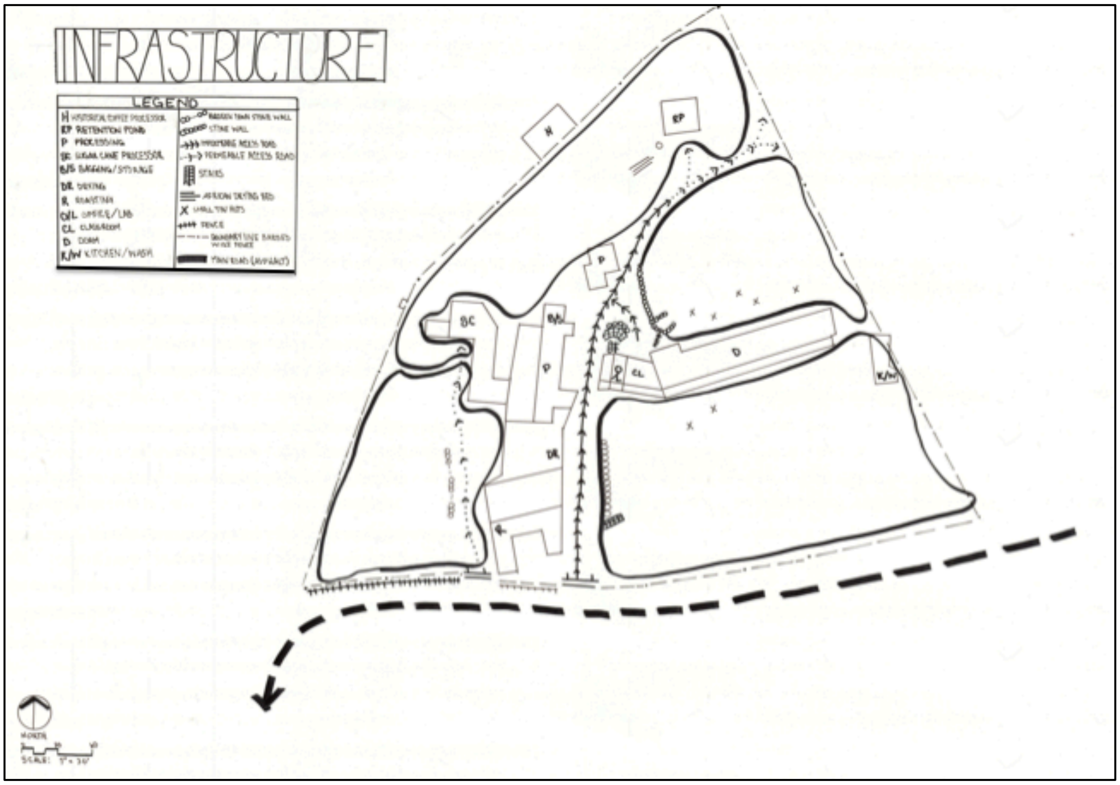

Figure 7. Infrastructure.

Observing and noting the current infrastructure gives us the opportunity to see how current features are affecting the land. For example, the cemented road, which makes up the main entrance road, causes rainwater runoff while the second entrance, which is a permeable dirt road, collects and holds runoff from the buildings. The buildings not only expel wastewater but they are also the largest source of energy consumption. With this said, rain barrels can be installed to collect the roof rainwater and green energies like wind turbines and solar panels could be used to provide energy to this source. Observing infrastructure provides insight into what actions are currently done on site. For example, the largest building on the property (the processing plant) collects, washes, dries, roasts, stores, and packages coffee. The building on the opposite side of the road provides housing for workers, is an office, classroom, and laboratory for cuppers (certified coffee tasters and judges). Other infrastructure such as fences can provide insight into the relationships between the people on the farm. For example, on the plot 4 site there is another set of stairs close to the road and a fence that separates the office, lab, and classroom from the dorms. This could imply privacy for the workers or exclusion of the worker families from the main center of the activity on the farm. Whichever is the case observing such things provides insight into the relationships on site.

Vegetation and Wildlife

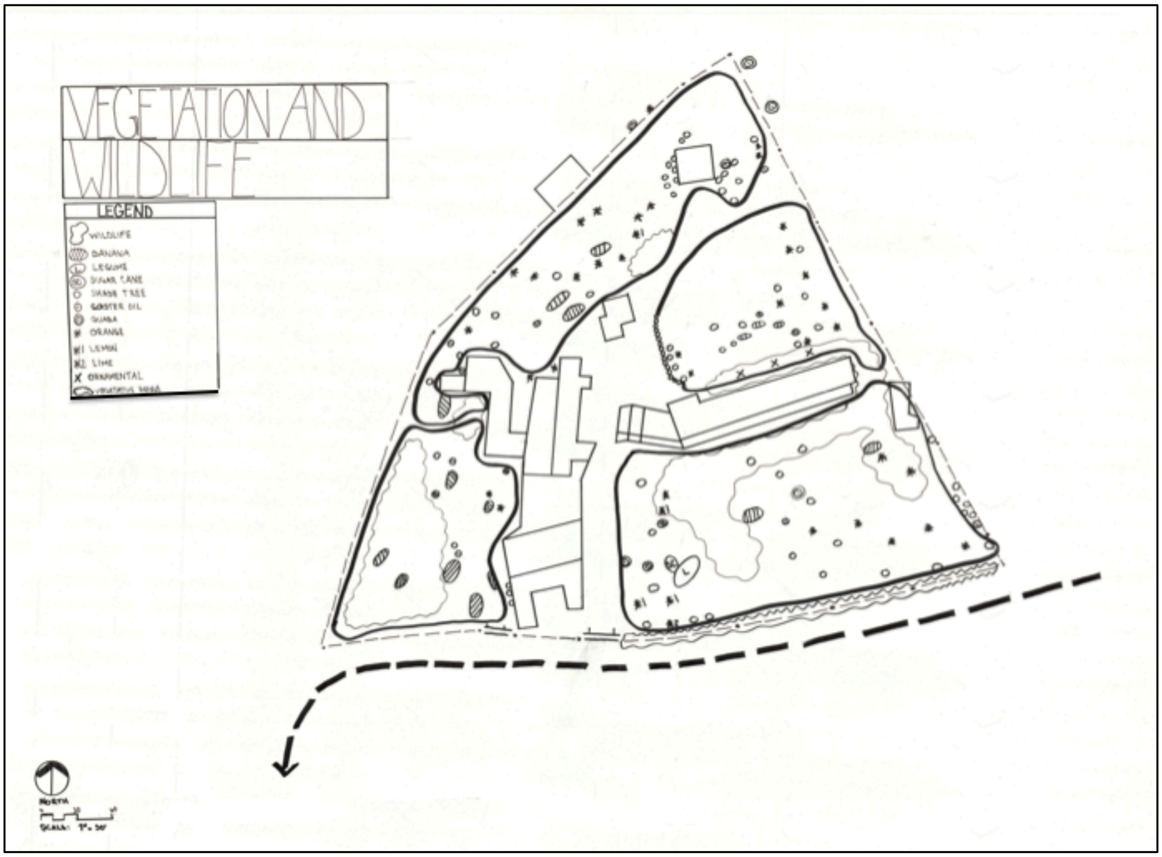

Figure 8. Vegetation and Wildlife site analysis.

Vegetation is an indicator of soil health, economic viability, and coffee tree health. Specific trees need specific requirements to grow. Knowing the requirements of the shade trees present on site provides insight as to what is available in terms of nutrients, sun, water, etc. Specific trees can also indicate soil type. Shade trees, fruit trees, leguminous trees, and sugar cane are noted throughout the plots. There are many orange and banana trees on site, which present themselves as economic opportunities via cash crops. The leguminous trees could provide the coffee with nitrogen while the banana trees provide organic matter and potassium. The areas within the plots that are blank represent the rows of coffee trees. These areas are where intercropping schemes can be applied. Wildlife consists of birds, insects, butterflies, dogs, ducks, and chickens. The dogs, ducks, and chickens are closer to the dorms while the birds, butterflies, and insects are closer to the coffee fields and plot boundary. Wildlife is an indicator of ecosystem health. The areas in which there are birds, insects, and butterflies indicate that there is enough food and habitat for fauna to exist on site. The insects and animals also pose opportunity for fertilization, tillage, and biological control. Note that there is presumed to be more wildlife and what was noted on this map was what was observed. In addition, this layer only shows tree vegetation leaving out groundcover and shrub layers.

Vibes and Views

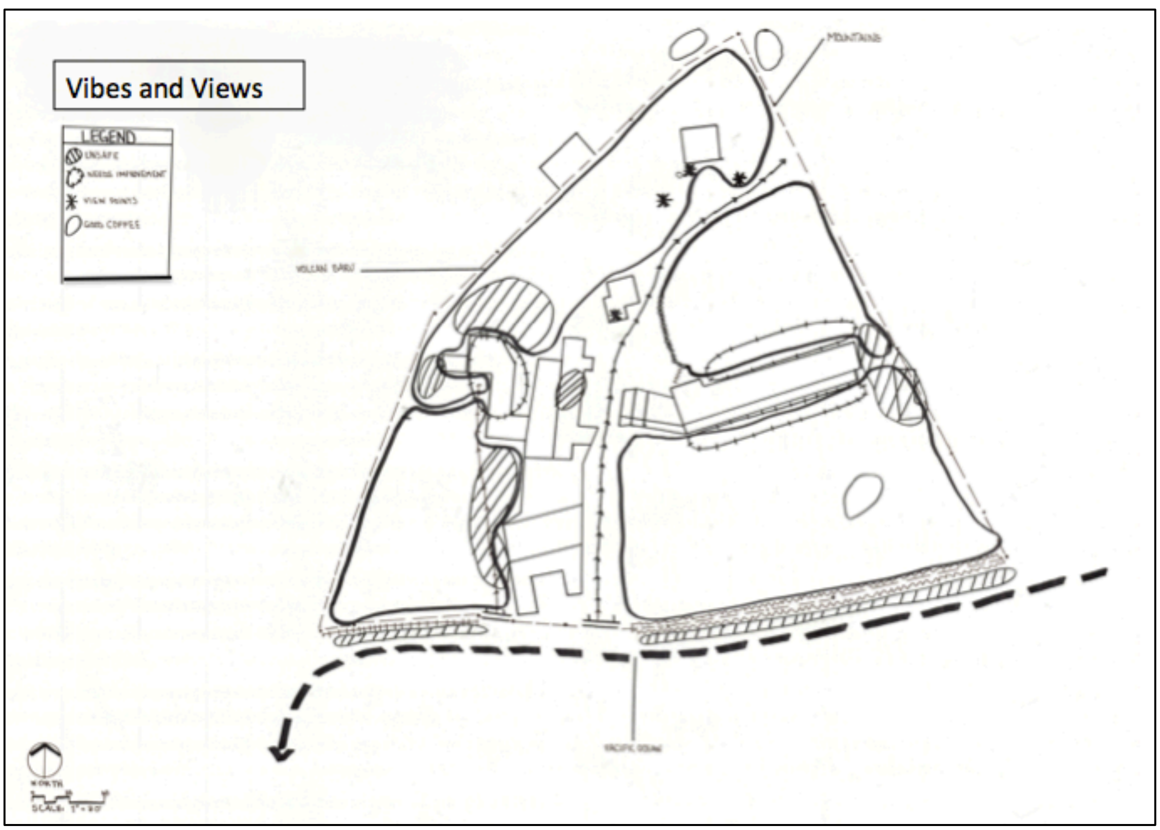

Figure 9. Vibes and views.

A large reason this plot was chosen for this design was because tourists are brought here to show the process of coffee from bean to cup. Not only does Maria want the tourists to have an enriching experience on her farm tour but she wants people to see these alternative practices she currently envisions for the farm. With this in mind, views and vibes becomes important for making the visitors feel safe and comfortable in order to have a rewarding experience. Noting the lookout points by the retention pond is important for knowing where to bring the tourists. If tourists were brought here they would see the coffee farm, processing plant, and all the way to the Pacific Ocean. These views coupled with senses of comfort and inspiration received from the land and what is done on it, can help spread the word and therefore bring further income and inspiration to the business.

There are locations on this site that either need improvement or feel unsafe. These areas are the processing building as a whole for there is a lot of machinery running and loud noises. Vegetation could be placed along this area to increase aesthetics and block some of the noise. Another area with feelings of unsafe is the abandoned sugarcane processing plant. The sugarcane plant could be reused as a composting bin recreating the space into something that is useful and interesting. The retention pond, which is a 30,000-gallon tank, currently has no fences making one feel like they could fall in at any moment. Fences could be made here. There are also areas for the pickers that are unsafe due to the steepness of the terrain. Infiltration steps and terracing can be applied to combat this issue. In addition there are areas that need improvement such as, the dorm washing and cooking facilities, which are scattered throughout plots 3 and 4. These facilities are poorly built and do not manage the water coming from them, allowing the excess water to drain out to the road or sit stagnant. New facilities could be built to organize the area and properly manage the excess water. Trash is strewn around the dorms and throughout the coffee farms making the farm look polluted, disrespected, and unnatural. Trash bins and informative conversations about the impacts of unmanaged trash could help emphasize the importance of proper trash disposal.

Microclimates

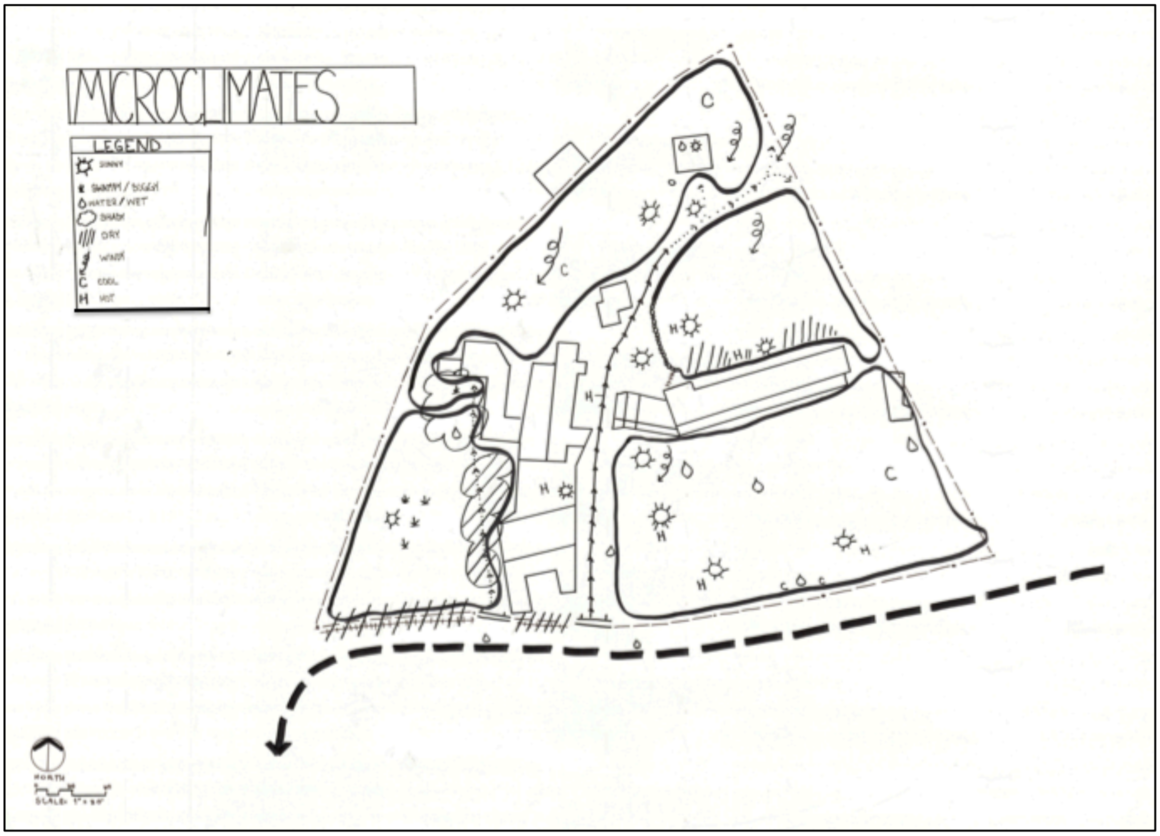

Figure 10. Microclimates.

