Developing a Conceptual Design for a Solid Waste Transfer Center in Monteverde, Costa Rica

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Developing a Solid Waste Transfer Center Design for Monteverde, Costa Rica

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Abstract

In Monteverde, Costa Rica, solid waste management (SWM) suffered from low recycling and organics recovery rates, causing environmental problems, and non-recovered waste disposal was costly. To help ASADA address these problems, we developed a conceptual solid waste transfer center (SWTC) design for Monteverde and made SWM system recommendations. Using observations, interviews, surveys, and archival data we identified solid waste recovery rates and suggested potential solutions, to improve the SWM system, that were effectively incorporated in a SWTC.

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- Katy VanDusen, CORCLIMA

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Imogen Cleaver-Stigum, Elçin Önder, Adrian Reddick, and Shelvey Swett were each responsible for the decision-making of a different aspect of the project:

<table>
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Imogen Cleaver-Stigum - Interviews and Survey Director</td><td>
Elçin Önder - Design Director</td></tr>
<tr><td>
Adrian Reddick - Engineering & Map Director</td><td>
Shelvey Swett - Writing Director</td></tr>
<tr><td colspan="2">Figure 0.1: The team and their decision-making responsibilities.</td></tr>
</table>

These four categories indicate which aspects of the project we were responsible for. However, we were all involved in all aspects of the project.

The author and editors and of each section are specified in Table 0.1:

Table 0.1: Report authorship by section

Section	**Author**	**Editors**
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Acronym	Definition
ASADA	Administrative Association for Sewers and Aqueducts
AyA	Costa Rican Institute of Aqueducts and Sewers
COMIRES	Commission for the Management of Solid Waste; Municipal Council for the District of Monteverde
CORCLIMA	Climate Change Resilience Commission of Monteverde
PRRSV	Valuable Solid Waste Recovery Program
SW	Solid waste
SWM	Solid waste management
SWTC	Solid waste transfer center
UCR	University of Costa Rica

Executive summary

Management of municipal solid waste represents a problem for many communities due to increasing waste generation and the burden it places on municipal budgets (Abdel-Shafy & Mansour, 1994). Poor understanding and implementation of solid waste management (SWM) practices can lead to human health problems, environmental damage, and high levels of carbon emissions.

In Costa Rica, municipalities are responsible for the management of their municipal solid waste (Sistema Costarricense de la Información Jurídica, 2016). Monteverde, Costa Rica, is an isolated, quickly developing community with a tourism-based economy that is burdened by an increasing amount of waste (Asociación Administradora de Acueducto y Alcantarillado Sanitario, 2019). There are low recovery rates of recyclables and organic waste, causing most of the waste to be sent to landfills instead of recycled or composted. A solid waste transfer center (SWTC) could help address both the environmental and financial aspects of the SWM problem.

The goal of this project was to develop a basic conceptual design for a SWTC and to make recommendations that promote a high participation rate in recycling and organics collection programs in Monteverde. To achieve our goal, we completed five objectives:

1. Identified how the SWM system in Monteverde worked, and how it evolved in the recent years;
2. Determined the historical trends and future projections in growth, composition, and geographic breakdown of the municipal solid waste in Monteverde;
3. Determined successes and shortcomings of the system according to experts;

4. Determined the successes and shortcomings of non-systemic factors according to residents and business owners; and
5. Designed a SWTC that would address the needs of Monteverde experts, residents, and business owners.

We achieved these objectives in three phases. First, we identified the SWM system through direct and participant observation. Second, we determined trends in solid waste production and the successes and shortcomings of the system and non-systemic factors through expert interviews, resident and business owner surveys, and archival research. Third, we designed the SWTC by consolidating our findings from phases 1 and 2 with flow-rate and spatial calculations to produce a SolidWorks SWTC design.

During the completion of our project, we found that the recycling system was insufficient, leading to a low recovery rate of recyclable materials. It was inconvenient and confusing for the users, so there was little participation in the recycling campaigns. Based on our findings we made the following recommendations:

1. Provide more convenient means of recycling for residents by improving the recycling campaigns, separating the mini collection centers into trash and recyclables sections, or implementing a road-side recycling collection route.

2. Determine the best way to improve the Municipal Recycling Center by looking into which improvement would be most impactful: staff, equipment, or space.

3. Encourage good recycling habits by using the slogan “clean, dry, and separated.”

We also found the system for managing organic waste to be lacking. There was minimal participation in the small centralized organics collection effort. The Monteverde ASADA could expand their program by:

1. Implementing centralized collection services for the commercial sector and collecting organic waste from businesses in densely commercial areas.

2. Delegating collection and transportation to the Municipality and focusing on organic waste treatment.

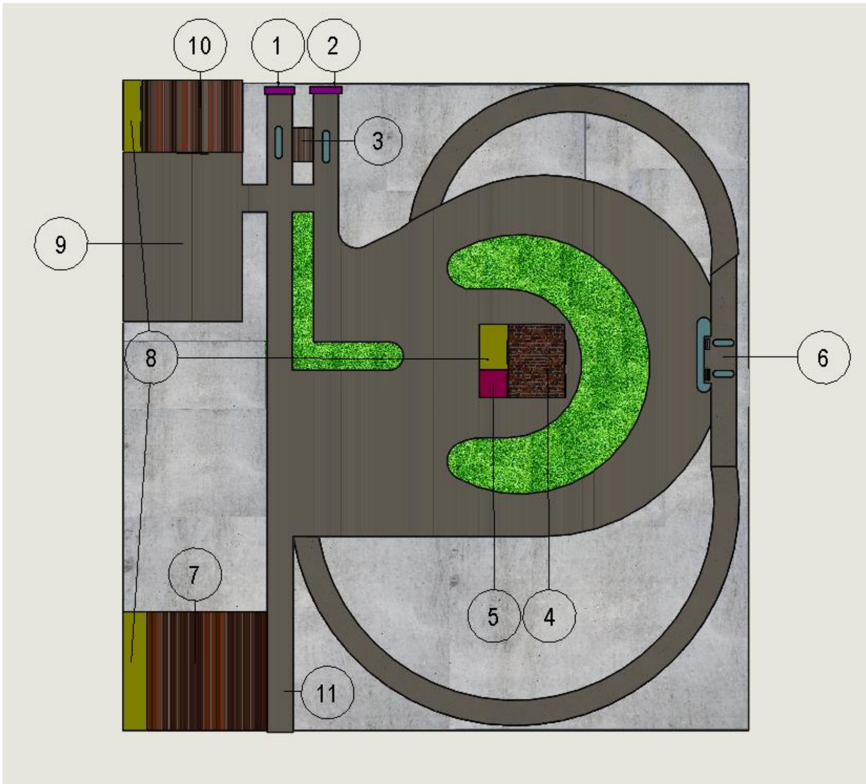
3. Servicing the neighborhoods most lacking in organics services by determining those locations and creating targeted and publicized organics collection routes there.

For the non-recoverable waste management system, we found the mini collection center infrastructure and waste collection services were insufficient. We learned of high rates of dissatisfaction with the system. We recommend the Municipality:

1. Implement collection routes for areas without service by expanding existing routes and implementing a new route.

2. Determine which mini collection centers experience the heaviest use by measuring the volume or mass of waste at the centers and improve the mini center infrastructure by adding more mini centers where they are most needed.

In addition to these systemic recommendations, we recommend that a SWTC be implemented in Monteverde. Before construction, the Municipality would need to determine its location and complete a full feasibility and technical design of the SWTC. To aid the inception of this feasibility study, we created a preliminary conceptual design of a SWTC as shown in Figure 0.2. Based on our findings, we recommend the elements listed in the figure be included in the transfer center for Monteverde.



1. Entrance
2. Exit
3. Weigh station
4. Recycling station
5. Possible non-traditional waste storage
6. Trash unloading station
7. Storage for organics
8. Areas for expansion
9. Parking lot
10. Management building
    - Swap area
    - Mini drop-off area
    - Education center
11. To the Environmental Technology Park

Figure 0.2: Preliminary conceptual design of the SWTC

Chapter 1: Introduction

Solid waste originates in the households, schools, and businesses of a community (EPA, 2019). Types of solid waste differ depending on their sources, but an important category is municipal solid waste - the organics, recyclables, and non-recoverables (trash) discarded by residents and businesses. Excessive municipal solid waste represents a major crisis for both rural and urban communities due to the increasing generation of waste and the burden placed on the municipal budget (Abdel-Shafy & Mansour, 1994). In rural communities of developing countries, the absence of effective waste-collection systems and convenient sanitary landfills leads to improper disposal of municipal solid waste. Poor understanding of proper solid waste management (SWM) practices can result in contamination of air, soil, and water, potentially leading to human health problems. Thus, municipal solid waste management is a major problem in many countries worldwide.

Currently, municipalities in Costa Rica are responsible for the collection, transportation, and final disposal of municipal solid waste (Sistema Costarricense de la Información Jurídica, 2016). While the systems are functional, there are factors inhibiting their improvement: inadequate community participation, lack of local SWM facilities, and the remoteness of the areas that pick up and manage waste from those that produce it. Monteverde, Costa Rica, is one of the small, relatively isolated, developing, and tourism-focused regions that are currently burdened by an increase of waste. Their SWM system is far from ideal in terms of its recycling rate, composting rate, and community participation (Asociación Administradora de Acueducto y Alcantarillado Sanitario, 2019). Monteverde also lacks proper facilities for the management of municipal solid waste, including its collection, treatment, and disposal.

Generation of municipal solid waste is increasing, and without the proper infrastructure in place to accommodate it, SWM problems will continue to occur (Androvetto et al, 2013; Chung & Lo, 2008; Guerrero et al, 2013; Hazra & Goel, 2009; Henry et al, 2006; Minghua et al, 2009; Sujauddin et al, 2008). Community participation in waste management systems influences their effectiveness (Ferronato et al, 2019; Gonzales-Torres & Adenso-Diaz, 2005; Zhuang et al, 2008). SWM practices critically impact the community, with environmental and health risks if done improperly (Vilaysouk & Babel, 2017; Zeng et al, 2016). One feature of a successful SWM system is a solid waste transfer center (SWTC); this is the site of consolidation, compaction, and redistribution within the larger SWM system (EPA, 2002). SWTCs separate organics, recyclables, and non-recoverables, minimizing materials sent to the landfill and maximizing profit through sending recyclables to recycling centers and selling organics as compost.

Past research highlighted the best SWM practices and the problems with the current system in Monteverde, and Justin Welch (2018), the Environmental Administrator of the ASADA in Monteverde, believes that implementing a better SWM system in Monteverde is critical. Research had not yet been done to determine how the implementation of a SWTC would affect Monteverde, and Welch stated that a transfer center designed to address the specific needs of the Monteverde community would be a critical step in achieving better SWM.

The goal of this project was to develop a basic conceptual design for a SWTC and to make recommendations that promote a high participation rate in recycling and organics collection programs in Monteverde. Thus, this project is the first integrated effort to develop a SWTC that responds to the present and future SWM needs of Monteverde. To achieve our goal, we completed five objectives:

1. Identified how the SWM system in Monteverde worked, and how it evolved in the recent years;
2. Determined the historical trends and future projections in growth, composition, and geographic breakdown of the municipal solid waste in Monteverde;
3. Determined successes and shortcomings of the system according to experts;
4. Determined the successes and shortcomings of non-systemic factors according to residents and business owners; and
5. Designed a SWTC that would address the needs of Monteverde experts, residents, and business owners.

We achieved these objectives in three phases. First, we identified the SWM system through direct and participant observation. Second, we determined trends in solid waste production and the successes and shortcomings of the system and non-systemic factors through expert interviews, resident and business owner surveys, and archival research. Third, we designed the SWTC by consolidating our finding from phases 1 and 2 with flow-rate and spatial calculations to produce a SolidWorks deliverable. We presented our design to Monteverde's Municipal Council. We hope that our results and recommendations will help increase community involvement in the proper disposal of municipal solid waste and facilitate the implementation process of a SWTC in Monteverde, which can help reduce the impacts of improper SWM on the environment, local economy, and human health.

Chapter 2: Background & literature review

In this chapter, we discuss prior research on municipal solid waste, solid waste management (SWM) practices such as solid waste transfer centers (SWTCs), and the dangers of improper solid waste management for the environment and human health. We also review how these topics relate to the specific waste management system in Monteverde, and non-systemic factors that affect solid waste management there.

2.1. Municipal waste management

Solid waste can refer to a variety of discarded materials. In this report, we operationally define municipal solid waste as the organics, recyclables, and non-recoverables (trash) discarded by residents and businesses. The term *municipal* refers to the type of waste, not the body who is managing its disposal; municipal waste can be managed by a municipality or a private entity. Problems with municipal solid waste management are common world-wide (Organisation for Economic Co-operation and Development, 2017). With thousands of tonnes of municipal solid waste produced annually, efficient and effective systems of managing its treatment and disposal are critical. An increase in waste generation and inadequate infrastructure to support such an increase, such as sufficient SWM facilities, are the primary causes of waste management problems (Androvetto et al, 2013; Guerrero et al, 2013; Minghua et al, 2009; Sujauddin et al, 2008). In addition to the causes of these problems, we discuss attitudes towards solid waste management (SWM) practices and three examples of SWM in Massachusetts, USA.

Levels of waste generation rise annually in developing countries (Guerrero et al, 2013). Thriving economies and the constant development of new consumer goods have created a rapid cycle of purchase and disposal, and thus an increase in the weight of municipal solid waste produced per household. Additionally, economic growth and urbanization have produced an increase in the standard of living worldwide (Minghua et al, 2009). This urbanization, coupled with population growth, causes an increase in population density. All of these factors together mean a net increase in the solid waste that must be collected, processed, and disposed. This phenomenon occurs in small and large cities alike. Sujauddin et al (2008) found that increased solid waste (SW) generation correlates positively with the level of education of an individual.

With such an increase in waste production, the original management systems in place in developing countries are facing a challenge (Guerrero et al, 2013). Specifically, they often lack the infrastructure that is essential to enable a functioning system. Typical reasons for inadequacies are lack of organization and insufficient funding.

Waste management systems are complex and multi-dimensional (Guerrero et al, 2013). Without the proper expertise, technology, or organization, the city or municipality in charge of waste management will not be successful. Even a simple system of separation, collection, transportation, treatment, and disposal has multiple independent parts that need to be facilitated correctly to see progress and success. Furthermore, errors can occur at any point in the cycle. Reportedly, SWM problems can occur anywhere ranging from collection schedule misinformation, improper collection-route planning, and poor road conditions to a lack of affordable treatment systems put in place by authorities (Chung & Lo, 2008; Hazra & Goel, 2009; Henry et al, 2006).

Additionally, a municipality lacking the funds to properly manage waste will have problems (Guerrero et al, 2013). Elements like collection and transportation, SW center management and maintenance, and initial construction all need to be staffed and funded; this amounts to a high cost for the overall SWM program. Waste management can also take place in many different places like a solid waste transfer center, a waste-water treatment plant, a composting facility, a recycling center, and a sanitary landfill (J. Welch, personal communication, November 4, 2019). The SWM program would require sufficient funds to operate, improve, and transport between such locations. A high functioning system is achieved at a high cost, which municipal authorities may be unable to pay (Guerrero et al, 2013). In cases where government-run waste collection services are insufficient, households use private sector SW collection companies. This reduces the financial strain on the local government but relinquishes a degree of control and uniformity of the SWM.

2.1.1. Attitudes towards waste management practices

In addition to SWM problems relating to volume and infrastructure, attitudes of the community toward waste management influence SWM system implementation (Ferronato et al, 2019; Gonzales-Torres & Adenso-Diaz, 2005; Guerrero et al, 2013; Minghua et al, 2009; Sujauddin et al, 2008; Zhuang et al, 2008). Attitudes can vary from household to household, depending on numerous factors, but there tend to be common attitudes shared by communities as a whole. In general, citizens around the world expect municipal authorities to take primary responsibility for SWM, but the majority are willing to pay a small monthly price for waste collection services (Ferronato et al, 2019; Sujauddin et al, 2008). Attitudes are affected by how much community residential committees are involved with SWM, and communities as a whole can develop strong recycling habits through social influence, altruism, and regulatory factors

(Gonzales-Torres & Adenso-Diaz, 2005; Zhuang et al, 2008). The perceived market for recycled goods in an area also influences overall positions on SWM (Minghua et al, 2009).

The degree to which waste management and separation services are utilized by the public varies with gender, peer influence, size and location of household, membership in environmental organizations, and fees for collection services (Ekere et al, 2009; Scheinberg, 2011; Tadesse et al, 2008). Homes that lack adequate disposal bins or are far from local disposal bins are more likely to dump in open areas and roadsides than seek out functioning containers. Additionally, moderately high fees at disposal sites correlate more strongly with high recovery rates than low or high fees, although this is not a causal relationship (Scheinberg, 2011). High recovery rates, in particular, are associated with systems that use the fees to further invest in the SWM system. Many of these factors affecting SWM can be seen in operation in examples of systems in Massachusetts.

2.1.2. Waste management in Massachusetts

Three examples of waste management in Massachusetts illustrate systems of waste collection, waste drop-off, and composting (Casella Waste Systems, 2019a; Casella Waste Systems, 2019b; Casella Waste Systems, 2019c; Casella Waste Systems, 2019d; City of Worcester, 2019; T. Markham, personal communication, December 11, 2019; Town of Wayland, 2019). One example of waste collection is Casella Waste Systems (CWS) (2019b) in Southbridge, Massachusetts. CWS is a private company that demonstrates a strong system. We operationally defined a strong system as one that safely and cost-effectively processes and sorts municipal solid waste, keeps their treatment practices local, meets the SWM needs of its stakeholders, and achieves environmentally sustainable SWM practices. For garbage and recycling pickup, households simply place waste and recyclables in two separate curbside containers. CWS then sorts and processes those materials in facilities such as a SWTC. Once sorted, non-recoverables are transported to landfills (Casella Waste Systems, 2019c). CWS works with local municipalities to run environmentally sound landfill facilities. Recyclables, once sorted at a SWTC, are relocated to one of CWS's seven recycling centers in and around Massachusetts (Casella Waste Systems, 2019d). These facilities help guarantee that recyclable materials are not shipped to locations outside of North America, and that the profits gained from processing the recycling return to the community (T. Markham, personal communication, December 11, 2019). CWS also operates a diverse organics program (Casella Waste Systems, 2019a). They offer services to process organic waste with services like composting, anaerobic digestion, and food scraps collection. CWS offers online services including an interactive sustainability report, applications for curb-side service and dumpster rental, and news updates on the company's recent community involvement. An environmental manager at Southbridge's Casella branch attributes the success of their program to the state-of-the-art design of their facilities, in particular the proper construction and maintenance of their landfills and transfer centers (T. Markham, personal communication, December 11, 2019). Because of the quantity and variety of services provided and their environmental efforts, we have determined CWS to be a successful SWM system.

Another type of SWM system is a recycling collection center where citizens of communities can bring their recyclable municipal solid waste and separate it on site (Town of Wayland, 2019). Wayland Town's (2019) recycling center operates by charging an annual fee of $165 for a permit sticker placed on a vehicle. Within the center, users sort recyclables into large bins that correspond to each category of recyclable material. The station also includes other in-person services like lightly used book exchanges and other second-hand possession swapping.

Furthermore, the center serves social purposes as well as practical ones; it is a go-to meeting hub where friends can chat, and often political candidates are found campaigning there. Online, they offer services like a Recycling Directory and Recyclopedia, a Transfer Station Disposal instruction list, and advertisements for days and times when they dispose of large or hazardous items like appliances and electronics. This example also demonstrates that SWM systems that use drop-off methods in addition to collection methods can also be successful systems.

The final example, through the City of Worcester (2019), is an at-home-composting and compost-collection program. The City of Worcester boasts the largest municipal composting program in Massachusetts, which includes services for leaf and yard waste collection, a residential compost drop-off center, and an opportunity to purchase at-home composting bins that are emptied by the city biweekly. Their website offers descriptions of the three primary services provided, as well as additional resources giving citizens further access to information about composting. While not in use by the majority of the Worcester population, this system achieves success due to its low cost and variety of services. Yard waste collection and residential compost drop-off are free services, and at-home composting using the “Earth Machine” (para 2) has an up-front cost of $45 for purchase of the bin. Furthermore, the three possible composting options allow users to participate in the system to the degree that they are able.

2.2. Waste management and its importance

The waste management cases identified in Section 2.1.2. exemplify three steps to create a good solid waste management system (Casella Waste Systems, 2019a; Casella Waste Systems, 2019b; Casella Waste Systems, 2019c; Casella Waste Systems, 2019d; City of Worcester, 2019; Guerrero et al, 2013; Town of Wayland, 2019; Wu et al, 2014). The three steps are: identify accessible locations, create organized citizens groups, and encourage citizen involvement.

Complete and correct municipal solid waste disposal helps a community's health, economy, and municipal government support.

Having an accessible location and a well-timed schedule for waste collection means there is a higher possibility of collecting all available material currently in the town or city (Guerrero et al, 2013). In cases of inconvenient and inaccessible location and timing, people are more likely to throw recyclable material into the trash rather than making a separate errand to take it to the transfer center. This problem becomes even more critical in cases where municipal solid waste is generated at rapid speeds, like in large companies where multiple weekly collections or drop-offs of waste are needed (EPA, 2016).

Two more essential steps in creating a thriving SWM system are establishing organized citizen groups and encouraging citizen participation (Vining, 1992). If the residents of the city or town are not supportive of the Municipality's environmental efforts, it is difficult to achieve effective recycling and composting. Organized groups of involved citizens can help to further encourage the community's engagement in SWM practices.

2.2.1. Importance of good solid waste management

Improper waste management has a plethora of ill effects: contaminated rivers and groundwater, poor air quality, and increased greenhouse gas production, all of which also pose health risks to the local population (Alatout et al, 2014; L. Abu-Lail, personal communication, October 28, 2019). Cities where citizens cannot correctly dispose of their solid waste are more likely to contract with waterborne diseases. Individuals can bury their solid waste in their backyard or dump it in the street, which are acts detrimental to both community sanitation and the environment. Solid waste releases chemicals as it degrades over time, and chemicals released into the ground can infiltrate the ground water.

Additionally, decomposition of organic municipal solid waste in a landfill emits significantly more greenhouse gases than it would if composted (K. VanDusen, personal communication, February 2, 2020). Another source of greenhouse gas emissions within municipal solid waste is nitrogen-based fertilizers. With a successful organic material disposal program, compost is a product and can replace these fertilizers.

Finally, waste being thrown into the street can also affect the economy of a town. Tourists, for example, are less likely to visit a place where trash causes illnesses and there is a foul odor in the air, or even places where lots of trash is visible. Both health-wise and environmentally, good solid waste management is essential.

2.2.2. Solid waste transfer centers

One element of an economical, sanitary, and environmentally conscious SWM system is a solid waste transfer center (SWTC). A SWTC serves the purpose of "consolidating waste from multiple collection vehicles into larger, high-volume transfer vehicles for more economical shipment to distant disposal sites" (EPA, 2002, p 2). Most SWTCs contain an open receiving area, where citizens can drop off their trash, recyclables, and organics (EPA, 2002). From there, the municipal solid waste is distributed and organized further. Non-recoverables are typically compacted and loaded onto vehicles bound for landfills. Recyclables can be specifically sorted at the SWTC or sent to an alternate location for sorting and bundling. Organic waste travels to another facility on site, or nearby, to be separated and treated using an anaerobic digestion center, where its conversion to compostable material produces energy.

Some elements are universally present in SWTCs because the transfer process could not be properly completed without them (EPA, 2002). Additionally, depending on the location, respective flow rates, and needs of the community, there are other elements that make each

SWTC unique. The typical elements included in a SWTC are some sort of transfer technology protected by a partial or full covering, a drop-off station, an exportation station, a weigh station for incoming and outgoing trucks, a management building, a parking lot, a fence, and a gate.

Technology and details unique to a certain SWTC include climate and weather preparations, a community education center, green technology, a covering station, some type of swap meet, and public restrooms (EPA, 2002). Some SWTCs have material recovery programs, vehicle maintenance areas, areas marked for potential future expansion, and a queuing zone for cars during busy hours. In some cases, these centers are also built to blend into the community around them, conserving the aesthetic of the location.

2.3. Solid waste management in Monteverde

In Costa Rica, SWM is often divided up between facilities in different municipalities (Ministerio de Salud, 2016; J. Welch, personal communication, November 11, 2019). Some have facilities that package recycling to be bought and processed elsewhere, while others have facilities that manage solid waste bound for landfills. In Monteverde, Costa Rica, for example, there is no waste compacting facility, so solid waste must be sent elsewhere to be processed fully. We operationally defined the SWM system in Monteverde as the infrastructure, services, and education. Other factors that influence SWM, such as geography and the attitudes and habits of the community, were operationally defined as non-systemic factors. SWM issues in Monteverde are affected by a variety of factors, including national government and various local organizations (Androvetto, 2013; ASADA, 2019; Obermiller, 2015; Sistema Costarricense de la Información Jurídica, 2016). In this section we will look at the specifics of SWM in Monteverde and examine how each of these factors affects the system.

The Monteverde ASADA (*Asociación Administradora de Acueducto y Alcantarillado Sanitario* - Administrative Association for Sewers and Aqueducts) is particularly concerned with SWM because improper disposal of SW can affect environmental health, water quality, sanitation, and air quality in the community (Sheffield, 2017; J. Welch, personal communication, November 11, 2019). If citizens are not provided with sufficient waste management services such as collection, they may turn to waste disposal methods that could harm the community and environment. While people in Monteverde do not generally burn waste, the SWM system could still better serve the people by making sustainable waste disposal methods easier to participate in. As a water protection agency, the ASADA is concerned with this issue is that improper SWM can result in groundwater pollution. This is both an environmental problem and an issue of sanitation and health for the local people. For example, when people do not have convenient opportunities to dispose of solid waste properly, it becomes polluting to the water supply. In 2019, volunteers pulled out over three tonnes of solid waste from a stream in Monteverde (J. Welch, personal communication, November 11, 2019). This illustrated the effects of bad solid waste management on water sanitation. Another way water becomes polluted through improper disposal is when people bury their solid waste, which can contaminate the subterranean aquifers in the Monteverde area.

In addition, SWM centers themselves can cause water pollution (EPA, 2001). Waste treatment facilities produce organic sludge as a byproduct. The current waste management facility in Monteverde allows this sludge to be discharged into the local stream, becoming a source of contamination for both Monteverde and other places downstream (J. Welch, personal communication, November 11, 2019). This causes health and sanitation issues because the stream becomes polluted.

An important impact of the current SWM system in Monteverde is that it causes more greenhouse gas emissions than an improved system would (EPA, 2016; J. Welch, personal communication, November 11, 2019; Welch, 2018). Because of the limited collection services in the current system, recyclables and organics are sent to the landfill, which produces more carbon emissions than processing them alternatively (EPA, 2016). This is an important effect of municipal solid waste mismanagement in Monteverde because it contributes to climate change.

2.3.1. Influence of government and local organizations

The national government in Costa Rica requires that each district, like Monteverde, have its own plan for Integrated Solid Waste Management (Sistema Costarricense de la Información Jurídica, 2016). The *Instituto Costarricense de Acueductos y Alcantarillados* (AyA) (Costa Rican Institute of Aqueducts and Sewers) requires that each district have an ASADA to carry out that plan for the district. The mission of the ASADA (2019) in Monteverde is to protect the water sources there in accordance with regulations from the Ministry of Health and AyA. This mission also extends to other issues that affect the water. In Monteverde, this means that the ASADA is utilizing its power and resources to work on the issue because improper SWM is one of the major threats to water protection and good sanitation (J. Welch, personal communication, November 11, 2019).

AyA sets the engineering standards for the facilities and the waste management and water protection (J. Welch, personal communication, November 11, 2019). AyA is responsible for building the waste management facilities, but once they are built, the local community organizations such as the ASADAs become responsible for utilizing them in ways that benefit their particular community’s water protection. This means that ASADA's project of engineering the SWM system in Monteverde will be affected by the engineering regulations from AyA. For example, they require SWM facilities to have scales to measure all the solid waste that pass through them.

The Ministry of Health also regulates the waste management in Costa Rica, with a focus on setting sanitation standards for water quality (Androvetto, 2013; J. Welch, personal communication, November 11, 2019; Ministerio de Salud, 2016). Therefore, the ASADA (2019) is also working under sanitation regulations from the Ministry of Health while working on their SWM system as it relates to water quality and sanitation (Sistema Costarricense de la Información Jurídica, 2016). For example, all facilities, including SWTCs, must obtain *Permiso Sanitario de Funcionamiento*, or PSF, which is permission to function based on sanitation standards, from the Ministry of Health. The Ministry of Health also has regulations specific to facilities that recover materials, such as recycling centers. These regulations from the Ministry of Health are intended to comply with Law 8839, the Law for Integrated Waste Management (La Asamblea Legislativa de la República de Costa Rica, 2010). This law dictates that everyone in Costa Rica should have access to integrated waste management services that are sustainable, maximize reuse of materials, and prioritize public health

La Comisión de Manejo Integral de Residuos Sólidos, COMIRES, the Commission for the Management of Solid Waste, is a municipal commission in Monteverde that involves several other organizations, including the ASADA (Welch, 2018). Their mission has been to develop plans for SWM in Monteverde in accordance with federal laws, while encouraging participation from local government, public institutions, and nongovernmental and academic institutions in this initiative. They have aimed to reach this goal through strategic initiatives in infrastructure, service, and education. Since COMIRES is another local organization working on SWM, this organization is another stakeholder in the process and has a significant effect on how the SWM system should be designed. COMIRES has also published research on the current state of SWM in Monteverde, including research on the qualities of various types of solid waste produced in Monteverde and where these different types of waste end up. This research documents the improvements in Monteverde waste management since 2012, such as the amount of waste properly recycled, and the problems that remain with the systems in place.

2.4. Summary

In this chapter, we discussed previous research on SWM and its problems, popular attitudes toward municipal solid waste, the importance of good SWM, and SWTCs. We mentioned the environmental dangers of incorrect solid waste management, and how it can cause a multitude of health problems. We also discussed these topics in the specific context of Monteverde, looking at the current state of the SWM system and the structures it is operating within, such as the ASADA and COMIRES. However, current research has not yet looked at how to implement a SWTC in Monteverde in a way that considers the particular situation of the community and the needs and opinions of the Monteverde citizens and stakeholders. In the next chapter, Methodology, we discuss how we plan to carry out research that will elucidate what is required for a better SWM system in Monteverde, implemented through a SWTC.

Chapter 3: Methodology

The goal of this project was to develop a basic conceptual design for a solid waste transfer center (SWTC), and to make recommendations that promote a high participation rate in recycling and organics collection programs in Monteverde. We aimed to design a SWTC that would be beneficial to Monteverde while taking into consideration the natural environment, sociocultural context, public health considerations, and economic factors. In order to achieve our goal, we accomplished the following objectives:

1. Identified how the current solid waste management (SWM) system in Monteverde worked, and how it evolved in the recent years;
2. Determined the historical trends and future projections in growth, composition, and geographic breakdown of the municipal solid waste in Monteverde;
3. Determined successes and shortcomings of the system according to experts;
4. Determined the successes and shortcomings of non-systemic factors according to residents and business owners; and
5. Designed a SWTC that would address the needs of MV experts, residents, and business owners.

This chapter details the methods we used to accomplish our goal. We selected each approach for its ability to help meet our objectives, and further justification for our selections are given in this chapter as well. The five objectives above correspond with the following five sections of this methodology chapter. To best reach our goal, we achieved our objectives in three phases, demonstrated in Figure 3.1 below. Phase 1 helped us achieve our first objective because having a strong baseline understanding of Monteverde's SWM system was a critical preceding step to asking educated and focused questions in our interviews and surveys. Phase 2 helped us achieve the second, third, and fourth objectives because they all provided us information that allowed for the creation of the most effective and necessary design of the SWTC, which was phase 3.

