# Designing a Sustainable Water Supply Network for El Cuerpo de Bomberos Training Practices

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*Talon Boie*
*Kerry Muenchow*
*Theodore Vangos*
*Kelly Vodola*


BENEMÉRITO CUERPO DE
BOMBEROS
DE COSTA RICA

# Designing a Sustainable Water Supply Network for El Cuerpo de Bomberos Training Practices

An Interactive Qualifying Project Submitted to the Faculty of *Worcester Polytechnic Institute* in partial fulfillment of the requirements for the Degree of Bachelor of Science

Submitted By:
Talon Boie
Kerry Muenchow
Theodore Vangos
Kelly Vodola

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Report Submitted to:

James Chiarelli, Co-Advisor
Stephen McCauley, Co-Advisor
El Cuerpo de Bomberos, Sponsor
*Worcester Polytechnic Institute*

# Abstract

The purpose of this project was to increase water sustainability by designing a water collection and storage system at the Bomberos' National Fire Academy in San José, Costa Rica. Interviews with stakeholders revealed that the key design priorities were for an "effective, beautiful, and inexpensive" system. The project resulted in designs for a sediment filter, water storage tank, rainwater harvesting system, and water recycling system. The proposals provided the Bomberos with a return on investment of approximately three years.

# Acknowledgements

We would like to give sincere thanks to our sponsors, the Cuerpo de Bomberos, Costa Rica, especially those at the National Fire Academy; Director Ronny LaTouche, Training Operations Director Allan Rodriguez, and Academy Sub-Director Norman Chang, who guided our team to throughout the completion of our project. Allan and Norman used their engineering experiences to guide us to complete a successful IQP project. Their insight with the technical aspects in our designs was key and without them we would not have been able to complete our project.

We also would like to thank Doña Marcela Music and Don Jim Music for the hard work that they put in to connecting us with our sponsors. Their deep ties with Worcester Polytechnic Institute have allowed for several years of impactful projects with El Cuerpo de Bomberos. Mr. and Mrs. Music are the reason that we were able to work with the Bomberos in the first place.

From the state firefighter training academy in Stowe, Massachusetts, Joseph Klucznik and James DiRico deserve a big thank you for sharing their knowledge on the firefighter training system at their academy with us. They took time out of their busy schedules to assist us in learning about firefighter training. In addition, the tour they gave around their facilities offered great insight into system designs for our project.

We would like to thank both of our esteemed advisors, Professors James Chiarelli and Stephen McCauley, for the amount of time and effort they put in to helping develop our project. Their constant support and guidance kept our team on track from start to finish. They spent hours out of their day working with us to produce a complete and fully formed project and presentation.

Finally, we would like to thank Worcester Polytechnic Institute for making this entire trip not only possible, but successful as well.

# Executive Summary

Water scarcity is a global resource concern that is often considered with reference to potable water consumption and availability of water for sanitation. One important subset of water use is firefighting, which is often overlooked in water conservation plans as it is deemed a necessity for public safety. While water use should not be limited in emergency situations, water expended during firefighter trainings is significant and often unregulated. In some areas of Costa Rica, this leads to tensions between the public and the Costa Rican Fire Department (El Cuerpo de Bomberos), as firefighters draw from the municipal, potable water supply for emergencies and trainings alike. Due to this, the firefighters (Bomberos), try to minimize their water use in trainings, despite the benefits of these simulations.

Our goal was to work with the Bomberos at their Training Academy in San José, Costa Rica to design an integrated water collection and storage network including a rainwater capture and water recycling system, that safely and sustainably addressed their water demands for training. Understanding the potential impact these systems have on the stakeholders was essential. The stakeholders' desired designs that followed the "3 B's: Bueno, Bonito, y Barato," translated as "effective, beautiful, and inexpensive". Our designs would significantly increase water availability for trainings at the Academy, allow for more frequent use of firefighting equipment, prevent possible disruptions in the training schedule, and possibly reduce tensions between firefighters and communities.

**Project Objectives**

1. Understand the needs and motivations of the stakeholders for a water collection, recycling and storage system and gauge the potential project impact on stakeholders to ensure that the project appropriately fulfills the water needs for training at the Academy.
2. Understand water practices used in firefighter training abroad and in San José.
3. Analyze the existing infrastructure for rainwater collection, water recycling, and water use at the Bomberos' Academy.
4. Develop a model of monthly water availability and use at the training Academy that considers annual rainfall quantities, water recycling potential, and water use during training.
5. Design an integrated water collection and storage system on the Academy grounds for rainwater and water expended in training exercises.

We gathered information about motivations for the project and its potential impact from interviews at the National Academy and fire stations in Cartago and Pacayas, and then used this to guide our design work and recommendations throughout the process. To design an integrated water collection and storage network, we compared water practices between San José Academy and the Massachusetts Firefighting Academy, calculated rainfall and water use totals, and collected technical data required for creating rainwater harvesting and water recycling systems.

The main deliverables for the project were to design a rainwater harvesting system and a water recycling system at the Academy. For both of these systems, we created a series of design proposals from which the Bomberos could choose to best fit their needs. To ensure the feasibility and usability of the systems, we presented design iterations to the Academy Training Director and Sub-Director throughout the process, and re-designed based on their feedback. The proposed designs additionally included maintenance and safety plans to ensure system longevity. For each design, we provided cost estimates to aid the Bomberos in their decision of which design proposals to

implement. Cost information was collected through communication with local vendors and sponsors, and was synthesized to create appropriate design proposals as outlined below.

**Findings for Water Systems Designs**

***Stakeholder Perspectives***

The Bomberos shared the view that water is undervalued and poorly rationed in Costa Rica because of its prevalence and inexpensive cost. Overall, the firefighters claimed that there was a general lack of awareness about water use and waste in Costa Rica, with some saying that the country is missing the "culture, education and technology to create a sustainable system" regarding water use. As participants in the Blue Flag sustainability program, the Bomberos are leaders in sustainability, especially as it relates to water use. Our project aimed to mitigate this cultural barrier with our system designs.

***Current Infrastructure***

The layout of the training ground area related to our project at the San José Academy can be found in Figure ES.1 below. Within the Academy training grounds, the Smoke and Maintenance Buildings, Training Plaza, and Training Tower had inefficient or ineffective infrastructure for water capture and recollection. The only training building without an established water collection infrastructure was the Search and Rescue Building. Established drains and sediment traps presented a safety hazard as they could be opened by anyone.

***Water-Use***

Based on our findings of rainfall data in San José, available roof area at the Academy, and current training practices that require water, we a designed user-friendly, computational water-use model in Excel. The Bomberos can input water amounts demanded for specific trainings and their monthly frequencies, which are used to calculate the amount of water expended during training throughout a year. The model shows the quantity of recycled water available and the amount of rainwater that could hypothetically be collected throughout a given year. The model also yields graphical representations of the amount of water available for trainings.

Using information about training activities, we calculated that the Bomberos use 176,000 gallons of water per year in training, with an average of 14,700 gallons per month. From buildings and new installations on the training grounds at the Academy, almost 666,000 gallons of water can be collected from rain on an annual basis. With implemented infrastructure and pre-existing conditions for water capture and recycling, the amount of water needed for training can be completely provided six times over.

**Designs for Integrated Water Capture and Storage System**

We aimed for our designs to be as-built, or extensions on the infrastructure already in-place at the Academy. The main designs included a tank, sediment filter, rainwater capture system, water recycling system, and corresponding water conveyance systems (Figure ES.1).

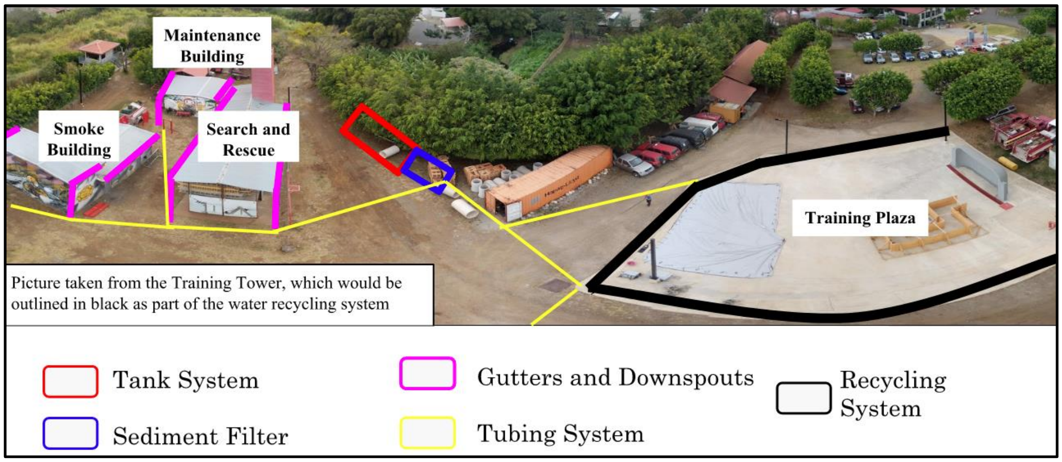
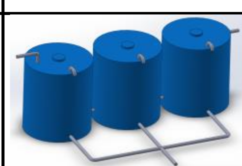
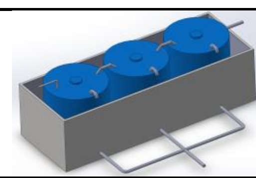
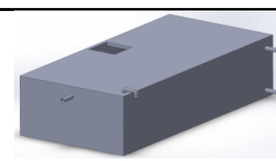


Figure ES.1. Overview of proposed designs at the San José Academy

***Water Storage Tank***

The largest design component for the project was the water storage tank located on the training grounds (shown in red in Figure ES.1). The proposed designs for the water storage include three options: a below-ground plastic tank system, a below-ground concrete tank, and an above-ground plastic tank system. Dimensioned SolidWorks models of each design were given to the Bomberos. A comparison of the designs can be seen in Table ES.1 Each design choice would provide a 17,436 gallon storage capacity, surpassing the average amount of water needed, 14,7000 gallons, for a month of training. All tank-system options have inlets with valves to control water flow from the sediment filter, outlets with proper connections for fire trucks, air tubes which act as a pressure relief and ventilation system, an opening for maintenance access, and an overflow pipe which would redirect water to an existing overflow canal structure. We also created a safety and maintenance plan for each design to align with the Bomberos' objectives and prevent misuse.

Table ES.1: Comparison between possible tank system designs

| Feature | Above-Ground System (Plastic) | Below-Ground System (Plastic) | Below-Ground System (Concrete) |
|---|---|---|---|
| Models |  |  |  |
| Height of Tanks Above-ground (m) | 3.65 | 0.5 | 0 |
| Length without connections (m) | 9 | 10.3 | 8.25 |
| Width without connections (m) | 3 | 3.76 | 4 |
| Approximate Cost (colones) | ₡7.081.043 | ₡7.818.243 | ₡1.690.646 |
| Approximate Cost (dollars) | $12,533 | $13,933 | $3,088 |
| Other Requirements | Needs a pump | None | None |

***Sediment Filter***

To limit contamination in the stored water, we designed a sediment trap in the form of a settling tank that filters water before it reaches the tank system (shown in blue and red in Figure ES.1). As water flows through the sediment trap, there is time for the natural separation of contaminants based on their density. We chose to design our own sediment filter to have the appropriate capacity to filter the amount of water required at a reasonable cost (Figure ES.2).

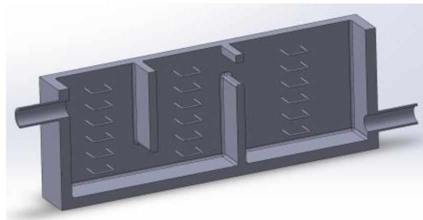


Figure ES.2 Sediment Filter Model

***Water Recycling System***

To maximize the collection of expended water for recycling, we designed an improved version of the Academy's current drainage system for collecting runoff water in the Training Plaza (shown in black in Figure ES.1). The design calls for the addition of a concrete capture surface and a grate screen covering the drain area as a preliminary filtration system for large contaminants and safety measure (Figure ES.3). The proposed structure would redirect water toward the current drains. For the Training Tower and Training Plaza we also proposed adding pipes to redirect the expended training water to the storage tank system (shown in yellow in Figure ES.1).

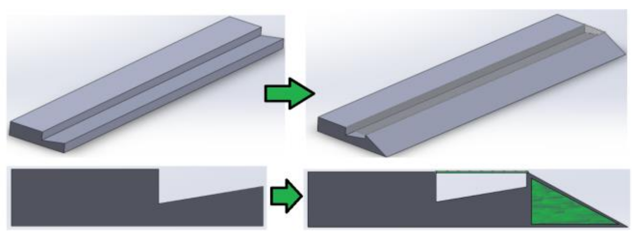


Figure ES.3 Proposed addition for water recycling system on Training Plaza

***Rainwater Harvesting System and Water Conveyance Systems***

Much of the rainwater harvesting infrastructure already existed at the facility, thus we only proposed downspouts, gutters, and drains for the Search and Rescue Building (shown in purple in Figure ES.1). Additionally, we proposed new piping from the three buildings (shown in yellow in Figure ES.1-) to direct the collected rainwater to the sediment filter and storage tank system (shown in red and blue in Figure ES.1).

***Material Cost Estimates***

The ability to implement the proposed designs requires that the Bomberos have funding for the material costs in addition to installment and future maintenance costs. We thus included material cost estimates for each proposed design with prices from local vendors as seen in Table ES.2 below.

Table ES.2: Estimated material costs for each design

| | **Tank: Below-ground Plastic** | **Tank: Below-ground Concrete** | **Tank: Above-ground Plastic** | **Sediment Filter** | **Rainwater Capture System** | **Water Recycling System** |
|---|---|---|---|---|---|---|
| Colones | 7.818.243 | 1.690.646 | 7.081.043 | 212.134 | 341.800 | 2.330.515 |
| Dollars | $13,933.17 | $3,087.87 | $12,532.82 | $375.46 | $604.96 | $4,124.80 |

Based on the amount of money that the Academy annually spends on water and spaced over a 20-year lifetime of the proposed systems, the designed systems could save the Academy over $6,000 on an annual basis with an approximate return on investment (ROI) of 3 years.

## Additional Recommendations

### *Construct a Second Rainwater Harvesting System*

Upon analyzing the roofs in the Administration Area of the Academy, we discovered there was 1435$m^2$ of roof area with already-established infrastructure to collect rainwater. Using this information and the average rainfall data for San José, we determined that almost one million gallons of rainwater could be captured on an annual basis from the roofs in the Administration Area. If the Bomberos take full advantage of all available water, they could expand their training schedule to include more water trainings, or the non-potable water could be used for other purposes, including washing floors and fire trucks or for sanitary services. We developed three general concept designs for possible tanks and a sediment filter to be located in a large, open area available behind the Administration Area.

### *Implement an Additional Water Recycling System*

To maximize the efficiency of water collection on the Training Tower area, we recommended replacing the gravel area with sloped concrete leading down to long sections of grates. The grates used would be similar to those already in place around the Training Tower. With both modifications, larger quantities of training water would be recaptured.

### *Install Water Contamination Prevention Measures*

Currently the Bomberos initiate some training fires using diesel and gasoline, which contaminates the water. We recommend that they purchase an oil-water filter to complement the sediment filter, or that they start fires using propane torches to avoid contamination since the gas from the torch and water would not mix.

## Future Project Implications

With an implemented, sustainable water system, the Academy will be able to meet its water needs for trainings and potentially expand training practices. With changing climate patterns and growing water scarcity around the world, we see a potential for similar projects in other fire departments or facilities with high water use. While visiting the fire station in Pacayas for interviews, we discovered the directors were interested in a similar water storage and rainwater collection system. This interest stems from the high quantity of annual rainfall that is currently unused, and the tensions created between the community and firefighters when they use municipal, potable water supplies during trainings. While many of the general recommendations can be applied to individual stations, specific designs or qualitative analysis will vary by location, depending on rainfall patterns, training facilities, and training activities. Although specific to the San José training Academy, we hope the general recommendations and detailed procedures can be used to undertake future projects.

# Authorship Page

**Abstract:** Kelly Vodola
**Executive Summary:** Kelly Vodola, Kerry Muenchow
**Introduction:** All
**Background:**

- **El Cuerpo de Bomberos:** Kerry Muenchow, Theodore Vangos
- **Training Practices and Water Use in Training:** Talon Boie, Kerry Muenchow, Kelly Vodola
- **Observation of Massachusetts Firefighting Training Academy:** Talon Boie, Kerry Muenchow
- **Water Access and Regulation in Costa Rica:** Kerry Muenchow
- **Rainwater Harvesting Design Components:** Kelly Vodola
- **RWH for use in firefighting:** Kerry Muenchow
- **Water Re-collection and Recycling:** Theodore Vangos
- **Contamination of Water:** Kelly Vodola

**Methodology:**

- **Gauge the Project Impact and Motivations of Stakeholders:** Kerry Muenchow
- **Understand Water Practices Used in Firefighting:** Talon Boie, Kerry Muenchow
- **Analyze the Existing Infrastructure:** Kelly Vodola, Theodore Vangos
- **Develop a Water-Use Model:** Theodore Vangos, Kelly Vodola
- **Design an Integrated Water Collection and Storage System:** Kerry Muenchow

**Findings and Analysis:**

- **Project Impact and Motivations of the Stakeholders:** Kerry Muenchow
- **Water Practices Used in Firefighting:** All
- **Existing Infrastructure:** Kelly Vodola, Kerry Muenchow
- **Model for Water Use and Availability:** Kerry Muenchow, Kelly Vodola
- **Integrated Water Collection and Storage System:** All

**Deliverables and Proposed Designs:**

- **Water Availability and Use Model:** Kelly Vodola, Kerry Muenchow
- **Water Storage Designs:** All
- **Rainwater Harvesting System Design:** Kelly Vodola, Kerry Muenchow, Theodore Vangos
- **Water Recycling Design:** Talon Boie, Kerry Muenchow, Theodore Vangos
- **Material Cost Estimates for Designs:** Talon Boie

**Recommendations:**

- **Rainwater Harvesting System:** Kelly Vodola
- **Recycling System:** Theodore Vangos
- **Additional Recommendations:** Kelly Vodola

**Conclusion:** Kelly Vodola, Kerry Muenchow
**Appendices:** All

**All sections edited by entire team**

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# 1.0 Introduction

Costa Rica is often hailed as one of the most sustainable and environmentally-friendly countries in the world. In 2013, Costa Rica was recognized as the second-best country in balancing environmental sustainability with politics, society, and economics by the World Energy Council Energy Trilemma Index (Omega, 2018). While there is a great focus on sustainability, public safety should remain at the forefront of any policy or practice. As public safety personnel, firefighters undergo hours of training to prepare for all types of emergencies at any moment. In 2002, the fire department of Costa Rica, (El Cuerpo de Bomberos de Costa Rica), constructed a training Academy, La Academia Nacional de Bomberos, (The National Firefighter Academy). The Academy offers dozens of courses and highlights numerous simulators and on-site structures for firefighter training (Bomberos Academia: Historia, 2017).