Microclimates are areas for unique growing opportunities. On this site there are many microclimates due to the topography of the landscape. The hottest areas are around the dorms because they are protected from the wind and are un-shaded. Gardens could be placed in the sunny spots and shade trees could be planted to cool the area. Plot 1 is the coolest area of the property because it is shaded from the building and has a marshy water component, which also cools the area. Hangout areas could be placed in this plot as well as cool climate plants. Plot 2 and 3 are exposed to both strong wind and sun. Wind turbines could be placed here as well as windbreakers to capture and combat the high volume of strong winds. An important note is that there was not a pattern within the various microclimates. For example, not all sunny spots are hot. This is usually due to the strong winds going through the area. Another is that there are shady spots that are dry and others that are wet.

There were also spaces where it was sunny but water was still present. Increased management of these microclimates could create more of a pattern throughout the landscape.

Zones of Use and Circulation

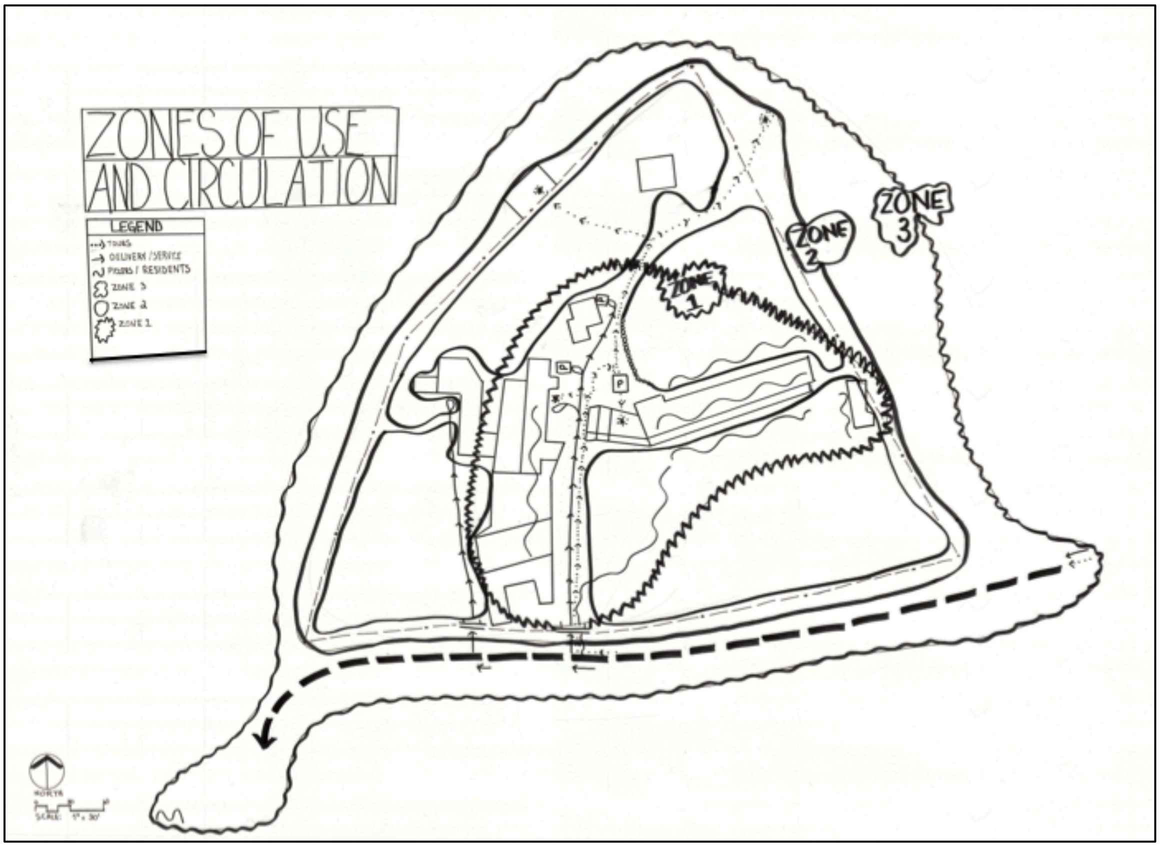

Figure 11. Zones of use and circulation patterns.

Zones of use are important when designing so that one understands where to appropriately place the various features of the design. Proposing design components that require a lot of attention should be placed in areas where there is a lot of human activity. The zones of use on this map are scaled 1-3. The zones are defined using the perspective of the people who work on the land the most whether they are the pickers, distributers, processors, etc. Circulation was split amongst pickers, service, and tour groups. Zone 1 encompasses the traffic from tours groups, service vehicles, and residents. It is clear through these observations that zone 1 has the most human activity, which means that design features that require the most attention should be paced here. Zone 2 represents the coffee plots which people interact act with at different intensities throughout the year due to harvesting, pruning, and low maintenance times of the year. Features placed here should have similar maintenance requirements as coffee. Zone 3 represents the road and immediately outside the property line. Though the road is a crucial access point, the design has little control over how the road can be changed, as is the same with outside the property. However, this area directly interacts with the farm and therefore should be considered during the design process. Another benefit of understanding circulation is acknowledging what the current paths are doing to the landscape. For example the main road into the farm is paved because of the extreme rain and mud of the rainy season. However, this also allows water to flow directly down and out of the farm instead of across and within the farm plots. Recognizing this impact allows for the proposal of a technology, that captures this water and redistributes it to the rest of the property.

A&A Summary

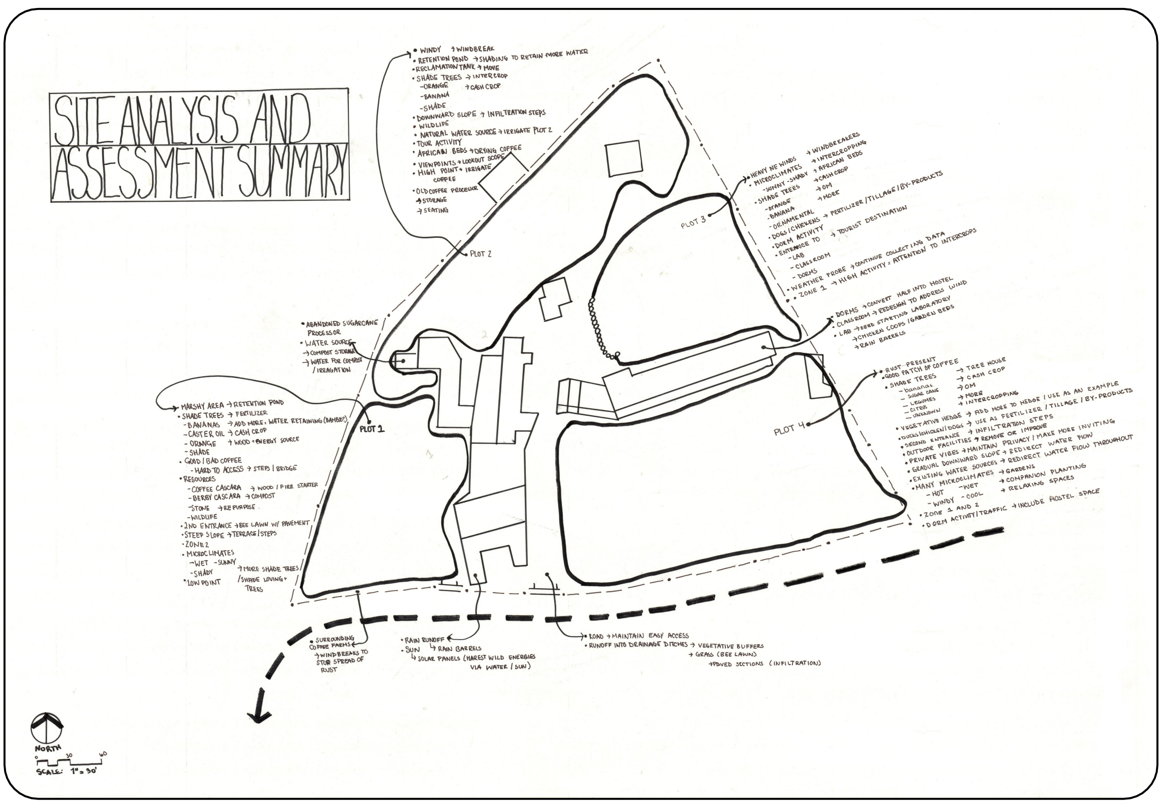

Figure 12: Analysis and Assessment Summary.

The analysis and assessment summary is a summary of the 7 layers of site analysis. This summary explains the *what* and the *so what* of each element discovered in the analysis. The *what* is the actual element and the *so what* is why it is important. Some important analyses noted in this summary are the impacts of water flow, current resources available on site, existing vegetation and wildlife, and the potential of existing infrastructure. These specific analyses provided a lot of information for what can be done and what is most needed on the site.

Design Concepts

The two concepts shown below were separated by, vegetation/wildlife and people/infrastructure. This separation provides distinction between the many proposed elements. Large bubbles were used to loosely describe the main ideas and their locations on the site. After further research was done on these elements, some elements were included in the more detailed final design as well as additional elements added during the final design process.

Vegetation and Wildlife

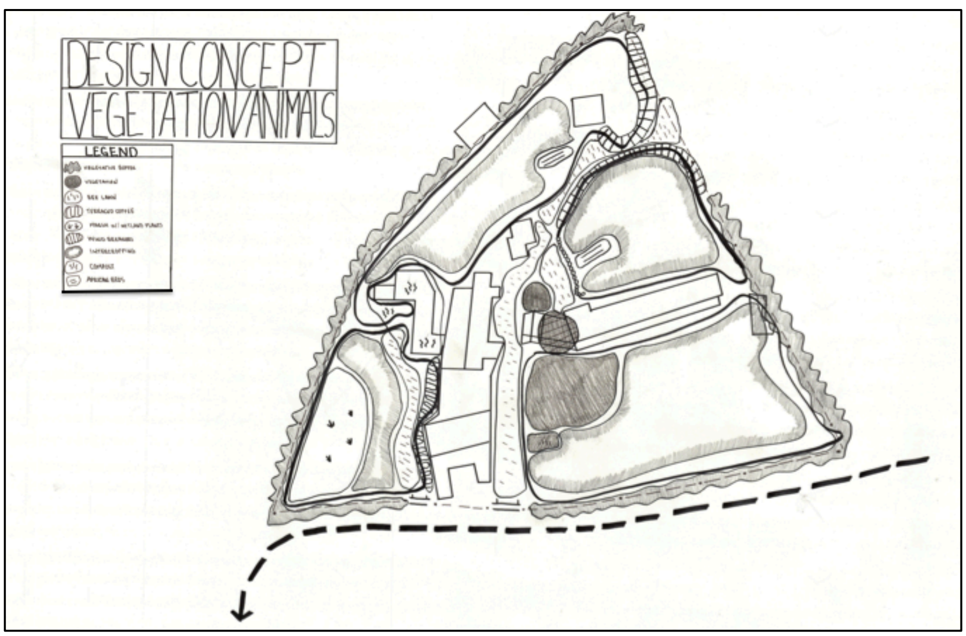

Figure 13: Vegetation and animals design concept.

This design concept represents the main vegetative and animal based elements. Such elements include vegetative buffers, windbreaks, intercropping, terraced slopes, compost, marshland, and bee lawn. This concept helped grasp the main ideas for the property. With these ideas in mind more research was conducted to determine what kinds of plants will be needed, what kind of intercropping systems are most appropriate, how much room is needed for vermicomposting, etc.

People and Infrastructure

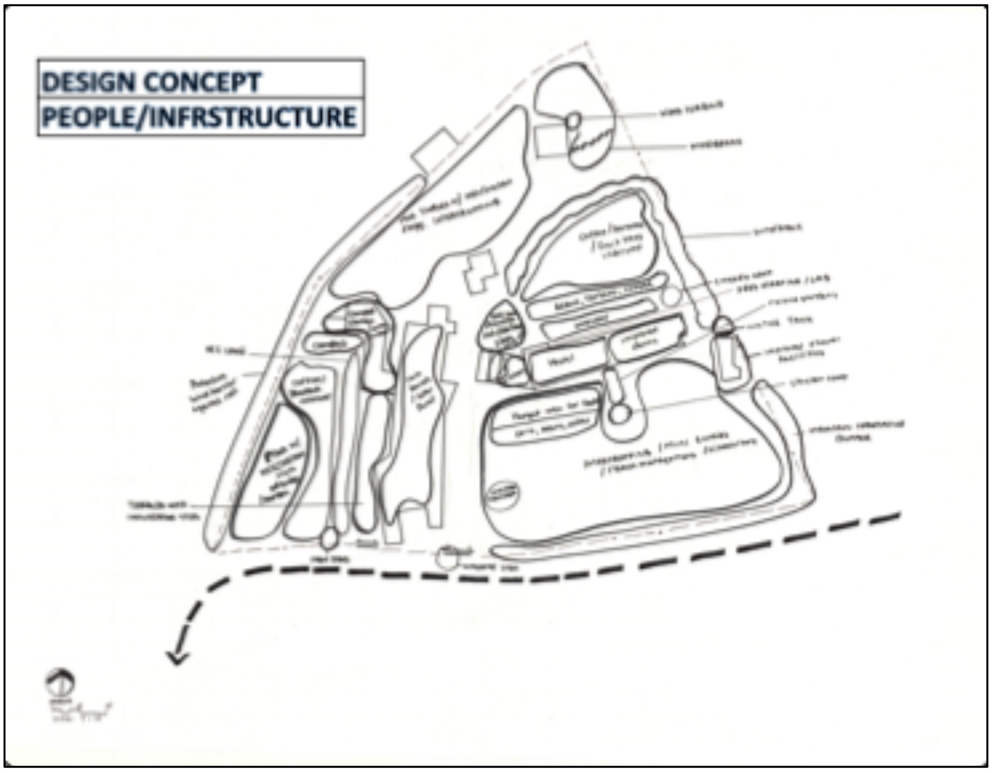

Figure 14: People and Infrastructure design concept.

This design concept represents the elements that are people oriented and require built infrastructure. Such elements include rain barrels, solar panels, infiltration steps, hostels, improved wash facilities, and others. Similar to the first design concept, more research on how much labor, time, money, and building resources was needed in order to gain a better understanding of where and if these elements should be applied.

Detailed Designs

The final schematic plan consists of multiple detailed design elements. In order to better translate their role in the overall design, each element is explained with further detail. The numbers associated with each detail correspond with the numbers on the schematic plan. This is to demonstrate their position on the site. The locations of the details that do not have corresponding numbers are explained within their descriptions. These elements include:

- Intercropping (6)
    - Coffee and banana
    - Coffee, bananas, fruit/timber trees
    - Coffee, tomato, beans
    - Coffee and herbs
- Windbreakers/Vegetative Buffers
- Chinampas (2)
- Compost (3)
- Rain Barrels
- Terraces (1)
- Retention Pond (4)
- Chicken Coop (7)
- Diversion Channels/Swales (14)
- Infiltration steps/Permeable pavement (5/15)
- Hostel (12/13)
    a. Tree house
    b. Farm Stand/ Reception/ Communal Spaces
    c. Garden, Wash, Compost feature
    d. Dorm Improvements
- Nursery (11)
- Solar Panels (9)

Each element is given a written description of what it is and why it is recommended for the site . Accompanying sections, details, and photos are included below and on the final base map to provide more clarity in the written report and to show exact location on the site. For each section, permaculture principles are referenced to show how each element is adhering to at least three of the principles defined by Mollison, which are as follows; 1. Relative location, 2. Each element performs multiple functions, 3. Function supported by many elements (redundancy), 4. Zone planning, Sector planning, 5. Bio resources, 6. Small-scale intensive systems, 7. Plant stacking, and 8. Diversity. These principles are noted in italics underneath each heading.

Intercropping

Multiple function, Redundancy, Diversity, Plant Stacking

Intercropping is multifunctional, fosters biodiversity, and is supported by many elements. The intercropping combinations mentioned below create biodiversity through stacking a diversity of tree and plant species including, coffee, banana, tomato, beans, herbs, fruit trees, and timber trees (see specific plant lists in appendix). An increase in flora diversity translates to an increase of fauna diversity particularly regarding, bird species, soil organisms, and insects. This increase could be attributed to the increase in wildlife habitat and the attraction of different fauna to different flora species. This bio diverse function is one of the many functions intercropping fosters. Other functions include, a diversified income through the sell and use of fruit and timber products, OM creation which increases beneficial soil organism activity and provides necessary nutrients to the coffee tree, the control of leaf rust spread from tree to tree by creating a break in the rows of coffee, creation of mutual beneficial relationships, and a food source for on site residents. These functions are supported by multiple elements such as, mutual beneficial relationships between the intercropped species via nutrient uptake and availability within soil, OM deposition, and attraction of biological control agents, water diversion channels that provide the crops with water, and microclimate management through the use of shade trees which is said to decrease temperatures by 2 degrees, allowing the coffee crop to adjust to a changing climate (CGIAR, 2011).