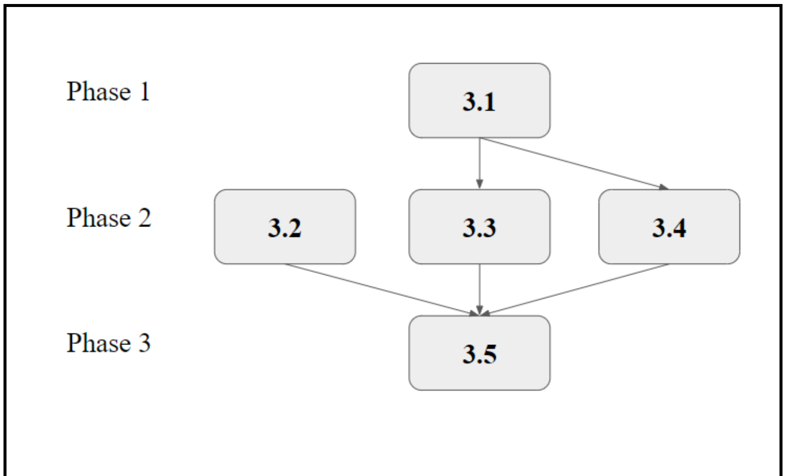


Figure 3.1: Phase flow diagram for the five objectives

3.1. Identifying the SWM system

Phase 1 consisted of identifying how the current SWM system in Monteverde worked, and how it evolved in recent years. We achieved this objective through direct and participant observation as well as discussions with people involved in the SWM system. To identify how non-recoverables were treated within the SWM system, we directly observed the collection process. To see the recycling side of SWM, we volunteered in a Recycling Campaign and participated in a COMIRES council meeting. To identify the role of organic waste in the system, we discussed and visited the pilot composting facility with Justin Welch of ASADA.

While doing participant observation, we had to balance what we were seeking for our project with others' expectations. Although we had specific ends we were seeking, we were mindful of our position as outsiders working with more experienced SWM experts; we were not only there to complete our own project, but also to be helpful and respectful to those we were with. For example, when COMIRES asked us to distribute flyers to educate the public about the recycling campaigns, we agreed to do this even though it did not directly address any of our project work. However, we also made it relevant for our own objectives by conducting our survey at the same time as we were distributing flyers. Another example of this was volunteering for the recycling campaigns. We volunteered for a recycling campaign during our first week in Monteverde to collect observations about how they were functioning. While we were there, we were not only gathering information for our own project, but actively helping the other volunteers deal with the recycling. However, in the later stages of the project, we had to be careful not to recommit ourselves to more recycling campaigns that were no longer going to be relevant for our research.

3.2. Determining SW trends and projections

The first step in phase 2 was to determine the historical trends and future projections in growth, composition, and geographic breakdown of the municipal solid waste in Monteverde. To do this we analyzed data provided to us by *La Comisión de Manejo Integral de Residuos Sólidos* (COMIRES) about the production levels of trash, recycling, and organics. We looked at the data from the years between 2012 and 2019 in order to determine trends in growth, content, and disposal practices.

We combined the data about the trash volume from a COMIRES report from 2012 to 2017 with current data provided to us as raw numbers from COMIRES and converted it into a graph (Welch, 2018). We also graphically combined the recycling volume and content-breakdown from COMIRES between the years 2014 and 2018 with raw data from 2019.

3.3. Determining systemic successes and shortcomings

The next step in phase 2 was to determine the successes and shortcomings of the system according to experts. As mentioned in chapter 2, we defined the system operationally as the infrastructure, services, and education that contribute to solid waste management. We conducted interviews with professionals from COMIRES, the Municipal Recycling Center, and the Ministry of Health. We wanted to determine their points of view because we needed to make sure an improved SWM system would be both feasible and convenient for the people who would be in charge of carrying it out. We elected to interview Sarah Dowell, a Monteverde citizen and member of COMIRES, because she was able to show us the perspective of a user of the Municipality's SWM system. We interviewed Katy VanDusen, another COMIRES member and the coordinator of CORCLIMA (Commission for Resilience to Climate Change in Monteverde). She explained to us the environmental and climate-change-motivated perspective on good SWM. Third, we interviewed Esteban Aguilar of the Ministry of Health, the administration presiding over the practices the COMIRES council hopes to enact, to understand the policy and regulation viewpoint with respect to implementing a SWTC. Esteban was also a knowledgeable source about the transfer centers and helped advise us on transfer center elements which were most applicable to Monteverde. Finally, we interviewed William Arguedas, the Administrator of the Municipal Recycling Center, to obtain more specific technical statistics about the daily inner workings and flow rates of Monteverde's recyclables. These interviews were semi-structured because while we had specific questions to ask each person based on their positions within their organization, we also wanted them to be able to lead the interview and discuss what they believe is most important. We collected qualitative data from these interviews, which helped us evaluate the information we had with respect to the trends we saw in the COMIRES' data. With the qualitative data we obtained, we had a better understanding about the achievements and failures of the current SWM system in Monteverde. We wrote the specific questions for each interview based on the individual's expertise, and the questions, interview protocols, and goals are in Appendices F through I.

An ethical consideration of our project was balancing the many points of view on SWM. We had to consider the perspectives employees and volunteers from various aspects of the SWM system. We considered each of these perspectives as equally important, because a successful SWM system will need to consider the community members using it as well as the people implementing it.

3.4. Determining non-systemic successes and shortcomings

To achieve the final objective in phase 2 and determine the successes and shortcomings of non-systemic factors according to residents and business owners, we analyzed pre-existing survey data and conducted our own survey. More specifically we wanted to find out what the local stakeholders thought of the historical and current SWM system and why they had not all been successfully recycling or disposing of organics with the current SWM system. We also wanted to find out what changes to the SWM system would be beneficial from their point of view. The points of view of the residents and local business owners about SWM in Monteverde were valuable because any additions to the system must satisfy the needs and preferences of the users.

We determined the successful and limiting factors for the residents' by analyzing survey data collected by the University of Costa Rica in 2018, and by conducting our own survey (UCR, 2018). The UCR data focused on whether residents recycled and composted, and what specifically happened to those recyclables and organics. The sample size was 150 residents. We supplemented this survey data with our own survey that focused on the residents' suggested improvements to the system as well as their attitudes towards the implementation and future existence of a SWTC.

We elected to conduct a survey because it would be a more effective way to gather data from a larger number of people and was more easily quantifiable compared to other research methods like focus groups and individual interviews. We separated our survey responses based on the geographic location of the household taking the survey to see if the location, relative to collection routes or SWM facilities, influenced the opinions of SWM practices. We conducted the survey orally in Spanish and surveyed in four neighborhoods in Monteverde, which provided us with a geographical range of respondents. In total, we surveyed 50 residents. The survey questions for Monteverde residents are specified in Appendix D.

We had to consider ethics during our survey. We made sure to follow survey protocol for each one, informing the participant that their participation was completely voluntary and being careful to read their level of interest in answering the questions. These protocols ensured we did not survey people who did not want to be surveyed or who did not have time to participate. In addition, it was important to consider the perspectives of people from across Monteverde equally, regardless of their geographic location or any other qualities.

When determining the successful and limiting factors of the SWM system for business owners in Monteverde, we analyzed pre-existing SWM data gathered in the 2018 UCR survey (UCR, 2018). The UCR survey asked 30 different businesses how they disposed of their organic waste and recyclables. Additionally, we obtained data from the Municipal Recycling Center about how many businesses that participate in the monthly recycling campaigns (S. Dowell, personal communication, February 10, 2020).

3.5. Designing the SWTC

Phase 3 of our methodology consisted of designing a SWTC that would satisfy the needs of Monteverde experts, residents, and business owners. We designed this SWTC in several steps. First, we performed archival research on technical and non-technical elements that are universal to all SWTCs and unique to some SWTCs. We started our initial design based upon the elements that are universally present in transfer centers, adding elements to the design when it was later demonstrated by interview and survey responses and quantitative analyses that they were needed. Second, we performed a quantitative analysis of the annual, monthly, bi-weekly, and daily flow rates of non-recoverables, recyclables, and organics collected in Monteverde to determine how much space and technology would be required within the transfer area of the SWTC to sufficiently handle the respective flow streams. Next, we created a cost-benefit profile analyzing the trade-off implications of systems that could be used to improve the separation, compaction, and general management of the non-recoverable, recyclable, and organic material flow-rates. We analyzed six technologies to manage non-recoverable materials, five technologies to manage recyclable materials, and five technologies to manage organic materials. Justin Welch provided all of the technology options to us.

We then presented this information to COMIRES, received their feedback, and integrated that feedback into our design. Finally, we produced a Computer Aided Design (CAD) of the SWTC we have suggested Monteverde introduce and install using SolidWorks. It was important for us to get feedback from COMIRES during the process of designing the SWTC because they would be the group who connects our project to further developments of the transfer center and the SWM system. Also, meeting with a larger, more diverse group provided additional insights to the shortcomings of our basic design, helping to direct us in the most focused direction for future design development.

3.6. Summary

In this chapter, we discussed the three phases within our methodology that we completed to accomplish our project's goal. In phase 1, we identified how Monteverde's current SWM system works and its development in recent years. We did this through direct and participatory observation of the system, focusing on the processes of managing non-recoverables, recyclables, and organic material. In phase 2, we determined the historical trends and future projections in growth, composition, and geographic breakdown of the municipal solid waste in Monteverde by analyzing data from COMIRES about trash and recycling. We also determined any successes and shortcomings of the system through interviews with four SWM experts. Then, we determined the successes and shortcomings of non-systemic factors according to residents and business owners by analyzing existing survey data from the UCR (2018) and performing our own surveys. Finally, in phase 3, we used data analysis and SolidWorks software to develop a conceptual design for a SWTC that would satisfy the needs of MV experts, residents, and business owners. In the following chapter, we will present the findings from our research that show how we accomplished each of our five objectives and our goal.

Chapter 4: Findings

The goal of this project was to develop a basic conceptual design for a solid waste transfer center (SWTC) and to make recommendations that promote a high participation rate in solid waste management (SWM) programs in Monteverde. To achieve our goal, we completed five objectives:

1. Identified how the current SWM system in Monteverde worked, and how it evolved in recent years;
2. Determined the historical trends and future projections in growth, composition, and geographic breakdown of the municipal solid waste in Monteverde;
3. Determined successes and shortcomings of the system according to experts;
4. Determined the successes and shortcomings of non-systemic factors according to residents and business owners; and
5. Designed a SWTC that would address the needs of Monteverde experts, residents, and business owners.

In this chapter, we present and analyze the results we obtained from achieving each objective.

4.1. Monteverde's SWM system: 2012 to present

The Monteverde SWM system had evolved in many ways since 2012 (Welch, 2018). It was essential to identify this evolution in order to determine both the technical reasoning, as well as the local, social perceptions about the current system. COMIRES (*La Comisión de Manejo Integral de Residuos Sólidos* - the Solid Waste Management Commission for Monteverde) estimated that about 30% of solid waste in Monteverde could be recycled, 40% could be composted, and 30% was non-recoverable waste. Figure 4.1a presents this data. However, in 2017, the Monteverde Municipality recycled only 7.9% of solid waste and composted none, as shown in Figure 4.1b. This meant that most of the recycling and all the organic waste went to the Zagala Municipal Landfill. In addition, the transportation costs of sending nearly all the municipal solid waste to the landfill were high (J. Welch, personal communication, January 17, 2020). They would save money by diverting valuable recyclables from this stream to larger recycling centers, and by selling compost made from organic waste.

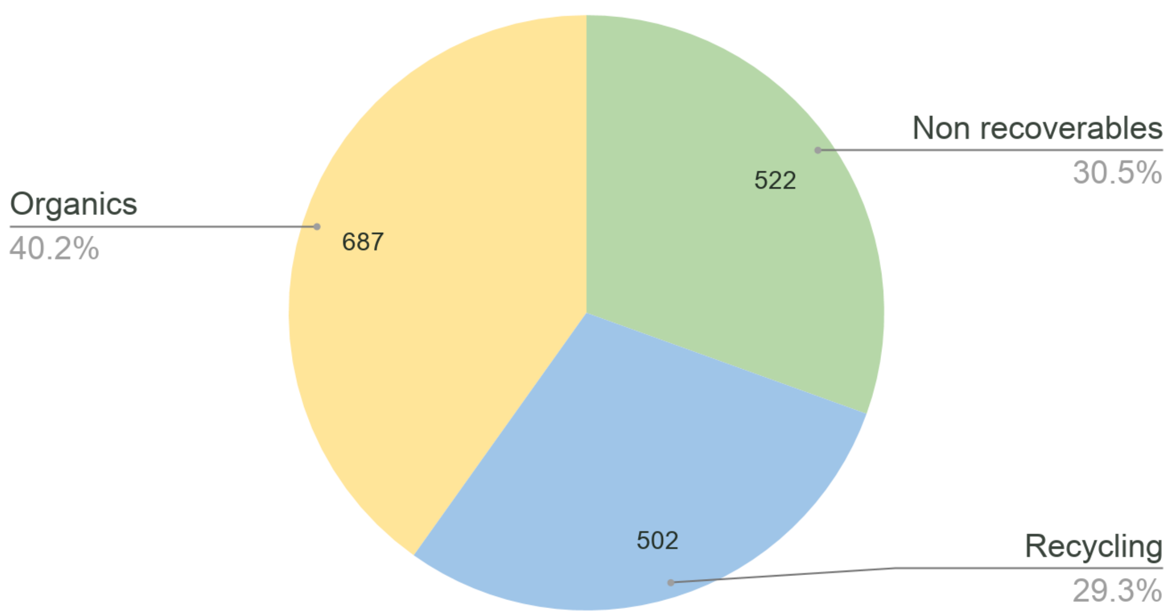


Figure 4.1a: Estimated weight in each category of waste in 2012 (tonnes). (Welch, 2018).

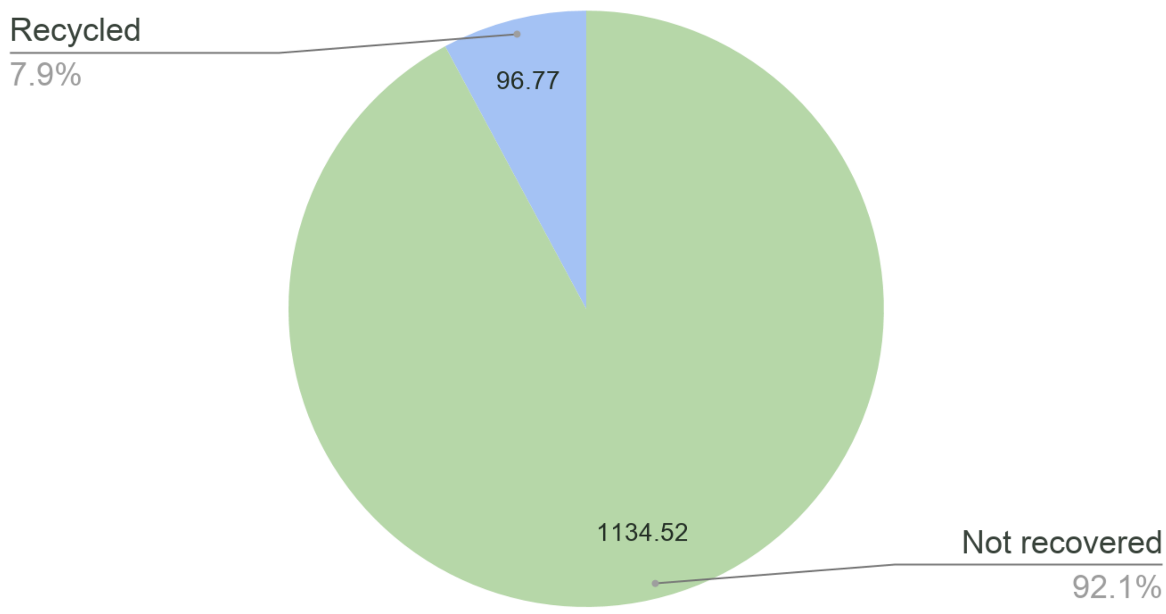


Figure 4.1b: Weight captured in each category of solid waste in 2017 (tonnes). (Welch, 2018).

Currently, the Monteverde SWM system deals with non-recoverables, recyclables, and organics in different ways (Welch, 2018). The Municipality collected non-recoverables along three designated routes: Route 1 on Mondays and Thursdays, Route 2 on Tuesdays and Fridays, and Route 3 every 15 days. During the busiest tourism season in Monteverde, October to April, collection along Routes 1 and 2 occurred three times per week instead of two to accommodate the extra waste generated. One option residents and businesses used to dispose of their non-recoverables was leaving bagged trash on the roads serviced by a collection route. The Municipality only offered this service for non-recoverables, and its convenience contributed to the large quantity of recyclable and organic material also received in this service. One way to increase the recovery rate of recyclables would be to offer a street-side collection of recyclables. We do not recommend a service like this for organics because we found that dogs frequently ripped open the trash bags in which they could smell food. Recyclables, if cleaned, dried, and bagged could successfully be collected without interference from animals on the street. This addition to the SWM system would require the Municipality to contract collection trucks and staff them - costing both money and manpower.

The other option residents and business owners used to dispose of their non-recoverables was to place them in mini collection centers (*mini centros de acopio*). These are small cement buildings, placed strategically along the collection routes in various sectors, where people can leave trash for pickup. Figure 4.2 displays an example of a mini collection center.

Figure 4.2: One of the 19 mini collection centers

Upon first design, the Municipality intended these mini centers to receive both non-recoverable and recyclable material, each through a separate window. However, there were no dividers inside the mini centers to separate non-recoverables from recyclables. Hence, these centers only collected trash. Since these mini centers provided only a space for trash disposal and not for recyclable material, they contributed to the low levels of recyclables recovery. Thus, by implementing a divider in these units, the percentage of recyclables collected by the Municipality would likely increase. We recommend dividing the mini centers because we observed that there was already a lot of recycling placed in the mini centers, so the residents would not need to dramatically change their habits. This fact would be a benefit for this option to improve recycling ease. It could be difficult to install a divider in the existing collection structures as the process may require specialized tools like welding materials or power tools. It is also important to note that with separation of recyclables in the mini collection centers, the district would need to implement a recycling collection route to pick up these materials. This new route would need to reach all 19 mini centers with enough frequency to effectively collect the recyclable material before the center filled. The Municipality would also need to contract one or more collection trucks, and to hire staff who would execute the routes. Furthermore, by using half of the volume of each mini center to collect recycling, the amount of space dedicated to non-recoverable collection would decrease. This would be especially impactful at the busiest mini centers during peak tourism season. To rectify this problem, the Municipality would need to implement a third, and perhaps even fourth, non-recoverable collection day.

To manage the recyclables collected in Monteverde, the Municipality had the Valuable Solid Waste Recovery Program (*Programa de Recuperación de Residuos Sólidos Valorizables*) (PRRSV). PRRSV, paired with the Municipal Collection Center (*Centro Municipal de Recuperación de Residuos Valorizables*) managed the collection and partial processing of recyclables. The Municipality established Municipal Recycling Center in 2013 as a collection facility for valuable recyclable materials including aluminum, cardboard and paper, plastics #1, 2, 4, 5, 6, and 7, Tetrabrik, and clear, brown, blue, and green glass (Welch, 2018). There was equipment in the collection center for processing of these materials, including a hydraulic compactor and receptacles for various materials. Until 2017, the center had only part-time employees; in 2018 it gained one full-time employee and one ¾ time assistant. In 2017, the Municipality acquired a truck dedicated to the PRRSV to collect recyclables. Organized by COMIRES, PRRSV's truck collected recycling every third Wednesday of the month through recycling campaigns at six sites around Monteverde called *Puntos Verdes*. Volunteers waited at the six sites while residents dropped off recycling for two hours. We volunteered at three different *Puntos Verdes* locations to gain an understanding of how the program worked through participant observation. Our observation revealed that few people came to any of the sites. We and the other volunteers at the *Puntos Verdes* concluded that a lack of communication between those organizing the January recycling campaign and the community members was probably the source of this confusion. The campaign had originally been scheduled for the day before, so when COMIRES changed the date, this caused confusion and misinformation among community members. However, this specific miscommunication about the date did not explain the historically low participation in *Puntos Verdes*. It was likely that the infrequency and scarcity of locations of *Puntos Verdes* caused this low participation. Having only six locations to recycle, once per month, and only for two hours at a time was not a sufficient service for the district's entire population plus a large tourist population. Furthermore, we found a large quantity of recyclable material inside the mini centers nearby the *Puntos Verdes* sites. We attributed this practice to the limited ability of the residents to recycle. This also led us to conclude that if the mini centers allowed for disposal of both non-recoverables and recycling, the residents would use them for both purposes.

A third option to increase recycling participation, besides installing a divider in the mini centers or implementing a recycling collection route, would be to increase the frequency of *Puntos Verdes*. Hosting *Puntos Verdes* twice monthly instead of once would decrease the need of the residents to store their recyclables for an extended period of time. The Municipality would need to organize and get volunteers (or staff) these additional campaigns. Adding additional *Puntos Verdes* locations to provide broader geographic service to the community would further increase the recycling recovery rates. However, in our research, we did not find out where the community needed additional *Puntos Verdes* sites, so that would be a compelling direction for future research. It would be helpful to know where there is the greatest need for additional recycling services if the Municipality decides to pursue this path to improving recycling recovery rates. In addition to implementing more dates and locations of *Puntos Verdes*, we recommend COMIRES provide more education about such services, hopefully further increasing participation levels and quality. One possible method of educating the residents about the program would be to distribute flyers like in Figure 4.3.

Figure 4.3: Puntos Verdes *informational flyers (Monteverde Municipality, 2020).*

The Monteverde ASADA managed organic waste by collecting barrels every Friday from eight businesses, including two hotels, four restaurants, the Santa Elena Cloud Forest Reserve office, and the ASADA Office, as well as six households (J. Welch, personal communication, January 28, 2020). The ASADA employees then brought the organic material to a pilot composting facility where they turned it into useful material and later sold to farms or individuals (Welch, 2018). The Municipality did not offer composting services additional to

ASADA’s, however many business owners and residents composted on their own or through private companies (UCR, 2018).

The current SWM system in Monteverde did not manage non-traditional waste. This waste could be electronics, batteries, refrigerant gases, construction rubble, scrap metal, and broken glass. Electronics, batteries, and refrigerant gases could be harmful to the environment (Adams, 2018). If combusted, these non-traditional wastes would release harmful chemicals. If sent to a landfill, they could leak toxins into the ground. While not specifically a greenhouse gas emission, this could be a high concern for waste management institutions. Furthermore, as the electronics industry develops, more electronic waste would be commonly disposed, meaning this would be of critical concern for Monteverde in the future. To achieve an ideal SWM system, the Municipality would need to come up with a way to manage these types of waste.

To summarize this section’s findings, COMIRES estimated that 30% of the collected solid waste could be recycled, yet the Municipality only recycled 7.9%. Second, we found that there was little participation in the recycling campaigns, likely because of insufficient communication. We proposed three possible courses of action for the Municipality to increase such participation. The Municipality could increase the frequency and number of locations of the *Puntos Verdes* campaigns, they could install dividers in the mini collection centers to allow collection of both non-recoverables and recyclables, or the Municipality could implement a road-side recycling collection route.

4.2. Trends and predictions in SWM

In this section we offer possible explanations for the trends in the tonnage of solid waste (SW) sent to the landfill between 2012 and 2019, as well as predictions for the tonnage that will be sent in the future. We also analyze the collection routes and the placement of collection centers relative to the population. This elucidated some of the problems with Monteverde's current SWM system and their possible causes, as well as potential solutions.

4.2.1. Waste trends

While data on municipal SW between 2012 and 2017 had already been analyzed by COMIRES, our analysis of SW data from 2018 and 2019 revealed new trends as well as new information.

In Figure 4.4, the moving average trendline (trailing 30 days) shows that the amount of SW disposed fluctuates throughout the year. We gathered this data directly from the slips given to the trucks dropping off waste at the landfill. There is a gap in the data during October 2018 because the Monteverde Municipality only had the data about the total sum of waste delivered to the landfill that month (included in the 2018 total), but not data about the daily amounts delivered. It also shows a general increase in the average daily tonnage brought to the landfill; individual daily truckloads increased in tonnage from an average of 4.81 tonnes in 2018 to 5.35 tonnes in 2019.

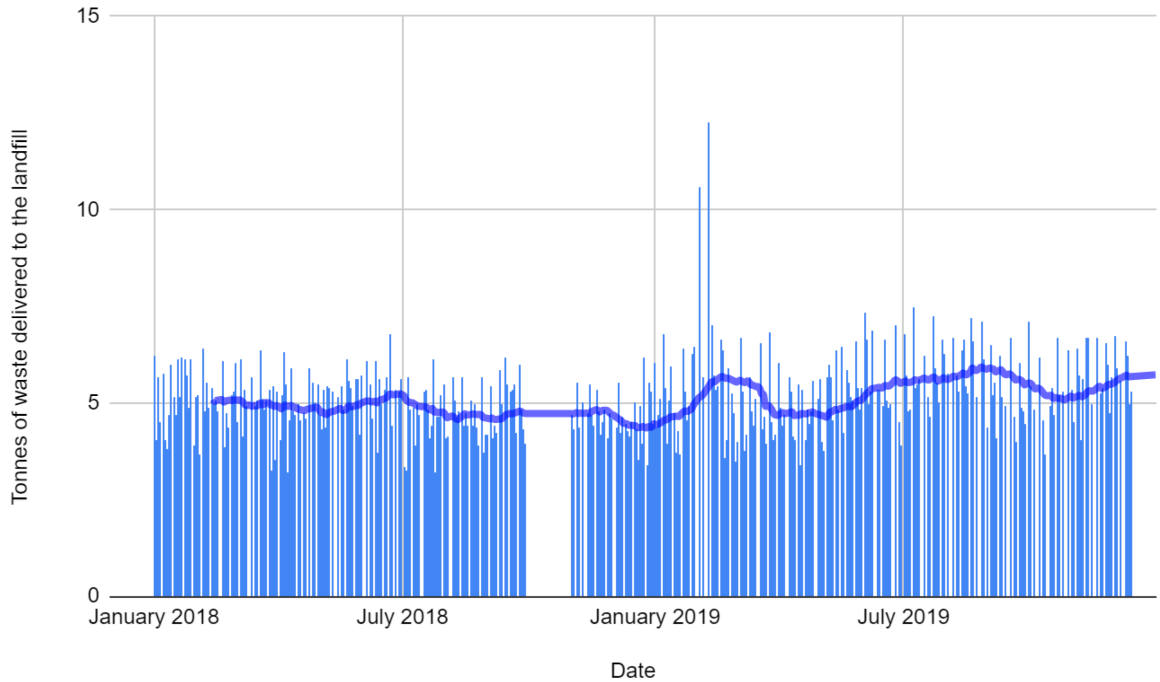


Figure 4.4: Tonnes of solid waste delivered to the landfill each day during 2018 and 2019. Data from the Monteverde Municipality (2020).

Combining this with the data analyzed by COMIRES from 2012-2017 revealed that while the SW tonnage delivered to the landfill continued to increase in 2018 as it had from 2012 to 2017, it decreased in 2019, as shown in Figure 4.5.

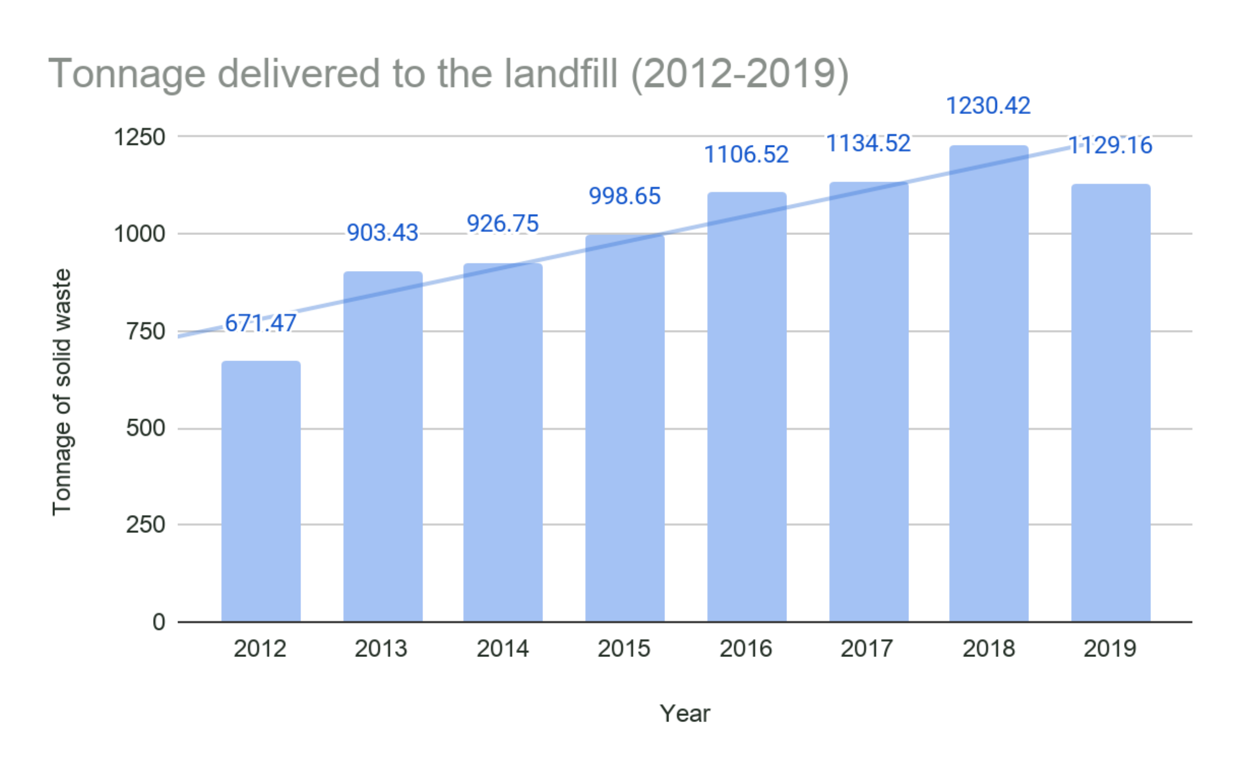


Figure 4.5: Annual tonnage of solid waste delivered to the landfill from 2012 to 2019. Data for 2012 to 2017 from Welch (2018) and data for 2018 to 2019 from the Monteverde Municipality (2020).

However, tourism as well as the local population continued to grow in Monteverde (J. Welch, personal communication, January 28, 2020). Therefore, one possible explanation for this recent reversal of the increasing trend in non-recovered SW is that while the overall amount of solid waste continued to increase, Monteverde diverted more of the waste from landfills and instead recycled or composted it. However, there was limited data about the amounts of recycling and organics diverted from the landfill in 2018 and 2019.

The total amount recycled in Monteverde increased steadily between 2012 and 2018 (Welch, 2018). The amount recycled increased at a faster rate. This indicated that the recycling program was increasing in effectiveness. It also showed that the total amount of trash the district must accommodate was increasing. These trends can be seen in Figure 4.6.