While this program is widely beneficial in providing hands-on experiences for Costa Rican firefighters, trainings have a very high water demand, which stresses city resources. All the water used at the Academy is potable (drinkable) water coming from the San José municipality water supply. Water of a potable quality is unnecessary for training practices, and high use of the municipal potable water supply often prompts disagreements within the local community. The high water usage at the training Academy not only contradicts Costa Rican values of environmentally-friendly practices, but can additionally delay the training schedule as long periods of time are required to recharge the water supplies between training activities. This waiting period impacts the ability of firefighters to fully take advantage of the resources at the training Academy, adversely affecting public safety.

Rainwater harvesting (RWH) and water recycling are economic and environmentally-conscious ways to fulfill water demands from uses ranging from single-family homes to industrial facilities. A typical rainwater capture system is a series of gutters attached to roofs which collect the water and feed it into a series of tanks. The rainwater capture system is a potential method to increase the amount of water available at the training Academy as it productively utilizes water that would otherwise go directly to storm sewers as runoff. Rainwater collection at the Academy would take advantage of the rainy season in Costa Rica. Collecting rainwater for use in firefighting training activities is a sustainable and feasible option in San José, where an average of 3000 mm of precipitation fell annually between 1901-2015 (World Bank Group, 2017). While there is a large amount of information available regarding the use of rainwater harvesting for potable purposes and agricultural use, there is little research addressing water usage during firefighter trainings.

Another aspect of increasing the sustainability of water use at the Academy is recycling and reusing water expended during training exercises. A water recycling system includes a collection system, network of pipes, sediment traps, a storage tank for recollected water, and safety measures necessary for all the designs. Implementing a storage tank for already-spent water comprised of sediment traps, proper piping, and appropriate safety procedures, would greatly increase the sustainability and safety of the firefighting Academy, and fulfill a portion of the high water demand with recycled water.

Our goal was to work with the Bomberos to design an integrated water collection and storage system including a rainwater capture and water recycling system that safely and sustainably addressed their water demands for training. Understanding the potential impact of these systems on stakeholders at Academy was essential. The integrated water collection and storage system consisted of two focuses to alleviate the water concerns of the training activities. The first was to sustainably increase the total amount of water available at the training site through rainwater capture and storage. The second was recycling and reusing the water expended during training exercises. A collection network for rainwater and spent water will eventually allow for more frequent use of fire fighting equipment and prevent possible disruptions in the training schedule at the San José Academy. This project not only increases the sustainability of training operations, but also demonstrates a greater understanding of water needs for firefighter training.

# 2.0 Background

This chapter provides a brief overview of El Cuerpo de Bomberos in Costa Rica, firefighter training practices at the San José Academy and abroad, rainwater harvesting systems and their previous implementation for firefighting, water recycling system designs and their current use at other firefighter training facilities, and separation of fire accelerants from water supplies.

## 2.1 El Cuerpo de Bomberos

The Costa Rican Fire Department was officially organized in 1865. With volunteer and salaried firefighters located at 76 stations throughout the country, the Bomberos play a vital role in local communities across the nation. Annually, the Costa Rican Fire Department responds to over 50,000 emergency calls. These emergencies include a number of fire-related incidents: structural fires of houses or buildings; fires on public and private properties (including mountainous regions or landfill sites); fires on boats, aircrafts, and motor vehicles; and situations involving hazardous materials (Volunteer BaseCamp, n.d.).

The central training Academy in San José houses training and operations directors in addition to providing numerous training courses to firefighters and members of the public. In 2017, the training center advertised 29 courses for firefighters and support staff in addition to nine courses open to the public. The courses open to the public include training business leaders how to defend their property against fire while promoting environmentally-friendly, sustainable practices at these companies. The Academy participates in the Blue Flag (Bandera Azul) sustainability program which was “founded with the purpose of improving education and information regarding the environment. Since then [Bandera Azul] has been helping to promote the protection of the natural surroundings and increasing public knowledge in this regard” (Delfina Travel Group Inc, 2018).

The training facility is equipped with classrooms, simulators, buildings, and cars for practice rescues and training (Bomberos Academia, 2017). The training Academy was established in 2002 when a new law, allocating 4% of the first payment of every new insurance plan purchased in the country to the firefighters, boosted funding for the Costa Rican Fire Department (Volunteer BaseCamp, n.d. ).

Figure 1: Aerial photograph of the National Training Academy (Norman Chang, 2017)

The layout of the Academy is predominantly separated into two large sections: the training grounds area and the academic buildings. The training grounds area consists of five large scale training constructions. The largest training building is an eight-floor, concrete tower (Training Tower) used by the Bomberos to practice general firefighting techniques in tall buildings with sprinkler systems, and repelling and climbing buildings. Next to the tower is a large cement training pad with a raised, concave wall on one side (Training Plaza). This area is mainly used for practicing proper equipment use such as operation of fire hoses. A wooden maze is sometimes placed on the concrete training pad to practice transporting the hose through tight, confined spaces. There are also two buildings, each two floors tall, South of the tower that are used to practice search and rescue exercises and navigation in buildings full of smoke (Search and Rescue Building and Smoke Building). Additionally, there is a structure that resembles the grid of multi-floor building with adjustable walls that can be set-up in any configuration, allowing firefighters to practice different scenarios in a single building. An overview of the Academy infrastructure can be seen in Figure 1 above. While these structures are all used to train for firefighting, there is little to no actual fire used in the training exercises themselves.

The academic buildings consist of several classrooms that are all within close proximity to one another (red-roofed building cluster in Figure 1 above). Next to the classrooms is the Administration Building, which holds the offices for all the instructors and coordinators. Except for two covered walkways connecting the Administration Building to the classrooms and the

Search and Rescue Building, all buildings have gutters, downspouts, and drains. There is a strong capacity for rainwater harvesting at the Academy because of this already in-place infrastructure.

In the training area, there are various dirt areas where water runoff has cut through, suggesting the lack of drain efficiency to collect water used in training exercises used in this area. The Academy grounds are still growing, with plans to construct a new, 3-story building at the Academy for more office space and more classrooms. This building is projected to have a rainwater harvesting system and a network of 6 hydrants (Norman Chang, sub-director of Academy). Full notes and pictures of the Academy and structures can be found in Appendix A.

The Academy typically runs up to thirteen trainings per month. Similar to practices in the United States, trainings include simulated structure, car, and dumpster fires in addition to specific equipment testing. Currently, the Academy uses potable water from the San José municipal water supply for trainings with water, supplemented from an on-site well and water trucked in from other, nearby stations. Except for the well water, all water used in trainings is from potable, municipal supplies.

One of the unique aspects of El Cuerpo de Bomberos de Costa Rica is that the phrase "protection of the environment" is mentioned in both their Mission and Vision statements (Bomberos Misión, 2017). The commitment of the fire department to protect the environment directly through fire prevention and extinguishing in addition to indirect protection by implementing water conservation practices in training exercises aligns with the environmentally-conscious mindset of Costa Rican policy and culture.

## 2.2 Training Practices and Water Use in Training in San José and Abroad

Training for emergency response personnel is essential to ensure preparedness in high-stakes situations. Simulated structure fires, car fires, dumpster fires, and rural fire port-a-pond practices (as used in forest fire simulations), are common types of trainings undergone by firefighters to prepare for emergency situations. These trainings usually include a classroom segment and a practical, where firefighters receive hands-on experience fighting fires in controlled situations. In addition to simulated fires, equipment trainings use water to teach firefighters how to appropriately operate pumps, hoses, and other equipment. All of these trainings are essential for firefighter knowledge, yet require large amounts of water.

Specific water use during trainings is often determined by the equipment used in each type of training. According to Kurt Muenchow, 12-year veteran of the Inter-Canyon Fire Rescue Department in Conifer, Colorado in the United States, rural-setting fire simulation trainings typically use the largest amount of water, as port-a-ponds with a ten thousand gallon capacity are used to store water where hydrants are not available. In the case of urban-setting structure, vehicle, and debris fires, water tanks on trucks are used, limiting the water use per training to 500-600 gallons (Muenchow, personal communication, November, 2017). According to Paul Vodola of the Greenwich Fire Department in Greenwich, Connecticut, water-use during typical firefighter trainings can total between 1000-18000 gallons per minute depending on equipment use. Different types of trainings result in various contaminants running into the spent water. If wood or hay is burned, the spent water will contain a large amount of particulate matter. If a vehicle is burned in training, the contaminants can negatively impact water quality, including derivatives from plastic and rubber products (Vodola, personal communication, November, 2017). In the United States, firefighters are usually required to undergo training in each of these specific scenarios on an annual basis. Depending on the requirements for each station and the number of firefighters who need to undergo each of these trainings, the water-use throughout a year is incredibly high at training facilities.

The Cuerpo de Bomberos in Costa Rica offers a number of training courses that include on-site simulations which require water-use. Courses like 'Control Principles of Fires' and 'Brigade Rescues' are open to the public and include hands-on training at the Training Academy (Bomberos Captación, 2017). For salaried and volunteer firefighters, there are different, more specific training courses. Groups of 24 Bomberos take two courses per year, each course lasting between two and five days. According to the National Fire Academy's training coordinator, Allan Rodríguez, the average amount of water used on a typical day of training exercises is about 3,000 gallons. However, some exercises require much more water than others. Training exercises that have the highest demand for water include search and rescue exercises, fire hose practice, and large simulated fires on the tower. In search and rescue exercises, a labyrinth-like building often has fires that must be put out in the context of a simulated human rescue. In fire hose practice, firefighters shoot water at a large, convex concrete wall. Large simulated fires, shown in Figure 2 below, involve the largest fires in training.

Figure 2: Image of a Principle Control of Fires training (Bomberos Servicios, 2017)

## 2.3 Observation of Water Management Practices at Massachusetts Firefighting Academy

To become familiar with training practices that involve water and to see a system that we could possibly adapt to fit the technical and financial needs of the Bomberos in Costa Rica, our group visited the Massachusetts Firefighting Academy in Stow, MA.

### 2.3.1 Training Activities

The Massachusetts Firefighting Academy (MFA) conducts trainings at two locations: Stow and Springfield, Massachusetts. In order to gain a better understanding of typical firefighting training activities involving water, we visited the Stow campus of the MFA. According to the Deputy Director of the firefighting Academy, Joseph Klucznik, recruit training programs are run 5 days a week, all year long. Programs begin with classroom segments on fire safety and progress into rigorous fire simulation exercises. These simulations include but are not limited to fires involving: a four story burn building, a dumpster prop, and car props (See Appendix B). These simulation exercises are used to teach proper equipment use and safe fire-fighting methods. However, to ensure that these exercises are as realistic as possible, there are often intense fires which require a large amount of water to be extinguished (Klucznik, personal communication, December, 2017).

### 2.3.2 Facility Logistics of MFA

In order to conduct the numerous training exercises involving water, the Stow facility utilizes a 44,000 gallon concrete water tank coupled with a multi-step water recycling system. The largest use of water takes place during the burn building exercises. To accommodate these needs, the building is equipped with scuppers that allow water to cascade down the building and onto the asphalt. From here, the water flows to drains located around the campus. Once collected, the water is treated, sent through sediment filters and cycled back to the main tank for later use. According to Klucznik, about 75-80% of the water is reclaimed in the process and saves thousands of extra gallons from being pulled from the reservoir across the street. Our group was able to observe the entire process during our visit to the facilities. Notes and pictures can be seen in Appendix B.

## 2.4 Water Access and Regulation in Costa Rica

Roughly 81% of the Costa Rican population has access to potable water through the public utility, and 92% have access to sanitation services (Fondo del Cooperacion de Agua, n.d.). Water-use in Costa Rica is regulated under the Ley de Agua No. 276 (Water Law No, 276), established in 1942 (Paniagua, 2015). The law defines that surface and groundwater is publicly owned and allocated for use through a series of “entitlements”. Water and sanitation services are provided by the national utilities organization, the Costa Rican Institute of Aqueducts and

Sewers (Instituto Costarricense de Acueductos y Alcantarillados), which charges for water on the basis of quantity of use. The current price is 1.6 colones ($0.0028) per cubic meter (264 gal) of water, although this price is dependent on the type and frequency of use. The largest water use throughout Costa Rica is agriculture, accounting for 71% of water in the country (OECD, 2015). In rural areas, rainwater is often collected and used for agriculture, cooking, and occasionally drinking for individual families.

In recent years, with El Niño conditions, there is a greater push to use rainwater as an alternative water source. El Niño is the part of a cyclic pattern during which the Pacific Ocean has surface temperatures much higher than normal, greatly affecting local weather patterns (NOAA, 2009). In the case of Costa Rica, these events cause droughts, especially along the northern coast of the country (Sarouhan, 2015). Rainwater collection is not regulated in Costa Rica, encouraging individuals to build their own systems. Costa Rica also sends representatives to participate in regional conferences about rainwater harvesting and learn how to most effectively implement the practice in Latin America (Paniagua, 2015).

## 2.5 Rainwater Harvesting Design Components

Rainfall feeds rivers, lakes, and groundwater; secondary water sources on which humans depend for their water needs. A primary source of water, rainwater, is often overlooked and has untapped potential. Rainwater collection takes advantage of natural precipitation and has been used for thousands of years. Rainwater harvesting systems are most commonly found in agricultural irrigation practices and residential areas around the world (Kinkade-Levario, 2007). One of the most important aspects to consider is safety, as each part of the harvesting process has the potential to contaminate the water or cause problems with equipment degradation.

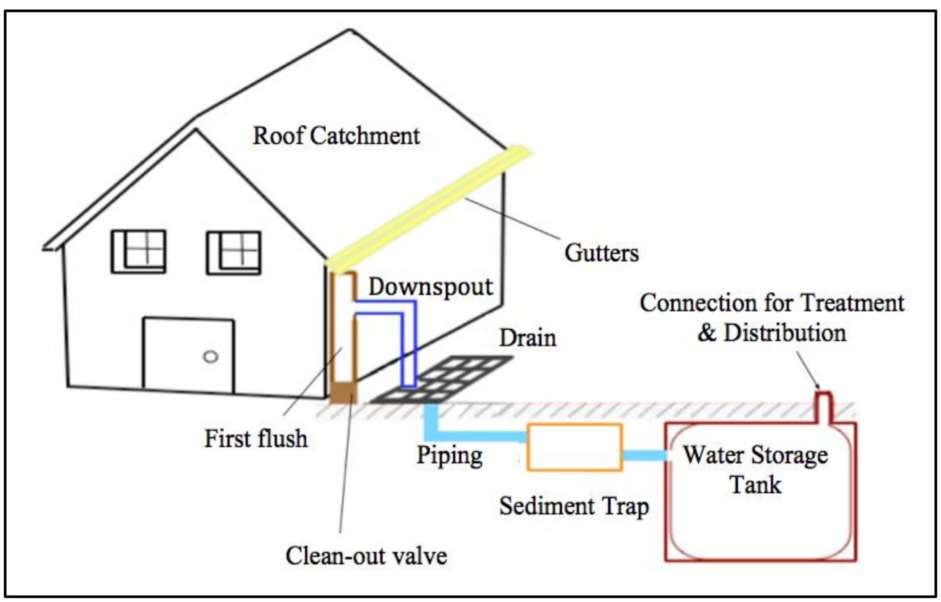



Figure 3: Schematic of basic RWH system components (Vodola, 2018)

### 2.5.1 Wet Rainwater Harvesting Systems

For the number of surfaces available to collect water on the training Academy campus, a 'wet' rainwater harvesting system is more efficient as it allows for a greater storage capacity. A wet system involves a network of underground pipes to connect downspouts from different locations and convey this water to a central tank or collection basin. Vertical pipes are needed for the water underground to eventually spill into storage tanks. Wet systems increase the surface area for water collection and allow for the tank to be in any location, but this can be expensive depending on the volume of collection desired and has potential for various maintenance complications (Innovative Water Solution, 2009). Typically, a method of freeze protection should be included within protocols for the conveyance, but San José rarely experiences temperatures that would merit these precautions. There is a risk of bacterial growth in stagnant water that sits in the storage containers for rainwater harvesting systems, so biofilms or a mixing apparatus are often incorporated if the water is not continually in movement (Kinkade-Levario, 2007).

The basic components of a wet rainwater harvesting system; a catchment surface, conveyance system, roof washing, storage tank, distribution, and treatment are described below. Figure 3 above shows a basic schematic that includes all of these components and their typical locations.

### 2.5.2 Catchment Surface

Roof catchments are the simplest for rainwater harvesting (Kinkade-Levario, 2007). The catchment surface should not be made of wood shingles or lead-containing metals to avoid harmful contaminants. Suggestions for the material are asphalt shingles or metal. The slope of the roof is also important because a steep roof sheds runoff more quickly and lessens the risk of contamination (Texas A&M, 2017). Any surface with a slope exposed to the elements can also function as a rainwater capture surface.

### 2.5.3 Conveyance systems

The conveyance system is comprised of gutters and downspouts that move water to the storage tanks. The sizing of these pipes and proper installation are important factors (Texas A&M, 2017). Gutters and downspouts are easily obtainable, as they are standard household construction materials. Gutters should have a square, rectangular, or half round shape and be at least 5-6 inches wide. Their outer edges should be taller than the roof's edge and they should contain splash guards to prevent water loss. Gutters should "slope towards downspouts at one-sixteenth to one-quarter inch per 10-foot length of gutter" (Kinkade-Levario, 2007, p.38). Gutters feed into downspouts. Downspouts with a 1-inch diameter should be able to drain approximately 100 square feet of roof area.

Methods to determine gutter and downspout sizing can be found in International Plumbing Code, by the International Code Council (ICC), or other reputable sources (Novak, Giesen, Debusk, 2014). To help contribute to a long lifespan and efficiency of the gutters, they should be kept clean. Leaf screens made of mesh wire help reduce debris and mosquito inhabitants, and time required for maintenance (Kinkade-Levario, 2007).

### 2.5.4 Roof Washing and Contaminant Prevention

Roof washing refers to designed systems that remove contaminants and debris from the rainwater. Some examples of this include first-flush filters and sediment traps. A standpipe water diverter is a simple first flush device that must be emptied after every rainfall event. Sediment traps are key components in rainwater harvesting systems that prevent debris and dirt from entering the water supply (Kinkade-Levario 2007). The initial rainfall will wash debris and pollutants into the harvesting system because it comes into contact with the catchment surface first, and later rainfall will contain cleaner water. Sediment traps help separate the initial water that contains sediment from the less-contaminated water and are often used for large-capacity, rainwater harvesting systems. The specific design depends on the capacity of the rainfall collection system. Residential sediment traps involve a small holding tank to trap the debris (OnlineTips, 2017).