Intercropping is recommended in many ways throughout the site. The main combinations include:

1. Coffee and banana
2. Coffee, bananas, fruit/timber trees
3. Coffee, tomato, beans
4. Coffee and herbs

Below, these combinations are further explained with diagrams and the specific benefits each system provides.

Coffee and Banana

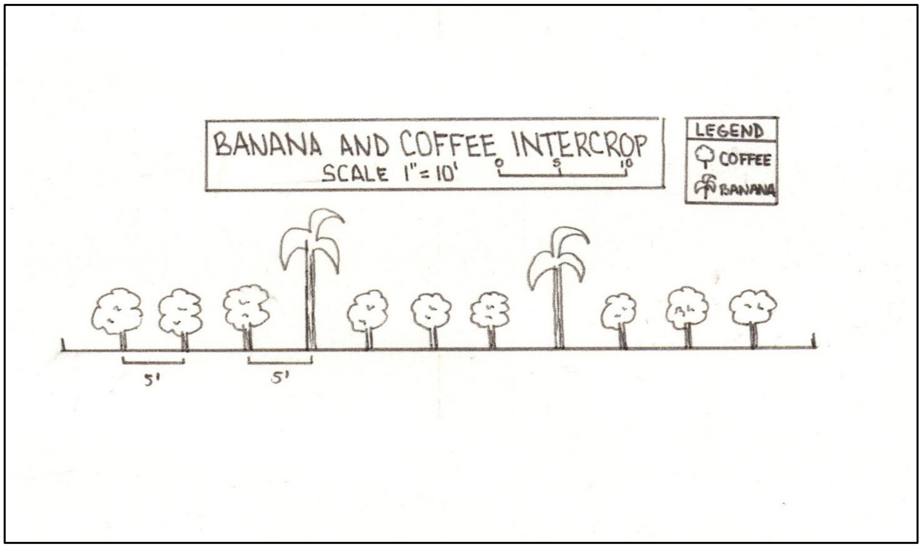

Figure 15: Coffee and banana intercrop system.

Studies done in Uganda have shown that coffee and banana intercrops increase income by 50% through the sale of coffee and bananas (CIALCA, 2006). Physiologically, bananas are able to uptake potassium from the soil and make it available to coffee through its leaf litter. Bananas have sucker roots and produce one bunch of bananas per trunk. In order to manage their spread and risk of competition, the trunk should be cut after it fully produces a bunch of bananas so that its sucker root can grow and the cut trunk can be used for OM along with the leaf litter. The leaf litter and cut trunks are directly applied in a circle around the coffee tree allowing the nutrients to decompose into the soil. This diagram has 5ft of spacing between the banana and coffee trees. Ideally, there would be 8ft between the trees however, due to the amount of space available on the farm, 5ft is most applicable (CIALCA, 2006).

Coffee, Bananas, Fruit Trees

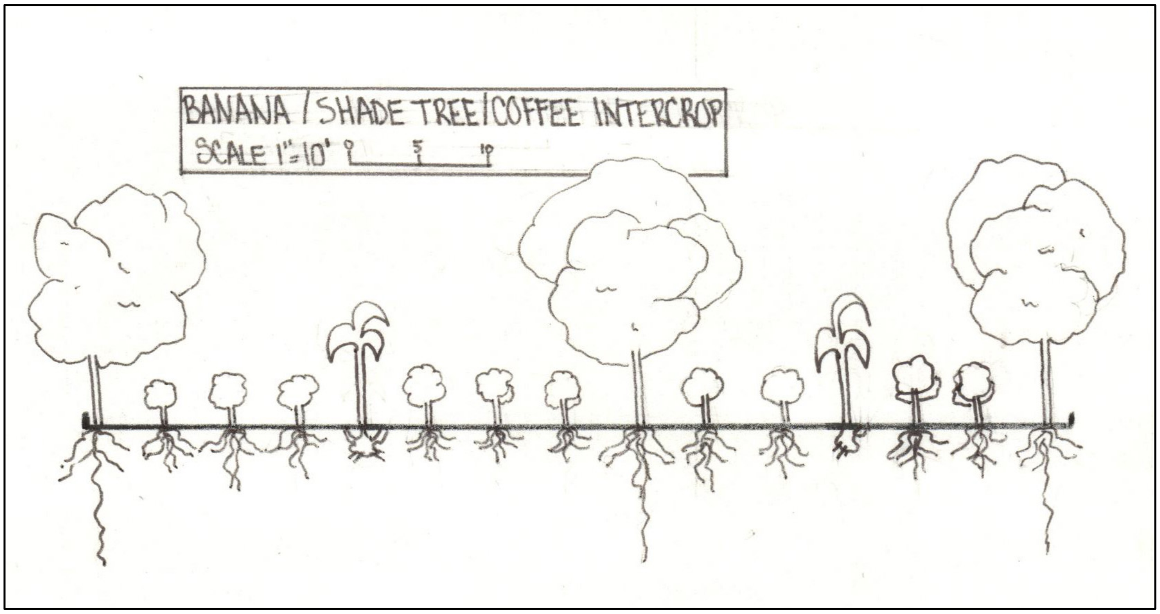

Figure 16: Coffee, Bananas, Fruit trees intercrop system.

Incorporating fruit and timber trees into the intercropping systems provides benefits such as longer tap roots that can reach nutrients further down in the soil and make them accessible to the shallower levels of soil that coffee grows in, provides greater shade and microclimate creation and management, and provides a diversity of nutrients via leaf and fruit litter. In general fruit trees increase OM (avocado and banana have the highest biomass turnover), increased yields (mango and macadamia in particular), increased PAR (particularly high when combined with avocado, guava, loquat. Also PAR increases the further away coffee is from the shade tree), lower leaf temperatures during the day and warmer temperatures during the night, decreases in humidity, wind speed, and leaf temp during the dry season, and increases in stomatal conductance (optimizes and balances photosynthetic performance), and soil moisture content (Margaret, 2008). Regarding soil nutrients avocado provides phosphorus and mango, macadamia, and banana provide potassium (Margaret, 2008). Lastly Inga, Poro, and any leguminous specie provides nitrogen through nitrogen fixation.

Coffee, Tomato, and Beans

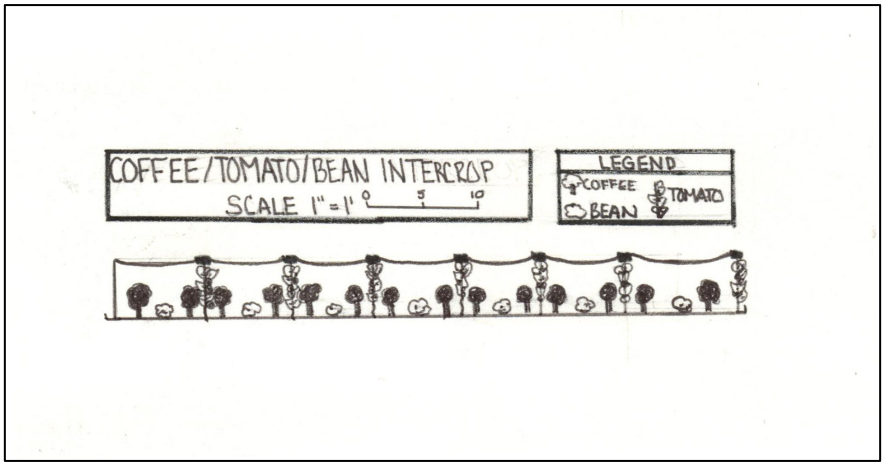

Figure 17: Coffee, tomato, bean intercrop system.

This intercropping system is best used for young coffee trees 3-5 years. The beans provide nitrogen to the soil, and the tomatoes act as shade and wind protection for the smaller trees. Together the beans and tomatoes extinguish weeds, cool soil temperatures, and supplement the money lost during replanting process (FAO, 2013). It is important to note that the tomatoes are trellised.

Coffee and Herbs

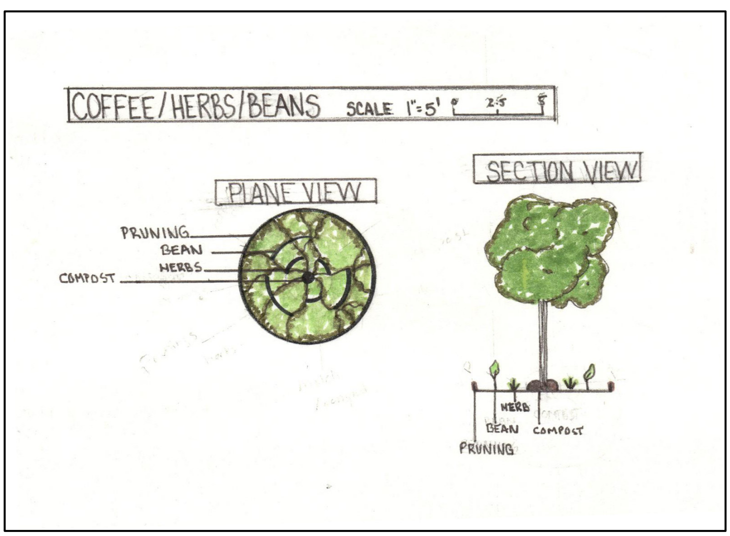

Figure 18: Coffee and herbs intercrop system.

Herbs are a great biological control agent against pests. Planting herbs around the base of a coffee tree acts similar to planting herbs around orchards, which are also sensitive to pests. Herbs both attract beneficial insects that prey on the pests as well as deter pests through allelopathic signals and toxins. When applied to young plants, mint, basil, oregano, and sage can help activate horizontal growth (Bustos, 2008)

Windbreakers /Vegetative Buffers

Relative location, Diversity, Multiple functions, Sector-planning

According to the data analyzed from the weather probe, winds are strongest during the dry season and almost completely die out during the rainy season. Windbreakers are placed in the areas of the site that receive the strongest and most frequent winds throughout the dry season. Two windbreakers will be planted, one along the retention pond area of plot 2 and one along the road boundary area of plot 3. The placement of these windbreakers should help protect the crop from the strong winds coming down from the northeast. This area is important because during the site analysis it was evident that the first few rows of trees were severely affected by the wind. Besides wind protection, the most important uses of these windbreaks are to mitigate the spread of the coffee leaf rust (which is a wind spread fungus). Vegetative buffers were added all along the property line in order to discourage the spread of coffee leaf rust from farm to farm. The windbreak locations around plots 2 and 3 and the vegetative buffer around the property lines are shown in figure 9.

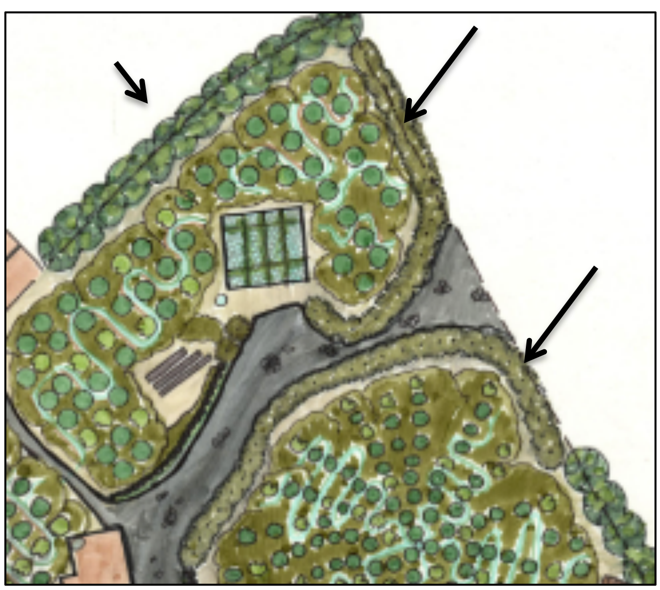

Figure 19: Shows the location of the two windbreaks on the final site map.

Despite their similarities, windbreaks and vegetative buffers are separated into two categories for two main reasons. The first is in regard to a windbreak, which can either be created using vegetation or industrial resources such wooden posts with burlap netting in between (reference appendix). Vegetative buffers will always consist of some form of vegetation and in this case, is placed around the property regardless of where the strongest winds are present.

When planting a windbreak it is important to understand how wind flows in order to plant an effective windbreak. Figure 10, designed with inspiration and acquired knowledge from an article written by Wilkinson (1999), shows the science behind a windbreak system. By planting two to five trees to block the crop from the prevailing winds and around the border of the crop, the strongest winds will remain at the highest trees while the wind over the crop becomes filtered and slowed.

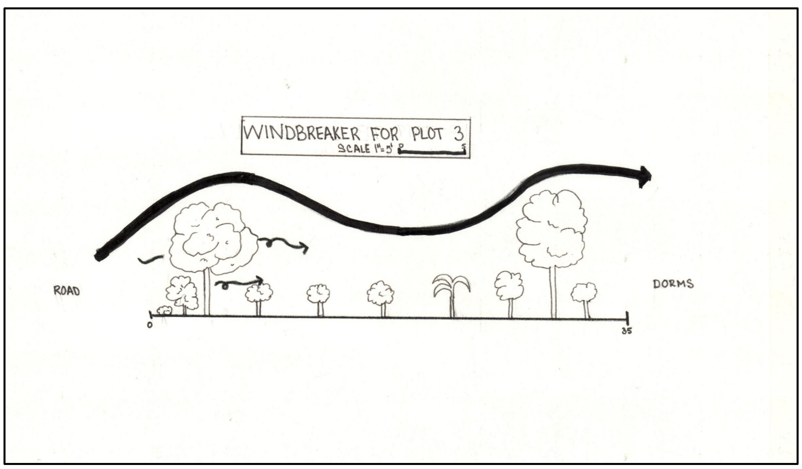

Figure 20: An example of how two trees placed together act as a windbreak in plot 3. The smaller trees are coffee and banana.

Due to the small land area of this site, this will be the most appropriate windbreak structure to use while still remaining functional. While a windbreak is needed, there remains an emphasis on the production of coffee. In addition, coffee is self-pollinated and therefore needs some form of wind. This structure will allow wind to move through the coffee crop while protecting the coffee from the strongest gusts. In order to make the windbreak profitable beyond wind protection, there will be a diversity of species including rose, mango, avocado, and berry bushes. These species will provide a diversified income through the sale and consumption of their fruit and timber. Planting rose is important because it acts as an indicator of coffee leaf rust. Rose is also susceptible to this disease and show signs of its appearance before coffee. Therefore, if the rose along the border of the plot is infected the farmer can prepare for the rust on his/her coffee trees.

Constructing a windbreak and vegetative buffers adheres to a few permaculture principles. Planting a windbreak where the wind is the strongest and most consistent is an example of *relative location.* This design also proposes a mixture of tree species, which adheres to the permaculture principle of *diversity.* Similar to the intercropping system, the abundance of tree species fosters an abundance of wildlife species which further contributes to the farms overall biodiversity. A unique feature of the windbreak and vegetative buffer is that they are part of an edge ecosystem. Edge ecosystems are valued for their high amounts of diversity, which is attributed to its placement between two greater ecosystems. For example, this site is surrounded on three sides by coffee farms. Placing a vegetative buffer between Maria's farm and these other farms creates an edge. This edge will have diversity in its own trees species and wildlife as well as, the diversity of species from both sides of its edge passing through. The windbreak performs *multiple functions* including but not limited to, protecting the coffee trees from the most damaging winds, mitigating the spread of coffee leaf rust, providing additional income through the sale of fruit and timber products, privacy, habitat for wildlife, OM and soil nutrients, carbon sequestration, and microclimate management.

Chinampas/Marsh Pond

Multiple functions, Biodiversity, Relative Location, Small-Scale Intensive System, Bio resources

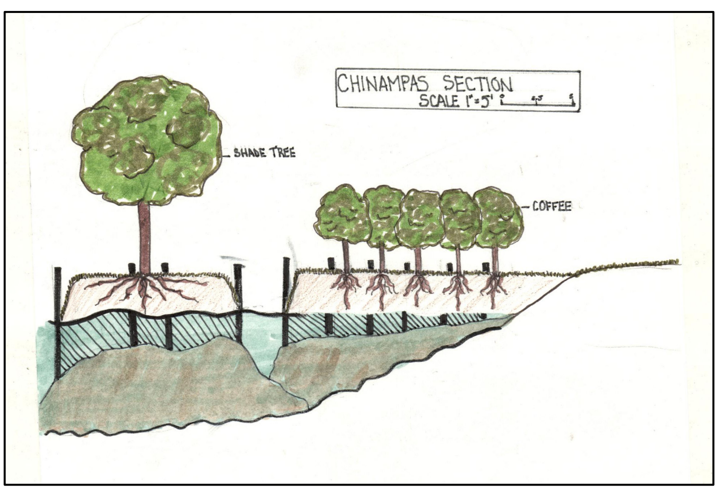

Figure 21: Chinampas system.