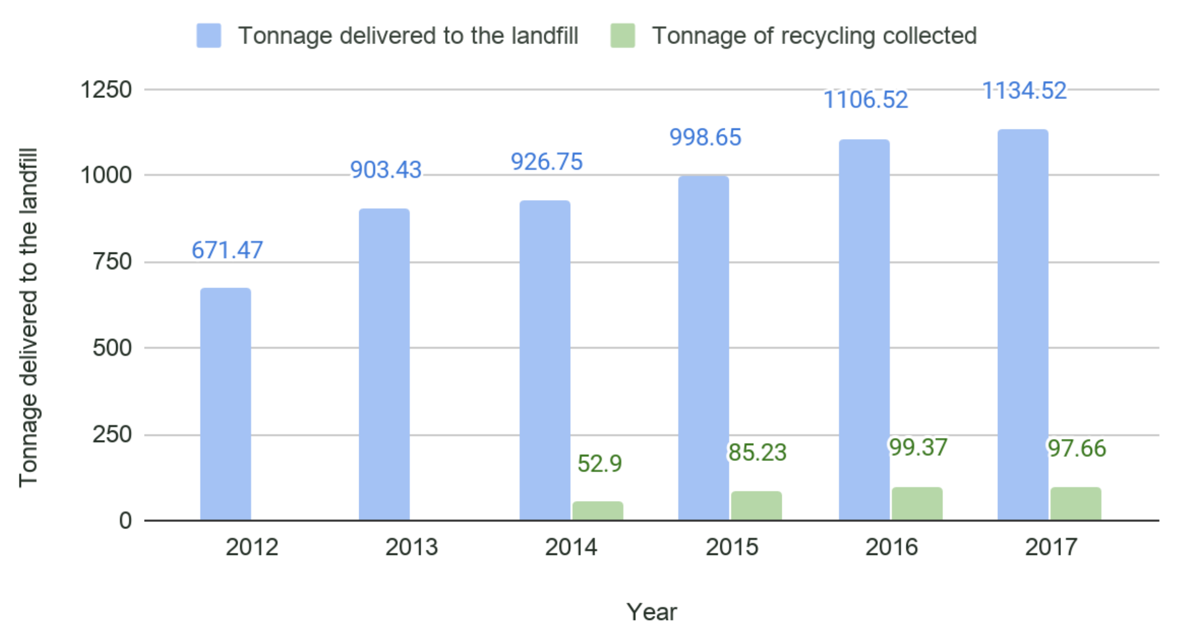


Figure 4.6: Tonnage of solid waste delivered to the landfill and tonnage of solid waste recycled in Monteverde 2012-2017. Data from Welch (2018).

This information informed our predictions about the amount of municipal SW Monteverde would have to manage in the future. While the waste delivered to the landfill did decrease from 2018 to 2019, the longer-term trend indicated that the tonnage of SW was steadily increasing. In addition, even if the recovery rates for recycling and organics did continue to improve, the Monteverde SWM system should still be prepared for an increase in the amount of solid waste delivered to the landfill, as Monteverde's tourist and resident populations continued to increase as predicted.

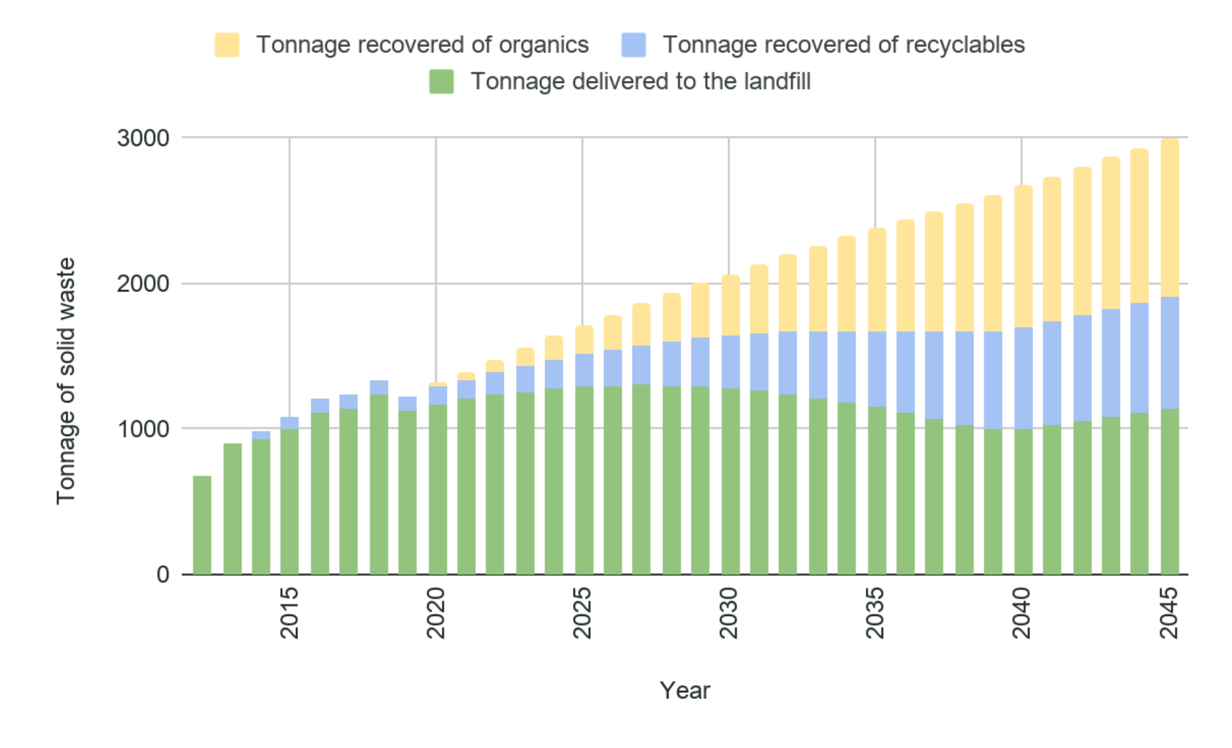


Figure 4.7: Predictions of solid waste tonnage through 2045. Data for 2012 to 2017 from Welch (2018) and data for 2018 and 2019 from the Monteverde Municipality (2020).

Figure 4.7 illustrates our predictions about the amounts of solid waste Monteverde will deliver to the landfill through 2045 based on the data from 2012 to 2019. These predictions are calculated by assuming a continuation of the growth rate of the total tonnage of solid waste (both recycled waste and non-recovered waste) from 2014 to 2019 (because there is no data on amounts of waste recycled in 2012 or 2013). Our predictions also account for an increasing recovery rate for both recyclables and organics, with the anticipated improvement of these recovery programs. The constant increase in the total amount of solid waste produced in Monteverde should continue due to continued growth in the local population as well as tourism. However, as efforts are made to decrease the amount of waste produced per person, this total might deviate from the prediction. We predict the recycling rate and organics recovery rates to increase by about 1% and 2% of total waste annually until 2040, respectively. They then would reach their maximum recovery rates, 28% and 39%, respectively. As mentioned previously, the ideal recovery rates for recycling and organics were 29.3% and 40.2%, respectively (Welch, 2018). We used slightly lower maximum recovery rates to account for human error in the process. For example, waste producers like residents might not sort their waste perfectly, or there might be some error from waste management employees. As the graph shows, if these ambitious increases in recycling and organics recovery rates occur, the amount of solid waste delivered to the landfill could decrease before 2041, when it would continue increasing again. However, these recovery rates would be dependent on many factors, which we will discuss in section 4.3. In addition, this prediction assumes it would be possible to approach the ideal recycling and organics recovery rates, letting few recyclables and organics reach the landfill. A SWTC would have to account for projections of increase in the flowrate of all solid waste, as well as the increase in recovery rates of recycling and organics. This would require the SWTC to have dimensions large enough for the 25-year growth projections, as well as an area for expansion if needed.

4.2.2. Geographical analysis of solid waste services

From an investigation of the collection routes and mini collection centers around Monteverde, we found that much of Monteverde's population goes without trash and recycling collection services. We created Figure 4.8 to illustrate the trash collection routes.

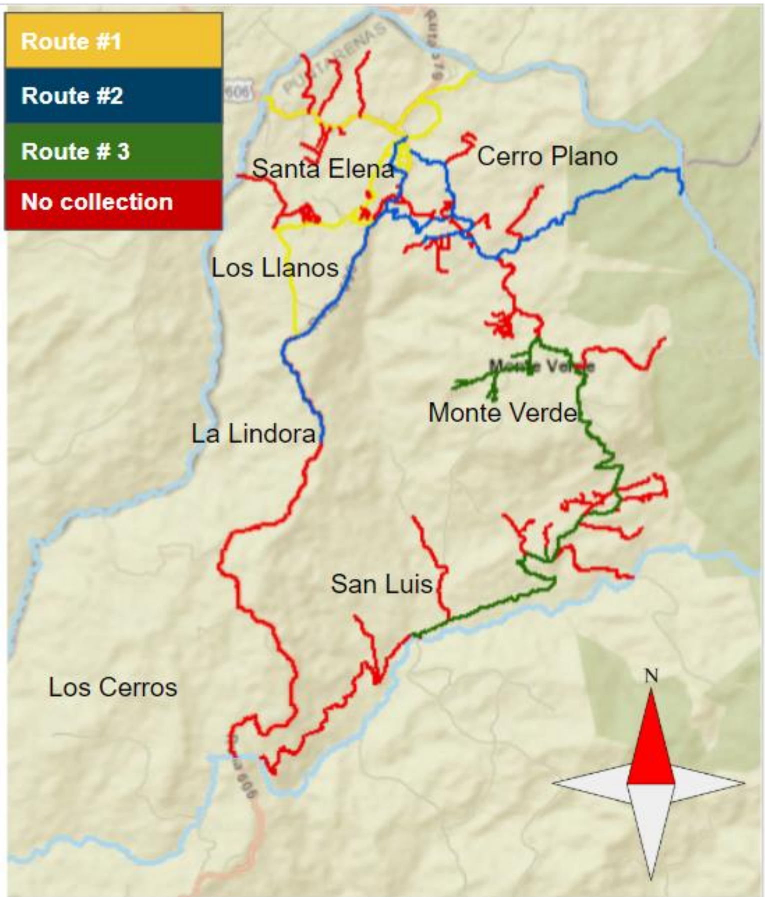


Figure 4.8: Map of Monteverde's non-recoverable solid waste collection routes and areas with no collection. (Welch, 2018).

Yellow represents Route 1, blue represents Route 2, green represents Route 3, and red represents roads that have no trash collection services. The Municipality serviced Routes 1 and 2 twice per week and Route 3 every 15 days. Figure 4.8 illustrates that the population of Los Cerros and San Luis went without service by a collection route, and the other five sectors had large geographic gaps in service.

To decrease the gaps in collection routes, we recommend the Municipality implement an additional route to service southwestern Monteverde and expand Routes 1, 2, and 3 to service the side streets. One reason why routes were not present in the far reaches of the district was because of the road quality. The municipal collection truck could not safely go down some of the smallest gravel roads. Because of this finding, we recommend the Municipality explore the costs and benefits of paving roads where trash collection services were not present. We also recommend that, as the Municipality adds these collection services, COMIRES be attentive to the advancement in infrastructure. As the roads improve, it would be important for COMIRES to be responsive and push for the implementation of collection services in those locations. Implementing more collection routes would cost the Municipality money due to the need for trucks and drivers. However, it could greatly benefit the sectors that lacked sufficient SWM services, as well as improve satisfaction of the SWM system. While looking to implement these additional routes, it would be important to consider the environmental impact of the added transportation.

Additionally, a factor that would influence the relative need of particular areas to have collection routes would be population density and the predicted geographic population growth. We show the predicted population growth throughout Monteverde in Figure 4.9.

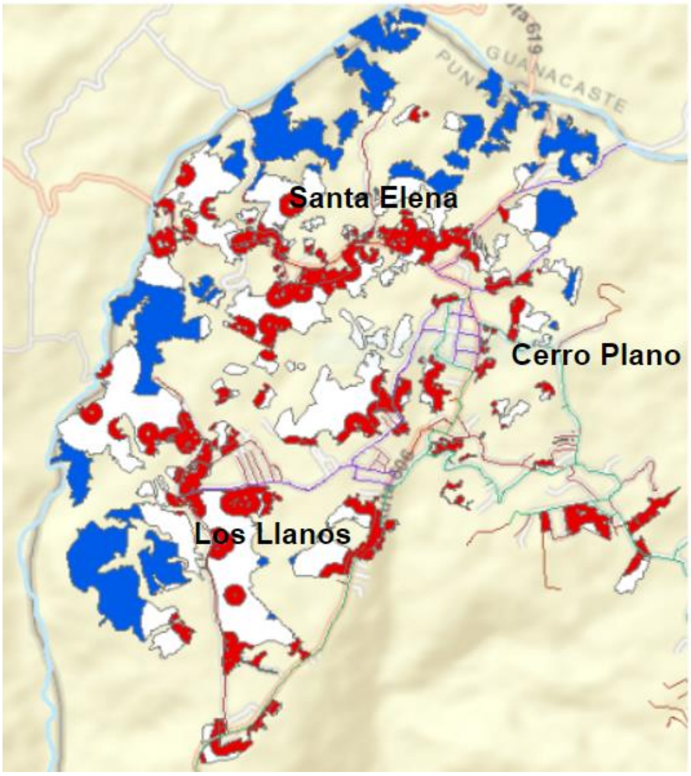


Figure 4.9: Predicted population growth for 2030 (red), 2050 (white), and 2070 (blue) (R. Chinchilla, personal communication, January 31, 2020)

Figure 4.9 shows the predicted population growth for 2030 in red, for 2050 in white, and for 2070 in blue. This data was very general, so we did not have access to discrete numbers that correspond to the density of population in each area. However, it helped us a generally determine the areas Monteverde should expect to see growth. The data available to us was limited to northern Monteverde (Santa Elena, Cerro Plano, and Los Llanos), but it further emphasized the need to service the side streets in the collection routes.

We created Figure 4.10 to visualize the positions of the mini collection centers around Monteverde in green, as well as the main Municipal Collection Center as a star. The blue circles indicate the six *Puntos Verdes* locations. These two figures together show that while San Luis did not fall within a collection route, it had several mini collection centers for trash disposal. It shows that the collection routes did not service Los Cerros and the majority of San Luis, Monte Verde, and La Lindora, nor did these areas have nearby mini collection centers. This leaves this area largely without SWM services.

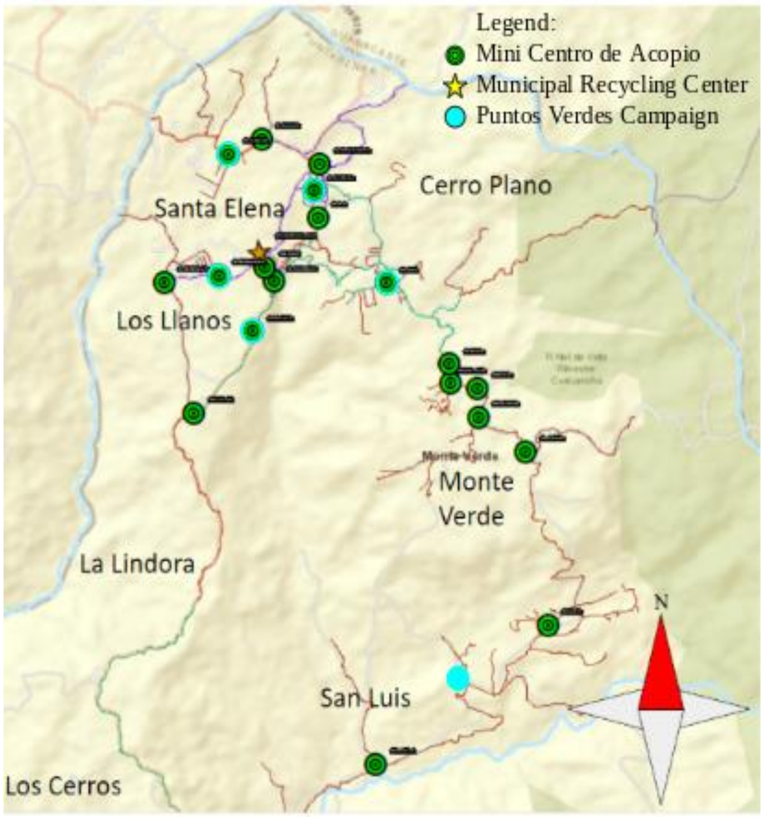


Figure 4.10: Map of Monteverde centers for solid waste collection. Data from J. Welch (personal communication, February 2, 2020).

Because of this inconsistent distribution of mini centers across Monteverde, some mini centers filled up faster than others. In addition, some residents had to walk more than 500 meters to reach the nearest mini center. We also found that there was only one mini center in Valle Bonito (a neighborhood within Los Llanos), the most populated sector in Monteverde. We recommend that COMIRES analyze which mini centers are being used most heavily. To answer this research question, they could use one of two methods. First, they could analyze the distribution of the mini centers compared to the population of each neighborhood to determine which mini centers are being used by the most people. In this method, they could also find out how far each resident must travel to reach the mini center. This method could be relatively easy because it would only require analysis of existing data. However, it would not consider the possibility of different sectors producing different amounts of waste per resident. The second method we recommend for COMIRES would be to measure the volume of waste coming from each mini center to determine which are most heavily used. While this would produce more accurate data about the amount each mini center is used, it would also be more difficult and time-consuming to execute. Once researchers determine which mini centers the community used most heavily, they could use that data to determine which area have the highest need for either expansion of the dimensions of the existing mini center or construction of an additional mini center.

To summarize this section, we first found that the total amount of municipal solid waste in Monteverde had increased between 2012 and 2018. We also found that much of the community goes without solid waste collection services, either through lack of mini collection centers, or not being located on collection routes. We recommend that existing collection routes be expanded, and a route added in southwestern Monteverde by the Municipality. We also recommend that research by COMIRES showing the mini collection centers of highest use be used to then implement those centers as well as more mini centers in southern Monteverde.

4.3. Successes and shortcomings of the SWM system

To determine the successes and shortcomings of Monteverde's SWM system, we interviewed four SWM experts. Our overarching objective was to identify what does and does not work well from different points of view within the existing system. We also wanted to get recommendations for elements to include in the SWTC design. Table 4.1 highlights the responses each of the interviewees provided to our questions.

Table 4.1: SWM system successes and shortcomings according to experts		
	Successes	**Shortcomings**
Sarah Dowell A voluntary citizen participant in COMIRES & the Monteverde recycling campaigns	• Strong original concept for the mini collection centers • Positive citizen response when learning about recycling	• Lacks *gestor ambiental* (environmental manager) • The mini centers lack mesh separator; it's difficult to recycle • Lacks proper signage about recycling at mini centers • *Puntos Verdes* is too infrequent and not widespread
Katy VanDusen The CORCLIMA coordinator and a COMIRES council member	• System offers a strong foundation for growth • The work people like Justin and COMIRES do is impactful in making Monteverde a model for carbon neutrality (SWTC plans, pilot composting plant & services)	• Lacks composting system • Lacks program for safe disposal of refrigerant gases • Recycling system is fine, but it is not hugely impactful as a climate action
Esteban Aguilar An employee of the Ministry of Health, the organization that manages municipal SW in Monteverde	• Each year a higher percentage of recycling and organics are recovered, despite the increasing waste generation • There are not problems with sanitation	• The Municipal Recycling Center is too small • Monthly recycling campaigns are insufficient and infrequent • Transportation of SW is difficult in areas far from mini centers or collection routes • Poor separation of organics and recyclables from non-recoverables • Tourism generates a lot of trash
William Arguedas The administrator of Monteverde's Municipal Recycling Center	• The collaboration with businesses • Cleanliness and sorting of recyclables delivered to the recycling center	• Lack of staff, equipment, space, and information • Insufficient communication between the Recycling Center staff and the Monteverde recycling system as a whole

The ultimate takeaways we received from these interviews were that Monteverde's SWM system offered a strong starting point for growth but required many changes to function with the highest proficiency. All the experts expressed satisfaction with the current system. They also all made recommendations for improvement. The questions and themes from these expert interviews can be found in Appendices F through I.

Sarah Dowell stressed the importance of the mini collection centers functioning with their intended purpose - to collect both non-recoverables and recycling. Their initial design had a wire barrier splitting the building in half, with one window intended for dropping off trash and the other recycling. An example of a mini center without a divider can be seen in Figure 4.11 below.

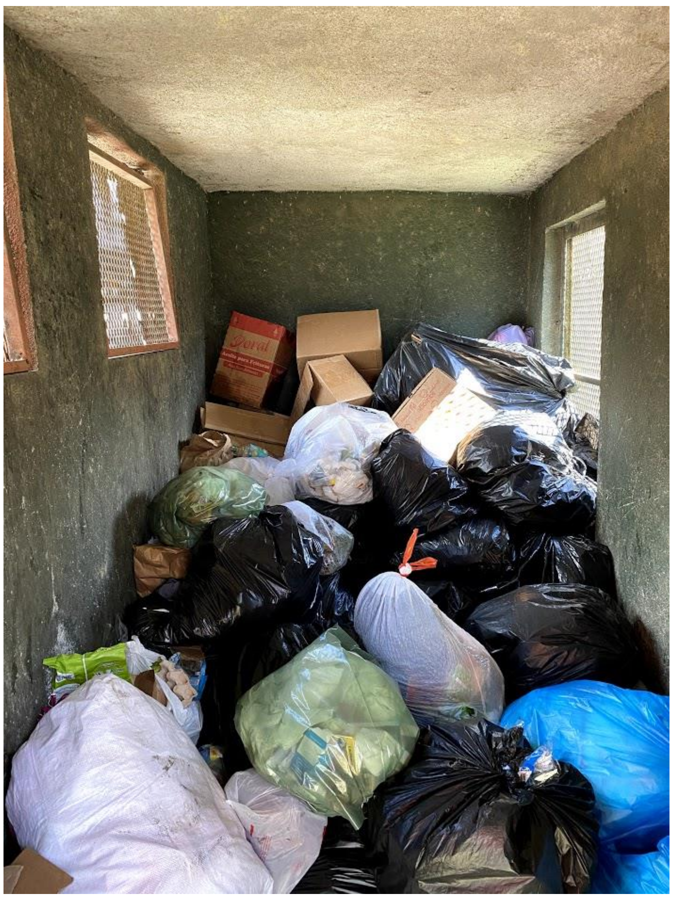


Figure 4.11: A mini collection center without a wire divider

Without the wire dividers, the Municipality took the contents of the mini centers to the landfill. A problem with this process that Sarah Dowell expressed was that many community members still put their recycling in these buildings, even though the only way to recycle in Monteverde was to bring recyclables to the Municipal Recycling Center once per month or to participate in *Puntos Verdes*. This confusion was not unfounded. Many of the mini centers were decorated with art encouraging the user to reuse and recycle. We have included examples of this in Figure 4.12.

Figure 4.12: Recycling-themed decoration on mini collection centers

To achieve a higher recovery rate of recycling, Sarah Dowell recommended that wire dividers be installed in the 19 mini centers within the Municipality. This would promote more convenient recycling for the users of the system. With more opportunity to properly dispose of recyclables, one could expect a higher participation rate.

Katy VanDusen stressed the importance of the prevention of greenhouse gases through managing the organics produced. Such organics management is currently minimal. A 2016 study by CORCLIMA found that 9% of Monteverde's emissions were from solid waste - mainly from organics (CORCLIMA, 2019a; K. VanDusen, personal communication, February 5, 2020). These emissions could be reduced by composting the organic waste. Composting is an effective climate action because the decomposition of organics in landfills produces CH_4 (methane gas), while it only produces CO_2 (carbon dioxide) through composting. This is important because CH_4

is approximately twenty-four times more potent a greenhouse gas than CO_2. Furthermore, selling the compost produced from organic municipal waste could reduce the need for nitrogen-based fertilizers, which are another producer of potent greenhouse gases. As of 2016, 4% of Monteverde's total carbon emissions were from fertilizers, as shown in Figure 4.13 in light green. It was important to eliminate the use of nitrogen-based fertilizers because they decompose into NO_x (nitrogen oxides) which are 333 times more potent than CO_2.

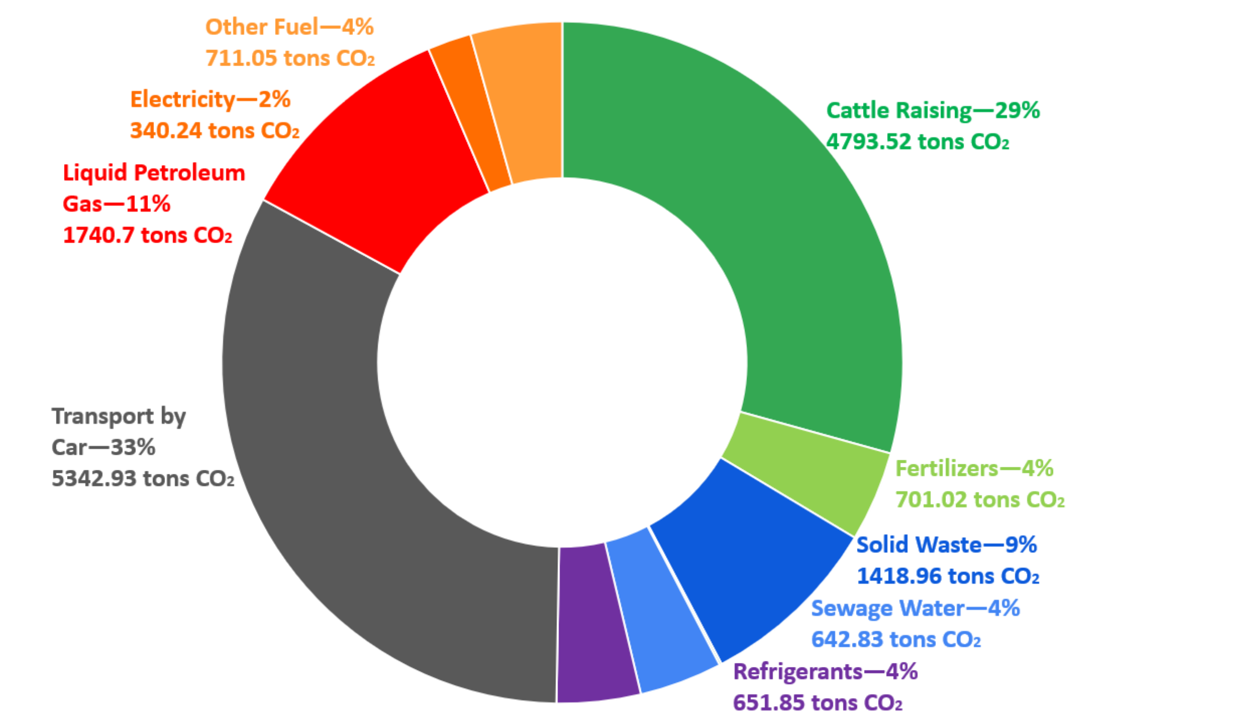


Figure 4.13: Monteverde's carbon emissions in 2016, broken down by source. The total emissions were 16,359.8 tonnes. The figure is adapted from CORCLIMA (2019a).

Additionally, the nutrient rich compost, which would be a product of the SWM system, would be a source of profit that could in turn fund other developments in the system. Since beginning to sell the products of the pilot composting facility in Monteverde in June 2019, the ASADA had made $340 selling compost and around $2,400 selling waste vegetable oil (J. Welch, personal communication, February 20, 2020). There was a new, larger composting plant under construction, and once completed, Welch anticipated it would have the capacity to gross

$7,000 annually. The challenges to achieving this were building a sufficiently large composting facility and developing some means of collecting more of the Municipality's organic waste.

Katy VanDusen also pointed out the current SWM system's lack of a program to safely dispose of refrigerant gases. Halocarbons such as chlorofluorocarbons are released from leaks in refrigerators, freezers, air conditioners, and dehumidifiers or when they are improperly disposed of. These gases are between 1000x and 12000x more potent than CO_2 (K. VanDusen, personal communication, February 5, 2020). A program to manage refrigerant gases would be a valuable addition to the SWM system, particularly with respect to achieving CORCLIMA's goals of carbon-neutrality for Monteverde. However, these gases could not be mixed with one another, so the Municipality would need to provide several containers for storage and safe transportation to an alternate facility where the gases could be disposed of in a high temperature furnace. We recommend that the Municipality conduct further research on the implementation of containers to store refrigerant gases in the SWTC. Before designing and installing such containers, the Municipality would need to collaborate with CORCLIMA in determining what refrigerant gases are most prevalent in Monteverde, and how best to capture, store, and transport them.

Esteban Aguilar stressed that the Municipal Recycling Center was too small and not well enough staffed to sufficiently process the recyclables produced in Monteverde. He also noted that the monthly recycling campaigns were too infrequent to properly manage the flow of recycling. Esteban also mentioned that there was only a small budget allocated to managing municipal solid waste. All these factors contributed to low recovery rates of recycling, because the Municipality did not collect recyclables often enough, so the community mixed the recyclables in with non-recoverables.

William Arguedas reiterated Esteban's concerns about the insufficiencies of the Municipal Recycling Center. Primarily, he addressed the center's inadequate staffing level, equipment, and space to process the delivered recyclables each month. If the Municipality addressed one of these inefficiencies, there could be drastic improvement in the functioning of the center. It would be beneficial to pursue research on which of these aspects, if improved, would most affect the functioning of the Municipal Recycling Center. This is a compelling area of future research. Each of these limitations could be addressed by additional funding from the Municipality. However, as Esteban stated, the Municipality has a very limited budget allocated to SWM, so it is critical that the best option is taken when considering additional funding. Another path of future research would be to explore the community attitudes toward charging to use the municipal recycling services. It would be important for the Municipality to know whether a charge on municipal SWM services would improve the recycling center or decrease community participation in SWM programs.

In his interview, William Arguedas used the phrase "*limpio, seco y separado*" (clean, dry, and separated) when referring to the ideal condition that the Municipal Recycling Center could receive recycling from the public. We recommend for the Municipal Recycling Center to employ this phrase as a slogan for good recycling habits, using it on signage. This recommendation would be relevant whether they decide to increase *Puntos Verdes*, separate the mini centers, or implement a road-side collection service.

To summarize this section, we found that the experts agreed that, for the citizens and businesses in Monteverde, it was difficult to recycle. Also, we found that the Municipal Recycling Center lacked staff, equipment, space, and information to function most effectively. Additionally, the current SWM system was not optimized with respect to its carbon emission levels. The lack of composting of organic waste coupled with the absence of a program to manage refrigerant gases increased Monteverde's greenhouse gas emissions.

Based upon our findings from the interviews with the four experts, we recommend the Municipality improve signage in the SWM system and use the slogan "*limpio, seco y separado*." We also recommend that they conduct further research on what aspects of the Municipal Recycling Center would be most important to improve as well as explore the effects of charging residents and business owners who use the trash collection services to fund the center's development.

4.3.1. Expert recommendations for the SWTC

Table 4.2 highlights the features, technologies, and services that each of the four experts recommended to include in the SWTC.

Table 4.2: Expert recommendations for the SWTC

	Recommendations for the SWTC
Sarah Dowell	• More frequent hours of operation than the Municipal Recycling Center and the recycling campaigns
Katy VanDusen	• Containers to safely separate and store refrigerant gases • An efficient and effective composting system • Public education services
Esteban Aguilar	• A drop-off location for materials that could have further value or use in the community • Processing, burning, and compacting would not occur on site. The materials would be transported to an alternate location with more resources
William Arguedas	• Incoming streams of recycling cleaned, dried, and separated by the user

One future research question we recognized was what specifically must be done with the refrigerants in the SWTC. Our design contained a space dedicated to non-traditional waste.

However, it needs to be determined what refrigerants are most prevalent in Monteverde. The Municipality could also identify how to best capture and store them, how they will be transported to the SWTC, and who will be the staff members at the SWTC responsible for the refrigerants. In addition, we recommend for the Municipality to conduct future research on how the organic waste will travel from the residences and businesses in Monteverde to the SWTC. This could be achieved through collection services or by having the community members bring their organic waste to the SWTC or another collection location. Research on this should consider the costs and benefits of each method.

4.4. Successes & shortcomings of non-systemic factors

To identify the non-systemic factors influencing low recovery rates of recyclables and organics, we analyzed the results from a survey conducted in 2018 by the University of Costa Rica (UCR) (2018). The researchers collected this data from 150 residents and 30 businesses around Monteverde. This section also highlights the results from a survey we conducted with residents in Monteverde to collect supplementary information.

One limitation of the surveys conducted and analyzed were the sample sizes. The survey conducted by UCR researchers obtained sample sizes of only 150 residents and 30 businesses, so there may have been some error when generalizing these survey results to the entire community. The survey we conducted had a sample size of 50 residents, leaving even more room for error when generalizing. In addition, the survey we conducted used a convenience sample; we interviewed people in relatively densely populated areas who happened to be home while we were conducting the survey. This could produce even more error because while we did not hypothesize that the survey results for our survey questions would vary by sector, it was possible that people who happened to be home during the daytime have different opinions on solid waste than people who would not be home during the day.