Gutter leaf screens and downspouts also contribute to keeping rainwater free of dirt and debris by preventing entry of large contaminants. A downspout contains a self-cleaning piece called a rain head. Rain heads are square funnels with screens set at angles that force debris towards the screen's lower edge (Kinkade-Levario, 2007). Small particles in the water are dangerous because they can wear down pumps and hoses and cause ruptures during training activities.

Basket filters are an inexpensive and easily installed filtration method. They sit in the access-way of a storage tank to prevent anything sizeable from entering (Novak, Giesen, Debusk, 2014). Pre-storage treatment cleans rainwater before it enters the storage tank and can be achieved by screening. Post-storage treatment depends on the intended usage of water. For example, water intended for fire protection would need fewer stages of treatment than water intended for consumption (Texas A&M, 2017).

### 2.5.5 Storage Tanks and Associated Safety Measures

The storage tank must include a rainwater inlet. The water can enter from top, side, or bottom of the storage tank, and there must be pressure relief ventilation for incoming water. Especially if the tank is filled using a pump, if the pressure becomes too great, the tank can begin to crack or even break apart entirely, potentially causing serious injuries to people surrounding it (Friedman, 2016). A water level indicator is often used to monitor water level within the tank and communicate that information to a centralized location. An overflow system is designed to allow excess water to flow to an appropriate pathway for proper reuse or further storage (Novak, Giesen, Debusk, 2014).

The storage tank should contain non-hazardous water and be made out of a secure material to prevent any accidents. The opening should be large enough for easy access but have a water tight cover with a lock to avoid any accidents with children, non-authorized personnel, or animals in the nearby area. Inlets and outlets should also have screens and valves that can permit control of water flow and stop flow when people are working on maintenance of the tank. For extra safety measures, an inline flame arrestor can be installed. This is a section in a pipe containing a wound, crimped, metal ribbon-type flame cell element which would stop any possible flames from entering the tank in case any petroleum or gasoline entered with the water (EWP, n.d.).

Since the Bomberos use thousands of gallons of water per training exercise, the designed tank must have a large capacity. Water storage tanks at other fire stations range in volume from thousands to millions of gallons.

Common materials used are concrete, stainless steel, or coated steel to withstand the pressure the of the water on a full tank (National Fire Protection Association, 1998). The storage tank material should be non-reactive and non-corrosive. Concrete is a strong material that can withstand high pressures and has a lower risk of biological growth buildup in comparison to plastic tanks. Concrete can be buried underground, which typically occurs with larger tank installations for aesthetic and safety reasons. Concrete is an effective underground tank choice because the material reduces problems of wall deterioration from contact with soil. The walls of the cistern should be approximately four to six inches thick (Bucklin, 2009). Concrete is susceptible to cracks and leaks, but this damage is reversible with preventative equipment. There should be an easy mechanism to drain the tank for quick repairs in the case of cracking. If cracking is a continuous issue the user may want to consider a plastic liner, which can be expensive. Another maintenance precaution involves washing the cement every few years to counteract lime in water. A disadvantage of concrete is its inadaptability once it cures. Due to this property, the inlet cannot be easily altered, and it would be difficult to add additional pipes in the future. Plastic tanks are typically polyethylene and are lightweight and easy to install. Plastic tanks can withstand earthquakes and other natural disasters more easily than concrete because of its flexibility. The main upkeep for plastic tanks involves cleaning sediment buildup on an annual basis (Promax, 2017).

### 2.5.6 Conveyance and Treatment

Conveyance refers to the devices utilized for moving water from its storage tank to the ultimate intended location by gravity or pump. With long distances, energy loss due to friction is an important variable to take into consideration. (Texas A&M, 2017).

Treatment of water is part of the post-storage treatment process. Some potential contaminants include gross pollutants, sediment, oil and grease, nutrients, pesticides, bacteria, dissolved metals, and mercury (Novak, Giesen, Debusk, 2014). Typically, treatment of water involves a second round of filtering and in some cases, distillation and additives, are needed to disinfect the rainwater. Since firefighting training only requires non-potable rainwater, many of these additional treatment precautions are not necessary.

### 2.5.7 Cost Analysis

Pricing depends heavily on the size and quality of the material of the component. Different roof washers are available for different flow capacity requirements and roof washers that require less maintenance tend to be more expensive. The starting price for these is typically around $500 (Plum Creek, 2006).

The tank is the most expensive part of the harvesting system. One type of storage tank is made of fiberglass. This cost-effective option is about $6000 with resins approved for potable water storage (Plum Creek, 2006). Steel tanks call for a concrete base. Fiberglass, plastic, and concrete tanks do not need this liner. Concrete tanks are estimated at a price range between $0.35 to $1.50 per gallon it holds. Fiberglass tanks are typically $0.50 to $2.00 per gallon, polyethylene tanks from $0.5 to $1.90 per gallon, and metal galvanized steel tanks from $0.30 to $2.79 per gallon (Kinkade-Levario, 2007). Concrete and polyethylene tanks are the most common types found in Latin America due to low cost and wide availability.

When selecting gutters, the best option is the thickest metal available composed of primary materials. Thin and cheap materials are easily damaged or corroded. Galvanized steel gutters are a strong economical choice, but they rust faster and are weaker than the more expensive stainless-steel gutters (Kinkade-Levario, 2007). Galvanized steel in the United States is priced between $4-$8 per linear square foot, while stainless steel gutters are about $20 for the same distance (Kompareit, 2017). Plastic gutters are often those found and used throughout Latin America for a lower price. Pump costs depend on the length of distance and the efficiency of movement. The price for a basic pump with a pressure tank is roughly $500 (Plum Creek, 2006).

Improper filtration can be a safety hazard, so these devices should not be neglected. A disposable sediment filter is only $3, but it must be changed monthly. Meanwhile, a charcoal filter is priced at $10 and must be changed every 3 months (Plum Creek, 2006). First-flush devices should have a volume of 10 gallons per 1000 square feet of roof area it covers. After rainfall, contaminated water must be drained either manually or automatically from the device. Once a year, someone will need to evaluate for sediment and debris content and remove the contaminants if any are present (Kinkade-Levario, 2007). This maintenance will help lower the risk of unforeseen replacement or restoration costs. A 3" diameter first flush diverter is around

$30 and the chamber section is around $25 per foot (and a foot can store 6 gallons with a 12” diameter) (Rain Harvest Systems, 2017).

For water recycling, sediment trap prices range depending on excavation processes and the sizing. Without excavation costs considered, the total price range is between $600 and $1500 for the underground structures. For large sediment traps that require earthwork contractors to be involved the price may be more between $1500 and $5000. Earthwork costs are about $3 for every cubic yard of excavated soil (Yolo County Resource, 2017).

### 2.5.8 Rainfall Trends in San José

San José experienced consistent rainfall patterns over the past six years. The trends consist of low rainwater totals in the first third of the year, immense amounts in the middle third of the year, and lower amounts in the last third of the year. Rainwater harvesting takes advantage of the rainy season, May through November, in Costa Rica. As shown in Figure 4, the Climate Research Unit (CRU) of University of East Anglia compiled mean monthly historical rainfall and temperature data in San José, Costa Rica during the time period of 1901-2015. The data show that October is the wettest month in San José, receiving 410 mm of water on average (World Bank Group, 2017).

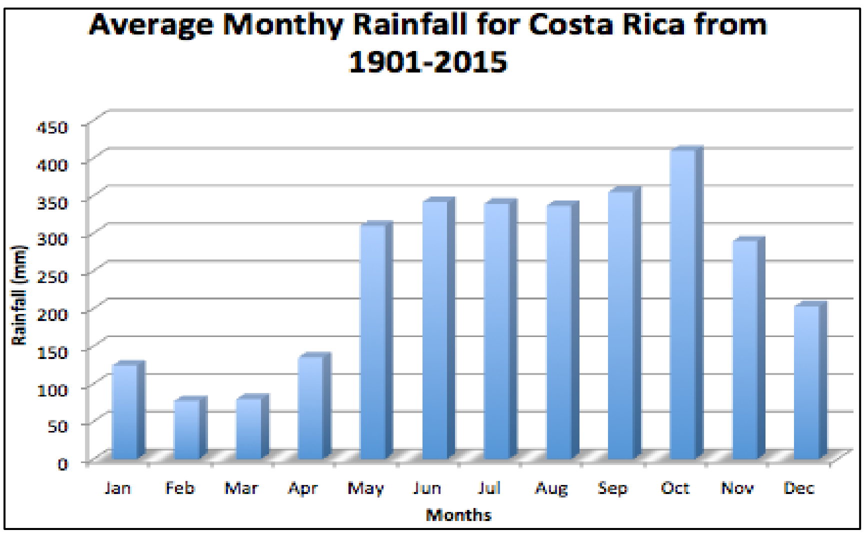



Figure 4: Average monthly rainfall totals for Costa Rica (World Bank Group, 2017)

Rainfall is unpredictable but analyzing the data from past years suggests that installing the harvesting system is worthwhile and effective. In addition to the data from 1950-2015, other weather sources were evaluated to verify the accuracy of monthly averages and yearly annual precipitation. These sources confirmed an annual rainfall range between 2000-4000 mm in San José, and similar trends in wet and dry months to the data used in the water-use model (Climate-Data, n.d.; Costa Rica Guides, 2017). After this evaluation of rainfall, it seemed feasible to design this rainwater harvesting for a secondary water source for the firefighters training.

## 2.6 Rainwater Harvesting for Use in Firefighting

Rainwater collection systems are implemented worldwide for a variety of potable and non-potable uses, many of which include firefighting efforts. In areas where there is a shortage of water, these systems are often the only source of water available for use. In Costa Rica, there are areas with a surplus of water as well as areas in heavy drought conditions. By capturing the rainwater available during the rainy seasons in Costa Rica, the training Academy would be able to greatly reduce the high amount of potable water used for training purposes.

In 2015, the United States Forest Service concluded that the use of rainwater harvesting systems for fighting wildfires would be highly advantageous as it would improve accessibility to water closer to natural fire breaks. After three years of observing Chile's rainwater harvesting systems on their fire departments, Garcia and colleagues determined that these systems were an exceptional opportunity for minimizing firefighting costs. The project implemented cement catchments and proved that harvesting systems could be installed on clear, flat, and sloped areas. (Garcia, Valdes, Neary, and Pizarro, 2015). The fire department in Singapore uses water collected from rainwater harvesting on its Changi Airport for fire-fighting drills (UNEP, n.d.). Water catchment systems provide a sustainable source for processes or activities with heavy water use, particularly when potability is not a requirement for the use.

There is a growing focus on the use of rainwater capture in fire suppression systems and as reservoirs for use during fires. The U.S. states of Texas, Virginia, Georgia, and North Carolina released design guides and regulations for using rainwater harvesting to supply fire sprinkler systems (EPA 2013). In these cases, rainwater is collected from roofs and blacktop areas and directed into cisterns for storage. The cisterns are either directly connected to fire sprinkler systems or to hydrants for use in emergency situations.

No international codes or federal regulations in the US have been developed to address general use of rainwater, for example, in household or agricultural uses. However, rainwater used to supply sprinkler systems must adhere to the National Fire Protection Association 13 code due to dependence on water from an inconsistent source (Boulware, 2007). These specific regulations attempt to ensure that there is a sufficient amount of water available in the cisterns at any point to respond to a fire emergency, and that there are enough controls to prevent the backflow of the non-potable rainwater into the uncontaminated, potable supply (EPA, 2013). Although these limitations apply to rainwater harvesting systems connected to sprinkler systems and hydrants, the same limitations are not necessarily of concern with rainwater capture for training practices.

## 2.7 Water Re-collection and Recycling

### 2.7.1 Water Recycling Systems

Firefighting requires the use of large quantities of water over very short periods of time. While fires in emergency situations often involve a greater water use than that in training situations, the magnitude of each scenario remains relatively constant (Fry, Lustig, 1963). Most stations obtain their water for emergencies and trainings from outside sources such as lakes and reservoirs, often stressing municipal water supplies (Ghose, 2015). A possible water recycling solution is to implement an underground water catchment system for the area to which the water used in training flows. The most common and cost-effective water recycling design is to create an open volume slightly underground to capture the water that travels across that area. Once the water is caught in the artificial drain, it will run through a series of sediment traps, separating the large particles, then the small particles, ultimately leading to a large storage tank. These systems are commonly used to circulate the water for surrounding vegetation, but can easily be implemented for water reuse in firefighter Academy trainings. Once the water is cycled through the filters, instead of releasing it back into the environment, it can be stored in separate tanks and moved to the training facilities when necessary (Innovative Water Solutions LLC, 2009).

While there are other methods of water recycling that involve chemical cleaning and filtering with carbon bricks, the method of underground storage is the most practical for the Bomberos due to the low maintenance cost. This system does not require purchasing chemicals to upkeep the system, and there is a low time commitment for maintenance and operation of this recycling method. All methods of water recycling will enable the majority of the expended water to return to the system, resulting in its classification as self-supplying.

### 2.7.2 Sediment Traps

In order for any water recycling and recollecting system to properly operate, sediment traps must be used. If sediment is not separated from the water before it goes through a pump or hose, it will slowly erode the material it comes in contact with and require frequent replacement of equipment. The first and most common form of sediment traps are screens. These are barriers that are made up of mesh to catch physical particles of varying size while allowing water to flow through. The holes in the mesh vary in size throughout the system, starting with coarse screening (>40mm holes), moving to medium screening (40mm to 10mm holes), and ending with fine screening (<10mm holes) (Sookbirsingh, n.d.). After each screen, a system is setup to clear away the particles from the mesh. These systems can include a mechanical arm or can simply be an open area for the sediment to fall into. Another form of sediment filtration are flushes. While these are not always classified as traps, they are extremely important filters that help clean areas like rooftops when dealing with rainwater capture. First flushes allow for the initial particles and organic byproducts to be cleaned off the roof and not flow through the entire system (Rainwater Connection, n.d.).

The sediment traps used for recycling water are below-ground screens after the water inlet to the tank. These filters will prevent any solid substance in the water from traveling through the system, requiring few resources to maintain the recycling system. Nearly the entire capture system, including the inlet, sediment filters, and the pump, must be underground at a training facility to be out of the way of daily operations. Particles caught in the sediment traps should be separated into tanks that can be emptied and cleaned after extended period of time. For any type of water recycling or rainwater capture system, sediment traps are filters that utilize gravity to allow the natural separation of dense particles from water. This limits maintenance time and costs incurred from cleaning out sediment traps and waste storage tanks.

### 2.7.3 Example of a Water Recycling Module in Australia

A case study of a successful water recycling system is a module developed by for the fire departments in Australia. Beginning in 2008, intense droughts prompted a wide water conservation effort in the largest fire district in Melbourne, Australia. Due to droughts, the Metropolitan Fire Brigade designed and piloted a water recycling module for training exercises and implemented rainwater collection systems on their fire departments to lower water usages during the severe droughts (Metropolitan Fire Brigade, 2009). The water recycling module is a regulated pump which connects to a seven-thousand liter water storage unit. The module is transportable and is brought to individual stations around Australia for trainings (Smart Water Fund, n.d.). The initial analyses found this module saved 480 million liters of water per year (an equivalent of 48,000 U.S. dollars). In addition to reducing the amount of water expended during training, the Fire Brigade saved $12,000 on fuel by reducing the number of drives tankers had to make to obtain water from pumping stations (Smart Water Fund, 2012). Although prompted by a necessity to conserve water, the water recycling efforts show the feasibility and benefits.

## 2.8 Contamination of Water

Water collected through any process can easily be contaminated by outside sources, including dirt, organic matter, and gasoline. An understanding of possible contaminants and separation processes is important to ensure a cleaner water supply and maintain safety in the designed systems.

### 2.8.1 Separation of Gasoline and Diesel from Training Water

The Bomberos currently use one gallon of diesel and two gallons of gas to start training fires in the Search and Rescue Building and on occasion in the Training Tower. To recycle this water, there needs to be a system in place to assure the water does not contain dangerous amounts of contaminants that could possibly fuel the fire instead of suppressing it.

An option to separate oil from water is the PIG Oily Water Drum Filter from New Pig (Figure 5). New Pig Corporation is a United States-based company with international distributors in Central America. Their water drum design uses gravity to separate oil from water and has a flow capacity of eight gallons of liquid per minute. The drum filter includes a hose connection for draining of filtered water. The drum can also absorb up to 33 gallons of oil and users may purchase replaceable filters once the drum becomes full. (New Pig Corporation, 2018).

Figure 5: New Pig (n.d). *PIG Pour-Through Oily Water Filter*. Retrieved from https://www.newpig.com. Permission to reprint from New Pig Corporation.

## 2.8.2 Avoiding Contamination of Training Water

The Bomberos currently use diesel and gasoline accelerants, class B flammable liquids, to start training fires. However, this is not the only method available to begin these fires. Avoiding the need for separation of gasoline and diesel from water may be the easiest, safest, and most environmentally-friendly alternative to light fires. The Bomberos could instead use a propane torch with wood to start training fires. In this case, the gas from the torch would not mix with the water used to put out the fire because they are different states of matter. According to Paul Vodola, The Inferno Propane Torch Kit (Figure 6) could be used to start the training fires and is only about $50 from Home Depot, an international company with a location in Costa Rica. (Vodola, personal communication, January, 2017).

Figure 6: Home Depot (n.d.). *Inferno propane torch kit.* Retrieved from https://www.homedepot.com. Permission to reprint from Home Depot.

# 3.0 Methodology

Our project aimed to work with the Bomberos to design an integrated water collection and storage system including a rainwater capture and water recycling system that safely and sustainably address their water demands for training. Understanding the potential impact these systems had on training directors, station chiefs, and firefighters who undergo training at the Academy was essential. We intended to achieve this goal through five objectives:

1. Gauge the needs and motivations of the stakeholders for a water collection, recycling and storage system and gauge the potential project impact of stakeholders to ensure that the project appropriately fulfills the water needs for training at the Academy
2. Understand water practices used in firefighting abroad and in San José for the optimal system design
3. Analyze the existing infrastructure for rainwater collection, water recycling, and water use at the San José Academy
4. Develop a model of monthly water availability and use at the training Academy that considers annual rainfall quantities, and recycling potential in addition to use during training
5. Design an integrated water collection and storage system on the Academy grounds for rainwater and water expended in training exercises with a set of safety and maintenance procedures

We used information about the motivations and potential project impact to guide our design work and recommendations made throughout the process. Before creating useful designs, we needed to understand the quantity and quality of water needed for training at the Academy. For this reason, understanding the training activities and their water use was crucial for the project. The main deliverables for the project were designs for a rainwater harvesting system and a water recycling system at the Academy. For water storage, we proposed three tank designs from which the Bomberos could choose to best fit the needs of the Academy. To ensure the feasibility and usability of the designs, we presented design iterations to the Training Director at the Academy throughout the process, and re-designed based on their feedback. These system designs additionally included maintenance and safety plans to increase the system longevity. For each of the proposed designs, we provided a cost estimate to aid the Bomberos in their decision of which system to implement.