The marshland, which is located at the lowest point of the property in plot 1, collects the water that flows down from the surrounding steep slopes. In the final design, this wetland was emphasized and a pond was created in this location with a chinampas system for growing coffee. Chinampas agriculture is an ancient agricultural practice used by the Aztec Empire. The Aztecs built intricate fields in the drained swamps of the Mexican lake fields in order to grow food for their massive population (Popper, 2000). A similar system is applied to this marshy pond area. The chinampas system (figure 22) is the most experimental aspect of the farm and has the potential to act as an experimental plot, by testing how well coffee does with access to that much water. The coffee patch is attached to the land and stretches out into the pond. The raised land is 15ft long and 7ft across. This will allow harvesters to walk on either side to harvest the berries and conduct maintenance. If more walking space is needed walking bridges can be constructed on either side of the raised land. Currently there are bridges that connect the raised beds to each other for easier circulation between beds during the harvest season. The individual tree acts as a shade tree for each bed. Other features around the pond include a bamboo patch for holding and distributing water throughout the dry season while acting as a timber source and windbreak, and a raised bed for waterfowl habitat.

The reasons behind the application of this element are to help coffee adapt to a changing climate by planting it in an area where there is a constant supply of water, fertilizer, compost, and pest control, introduce a new technology to coffee farming, and make use of a space otherwise unproductive in terms of coffee yields. In general the chinampas system is said to protect the crop from pests, resist droughts and floods, aids microbial activity in the soil by maintaining moisture content, creates fertile soils, conserves 80% water used in agricultural systems, and compared to other agricultural systems is 7 times more productive for every m2 (Laado, 2013). This element addresses the *multiple functions* principle by, acting as a water catchment system capturing the excess water runoff from rain barrels, slope, and diversions channels, creating habitat for wildlife, securing a supplemental water source for the processing plant in case of an emergency, adding aesthetic value to the property for the tourist and hostel residents, and fostering *biodiversity* of new aquatic flora and fauna species. Creating a pond where water already natural flows is an example of relative location or adding elements where they make the most sense. Lastly, chinampas is a small-scale intensive system that stacks many elements and functions to maintain a self-reliant system.

Compost-vermicomposting

Multiple Functions, Biodiversity, Relative Location, Energy-efficient planning, Small-scale Intensive Systems

Vermicomposting is a proposed method of OM application to increase soil nutrients. This method of compost was chosen for two reasons. One due to Maria's mention of it in her goals and two because it is the most powerful organic fertilizer in terms of nutrient richness (Advait). Studies say that a farmer only needs to apply 20% vermicompost in order for it to sufficiently fertilizer a plant (Advait). In addition, using this method of fertilizer avoids the need for chemical fertilizers and pesticides. Avoiding chemical application allows soils and the microorganisms living within the soil to continue to grow in a healthy environment, and with healthy soils we can expect healthy coffee trees. Not only is it an organic fertilizer that fosters productive soil but by applying it in such small increments, it allows the farmer to lengthen the lifespan of this crucial resource. This method addresses multiple permaculture principles such as *biodiversity, multiple functions,* and use of nutrient resources. Not only are worms, a bio resource, being added to the soil ecosystem but an increase in soil organisms through the OM is also considered an increase in biodiversity. This feature or element in the overall system serves functions beyond nutrient-rich organic compost. It collects waste, creates biodiversity, and increases self-sufficiency of the site.

Requirements:

- Temperatures 60-85 degrees
- A roof to keep away direct sun, rain, birds
- Concrete floor and wall
- Bedding: Shredded paper, cardboard, manure, or any carbon-based material
- Starter worms (1/4-1/2 kilo)
- Water

- Food

In the design the proposed area for the vermicomposting is in the old sugar cane processor. This area was chosen because it is close to the main food source for the worms (the coffee cherry parchment) and has similar infrastructure (concrete floor and wall) used in commercial Vermicomposting. In addition, this processor has a working water spigot that pumps water into the concrete basins. One of the basic permaculture principles is *Relative Location.* This encourages the idea of placing design features close to the areas they are being used for in order to avoid unnecessary labor and energy. By using an abandoned sugarcane facility, which already has a water source, is close to the main food source, and in close proximity to all four plots, this feature adheres to this principle. Another way to make the process more efficient is to reroute the disposed cherry parchment directly into the sugarcane facility instead of, dumping the cherry down the slope and then shoveling it into bags for transport. Rerouting the dumping site adheres to the principle of *efficient energy planning* which suggests harvesting wild energies (wind, water, wood, topographical features like hillsides) to lessen the need for fossil fuel energy sources.

If this area proves to be an issue there is another location suitable for vermicomposting. This is the building located closest to the retention pond just outside of the property line. This building is located up the hill from the coffee cherry parchment dump. This location is good because the land is flat, it has a roof, there is room for compost bins, and it is located closer to plot 2 and 3. The only issues would be water supply and movement of the cherry cascara up to the compost bins.

The process:

A good first step is to have the appropriate materials for the size of operation (Advait). Buying starter worms is the next step. Starter worm species include *Eisenia fetida, Perionyx excaratus, Eudrilus eugeniae,* and *Jampito mauritii.* Worms eat ½ of their weight in food per day so consider being able to provide that weight in food each day. For this study, the worms will be fed mostly with the coffee berry parchment. Other food items include, coffee grounds, papaya, banana, and mangos, and decaying leaves or plant matter. The bins should include bedding as the bottom layer, the worms above the bedding, food on top of the worms, and then alternating layers of bedding-food-bedding-food as you continue. It is important to keep the bins moist, which can be watered as well as covered with a burlap sack to hold in moisture. Moisture helps cool the center of the bin, which can overheat. In order to harvest, a bright light is shined onto the worms or the cover is lifted so that the worms move toward the bottom of the bin. Once the worms have retreated from the light, the top layer of compost can be removed and the process continued until all available OM is gathered. Some suggest collecting the “leachate” or the water that leaked through to the bottom of the bin as an added fertilizer (Advait).

Rain Barrels

Energy-Efficient Planning, Multiple functions, Small-Scale Intensive Systems

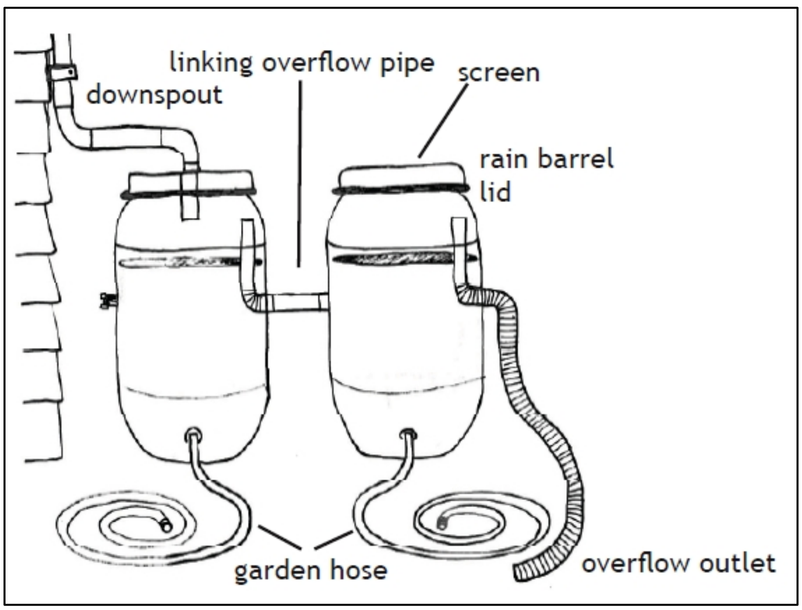

Figure 22: Rain barrel diagram sourced (VT DEC, 2013).

Rain Barrels are placed throughout the site in order to capture the rainwater that flows off of rooftops. The diagram above shows how rainwater is collected and distributed. The water enters the barrel, which is connected to a spigot that distributes water through irrigation pipes or building piping systems. Any overflow from the rain barrels is diverted into drainage ditches and/or a tank depending on the location. Rain barrels can be purchased or made using local materials. Such materials include a new trash barrel, wooden barrel, or any container that can hold at least 50 gallons. In addition to the container, a drill, spigot, and piping will complete the materials list. Roof calculations provide insight into the amount of water that can be collected off of the roof. The calculated amount of roof rainwater translates to the amount of rain barrels needed to capture this water. Below is the equation:

Sq2 X H=Vl of water

H= amount of rainfall (in) during the dry and rainy seasons

Rain barrels address *multiple functions* by collecting wastewater, irrigating a landscape, and providing water for human facilities. It is an *energy-efficient technology* because this system provides the resources necessary to supply water on site without using any additional, fossil fuel based energies. In addition, because the water is captured on site and distributed back to the site, this creates a *small-scale intensive water system.*

Retention Pond

Bio resources, Biodiversity, Multiple functions, Energy-Efficient Planning

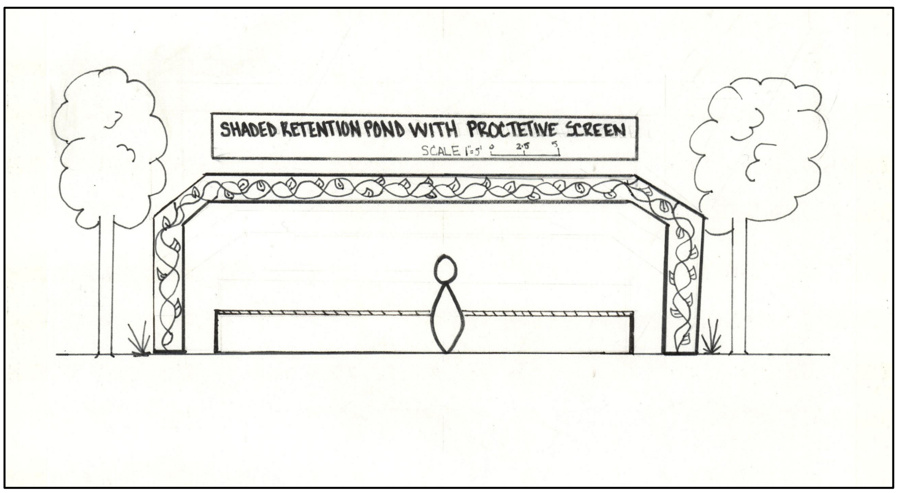

Figure 23: Retention pond.

The retention pond is a 30,000 gal tank that is located at the highest point of the farm. Its main purpose is to provide water to the processing plant. Currently, the tank has zero protection from the sun, leaf debris, and people. Without protection from the sun, the water that could be used for the processing plant is evaporating. To maintain the most amount of water throughout the dry season, when water is most scarce, a vegetative trellis was placed over the tank. This trellis is a wooden structure with BLANK growing over, allowing rain to enter during the rainy season (with some pruning) and water to remain in the tank during the dry season. A protective screen was laid over the tank in order to catch any leaf litter that may fall from the trellis as well as act as a protective barrier to the people working or visiting this area. The vegetative trellis serves *multiple functions* by shading the pond, creating habitat, and fostering biodiversity. This element uses flora as a *bio resource* to solve the issue of evapotranspiration. Using this bio resource saves on energy costs resulting in *energy-efficient planning.*

Terraced Slopes

Relative Location, Bio Resources, Biodiversity, Slope Planning

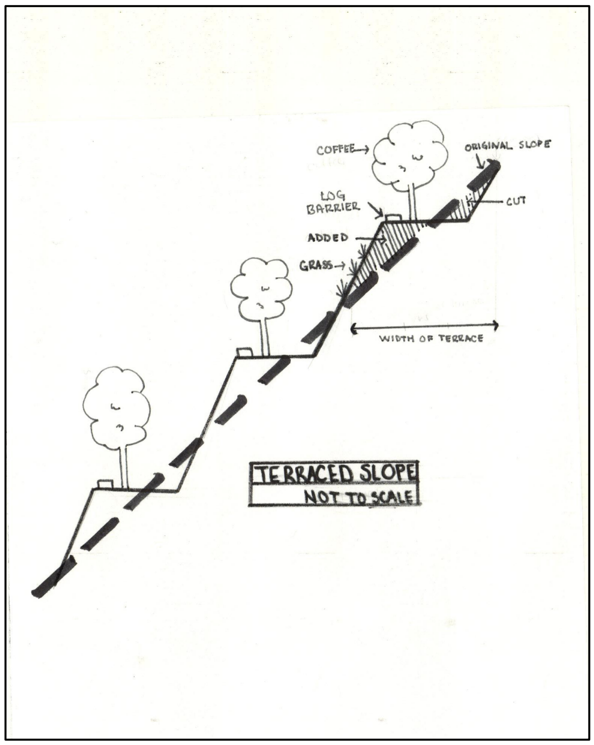

Figure 24: Terraced slopes.

There are locations on site where coffee is grown and harvested on steep slopes. As a harvester, walking along these steep rows is challenging. In addition, water rushes down the slope collecting and carrying topsoil, the most nutrient-rich layer of soil, down with it. In these areas, the impact of erosion and water loss was evident regarding dry, crumbly topsoil, stressed coffee, and slippery grounds. To address this issue, terraces were applied. Terraces are cuts made into the slope that create a staircase like feature.

This technology helps to slow soil erosion, slow water flow and infiltrate water to the coffee roots, recapture topsoil, create OM, and create a safe walking space for harvesters.

Figure 24 shows coffee growing on the ledges of the terrace. At the edge of the terrace is a log (retrieved from pruned branches throughout the farm) that collects any debris coming down from the terraces. The collection of debris creates OM for the coffee trees located on the ledges. These logs also help with the collection of water and soil nutrients, slowing the flow and allowing them to infiltrate into the ground. Lastly, grass is grown on the small slopes in between the terraces in order to help maintain shape and further prevent erosion.

This specific terrace style is called *reverse-sloped benches*, which is useful in humid climates (FAO, 1989). The FAO, suggests small farmers to use this terrace style for collecting runoff on a 7 to 25° (12-47%) slope (FAO, 1989). Though Maria's operation as a whole is large, this specific plot is small and one of its main issues runoff and soil erosion. Therefore, this style seems most appropriate. The FAO also suggests implementing a terraced landscape 1/3 at a time in order to help the farmer deal with the costs and labor of building a terraced landscape (FAO, 1989). For this particular site and with coffee as a perennial crop, the implementation of this feature may work best if it is done all at once. The area where this is applied is small in comparison to the main coffee producing plots and in need of new trees. Due to these factors, the terracing could occur without the economic strain.

Terraced slopes address *slope planning,* which is a principle unique to this particular element. The issues of slope are addressed using this terraced system, which if done correctly should help manage the issues associated with sloped landscapes such as soil erosion and water loss. The terrace system has multiple functions such as erosion control, water capture and distribution, and *biodiversity* with the implementation of grasses along the slop sides. *Bio resources* include the logs that capture OM and the reconstruction of the land, which helps manage the flow of water.

Diversion Channels and Swales

Energy-efficient planning, Multiple functions, Biodiversity, Bio-resources

A swale (see appendix) is a permaculture-based technology that essentially collects, holds, and slowly distributes water throughout the landscape over time. In order to create a swale one digs channels into the soil along contour. For this project it was difficult to find a topographic map that showed contour lines specifically of the property. As a result, swales were not applied to this space at this time however, if at some point a topographic map is found or created then swales are the most viable option for managing water collection and distribution throughout the site.

In the meantime, this project suggests the use of diversion channels, which are applied to all four plots. During the site analysis, water was found flowing downward in a straight line from the various water sources throughout the property including, outdoor washing facilities, natural springs, and the natural flow of rainwater down a slope. To respond to these natural water sources as well as the addition of new water facilities, diversion channels begin at these sources and continue to weave throughout the plot. The channels are dug out with water loving plants planted along the edges to help maintain structure and maintain water in the channel so it can distribute slowly over time. The basic idea behind this method is to distribute water evenly to all coffee trees and to avoid erosion of a single area. Once a topographic map is found, this system can be incorporated with the swale system.

These swales address the *multiple functions* principle in that they collect and hold water within the landscape, slow erosion by properly managing the flow of water, and irrigate the entire plot of coffee by winding through the landscape. By utilizing gravity to move water through the entire landscape a swale system can also be considered *energy-efficient*.