4.4.1. Residents' opinions

First, we analyzed the results from the survey conducted by UCR researchers. We separated the survey results from residents into three groups based on which area of the district of Monteverde they were from. Sector A consisted of Santa Elena and Cerro Plano. The majority of the mini collection centers were in this area, and trash collection routes thoroughly serviced this sector. Sector A had three *Puntos Verdes* locations. Sector B consisted of Los Llanos and Monte Verde, which were close to several mini centers but not as many as in Sector A. Collection routes did not service sector B, and the area had only two *Puntos Verdes* locations. Sector C encompassed the remaining zones, including San Luis, Los Cerros, and La Lindora. Much of this region did not have mini collection centers and was not serviced by any collection routes. This sector had one *Puntos Verdes* location. Sector C was also less densely populated than Sector B. Sector A was the most densely populated. Sectors A, B, and C had response sample sizes of 84, 39, and 27, respectively (UCR, 2018). A visual representation of these neighborhoods is shown in Figure 4.14.

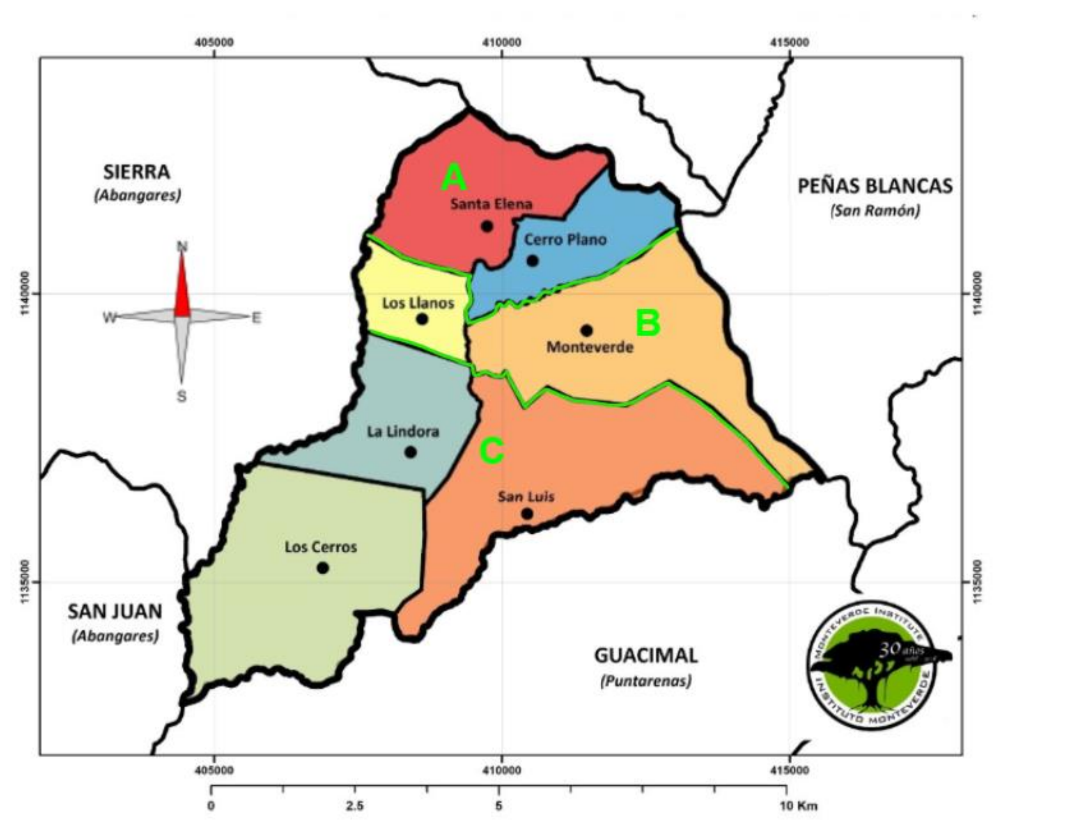


Figure 4.14: Map of the communities within the district of Monteverde, Puntarenas (Monteverde Institute, 2016).

Through our analysis of the UCR's data, we found significant differences in the opinions of residents based on their location within Monteverde (2018). Those in Sector C, furthest from mini collection centers and the collection routes, were much less pleased with the SWM services than those closer to the collection centers and routes. Figure 4.15 demonstrates these findings.

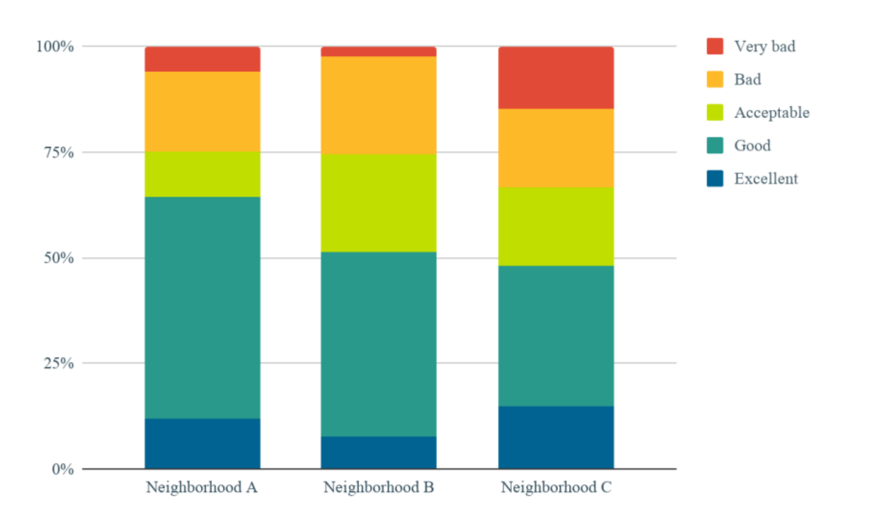


Figure 4.15: Monteverde residents' responses to the question "How do you find the current solid waste management services?" by sector (UCR, 2018).

We also found that the way people disposed of their recycling also varied based on their location. Greater proportions of residents in Sectors C and B did not recycle compared to residents of Sector A. These survey responses are displayed in Figure 4.16. The reasons behind these responses are examined in Figure 4.17.

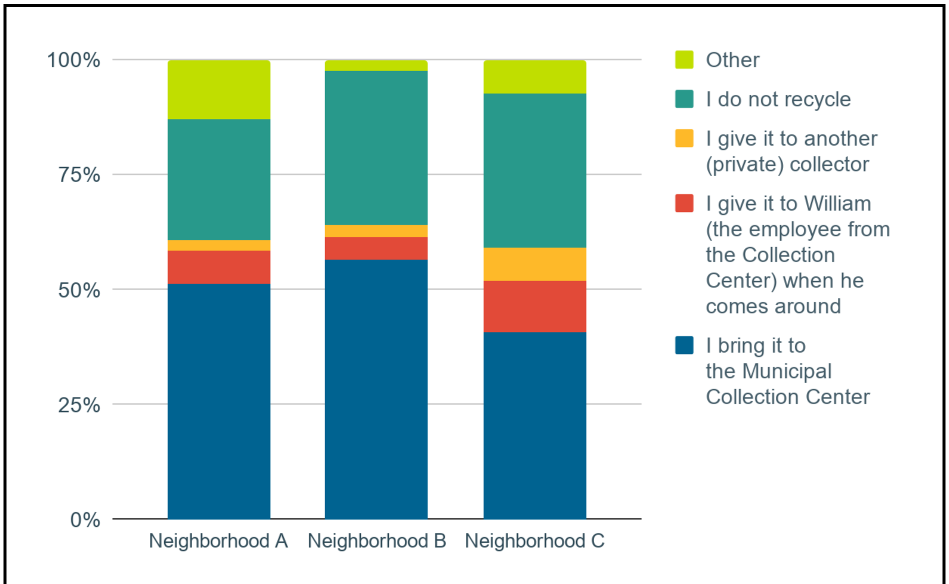


Figure 4.16: Monteverde residents' responses to the question "What do you do with your recycling?" by sector (UCR, 2018).

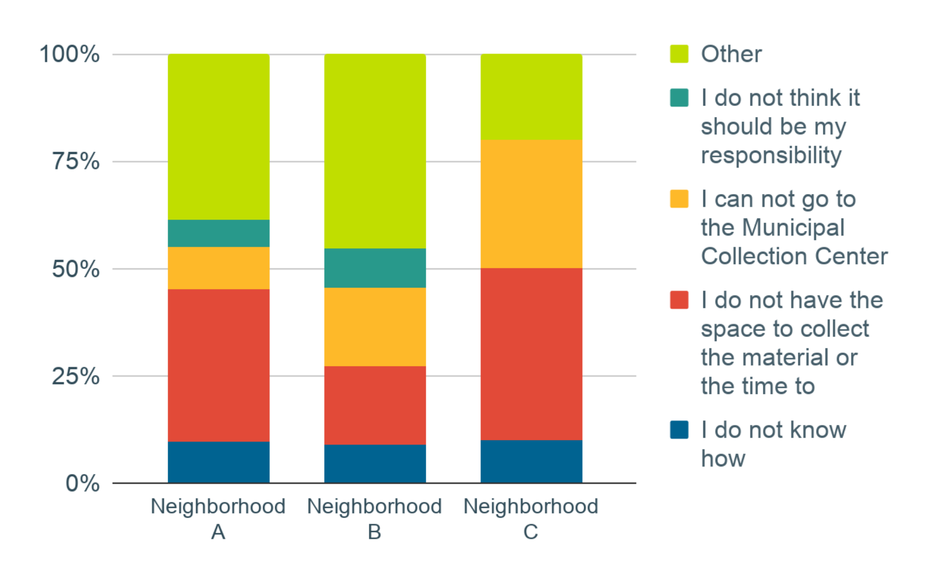


Figure 4.17: Monteverde residents' responses to the question "If you do not recycle, why?" by sector (UCR, 2018).

In Figure 4.17, the orange sections of each bar, representing inability to go to the Municipal Collection Center, are much larger in sector B than A and in sector C than B, which implies that the distance to the collection centers is a factor. These survey results showed that living a greater distance from a mini collection center resulted in lower recycling rates. In addition, the red bars indicate that many people did not have the space to store their recycling, so recycling campaigns were too infrequent to help these residents with recycling. When the campaigns only happened once a month, people needed to store their recycling for a whole month before disposing of it. If they missed the two-hour time slot one month, they would have two months' worth of recycling to store.

Another important result shown in Figure 4.17 is that there were very small proportions of people in each sector that did not know how to recycle (dark blue), and even fewer respondents said they did not think recycling should be their responsibility (dark green). This indicates neither community attitudes about recycling nor a lack of education about how to recycle probably caused the low participation rates in recycling.

The UCR survey looked not only at residents' recycling habits, but also at how they managed organic waste (2018). Figure 4.18 shows that most residents disposed of their organic waste differently than their non-recoverable waste:

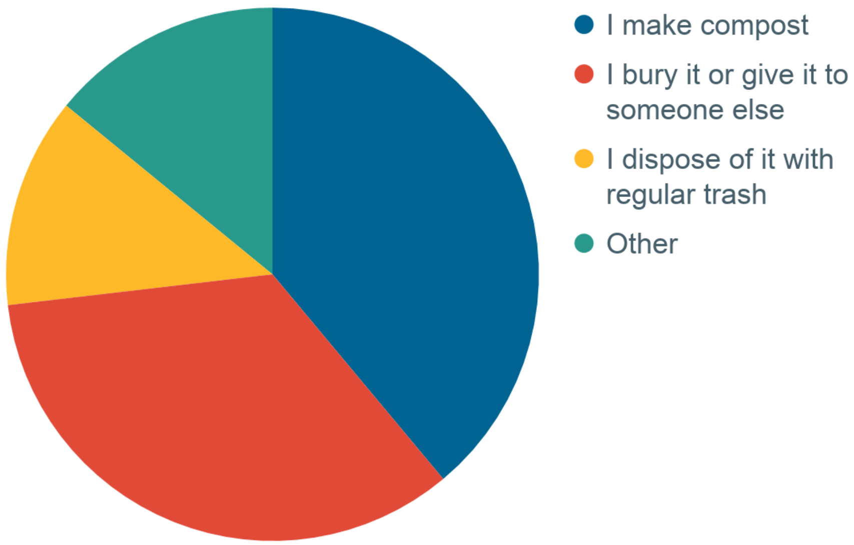


Figure 4.18: Monteverde residents' responses to the question "What do you do with your organic waste at home?" by sector (UCR, 2018).

These survey results showed that many residents already diverted much of their organic waste from the landfill. Residents of sector C were more likely to compost at home than residents of sector B, and B more than A. This was likely because sector C was more rural and less densely populated than sector B, and B than C. Residents in more rural, less densely populated areas were more likely to have a space where they could dump or bury their own organics. Residents in the more urbanized sector A would not have the space or opportunity.

Despite the high participation in alternative composting services, COMIRES still found 40% of the municipal solid waste sent to the landfill to be organic waste (Welch, 2018). Thus, more than 40% of the total waste actually produced in Monteverde was organic waste. This indicated that there was still room for improvement with organics recovery.

Ultimately, there was an insufficiency in the knowledge that the Municipality and ASADA had about the details of the disposal of organic material in Monteverde. The research conducted by COMIRES (Welch, 2018) and the UCR (2018) described the general waste breakdown of 40:30:30 and some community attitudes and habits. However, we found that an organized effort to identify the organic material disposal habits in all of Monteverde, with consideration of nuance and variety by area, had not been done. We recommend that either ASADA, COMIRES, the Municipality, the UCR, or another WPI IQP team perform this exploration. To achieve this recommendation, researchers from one of the mentioned groups would conduct a comprehensive survey, specific to organic material disposal, reaching a broad portion of Monteverde's population. This survey would include both residents and businesses (mentioned further in the following section of this report). The researchers would also determine what other private organics collection programs exist in the district, and they would contact those businesses to find out who they service in Monteverde. Next, with the habits of the community more explicitly identified, we recommend that the ASADA assess the needs of the community in each area and eventually implement services for organic waste.

Finally, we analyzed the results from the survey we conducted of Monteverde residents in Cerro Plano and Perro Negro. Our survey had a response sample size of 50. Initially, we asked if the resident separated their recycling from non-recoverables. Of the 50 surveyed, 40 residents said they did separate recyclables either through the Municipal Recycling Center, mini collection centers, *Puntos Verdes*, or another way. After briefly explaining what a SWTC was, we asked if they would be interested in using one. Forty-six residents responded to this question. Of the 40 people who separated their recyclables, 37 said they would use a SWTC if it were in Monteverde. In addition, of the ten who did not say they separated their recycling, five said they would use a SWTC. Only four said they would not use the SWTC. From these results, we concluded that residents were interested in having a SWTC, and that it might even reach some people who currently do not recycle, which could increase the recycling recovery rate.

We also asked the residents about what non-technical elements they would like to see in the SWTC that would benefit the community. Many residents lamented about usable items being thrown away in the mini collection centers. These included clothes, toys, and household items. When we mentioned the possibility of including a swap area for second-hand items in a SWTC, 40 said they would like to see this element in the SWTC and 4 responded they would not be interested. In addition, when we mentioned the possibility of an educational element in the SWTC, 38 were in favor of this idea, whether in the form of workshops, environmentally focused education, or education about how to properly recycle. Only five responded they would not be interested in education. Because we found a high level of interest in these two particular non-technical SWTC elements, we recommend the Municipality implement both a swap area and an educational area in the SWTC.

Our survey was limited by the number of people we were able to access. This was not a representative sample of Monteverde as a whole. Even combined with the 150 residents reached in the 2018 UCR survey, it was still a small sample size. Additionally, we recognized that the data differed by two years, further limiting the results. However, since both the UCR survey and our own suggested similar results that the findings of the expert interviews corroborated, we felt that the conclusions from this section were valid enough to make recommendations upon. Another limitation was that a specific site for the SWTC had not yet been chosen. This meant that we could not ask survey questions that considered the location of the SWTC. For example, the question we asked of residents, “Would you visit a SWTC?” might have produced different results if the residents had known how near or far the SWTC would be from their sectors.

4.4.2. Businesses’ opinions

First, we analyzed the composting practices among Monteverde businesses. There were eight Monteverde businesses that had their organic waste picked up by the ASADA for composting (J. Welch, personal communication, January 28, 2020). These included four restaurants, two hotels, and two other organizations (the ASADA and the Santa Elena Cloud Forest Reserve).

Using data from the survey conducted in 2018 by UCR of Monteverde businesses, we stratified the data by type of business, separating them into three categories: stores (including clothing stores, supermarkets, etc.), independent restaurants (including cafes and sodas, etc.), and hotels (not including Airbnbs), with respective response sample sizes of 10, 9, and 11.

UCR researchers found in 2018 that 80% of businesses surveyed disposed of their organic waste in a method other than with non-recoverables. Figure 4.19 shows that many more restaurants and stores than hotels disposed of their organic waste with their non-recoverables.

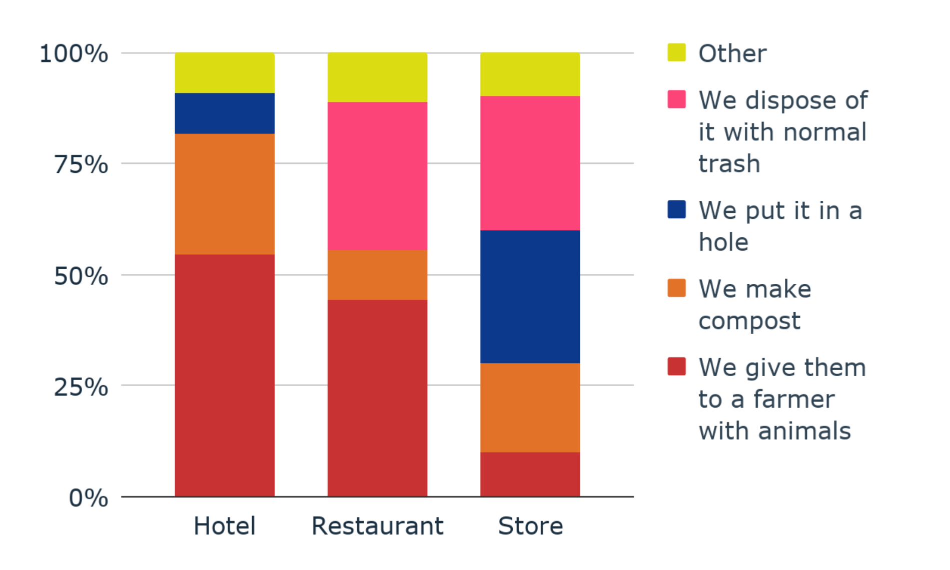


Figure 4.19: Monteverde businesses' responses to the question "What do you do with your organic waste?" by business type (UCR, 2018).

We also found that 96% of businesses surveyed already separate their organic waste (UCR, 2018). Most businesses who did not separate their organic waste responded that they did so because they did not have space or time to participate in composting practices, and 33% responded that they did not know how. However, 86% of businesses surveyed were interested in centralized organic materials collection and 8% responded that they "might" be interested. This indicated that there were many more businesses in Monteverde interested in participating in an organics collection program than businesses that were participating. Because of this high level of interest in a centralized organics collection program for the commercial sector, we recommend that ASADA focus further efforts in this area. This sector was a high producer of organic waste, and, in the most densely commercial areas, there was little land area for businesses to compost on their own. Furthermore, the UCR survey showed that many of the businesses that gave organics to farmers or put their organic waste in a hole might prefer a centralized collection system to the way they disposed of organics currently. We recommend that the ASADA publicize these services by, for example, distributing flyers across Monteverde and talking to residents while they go. This was the accepted practice for informing the public about *Puntos Verdes*, so it would be simple to implement for organics information.

We also found that 60% of businesses brought their recycling to the Municipal Recycling Center or gave it to William Arguedas, who brought it to the collection center. This showed that they knew of the proper way to dispose of their recycling, and that they were willing to put in extra effort to get their recycling to the correct place. However, a significant 35% of the restaurants and hotels either brought their recycling to the mini centers or did not recycle. This showed that these businesses had misinformation about the mini collection centers or that the recycling services were not sufficient for them to be able to recycle. Seventy-five percent of the businesses that did not recycle say the reason was that they did not know how. This data is summarized below in Figure 4.20.

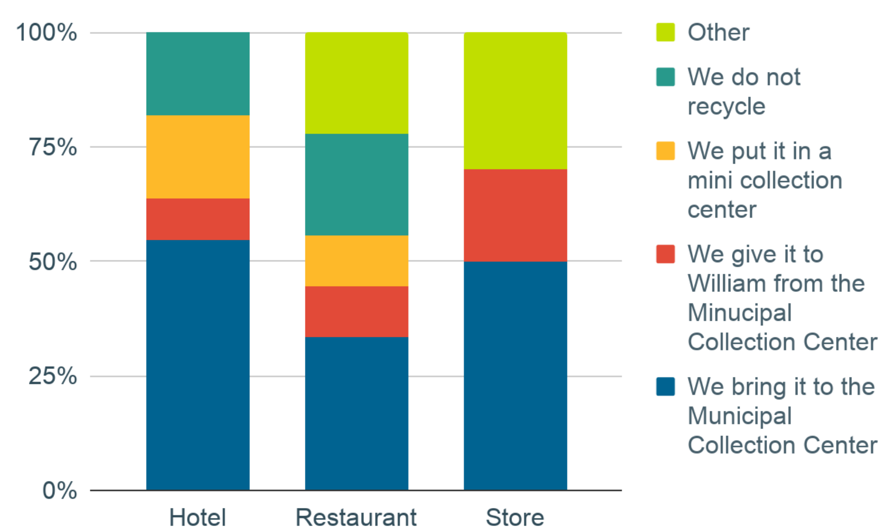


Figure 4.20: Businesses' responses to the question "What do you do with your recycling?" by business type (UCR, 2018).

The survey by UCR (2018) also addressed what businesses did with non-traditional waste such as electronics, construction materials, and other non-traditional or dangerous non-recoverables. When further examining non-traditional waste disposal, we noted that 30% said they had this waste saved and did not know how to dispose of it. This reflected a gap in the services provided by the Municipality and the education of the community about solid waste. People did not understand the system well enough to know what to do with particular types of waste. Figure 4.21 displays these findings.

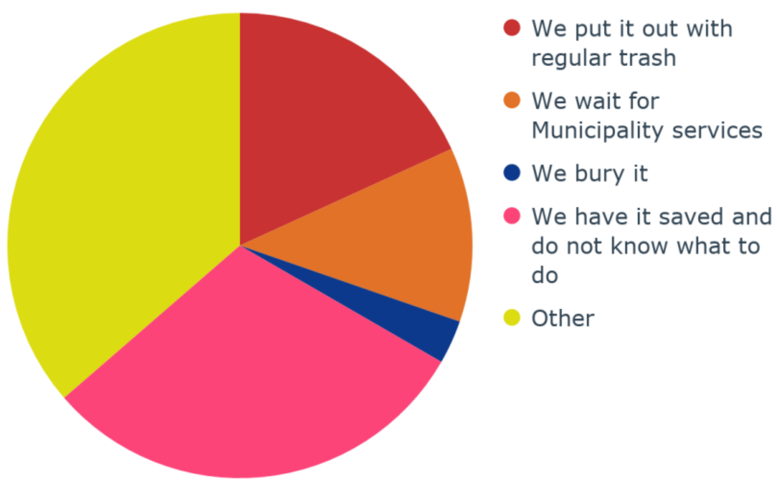


Figure 4.21: Businesses' responses to the question "What do you do with your non-traditional waste?" for businesses who produce non-traditional waste (UCR, 2018).

To summarize this section, we first found that residential sectors furthest from mini collection centers and not serviced in collection routes were most displeased with the system and recycled the least. Second, there was misinformation about what waste the mini collection centers were to be used for. Third, the recycling services were too infrequent. Fourth, we found that many residents and businesses surveyed participated in an organics-disposal program other than the municipal collection system. We also found that 86% of businesses surveyed were interested in centralized organic materials.

To address the low recovery rates of organics while considering that some people dispose of organics at home, we recommend several steps. First, the ADASA would need to implement centralized collection services for the commercial sector. Once implemented, ASADA could delegate collection and transportation to the Municipality, so they could focus on the treatment of organic waste. Then, ASADA could research which neighborhoods have the greatest need for organics services. They would then implement targeted and publicized organics collection routes.

4.5. The SWTC design

In this section, we review the technical and non-technical elements of a SWTC. We also discuss the findings from our presentation to and discussion with COMIRES. We detail our findings from the quantitative analysis of the flow rates of organics, recyclables, and trash in Monteverde. We also present a qualitative cost-benefit analysis for the transfer technology used to manage non-recoverables within the SWTC. Finally, we present the preliminary SolidWorks design of a SWTC.

This SWTC would be one part of an Environmental Technology Park (ETP), which would also contain a Composting Facility and a Wastewater Treatment Plant. Figure 4.23 shows the interaction of the SWTC with the rest of the ETP:

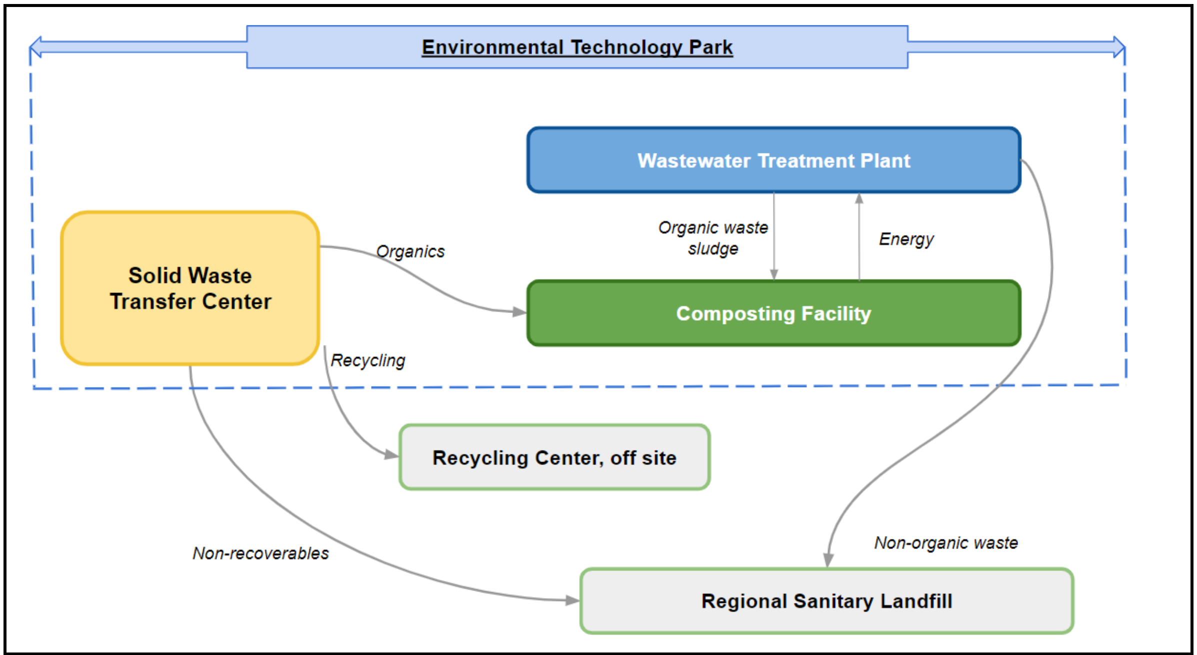


Figure 4.22: ETP layout (J. Welch, personal communication, February 20, 2020).

4.5.1. Universal & unique elements of SWTCs

We previously discussed the unique and universal, technical and non-technical elements of SWTCs. Table 4.3 below summarizes that information. When creating a SWTC design for the Municipality to implement in Monteverde, we started by including the universal elements of a SWTC.

Table 4.3: Universal and unique elements of SWTCs	
Universal	**Unique**
TECHNICAL	**TECHNICAL**
• Transfer technology • Partial or full covering to protect the transfer technology • Drop-off station • Exportation station • Weigh station	• Climate and weather preparations • Use of green technology • Material recovery programs • Vehicle maintenance station • Covering station (depending on the type of transfer technology) • Cleaning station
NON-TECHNICAL	**NON-TECHNICAL**
• Management building • Parking lot • Fence • Gate	• Community education center • Swap meet/exchange area • Public restrooms • Space for future expansion • Queuing zone for busy hours • Architecture to blend in with the aesthetics of the location

One of the criteria stressed to us by our sponsor, Justin Welch, was the need for the SWTC to achieve its purpose in Monteverde's SWM system at the lowest possible cost. Therefore, we started with only the most basic of technical and non-technical elements that could be implemented in a transfer center.

4.5.2. Presentation to COMIRES

Here we discuss the results of our SWTC and SWM themed presentation to COMIRES. With our identification of Monteverde's SWM system and its trends in growth and composition, and our geographic analysis of the system, we consolidated and presented the information most pertinent to COMIRES' expertise. We also presented a preliminary sketch of the SWTC. A copy of this presentation is in Appendix E.

The comments from the COMIRES members updated us with more recent data about the SWM, including specification on the non-recoverables collection routes, yearly recycling tonnage breakdowns, and non-traditional waste management. The council members also stressed the importance of the flow and spatial breakdown of the SWTC. There should be space near the entrance to the center where the public could bring their individual municipal solid waste without being too close to equipment and larger scale processes. Some council members also suggested that further separation of each organics, recycling, and non-recoverables should occur in three different buildings. COMIRES members also told us that they wanted the SWTC to address non-traditional waste. This area would collect electronics and batteries, both of which would be dangerous for the environment if sent to a landfill. It would also accept scrap metal, construction, rubble, and broken glass. These were not considered “municipal” solid waste, but they were important for the SWTC to collect. After collection, the non-traditional waste would be sent to another facility where it could be managed properly.

4.5.3. Flow-rate analysis

In this section, we discuss the calculations for non-recoverables, recyclables, and organic waste flow-rates that helped us determine the space needed in the SWTC to store each flow. We first calculated the total waste produced between 2014 and 2019 from the flow rate data for non-recoverables, organics, and recyclables that showed how much waste was produced in Monteverde. Later, we took a linear annual increase of the total waste data to calculate the future tonnage projections until the year 2045. For the waste distribution, we knew it was divided as 30% recycling, 30% non-recoverables, and 40% organics, so we performed our calculations based on the assumption that the SWTC would be collecting waste in those ratios. Based upon the mass produced per week of each type of waste, and the volume that a barrel (for organics) or a bale (for recyclables) could hold, we calculated the expected number of barrels and bales that would be produced per week. For the non-recoverables, there was not a specific type of a sack or barrel used for the collection. Therefore, we determined the amount of space needed by calculating how much space the waste takes up in the collection truck. These calculations were essential to make sure that our design could adapt to the Monteverde community's growth. It was important to note that not all the barrels and bales would be staying in the SWTC at the same time, and they would cycle through the transfer center twice per week.

Table 4.4: Space required in the SWTC for each type of waste based on our future predictions for 2045

Type of Waste	**Average produced (tonnes/week)**	**Storage required in SWTC (m^3)**
Non-recoverables	21.8	Going directly to the compaction truck - no storage space needed in the SWTC
Recyclables	10.8	797
Organics	29.1	240

We performed this analysis on a spreadsheet, and a copy of the calculations can be found in Appendix J.

Since tourism and population, and thus waste generation, were expected to grow, it was critical that the SWTC design be able to manage not only current levels of municipal solid waste, but future amounts as well. These growth calculations and analyses can also be found in Appendix J. To have at least 797 m^3 of space for recyclable materials (see Table 4.4), we made that building's dimensions 18m by 15m by 3m, giving 810 m^3, just more space than our estimated required number. We decided on these dimensions also considering that the recyclable materials were typically picked up from the recycling station every two months (J. Welch, personal communication, February 27, 2020). For organics building, we made the dimensions

9m by 9m by 3m, giving 243 m^3, also slightly larger than required. We planned that the trucks could take organic waste directly to the composting facility in the ETP or to store them temporarily in the SWTC. Therefore, these calculations were made considering the possibility that the barrels would need a place to stay in the storage area.