Overall, this project yielded system designs that sustainably addressed the water use demands of the stakeholders at the Academy. If implemented, there would be an increase in public safety as consistent access to water would enable more firefighters to undergo more frequent water trainings. The increase in water practices would result in firefighters better prepared to respond to emergency situations. To achieve our objectives we collected and synthesized information through a series of quantitative and qualitative evaluations to create appropriate designs as outlined below.

## 3.1 Gauging the Project Impact and Motivations of Stakeholders

In order to design effective and sustainable rainwater capture and water recycling systems, we needed to understand the wants and needs of the Bomberos at the San José training Academy. Assessing the motivations for the project ensured that our final recommendations and designs were useful for the Bomberos and could be easily implemented. The impact of the project was dependent on our understanding of why the project was proposed and the desired outcomes.

The stakeholders for this project were identified as the directors of the Academy, the station chiefs at individual fire stations around the country, and the firefighters who undergo trainings at the Academy. In San José, we conducted interviews with the main stakeholders of the project to assess their wants, needs, and limitations for a rainwater collection and recycling system. We interviewed three directors of the Bomberos: Ronny LaTouche (director of the National Fire Academy), Allan Rodriguez (classroom and training coordinator), and Norman Chang (sub-director of the Academy), to gain critical information about their motivations for the project. Interviewees also included three station chiefs, three salaried firefighters, and one volunteer firefighter from both the fire station in the city of Cartago and from a fire station in rural Pacayas. These interviewees were a sample of station chiefs and firefighters who undergo yearly trainings at the Academy.

Interviews included questions about personal viewpoints on sustainability and water use in Costa Rica and about the importance of these themes for the Bomberos as an organization. From these questions, we learned about the values of those in charge of the training Academy to better understand why this project was proposed. We also learned about the values of those who undergo the trainings to determine if perspectives on water sustainability were commonly shared and to ensure our designs aligned with these. After learning about the motivations for the project from interviews, we were able to design specific goals and objectives for the final deliverables. Information from these interviews helped us make culturally-appropriate and practical design recommendations that the stakeholders were comfortable with. Individual interviews enabled the team to understand the perspectives of the firefighters with relation to how a system may affect their trainings. Additionally, information gathered during these interviews ensured feasibility of the project as we learned how future managers and users of a system would be affected. We also evaluated the willingness and ability of the Academy to operate and maintain our proposed systems. Specific questions for these interviews can be seen in Appendix C.

In understanding the needs of the Bomberos at the training Academy, we considered the impact of bias and external influences in evaluating information gained from interviews.

Especially in Latin America, it was important to remember cultural, non-combative tendencies. These tendencies lead to answers where the interviewee changes the subject, or provides a vague or uncommitted answer if there is something proposed that they do not agree with. We designed our questions to be more open-ended, which enabled us to identify any opposition to an idea without putting the interviewee in a position where they felt uncomfortable outright disagreeing. This was considered in the development of interview questions.

All interviews were conducted in Spanish and recorded for later translation. Notes were additionally taken during the interview by two team members. The team later listened to the recordings and transcribed and translated additional notes in English. Full notes from the interviews can be found in Appendix D.

## 3.2 Understanding Water Practices Used in Firefighting

To design a system that accurately fit the needs of the Bomberos, our group had to understand the practices involved in firefighting. Without a full understanding of the practices, there could have been misinterpreted design requirements and miscalculations that would have affected the success of the systems.

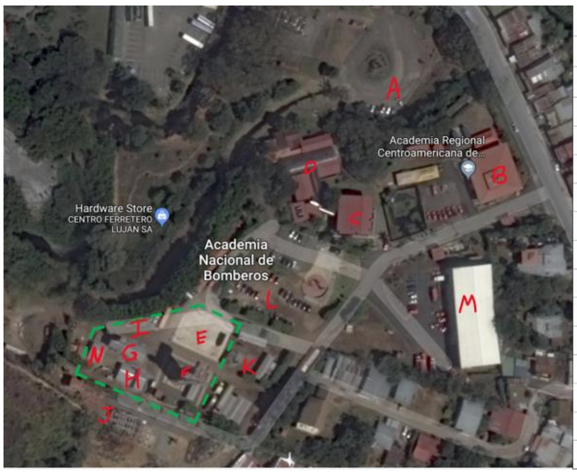
To better understand water use related directly to firefighting, interviews were conducted with training Academy directors and firefighter chiefs at both the Massachusetts Fire Academy in Stow, MA prior to our arrival in Costa Rica, and at the National Fire Academy in San José. By comparing training activities and facilities capabilities, we were able to adapt information and techniques utilized at the Massachusetts Fire Academy. We chose to interview the directors and chiefs as they typically have the most insights and experience. We asked questions that ranged from technical details of the training exercises to opinions on the most beneficial training exercises being conducted. We also developed a general schedule of the trainings from interviews in order to have an idea of the frequency of trainings at both academies.

At the Massachusetts Fire Academy, we interviewed facilities manager James DiRico and the director of training operations, Joseph Klucznik. They gave us insight on facility capabilities and training practices used at the Massachusetts Fire Academy. Responses from these interviews also served as means of comparison with the San José National Fire Academy. Notes from interviews and observations at the Massachusetts Fire Academy can be found in Appendix B.

At the National Fire Academy in San José, interviews with the directors of the Academy, (Ronny LaTouche, Norman Chang, and Allan Rodriguez) provided answers and information more specific to our project designs. We focused many interview questions on technical information about the types, frequency, and water use of different trainings at the Academy. We also asked about how they currently obtain water for training and its approximate costs. We developed a better idea of the current process of obtaining and storing the water on the Academy through the interviews. Through a combination of these responses about water practices used in firefighting, some design parameters were established that helped us create a system best tailored to fit the logistical and technical needs of the Bomberos.

## 3.3 Analyzing the Existing Infrastructure for Rainwater Collection, Water Recycling, and Water Use at the San José Academy

The most cost-effective and simplest designs for the training Academy were “as-builts” or designs which utilize the current infrastructure. For this reason, understanding and documenting the current buildings, piping, and other structures at the Academy was important.




| Location Label | Name of Location (English) | Name of Location (Spanish) | Surface Area (m^2) |
|---|---|---|---|
| A | Empty Rotary | Rotonda Vacio | [redacted] |
| B | Storage Building | Bodega | [redacted] |
| C | Administrative Building | Edificio de Administrativo | 1434.46 |
| D | Classrooms | Aulas | |
| E | Training Plaza | Plaza de Entrenamiento | 496.44 |
| F | Training Tower | Torre de Entrenamiento | 100.9 |
| G | Search and Rescue Building | Edificio de Busqueda y Rescate | 122.85 |
| H | Smoke Training Building | Edificio de Entrenamiento de Humo | 114.88 |
| I | Location of Water Tank | Ubicacion del Tanque de Agua | [redacted] |
| J | Adjustable Training Building | Edificio de Entrenamiento Adjustable | [redacted] |
| K | Hazardous Materials | Materiales Peligrosos | [redacted] |
| L | Parking Lot | Estacionamiento | [redacted] |
| M | Storage Building | Edificio Almacenamiento | [redacted] |
| N | Maintenance Building | Edificio Mantenimiento | 60.9 |
| - - - - | Training Area | Area de Entrenamiento | [redacted] |

Figure 7: Map of Bomberos Training Academy

We documented the physical layout and existing infrastructure of the training Academy with a series of pictures. For ease of reference and consistent documentation, the pictures were labeled to correspond with those areas on the aerial map (Figure 7). These pictures documented the current locations and conditions of gutters, pipes, and sediment traps at the Academy. We additionally used Paint X Lite to draw out the identifiable and assumed existing infrastructure for documentation and ease of descriptions. Pre-existing conditions were used as a basis to suggest useful additions or changes in the physical structures at the Academy and as the basis to develop maintenance and safety plans.

We additionally identified the areas on the training grounds where water is used. To determine the direction of water flow from these training areas, we used AutoCAD diagrams of the training grounds and interview questions. Because the AutoCAD drawings only included partial sections of the piping, we devised another possible test to determine the piping infrastructure. This solution was to manually pour water down the drains and tracking the outlet. By controlling the amount of water that is put into the system and timing the process from start to finish, we could determine the amount of water that is conserved as it travels throughout the pipes and the average velocity at which it flows. Once we determined the path the water flows, we could also measure the degree of slope the pipes lay at to get a more accurate flow rate. Unfortunately, the Bomberos suggested not to use this plan as it required wasting large amounts of water, which would be counterintuitive to our project goal of increasing water sustainability. For this reason, we made some educated assumptions about underground piping infrastructure.

We took measurements of the grates and drains already in place for each of the training areas, such as those already implemented in the Training Tower and Training Plaza. The dimensions of the grates and drains were recorded and visually represented by creating SolidWorks models. We also documented the initial conditions by taking pictures of the different drains, grates, and building components and documenting their locations using Paint X Lite. The diagrams showed the locations of the drains, gutters, downspouts, and piping already in place around the Training area, in addition to the sizing of these pipes.

## 3.4 Develop a Model for Water Availability and Use at the Training Academy

We developed a computational water-use and availability model using Microsoft Excel in order to design tanks for the facility and leave the Bomberos with a tool to plan water usage for different trainings. The model provides a graph of the amount of water available for training throughout different times of the year based on the roof sizes, rain data from San José, water expended in training, and water recycled from training activities. We compared historical rainfall trends to determine the most accurate information to include within the water-use model.

The training schedule was put into the model in terms of water uses associated with specific trainings during different months. The model then yields a graph of the amount of water available for training from rain and recycling in comparison to the water needed for training to ensure that there is a sufficient quantity. If there is not a sufficient quantity of water available for training during any month, the model indicates this, highlighting the month with the water deficit in red. Incorporated into the model are assumed efficiency values for the cleanliness of roofs and conveyance pipes and the designed recycling systems. This model was used to size the tanks designed for the Academy facilities based on the amount of water used and water available. This idea was adapted from work completed by the Worcester Polytechnic Institute (WPI) chapter of Engineers Without Borders (EWB-WPI, 2012).

## 3.5 Design an Integrated Water Collection and Storage System on the Academy Grounds for Rainwater and Water Expended in Training Exercises

The design objective of the project was highlighted as the Bomberos' main project goal. The project design consisted of three main constructions: a tank storage system with a sediment filter, a rainwater harvesting system, and a water recycling system with an associated water conveyance network. The process undertaken to design each of these components was conducted through a similar general method. The general design method included taking measurements of the areas for the possible systems, representing design ideas with SolidWorks models and schematic outlines, and considering safety and maintenance plans. Approximate material costs were also calculated for each of the designs. The specific methodologies for the design of each part of the water collection and storage system are outlined below.

### 3.5.1 Design of a Water Storage System for the Academy Grounds

The design of a water storage system for the Academy required designs for two components; a sediment trap to remove particulate contaminants in the water and the tank system. The first step of design was taking measurements of the available space for a sediment trap and tank. Measurements were taken with tape measures and verified using the measurement feature on Google Earth Pro.

We created a 3D SolidWorks model of the tank system based on the collected measurements and requirements including the general shape, necessity of sediment filters, and desired safety mechanisms. These models were produced by creating sketches of each feature in SolidWorks, and then extruding and sweeping them as needed. Every component of each part can be easily altered to accommodate any future changes that the Bomberos want to make in the designs.

We also developed a comparison table that considered different design factors, for both above and below-ground designs for the tank. Some of these factors include materials, locations, effect on future infrastructure development at the Academy, ease of installation, and maintenance requirements.

When designing the tank for the system, the safety of those around and working on the tank was prioritized. We observed the safety measures already in place around the training grounds and created an improved safety plan for future designs.

We completed two iterations of this design to ensure the wants and needs of the stakeholders were met. The first tank design iteration was created in the manner outlined above and presented to the directors at the Academy. The team received feedback on the conceptual tank system design and applied the new constraints to the final design options.

### 3.5.2 Design of a Rainwater Harvesting System on the Training Buildings

Many variables were considered for designing a rainwater harvesting system. The methods to obtain main design components involved measuring key structures and parameters, determining current state of the pipe infrastructure, creating SolidWorks models to visualize the design, and creating safety and maintenance procedures for possible designs.

The rainwater harvesting system required measurements of the roof surface areas to calculate the volume of rainwater collected from the surfaces. Sizes of roofs were determined by using measuring tapes around the footprints of buildings, landscape measuring apps like Smart Measure, and Google Earth Pro software. Primary heights, lengths, and widths of buildings were measured with a tape measure and then verified using Smart Measure, an app which takes measurements by triangulating distances from the user height and a point on ground-level. Measurements were verified with Google Earth Pro. In addition to overall roof dimensions, we measured side lengths and heights of the buildings for gutters and downspouts. We also measured the distance from the bottom of the buildings to the intended location of our storage tank to ensure that we had the proper length for all necessary pipes for the rainwater harvesting system. This measurement also allowed us to plan a nonintrusive pipe network path. We also decided which slopes and roof materials were suitable for rainwater harvesting.

Using the collected measurements and current capacity for a system at the Academy, we created visual representations of our design recommendations for the rainwater collection system. For this representation, we established a 3D model of the systems in SolidWorks. We also produced 3D models of the individual components of the systems that can be easily adjusted for design flexibility. The final designs include a water storage tank system, sediment filter, piping network, gutters, and downspouts. Lastly, we established safety guidelines and maintenance procedures to lower risk for all personnel at the Academy, and to keep our designs continually working efficiently.

### 3.5.3 Design of a Water Recycling System for Water Expended During Training Exercises

When creating the designs for the water recycling system, the most important factors we considered were the amount of water that the Bomberos used during their trainings and the amount that could be recollected. The purpose of a recycling system is to significantly reduce the waste of potable water that occurs during training exercises. To establish a recycling system we needed to understand where the water was collected, the direction of its flow, the approximate speed of the flow, and how much could be recovered and reused. From this understanding, we created a fully optimized piping system to direct the recycled water to a storage tank.

The water use information was collected through interviews, as outlined in Section 3.2, and used in the designs. We documented information about the current water use infrastructure, as described in Section 3.3. The water recycling system design required measurements of the training areas at the Academy to determine the flow and location of water use from the training surfaces. With a designed water recycling system on these surfaces, the surfaces would also have the ability to collect rainwater. Sizes of these areas were determined using measuring tapes around the outside of the training surfaces. We used these measurements to create SolidWorks models of the training area and accurately determine the available surface areas for water collection. The proposed recycling system designs were additionally constructed using SolidWorks to model the function of the design proposals.

### 3.5.4 Material Cost Estimates for Associated Design Proposals

The final design recommendations for the training Academy are only effective if the Bomberos are able to implement them. The ability to implement the designs requires that the Bomberos have the funding for the proposed designs. To facilitate this, we included cost estimates for the materials required by each proposed design. The Bomberos can use these cost estimates to aid their decision of which designs best fit their Academy.

To produce these cost estimates, we travelled to local hardware stores of El Lagar and EPA to get unit prices on locally-available materials and estimates for piping, gutters, and smaller components of our design. We additionally emailed and called larger hardware and construction supply vendors in the San José area to obtain cost estimates for larger materials in the project. These hardware stores included EcoTank, Cemex, Amco, Ich Prefabricados, INPREFA S.A. and Soluciones Modernas Prefabricadas. Each design recommendation was broken into the type and quantity of material needed in a spreadsheet, so a total price could easily be calculated. If the Bomberos want to use a different vendor than the ones we visited, they can easily change the unit price in the spreadsheets for the desired part and calculate the actual price.

We used the price estimates with the average annual cost of water at the Academy to complete an analysis of estimated savings with our systems. We divided the total material costs of the systems over the 20-year lifetime of the designed tanks to provide an annual cost for the proposed systems. To determine an approximate return on investment for the proposed designs, we divided the average annual cost of water at the Academy by the initial material costs.

# 4.0 Findings and Analysis

The following section outlines the qualitative and quantitative data collected over the course of the project. We evaluated motivations of the stakeholders and the possible project impact through interviews, compared water practices between the San José Academy and the MFA, calculated rainfall and water use totals, and collected technical data required for RWH and water recycling. Pertinent project data are outlined below with references to specific appendices for full data and findings.

## 4.1 Project Impact and Motivations of the Stakeholders

The initial rationale for conducting interviews was to understand the specific wants, needs, and limitations of the Bomberos with regard to water use for training activities. Throughout the course of ten interviews with directors at the Academy and station chiefs, salaried, and volunteer firefighters from fire stations around the San José area, we learned about the deeper motivations and importance of the project in addition to understanding social and technical considerations.

For all of the directors, the biggest motivation to create a water capture and recycling system was a desire to minimize the use of potable water supplies for training exercises. While water resources are not scarce in many areas of Costa Rica, all the water used in daily activities, including that used in firefighter training, comes from a potable supply and is typically not recycled. The Academy has high visibility in the San José community as in addition to firefighters, they train business owners in fire safety and suppression techniques to protect their property. The Bomberos champion sustainable practices on the Academy campus by participating in the Blue Flag sustainability program (Bandera Azul), becoming leaders in the community and promoting sustainability. Part of their courses for local business owners includes a promotion of the Blue Flag program. Because they use large quantities of water, the Bomberos have a greater appreciation for the need for sustainable water practices, which was the impetus for our project. Both the desire to reduce their stress on potable water supplies and their position as a leader in the community and of sustainable practices demonstrated their motivations for our project. Throughout the design process, we needed to keep in mind our systems and recommendations should be visible and replicable so the Bomberos can promote them to the business leaders in the training courses.

An interesting finding from the interviews at the stations in Cartago and Pacayas was that fire stations around Costa Rica cannot use water during their individual station trainings because of conflicts with local communities about ‘unnecessarily’ depleting their potable water supply. At both stations, the only appropriate use for large amounts of water is for fire emergencies, not trainings. Thus, the only time that the Bomberos use water during trainings are when they take courses at the Academy. Every salaried firefighter is required to attend 2-3 courses per year, although many are eager to take more to become “more professional” firefighters.