Infiltration Steps/Permeable Pavement

Multiple functions, Biodiversity

Infiltration steps will replace the steps located in plot 4 and by the office/lab/classroom building. These infiltration steps will be surrounded by shrubby plant species that are water loving. Using these steps is important for keeping water on site as long as possible by infiltrating the water into the ground versus onto the road. They will foster *biodiversity* by incorporating various plant species, address *multiple uses* by slowing the flow of water, keeping the water within the soil as long as possible, slow and even stop soil erosion, create an easier walking area for workers and tourists, and add aesthetic value. To learn how to create these steps reference the guide in the appendix.

Another mechanism for maintaining water on site is through permeable pavement. The site currently has concrete slabs for the main entrance road. This is to manage the heavy rains during the rainy season so that vehicles can still access the property without getting stuck on muddy roads. Replacing the main entrances with permeable pavement will allow vehicles to continue traveling in and out of the site during the times of heaviest rains while allowing the water to stay on the site for as long as possible. Lining the roadside and center of the road with small bushes will increase *biodiversity* and help keep the water and basic iron/nutrients in the soil instead of the industrial drainage ditches. In addition, having a center row of bushes will save money by decreasing the amount of pavement needed. The permeable pavement also allows for grass to grow in between the pavers. This space could be planted with clover, thyme, or any type of bee lawn in order to attract pollinators. The bushes along the roadside could also be pollinator species. Lastly, applying permeable pavement in this climate is good for the longevity of the materials. With similar year round temperatures and rain as the main precipitation, there are little climatic features that will degrade the pavement sooner then its lifespan. To view a photo and section of permeable pavement reference the appendices.

Hostel and Dorm Features

Multiple functions, Redundancy, Small-Scale Intensive systems, Energy-efficient Planning

One of Maria's main goals is to encourage a paradigm shift when thinking about agriculture. She wants her farm to act as a model or showcase of alternative agriculture technologies in order to inspire a shift in the way people think about coffee production and agriculture as a whole. Currently, Casa Ruiz facilitates tours that visit this specific site. In addition to having people visit her farm on tour, Maria wanted to create and maintain a hostel for tourists, researchers, students, or anyone interested in her farm. In response to this request, a hostel was created using a section of the dorms currently used for workers as well as adding additional housing via tree houses. Three tree houses were suggested for this project however more could be added over time. The reason behind tree houses as the main housing system for visitors stems from the lack of land area available. Since the main priority of this land is coffee production, taking up the space for housing would result in a loss of production. A permaculture principle that addresses this issue is the idea of *redundancy.* In this situation, taking advantage of vertical space will allow for a shade tree that could either produce fruit, nitrogen fixing, or timber, a living space, and an area for cooking and community engagement. Below is a design concept of what a tree house would look like and the stacked functions it presents.

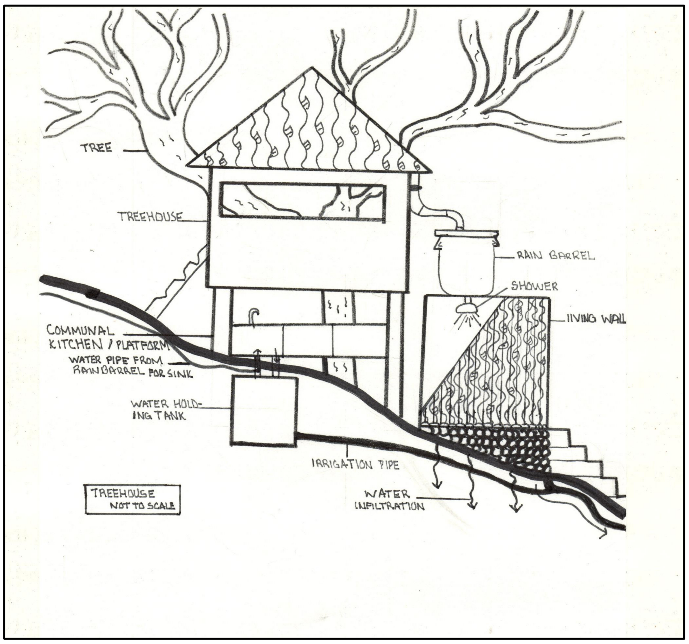

Figure 25: Tree house setup for Hostels.

The tree house acts as both a living space and communal space. In this concept, the bottom half of the structure is devoted to the communal kitchen for all members of the hostel to use. The excess water used in the sink is stored in an underground water tank, which is attached to an irrigation pipe that feeds the diversion channels. The shower that runs off the side of the tree house is fed through the rain barrel, which collects water from the roof. The excess shower water is then filtered through the stone pebble floor and through the main drain, which is connected to the same irrigation pipe as the water tank. There is a vegetative wall on the roof of the house as well as the shower. There are also vegetative walls around the shower for privacy. A rain barrel from the dorms provides water to the sink and the cooking stoves are fueled using firewood from on site. The housing portion of the tree house is on the top layer.

It is important to note that this is only a concept depicting some of the stacked functions the tree house can inspire. Other functions could be a two story housing setup, an additional communal hangout area underneath, outdoor classroom, growing area, etc. Composting toilets could also either be attached to the shower setup and further away with with a similar vegetative barrier. Further details are needed for exact measurements, what trees to use for this setup, and how many to include based on demand. If trees need to be planted in order to build the tree houses that a temporary built house on stilts could be made when waiting for the trees to grow.

Garden, Wash, Compost element

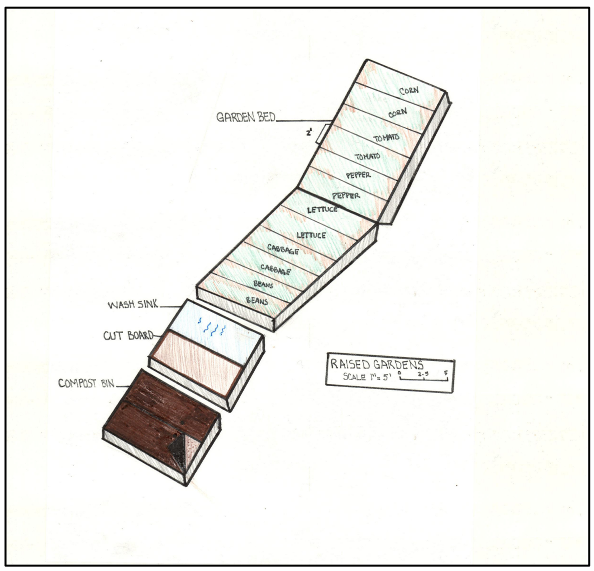

Figure 26: Garden, Wash, Compost.

The feature represented in the Figure ABOVE is a garden, wash and cut station, and compost station. This feature acts as a barrier between the hostel and worker dorms while providing opportunity for interaction and on site food production and consumption. The crops chosen for this garden are a representation of some of the main staples of the Panamanian diet (corn, beans, tomato, lettuce, peppers) that I observed from studying abroad. The wash and cut station is available for processing these vegetables and the compost is for disposing of any waste. There are two of these structures placed side by side (see schematic plan for detail) one for the hostel residents and the other for the worker residents. These garden plots are located in zone 1 which is where most human activity occurs. It is also placed in the sunniest section of plot 4. Together the placement of this feature allows for prime growing conditions and attention to its weeding, harvesting, fertilizing needs.

Farm Stand/ Reception/ Communal Spaces

The space between the lab and the dorms was originally designed to be an outdoor classroom. However, due to tunneling winds, which make it hard to teach and listen comfortably, it has been under utilized. A proposed reuse of this space is to have the hostel reception in this area along with a farm stand that sells the variety of fruit grown on the farm. This farm stand will not only provide income through the selling to tourists and hostel residents but it will also allow for further connection between visitors and land through the act of directly consuming its products. This space is located in zone 1, where activity from lab work, tour guides, and workers occurs. Placing the farm stand and reception in this location will make this the central hub of the farm with little change to the current flow of circulation. This is also adjacent to the dorm style hostels and the tree house hostel, allowing for easy communication between the farm and guests.

In order to address the wind tunneling issue, the already existing chicken wire walls will transform into vegetative walls. The leafy vines will help block the impact from the strongest winds while allowing some wind to pass through for cooling purposes. The reception area and hangout spaces were not heavily detailed inspiration can be gained through the visitation of other hostels around Boquete.

Dorm Improvements

While it was a goal to incorporate a hostel in this design, it was also important to maintain on site housing for the harvesters and workers. The section of the dorms not set aside for hostel space was designated to the harvesters and workers. There is currently a washing station on this side of the building, which was improved with vegetative roofs, rain barrel collection and distribution to the shower and cooking facilities, improved cooking facilities through the creation of an outdoor kitchen and food prep station similar to the hostel setup except for the two stories. There is also a hangout location for the families to gather and spend time together.

Chicken coop

Bio Resource, Multiple functions, Biodiversity, Small-Scale Intensive System

There are two chicken coops on the property. One located in the zone 1 sections of plot 3 and one in plot 4. These are located here because they need and will receive most attention within these areas. Chickens are an incredible resource for any farming system. The niche analysis, an analysis of the needs and yields an element of a system can provide, below helps to shows how many yields a chicken can bring to a system. The yields highlighted in bold are considered the most important to this farm although this is up to interpretation.

Table 1: **Niche Analysis of a chicken.**

Niche Analysis of a Chicken	
Needs	Yields
Water	Eggs
Food	Waste management
Bedding	Meat
Space	Heat
Shelter	**Pest control**
Sanitation	**Tillage**
Other chickens	**Fertilizer**
	Education
	More chickens

There are many designs for a chicken coop some are designed to move throughout the landscape while others are more of a static, traditional layout. For this farm a design was created with inspiration from Mollison (2011). The structure adheres to the needs of a chicken while making collection of its yields quick and easy. In addition, the structure allows for water catchment and increased bio diverse vegetation.

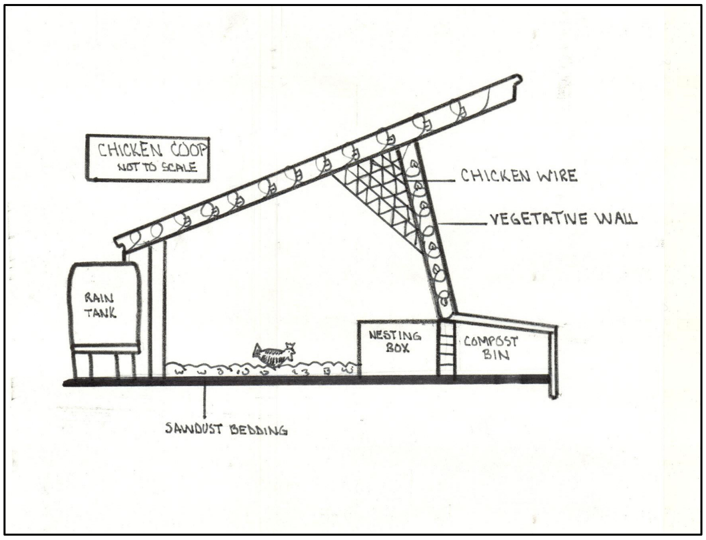

Figure 27: Chicken Coop.

Nursery

Relative Location, Zone-planning

A nursery was added in the sunny area after the farm stand reception area. This nursery is for starting specialty varieties of coffee trees. The nursery is structured similar to traditional coffee nurseries, which are rows of individual planted trees in small plastic bags. This element was placed in zone 1 so that it can receive the attention it needs. It is also placed close to the coffee, tomato, bean intercropping system, which is designed to benefit young tree. Though more research is needed, another idea coffee propagation is indoor seed starting with grow lights. This could be done in the lab.

Solar Panels

Redundancy, Energy-Efficient Planning, Small-Scale Intensive System

Solar panels are added on the roof in order to capture the wild energies of the sun. The rooftops were noted as some of the sunniest areas on the property. Placing solar panels in this location adheres to *redundancy* principle in that the energy they are creating is for the infrastructure supporting it as well as gathered from the sun. The energy from these panels is then used for the office, hostel, dorms, processing plant facilities. This element is *energy-efficient* in that it creates energy from wild energies. From receiving energy to turning on a light is an example of a *small-scale intensive system*.

Phase Plan

The following table splits up the detailed designs into implementation phases. A phase plan is important for showing the process of permaculture design. Permaculture requires close attention and hard labor in the initial implementation phases. However, once everything is in place, a low-maintenance, long-lasting coffee management system is created. With so many detailed designs it was important to split up the designs according to when they are most likely to be completed. The elements in years 1-5 include initial planting, re-planting, and simple infrastructure that can by implemented after funding is acquired. The elements in 5-10 require heavier labor, more resources, and more money. Fortunately, this is also a time when the trees planted in phases 1-5 years begin to grow big enough to be effective. Depending on the progress made in years 1-10, the third phase, years 10-20 should result in a low-maintenance functioning system. Year 20 and beyond refers to the evaluation phase providing time for any adjustments, data collection from on-going experiments and research or the creation of new research projects, and any required additions in response to changing climate and land use. This phase plan is adjustable and certain elements may be moved around once implementation begins however, it is a good guide to start with.

Table 2: Phase Plan

Phase Plan (years)				
	1-5	***5-10***	***10-20***	***20+***
	Rain Barrels	Effective windbreak/vegetative buffer/living walls	Full functioning system with low maintenance	Make adjustments depending on evaluation
	Solar Panels	Tree houses		
Proposed Element	Planting of new trees for intercropping and	Pond formation and chinampas		

	vegetative buffers			
	Burlap windbreak (before trees are tall enough)	Terraced slopes		
	Nursery			
	Hostel conversions			
	Farm stand/reception			
	Chicken coop			
	Trellis			
	Vermicomposting			
	Diversion channels/Swales			

Materials and Resources

Two of the biggest limiting factors for successfully completing a permaculture design are time and money. A goal of this project was to make changes that were precise (to save on time) and economically viable. Though there are elements of this design that require, labor, materials, time, and money there are available resources that can help with the process. Such resources include but are not limited to, community involvement, farmer cooperatives, grants, school groups, service programs, on site alternative incomes via hostels, cash crops, and the production and processing of high-valued specialty coffees. School groups and service programs encourage students to pay for educational learning experiences through the acts of service work and community service. If connections are made between this farm and those programs, students could come and build some of the proposed elements. Grants provide money that may be applied directly to building the proposed elements or help supplement the times where productivity is stunted by the building process. Diversified incomes on-site provide long-term solutions for a steady flow of income and financial stability if one income source fails.

There are many elements proposed in this final design. Besides the intrinsic benefits received from these elements they still need to be put in place. With help from the site analysis of resources on the property, a lot of these materials can be found on site. To start, the wood for the tree houses, chicken coop, trellises, chinampas bridges, and OM collecting logs can be retrieved from timber trees already found on the property and the proposed trees (bamboo especially). Other resources include excess leaf litter and prunings that provide OM material for on site compost facilities. The existing and proposed fauna on the farm such as, ducks and chickens provides fertilization, tillage, food, pest management and more (See table 1). Energy for the buildings can be efficiently sourced from wild energies such as the sun and rain via solar panels and rain barrels. The wind could also be harvested via a wind turbine. This was not included in this design due to the shadow and noise impacts of a wind turbine in small spaces.

Discussion

Permaculture is present in this project from start to finish. The entire process of design was done following the design process of permaculture. The goals articulation, site analysis, A & A summary, design concepts, and final design are processes representative of permaculture. The mindset used throughout this design was inspired by permaculture ethics, which exemplifies "Earth Care," "People Care," and "Fair share" (Morris, 2014; Holmgren 2002). Earth care is represented in the new management practices of vegetation, soils, water, and wildlife on the property such as the planting of fruit and timber trees, creation of ponds and chinampas systems, soil remediation via compost, addition of shade trees and intercropping systems, and additions of organic matter. The space addresses People Care through the additions of a hostel, dorm improvements and improvements on harvesting accessibility and safety for the workers living and working on site, and onsite access to food via the products received from the gardens and fruit trees. Fair share is represented through runoff management, habitat creation, and a decrease in fossil fuel dependence with help from solar panels and rain barrels. These elements demonstrate fair share by managing the farm's inputs and outputs into the surrounding environment so that they improve the greater ecological system the farm is a part of.