It is important to note that, before further design and construction of the SWTC, the Municipality would still need to consider the space to move around the materials with the necessary technical equipment, such as forklifts and pallets. We also did not perform calculations for the cost of materials, manpower, hours of service, and management. It would be important to determine all these needs of the SWTC before the actual construction occurs.

4.5.4. Selecting a management technology

We also analyzed possible technologies and systems that could be used to manage non-recoverables, recyclables, and organic material. We determined the anticipated benefits and costs of implementing each technology. We first examined three different trash management technologies: a compaction container, an open top/compaction truck, and a horizontal baler compactor.

The first technology option was a compaction container (EPA, 2002). The Municipality would need to either purchase or contract for this system. Before the non-recoverable waste would reach the compaction technology in the SWTC, the waste would be collected by regular collection trucks. Once collected, the non-recoverable waste would be dumped onto the tipping floor and pushed into the precompactor or the compaction container as shown in Figure 4.23. Once the container is full, the waste is compacted into a dense “waste log.” Finally, a company contracted by the Municipality would come to either remove the waste log with a special truck, displayed in Figure 4.23, or the entire container would be removed and replaced.

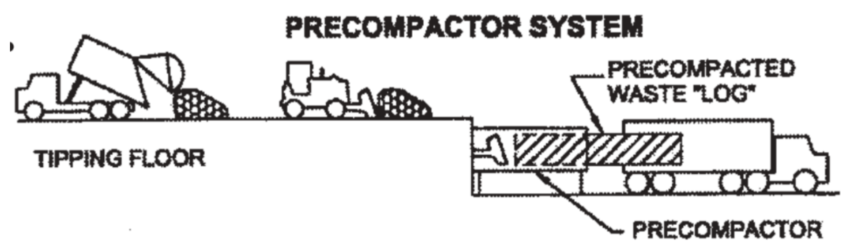


Figure 4.23: Compaction container system (EPA, 2002).

Using a compaction container system to increase the density of the waste leaving the SWTC would reduce the number of trips to the landfill. However, this choice would come with limitations. One limitation would be that the Municipality would have to either contract or purchase the compaction container, and they would need to contract a service to take the waste log to the landfill. However, the increased density of waste would mean that fewer trips to the landfill would be occurring, so the carbon emissions would be lower from reduction in transportation. The Municipality would also have savings on fuel and wear on the tires. This cost reduction could eventually offset the cost of the compactor system. Additional points to be considered before implementing this technology in the SWTC would be how often compaction would occur, where the container would be located in the center, and how the waste would be loaded into the system.

The second technology option was the open top container (EPA, 2002). The Municipality would either purchase or contract to implement this technology. Once at the SWTC, municipal waste collection trucks would drive onto a raised level of the SWTC and release the waste into the open container below. This is illustrated in Figure 4.24.

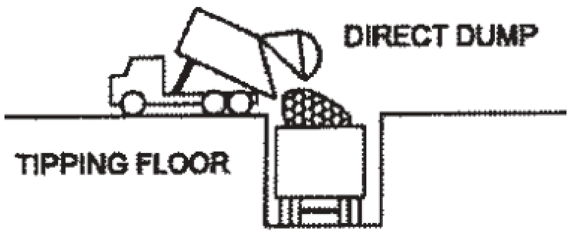


Figure 4.24: Open top trailer system (EPA, 2002)

Figure 4.25: Funnel into open top trailer (Cooperación Suiza, 2017)

Once the large, open top trailer fills, the truck would go to the landfill. By consolidating the waste in a larger vehicle, the Municipality would reduce the number of trips going to the landfill per week. However, this method could result in spilled materials, so the station where the smaller trucks would unload into the larger vehicle would need a funnel to help contain the spillage, as shown in Figure 4.25.

Using the same set-up in the SWTC of a raised level used for dumping waste into a container below, the Municipality could use a compaction truck (EPA, 2002). The primary functional difference between the open top and compaction trucks would be that the compaction system would compact the loaded waste intermittently to provide more room for additional loads. However, the compaction system would cost more to use. The truck would need to be made of reinforced material and have the compaction technology, both of which would add to its price. The system would most likely need to be contracted, so a third party would manage the transportation, maintenance, and cleaning.

The third technology option for non-recoverable management is the use of a horizontal baler (EPA, 2002). The municipal collection trucks would unload the waste on the tipping floor. The trash would then be pushed along the floor into the top-loading baler. This is demonstrated in Figure 4.26. The baler machine would then compress the waste into a dense bale, which would be loaded onto a flatbed trailer by a forklift. Once the trailer is filled, the bales are secured and taken to the landfill.

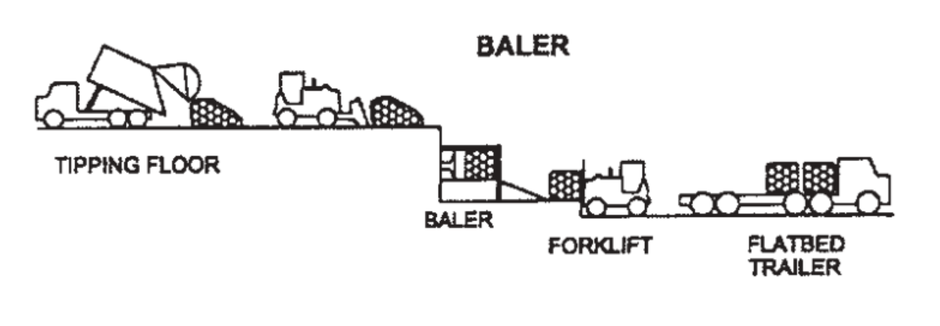


Figure 4.26: Horizontal baler system (EPA, 2002)

The Municipality would need to purchase or contract for the baler system, the forklift, and the flatbed trailer truck, all of which increase capital cost. However, the high-density waste bales would decrease the number of trips to the landfill.

We next examined two options for processing recyclables: on-site or off-site processing. For either case, recyclable material would need to be collected from around Monteverde and transported to the SWTC. For the on-site processing, materials would be unloaded at the transfer center by the municipal trucks and sorted by hand. They would be sorted into industrial sacks before being compressed.

This method would allow Monteverde to earn money for the materials that they ship out of the province, their only cost being collection. Two of the biggest limitations would be the amount of manpower needed to separate and process the materials, and the organization that would make collection possible. To account for the second limitation, the Municipality could implement one of our recommendations mentioned in section 4.1 about improving the recycling system.

The second option for managing the recyclable materials at the SWTC would be off-site processing. This would only involve collecting the recyclables in a single stream (no separation) and transporting them to an alternate location. This would not be a source of profit for the Municipality, but in smaller districts, like Monteverde, this option could be preferable. Off-site processing would shift the focus to high recovery rates instead of material processing. The collection and storage of recyclable material until contracted companies retrieve them would take up space, but the benefit of reduced man-hours should outweigh that cost.

Processing off-site could reduce the amount of space and time dedicated to recycling. With fewer weekly man-hours spent on the separation and compaction of recyclable materials, the recycling management staff at the SWTC could focus on other things. For example, they could dedicate more time to educating the community about good recycling habits or open the center for more hours per month to allow recycling drop-off.

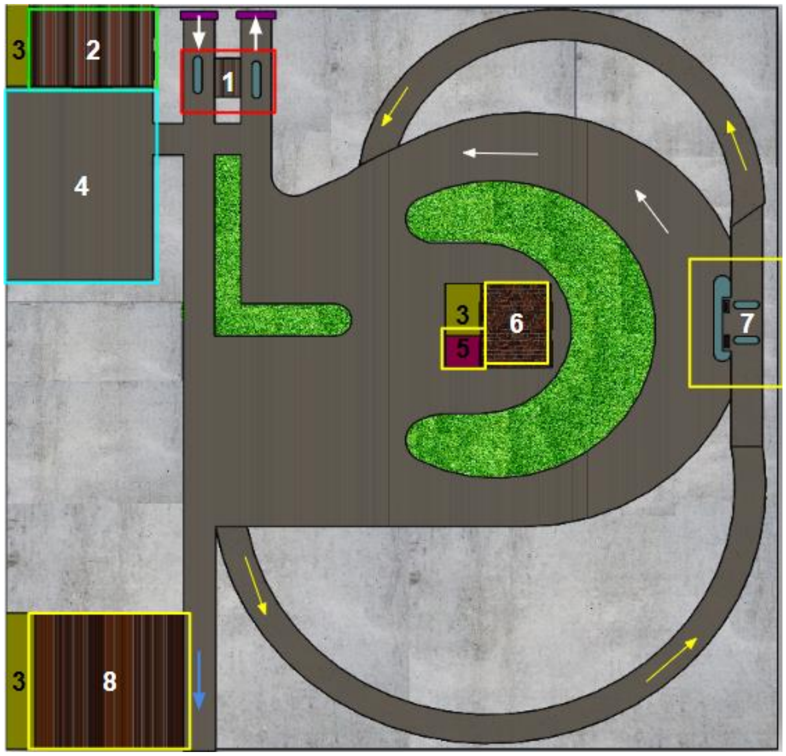
We explored two options for how organic waste would be managed in the SWTC. In both cases, the organic material would need to be collected by the Municipality and transported to the transfer center. This could be done in various ways, which we detailed earlier in this chapter. The first management option for the organic material would be to bring it to the SWTC and store it on site before transferring it to the Composting Facility. This would require space for the barrels to be stored within the transfer center. It would also require two steps: transporting to the storage facility and then transporting to the Composting Facility. However, this option would account for high flow-rates of organic material by ensuring all of the barrels do not need to build up in the Composting Facility.

The second option would be to transport the organic waste barrels through the SWTC, without stopping, and go directly to the Composting Facility. This option would not require a location to store the barrels within the transfer center. The only impact on the SWTC would be the road traffic through to the other parts of the Environmental Technology Park. A benefit of choosing between these two options is that the managers of the SWTC could easily swap between methods when necessary, once the storage building is constructed. If the storage area is not used for organics barrels, it could be used for other processes.

All the qualitative analysis of the management technologies mentioned above are summarized in Appendix K. One limitation of our research, analysis, and recommendations for management technologies was that a specific site for the SWTC had not yet been chosen. This meant that the calculations in section 4.5.3. and our cost-benefit considerations for the management technologies had to consider the fact that this center might be in a variety of locations. Furthermore, these locations could have important geographic discrepancies and spatial differences, so our analysis had to be very general.

4.5.5. SolidWorks design

We mentioned some scenarios for the possible designs in the previous section. In this section, we present which ones we selected for the respective waste materials: non-recoverables, recycling, and organics. These technologies are what we recommend the Municipality explore more carefully in the Full Feasibility Study they will later perform. We display the technical and non-technical elements of the SWTC in Figure 4.27.



1: Weigh station

2: Management building

3: Areas for expansion

4: Parking lot

5: Transfer area: potential non-traditional waste storage area

6: Transfer area: Recycling separation area

7: Transfer area: Trash loading and unloading zone

8: Transfer area: Organics (or miscellaneous) storage area

Figure 4.27: Preliminary conceptual design of the SWTC | *Key*

For the non-recoverable management technology, we recommend that the open-top compaction truck system be used. The municipal waste collection trucks would follow the yellow arrows to the raised platform in Box 7. This road would ideally be constructed on a slight hill to assist in creating the raised level. The smaller trucks would unload their waste loads through a funnel system into the larger, open-topped compaction vehicle below. A more detailed sketch of this process is in Appendix M. Once the compaction truck fills, it would leave the SWTC for the landfill. It would follow the white arrows.

For the recycling management system, we chose on site processing. Since this was the accepted practice at the Municipal Recycling Center, we recommend this strategy, but the recycling area in the SWTC would need to have even more space than the current center. The recycling station, Box 6 in Figure 4.27, was designed to be larger than the Municipal Center.

This area would have various sizes of bags and bins for the recyclable material to be separated into. Materials like paper, cardboard, and some plastics would then be compacted. A more detailed sketch of this building is in Appendix M.

For organics, we recommend having storage space in the transfer center for the organic waste barrels. This is Box 8. In this situation, the storage might or might not be used for organics, but we believe that it would be better to have the space than not have it. The municipal trucks could stop and drop off or pick up barrels before or after visiting the composting facility. The road that would go to the rest of the Environmental Technology Park is marked with the blue arrow.

In our design, we also created a possible storage area for the non-traditional waste. Since the municipality was not collecting these materials while we completed our project, we did not have data on these materials. Therefore, we did not have enough information to decide on the exact dimensions needed in the storage area. However, we decided that this would be a part of the recycling center, or next to it which is the Box 5. We recommend that this would not be an early priority for construction in the SWTC, but once the Municipality has a more developed system for the non-traditional waste collection, the space could be implemented. The mini drop-off area in the management building would also contain a bay for the non-traditional waste.

We also included non-technical elements in our design. The entrance and exit are marked at the top of the figure with gray arrows. The weigh station, a checkpoint for the incoming and outgoing vehicles to measure their loads, is Box 1. Next to the entrance there is a management building, Box 2; a parking lot, Box 4; and an expansion area, Boxes 3. We designed the management building to have offices, an education center, a swap area, restrooms, and a mini drop-off area. The mini drop-off area would allow residents or individual visitors to dump their waste without going all the way into the SWTC. It would include bays for organics, recyclables, non-recoverables, and non-traditional waste like electronics. General considerations we acknowledged for our SWTC design were to have a smooth flow of traffic throughout the SWTC and to require only the simplest construction technologies to achieve it.

4.5.6. Full design for the SWTC

This project helped collect information about the need for and the potential implementation of a SWTC for the Monteverde community. However, some research questions remain about SWTCs and related topics. For our SWTC design to become a reality, the Municipality would need to complete a full feasibility study and technical design. In addition to the feasibility study, they would also need to conduct more research on potential sites for the Environmental Technology Park (and the SWTC within it). The technical design could vary greatly depending on which site is chosen. To choose the site, researchers would need to conduct research on the opinions of local people about using that site for a SWTC, the effect it would have on nearby tourism and other industries, the differences in building and operation costs for each site, and the distance from the population centers.

4.6. Summary

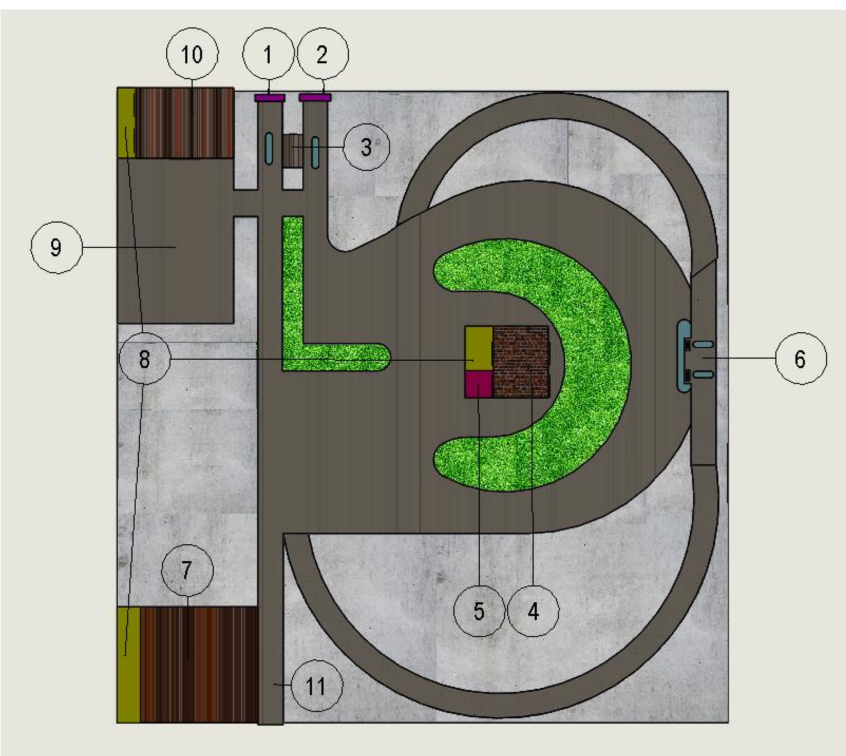
This chapter discussed the results we found to help us achieve our goal of developing a basic conceptual design for a SWTC and making recommendations that would promote a high participation rate in SWM programs in Monteverde. After we identified how the current SWM system in Monteverde worked, and how it had evolved in recent years, we found specific information about the recovery rates of each type of solid waste and several possible reasons for these statistics. By achieving our second objective, we found the historical trends in growth, composition, and geographic breakdown of Monteverde’s municipal solid waste and made projections for future behavior. Based on interviews with experts and surveys of residents and business owners we found the successes and shortcomings of the SWM system as well as various non-systemic factors. Finally, we produced a basic conceptual design as a recommendation for a site specific SWTC. In the next chapter we discuss our recommendations for each of the results we found while accomplishing our goal. We also suggest plans for future research.

Chapter 5: Conclusions and recommendations

The primary goal of this project was to develop a basic conceptual design for a solid waste transfer center (SWTC) and to make recommendations that promote a high participation rate in recycling and organics collection programs in Monteverde. This deliverable and our recommendations are summarized below.

5.1. SWTC recommendations

Based on our findings, we recommend the SWTC for Monteverde include the elements listed in Figure 5.1.



1) Entrance
2) Exit
3) Weigh station
4) Recycling station
5) Possible non-traditional waste storage
6) Trash unloading station
7) Storage for organics
8) Areas for expansion
9) Parking lot
10) Management Building
    - Swap area
    - Mini drop-off area
    - Education area
11) To the Environmental Technology Park

Figure 5.1: Preliminary conceptual design of the SWTC

5.1.1. Future research for the SWTC

Before constructing the SWTC, the Municipality would need to determine the location and complete a full feasibility and technical design of the whole Environmental Technology Park. Also, COMIRES, with some instruction from CORCLIMA, would need to research how refrigerant gases could be transported to and stored in the SWTC. Our design did not fully develop a space for non-traditional waste, so this element would need to be further explored.

5.2. Recommendations based on findings

To achieve the SWTC's potential, we recommend the following SWM system changes.

5.2.1. Improve the recycling system for the users

We found that there was little participation in the recycling campaigns, the recycling system was inconvenient and confusing for the users, and that the Municipal Recycling Center had insufficient staff, equipment, space, and information. Based on our findings we made the following recommendations concerning the recycling system:

1. Provide more convenient means of recycling for residents. We recommend this be accomplished one of three ways. First, COMIRES could make *Puntos Verdes* more frequent and widespread. They would have to determine where additional *Puntos Verdes* sites are needed.

Second, the Municipality could install dividers in the mini collection centers, thus collecting both recyclable and non-recoverable waste. They would also create and fund a recycling collection route and increase the non-recoverables collection frequency.

Third, the Municipality could implement a road-side recycling collection route independent of the mini centers. They would need to create and fund this route and educate the public about its implementation.

2. Determine the best way to improve the Municipal Recycling Center. We recommend that the Municipality perform further research on how best to improve the recycling center. We also recommend that the Municipality explore the community's attitudes towards charging for the use of municipal solid waste management services.

3. Encourage good recycling habits. We recommend that COMIRES work to improve recycling habits among all residents and businesses. They could use the slogan "*limpio, seco y separado*" when informing the public about good recycling practices, but more exploration will be needed in order to really establish good habits.

5.2.2. Expand the organics program

We found that Monteverde's SWM system was not optimized with respect to its greenhouse gas emission levels. We also found that 86% of businesses surveyed were interested in centralized organic materials collection, and there was little nuanced understanding of the residential organic material disposal habits. To expand the organics program, we made these recommendations:

1. Implement centralized collection services for the commercial sector. We recommend that ASADA arrange for collection of organic waste from businesses in densely commercial areas.

2. Delegate collection and transportation. We recommend that, once the services for the commercial sector are implemented, ASADA delegate the transportation responsibilities to the Municipality and focus their efforts on organic waste treatment.

3. Determine the neighborhoods most lacking in organics services. We recommend that the ASADA perform research on the amount of organic waste disposed as non-recoverable waste in each neighborhood in Monteverde. They could examine the composition of the trash from mini centers and collection routes to determine which areas send most organics to the landfill.

4. Create targeted and publicized organics collection routes. We recommend the Municipality implement organics collection in the areas determined by ASADA. We recommend the ASADA spread information about these composting services through flyer distribution.

5.2.3 Improve the non-recoverables system for users

We found that the mini center infrastructure and waste collection services were not sufficient. We recommend the following:

1. Implement collection routes for areas without service. We recommend the Municipality use our Figure 4.8 map to expand Routes 1, 2, and 3 and implement a route in the southwest.

2. Determine which mini collection centers experience the heaviest use. We recommend that COMIRES measure the amount of waste collected at each of the mini centers to determine where there needs to be improvement, such as larger or more mini centers.

3. Improve the mini center infrastructure. We recommend the Municipality fund the addition of more mini centers in southern Monteverde.

5.3. Concluding remarks

We hope that our findings and recommendations are beneficial to Justin Welch, to the ASADA, to COMIRES, and to the Monteverde community as a whole. The opportunity that the SWM stakeholders have to advance Monteverde's system with the further exploration and ultimate installation of a SWTC is exciting and impressive. With a few focused and intentional steps regarding the management of non-recoverable, recyclable, and organic waste, we expect that Monteverde will see marked improvement in their recovery rates and the community attitudes and habits. Although our recommended changes may take years to implement fully, we are hopeful that these changes will improve the lives of Monteverde's residents.

References

Abdel-Shafy, H. I., & Mansour, M. S. M. (1994). Egyptian journal of petroleum. *Applied Catalysis A, General, 118*(2), N16. doi:10.1016/0926-860X(94)80323-4

Adams, R. (2018) E-waste and how to reduce it. Retrieved from https://climate.org/e-waste-and-how-to-reduce-it/

Alatout, S., Hamilton, B., Song, J., Stern, G., Fenelon, W., Ziglinksi, J. & Hrebik, J. (2014). Waste. Retrieved from https://blogs.nelson.wisc.edu/es112-308-4/waste/

Androvetto, E., Alpizar, W., & Arauz, V. (2013, May). *Costa Rica - Ordinary solid waste: Executive Summary.* Paper presented at the Global NAMA Financing Summit. Retrieved from http://ccap.org/assets/Costa%20Rica_Waste_May_2013_NAMA_Executive_Summary.pdf

Asociación Administradora de Acueducto y Alcantarillado Sanitario de Monteverde. (2019). Quienes somos [Who we are]. Retrieved from http://aguapuracr.com/quienes-somos/

Casella Waste Systems. (2019a). Casella organics. Retrieved from https://www.casella.com/casella-organics

Casella Waste Systems. (2019b). Casella sustainability. Retrieved from https://www.casella.com/about-us/casella-sustainability

Casella Waste Systems. (2019c). Landfills. Retrieved from https://www.casella.com/services/landfills

Casella Waste Systems. (2019d). Recycling. Retrieved from https://www.casella.com/services/recycling

Chung, S. S., & Lo, C. W. H. (2008). Local waste management constraints and waste administrators in China. *Waste Management*, *28*(2), 272-281. doi:10.1016/j.wasman.2006.11.013

City of Worcester. (2019). Composting program. Retrieved from http://www.worcesterma.gov/trash-recycling/composting

Clipart Station. (2020). Family Tree Clipart 7. Retrieved from https://clipartstation.com/family-tree-clipart-7-2/.

Cooperación Suiza. (2017). Planta de transferencia de residuos sólidos - ChiclaYo limpio . Retrieved from https://www.youtube.com/watch?v=bFfxEpdwvfI

CORCLIMA. (2019a). Measuring changes. Retrieved from http://corclima.org/midiendo-cambios/

CORCLIMA. (2019b). Who we are. Retrieved from http://corclima.org/quienes-somos/

Ekere, W., Mugisha, J., & Drake, L. (2009). Factors influencing waste separation and utilization among households in the Lake Victoria Crescent, Uganda. *Waste Management, 29*(12), 3047-3051. doi:10.1016/j.wasman.2009.08.001

Environmental Protection Agency. (2002). Waste transfer stations: A manual for decision-making. Retrieved from https://www.epa.gov/landfills/waste-transfer-stations-manual-decision-making

Environmental Protection Agency. (2016). Climate change and municipal solid waste. Retrieved from https://archive.epa.gov/wastes/conserve/tools/payt/web/html/factfin.html

Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health, 16*(6), 3-28. doi:10.3390/ijerph16061060

Gonzales-Torres, P. L., & Adenso-Diaz, B. (2005). Influence of distance on the motivation and frequency of household recycling. *Waste Management, 25*(1), 15-23. doi:10.1016/j.wasman.2004.08.007

Guerrero, L., Maas, G., & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management, 33*(1), 220-232. doi:10.1016/j.wasman.2012.09.008

Hazra, T., & Goel, S. (2009). Solid waste management in Kolkata, India: Practices and challenges. *Waste Management, 29*(1), 470-478. doi:10.1016/j.wasman.2008.01.023

Henry, R. K., Yongsheng, Z., & Jun, D. (2006). Municipal solid waste management challenges in developing countries – Kenyan case study. *Waste Management, 26*(1), 92-100. doi:10.1016/j.wasman.2005.03.007

Instituto Costarricense de Acueductos y Alcantarillados. (2017). *Informe de gestión UEN - Gestión ambiental* [UEN management report - Environmental management]. Costa Rica: Instituto Costarricense de Acueductos y Alcantarillados. Retrieved from https://www.aya.go.cr/transparenciaInst/informesFinGestion/INFORME%20DE%20GESTION%20GERARDO%20RAMIREZ%20VILLEGAS.pdf

Minghua, Z., Xiuman, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., . . . & Yi, L. (2009). Municipal solid waste management in Pudong New Area, China. *Waste Management, 29*(3), 1227-1233. doi:10.1016/j.wasman.2008.07.016

Ministerio de Salud. (2016). Plan nacional para la gestión integral de residuos. San José, Costa Rica: Gobierno de Costa Rica. Retrieved from https://www.ministeriodesalud.go.cr/index.php/biblioteca-de-archivos/sobre-el-ministerio/politcas-y-planes-en-salud/planes-en-salud/3025-plan-nacional-para-la-gestion-integral-de-residuos-2016-2021/file

Monteverde Institute. (2016). Map: Communities in the District of Monteverde, Puntarenas.

Monteverde Municipality. (2020). Data on daily tonnage delivered to the landfill.

Obermiller, M., & Ordonez, J. (2015). Recycling problems in paradise. Retrieved from https://www.earthday.org/2015/06/11/recycling-problems-in-paradise/

Organisation for Economic Co-operation and Development. (2017). Municipal waste, generation and treatment. Retrieved from https://stats.oecd.org/Index.aspx?DataSetCode=MUNW#Accessed1/23/2015

Scheinberg, A. (2011). *Value added: Modes of sustainable recycling in the modernisation of waste management systems* (Masters thesis). Wageningen University. Retrieved from https://research.wur.nl/en/publications/value-added-modes-of-sustainable-recycling-in-the-modernisation-o

Sheffield, J. (2017). Costa Rica's solid waste management. Retrieved from https://www.nosaracivicassociation.com/costa-ricas-solid-waste-management/

Sistema Costarricense de la Información Jurídica. (2016). *Reglamento municipal para el regulación del plan para la gestión integral de residuos sólidos (GIRS) aprobado por el concejo municipal de distrito de Monteverde* [Municipal regulation of the solid waste management plan in the district of Monteverde]. Costa Rica: SCIJ. Retrieved from http://www.pgrweb.go.cr/scij/Busqueda/Normativa/Normas/nrm_texto_completo.aspx?param1=NRTC&nValor1=1&nValor2=83327&nValor3=106933&strTipM=TC

Sujauddin, M., Huda, S. M. S., & Hoque, R. (2008). Household solid waste characteristics and management in Chittagong, Bangladesh. *Waste Management, 28*(9), 1688-1695. doi:10.1016/j.wasman.2007.06.013

Tadesse, T., Ruijs, A., & Hagos, F. (2008). Household waste disposal in Mekelle City, northern Ethiopia. *Waste Management, 28*(10), 2003-2012. doi:10.1016/j.wasman.2007.08.015

Town of Wayland. (2019). Transfer station & recycling center. Retrieved from https://www.wayland.ma.us/transfer-station-recycling-center

University of Costa Rica. (2018). Council on International Educational Exchange Survey: Organics.

Vining, J., Linn, N., & Burdge, R. J. (1992). Why recycle? A comparison of recycling motivations in four communities. *Environmental Management*, *16*(6), 785-797. doi:10.1007/BF02645669

Welch, J. (2018). *COMIRES: Evaluación quinquenal del sistema de gestión integral de residuos sólidos*. Monteverde, Costa Rica: Distrito Municipal de Monteverde.

Wu, D., Zhang, C., Lü, F., Shao, L., & He, P. (2014). The operation of cost-effective on-site process for the bio-treatment of mixed municipal solid waste in rural areas. *Waste Management, 34*(6), 999-1005. doi:10.1016/j.wasman.2013.12.002

Zhuang, Y., Wu, S., Wang, Y., Wu, W., & Chen, Y. (2008). Source separation of household waste: A case study in China. *Waste Management*, *28*(10), 2022-2030. doi:10.1016/j.wasman.2007.08.012

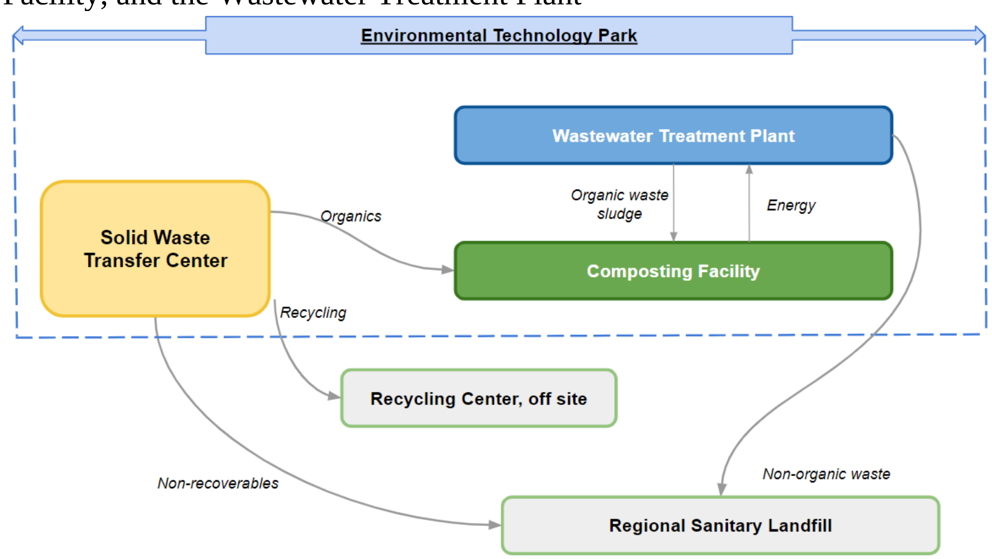
Appendices

Appendix A: Sponsor description

The Administrative Associations for Sewers and Aqueducts, or ASADA (2019) is the local regulatory authority for water and sewage. Cities in Costa Rica are required to form a local branch in order to maintain or improve their water quality. The sponsor of this IQP was Justin Welch, the ASADA's Environmental Manager.

The mission of the Monteverde ASADA is to improve the quality of life for the population in the District of Monteverde and nearby communities, for both current and future generations (2019). They aim to provide consistent potable water of high quality at a fair cost and regulate this service. They also aim to change the culture and motivate saving water. ASADAs are public, nonprofit organizations (ASADA, 2019). They are required by the Costa Rican government to be present in every district; however, the government does not fund them.

Appendix B: Glossary

Term	Definition
Environmental Technology Park	The area encompassing the Solid Waste Transfer Center, the Composting Facility, and the Wastewater Treatment Plant  *Figure A.B1: The Environmental Technology Park*

Mini collection center	Concrete units placed strategically throughout Monteverde that collect non-recoverable waste. They are emptied twice weekly.  *Figure A.B2: A mini collection center*
Municipal solid waste	The organics, recyclables, and non-recoverables (trash) discarded by residents and businesses. The term municipal refers to the type of waste, not the body who is managing its disposal; municipal waste can be managed by a municipality or a private entity.
Puntos Verdes	Monthly recycling campaigns on the 3rd Wednesday of each month at 6 locations across Monteverde. This is an opportunity for residents to dispose of their recyclable material.
System	The infrastructure, services, and education related elements of a process. Non-system elements include community attitudes, geographic variety, or habits.