The firefighters shared the view that water was undervalued and poorly rationed in Costa Rica because its prevalence and inexpensive price. Overall, the Bomberos claimed there was a general lack of awareness about water use and waste in Costa Rica, with some saying that the country is missing a “culture, education and technology to create a sustainable system” regarding water use. The Bomberos in Cartago claimed that the culture surrounding water use in Costa Rica is changing with the new generation becoming more environmentally-conscious. They explained that the new generation understands that water is an exhaustible resource and thus has a greater awareness of their water use. Because water is “an element required in [their] work”, the Bomberos are on the forefront of this cultural shift in perspectives. Our project is important as it will exemplify the shift in the Bomberos organization to a more sustainable system, and continue to spread this shift in society through their image as an organization.

## 4.2 Water Practices Used in Firefighting

The trip to the Massachusetts Fire Academy provided a number of design ideas and standards for efficiency in water recycling systems. Although there is no rainwater capture system, the facility has an effective water recycling system. Their current system is capable of recycling 75-80% of the water they use during their trainings (Klucznik, 2017). We found that they are able to achieve this goal as they hold the majority of their training exercises involving water in the area near their water recollection system (Figure 8). Other system aspects that we adapted from the MFA included the rationale for sizing of the tank (44,000 gallons) based on water training needs, the frequency of completely emptying and cleaning the recycling system tank, and the types of grates used on the drains of the system. All of this information was taken under consideration and adapted when designing our water recycling system for the San José Academy.

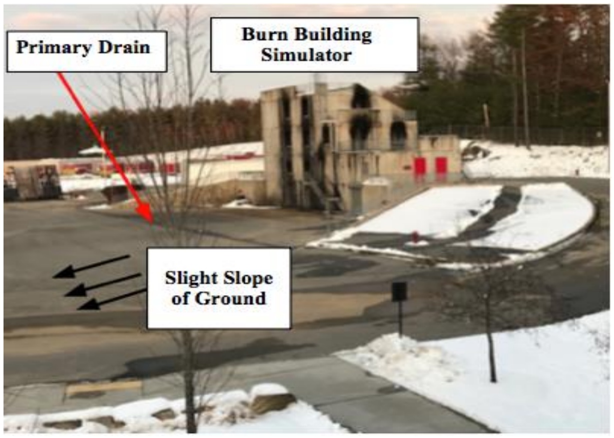



Figure 8: Main training area of MFA with labeled slopes and drains

In San José, the interviews with the directors at the National Firefighter Academy were helpful to determine more logistical aspects in our project. Some of these logistics included safety considerations, information about maintenance for their systems, the advantages of a proposed distribution network, and the construction of many new, large developments in the near future. We found there were already facilities personnel that complete small maintenance tasks for any system on the Academy grounds. In addition, we discovered that the largest of the new buildings to be constructed also includes plans for a rainwater harvesting system for greywater collection, and treatment and a distribution network of hydrants. This was a consideration that we had to make for our designs because it serves as an additional large source of water available to use.

Table1: Comparison of metrics between MFA and San José Academy.

| | MFA | San José Academy |
|---|---|---|
| Number of Students at a Given Time (Average) | 144 | 40 |
| Size of Academy (m^2) | 58,222 | 70,000 |
| Most Water-Intensive Training | Burn Building | Tower Training |
| Number of Different Courses Offered | 300+ | 41 |
| Current Water Storage Capacity (Gal) | 44,000 | 34,080* fed by a well on the property and not frequently used |
| Materials Used to Start Fires | Straw and Wood | Little fire used, gas and diesel occasionally used |

As seen from the information in Table 1 above, the MFA has a slightly greater overall capacity than the San José Academy. This capacity is shown especially by the number of students at the Academy at a given time, where the MFA has over three times the number of students and almost eight times the number of different courses than at the San José Academy. The MFA also has a slightly different training structure where they hold ongoing training programs instead of a set number of certain types of classes. While the current training capacity of the MFA is greater than that in San José, there are many similarities in the infrastructure and water use between the two academies. For this reason, we adapted some of the design considerations from the MFA for our San José Academy designs, on a reduced scale.

After interviews from both locations were completed, we obtained a greater understanding of water practices in firefighting. We also observed some similar perspectives in both academies related to water use in training exercises. The director of the Massachusetts Fire Academy, Joseph Klucznik and the director of the National Academy in San José, Ronny LaTouche both felt that of all exercises conducted every year, the most beneficial exercises involve using water for simulated fires.

## 4.3 Existing Infrastructure for Rainwater Collection, Water Recycling, and Water Use at the San José Academy

The following sections document the infrastructure on the Academy grounds. This information was used as the basis for our designs.

### 4.3.1 Current Rainwater Harvesting Infrastructure

The Smoke Building and Maintenance Buildings have a pre-existing infrastructure of gutters, downspouts, and drains which were utilized in our rainwater harvesting system design. The water collected from these gutters is currently directed off the hillside away from the building complex, with no specific collection area. The current gutters, downspouts, and drains are outlined below in purple in Figure 9.

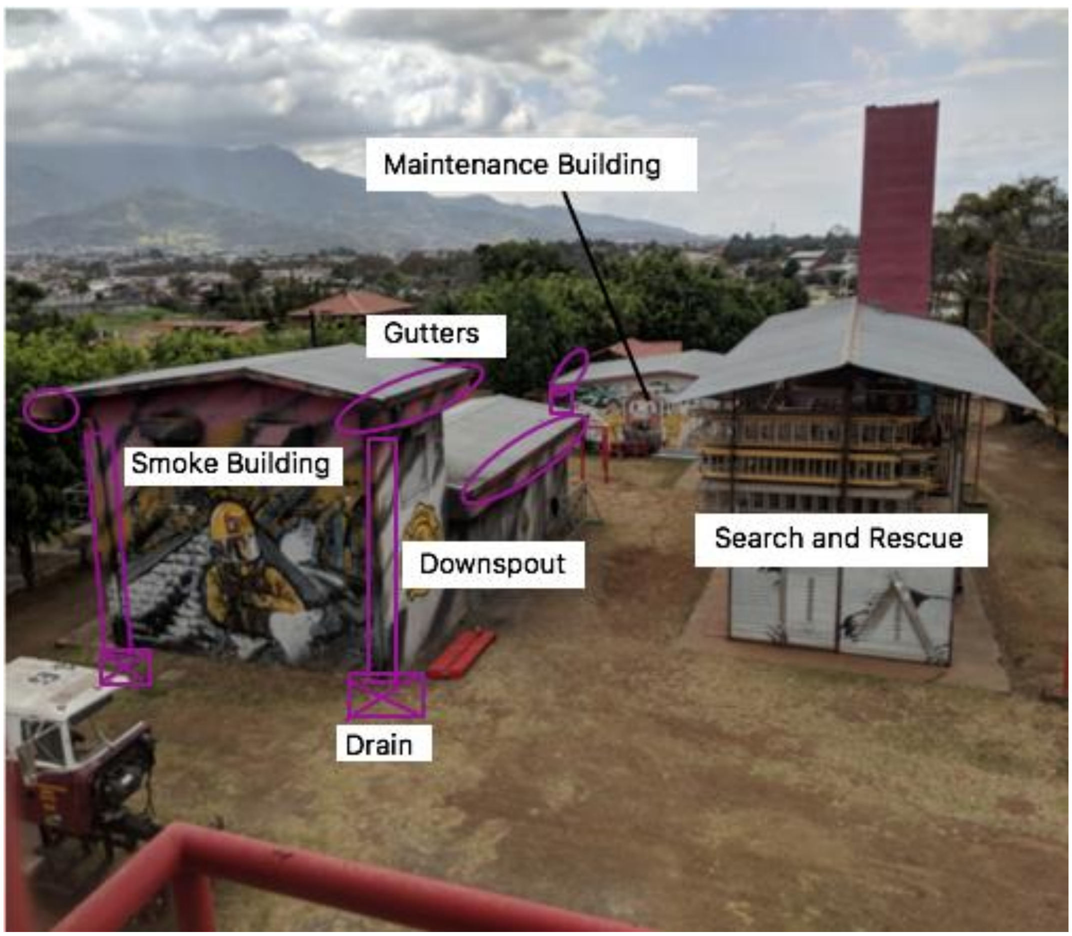



Figure 9: Existing Infrastructure for Smoke Building, Maintenance Building, and Search and Rescue Building

The only training building roof that does not have any established water recollection system is the Search and Rescue Building (Figure 10). The practices taking place here use 2,000 gallons of water per year, but there are no drains or proper runoffs established around the structure. While this is not a large amount of water relative to other practices, it would significantly reduce water waste if captured and recycled back into the storage tanks. The roofs should have gutters attached to catch rainwater, and the area around the building is sufficient to implement a drain system or cement-based runoff to catch water from the edges.

Figure 10: Close-up of Search and Rescue Building

We determined that there is no set schedule for cleaning rainwater harvesting system infrastructure, including the gutters, downspouts, roofs, and drains. Cleaning these areas only occurs whenever the maintenance personnel at the Academy feel it is a necessity, which can result in a number of clogged areas on the Academy. Examples of the current state of the rainwater harvesting infrastructure can be seen in Figure 11 and 12 below.

Figure 11: Example of a clogged downspout drain on the Maintenance Building

Figure 12: Example of a gutter system clogged with dirt and leaves at the Academy

## 4.3.2 Existing Training Area Infrastructure

After observing and measuring the drains currently in place around the Training Plaza and Training Tower, we had information for a design to improve the water capturing and recycling capabilities. The current drain system on the Training Plaza is three small drains surrounding the area with a slight degree of slope of the Training Plaza to assist water flow towards the drains (See Figure 13). The grates around the Training Plaza were extremely small and clogged with sediment and rocks. We determined that this was an ineffective system since the quantity of water used in training is likely greater than the capacity of the blocked drains. The Bomberos already have a small 4,000L tank in place under the Training Plaza, connected to a single drain at the base of the concave wall on the structure. The drain for this tank is too close to their concave collection wall, which causes a low recapture efficiency. No effective sediment filter or safety mechanisms are in place for this tank. Pictures of the initial conditions can be seen in Appendix A. A map of the Academy piping layout can be seen in Appendix E.

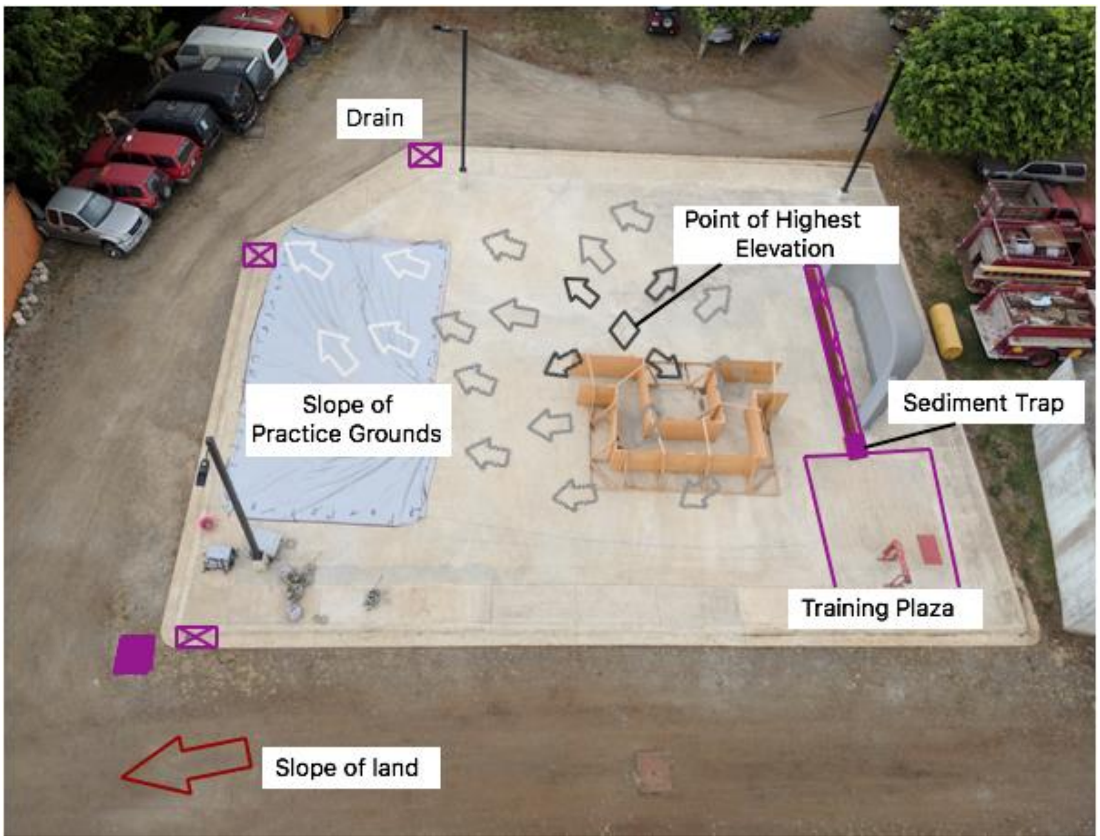



Figure 13: Existing infrastructure for Training Plaza without piping shown

The Training Tower has a drain on each side of the tower that is covered by two long grates with wide openings. This is a relatively efficient drain as they are long, sloped, and large enough to capture whatever water lands on or flows towards them (Figure 14). The main inefficiency with the current system is the distance of the grates from the tower. Since the tower is eight stories tall, any water that sprays off the edge travels a significant distance before coming into contact with the ground. The grates that are already in place are too close to the base of the tower to catch all of the water used in the tower. Additionally, there is a large area of gravel surrounding the Training Tower beyond the concrete pad and the grates. Any water that hits the gravel is lost as it cannot flow through this medium. There are no safety hazards with the current system, thus any new system implemented should have established precautions.

Figure 14: Drain system and gravel around the Training Tower

### 4.3.3 Existing Water Conveyance Infrastructure

Since much of the Academy was constructed in multiple phases, the existing water conveyance piping networks are poorly documented and difficult to discern. Some of the piping infrastructure was determined from AutoCAD diagrams of the buildings on the grounds. We estimated from the piping diagrams and observations of the ground that water from the training buildings is directed by pipes to the hill in the opposite direction of training grounds (Figure 15). We also estimated that the water generally flows to a concrete canal structure on the far side of the hill away from the training grounds. With the lack of a full piping schematic, it was difficult to determine the exact piping connections underground in the area of the training grounds, thus the designs are based on our observations of the probable piping schematic. Probable piping schematics can be seen in Figure 15 and 16 below. The provided AutoCAD schematic can be found in Appendix E.

Figure 15: Current piping infrastructure for Smoke Building, Maintenance Building, and Search and Rescue Building. The purple shows that the water flow is currently in the opposite direction of the central training grounds.

Figure 16: Current piping for Training Plaza and Training Tower. Purple shows water flows downhill away from central training grounds.

## 4.4 A Model for Water Availability and Use at the Training Academy

We developed the water-use model to design the tank system for the facility and leave the Bomberos with a tool to plan trainings around water availability. The water-use model required a series of inputs: information about the training schedule at the Academy, the roof area available, and rainfall data.

### 4.4.1 Water-Use During Training

The 2017 training schedule, (Figure 17), combined with the water-use estimation for hose practices that the Bomberos are implementing in the coming year, indicate that an average year of training requires 176,000 gallons of water (Figure 18 cell L15). From this schedule, we additionally calculated that an average of 14,700 gallons of water is used per month for training.

| | | | | |
|---|---|---|---|---|
| AGO | 32 | VERTICAL BÁSICO (6-11) | MOVE-CONDUX (6-14) | CBF-VOL@B. AIRES (11, 12, 18, 19) |
| | 33 | EQ. COMB (13-14) | SCI-B (13-14) | EQ. COMB (16-17) |
| | 34 | SBV (20-24) | REL. PUBLICAS (20-24) | MEI-VOL@PUNTARENAS (24-26) |
| | 35 | SCI-I (27-31) | AD. EMPR (28-31) | CARTOGRAFIA@TILARAN (29-31) |
| SET | 36 | PR. ESCENA (3-5) | EQ. COMB (3-4) | EQ. COMB (6-7) |
| | 37 | MECANICA BASICA (10-12) | SIST. FIJOS (11-14) | PRIMAP (12-14) |
| | 38 | CONT. ADMINISTRATIVA (17-21) | PRIN@PUNTARENAS (18-21) | SEG. HUMANA (19-21) |
| | 39 | VERTICAL II@CARTAGO (24-28) | OFFICE@HEREDIA (24-28) | SER. CLIENTE@PUNTARENAS (27-28) |
| OCT | 40 | CRECL (1-5) | CARTOGRAFIA (3-5) | |
| | 41 | PRIN@PUNTARENAS (8-11) | REDAX INF. TEC (9-11) | |
| | 42 | CORIMP@GUADALUPE (15-24) | SBV (15-19) | SERV. CLIENTE (15-16) |
| | 43 | CPI (22-26) | | |
| | 44 | COMUNICACIONES@F5 (29-31) | LIDERAZGO (29 OCT-1 NOV) | CARTOGRAFIA@TILARAN (31 OCT-2 NOV) |
| NOV | 44 | PRIMAP-VOL@SIQUIRRES (2-4) | | |
| | 45 | VERTICAL BÁSICO (5-10) | SCI-I (5-9) | SCI-B-VOL@PUNTARENAS (10-11) |
| | 46 | SIS. FIJOS (12-15)--3000 GALONES | SEG. HUMANA (12-14) | |
| | 47 | CBF (19-22) | RESCATE VEHICULAR (19-23) | |
| | 48 | EIR (27-30) | AC BLOQUE 1@TRES RÍOS (26-30) | |
| DIC | 49 | VERTICAL II (3-7) | SCI-B (2-4) | PRIMAP (5-7) |
| | 50 | BRIE (11-14)---1000 GALONES | | |

Figure 17: Example of San José Academy training course schedule including courses, locations, and the days of the month when they occur. Cells highlighted in blue are trainings that use water.