The design features incorporate the eight most important permaculture principles, 1. Relative location, 2. Multiple functions, 3. Redundancy, 4. Cycling of energy, 5. Nutrient resources, 6. Small-scale intensive systems, and 7. Zones of use, 8. Diversity (Morris, 2014; Mollison, 1988; Falk, 2013). These principles were referenced and adhered to in order to make a system that is truly permaculture-based. As a result, this design proposes a self sufficient, resilient coffee farm that is both a model and inspiration to fellow coffee farmers.

When referring back to the original goals for the site, some were met and some need more work beyond this project to be fully satisfied. Although the final design meets a majority of the initial goals, implementation of the proposed elements is needed to finalize these goals. Referring to Maria's goals, the final design proposes a site that is highly specialized, innovative, and experimental with incorporated educational opportunity and alternative methods to inspire a paradigm shift in the farm's visitors. A hostel was created and the additional design elements are systemic and positively economic. The goals of the researcher were also met except for soil understanding and understanding indicators on the farm.

The goals that were unable to be met completely was a result of time and knowledge limitations. Surpassing soil and water management to reach soil and water understanding was difficult with the amount of time and expertise available. To go further, more research is needed to understand the soil and water properties specific to the site. As a result, the overall design focuses more on the management of soil and water with room for more education on these topics. Another goal that needs further research is planting high valued species. Similar to the limitations of soil and water understanding, there was little previous understanding of plant science. Again due to the time limitations, a general plant list was created however more research is needed specifically from the site as well as from the literature about what plant species are most appropriate. One success in this realm is the intercropping of banana and coffee. There is a decent amount of literature on the subject and so it was easy to determine whether it was a viable option for the site even without complete soil and water understanding. Determining indicators was also difficult without a greater understanding of soil, water, and plant science. By understanding the science behind these elements, discovering helpful indicators that expose potential issues will be easier to determine.

Lastly, precision was addressed through the process of diversification. Mistakes are inevitable especially in the process of design where everything is and should be constantly changing and revolving. In order to prepare for mistakes to occur without stressing the economic and timely success of the farm, each proposed element was supported by many others elements to eliminate the impact of failure. Even if an entire proposed element were to fail, the farm will still have at least three other options for remaining functional and profitable. For example, if the chinampas system yields more harm then good, the farm still has the chance to succeed through its other elements such as intercrops, terraced slopes, etc. Viewing precision in this way takes the pressure off of making mistakes and instead creates opportunity to learn from them.

Research suggests that climate change will increase temperatures threatening the physiology of the coffee plant and the increase of pest and disease incidence, deregulates rainfall patterns, increases wind, and increases severe storm frequencies (CoffeeClimate, 2015). This design recognizes these challenges and uses them as a chance to create a unique and working coffee production system. Technologies such as diversified and edible windbreakers help handle the increase of wind and increased incidence of leaf rust disease. Applying windbreakers to prevent the spread of leaf rust, shade trees to create a beneficial microclimate, and using organic fertilizers coincide with the literature's suggestions for managing a healthy ecosystem that is able to withstand leaf rust (Avelino, 2004). Shade tree microclimates, retention ponds, rain barrels, and diversion channels address changing water patterns by supplying water throughout the year. Shade trees address leaf rust disease by breaking up the rows of coffee and slowing the spread from coffee tree to coffee tree as well as creating habitat for natural enemies (Samnegard, 2014). Organic onsite compost addresses current nutrient lacking in the soils while maintaining soil moisture, diversity, and nutrients. This practice also avoids the need for chemical fertilizers/pesticides, which are harmful to the environment (Martinati, 2008). Along with organic compost is intercropping systems with coffee and fruit and timber trees, vegetable crops, and herbs. Not only does this diversify income and diet (for workers and tourists) but it also allows for mutually beneficial relationships between two or more plants. Bananas and coffee is a main method of intercropping inspired by the research done in Uganda (Bio.Int.; CGIAR, 2011; CGIAR, 2013; CIALCA, 2006; Nasaira, 2015; Peterson, 2012; Van, 2011). Intercropping with herbs and fruit trees is another feature of this design and was also inspired by the literature (Bustos, 2008; Mithamo, 2008). Solar panels and rain barrels harvest the wild energies onsite. A hostel and improved worker housing provides greater benefit to the people directly involved with the site. It also provides opportunity for other people to witness permaculture applied to coffee systems.

Though this project succeeded in a permaculture-based, self sufficient, and resilient coffee system design, there is room for improvement. When designing any site, it is important to spend as much time as possible on site. Permaculturalists suggest a minimum of ten years on site and even then there is still so much a designer will not understand. Spending this time gives the designer an understanding of the main cycles and features of the landscape. For this project I was only able to spend a week on the farm during one season. Even spending a full week analyzing this plot, I could feel the time limitations when trying to design across seasons and years. I simply did not know enough about the landscape's nuances and seasonal changes to understand how best to tackle and identify the problems. This is where Maria became the most important part of this design. Although I could not spend a lot of time on the land, she has spent a majority of her lifetime studying and working on this land. Asking her questions and hearing her observations of the land overtime and including these with my own observations, made the design more effective and precise.

Lastly, designing requires a person to remain humble, flexible, and adaptable. This landscape was not something I had previously studied or worked with. Because no site is the same, no matter how much design experience I had before this project or how many design professionals I spoke with, the site was unfamiliar. As a result, the process was constantly changing which required personal flexibility and adaptability.

Conclusion

Coffee leaf rust and climate change are two epidemics racing through coffee producing countries, threatening an end to this crop. This thesis uses the theory and practice of permaculture in order to design a coffee management system for a coffee farm owned and run by Maria Ruiz of Casa Ruiz in Palmira, Boquete, Panama. The final product of this thesis is a coffee management design for Maria's plot that addresses a majority of the initial goals set by Maria and the researcher. As a result, the design ultimately promotes resilience to coffee leaf rust and climate change. Due to time and money constraints, this thesis only covers the design aspect of this project. Further research on some of the proposed elements and implementation of the design is needed in the future.

Permaculture design is not widely applied to tropical climates and coffee management systems however the potential is there. After completing this project, the design process seems applicable to farms of all sizes. This process, though easily replicable across farms, also allows for the design to be site specific with help from the site-specific goals articulation and site analyses process. The most limiting factors of permaculture design determined throughout this process are time, money, and the ability to take the risk of changing the farm's current management system. One way to address the limiting factors could be to create supporting governments that subsidize the transformation process. Another way could be through community involvement, grant writing, networking to student service-learning based programs, and emphasizing the use of the resources found during the site analysis. It was evident through the hard work put into this project, that as long as the farmer is willing to take the initial risk of transforming his/her farm under the umbrella of Permaculture, the limitation of time and money can be overcome.

In addition to the final design, this thesis acts as a model that can be referred to by coffee farmers around the world in order to increase the application of permaculture in coffee production systems. A few key recommendations are listed below for farmers who want to continue the use of permaculture design in order to combat the large-scale issues that coffee production faces. These recommendations stem from the lessons learned from this study. They are as follows:

1. Spend time (a minimum of ten years) on the landscape during each season.
2. Make observations regarding the site analyses topics throughout your time on the farm.
3. If you are unable to spend ten years on the site, speak with people who have spent time on the site, look up the history of the land uses changes, and speak with the people who currently use the land (pickers, owners, service).
4. Study tropical plants, soils, and coffee ecology.
5. Remain humble while learning site characteristics and the design process.
6. Share your permaculture designs to provide more resources of tropical permaculture to the general public.

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Appendices

Appendix A: Plant Lists

Plant Lists		
Herbs (Plant during dry season)	**Vegetables**	**Fruits**
• Aloe Vera • Basil • Brahmi (an amazing medicinal herb) • Chillies • Cilantro • Cinnamon (the bark of a tree) • Cloves (flower buds of a tree) • Comfrey (medicinal herb and great soil improver) • Coriander • Galangal • Garlic Chives • Ginger • Kaffir lime (a citrus tree, the leaves are used as a herb/spice) • Lemongrass • Mint • Nutmeg (another large tree) • Oregano • Parsley • Pepper • Rosemary • Stevia (a natural sweetener) • Thyme • Tumeric • Vanilla	• Amaranth (use leaf amaranth like spinach) • Arugula (rocket) • Asian Greens • Beans (try snake beans and winged beans in the tropics) • Bell Peppers • Cabbage • Capsicum (that's the Australian name for peppers) • Cassava (starchy tubers) • Ceylon Spinach • Chard (silverbeet, similar to spinach) • Chinese Cabbages • Chilli Peppers • Cucumbers • Eggplant (aubergine) • Endive • Kang Kong (water spinach) • Lettuce • Luffa (angled luffa is a great zucchini substitute) • Okra • Peppers • Pumpkins • Radish • Rocket (arugula) • Silverbeet (chard, similar to spinach) • Squash • Sweet Corn • Sweet Potatoes (instead of normal potatoes)	• Acerola Cherries • Avocados • Bananas • Barbados Cherries • Chashews • Carambolas • Citrus (general) • Custard Apples • Dragon Fruit (Pitaya) • Guavas • Grapefruit • Grumichamas • Jaboticabas • Jackfruit • Kakadu Plums • Lemons • Limes • Lychees • Mangoes • Mulberries • Oranges • Papayas • Passionfruit • Pineapples • Rambutans • Sapodillos • Soursop • Star Fruit • Watermelons

	• Tomatoes • Water Chestnuts • Zucchini	
Note: Plant list sourced from http://www.tropicalpermaculture.com.		

Plant List Continued	
Timber Trees	**Nitrogen Fixing/Fruit Trees**
Mahogany	Inga**
Cedar	Poro **
Gabriela Jimenez	Durian
Pablo Siles	Guava
Eduardo Somarriba	Lychee
Bruno Rapidel	Cinamon
Oscar Bustamante	Avocado
Charls Starver	Lowchill stonefruit
Rose	Citrus
Rubber	Macdamia
	Sugarcane
	Mango
Information sourced from (Maragret, 2008; CIALCA, 2006; CGIAR, 2011, FAO, 2013)	

Appendix B: Infiltration Steps Guide

INFILTRATION STEPS

~retrofitting steps to control erosion on paths~

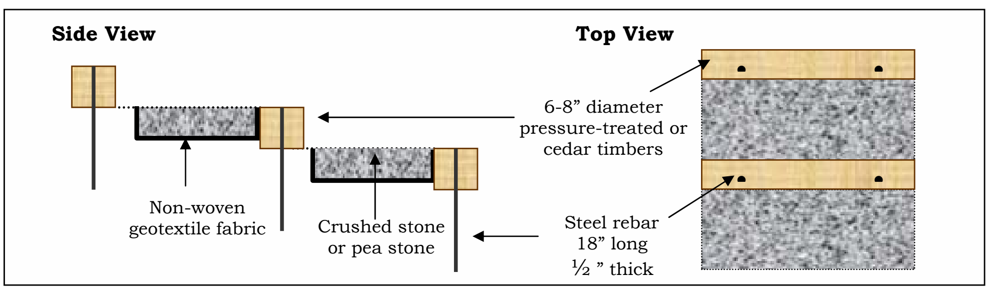
Portland Water District

Purpose: Infiltration steps use crushed stone to slow down and infiltrate runoff. They are effective on moderate slopes, but consider building wooden stairways on 1:1 slopes (45°) or areas where rocks or surface roots make it difficult to set infiltration steps into the ground.

Note: Prior to installation, contact the Maine DEP and town Code Enforcement Officer to find out if permits are required.

Installation: Infiltration steps are steps built with timbers and backfilled with crushed stone or pea stone to help water soak into the ground. See separate factsheet for new infiltration step construction. Many existing timber steps can be retrofitted to create infiltration steps by making the following changes:

1. Remove several inches of soil from behind each step. Dispose of excavated soil in a place where it will not wash into the lake or other resource.
2. Line the bottom and sides of the excavated area with non-woven geotextile fabric. This felt-like fabric allows water to infiltrate but will separate the stone from the underlying soil.
3. Backfill the hole with washed ¾" crushed stone or pea stone so that the tread is level or it just slightly slopes up to meet the above step. Pea stone is comfortable on bare feet but also usually more expensive. Paving stones can also be set into crushed stone to provide a smooth surface for bare feet - as long as ample crushed stone is exposed to allow infiltration.
4. If the timbers are not firmly secured, drill ½" diameter holes, 6" from the ends of each timber. Drive ½" diameter, 18" long steel rebar through the holes with a sledge hammer. For gentle slopes, wooden stakes or large rocks can also secure the timbers.



Materials: Crushed stone and pea stone can be purchased from gravel pits. Contact your local Soil and Water Conservation District for suppliers of non-woven geotextile fabric. Other geotextiles, including landscaping weed barrier, can be substituted for smaller projects. Pressure treated timbers, cedar landscape timbers and steel rebar can be purchased from lumber and hardware stores. Some stores will cut rebar to the specified length for a small fee. Otherwise, rebar can be cut with a hack saw.

Maintenance: Replace rotten timbers. If the crushed stone or pea stone becomes filled up with sediment over time, remove, clean out sediment and replace.

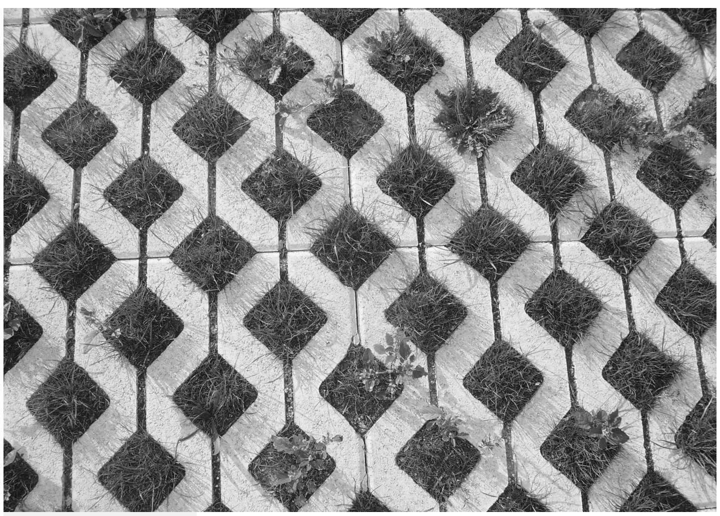
Part of the ***Conservation Practices for Homeowners*** Factsheet Series, available at:
Maine DEP (800.452.1942); http://www.maine.gov/dep/blwq/docwatershed/materials.htm
Portland Water District (207.774.5961); http://www.pwd.org/news/publications.php

May 2006 DEPLW0774

Appendix C: Permeable Pavement Section

Appendix C has been omitted in this online version. The full version is available only in the UVM Environmental Program office.

Appendix D: Permeable Pavement Photo



en.wikipedia.org

Appendix E: Swale Diagram

Appendix E has been omitted in this online version. The full version is available only in the UVM Environmental Program office.