Appendix C: General interview and survey protocol

A version of this interview protocol was used in every interview we conducted for this project.

Requesting interview

English version:
Dear Mr./Mrs./Dr. X,

We are a student team of juniors at Worcester Polytechnic Institute working on a project about waste management in Monteverde. We are looking to interview Monteverde SWM experts to understand the solid waste management system from the perspective of those who use it. We believe that our project would benefit greatly from us asking you a few questions. Would you be open to giving us 30 minutes of your time in an interview? If yes, would you be willing to let us take notes during the interview?

Thank you,
Imogen Cleaver-Stigum
Elçin Önder
Adrian Reddick
Shelvey Swett

Spanish version:

Señor(a) X,

Somos un equipo de alumnos del Instituto Politécnico de Worcester, en los EEUU, trabajando en un proyecto sobre el manejo de residuos sólidos. Queremos hacer unos entrevistas con expertos sobre el manejo de residuos sólidos de Monteverde para descubrir cómo les afecta el manejo de residuos sólidos. Creemos que la entrevistas nos ayudaría mucho con nuestro proyecto. ¿Nos hará el favor de hacer una entrevista de 30 minutos? ¿Nos permitirá hacer apuntes durante la entrevista?

Gracias,
Imogen Cleaver-Stigum
Elçin Önder
Adrian Reddick
Shelvey Swett

Introduction

English version:

Dear Mr./Mrs./Dr. X,

Thank you for fitting this interview into your schedule. We are working on a project about solid waste management in Monteverde, so we would like to talk to you about your solid waste disposal. Before we begin, we would like to ask how you would like us to use this interview. Please note that you have the right to answer “no” to any of these three questions. You are also welcome to choose to not respond to any of our questions we ask in the interview.

- Would you be comfortable with us using your name?
- Would you be comfortable with us taking notes during the interview?
- Would you be comfortable with us quoting your interview responses?

During this interview (Imogen/ Elçin/Adrian/Shelvey) will be asking you questions while (Imogen/ Elçin/Adrian/Shelvey) records your answers and takes notes. Let us begin.

Spanish version:

Señor(a) X,

Muchas gracias por dejarnos el tiempo para hacer la entrevista. Estamos trabajando en un proyecto sobre el manejo de residuos sólidos en Monteverde, y nos gustaría hablarle a usted sobre la disposición de los residuos sólidos. Creemos que la información compartida en las entrevistas nos ayudará mucho. Antes de empezar, tenemos unas preguntas sobre cómo le gustaría que usemos esta entrevista para nuestro proyecto. Tienes derecho a responder “no” a cualquiera de estas preguntas.

- ¿Nos permite usar su nombre?
- ¿Nos permite citar sus respuestas?
- ¿Nos permite hacer apuntes durante la entrevista?

Durante esta entrevista, (Imogen/ Elçin/Adrian/Shelvey) hará las preguntas mientras (Imogen/ Elçin/Adrian/Shelvey) hace los apuntes. Empezamos.

Post-interview procedures

English version:

Thank you for your excellent and informative answers. Now that the interview is completed, we would like to reiterate the following questions. Remember, you are able to change your answers or respond "no" to any of these questions.

- Are you still comfortable with us using your name in our report?
- Are you still comfortable with us quoting your interview responses?
- Are you still comfortable with us using our notes from the interview?

Thank you for your time.

Spanish version:

Gracias por sus respuestas muy informativas. Como hemos acabado la entrevista, queremos repetir estas preguntas. Tienes derecho a cambiar sus respuestas a cualquiera de estas preguntas.

- ¿Todavía nos permite usar su nombre?
- ¿Todavía nos permite citar sus respuestas?
- ¿Todavía nos permite citar los apuntes de la entrevista?

Gracias por su tiempo.

Thank-you email to send out the next day:

English version:

Dear Mr./Mrs./Dr. X,

Once again, thank you so much for meeting with us and answering our questions so well. We appreciate that you took time out of your schedule to help us. Upon reflection after the interview, we have just a few more questions to ask you

- X
- X

If possible, please email us with your responses at your earliest convenience.

Thank you,
Imogen Cleaver-Stigum
Elçin Önder
Adrian Reddick
Shelvey Swett

Spanish version:

Señor(a) X,

Muchas gracias por reunirse con nosotros, y por responder a nuestros preguntas. Después de reflexionar, tenemos unos cuestiones más:

- X
- X

Si es posible, por favor envíenos un email con sus respuestas cuando pueda.

Gracias,
Imogen Cleaver-Stigum
Elçin Önder
Adrian Reddick
Shelvey Swett

Appendix D: Survey questions for residents

Goals

1. Understand reasons behind residents' lack of participation in municipal recycling and organics collection and what improvements they would like to see
2. Understand what residents who do participate like about the current system (what we should not change about it) and what improvements they would like to see
3. Understand residents opinions on a SWTC/Environmental Technology Park and what they might like to see there

English version:

1. Do you separate recycling from trash?
    a. *Yes*
        i. How do you dispose of recycling?
            1. *Puntos Verdes*
            2. *Collection Center*
            3. *Private/other company*
            4. *Other: ___________*
        ii. What do you like about your recycling program?
        iii. What would make recycling more convenient for you?
            1. *Different times for Puntos Verdes*
            2. *Activating the mini centros de acopio*
            3. *Single stream recycling*
            4. *Other: __________*
    b. *No*
        i. Why not?
            1. *Don't know how to separate it*
            2. *Don't know where to put it / how to get it collected*
            3. *Because the mini-centros de acopio are not activated*
            4. *Other: ___________*
2. A SWTC is a place where municipal solid waste can be taken and sorted into its parts: non-recoverables, recycling, and organics. How much would the presence of a SWTC affect your life?
    a. *A lot*
    b. *Medium*
    c. *Little*

3. Would you visit (use it) a SWTC?
    a. *Yes*
        i. What would you like to see in a SWTC?
            1. *Swap area*
            2. *Tours*
            3. *Public bathrooms*
            4. *Education about solid waste and its environmental impact*
            5. *Other: _________*
    b. *No*
4. If there was a site for recyclables, organics, electronics, non-traditional waste that was consistently open, would you use it?

Spanish version

1. ¿Separa sus desechos reciclables y desechos ordinarios?
    a. *Sí*
        i. ¿Cómo desecha usted sus residuos reciclables?
            1. *Puntos Verdes*
            2. *Centro de Acopio Municipal*
            3. *Se lo doy a otro recolector (privado)*
            4. *Otro: ___________*
        ii. ¿Que le gusta del sistema de reciclaje que usa?
        iii. ¿Qué cambios al sistema harian mas convenientes reciclar?
            1. *Otro horario para Puntos Verdes*
            2. *Activar los mini-centros de acopio*
            3. *No tener que separar los desechos reciclables*
            4. *Otro: __________*
    b. *No*
        i. ¿Porque no?
            1. *No sé separarlo*
            2. *No sé donde ponerlo*
            3. *Porque los mini-centros de acopio no están activados*
            4. *Otro: ___________*
2. Un centro de transferencia de residuos sólidos es una lugar donde se llevan y se clasifican los residuos sólidos en: no recuperables, reciclables y orgánicos. ¿Hasta qué punto se afecta su vida la presencia de un centro de transferencia?
    a. *Mucho*
    b. *Mediano*
    c. *Muy poco*
    d. *No se*
3. ¿Visitaría un centro de transferencia?
    a. *Sí*
        i. ¿Que le gustaria que hay en el centro de transferencia?
            1. *Un área para el intercambio de cosas de segunda mano*
            2. *Excursiones por el centro para turistas y ciudadanos*
            3. *Baños públicos*
            4. *Enseñanza sobre residuos sólidos y su impacto ambiental*

5. *Otro: _________*

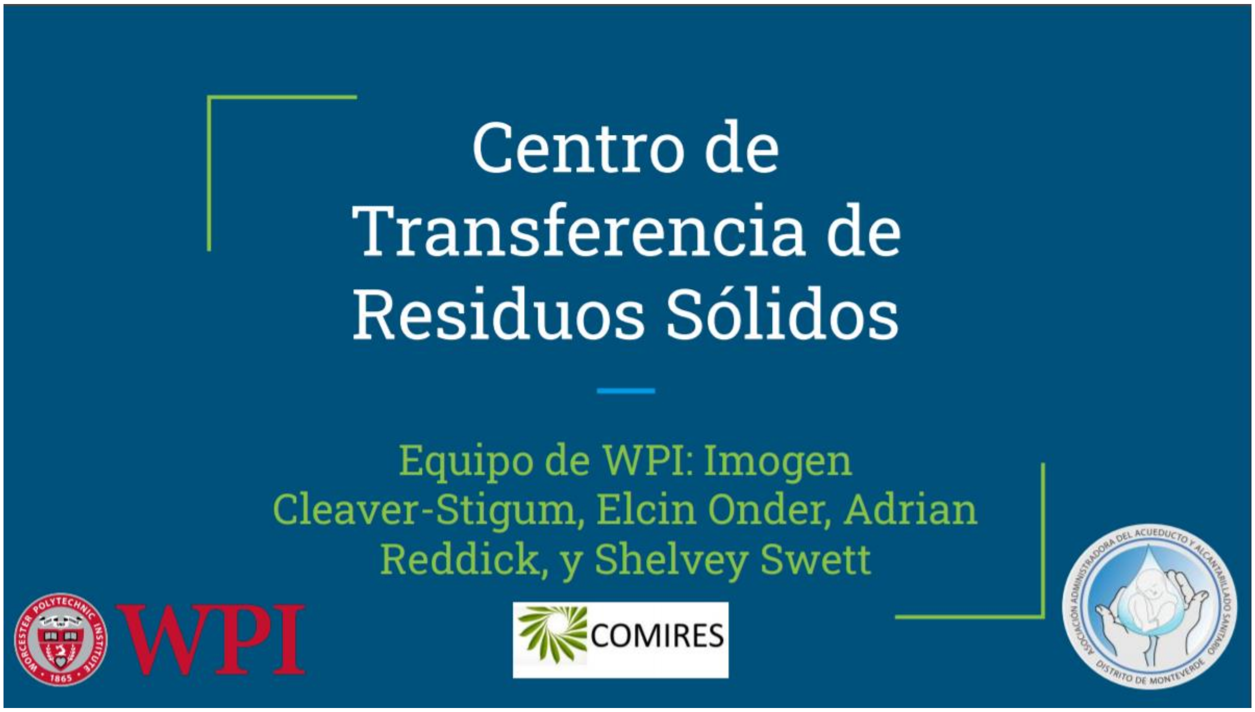
b. *No*

4. Si hubiera un sitio para reciclaje, desechos orgánicos, desechos electrónicos, desechos no tradicionales, etcétera, ¿lo usaría?

Appendix E: COMIRES presentation

Table A.E1: COMIRES members' comments

Comment theme	**Comment details**
Collection routes	• Routes 1 and 2 were updated to their current paths • Route 3 was planned and added to the map (Figure 4.8)
Recycling data breakdown	• We were asked to add 2019's recycling data breakdown to a graph containing the growth and composition of the years 2014 to 2018
What we do not collect	• *No recuperables* was changed to *no tradicionales* • A special waste category was added containing: refrigerant gases, electronics, scrap metal, batteries, broken glass, and construction rubble • The council deemed necessary a location for the disposal of these materials
Graph labels	• Neighborhoods A, B, and C were renamed sectors (Figure 4.15) • We added a legend specifying which neighborhoods are in each sector
Recycling volume	• Volume, in addition to tonnage, needed to be found for each type of recyclables
SWTC	• There should be a coherent flow for the center • Further separation of each type of municipal solid waste should occur in its own building. Add building specifically for organics, recyclables, and non-recoverables • There should be a space where individuals can come to dispose of their own municipal solid waste. It cannot be too near to dangerous machinery, or inhibit the transfer center's function • Members emphasized the need for space to store non-traditional waste

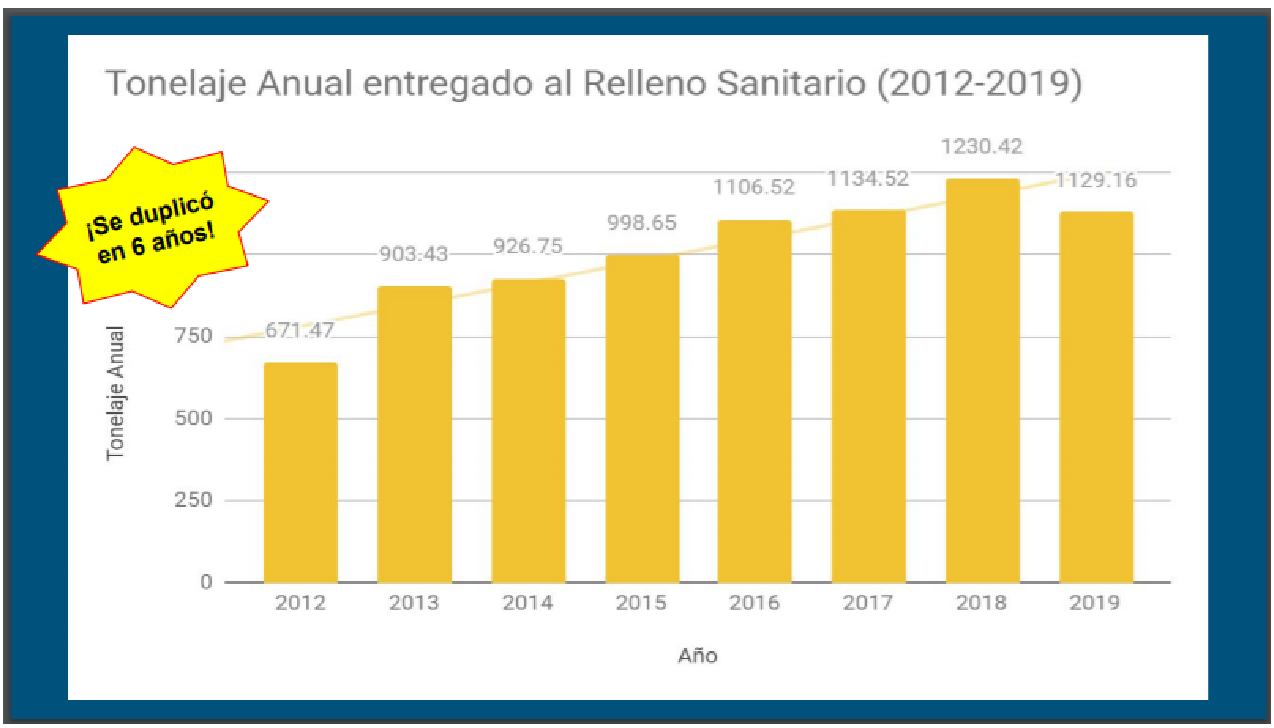

Centro de Transferencia de Residuos Sólidos
Equipo de WPI: Imogen Cleaver-Stigum, Elcin Onder, Adrian Reddick, y Shelvey Swett
WPI
COMIRES
DISTRITO DE MONTEVERDE

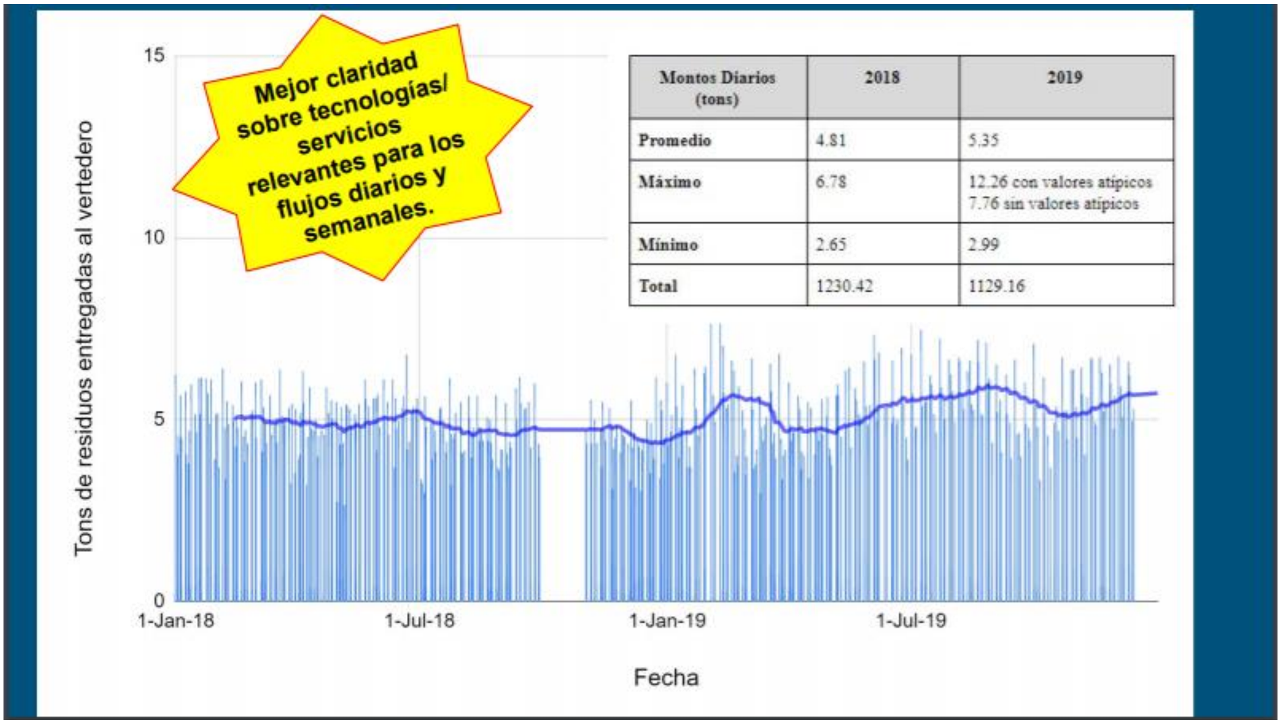

Hítos Importantes de COMIRES
2012
La recolección de residuos sólidos ordinarios incluyó dos rutas, cada una con dos días de servicio (abarcaba aproximadamente 92% de la población total del Distrito.)
2013
Los residuos ahora se entregan al relleno sanitario TecnoAmbiente. El servicio será en cuatro ocasiones semanales como mínimo.
Se dio apertura a un Centro Municipal de Recuperación de Residuos Valorizables, o Centro de Acopio, de 422 m².
El Centro recibía material in situ mediante campañas mensuales.
2017
Además, se construyeron 20 mini-centros de acopio con el fin de disminuir la dispersión de basura por la calle causada por los animales, vientos y lluvias. Aún no se ha establecida una ruta diferenciada ni para reciclaje ni se han habilitado los mini-centros como puntos de recolección.
Se adquirió un camión dedicado al Programa de Recuperación de Residuos Sólidos Valorizables (PRRSV) en donde el encargado dedica tiempos libres para recoger material.
2020
A veces se requieren hasta 5 viajes por semana para descongestionar los sectores con mayor producción de residuos. Todavía falta recolección en ciertos sectores del Distrito.
COMIRES organiza una campaña llamada Puntos Verdes, que es la recepción de materiales reciclables en 6 sitios designados en todo el Distrito.

Línea Base 2020

Rutas de Recolección de Basura


Ubicaciones de los 19 mini-centros de acopio
Santa Elena
Cerro Plano
Los Llanos
Monte Verde
La Lindora
San Luis
Los Cerros
N

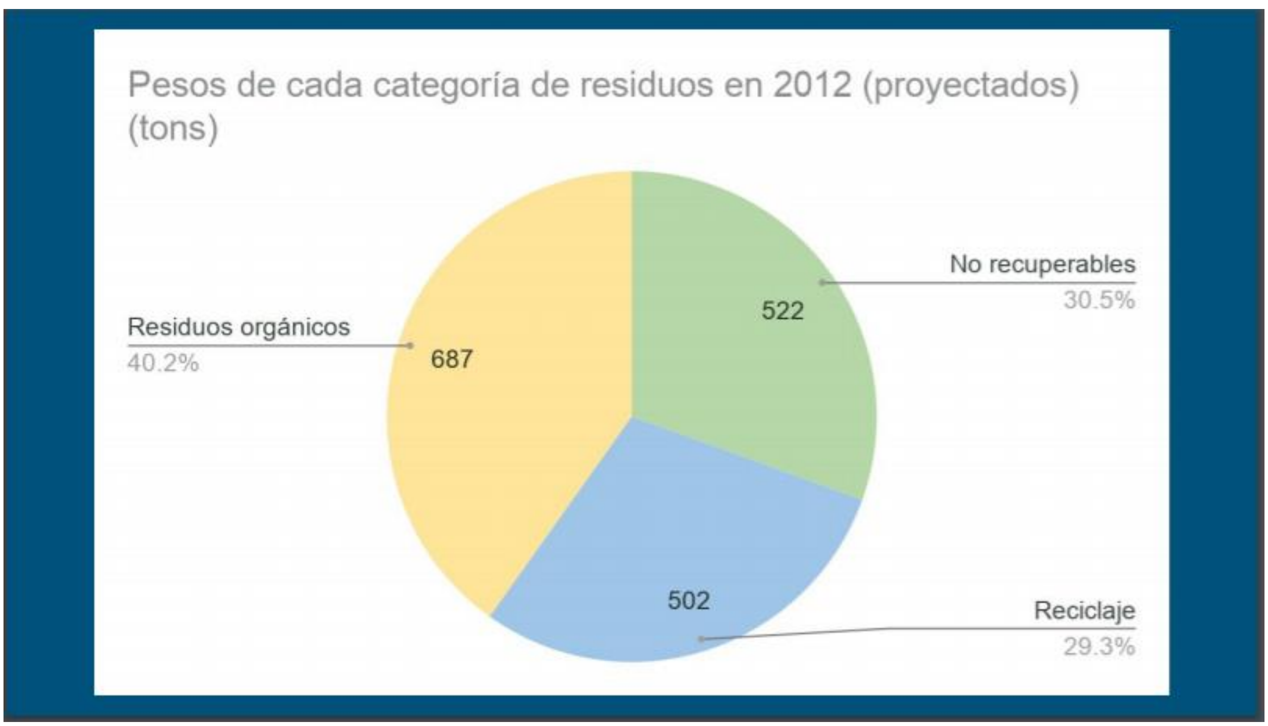

Tonelaje Anual entregado al Relleno Sanitario (2012-2019)
¡Se duplicó en 6 años!
Tonelaje Anual
0
250
500
750
671.47
903.43
926.75
998.65
1106.52
1134.52
1230.42
1129.16
2012
2013
2014
2015
2016
2017
2018
2019
Año

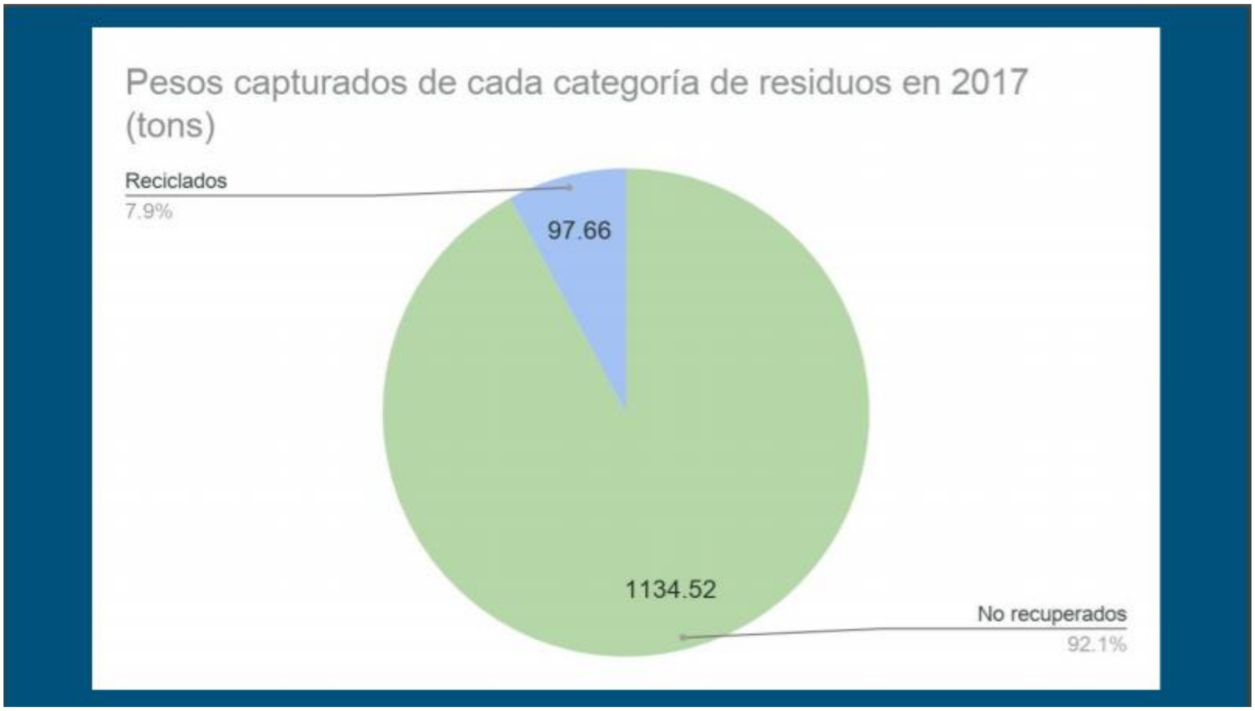


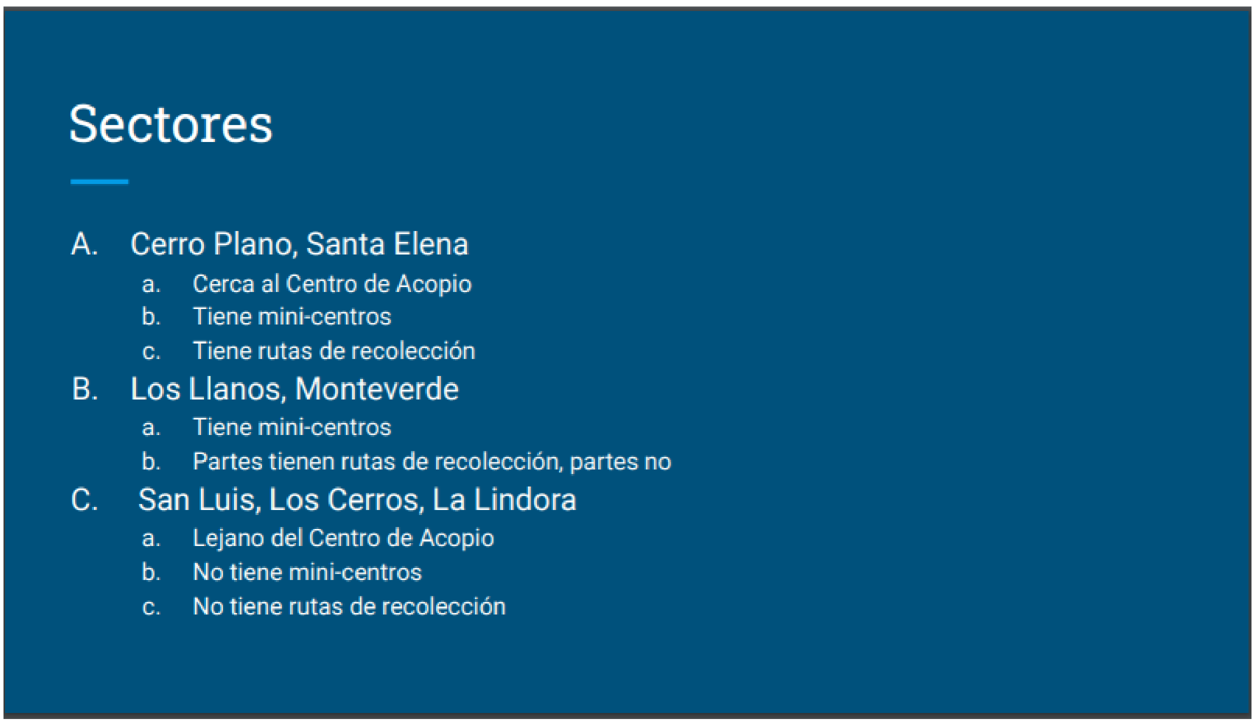
Montos Diarios (tons)	2018	2019
Promedio	4.81	5.35
Máximo	6.78	12.26 con valores atípicos 7.76 sin valores atípicos
Mínimo	2.65	2.99
Total	1230.42	1129.16

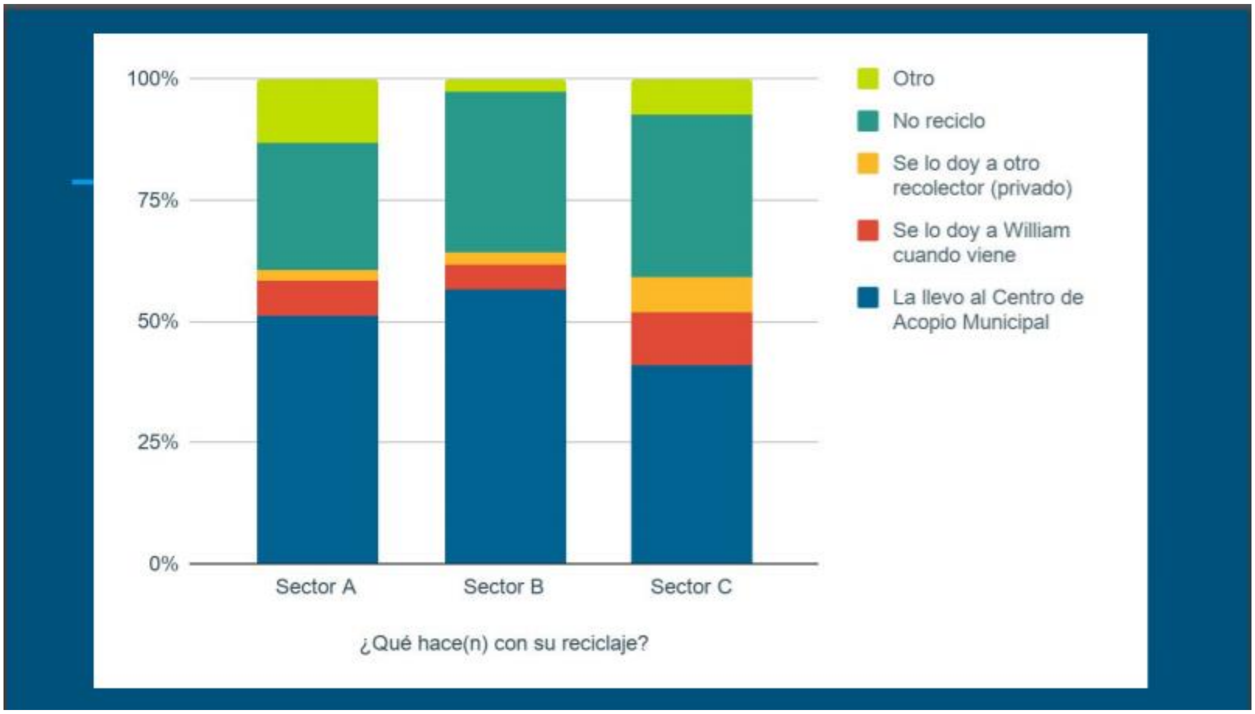
Figura 8. Toneladas de Material Valorizable Recibidas, Procesadas y Comercializadas mediante el Centro de Acopio Municipal (2014-2018).