Additional available water comes from the current and proposed recycling systems for water expended during training practices. The recycled water amount was calculated as the water expended for trainings multiplied by an efficiency factor (Figure 18). We chose conservative efficiency factors to ensure the Bomberos would have a relatively accurate amount of water available. The efficiency factor for Search and Rescue Building is 0 as they currently use mist, which is difficult to recycle. For the Training Tower, a 0.3 efficiency factor was chosen to represent the current drain system, which is too close to the base of the tower and does not capture the majority of water. For the Training Plaza we chose a 0.8 efficiency factor because the firefighters at the MFA are able to recollect this amount from trainings and our proposed design aims to mimic that at the MFA. The Training Plaza drain already in this area, connected to their current 4,000 L water storage tank, (Figure 13) would recollect some of the other 20 percent of water expended. Based off the water use values from training and these assumed efficiency factors, it was calculated that approximately 418,000 L of water could be recollected after use in training (Figure18 cell M15).

| Training Activity | Approximate Water Use (L) | Approximate Water Use (gal) | Efficiency Factor |
|---|---|---|---|
| Chorros | 11355 | 3000 | 0.8 |
| Sistema fijado | 11355 | 3000 | 0.3 |
| Busca y Rescate | 3785 | 1000 | 0 |

| Month | Frequency of Chorros | Frequency of Sistema Fijado | Frequency of Busca y Rescate | Water Use from All Combined Trainings (L) | Water Use from All Combined Trainings (gal) | Volume of Water Recycled (L) | Volume of Water Recycled (gal) |
|---|---|---|---|---|---|---|---|
| Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mar | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| Apr | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| May | 4 | 4 | 0 | 90840 | 24000 | 49962 | 13200 |
| Jun | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| Jul | 4 | 4 | 0 | 90840 | 24000 | 49962 | 13200 |
| Aug | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| Sep | 4 | 4 | 4 | 105980 | 28000 | 49962 | 13200 |
| Oct | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| Nov | 4 | 4 | 0 | 90840 | 24000 | 49962 | 13200 |
| Dec | 4 | 0 | 4 | 60560 | 16000 | 36336 | 9600 |
| **Total** | | | | 666160 | 176000 | 417864 | 110400 |

Figure 18: Inputs tab on the water-use model showing type, water use, and frequency of different trainings to determine water used for training and recycled at the Academy

## 4.4.2 Water Collection Area Measurements

We determined that the roofs on the Smoke Building, Search and Rescue Building, and Maintenance Building could be used as rainwater collection surfaces based on roof size, adequate slopes, and proximity to the other training grounds. The roofs of these three buildings were determined to have a combined surface area of 300$m^2$ based off measurements and the SolidWorks models (Figure 19).

Furthermore, if an effective water recycling system is implemented on the training grounds with piping that conveys recycled water to the tank, the training ground surfaces would act as additional rainwater catchment surfaces. The total rainwater collection surface area measurements calculated added the 144$m^2$ of rainwater catchment area for the concrete base of the Training Tower area and the 496$m^2$ of surface area from the Training Plaza to the roof areas. Between the three roofs, the Training Tower base, and the Training Plaza, the total rainwater catchment surface area totals at 940$m^2$ in the area of the training grounds.

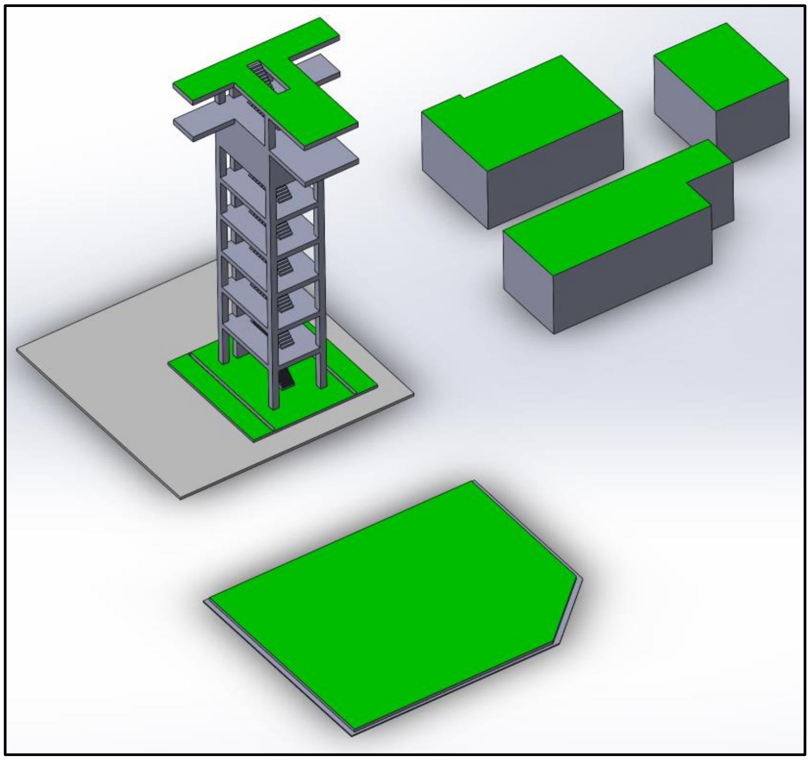


Figure 19: Training Area RWH surface area

### 4.4.3 San José Rainfall Data

After finding rainfall data for San José from 1950-2015, we took the monthly averages to calculate water availability. The data show a yearly average rainfall of 3000 mm in San José (Figure 20). In addition to the data from 1950-2015, other weather sources were evaluated to verify the accuracy of monthly averages and yearly annual precipitation. These sources confirmed an annual rainfall range between 2000-4000 mm in San José, and similar trends in wet and dry months to the data used in the water-use model (Climate-Data, n.d.; Costa Rica Guides, 2017).

Based on rainfall data and the roof areas at the Academy, the model calculated that just under 600,000 gallons of rainwater can be collected per year (Figure 20). The total volume was calculated from the total amount of rainfall in San José multiplied by the Academy roof area with an assumed efficiency factor of 0.8 based on previously-designed rainwater harvesting systems due to rain speed, roof slopes, and system cleanliness (EWB-USA WPI, 2012).

| Water Collection Surface Area (m^2) | 879 | Month | Month | Rainfall Data (mm) | Volume from Rain (L) | Volume per Month (Gallons) | Volume per Month from Recycled Water (L) | Volume per Month from Recycled Water (gal) | Withdrawl per Month (L) | Withdrawl per Month (gal) | Total Volume in Tank (L) | Total Volume in Tank (gal) | Total Tank Volume* (gal) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Approx. Efficiency | 0.8 | Jan | Feb | 124.1 | 87267.12 | 23056 | 0 | 0 | 0 | 0 | 87267 | 23056 | 5619 |
| Effective Surface Area (m^2) | 703.2 | Feb | Mar | 76.9 | 54076.08 | 14287 | 0 | 0 | 0 | 0 | 141343 | 37343 | 19906 |
| Tank Storage Capacity (L) | 66000 | Mar | Apr | 79.4 | 55834.08 | 14751 | 36336 | 9600 | 45420 | 12000 | 188093 | 49694 | 32257 |
| Tank Storage Capacity (gal) | 17437 | Apr | May | 134.8 | 94791.36 | 25044 | 36336 | 9600 | 45420 | 12000 | 273801 | 72338 | 54901 |
| | | May | Jun | 309.5 | 217640.4 | 57501 | 49962 | 13200 | 90840 | 24000 | 450563 | 119039 | 101602 |
| | | Jun | Jul | 341.2 | 239931.8 | 63390 | 36336 | 9600 | 45420 | 12000 | 681411 | 180029 | 162592 |
| | | Jul | Aug | 338.9 | 238314.5 | 62963 | 49962 | 13200 | 90840 | 24000 | 878847 | 232192 | 214755 |
| | | Aug | Sep | 336.2 | 236415.8 | 62461 | 36336 | 9600 | 45420 | 12000 | 1106179 | 292253 | 274816 |
| | | Sep | Oct | 354.6 | 249354.7 | 65880 | 49962 | 13200 | 105980 | 28000 | 1299516 | 343333 | 325896 |
| | | Oct | Nov | 409.4 | 287890.1 | 76061 | 36336 | 9600 | 45420 | 12000 | 1578322 | 416994 | 399557 |
| | | Nov | Dec | 289.2 | 203365.4 | 53729 | 49962 | 13200 | 90840 | 24000 | 1740809 | 459923 | 442486 |
| | | Dec | Dec | 202.8 | 142609 | 37677 | 36336 | 9600 | 60560 | 16000 | 1859194 | 491201 | 473763 |
| | | | Total | 2997 | 2107490 | 556801 | 417864 | 110400 | | | | | |

*number is the amount of surplus water overflow from the tank

Figure 20: Water-use model tab calculating volume of rainfall, volume of water from recycling, water use/withdrawal, and total volume of water in the tank with the designed system parameters

### 4.4.4 Combined Water-Use

All water volume in the model spreadsheets was converted to gallons for ease of viewing. Water available throughout the year from rainwater and recycling compared to water used in trainings can be seen in Figure 21.

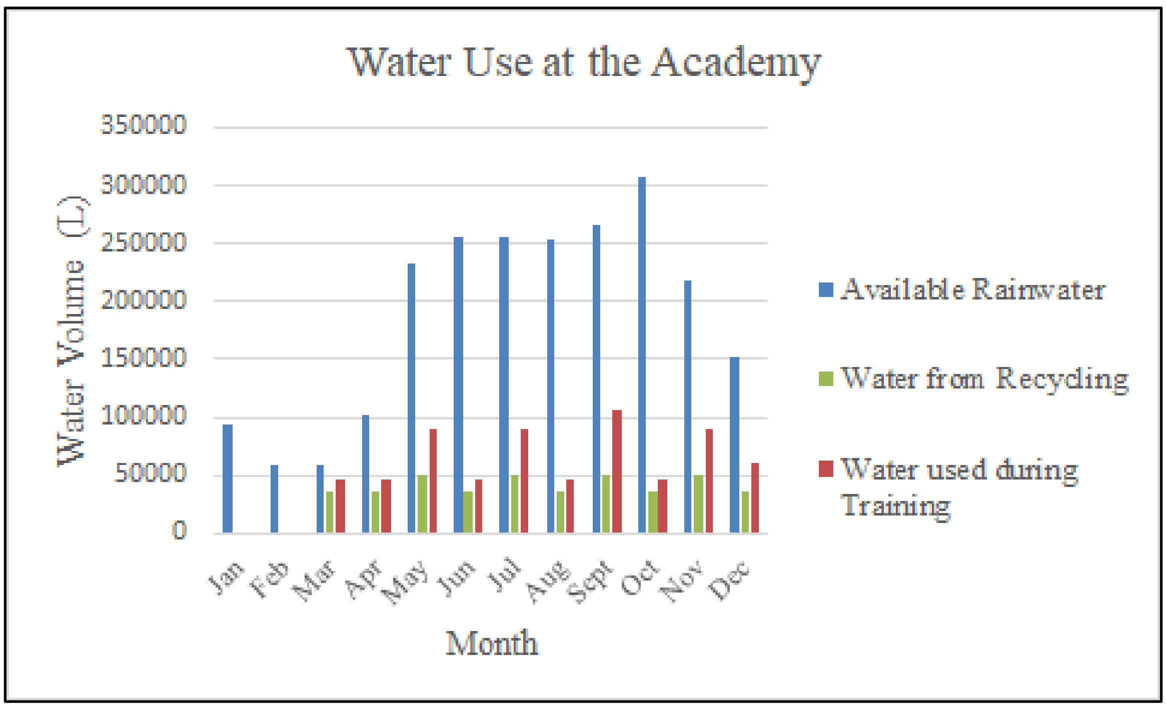



Figure 21: Graph of monthly water available from rainfall and water recycling, and water used during trainings.

The water that can be collected for recycling is almost the same amount of water required for training, and the amount of rainwater that can be collected greatly surpasses the amount needed for trainings. This model was made with the assumption that our design systems have been installed so all roof area and training grounds analyzed have the potential to collect rainwater.

With a total rainwater and recycled water availability of approximately 710,000 gallons per year and a water use of 176,000 gallons annually, the amount of water available greatly surpasses the water demand at the Academy.

## 4.5 Integrated Water Collection and Storage System Design on the Academy Grounds for Rainwater and Water Expended in Training Exercises

The integrated water collection and storage system on the Academy grounds required measurements and design developments for the water storage tank system, the rainwater harvesting system, and the water recycling systems. The following sections outline the possible location and measurements for these system design components.

### 4.5.1 Tank Location and Area

From interviews, slope of the land, and proximity to the training ground where the water is used, the best space for the water storage tank was determined to be on the other side of the road next to the Search and Rescue Building (Figure 22). The tank system and sediment trap available area near the training grounds is restricted in capacity by the physical area available in the proposed location. The surface available area from measurements can be seen below. These measurements take the width of the area from the road to the edge of the tree wall. The area directly behind the orange storage structure was not considered as “area available” because there is a pre-existing retention wall made up of tires, rocks, and dirt, which would be difficult and expensive to remove. The main consideration for the tank placement in this area was keeping it out of the roadway for the unobstructed passage of firetrucks to the training grounds.


Figure 22: Training grounds area available for water storage system and sediment trap. The roof seen on the left side of the picture is that of the Search and Rescue Building.

The surface areas for the tank system and sediment trap were calculated as:

Total Surface Area Available for Training Grounds Tanks: 60.5 $m^2$

Total Surface Area Available for Training Grounds Sediment Trap: 18 $m^2$

The overflow for the tank system should lead out of the hillside in the opposite direction of the Search and Rescue Building to an already-existing canal outlined in purple in Figure 23. We assumed that this is where excess water from the training grounds currently goes.

Figure 23: Perspective from behind hill for proposed water storage tank design. Existing water conveyance system is marked in purple.

## 4.5.2 First Design Iteration

Our first tank design iteration included a concrete, underground water storage tank with a built-in sediment filter, to be placed in the area to the side of Search and Rescue Building (Figure 24 and 25). The internal sediment filter component was comprised of two, different-size mesh types that could be removed to clean out the tank. The tank also had doors with locks to prevent any accidents. Inside, there were metal rungs for easy access of authorized personnel to upkeep maintenance. This proposed design had a holding capacity of roughly 16,500 gallons and concrete walls on all sides of the tank that were 0.127m (5in) thick. Full dimensions, slope, and specific design details can be found in Appendix F.

This proposal was a creative design approach, but after feedback from our sponsors, we learned their higher design priorities were material availability, convenience-of-use, and associated costs. While the sediment filtration system within the tank was efficient because it condensed the sediment filter and tank into a single system, it was too difficult to customize with no similar designs already available in Latin America. Additionally, because of this unique feature, the tank design was not cost effective. There was also concern about lifting sediment filters out of the ground for cleaning, because they would be heavy and large, especially for a single person to handle. We were able to improve these aspects of design in future iterations.

While we had those aspects to improve, our initial design had many beneficial components. The tank stored the approximate capacity of water that they needed, the rounded inside edges minimized sediment buildup, proper piping was in place, the tank was completely submerged underground so gravity could promote natural water movement, and some safety procedures were established. These were features we kept in the following design iteration.

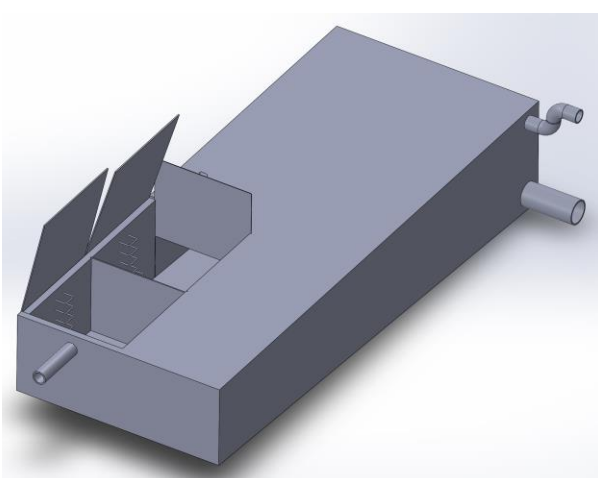


Figure 24: Below-ground water storage tank design for training ground area

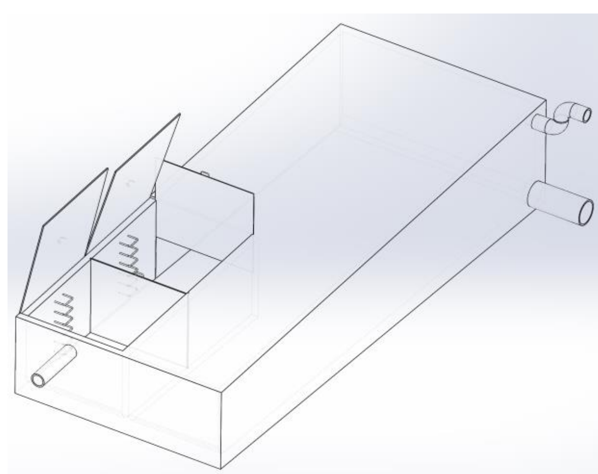


Figure 25: Below-ground water storage tank assembly for training ground area

### 4.5.3 Costs of Materials

As in any project, the cost of the materials and labor is usually the limiting factor for designs. We created a spreadsheet of the material costs from different distributors in Costa Rica. As seen in Table 2 below, the four main distributors were EcoTank, El Lagar, EPA, and Amco. EcoTank is a leading distributor of plastic tanks in Costa Rica and was chosen as the supplier for our plastic tanks. We contacted EcoTank directly for a quote for their largest (22,000 L) tanks see Appendix G. We obtained a unit price for different strength concretes and a quote for our subterranean tank from Amco, a local concrete company. Both EcoTank and Amco are a short drive from the Academy. El Lagar is similar to a Home Depot in the United States and had everything in stock ranging from concrete mixes to water pumps. The majority of materials needed for the project was found here. EPA was another hardware store vendor with a slightly different material selection, but slightly higher costs than those at El Lagar. Table 2 below shows the prices for the materials necessary for the designs. A full list of items priced and with different qualities can be found on our master spreadsheet (Appendix H).

Table 2: Costs for applicable design materials from four local distributors and hardware stores

| | Distributor | | | |
|---|---|---|---|---|
| | **EcoTank** | **El Lagar** | **EPA** | **Amco** |
| ***Tanks*** | | | | |
| **Custom Concrete Tank** | | | | **c1.103.960 (w taxes)** |
| **22,000 L Industrial EcoTank** | **c2.12.296,82 (w/ taxes)** | | | |
| **Tank Excavation Cost per Hour** | | | | **c67.800** |
| ***Concrete*** | | | | |
| **6m long Rebar (Parilla#4)** | | | **c2.995** | |
| **Holcim Fuerte cemento** | | **c6.300** | | |
| **SuperBloque Total for Walls** | | **c464.000** | | |
| ***Piping*** | | | | |
| **4" 6m section Pressurized** | | **c18.000** | | |
| **2" 6m section Pressurized** | | **c16.060** | | |
| ***Piping Accessories*** | | | | |
| **2" pvc Ball Valve** | | **c2.941** | | |
| **4" pvc Ball Valve Mid Quality** | | **c58.490** | | |
| **4" pvc Ball Valve High Quality** | | **c73.570** | | |
| ***Filter*** | | | | |
| **Concrete for Custom Filter/Bag** | | **c6.300** | | |
| **EcoTank "Trampa de Grasa"** | | | **c34.950** | |
| ***Gutters*** | | | | |
| **"Pecho" gutter 3m section** | | **c14.000** | | |
| **"Lisa Alto" gutter 3m section** | | **c16.650** | | |
| **Downspout 5cm x 3m section** | | **c8.845** | | |
| ***Grates*** | | | | |
| **Filter #2006021 4"x8"** | | **c53.622** | | |
| ***Pumps*** | | | | |
| **DAB 2.5 hp (Jet) +2yr warranty** | | | **c295.500** | |

We additionally found that the Academy currently pays for their water used on a monthly basis. This cost was determined to be 3,989,537 colones ($7,061). This cost includes the cost of water used for cooking, drinking, cleaning, and sanitary services in addition to that used during training. This value was used as an average monthly cost of water for a cost-savings comparison for the proposed designs.