Appendix F: Temporary Windbreak

Appendix G: Soil Test Results

PLOT 1

Soil Test Report

Agricultural & Environmental Testing Laboratory and UVM Extension

The University of Vermont

Prepared For:

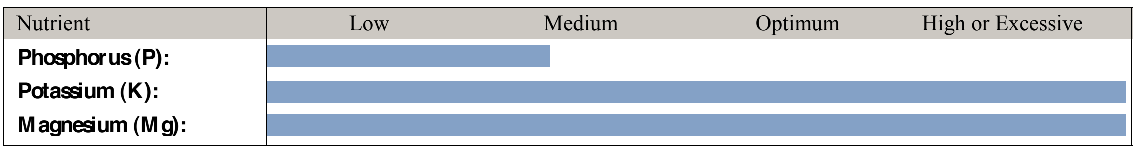
Angela Debettencourt
37 Hyde St
Burlington, VT 05401

adebette@uvm.edu
774-929-0054

Sample Information:
Order #: 701
Lab ID: S15-91101
Plot 1

Area Sampled: 0.25 acres
Received: 3/11/2015
Reported: 4/8/2015
VT County: Chittenden

Results



Analysis	*Value Found*	*Optimum Range (or Average *)*	*Analysis*	*Value Found*	*Optimum Range (or Average *)*
Soil pH (2:1, water)	5.9		Boron (B)	0.4	0.3*
Modified Morgan extractable, ppm			Copper (Cu)	3.7	0.3*
Macronutrients			Zinc (Zn)	18.4	2.0*
Phosphorus (P)	2.7	4-10	Sodium (Na)	3.4	20*
Potassium (K)	825	100-160	Aluminum (Al)	313	35*
Calcium (Ca)	1782	**	**Soil Organic Matter %**	1.0	**
Magnesium (Mg)	213	50-120	**Effective CEC, meq/100g**	12.8	**
Sulfur (S)	40.6	11*	**Base Saturation, %**		
Micronutrients			Calcium Saturation	56.9	40-80
Iron (Fe)	7.1	7.0*	Potassium Saturation	13.5	2.0-7.0
Manganese (Mn)	24.0	8.0*	Magnesium Saturation	11.3	10-30

** Micronutrient and S deficiencies are rare in Vermont and optimum ranges are not defined; thus average values in Vermont soils are shown instead.*
*** Ranges for Calcium, Organic Matter, and Effective CEC vary with soil type and crop.*

Reference:
UVM Soil Testing Lab Home Page http://www.uvm.edu/pss/ag_testing/

PLOT 2

The University of Vermont

Soil Test Report

Agricultural & Environmental Testing Laboratory and UVM Extension

Prepared For:

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Burlington, VT 05401

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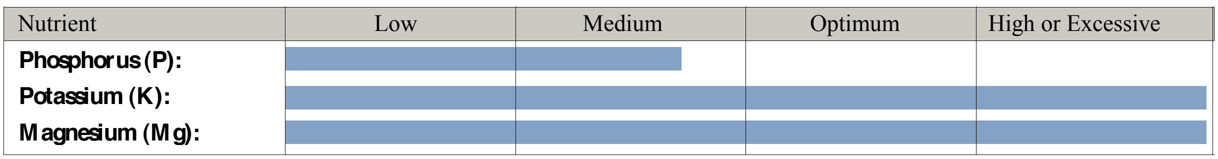
Sample Information:

Order #: **701**
Lab ID: **S15-91102**
Plot 2

Area Sampled: 0.25 acres
Received: 3/11/2015
Reported: 4/8/2015
VT County: Chittenden

Results



Analysis	*Value Found*	*Optimum Range (or Average *)*
Soil pH (2:1, water)	6.3	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	3.5	4-10
Potassium (K)	280	100-160
Calcium (Ca)	2724	**
Magnesium (Mg)	216	50-120
Sulfur (S)	56.3	11*
Micronutrients		
Iron (Fe)	6.3	7.0*
Manganese (Mn)	15.1	8.0*

Analysis	*Value Found*	*Optimum Range (or Average *)*
Boron (B)	0.4	0.3*
Copper (Cu)	2.0	0.3*
Zinc (Zn)	3.8	2.0*
Sodium (Na)	6.3	20*
Aluminum (Al)	174	35*
Soil Organic Matter %	16.5	**
Effective CEC, meq/100g	16.1	**
Base Saturation, %		
Calcium Saturation	67.0	40-80
Potassium Saturation	3.5	2.0-7.0
Magnesium Saturation	8.8	10-30

** Micronutrient and S deficiencies are rare in Vermont and optimum ranges are not defined; thus average values in Vermont soils are shown instead.*
*** Ranges for Calcium, Organic Matter, and Effective CEC vary with soil type and crop.*

Reference:

UVM Soil Testing Lab Home Page http://www.uvm.edu/pss/ag_testing/

PLOT 3

The University of Vermont

Soil Test Report

Agricultural & Environmental Testing Laboratory and UVM Extension

Prepared For:

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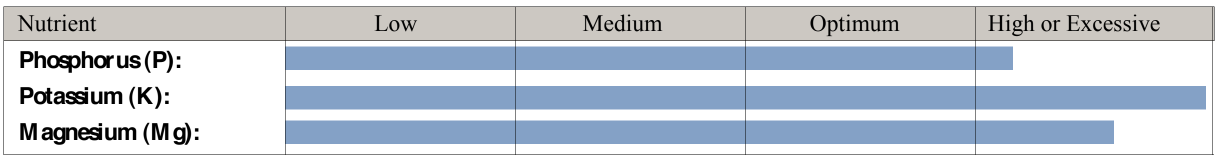
Sample Information:

Order #: **701**
Lab ID: **S15-91103**
Plot 3

Area Sampled: 0.25 acres
Received: 3/11/2015
Reported: 4/8/2015
VT County: Chittenden

Results



Analysis	*Value Found*	*Optimum Range (or Average *)*
Soil pH (2:1, water)	5.7	
Modified Morgan extractable, ppm		
Macronutrients		
Phosphorus (P)	15.2	4-10
Potassium (K)	242	100-160
Calcium (Ca)	1947	**
Magnesium (Mg)	167	50-120
Sulfur (S)	70.5	11*
Micronutrients		
Iron (Fe)	9.3	7.0*
Manganese (Mn)	19.5	8.0*

Analysis	*Value Found*	*Optimum Range (or Average *)*
Boron (B)	0.6	0.3*
Copper (Cu)	1.9	0.3*
Zinc (Zn)	5.1	2.0*
Sodium (Na)	50.2	20*
Aluminum (Al)	181	35*
Soil Organic Matter %	18.5	**
Effective CEC, meq/100g	11.7	**
Base Saturation, %		
Calcium Saturation	52.4	40-80
Potassium Saturation	3.3	2.0-7.0
Magnesium Saturation	7.5	10-30

** Micronutrient and S deficiencies are rare in Vermont and optimum ranges are not defined; thus average values in Vermont soils are shown instead.*
*** Ranges for Calcium, Organic Matter, and Effective CEC vary with soil type and crop.*

Reference:
UVM Soil Testing Lab Home Page http://www.uvm.edu/pss/ag_testing/

The University of Vermont

Soil Test Report

Agricultural & Environmental Testing Laboratory
and UVM Extension

Prepared For:

Angela Debettencourt
37 Hyde St
Burlington, VT 05401

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774-929-0054

Sample Information:
Order #: **701**
Lab ID: **S15-91104**
Plot 4

Area Sampled: 0.25 acres
Received: 3/11/2015
Reported: 4/8/2015
VT County: Chittenden

Results

Analysis	*Value Found*	*Optimum Range (or Average*)*	*Analysis*	*Value Found*	*Optimum Range (or Average*)*
Soil pH (2:1, water)	5.9		Boron (B)	0.3	0.3*
Modified Morgan extractable, ppm			Copper (Cu)	2.4	0.3*
Macronutrients			Zinc (Zn)	36.1	2.0*
Phosphorus (P)	6.9	4-10	Sodium (Na)	26.6	20*
Potassium (K)	383	100-160	Aluminum (Al)	197	35*
Calcium (Ca)	1854	**	**Soil Organic Matter %**	16.1	**
Magnesium (Mg)	139	50-120	**Effective CEC, meq/100g**	11.4	**
Sulfur (S)	48.6	11*	**Base Saturation, %**		
Micronutrients			Calcium Saturation	54.3	40-80
Iron (Fe)	20.6	7.0*	Potassium Saturation	5.8	2.0-7.0
Manganese (Mn)	33.3	8.0*	Magnesium Saturation	6.8	10-30

** Micronutrient and S deficiencies are rare in Vermont and optimum ranges are not defined; thus average values in Vermont soils are shown instead.*
*** Ranges for Calcium, Organic Matter, and Effective CEC vary with soil type and crop.*

Reference:
UVM Soil Testing Lab Home Page http://www.uvm.edu/pss/ag_testing/

Appendix H: Weather probe data sheets

MONTHLY CLIMATOLOGICAL SUMMARY for FEB. 2014

NAME: BND-1310 CITY: STATE:
ELEV: 3935 ft LAT: LONG:

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	70.0	79.0	2:00p	63.7	2:00a	0.1	5.1	0.00	6.3	25.0	11:30a	ENE
2	70.5	83.2	1:30p	64.3	6:30a	0.0	5.5	0.00	3.1	22.0	10:30a	ENE
3	70.0	80.0	12:30p	65.6	5:00a	0.0	5.0	0.00	3.1	22.0	10:00p	ENE
4	69.8	78.7	12:30p	65.3	4:30a	0.0	4.8	0.00	5.8	24.0	6:30a	ENE
5	68.8	76.4	1:30p	65.3	7:30p	0.0	3.8	0.00	6.4	25.0	3:30p	ENE
6	68.2	76.4	1:30p	64.2	4:00a	0.1	3.3	0.00	7.7	27.0	7:00a	ENE
7	68.7	78.3	3:00p	63.7	6:00a	0.2	3.8	0.00	7.3	25.0	10:00a	ENE
8	68.4	74.5	11:30a	63.3	3:00a	0.1	3.5	0.00	4.5	26.0	9:30p	ENE
9	70.8	76.9	3:30p	66.3	1:00a	0.0	5.8	0.00	6.2	24.0	9:00a	ENE
10	71.3	79.6	1:00p	67.2	5:00a	0.0	6.3	0.00	6.0	25.0	7:30a	ENE
11	70.9	78.0	1:30p	66.2	7:30a	0.0	5.9	0.00	4.8	27.0	10:30a	ENE
12	71.6	79.3	2:30p	67.0	4:00a	0.0	6.6	0.00	4.5	27.0	9:00a	ENE
13	71.2	80.8	3:00p	66.0	3:00a	0.0	6.2	0.00	3.2	24.0	10:30a	ENE
14	70.0	78.0	12:30p	63.5	6:00a	0.0	5.1	0.00	4.3	26.0	1:00p	ENE
15	72.0	78.1	2:30p	67.9	3:30a	0.0	7.0	0.00	9.4	36.0	12:00m	ENE
16	71.2	76.1	12:00p	67.6	11:00p	0.0	6.2	0.00	13.2	40.0	3:00p	N
17	71.1	76.6	3:00p	67.8	1:30a	0.0	6.1	0.00	12.6	33.0	1:00p	N
18	69.2	74.8	1:30p	65.8	10:30p	0.0	4.2	0.00	11.3	37.0	9:30a	N
19	70.0	77.1	11:00a	65.2	6:30a	0.0	5.0	0.00	7.9	29.0	12:30a	ENE
20	69.6	79.8	2:00p	63.2	6:00a	0.4	4.9	0.00	7.4	25.0	8:30a	ENE
21	70.1	80.3	2:30p	63.9	7:00a	0.0	5.2	0.00	5.6	24.0	12:30p	ENE
22	70.7	80.3	3:00p	64.4	1:30a	0.0	5.8	0.00	6.2	28.0	10:30a	ENE
23	70.2	77.3	3:00p	65.4	6:30a	0.0	5.2	0.00	6.0	28.0	1:00p	ENE
24	70.2	77.6	2:30p	66.0	3:30a	0.0	5.2	0.00	6.7	26.0	1:00a	ENE
25	70.0	78.7	2:30p	64.7	6:30a	0.0	5.0	0.00	6.9	28.0	1:00a	ENE
26	70.9	84.0	3:00p	62.5	12:00m	0.1	6.0	0.00	1.8	16.0	1:00a	ENE
27	71.4	82.4	1:30p	62.5	12:30a	0.1	6.5	0.00	0.9	15.0	11:30a	ENE
28	69.1	79.5	1:00p	61.3	4:00a	0.5	4.6	0.07	0.7	14.0	10:30p	N
	70.2	84.0	26	61.3	28	1.6	147.6	0.07	6.1	40.0	16	ENE

Max >= 90.0: 0
Max <= 32.0: 0
Min <= 32.0: 0
Min <= 0.0: 0
Max Rain: 0.07 ON 02/28/14
Days of Rain: 1 (>.01 in) 0 (>.1 in) 0 (>1 in)
Heat Base: 65.0 Cool Base: 65.0 Method: Integration

11 12 1 2 3 4
1 1 1 3 2 6 .2 5 6 1 0

ANNUAL CLIMATOLOGICAL SUMMARY 2014

NAME: BND-1310 CITY: STATE:
ELEV: 3935 ft LAT: LONG:

TEMPERATURE (°F), HEAT BASE 65.0, COOL BASE 65.0

YR	MO	MEAN MAX	MEAN MIN	MEAN	DEP. FROM NORM	HEAT DEG DAYS	COOL DEG DAYS	HI	DATE	LOW	DATE	MAX >=90	MAX <=32	MIN <=32	MIN <=0
14	1	78.3	65.6	70.4	0.0	1	168	83.4	4	63.3	28	0	0	0	0
14	2	78.6	65.0	70.2	0.0	2	148	84.0	26	61.3	28	0	0	0	0
14	3	79.6	64.7	70.7	0.0	2	180	83.2	25	57.6	8	0	0	0	0
14	4	80.0	66.4	71.7	0.0	0	202	84.8	7	61.1	7	0	0	0	0
14	5	79.1	64.8	70.7	0.0	1	178	85.1	4	60.0	3	0	0	0	0
14	6	78.8	66.5	71.4	0.0	0	139	83.3	29	63.3	13	0	0	0	0
14	7	78.8	65.8	70.9	0.0	2	93	83.8	27	61.7	19	0	0	0	0
14	8														
14	9	77.2	64.7	69.5	0.0	1	31	83.5	20	62.8	25	0	0	0	0
14	10														
14	11	77.9	63.6	69.8	0.0	5	147	82.9	22	60.8	11	0	0	0	0
14	12	78.3	65.2	70.5	0.0	4	175	83.2	1	60.2	24	0	0	0	0
		78.8	65.2	70.6	0.0	19	1462	85.1	MAY	57.6	MAR	0	0	0	0

PRECIPITATION (in)

YR	MO	TOTAL	DEP. FROM NORM	MAX OBS. DAY	DATE	DAYS OF RAIN OVER .01	.1	1
14	1	0.02	0.00	0.01	6	0	0	0
14	2	0.07	0.00	0.07	28	1	0	0
14	3	0.36	0.00	0.25	17	3	1	0
14	4	1.09	0.00	0.49	30	7	3	0
14	5	8.24	0.00	2.92	10	12	9	2
14	6	2.29	0.00	0.89	10	9	6	0
14	7	0.00	0.00	0.00	1	0	0	0
14	8							
14	9	1.28	0.00	0.70	22	4	4	0
14	10							
14	11	4.09	0.00	0.62	21	16	13	0
14	12	2.50	0.00	0.37	9	10	9	0
		19.94	0.00	2.92	MAY	62	45	2

WIND SPEED (mph)

YR	MO	AVG.	HI	DATE	DOM DIR
14	1	-5.5	40.0	22	ENE
14	2	-6.1	40.0	16	ENE
14	3	-5.8	36.0	27	ENE
14	4	-4.9	37.0	10	ENE
14	5	1.5	25.0	14	ENE
14	6	2.1	33.0	27	ENE
14	7	1.7	26.0	5	ENE
14	8				
14	9	0.7	28.0	21	ENE
14	10				
14	11	1.9	40.0	28	ENE
14	12	3.3	33.0	8	ENE
		3.6	40.0	JAN	ENE

Gets warmer to APRIL

Cooler after April

May – rainy – Nov.