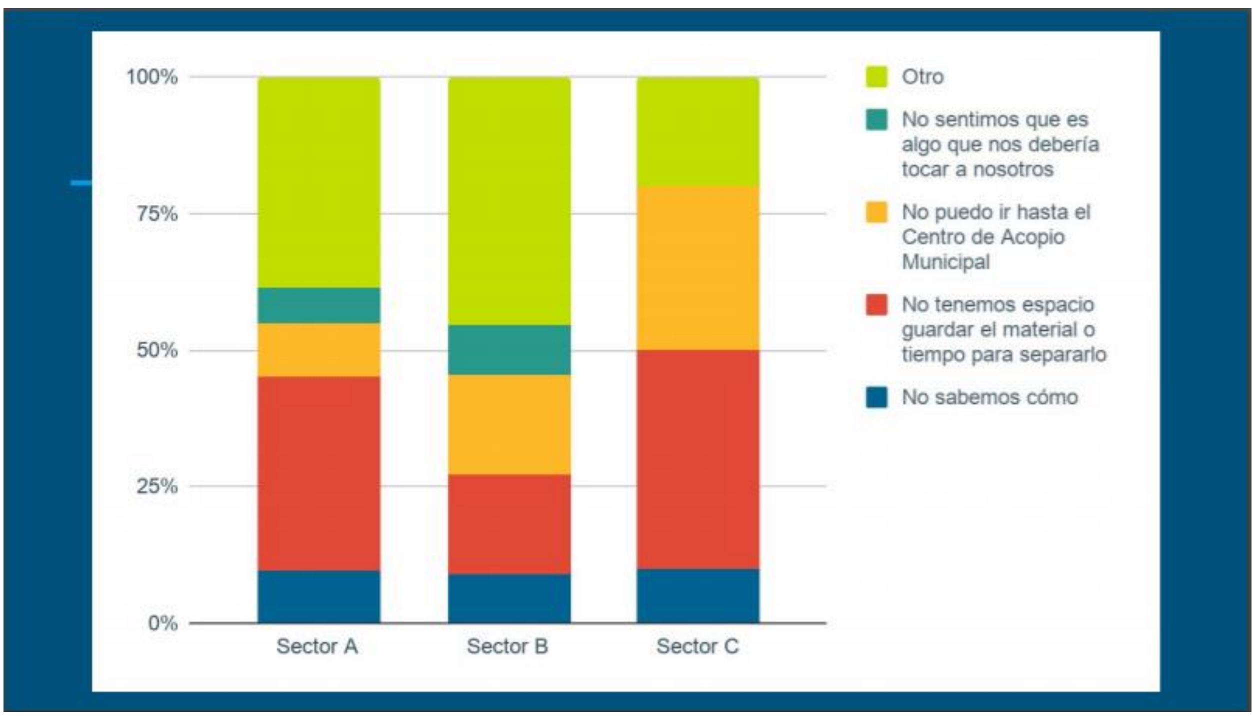

¿Qué recolectamos?
No recuperables (ordinarios)
Aluminio
Cartón
Lata
Papel
Plástico #1
Plástico #2
Plástico #3
Plástico #4
Plástico #5
Plástico #6
Plástico #7
TetraPak
Vídrio
COMIRES: Debemos identificar destinos finales y aceptabilidad de cada uno
¿Qué no recolectamos?
No tradicionales (no ordinarios)
Residuos orgánicos (ordinarios)
Residuos especiales
Refrigerantes
Electrónicos
Chatarra
Vídrio quebrado
Baterías
Escombros de construcción


Pesos de cada categoría de residuos en 2012 (proyectados) (tons)
No recuperables
30.5%
522
Residuos orgánicos
40.2%
687
502
Reciclaje
29.3%


Pesos capturados de cada categoría de residuos en 2017 (tons)
Reciclados
7.9%
97.66
1134.52
No recuperados
92.1%


Sectores
A. Cerro Plano, Santa Elena
a. Cerca al Centro de Acopio
b. Tiene mini-centros
c. Tiene rutas de recolección
B. Los Llanos, Monteverde
a. Tiene mini-centros
b. Partes tienen rutas de recolección, partes no
C. San Luis, Los Cerros, La Lindora
a. Lejano del Centro de Acopio
b. No tiene mini-centros
c. No tiene rutas de recolección


100%
75%
50%
25%
0%
Sector A
Sector B
Sector C
¿Qué hace(n) con su reciclaje?
Otro
No reciclo
Se lo doy a otro recolector (privado)
Se lo doy a William cuando viene
La llevo al Centro de Acopio Municipal


100%
75%
50%
25%
0%
Sector A
Sector B
Sector C
Otro
No sentimos que es algo que nos debería tocar a nosotros
No puedo ir hasta el Centro de Acopio Municipal
No tenemos espacio guardar el material o tiempo para separarlo
No sabemos cómo

Resumen del espacio en el Centro de Acopio

Willy dice: hay una falta de personal, de espacio, y de maquinaría en el Centro de Acopio

Espacio <u>total disponible</u> en el actual centro municipal de reciclaje: 422.4 m^3

Interiores 12 m x 10.6 m x 3 m = **381.6 m^3**

Exterior: 18.2 m x 1.2 m x 1.87 m = **40.8 m^3**

Volumen <u>total utilizado actualmente</u> para almacenar material sin procesar: 193.7m^3

	l	w	h	
Cardboard	4.4	3.61	2.65	m
Plastic	5.2	3.83	5.5	m
Glass	18.2	1.2	1.87	m
Aluminum/Paper/Tetrabrick	1.01	1.11	1.06	m

Más el espacio utilizado para almacenar material procesado (pacas, sacas y estañones), materiales de otros depts. y espacios para vehículos/otros usos.

Resumen del esfuerzo actual de recursos humanos en el Centro de Acopio

Administrador del centro, tiempo completo

\+ Asistente (¾-tiempo) con horas adicionales (contrato pendiente)

TOTAL: 84+ horas-hombre por semana para gestionar el volumen actual

Proyecciones a 2045

Proyecciones a 2045: Toneladas de residuos

Totales:

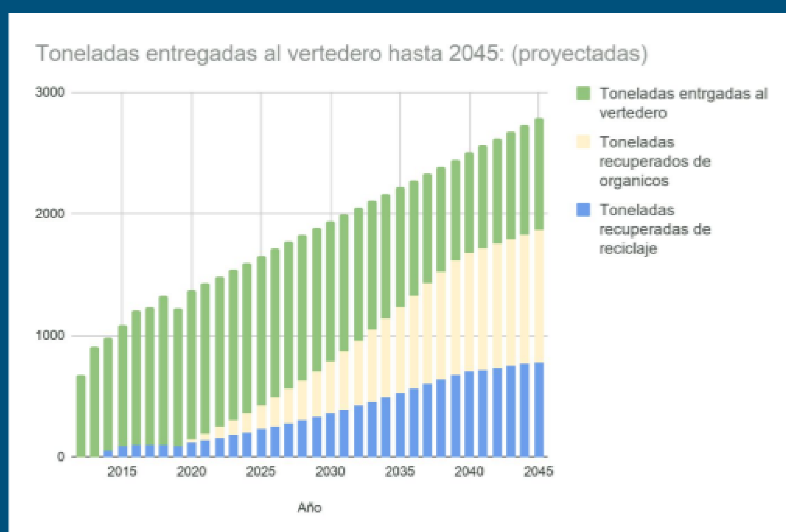
2025: 1656 tons

2030: 1938 tons

2035: 2221 tons

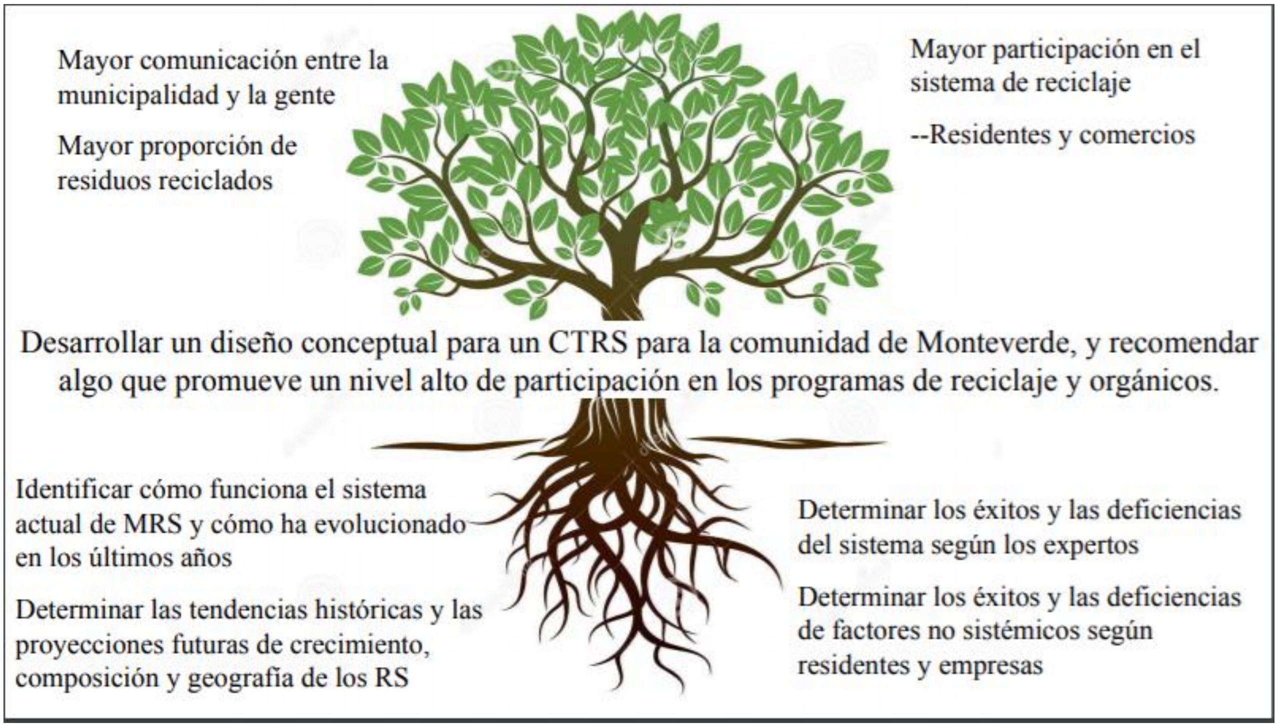
2040: 2503 tons

2045: 2786 tons



El Problema


Hay un nivel bajo de reciclar entre residentes y comercios
Cuesta mucho enviar los residuos sólidos en camiones
El agua de Monteverde se podría contaminar
--Podría causar problemas con el salud de la gente y el ambiente
Emisiones de gases de efecto invernadero por poner todo en el vertedero
La sistema de manejar los residuos sólidos no está funcionando idealmente
La gente no tiene información sobre manejar los residuos sólidos
No hay un centro de transferencia de residuos sólidos
La gente no participa en los programas de MRS y reciclaje
El sistema de reciclaje es complicado



¿Cómo podemos abordar este problema en una manera eficiente?

El hilo conductor es la logística de transportación

Vamos a abordar las logísticas de transportación con un **CENTRO DE TRANSFERENCIA DE LOS RESIDUOS SÓLIDOS** (CTRS)

¿Qué es un CTRS?

https://www.youtube.com/watch?v=bFfxEpdwvfI

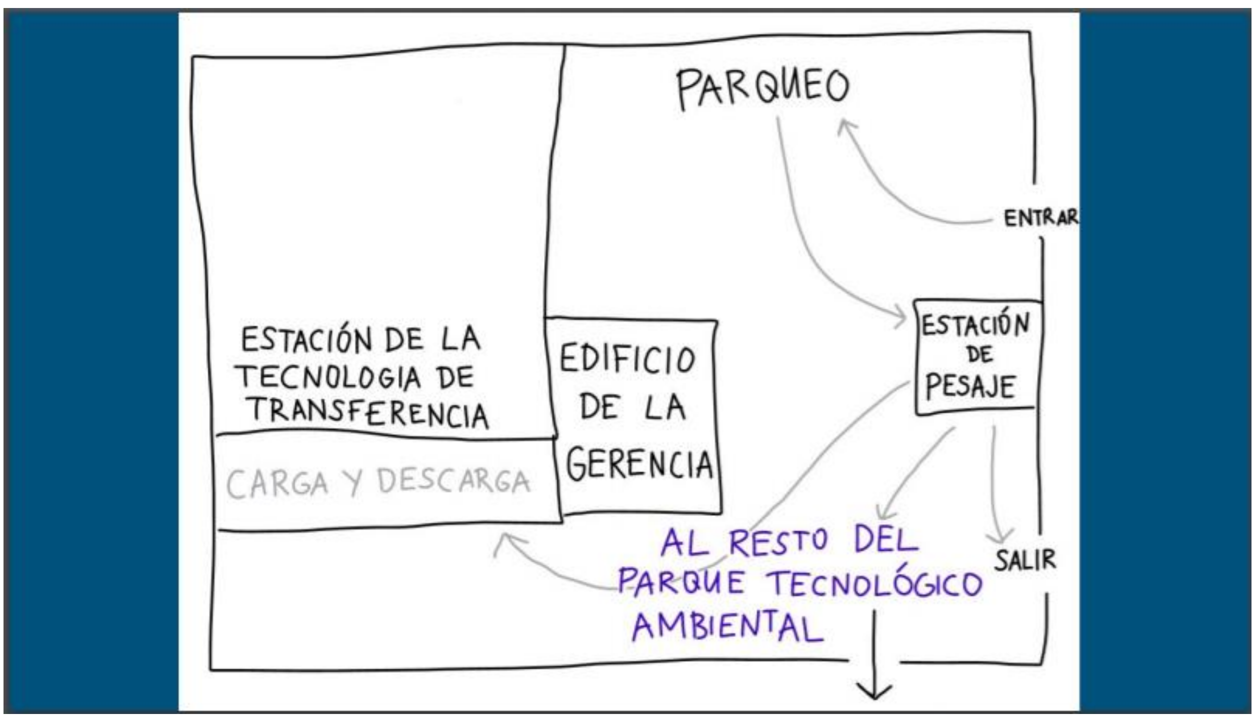
¿Cómo podría ser el CTRS?

Elementos típicos

- Tecnologia de transferencia
- ¿Uso público? ¿Solo los vehículos de colección?
- La exportación de los residuos sólidos
- Estación de pesaje
- Un edificio de la gerencia
- Una estación de limpieza
- Una estación para cubrir
- Parqueo
- Un centro para dejar (y clasificar) residuos
- Alojamiento (parcial o total)
- Una puerta y una valla

Elementos únicos

- Programa de recuperación de materiales
- Mantenimiento de vehículos
- Preparación por el clima
- Consideraciones ambientales
- Un Área de intercambio
- Baños públicos
- Un centro de educación público
- Zona de expanción
- Diseño similar de edificios locales (para armonizar)
- Zona del tráfico/hacer cola
- Capacidad a permitir varios vehículos (residencial, industrial, vehículos de colección, grande y pequeno)



Sector: No recuperable (tradicional)	Tecnología	Relevante para CTRS
	A. Camión tradicional	NO
	B. Camión compactador	NO
	C. Contenedor de compactactación	SI
	D. Trailer abierto	SI
	E. Compactador "baler" horizontal	SI

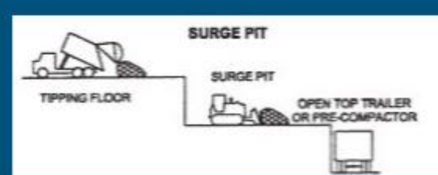
Sector: Reciclaje	Tecnología	Relevante para CTRS
	A. Recolección y procesamiento municipal	SI
	B. Recolección municipal y concesión/alianza local	SI
	C. Recolección municipal y concesión/alianza externa	SI
	D. Recolección contratada y procesamiento municipal	SI

Sector	Tecnología	Relevante para CTRS
Sector: Orgánico	A. Dinámica actual	NO
	B. Recolección municipal/planta centralizada	SI
	C. Recolección municipal/plantas descentralizadas	SI
	D. Campañas sostenidas de compostaje *in situ*	NO

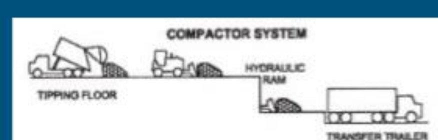
Tecnologia de transferencia

Tráiler de transferencia abierto
Permite la inspección de residuos sólidos antes de poner en el tráiler, no compacta los residuos sólidos, prefiere por operaciones de menor volumen

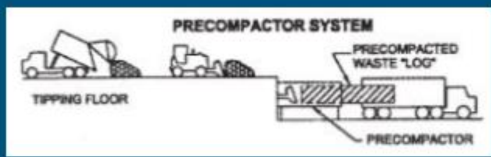
Pozo de espera
Un paso intermedio para guardar los residuos sólidos durante horas populares por el CTRS, los puede compactar antes de poner en el tráiler, puede disuadir la inspección



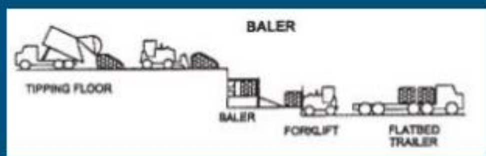
Sistema de compactación
El ariete hydráulico compacta los residuos sólidos, el tráiler tiene que hacer del acero reforzado



Tecnologia de transferencia



Sistema de pre-compactación
El ariete hydráulico a dentro del cilindro compacta los residuos sólidos antes de los ponen en el tráiler, valdría el precio alto ($250k) porque las cargas serán mayores



Sistema de "baler"
Compacta los residuos sólidos al fardos, los move al tráiler por montacargas, valdría el precio alto ($500k) porque las cargas serán mayores, prefiere por operaciones de mayor volumen

Sistema de recipientes "intermodal"
Los residuos sólidos están cargados al CTRS al recipiente "intermodal," cuando están llenos los transportan al vertedero, este sistema reduce el tráfico de los camiones al calles, permite viajar a sitios lejos

References by slide
2: Welch, 2018
6: Welch, 2018
7: Welch, 2018
8: Welch, 2018
10: Welch, 2018
11: Welch, 2018
13: UCR, 2018
14: UCR, 2018
15: Monteverde Municipality, 2020
20: Clipart Station, 2020
21: Clipart Station, 2020
23: Cooperación Suiza, 2017
25: EPA, 2002
30: EPA, 2002
31: EPA, 2002

Appendix F: Interview questions & themes - Sarah Dowell

Goals:

1. Further develop our understanding of the solid waste management system in Monteverde
2. Get a real feel (unbiased) for the recycling campaigns in Monteverde
3. Understand a citizen's point of view
4. Find out Sarah's suggestions for improvement so we can later build upon them

Themes:

1. The solid waste management (SWM) system in Monteverde with respect for non-recoverables consists of two collection routes, each driven bi-weekly (Rte 1 on Monday and Thursday, Rte 2 on Tuesday and Friday). Consumers can leave their bags of trash on the curb on their respective days to participate in this system. Another opportunity to dispose of trash is to place it in one of the 19 *mini centros de acopio* (mini collection centers) located around the municipality. These are emptied biweekly in accordance with which route they fall on. The recycling portion of the SWM system is less developed than the trash: in theory, citizens have the option to leave their recyclables in the *mini centros de acopio* as well as their trash, but in practice there are no wire mesh separators within the centers, so trash is mixed with recycle. The other option for recycling is to bring it to one of six *Puntos Verdes* (recycling campaign) locations or the *Centro de Acopio Municipal* once per month. The composting aspect of the municipal SWM is least developed. Currently, Justin Welch and the ASADA collects food scraps and compostable material from several local businesses (Hotel El Establo, Rest. Orquideas, Reserva Sta. Elena office, Rest. Taco Taco, Rest. Treehouse, Hotel Aguti, Whole Foods/Coffee Center, ASADA office) and six households. This is taken to a pilot composting facility.
2. According to Sarah, the *Puntos Verdes* are not an efficient way to collect recycling. Having only six locations across Monteverde, only once per month, is not a sufficient service to collect all of the recyclable material. This insufficient infrastructure promotes the habit of putting recyclables into the non-recoverables and sending them to the landfill. The first priority for recycling is to implement the dividers in the *mini centros* and to provide signage on each building to instruct the process. Ultimately, Sarah thinks there are better uses for the time and energy put into Punto Verdes. Sarah also stresses the need for a *gestor ambiental* (an environmental manager) who would not be an elected position and would oversee ongoing recycling work and local projects.
3. Sarah's perspective as a citizen is that the majority of the population is willing to recycle if given the opportunity (i.e. if there is sufficient infrastructure). Those that don't recycle seem to be those who are not familiar with the system or how to recycle. This is why it is critical to provide the facilities to recycle and educate the population with good signage.
4. Sarah emphasizes most heavily the *gestor ambiental*, providing recycling resources, encouraging composting in personal gardens, and providing education to the public.

Questions:

- What are you involved in within the community with respect to recycling or MSW management?
    - How long have you been volunteering for the recycling campaigns?
    - What prompted you to start?
- What do you think is going well with the recycling campaigns? What is lacking?
    - Concerning community participation?
    - Concerning incentivization?
    - Concerning the infrastructure provided by the municipality?
    - What would you like to see happen in the recycling campaigns? In practice? In preparation? In communication? In education?
- Do you have information on the types of businesses who recycle and do not? The types of people?
- What is the municipality's role working with COMIRES on the recycling campaigns?
- Who is volunteering for the recycling campaigns?
    - High schoolers?
    - COMIRES members?
    - Citizens?
    - Other?
    - Why are the different people volunteering?
    - How would the changes that we are talking about affect those who volunteer?
        - Students who have scholarships from this work?
- Is there any information you want to share about the recycling campaigns?
- What do you think about the method with which trash is collected currently?
    - What changes might you suggest making?
- What is your experience with different methods of communicating with the community about SWM?
    - What do you see as the best way to communicate with people about SWM and recycling efforts?
    - What do you see as the best way to educate people about recycling and SWM?
    - What is currently being done towards communication and education? What would you prefer to see happening?
    - What is the most common questions you have been asked during your volunteering time at the recycling campaigns
- Is there anything else you would like to add?

Appendix G: Interview questions & themes - Katy VanDusen

Goals:

1. Understand Katy VanDusen's role in solid waste management (SWM) in Monteverde.
2. Understand her environmental perspective on the SWM system and how it should be improved.
3. Learn about community education around climate change, environmentalism, and SWM.

Themes:

1. Katy VanDusen is the coordinator of CORCLIMA (*La Comisión hacia la Resiliencia al Cambio Climático de Monteverde*, Climate Change Resilience Commission of Monteverde) and a member of the COMIRES council. CORCLIMA performed research on emissions in Monteverde in 2016. Most pertinent to SWM are the 9% of annual emissions coming from solid waste, 4% from refrigerants (discussed in theme 2), and 4% from nitrogen-based fertilizers (which can be eliminated through use of compost from local organics). CORCLIMA performed this to know where the emissions are coming from, and to then communicate their findings as a means of motivation for mobilization.
2. Katy is excited about the prospects of the SWTC having a strong, positive, environmental impact on the SWM system in Monteverde. She highlights a few key elements that must be included including a program to account for separation of organics and a system to properly receive refrigerant gases. When organic material that is sent to the landfill biodegrades, it releases CH_4, a molecule that is 24x more potent (stronger at holding onto heat) a greenhouse gas than CO_2. If these organics are instead composted, the biodegradation process releases CO_2. Furthermore, 40% of all the landfill-bound municipal solid waste in Monteverde is organic material. It is important that we prioritize diverting these materials from the landfill to a composting system, thus minimizing greenhouse gas emissions and generating a profit through sold compost. Refrigerant gases like CFCs and halocarbons are released when refrigerators, freezers, air conditioners, and dehumidifiers are improperly disposed of, and these gases are between 100x and 12000x more potent than CO_2. Katy stresses the importance of having several cylinders equipped to store each separate refrigerant. The SWTC would be a location for trained individuals to bring smaller containers of the gases; once the large containers are full, they would be transferred elsewhere to be burned.
3. Katy is most excited about the opportunities for storytelling and TedTalks when communicating with and educating the Monteverde community about good SWM practices, climate change, and positive environmental action. Storytelling, particularly when performed by children about climate actions, is moving. It is important that you communicate about good SWM practices in a fun, tangible, and doable way. Right now, Katy and CORCLIMA are piggybacking on other events and having mini TedTalks to talk to people about circular economies, climate action, and what the average person can do and be involved.

Questions:

- What are the projects you are currently working on, with CORCLIMA or otherwise?
- How are you involved in the Monteverde SWM system?
  - What prompted you to get involved?
  - Is CORCLIMA involved in SWM in Monteverde? How?
- What do you see as the most significant environmental concerns within a SWM system?
- What do you see as the successes of the current SWM system in terms of the environmental impact? What do you attribute them to?
- What do you see as the faults of the current SWM system in terms of the environmental impact? What do you attribute them to?
- From an environmental sustainability perspective, what are some improvements you would like to see in the SWM system in Monteverde?
  - Technical/infrastructure?
  - Social aspects - education, communication?
  - Aspects of the services provided that could make the system more environmentally friendly?
- Do you believe that climate change influences people's attitudes towards SWM or their willingness to participate in the recycling programs?
- Have you seen environmentalism and climate change having any effects on the SWM system in Monteverde?
- We have seen that CORCLIMA has a lot of online resources about climate change and SWM. Can you tell us about any attempts to reach out and educate citizens about these topics?
- Do you have anything else to add?

Appendix H: Interview questions & themes for Esteban Aguilar

Goals:

1. Understand his work in solid waste management (SWM) in Monteverde.
2. Understand his opinions of SWM in Monteverde and how he thinks the system could be improved.
3. Understand the political factors that affect SWM.
4. Get his suggestions for elements that should be included in the solid waste transfer center (SWTC).

Themes:

1. Esteban works for the Ministry of Health in Monteverde, which manages solid waste within the municipality. The Ministry also oversees collection of non-traditional and dangerous waste. The Costa Rican government requires that municipalities collect municipal solid waste, but it is not required to process it. Esteban also participates in recycling campaigns, and works with Justin Welch and ASADA with organics collection.

2. Esteban stresses the importance of the municipality and citizens working together to have a high recovery rate of recyclables and organics. Every year, these recovery rates improve, and he hopes to see this trend continue, in particular because tourism continues to grow in Monteverde. Esteban believes that one recycling campaign per month is insufficient, as is the size of the Municipal Recycling Center. He thinks there should be a collection route for recyclables and organics. Esteban also wants to solve problems like dogs ripping open trash bags containing organics and the mixing of recoverable materials with the trash.
3. There is a limited amount of financial assistance that the municipality can dedicate to the SWM system. This creates challenges in funding projects and improving the SWM system.
4. Esteban stresses the need for composting technology at the SWTC. He also recommends not processing, burning, or compacting at the center, but to give the municipal solid waste to other businesses or sites with more resources. Also, he suggests that the SWTC have a location for materials that could have further value or use for the community (like tires or appliances). Esteban also recommends that a pilot project is enacted to see how the SWTC would function within Monteverde's SWM system.

Questions (English):

- What is your job within SWM?
- What political factors affect SWM in Monteverde?
- How do you think the recent elections have affected the SWM system?
- What is successful in the SWM system?
- What are some shortcomings of the current SWM system?
- What would you want to improve in Monteverde's SWM system?
- Do you know about Justin Welch's plan for a solid waste transfer center? What are technologies that you think are important to have in a SWTC?
- Is there anything else you would like to add?

Questions (Spanish):

- ¿Qué es su trabajo en el manejo de residuos sólidos?
- ¿Hay factores de la política que afectan el manejo de residuos sólidos en Monteverde?
- ¿Cómo cree que las elecciones que acaban de ocurrir van a afectar el MRS?
- ¿Cuáles han sido los éxitos del sistema actual de manejo de residuos sólidos?
- ¿Cuáles han sido los problemas del sistema actual de manejo de residuos sólidos?
- ¿Qué le gustaría mejorar del sistema de manejo de residuos sólidos en Monteverde?
- ¿Conoce usted el plan de Justin Welch para un centro de transferencia de residuos sólidos? ¿Cuáles son las tecnologías que cree que les vendrían mejor el CTRS?
- ¿Tiene algo más que añadir?

Appendix I: Interview questions & themes for William Arguedas

Goals:

1. Understand the successes and shortcomings at the recycling center and how he would like to improve it.
2. Understand his administrative point of view of the recycling center.
3. Get recommendations for technologies to incorporate into the solid waste transfer center (SWTC).
4. Reaffirm data about mass and volume flow rates for Monteverde.

Themes:

1. William says that some of the successes of the recycling center are the collaboration with businesses and the improvement of the quality of the recyclables delivered (cleaner and correctly sorted). Shortcomings of the center are the lack of staff, equipment, space, and information--all things which he would like to improve. William would also like to improve the amount of information he has access to about the public recycling practices outside of the recycling center.
2. William says that every day he learns new things at work, and again that he wishes he knew more information about recycling in Monteverde in general.
3. William stresses the importance of separation technology in the SWTC. He suggests using other country's SWTC or systems as models for Monteverde's. He recommends that all recyclables be cleaned, dried, and separated by the people who produce it.
4. The current Municipal Recycling Center is too small to properly manage the recyclables produced in Monteverde. The lack of staff, equipment, and space proves difficult in accounting for the steadily increasing levels of waste generation. 30% of the municipal solid waste in Monteverde is recyclable, but only 8% of the total SW is recycled at the center. William says that the current Recycling Center would not be able to manage all 30% if it were successfully collected.

Questions (English):

- What do you see as some successes of the recycling center?
    - What do you attribute them to?
- What do you see as some shortcomings of the recycling center?
    - What do you attribute them to?
- What are some things you would like to improve about the recycling center?
- Because of your unique administrative position at the recycling center in Monteverde, what perspectives and insights can you give us?
- How has the increase in the volume of recycling affected the recycling center?
- How would it impact the recycling center if closer to 30% of total solid waste was recycled, compared to the current 8%?
- What do you already know about Justin Welch's plan for a Solid Waste Transfer Center (SWTC) for the district?

  - Do you think a SWTC is viable considering the current and ideal recycling flow rates?
  - What technologies do you think are most applicable for the SWTC? Specifically for processing of recycling?
  - Right now, we have 2 distinct options for achieving sorting of the recycling: (1) having the citizens/consumers be responsible for cleaning and sorting their recycling (into vidrio, carton, botellas etc) or (2) collecting recycling in general and sorting it at the SWTC or an external location. Which do you recommend? Is there something else you think should be done to achieve sorting?
- Do you have anything else to add?

Questions (Spanish):

- ¿Cuáles han sido los éxitos del centro de reciclaje?
  - ¿A que los atribuye?
- ¿Cuáles han sido los problemas del centro de reciclaje?
  - ¿A que los atribuye?
- ¿Qué le gustaría mejorar el centro de reciclaje?
- Por su trabajo como Administrador del Sistema Municipal de Reciclaje usted tendrá una perspectiva única, ¿que nos puede decir sobre el centro y el sistema de reciclaje?
- ¿El aumento en el volumen de reciclaje ha afectado el centro?
- Si 30% de los residuos sólidos se reciclaban en lugar del 8% actual, ¿cómo afectaría esto el centro de reciclaje?
- ¿Conoce usted el plan de Justin Welch para un centro de transferencia de residuos sólidos?
  - Tomando en cuenta la tasa de flujo actual y la tasa de flujo ideal, ¿usted cree que un CTRS sería posible?
  - ¿Cuáles son las tecnologías que cree que les vendrían mejor el CTRS?
    - En general
    - Para el reciclaje
  - Actualmente, hay dos opciones distintas para limpiar y separar el reciclaje: que los ciudadanos lo hagan o que lo recoleccionan y lo separan en el CTRS. ¿Cual recomendaría usted?
- ¿Tiene algo más que añadir?

Appendix J: Excel calculations for waste flow-rate data & spatial breakdown

Table A.J1: Tonnage calculation for total waste		
Year	**Total tonnes produced**	**Total kilos produced**
2014	979.65	979650
2015	1083.88	1083880
2016	1205.89	1205890
2017	1232.18	1232180
2018	1357.66	1357660
2019	1442.808	1442808
2020	1532.64	1532640
2025	1981.8	1981800
2030	2430.96	2430960
2035	2880.12	2880120
2040	3329.28	3329280
2045	3778.44	3778440

Table A.J1 shows the actual tonnes and kilograms of total waste, including recyclables, non recoverables, and organics. The tonnages for 2014 - 2019 are actual tonnes and kilograms as recorded by the Monteverde Municipality. The tonnes and kilograms for 2020 - 2045 are predicted. We made these predictions using a linear trendline based on the tonnages for 2014 - 201. Tables A.J4, A.J10, and A.J23 represent these same calculations for the specific waste flows of organics, recyclables, and non-recoverables, respectively. These are calculated using 40%, 30%, and 30% of the total waste flow, respectively.