# 5.0 Deliverables and Proposed Designs

Presented below are the final water-use model with directions, design proposals, material cost estimates, and safety and maintenance guidelines created throughout the project. After presenting the water-use model, we describe our design plans for each of the main components of the proposed system. We begin with designs for three proposed tank systems and a discussion of the possible connection systems, followed by the design for a sediment filter. We then outline our proposed design for the rainwater harvesting system and water recycling system, with associated water conveyance infrastructure. The section ends with the material cost estimates for each design. These deliverables as shown were translated to Spanish and left with the Bomberos.

## 5.1 Water Availability and Use Model

Figures 26-28 below depict our computational, water-use model. This model allows the Bomberos to input water amounts demanded for specific trainings and the months and frequencies of those trainings (Figure 26). From these inputs, the model calculates the approximate volume of water available. If water levels are continually high as calculated by the model, the Bomberos can design a training schedule that optimizes the use of rainwater throughout the year, possibly adding additional trainings to their current schedule. The model also shows a graphical representation of the amount of water available during different months in the year, separated into water from rainfall and recycled water. The water demands from training is also on the graph so users can ensure that the amount of water available is sufficient for training. This idea was adapted from work completed by the Worcester Polytechnic Institute (WPI) chapter of Engineers Without Borders (Engineers Without Borders-WPI, 2012). Below are directions for using the model:

**Inputs Tab (**Figure 26)

1. List different training activities in the table on left (Column B).
2. Input estimates for amount of water used for each of the training activities (Column D).
3. Water recollection/recycling efficiency factors were estimated based on recommendations from various sources, but if they seem to be lower when the system is implemented, adjust those in Column E. (Rationale for assumed efficiency factors can be found in Section 4.4.1)
4. Input the frequency of the training activities in the months they occur in the right table (Columns H-J).

*Calculated from inputs:*

5. The amount of water used in all trainings for the month is calculated based on the types of trainings, frequency, and water use for each specific training session (Column L).
6. The volume of water recycled is calculated from the total water use from trainings and water recollection efficiency factor (Column N).

7. The final values in Columns I and N are an approximate annual total amount of water used and recycled.

| B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Training Activity | Approximate Water Use (L) | Approximate Water Use (gal) | Efficiency Factor | | Month | Frequency of Chorros | Frequency of Sistema Fijado | Frequency of Busca y Rescate | Water Use from All Combined Trainings (L) | Water Use from All Combined Trainings (gal) | Volume of Water Recycled (L) | Volume of Water Recycled (gal) |
| Chorros | 11355 | 3000 | 0.8 | | Jan | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sistema fijado | 11355 | 3000 | 0.3 | | Feb | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Busca y Rescate | 3785 | 1000 | 0 | | Mar | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| | | | | | Apr | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| | | | | | May | 4 | 4 | 0 | 90840 | 24000 | 49962 | 13200 |
| | | | | | Jun | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| | | | | | Jul | 4 | 4 | 0 | 90840 | 24000 | 49962 | 13200 |
| | | | | | Aug | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| | | | | | Sep | 4 | 4 | 4 | 105980 | 28000 | 49962 | 13200 |
| | | | | | Oct | 4 | 0 | 0 | 45420 | 12000 | 36336 | 9600 |
| | | | | | Nov | 4 | 4 | 0 | 90840 | 24000 | 49962 | 13200 |
| | | | | | Dec | 4 | 0 | 4 | 60560 | 16000 | 36336 | 9600 |
| | | | | | Total | | | | 666160 | 176000 | 417864 | 110400 |

Figure 26: Input tab for water-use model

**Training Grounds Tab** (Figure 27)

1. The surface area of the training building roofs and training grounds area with water recycling infrastructure are added to give the water collection surface area.
2. Water recollection/recycling efficiency factors were approximated based on recommendations from various sources, but if they seem to be lower when the system is implemented, adjust those in this left table (Texas A&M, 2017; Engineers Without Borders-WPI, 2012)
3. The product of the water collection surface area and the efficiency yields the effective surface area
4. Already included in the model are rainfall data for San José in mm (Column F).

*Calculated from models:*

5. These rain data are multiplied by the effective surface area and converted to L or gal to give the volume of water from rain per month (Column H).
6. Volume of recycled water and water withdrawal per month, Columns J and L, come from the Inputs tab (they have already been calculated)
7. Total volume available is calculated as the rainfall for the month added to the amount of water recycled from training minus the amount of water withdrawal per training (Column N).

The months are labelled so that the total volume in the tank is the water available at the start of each month. For example, 124.1mm of rain falls in January, with 0 gallons of water used for training and thus 0 gallons of water recycled. With this water accumulation and use in

January, the total volume of water available at the start of February is the equivalent of 124.1mm (23056 gal) of rainwater.

| A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Collection Surface Area (m^2) | 879 | | Month | Month | Rainfall Data (mm) | Volume from Rain (L) | Volume per Month (Gallons) | Volume per Month from Recycled Water (L) | Volume per Month from Recycled Water (gal) | Withdrawl per Month (L) | Withdrawl per Month (gal) | Total Volume Available (L) | Total Volume Available (gal) |
| Approx. Efficiency | 0.8 | | Jan | Feb | 124.1 | 87267.12 | 23056 | 0 | 0 | 0 | 0 | 87267 | 23056 |
| Effective Surface Area (m^2) | 703.2 | | Feb | Mar | 76.9 | 54076.08 | 14287 | 0 | 0 | 0 | 0 | 141343 | 37343 |
| Tank Storage Capacity (L) | 66000 | | Mar | Apr | 79.4 | 55834.08 | 14751 | 36336 | 9600 | 45420 | 12000 | 188093 | 49694 |
| Tank Storage Capacity (gal) | 17437 | | Apr | May | 134.8 | 94791.36 | 25044 | 36336 | 9600 | 45420 | 12000 | 273801 | 72338 |
| | | | May | Jun | 309.5 | 217640.4 | 57501 | 49962 | 13200 | 90840 | 24000 | 450563 | 119039 |
| | | | Jun | Jul | 341.2 | 239931.8 | 63390 | 36336 | 9600 | 45420 | 12000 | 681411 | 180029 |
| | | | Jul | Aug | 338.9 | 238314.5 | 62963 | 49962 | 13200 | 90840 | 24000 | 878847 | 232192 |
| | | | Aug | Sep | 336.2 | 236415.8 | 62461 | 36336 | 9600 | 45420 | 12000 | 1106179 | 292253 |
| | | | Sep | Oct | 354.6 | 249354.7 | 65880 | 49962 | 13200 | 105980 | 28000 | 1299516 | 343333 |
| | | | Oct | Nov | 409.4 | 287890.1 | 76061 | 36336 | 9600 | 45420 | 12000 | 1578322 | 416994 |
| | | | Nov | Dec | 289.2 | 203365.4 | 53729 | 49962 | 13200 | 90840 | 24000 | 1740809 | 459923 |
| | | | Dec | Jan | 202.8 | 142609 | 37677 | 36336 | 9600 | 60560 | 16000 | 1859194 | 491201 |
| | | | | Total | 2997 | 2107490 | 556801 | 417864 | 110400 | | | | |

Figure 27: Computational tab with rainfall data, recycling quantities, water use, and water collection areas on water-use model

When water levels are insufficient for the amount needed for training, the volume of water available automatically turns red, so the users know they will need a supplementary water source (Figure 28).

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Collection Surface Area (m^2) | 879 | | Month | Month | Rainfall Data (mm) | Volume from Rain (L) | Volume per Month (Gallons) | Volume per Month from Recycled Water (L) | Volume per Month from Recycled Water (gal) | Withdrawl per Month (L) | Withdrawl per Month (gal) | Total Volume Available (L) | Total Volume Available (gal) |
| Approx. Efficiency | 0.8 | | Jan | Feb | 124.1 | 87267.12 | 23056 | 0 | 0 | 0 | 0 | 87267 | 23056 |
| Effective Surface Area (m^2) | 703.2 | | Feb | Mar | 76.9 | 54076.08 | 14287 | 0 | 0 | 0 | 0 | 141343 | 37343 |
| Tank Storage Capacity (L) | 66000 | | Mar | Apr | 79.4 | 55834.08 | 14751 | 908400 | 240000 | 1135500 | 300000 | -29923 | -7906 |
| Tank Storage Capacity (gal) | 17437 | | Apr | May | 134.8 | 94791.36 | 25044 | 90840000 | 24000000 | 113550000 | 30000000 | -22645131 | -5982862 |
| | | | May | Jun | 309.5 | 217640.4 | 57501 | 49962 | 13200 | 90840 | 24000 | -22468369 | -5936161 |
| | | | Jun | Jul | 341.2 | 239931.8 | 63390 | 36336 | 9600 | 45420 | 12000 | -22237521 | -5875171 |
| | | | Jul | Aug | 338.9 | 238314.5 | 62963 | 49962 | 13200 | 90840 | 24000 | -22040085 | -5823008 |
| | | | Aug | Sep | 336.2 | 236415.8 | 62461 | 36336 | 9600 | 45420 | 12000 | -21812753 | -5762947 |
| | | | Sep | Oct | 354.6 | 249354.7 | 65880 | 49962 | 13200 | 105980 | 28000 | -21619416 | -5711867 |
| | | | Oct | Nov | 409.4 | 287890.1 | 76061 | 36336 | 9600 | 45420 | 12000 | -21340610 | -5638206 |
| | | | Nov | Dec | 289.2 | 203365.4 | 53729 | 49962 | 13200 | 90840 | 24000 | -21178123 | -5595277 |
| | | | Dec | Jan | 202.8 | 142609 | 37677 | 36336 | 9600 | 60560 | 16000 | -21059738 | -5563999 |
| | | | | Total | 2997 | 2107490 | 556801 | 92093592 | 24331200 | | | | |

Figure 28: Computational tab on water-use model exhibiting a hypothetical instance when there would be insufficient water to meet the demand for training. The deficit total is highlighted in red to alert the user to the lack of water

The general limitations for the model include changing rainfall patterns over time and an assumed approximate efficiency factor of 0.8 for the whole system (Figure 28). This assumed efficiency factor is dependent on the cleanliness, maintenance, and upkeep of the system components. Using the “Inputs” tab in the model, the Bomberos can plan future training schedules around water availability. The model is a one-year model, as we recommended that the

Bomberos fully empty their tank system once a year in January (when there is no training) to clean the tanks.

We left the Excel model and SolidWorks files with the Bomberos so they can make future adjustments to system designs. If the technology to use these files becomes unavailable, we also printed the designs and left them at the training Academy to act as blueprints for the recommended systems.

## 5.2 Water Storage Designs

The following section outlines the proposed designs for the water storage and collection systems on the Academy training grounds. The proposed designs include three choices for a water storage system: a below-ground plastic tank system, a below-ground concrete tank, and an above-ground plastic tank system. An overview of the systems that would lead to the storage tanks are outlined below (Figure 29).

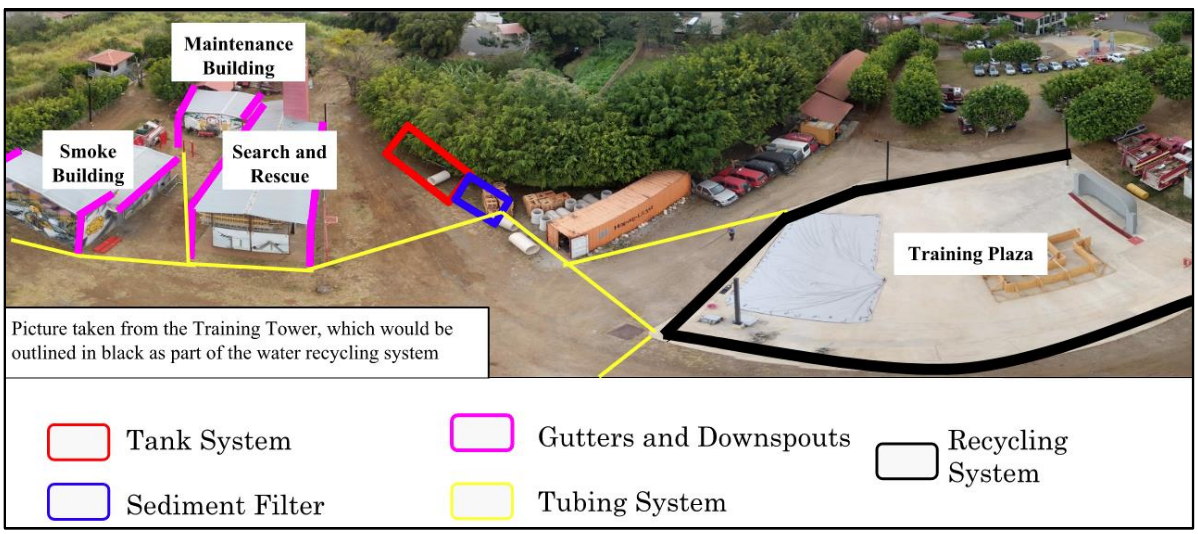



Figure 29: Overview of proposed designs at the San José Academy

For the plastic tanks, the local company EcoTank was chosen as the desired distributor for the low cost and convenience. EcoTank has prefabricated, plastic tanks with a 5,812 gallon capacity. Both of the below design proposals are three-tank systems as this would provide a 17,436 gallon storage capacity, while the average amount of water needed per month of training is 14,7000 gallons. Within each of the plastic choices, the tank system can be connected in two different ways; a waterfall connection or a bottom, U connection.

EcoTanks have adjustable inlets from 0.5 to 4 inches in diameter. The client can choose the most beneficial location on a tank for the inlet, without any additional cost. To connect the outlet to a firetruck a PVC fitting would need to be used to change the outlet pipe diameter to 4.5 inches.

Although EcoTank does not include an overflow system, their tanks are easily customizable. The plastic material of EcoTanks makes it possible to drill an overflow pipe at any desired location. Using a circular plastic saw attachment, one can drill a hole into the tank and secure a threaded bulkhead connection. An overflow pipe can then sit in this connection to direct excess water from the tank to the desired location. Whichever tank system and connection design is chosen, the tanks need to be preceded by a sediment filter. All of the design drawings and measurements with an analysis of various features is presented below.

Amco was chosen as the distributor for the concrete for the customized, below-ground tank due to their low cost, location near the Academy, and their prevalence in the region.

### 5.2.1 Below-Ground Plastic Tank System Design

The first option for the tank system is set down in a concrete structure so the tanks are predominantly underground. The inlet pipe for the tank system has a valve to control water flow inlet from the sediment filter in case of necessary maintenance. The outlet pipes also has a series of valves to isolate the tanks in case that maintenance and repairs are needed on a single tank in the system. Each tank has an air tube which acts as a pressure relief and ventilation system. The whole system has an overflow pipe which redirects water to the concrete canal structure along the back of the hill which currently acts as the main water conveyance system (See Figure 30).

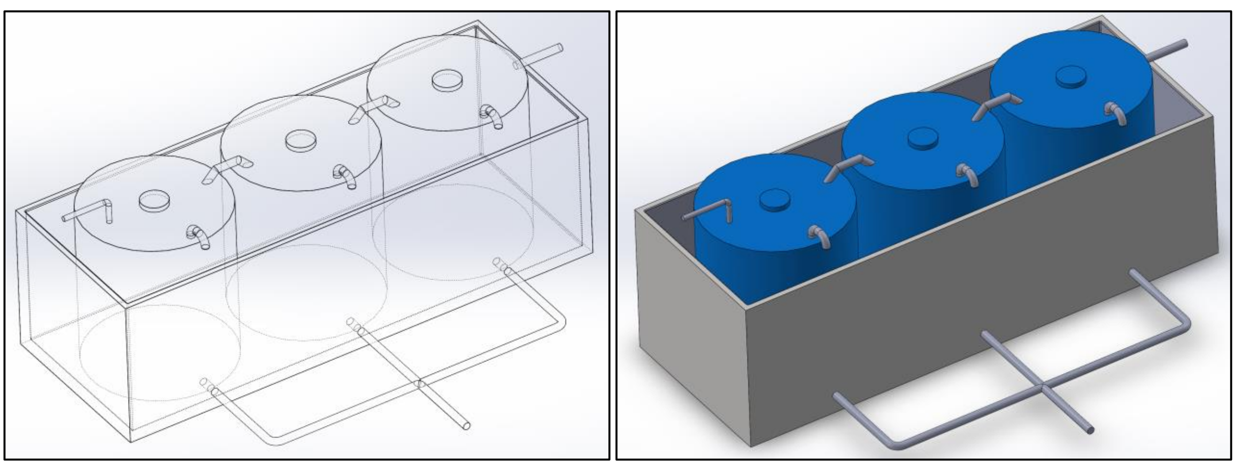


Figure 30: Models for the below-ground tank system with waterfall and U overflow connections

The concrete walls have a 0.127 m (5 in) thickness (Bucklin, 2009). For both above and below-ground options, the tank system is comprised of a three-tank series. Each tank is 3 m in diameter with a height of 3.65 m. The tank series requires 10.3 m in length of the available area near the Search and Rescue Building including the concrete walls and a 0.25 m space between each of the tanks. The tank series also takes up 3.76 m in width. The inlet, outlet, and overflow pipes have an outer diameter of 15 cm for easy connection to fire trucks. Full measurements for the system can be seen in the SolidWorks drawing in Figure 31.