Highest winds

* Gradually increases to warmer during Dry season Dec–April

* decreases in temp

gradual ↓ temp = rainy

↑ temp = dry

↑ rain = rainy May–Nov + End of April

Highest winds in Dry Season

MONTHLY CLIMATOLOGICAL SUMMARY for JAN. 2014

NAME: BND-1310 CITY: STATE:
ELEV: 3935 ft LAT: LONG:

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	70.9	77.8	1:00p	65.0	7:00a	0.0	5.9	0.00	2.9	24.0	10:00a	ENE
2	70.3	76.5	3:30p	66.5	3:30a	0.0	5.3	0.00	3.8	23.0	2:00p	ENE
3	70.7	78.3	3:00p	66.9	3:30a	0.0	5.7	0.00	5.1	23.0	4:00p	ENE
4	70.9	83.4	1:30p	64.5	6:00a	0.0	5.9	0.00	3.0	24.0	4:00p	ENE
5	70.9	80.6	1:30p	64.0	6:00a	0.0	5.9	0.00	1.5	21.0	2:30p	ENE
6	70.0	77.0	2:00p	65.4	9:30p	0.0	5.0	0.01	2.9	22.0	9:00a	ENE
7	69.3	77.3	1:00p	64.9	6:00a	0.0	4.3	0.00	4.2	25.0	12:00p	ENE
8	71.0	80.6	2:30p	66.1	7:30a	0.0	6.0	0.00	3.5	23.0	10:00a	ENE
9	69.2	76.1	11:00a	65.8	1:30a	0.0	4.2	0.00	2.3	19.0	12:00p	ENE
10	69.7	77.8	2:00p	65.8	3:30a	0.0	4.7	0.01	6.5	28.0	6:00a	ENE
11	69.9	77.3	11:00a	65.3	4:30a	0.0	4.9	0.00	3.1	22.0	12:00p	ENE
12	70.1	76.3	3:00p	64.6	7:00a	0.0	5.1	0.00	5.1	33.0	5:30p	ENE
13	71.0	78.0	2:00p	67.4	4:00a	0.0	6.0	0.00	6.2	26.0	6:00a	ENE
14	70.7	80.9	1:00p	65.7	1:00a	0.0	5.7	0.00	3.9	23.0	8:00p	ENE
15	70.9	78.7	3:00p	66.1	2:00a	0.0	5.9	0.00	5.9	28.0	9:30a	ENE
16	71.9	78.7	2:00p	66.7	1:30a	0.0	6.9	0.00	7.7	31.0	3:30p	ENE
17	71.3	78.9	2:00p	66.7	7:00p	0.0	6.3	0.00	4.4	26.0	1:00a	ENE
18	71.6	77.3	1:00p	66.7	6:00a	0.0	6.6	0.00	8.3	32.0	11:30a	ENE
19	71.6	78.7	3:00p	66.8	6:30a	0.0	6.6	0.00	7.4	27.0	2:30a	ENE
20	72.8	80.8	12:30p	68.8	5:00a	0.0	7.8	0.00	4.6	24.0	6:30a	ENE
21	70.7	78.4	1:30p	66.0	3:00a	0.0	5.7	0.00	5.0	26.0	11:00a	ENE
22	69.8	75.7	12:30p	66.6	3:00a	0.0	4.8	0.00	10.3	40.0	11:00p	ENE
23	69.5	75.1	12:30p	64.8	5:00a	0.0	4.5	0.00	11.0	37.0	8:30a	W
24	69.8	78.5	3:00p	64.7	4:30a	0.0	4.8	0.00	7.6	34.0	8:00p	ENE
25	70.3	77.6	1:00p	65.6	12:00m	0.0	5.3	0.00	8.8	29.0	4:30a	ENE
26	70.2	79.2	2:00p	64.9	1:30a	0.0	5.2	0.00	6.5	28.0	8:30a	ENE
27	69.5	78.7	3:00p	64.2	6:30a	0.0	4.6	0.00	5.1	23.0	2:00p	ENE
28	69.5	78.8	2:00p	63.3	4:30a	0.3	4.8	0.00	4.6	21.0	9:30a	ENE
29	70.0	78.7	11:30a	63.9	6:30a	0.0	5.0	0.00	4.6	26.0	2:00p	ENE
30	70.3	77.4	1:00p	65.8	3:00a	0.0	5.3	0.00	7.8	31.0	11:30p	ENE
31	68.4	76.7	1:00p	63.5	7:30p	0.3	3.7	0.00	6.5	29.0	1:00a	ENE
	70.4	83.4	4	63.3	28	0.6	168.4	0.02	5.5	40.0	22	ENE

Max >= 90.0: 0
Max <= 32.0: 0
Min <= 32.0: 0
Min <= 0.0: 0
Max Rain: 0.01 ON 01/06/14
Days of Rain: 0 (>.01 in) 0 (>.1 in) 0 (>1 in)
Heat Base: 65.0 Cool Base: 65.0 Method: Integration

11 12 1 2 3 4
2 1 0 3 7 3 7 1 6 1

MONTHLY CLIMATOLOGICAL SUMMARY for FEB. 2015

NAME: BND-1310 CITY: STATE:
ELEV: 3935 ft LAT: LONG:

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	71.4	78.3	2:30p	67.0	2:00a	0.0	6.4	0.56	8.1	30.0	1:30p	N
2	72.8	79.3	4:00p	67.4	2:30a	0.0	7.8	0.00	5.6	27.0	8:00p	ENE
3	71.9	78.7	1:00p	69.0	11:30p	0.0	6.9	0.00	11.6	34.0	8:00p	W
4	71.6	78.6	1:30p	68.3	11:00p	0.0	6.6	0.00	7.5	33.0	2:30a	ENE
5	71.5	80.2	11:00a	66.8	6:00a	0.0	6.5	0.00	3.1	26.0	1:00p	ENE
6	70.5	76.5	1:30p	68.2	4:00a	0.0	5.5	0.00	8.8	33.0	11:00a	W
7	70.0	75.6	3:30p	66.7	8:00p	0.0	5.0	0.00	7.9	29.0	8:00a	W
8	68.2	71.3	12:00p	65.5	7:30a	0.0	3.2	0.00	2.7	22.0	10:30a	ENE
9	67.7	74.3	9:30a	64.3	12:00m	0.0	2.7	0.28	0.0	7.0	10:00a	S
10	68.0	77.1	1:30p	60.0	7:00a	1.2	4.1	0.00	0.8	16.0	9:00p	S
11	69.8	81.0	2:30p	62.8	2:00a	0.2	5.0	0.00	3.8	25.0	9:00p	ENE
12	71.0	79.3	1:30p	63.7	5:00a	0.0	6.1	0.00	4.9	30.0	12:00m	W
13	71.4	78.7	1:00p	67.1	8:30p	0.0	6.4	0.00	12.5	40.0	10:00p	N
14	70.0	76.9	11:30a	65.3	8:00a	0.0	5.0	0.00	13.9	39.0	8:00p	N
15	69.9	75.3	2:30p	67.6	10:00p	0.0	4.9	0.00	9.7	31.0	2:00p	N
16	70.4	76.1	2:30p	66.6	5:30a	0.0	5.4	0.00	11.9	33.0	8:30a	N
17	72.6	82.3	1:00p	67.4	12:30a	0.0	7.6	0.00	6.5	25.0	12:30a	E
18	74.6	~~150.0~~	6:00a	34.4	6:30a	0.1	9.8	0.49	3.1	23.0	8:30p	W
19	70.7	77.8	11:30a	67.1	7:00a	0.0	5.7	0.00	9.4	34.0	4:00a	W
20	71.8	79.3	11:30a	65.1	3:30a	0.0	6.8	0.00	5.5	30.0	10:00p	W
21	71.3	78.6	3:30p	66.8	5:00a	0.0	6.3	0.00	7.8	33.0	9:30p	W
22	72.3	78.0	3:00p	67.1	6:00a	0.0	7.3	0.00	11.2	34.0	7:00p	N
23	72.6	79.2	3:30p	68.7	11:30p	0.0	7.0	0.00	9.8	36.0	10:00a	W
24	70.7	78.3	2:30p	65.7	12:00m	0.0	5.6	0.53	7.3	29.0	5:30a	ENE
25	71.5	83.7	3:00p	65.2	4:30a	0.0	6.5	0.00	3.8	21.0	9:00a	ENE
26	70.6	80.5	1:00p	60.8	6:00a	0.5	6.1	0.00	1.0	18.0	11:30p	S
27	72.5	80.2	12:30p	66.9	6:00a	0.0	7.5	0.00	6.7	28.0	10:00p	E
28	73.1	77.9	11:00a	67.3	6:00a	0.0	8.1	0.00	10.6	34.0	4:30p	N
	71.1	~~150.0~~	18	34.4	18	2.0	171.8	1.86	7.0	40.0	13	W

Max >= 90.0: 1
Max <= 32.0: 0
Min <= 32.0: 0
Min <= 0.0: 0
Max Rain: 0.56 ON 02/01/15
Days of Rain: 4 (>.01 in) 4 (>.1 in) 0 (>1 in)
Heat Base: 65.0 Cool Base: 65.0 Method: Integration

9:30 11 12 1 2 3 4

1 2 3 1 1 4 4 0 5 2 3 1

MONTHLY CLIMATOLOGICAL SUMMARY for JAN. 2015

NAME: BND-1310 CITY: STATE:
ELEV: 3935 ft LAT: LONG:

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	72.1	76.7	2:00p	69.5	6:30a	0.0	7.1	0.00	13.7	40.0	3:00p	W
2	72.2	79.4	3:00p	68.4	7:00a	0.0	7.2	0.25	12.0	40.0	5:30a	W
3	73.9	79.7	2:00p	70.9	3:00a	0.0	8.9	0.38	10.7	31.0	12:30p	W
4	73.9	80.4	1:30p	67.2	6:00a	0.0	8.9	0.00	11.1	37.0	11:00p	W
5	71.4	76.2	2:00p	66.7	12:00m	0.0	6.4	0.00	12.7	40.0	2:00p	W
6	70.2	76.7	3:00p	66.4	3:00a	0.0	5.2	0.00	8.6	35.0	6:30p	W
7	70.7	76.0	2:30p	67.0	6:30a	0.0	5.7	0.00	13.8	37.0	9:00p	W
8	69.5	74.4	1:30p	66.7	6:30a	0.0	4.5	0.00	15.4	38.0	11:30a	N
9	70.6	76.0	1:30p	67.2	2:30a	0.0	5.6	0.00	14.6	36.0	1:00a	N
10	71.7	77.6	12:00p	68.0	7:00a	0.0	6.7	0.00	14.2	35.0	2:30a	N
11	72.3	80.2	3:00p	69.0	4:30a	0.0	7.3	0.00	9.1	32.0	6:30a	W
12	73.7	81.2	2:30p	69.1	12:00m	0.0	8.7	0.00	6.5	33.0	9:00a	W
13	73.3	80.4	1:30p	68.5	7:30a	0.0	8.3	0.00	6.1	24.0	3:00a	ENE
14	72.6	78.7	1:00p	68.6	1:00a	0.0	7.6	0.00	8.1	29.0	11:00a	W
15	73.2	82.1	3:30p	68.4	6:30a	0.0	8.2	0.00	5.0	22.0	2:00a	ENE
16	73.0	79.8	2:00p	68.6	6:30p	0.0	8.0	0.00	8.5	33.0	9:30a	W
17	71.6	77.9	2:00p	67.7	12:00m	0.0	6.6	0.00	9.8	32.0	6:00a	W
18	70.5	76.8	3:30p	66.2	2:30a	0.0	5.5	0.00	7.7	28.0	11:30a	W
19	71.5	79.9	2:30p	66.6	5:00a	0.0	6.5	0.00	6.4	33.0	6:00a	ENE
20	71.4	78.4	3:30p	67.4	5:30a	0.0	6.4	0.00	7.2	28.0	3:30p	W
21	70.7	77.1	2:30p	66.8	12:00m	0.0	5.7	0.00	6.1	28.0	6:00a	ENE
22	69.4	76.9	11:00a	65.9	7:30a	0.0	4.4	0.00	4.6	25.0	11:30p	ENE
23	70.8	80.2	3:00p	66.5	12:00m	0.0	5.8	0.00	5.9	25.0	10:30a	ENE
24	68.8	75.8	11:00a	62.2	3:00a	0.1	3.9	0.00	5.1	30.0	1:00p	ENE
25	70.0	76.5	2:00p	66.1	12:00m	0.0	5.0	0.00	9.2	29.0	11:30a	E
26	69.6	75.4	3:30p	65.0	4:00a	0.0	4.6	0.00	10.3	34.0	8:30p	W
27	70.8	77.8	1:00p	67.5	1:00a	0.0	5.8	0.00	8.0	30.0	8:30a	W
28	69.2	76.4	1:00p	65.2	10:00p	0.0	4.2	0.00	10.4	37.0	10:30a	W
29	70.6	77.9	2:00p	65.6	1:30a	0.0	5.6	0.00	10.9	33.0	1:00a	N
30	70.4	77.6	3:00p	66.6	6:00a	0.0	5.4	0.00	8.6	35.0	8:00a	W
31	70.4	77.8	4:00p	65.4	6:00a	0.0	5.4	0.00	10.6	33.0	9:00p	N
	71.3	82.1	15	62.2	24	0.1	195.1	0.63	9.4	40.0	1	W

Max >= 90.0: 0
Max <= 32.0: 0
Min <= 32.0: 0
Min <= 0.0: 0
Max Rain: 0.38 ON 01/03/15
Days of Rain: 2 (>.01 in) 2 (>.1 in) 0 (>1 in)
Heat Base: 65.0 Cool Base: 65.0 Method: Integration

9.5
11 12 1 15 2 25 3 4
2 1 3 4 7 4 5 4 1

MONTHLY CLIMATOLOGICAL SUMMARY for MAY. 2014

NAME: BND-1310 CITY: STATE:
ELEV: 3935 ft LAT: LONG:

TEMPERATURE (°F), RAIN (in), WIND SPEED (mph)

DAY	MEAN TEMP	HIGH	TIME	LOW	TIME	HEAT DEG DAYS	COOL DEG DAYS	RAIN	AVG WIND SPEED	HIGH	TIME	DOM DIR
1	71.2	81.1	2:00p	65.1	6:30a	0.0	6.2	0.00	1.2	18.0	1:30p	ENE
2	70.4	78.6	10:30a	64.0	1:00a	0.1	5.5	0.00	1.4	21.0	9:00a	ENE
3	70.6	79.6	12:30p	60.0	6:00a	0.4	6.1	0.00	0.6	13.0	9:00a	S
4	72.5	85.1	12:30p	66.7	2:30a	0.0	7.5	0.00	2.8	21.0	12:00m	ENE
5	71.4	81.3	12:30p	62.7	4:30a	0.2	6.6	0.00	2.2	22.0	3:30p	ENE
6	71.5	79.1	12:00p	64.0	1:30a	0.0	6.5	0.06	0.9	14.0	1:30p	W
7	69.4	75.1	11:00a	65.3	3:30a	0.0	4.4	0.94	0.5	12.0	9:30p	SE
8	68.7	79.9	11:30a	62.5	5:00a	0.5	4.2	0.36	0.3	14.0	10:30a	S
9	69.4	76.4	10:00a	64.6	5:30a	0.0	4.4	0.78	0.6	16.0	9:30a	S
10	68.0	75.6	12:30p	65.7	12:00m	0.0	3.0	2.92	0.3	19.0	5:00p	S
11	68.8	80.2	12:00p	64.7	3:30a	0.0	3.8	0.13	0.4	16.0	10:30a	S
12	69.1	74.0	2:00p	64.4	2:30a	0.0	4.1	0.25	1.3	15.0	7:30p	ENE
13	70.8	77.5	3:30p	64.3	2:30a	0.0	5.8	0.00	3.8	22.0	12:00p	ENE
14	71.5	81.9	2:30p	65.6	3:00a	0.0	6.5	0.00	1.4	25.0	3:30p	ENE
15	71.6	80.2	10:30a	66.5	5:00a	0.0	6.6	0.00	1.5	19.0	12:30a	ENE
16	71.6	78.0	11:30a	68.2	7:00a	0.0	6.6	0.02	2.3	24.0	10:00a	ENE
17	72.7	81.1	2:00p	66.8	8:30p	0.0	7.7	0.00	3.1	24.0	6:30a	ENE
18	72.8	81.1	2:00p	67.5	4:30a	0.0	7.8	0.00	3.0	21.0	10:00a	ENE
19	71.8	79.9	4:00p	66.9	11:00p	0.0	6.8	0.00	3.6	24.0	10:30a	ENE
20	71.4	82.1	2:30p	65.6	12:00m	0.0	6.4	0.01	1.9	18.0	6:30a	ENE
21	71.7	83.0	12:00p	64.7	2:00a	0.0	6.7	0.00	2.6	18.0	7:00p	ENE
22	71.5	79.6	12:30p	64.6	6:00a	0.0	6.5	0.00	0.7	12.0	2:30a	S
23	71.3	78.6	10:00a	63.9	6:30a	0.0	6.3	0.00	1.4	17.0	2:30p	ENE
24	70.4	78.9	2:30p	64.1	12:00m	0.0	5.4	0.03	1.2	18.0	12:00p	ENE
25	70.3	77.5	11:30a	63.8	7:30a	0.1	5.4	0.00	0.4	13.0	10:30p	ENE
26	70.1	75.5	3:00p	63.9	6:00a	0.0	5.2	0.00	1.8	20.0	6:30p	ENE
27	71.9	82.3	2:30p	64.8	3:00a	0.0	6.9	0.01	1.8	20.0	9:30a	ENE
28	70.1	80.0	12:30p	64.9	1:00a	0.0	5.1	0.40	0.8	14.0	10:00a	ENE
29	69.8	75.2	12:00p	65.1	3:30a	0.0	4.8	0.01	0.7	9.0	4:00a	S
30	69.3	77.2	12:30p	63.8	5:00a	0.1	4.4	0.60	0.3	11.0	9:00p	WSW
31	69.4	75.8	3:30p	64.1	5:30a	0.0	4.4	1.72	0.2	14.0	5:30p	S
	70.7	85.1	4	60.0	3	1.4	177.6	8.24	1.5	25.0	14	ENE

Max >= 90.0: 0
Max <= 32.0: 0
Min <= 32.0: 0
Min <= 0.0: 0
Max Rain: 2.92 ON 05/10/14
Days of Rain: 12 (>.01 in) 9 (>.1 in) 2 (>1 in)
Heat Base: 65.0 Cool Base: 65.0 Method: Integration