Table A.J2: Seasonal calculation for the total tonnage				
Year	**Sum of December-March (tonnes)**	**Sum of April-July (tonnes)**	**Sum of Aug-Nov (tonnes)**	**Annual total (tonnes)**
2018	377.21	406.08	378.28	1161.57
2019	402.83	408.53	379.27	1190.63

Table A.J2 shows the breakdown of the tonnages of non-recovered waste delivered to the landfill by season. These calculations are significant because they show the differences between the tourist season and the seasons with less tourism. Tables A.J5, A.J11, and A.J24 show these calculations for the specific waste flows of organics, recyclables, and non-recoverables, respectively. For the space calculations of the recycling we considered the year 2045 so that it would be proportional to the population growth in Monteverde. We also considered for each material, when they are processed and not processed, would stay in the SWTC for four weeks. Later, we summed up all to determine the total space.

Table A.J3: Things to know for organics calculation
1 barrel = 0.142506 m^3

Table A.J4: Tonnage calculation for organics

Year	**Estimated tonnes of organics produced**	**Estimated Kilograms of organics produced**	**Average kg/week produced**	**Average total number of 160-kg barrels needed for one collection a week (rounded up)**	**Average total number of 160-kg barrels needed for two collections a week (rounded up)**	**Barrel volume in m^3 (rounded up) per week**
2014	391.86	391860	7535.77	24	48	6
2015	433.55	433550	8337.5	27	53	6
2016	482.36	482360	9276.15	29	58	7
2017	492.87	492870	9478.27	30	60	7
2018	543.06	543060	10443.46	33	66	8
2019	577.12	577120	11098.46	35	70	8
2020	613.06	613060	11789.62	37	74	9
2025	792.72	792720	15244.62	48	96	10
2030	972.38	972380	18699.62	59	117	11
2035	1152.05	1152050	22154.81	70	139	15
2040	1331.71	1331710	25609.81	81	161	18
2045	1511.38	1511380	29065	91	182	20

Table A.J5: Seasonal calculation for the organic waste				
Year	**Sum of December-March (tonnes)**	**Sum of April-July (tonnes)**	**Sum of Aug-Nov (tonnes)**	**Annual total (tonnes)**
2018	150.88	162.43	151.31	464.62
2019	161.13	163.41	151.71	476.25

Table A.J6: The volume of the respective containers (m^3)				
The volume of a bale	**The volume of half a bale**	**The volume of a barrel**	**The volume of a sack for tins**	**The volume of a normal sack**
0.60762	0.2808	0.142506	0.072	1

Table A.J7: The materials of the respective containers			
Materials that go to a bale	**Materials that go to half a bale**	**Materials that go to a barrel**	**Materials that go to a smaller sack**
Plastic	Cardboard	Glass	Tin
Aluminum	Tetra Brik		

Table A.J8: The density of the respective materials both unprocessed and processed		
Material type	**Density of the recycling materials (kg/m^3) for unprocessed**	**Density of the recycling materials (kg/m^3) processed**
Cardboard	64.66	427.35
Plastic	12.42	75.71
Tetra Brik	28.05	302.71
Cans	17.5	208.33
Aluminum	34	41.14
Glass	88.85	1859.57
Paper	127.23	712.25
Scrap metal	N/A	N/A
Electronics	N/A	N/A

Table A.J9: Total tonnage calculation for recycling

Year	Estimated tonnes of recycling produced	Estimated kilograms produced	Average kg/week produced
2014	52.9	52900	1017.31
2015	85.04	85040	1635.38
2016	99.37	99370	1910.96
2017	97.6	97670	1878.27
2018	127.24	127240	2446.92
2019	139.073	139073	2674.47
2020	155.39	155390	2988.27
2025	236.975	236975	4557.21
2030	318.56	318560	6126.76
2035	400.145	400145	7695.11
2040	481.73	481730	9264.04
2045	563.315	563315	10832.97

Table A.J10: Tonnage calculation for each recycling material for the year 2014

Year	Estimated tonnes of recycling produced	Estimated kilograms produced	Average kg/week produced	The amount of space needed for unprocessed materials per week (kg/bale)/m^3	The amount of space needed for processed materials per week(m^3)
2014					
Cardboard	12.13	12130	233.27	3.61	0.55
Plastic	5.9	5900	113.46	9.14	1.5
Tetra Brik	1.2	1200	23.08	0.82	0.08
Cans	0.84	840	16.15	0.92	0.08
Aluminum	0.17	170	3.27	0.1	0.08
Glass	26.84	26840	516.15	5.81	0.28
Paper	4.56	4560	87.69	0.69	0.12
Scrap metal	0.58	580	11.15	N/A	N/A
Electronics	0.68	680	13.08	N/A	N/A
Total	**52.9**	**52900**	**1017.31**	**21.09**	**2.69**

Table A.J11: Tonnage calculation for each recycling material for the year 2015

Year	Estimated tonnes of recycling produced	Estimated kilograms produced	Average kg/week produced	The amount of space needed for unprocessed materials per week (kg/bale)/m^3	The amount of space needed for processed materials per week(m^3)
2015					
Cardboard	26.52	26520	510	7.89	1.19
Plastic	7.59	7590	145.96	11.75	1.93
Tetra Brik	2.56	2560	49.23	1.76	0.16
Cans	0.12	120	2.31	0.13	0.01
Aluminum	0.69	690	13.27	0.39	0.32
Glass	35.45	35450	681.73	7.67	0.37
Paper	8.82	8820	169.62	1.33	0.24
Scrap metal	3.29	3290	63.27	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**85.04**	**85040**	**1635.38**	**30.92**	**4.22**

Table A.J12: Tonnage calculation for each recycling material for the year 2016

Year	Estimated tonnes of recycling produced	Estimated kilograms produced	Average kg/week produced	The amount of space needed for unprocessed materials per week (kg/bale)/m^3	The amount of space needed for processed materials per week(m^3)
2016					
Cardboard	28.38	28380	545.77	8.44	1.28
Plastic	7.71	7710	148.27	11.94	1.96
Tetra Brik	2.56	2560	49.23	1.76	0.16
Cans	1.49	1490	28.65	1.64	0.14
Aluminum	0.7	700	13.46	0.4	0.33
Glass	45.66	45660	878.08	9.88	0.47
Paper	9.33	9330	179.42	1.41	0.25

Scrap metal	0.39	390	7.5	N/A	N/A
Electronics	3.15	3150	60.58	N/A	N/A
Total	**99.37**	**99370**	**1910.96**	**35.47**	**4.59**

Table A.J13: Tonnage calculation for each recycling material for the year 2017

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2017					
Cardboard	30.3	30300	582.69	9.01	1.36
Plastic	7.44	7440	143.08	11.52	1.89
Tetra Brik	2.25	2250	43.27	1.54	0.14
Cans	1.52	1520	29.23	1.67	0.14
Aluminum	0.52	520	10	0.29	0.24
Glass	39.35	39350	756.73	8.52	0.41
Paper	12.52	12520	240.77	1.89	0.34
Scrap metal	0.81	810	15.58	N/A	N/A
Electronics	2.96	2960	56.92	N/A	N/A
Total	**97.67**	**97670**	**1878.27**	**34.44**	**4.52**

Table A.J14: Tonnage calculation for each recycling material for the year 2018

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2018					
Cardboard	61.73	61730	1187.12	18.36	2.78
Plastic	7.3	7300	140.38	11.3	1.85
Tetra Brik	2.41	2410	46.35	1.65	0.15
Cans	2.92	2920	56.15	3.21	0.27
Aluminum	0.79	790	15.19	0.45	0.37

Glass	41.65	41650	800.96	9.01	0.43
Paper	10.44	10440	200.77	1.58	0.28
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**127.24**	**127240**	**2446.92**	**45.56**	**6.13**

Table A.J15: Tonnage calculation for each recycling material for the year 2019

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2019					
Cardboard	62.662	62662	1205.04	18.64	2.82
Plastic	7.985	7985	153.56	12.36	2.03
Tetra Brik	2.807	2807	53.98	1.92	0.18
Cans	3.064	3064	58.92	3.37	0.28
Aluminum	0.893	893	17.17	0.51	0.42
Glass	47.888	47888	920.92	10.36	0.5
Paper	13.774	13774	264.88	2.08	0.37
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**139.073**	**139073**	**2674.47**	**49.24**	**6.6**

Table A.J16: Tonnage calculation for each recycling material for the year 2020

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2020					
Cardboard	72.96	72960	1403.08	21.7	3.28
Plastic	8.25	8250	158.65	12.77	2.1
Tetra Brik	3	3000	57.69	2.06	0.19

Cans	3.62	3620	69.62	3.98	0.33
Aluminum	1	1000	19.23	0.57	0.47
Glass	51.24	51240	985.38	11.09	0.53
Paper	15.32	15320	294.62	2.32	0.41
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**155.39**	**155390**	**2988.27**	**54.49**	**7.31**

Table A.J17: Tonnage calculation for Each Recycling Material for the year 2025

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2025					
Cardboard	124.45	124450	2393.27	37.01	5.6
Plastic	9.575	9575	184.13	14.83	2.43
Tetra Brik	3.965	3965	76.25	2.72	0.25
Cans	6.4	6400	123.08	7.03	0.59
Aluminum	1.535	1535	29.52	0.87	0.72
Glass	68	68000	1307.69	14.72	0.7
Paper	23.05	23050	443.27	3.48	0.62
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**236.975**	**236975**	**4557.21**	**80.66**	**10.91**

Table A.J18: Tonnage calculation for each recycling material for the year 2030

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2030					
Cardboard	175.94	175940	3383.46	52.33	7.92
Plastic	10.9	10900	209.62	16.88	2.77
Tetra Brik	4.93	4930	94.81	3.38	0.31
Cans	9.18	9180	176.54	10.09	0.85
Aluminum	2.07	2070	39.81	1.17	0.97
Glass	84.76	84760	1630	18.35	0.88
Paper	30.78	30780	591.92	4.65	0.83
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**318.56**	**318560**	**6126.16**	**106.85**	**14.53**

Table A.J19: Tonnage calculation for each recycling material for the year 2035					
Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2035					
Cardboard	227.43	227430	4373.65	67.64	10.23
Plastic	12.225	12225	235.1	18.93	3.11
Tetra Brik	5.895	5895	113.37	4.04	0.37
Cans	11.96	11960	230	13.14	1.1
Aluminum	2.605	2605	50.1	1.47	1.22
Glass	101.52	101520	1952.31	21.97	1.05
Paper	38.51	38510	740.58	5.82	1.04
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**400.145**	**400145**	**7695.11**	**133.01**	**18.12**

Table A.J20: Tonnage calculation for each recycling material for the year 2040

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**
2040					
Cardboard	278.92	278920	5363.85	82.95	12.55
Plastic	13.55	13550	260.58	20.98	3.44
Tetra Brik	6.86	6860	131.92	4.7	0.44
Cans	14.74	14740	283.46	16.2	1.36
Aluminum	3.14	3140	60.38	1.78	1.47
Glass	118.28	118280	2274.62	25.6	1.22
Paper	46.24	46240	889.23	6.99	1.25
Scrap metal	0	0	0	N/A	N/A
Electronics	0	0	0	N/A	N/A
Total	**481.73**	**481730**	**9264.04**	**159.2**	**21.73**

Table A.J21: Tonnage calculation for each recycling material for the year 2045

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**The amount of space needed for unprocessed materials per week (kg/bale)/m^3**	**The amount of space needed for processed materials per week(m^3)**	**The amount of space decided to have in the SWTC in total**
2045						
Cardboard	330.41	330410	6354.04	98.27	14.87	452.56
Plastic	14.875	14875	286.06	23.03	3.78	61.18
Tetra Brik	7.825	7825	150.48	5.36	0.5	23.44
Cans	17.52	17520	336.92	19.25	1.62	83.48
Aluminum	3.675	3675	70.67	2.08	1.72	15.2
Glass	135.04	135040	2596.92	29.23	1.4	122.52

Paper	53.97	53970	1037.88	8.16	1.46	38.48
Scrap metal	0	0	0	N/A	N/A	N/A
Electronics	0	0	0	N/A	N/A	N/A
Total	**563.315**	**563315**	**10832.97**	**185.38**	**25.35**	**797**

Table A.J22: Tonnage calculation for non-recoverables

Year	**Estimated tonnes of recycling produced**	**Estimated kilograms produced**	**Average kg/week produced**	**Average tonnes/week produced**	**Tonnes/m^3**
2014	293.9	293900	5651.92	5.65	0.82
2015	326.96	326960	6287.69	6.29	0.91
2016	361.77	361770	6957.12	6.96	1.01
2017	369.65	369650	7108.65	7.11	1.03
2018	407.3	407300	7832.69	7.83	1.14
2019	432.84	432840	8323.85	8.32	1.21
2020	459.79	459790	8842.12	8.84	1.28
2025	594.54	594540	11433.46	11.43	1.66
2030	729.29	729290	14024.81	14.02	2.03
2035	864.04	864040	16616.15	16.62	2.41
2040	998.78	998780	19207.31	19.21	2.79
2045	1133.53	1133530	21798.65	21.8	3.16

Table A.J23: Seasonal calculation for the non-recoverables

Year	**Sum of December-March (tonnes)**	**Sum of April-July (tonnes)**	**Sum of Aug-Nov (tonnes)**
2018	113.16	121.82	113.48
2019	120.85	122.56	113.78

Table A.J24: Tonnage calculation for each material per day

Year	Tonnes of organics/day	Tonnes of recycling/day	Tonnes of trash/day	Tonnes of total waste/day
2014	1.08	0.15	0.81	2.03
2015	1.19	0.23	0.9	2.32
2016	1.33	0.27	0.99	2.59
2017	1.35	0.27	1.02	2.64
2018	1.49	0.35	1.12	2.96
2019	1.59	0.39	1.19	3.16
2020	1.68	0.43	1.26	3.38
2025	2.18	0.65	1.63	4.46
2030	2.67	0.87	2	5.55
2035	3.16	1.1	2.37	6.64
2040	3.66	1.32	2.74	7.72
2045	4.15	1.54	3.11	8.81

Appendix K: Waste management system qualitative cost-benefit matrix

Table A.K1: Non-recoverable management technology matrix

Technology	**Anticipated costs**	**Anticipated benefits**	**SWTC impact?**
Compaction container	Denser waste loads, fewer trips to the landfill	Contract or purchase container	Requires space with cement floor and 220V connection
Open top/ compaction truck	Denser waste loads, fewer trips to the landfill	Contract or purchase either truck	Requires space with cement floor
Horizontal baler	Denser waste loads, fewer trips to the landfill, smaller than a classic compaction container	Contract or purchase baler and truck	Requires space with cement floor and 220V connection

Table A.K2: Recyclable management system matrix

Technology	**Anticipated costs**	**Anticipated benefits**	**SWTC impact?**
On-site processing	Space, manpower, equipment, time, transportation	Profit from selling processed material	Requires floor space and compaction technology
Off-site processing	Transportation	Frees recycling- management-staff to focus on collection and education over processing	Not applicable

Table A.K3: Organics management system matrix			
Technology	**Anticipated costs**	**Anticipated benefits**	**SWTC impact?**
On-site storage	Construction of storage area	Accounts for high flow-rate of material; extra storage could be used for other processes	Requires storage facility
Through-traffic only	Not applicable	Not applicable	Not applicable

Appendix L: Standard weight and volume tables

Table A.L1: Standard weight and volume of unprocessed recyclables				
Material	**Type of Container**	**Volume (L)**	**Mass (kg)**	**Mass (ton)**
Aluminum	Big sack	1000	34	0.034
Cardboard	Big sack	1000	960	0.96
Paper	Big sack	1000	200	0.2
Tin	Loose	1000	17.5	0.0175
Clear plastic	Big sack	1000	37	0.037
HDPE plastic	Big sack	1000	55	0.055
Tetrapak	Big sack	1000	1105	1.105
Glass	Sack	142.506	265	0.265

Table A.L2: Standard weight and volume of processed recyclables

Material	**Type of Container**	**Volume (L)**	**Mass (kg)**	**Mass (ton)**
Aluminum	Bale	280.8	25	0.025
Cardboard	Medium bale	607.62	120	0.12
Paper	Medium bale	607.62	200	0.2
Tin	Sack	72	15	0.015
Clear plastic	Bale	280.8	74	0.074
HDPE plastic	Bale	280.8	110	0.11
Tetrapak	Medium bale	607.62	85	0.085
Glass	Barrel	142.506	265	0.265

Table A.L3: Standard weight and volume of organic materials

Volume (L)	**Mass (kg)**	**Mass (ton)**
220	160	0.16

Appendix M: Solid waste transfer center design

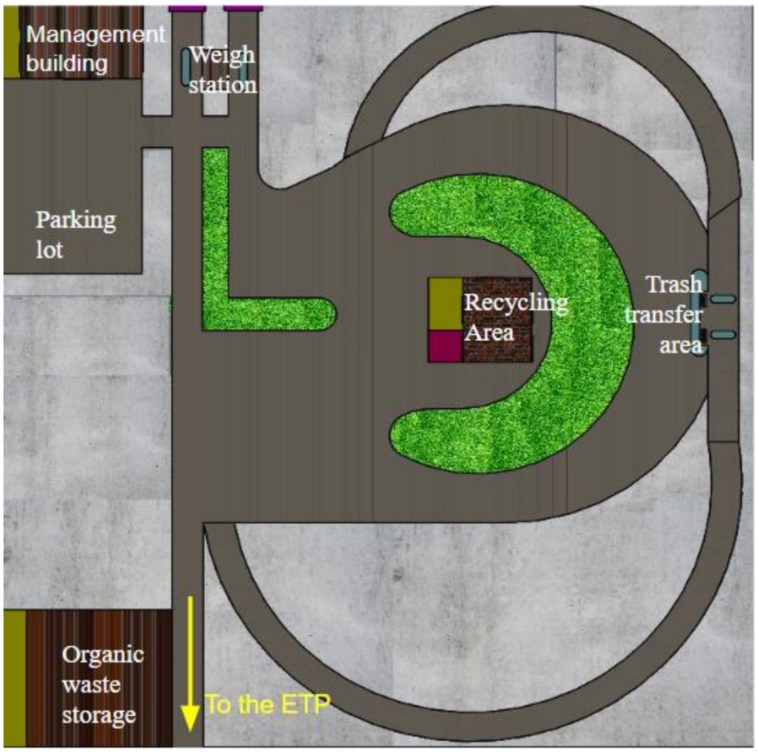


Figure A.M1: Preliminary SWTC sketch

The respective names of each element in our SWTC is shown in Figure A.M1.

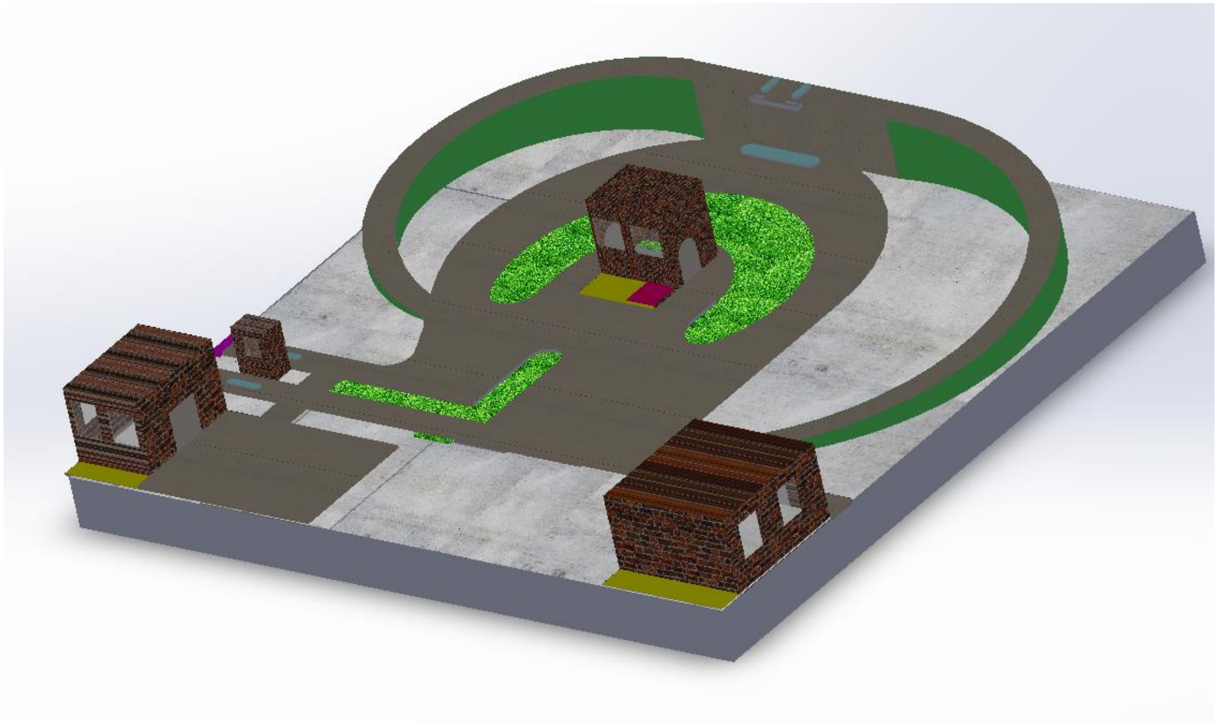


Figure A.M2: SWTC 3D from the right angle

This is the 3D version of our SWTC. Each element is designed for a specific use. Essentially, we have three buildings to process the respective materials: Non-recoverables, organics, recycling.

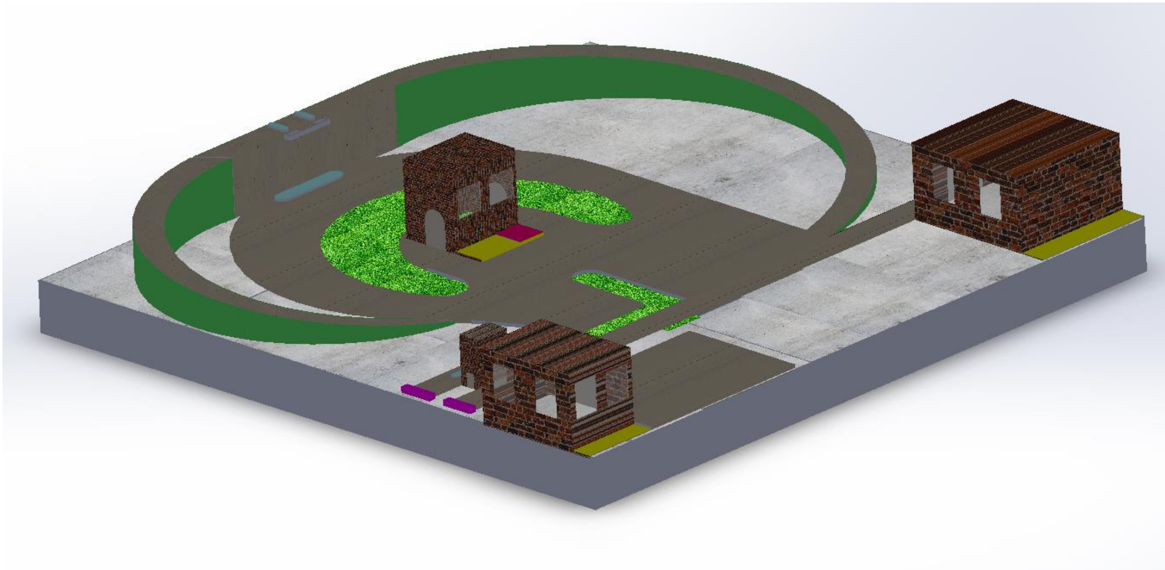


Figure A.M3: SWTC 3D from the left angle

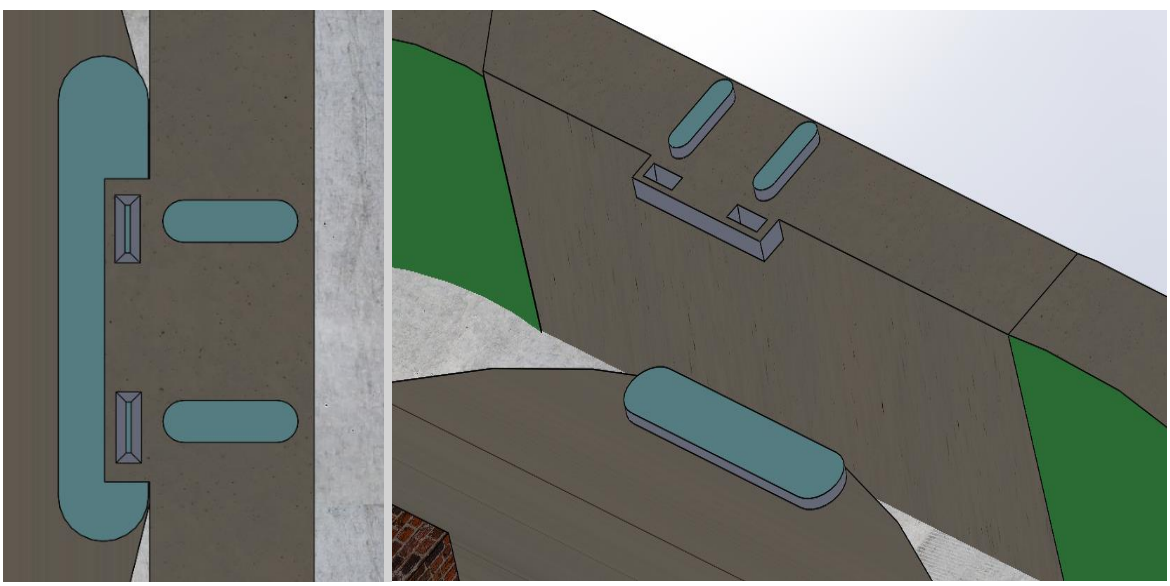


Figure A.M4: SWTC trash station

Our trash station is composed of two steps. The straight slots are used to illustrate the trucks. The municipal truck, shown in smaller slots, is up the hill where special funnels are designed for them to unload the trash in a clean way into the compaction truck waiting below, shown with the bigger slot.

Figure A.M5: SWTC storage area for organics

This building is designed as a storage area for organic materials. Essentially, we considered organic materials to go directly to the ETP. However, we wanted to create a storage opportunity as a solution to any possible problem might occur. This building is designed to have a place on the way from SWTC to the ETP.

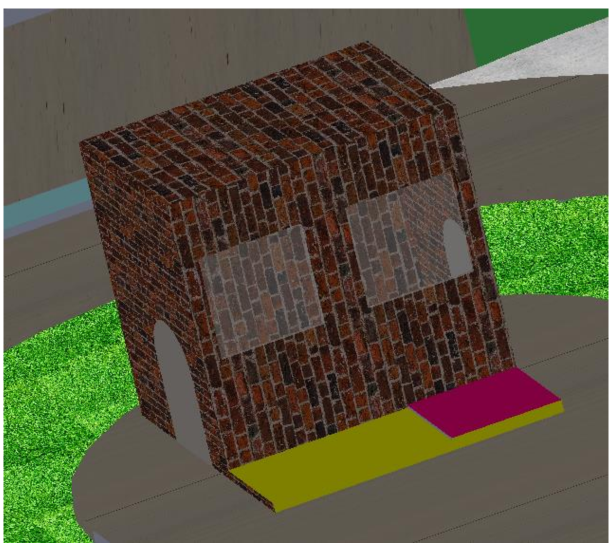


Figure A.M6: SWTC recycling station

Our recycling center is in the middle circle of the SWTC, suitable for a truck to come and drop off all the recycling into the station to be sorted out manually. The necessary space is taken under consideration for the trucks, the materials, and the equipment needed. The yellow space is designed for the future expansion and the space shown with pink is the possible space for the non-traditional waste management area.

Appendix N: Group reflection

After our time in Monteverde working with numerous organizations and people, we learned so much, and it was important to reflect upon our experience. In particular, we learned more about what it was like to work on projects in a real-world setting. There were so many elements and moving parts that we encountered and that none of us had anticipated. We often found ourselves with daunting tasks from our sponsor that needed to be completed by the next day. We also experienced periods where we felt like sitting ducks - with no tasks on the to-do list. Balancing the different levels of stress and responsibility was something that none of us were accustomed to. We also had to learn to manage satisfying all parties we worked with. Often, our sponsor and COMIRES wanted very technical results, but the requirements of an IQP did not always align with their goals. We worked hard to achieve all of the goals asked of us.

We also learned more about the process of completing an IQP. At first glance, our project goal presented as very technical. We struggled initially with the task of joining a seemingly technical task with a social-science project. However, as our work unfolded and we started performing our methods, we revealed the importance of designing a solid waste transfer center that could actually be used by a community. Simply building a transfer center in Monteverde was not going to change their solid waste management situation. We had to figure out how to make it accessible and desirable to a range of stakeholders. Ultimately, we felt like our combination of technical and non-technical recommendations captured beautifully the steps that should be taken to see our project through. If anything, communicating with both technical language and social language increased the impact of our work. At the conclusion of this experience, we could look back with striking clarity at the foreseeable effects our work would have on Monteverde - economically, socially, and environmentally.

We also experienced many challenges while completing this IQP. First, we were struck by the fact that, in the seven short weeks we had to work, we simply could not accomplish everything. We were hindered by both time and resource constraints. In our daily life at WPI, we were used to nearly instantaneous replies to email, something that does not occur on Tico Time. We found that if we sent an email at any point later in the week, we would have to wait for a response until Monday or Tuesday of the following week. This was especially difficult for us with respect to data. Because our project had technical elements, we dealt with lots of flow-rate and volume related data, all of which had to come from some source outside of our sponsor. We needed to complete the calculations in a timely manner, but often we did not have sufficient information to do so. Ultimately, this led to us not completing tasks that we would have liked to. Therefore, we recommended many tasks to the Municipality or COMIRES that would involve data collection. We were frustrated that we could not complete some of these calculations, but we outlined recommendations and steps to achieve them, so they would be completed after our stay in Monteverde.

We were able to transform another obstacle we experienced into a strength. At the start of working together, we outlined what we felt were our respective strengths and weaknesses. It seemed like we had a lot of shortcomings, but upon closer examination, we found that for each weakness a member had, another group member had that as a strength. During C-term, we divided our work between us, assigning each member to be the director of one aspect of the project. Even though they were acting as a leader, helping the other three members improve in each area, each person wanted to grow in their category as well. Shelvey felt she had strong writing skills, so she led the report-writing portion of our work. She helped Elçin and Adrian on their writing skills by talking through edits with them. However, she also wanted to hone her ability to write in active voice (versus passive, which is much more common in purely technical writing). Imogen was the strongest Spanish speaker in the group, so she facilitated the interviewing process. Imogen helped all the other members improve their Spanish skills by drafting their Spanish writing with helpful comments and corrections. However, she also wanted to develop her skills of combining eloquent speaking with good conversation flow. Elçin had experience using autoCAD software, so she took the lead on the design and calculation portion of our project. Accordingly, she wanted to work on providing quality visual support for her technical findings. Elçin helped teach Shelvey, Adrian, and Imogen about the process of transforming an idea to a visual creation. Finally, Adrian, our resident Civil Engineering major, led the engineering side of our work, teaching all three other members about specifics of her engineering sector and how they were useful in developing our project. She wanted to develop her skills in clearly communicating to the group her engineering findings and her reasoning for reaching them.

Ultimately, what made our teamwork so important was all of our four minds working collaboratively together, producing something way better than what could be made by an individual. Because each task leader worked with the three other members to help them grow as well (Shelvey by helping the group with their writing skills, Imogen with interviewing and Spanish skills, Elçin by teaching about the implementation of ideas into graphic designs, and Adrian informing the group about the engineering elements) we grew as writers, interviewers, designers, engineers, and ultimately as people more than we ever thought possible.