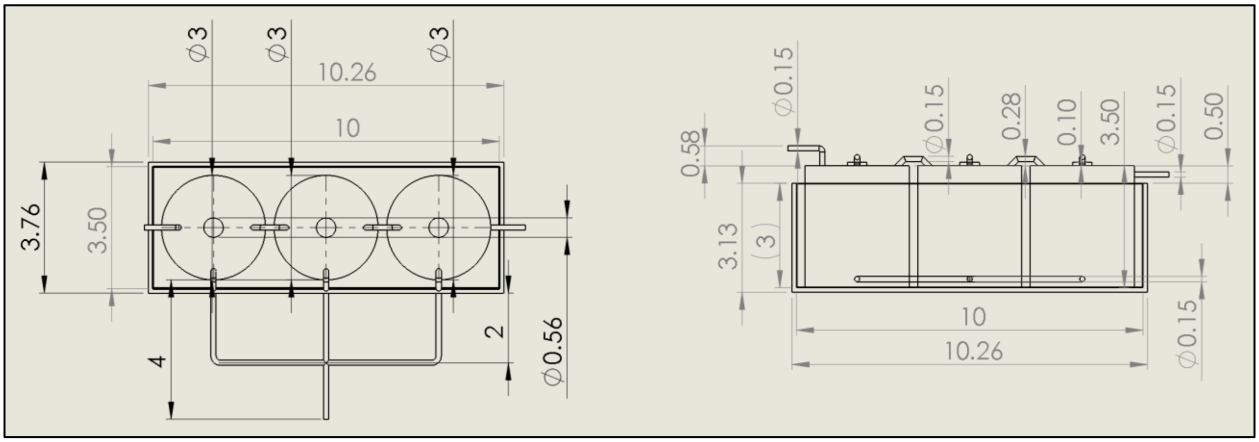



Figure 31: Dimensioned SolidWorks drawing of the below-ground, plastic tank system

### 5.2.2 Below-Ground Concrete Tank System Design

An alternative material for the below-ground recycling system is a fully concrete storage tank (Figure 32). This design resembles a simpler version of our first design iteration, (Section 4.5.2), but has smaller dimensions and less intricate features. The concrete option has the same capacity as the plastic tank series and dimensions of 8.25 meters long by 4 meters wide by 2 meters tall tank, with 13 centimeter thick walls. There is and inlet and outlet pipe attached to the tank, both of which have an inner diameter of 12 centimeters and an outer diameter of 15 centimeters, along with an overflow pipe that has the same dimensions. Both the inlet and outlet pipes have valves attached to them to prevent the water from flowing when needed. The airflow pipe is curved in an upside-down U formation to allow air to escape, but still prevent rainwater and other sediment from entering the tank. There is also an overflow pipe to allow excess water to flow when the tank is full and prevent any pipe bursting from pressure buildup.

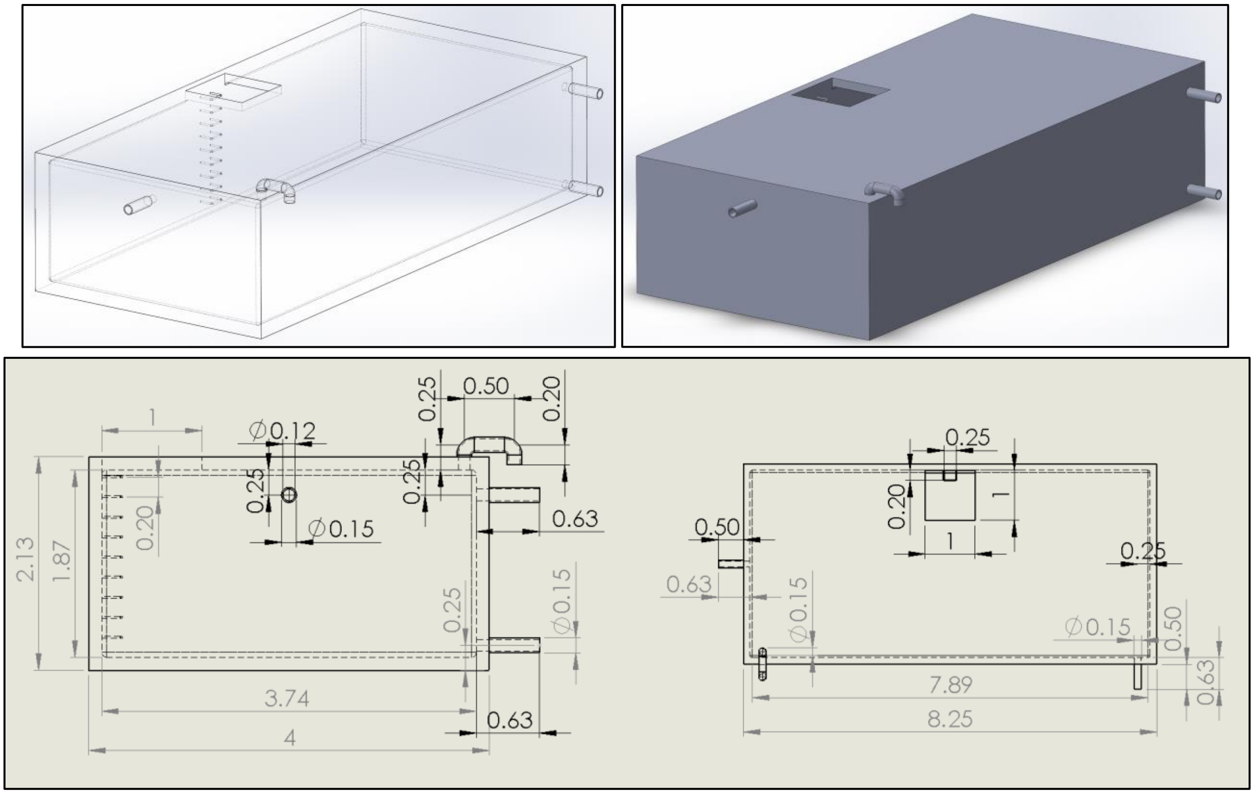


Figure 32: SolidWorks model and drawing for the below-ground concrete tank design

## 5.2.3 Above-Ground Tank System Design

The inlet pipe for the tank system has a valve to control water flow from the sediment filter in case maintenance is required. Connecting to the inlet pipe would be a 2.5 hp pump that forces the water from the sediment filter towards the inlet of the tank system. The outlet pipes also have a series of valves to isolate the tanks in case maintenance and repairs are needed on a single tank in the system. Each tank has an air tube which acts as a pressure relief and ventilation system. The whole system has an overflow pipe which redirects water to the concrete canal structure along the back of the hill which currently acts as the main water conveyance system (Figure 33).

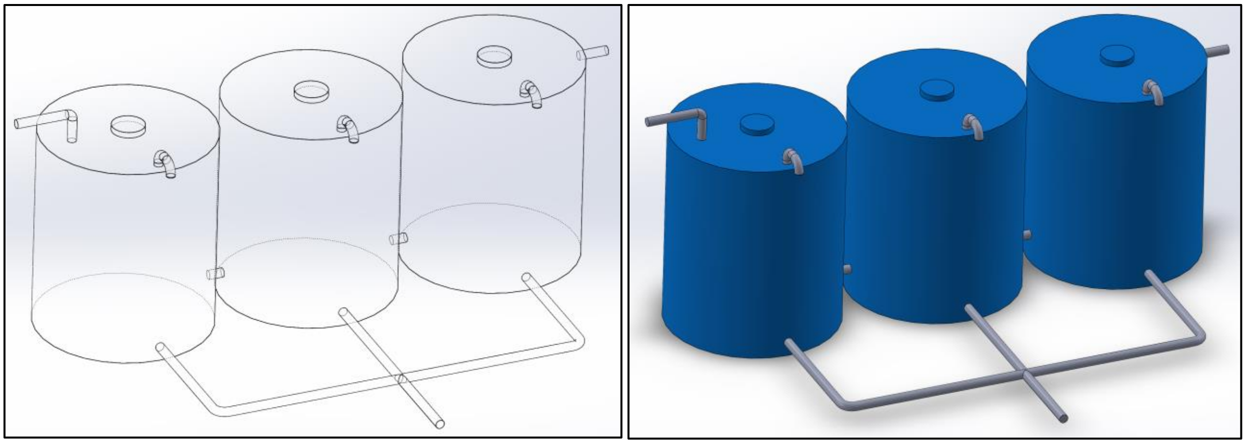


Figure 33: SolidWorks models for the above-ground tank system with bottom connections

For both above and below-ground options, the tank system is comprised of a three-tank series. Each tank is 3 m in diameter with a height of 3.65 m. The tank series requires 10.3 m in length of the available area near the Search and Rescue Building including the concrete walls and a 0.25 m space between each of the tanks. The tank series also takes up 3.76 m in width. The inlet, outlet, and overflow pipes have an outer diameter of 15 cm for easy connection to fire trucks. Full measurements for the system can be seen in the SolidWorks drawing in Figure 34.

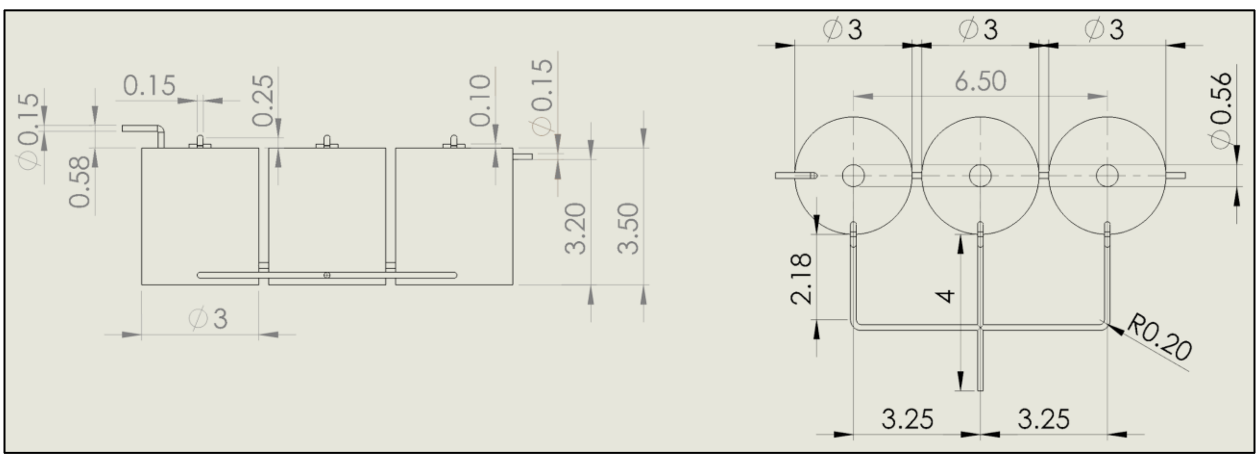



Figure 34: Dimensioned SolidWorks drawing of the above-ground tank system

## 5.2.4 Above-Ground, Below-Ground Tank System Comparison

The main difference between the tank system options are the cost and the other requirements (See Table 3 below). The concrete tank is much cheaper in terms of material costs but would have a much higher installation cost than the plastic tank systems. Between the above and below-ground systems, the main difference is the necessity for a pump, which requires much more, costly maintenance.

Table 3: Comparison between possible tank system designs

| Feature | Above-Ground System (Plastic) | Below-Ground System (Plastic) | Below-Ground System (Concrete) |
|---|---|---|---|
| Storage Capacity (gal) | 17,436 | 17,436 | 17,436 |
| Height of Tanks Above-ground (m) | 3.65 | 0.5 | 0 |
| Length without connections (m) | 9 | 10.3 | 8.25 |
| Width without connections(m) | 3 | 3.76 | 4 |
| Approximate Cost (colones) | ₡7,081,043 | ₡7,818,243 | ₡1,690,646 |
| Other Requirements | Needs a pump | None | None |

## 5.2.5 Tank System Connection Design Options

Within either the above or below-ground tank series, the tanks can be connected in two different ways. The first method is a waterfall connection between the tanks, where a pipe attaches at the top of one tank to the top of the next. This type of connection can be seen in the SolidWorks models in Figure 31. Using a  waterfall connection, the tanks fill in sequence, one at a time. All three tanks are connected at the bottom to draw water from a single connection port, regardless of which tank is filled. The waterfall connections would be isolated by putting closed ball valves on these bottom connections. Because of their location, maintenance on the waterfall connections is easier, although opening and closing valves to control water flow into specific tanks would be more difficult. Waterfall connections have the additional requirement that the heights of the tanks must be slightly offset in a sloped manner to facilitate the flow of water through the tank system.

The second tank connection option is a U-shaped pipe connection at the bottom of the tanks. This type of connection can be seen in Figure 33. For bottom connections, all three tanks would fill at the same rate, and the water level in all three tanks would remain constant. The same amount of water would be withdrawn from each tank with the bottom connections. This connection is more difficult to access if repairs or maintenance are required, but easier to operate in terms of filling tanks and using water.

## 5.2.6 Sediment Filter Design Options

A sediment filter is necessary before the water storage tank system to ensure that particulate contaminants do not enter the storage system. The recommended sediment filter is designed as a settling tank. As water flows through the tank, it has time for the natural separation of contaminants based on their density. Oils, fats, and other liquid contaminants will float to the surface of the water, as they have a lower density than water. Sediments will settle to the bottom of the tank, as they are much denser than water. This natural, mechanical process is facilitated by two vertical walls, which trap leaves and other, less-dense particulates.

We chose to design our own sediment filter to have the appropriate capacity to filter the amount of water required. The dimensions of the sediment filter are 4 m in length, 1 m in width, and 1.5 m in depth, with a total capacity of 1,585 gallons. Additional filter dimensions can be seen in Figure 35 below. Further rationale for the design of the sediment filter can be seen in Appendix I.

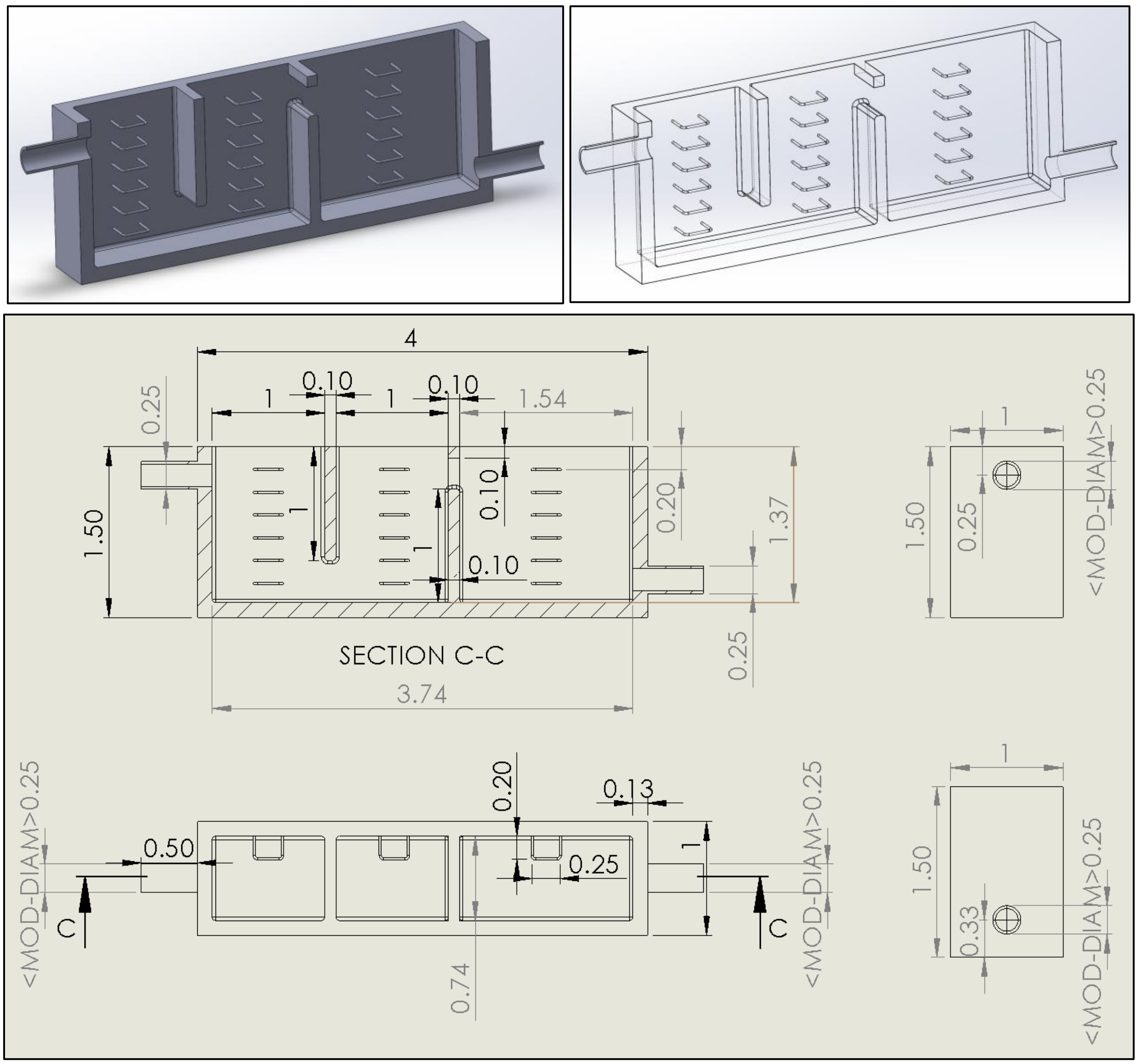



Figure 35: Pictures and dimensions of sediment filter. Order of views from left to right, top to bottom: solid, wireframe, side with section cut, front, top, back.

## 5.3 Rainwater Harvesting System Design

The following section outlines the proposed design for rainwater collection system that feeds the storage tank. The system design includes a water conveyance system consisting of gutters, downspouts, and piping to tank.

### 5.3.1 Water Conveyance and Piping Schematics

The current gutter, downspout, and drain infrastructure on the Maintenance Building and Smoke Building are utilized as part of the rainwater harvesting system design. Gutters, downspouts, and drains need to be added to the Search and Rescue Building (Figure 36). Added drains should have mesh screens, similar to other drains at the Academy, to prevent larger particles from entering. Piping underground would also need to be installed to redirect the water to the location of our designed tank (Figure 36).

The gutters for the Search and Rescue Building would be 15.3 m and 19.8 m long, the shorter length being on the North side of the building. Attached to the Easternmost side of each of the gutters would be downspouts that are each 3.7 m in length. Both of the downspouts would be connected to pipes that lead to the inlet of the sediment filter. The proposed drains at the bottom of the downspouts would have the same dimensions as the other drains that are currently implemented.

The piping from the Maintenance Building would need a pump because the grounds are slightly uphill. If a pump is not desired for cost and maintenance reasons, the rainwater harvesting system can be constructed without the roof of the Maintenance Building, only removing $61m^2$ (5%) of total roof collection area. Since the available water from recycling and rainwater harvesting on the other roofs and surfaces already greatly exceeds the demand for training and storage capacity of the tanks, this building could be excluded from the system without any negative effects. Cost estimates were calculated with the assumption that this building would not be included in the system.

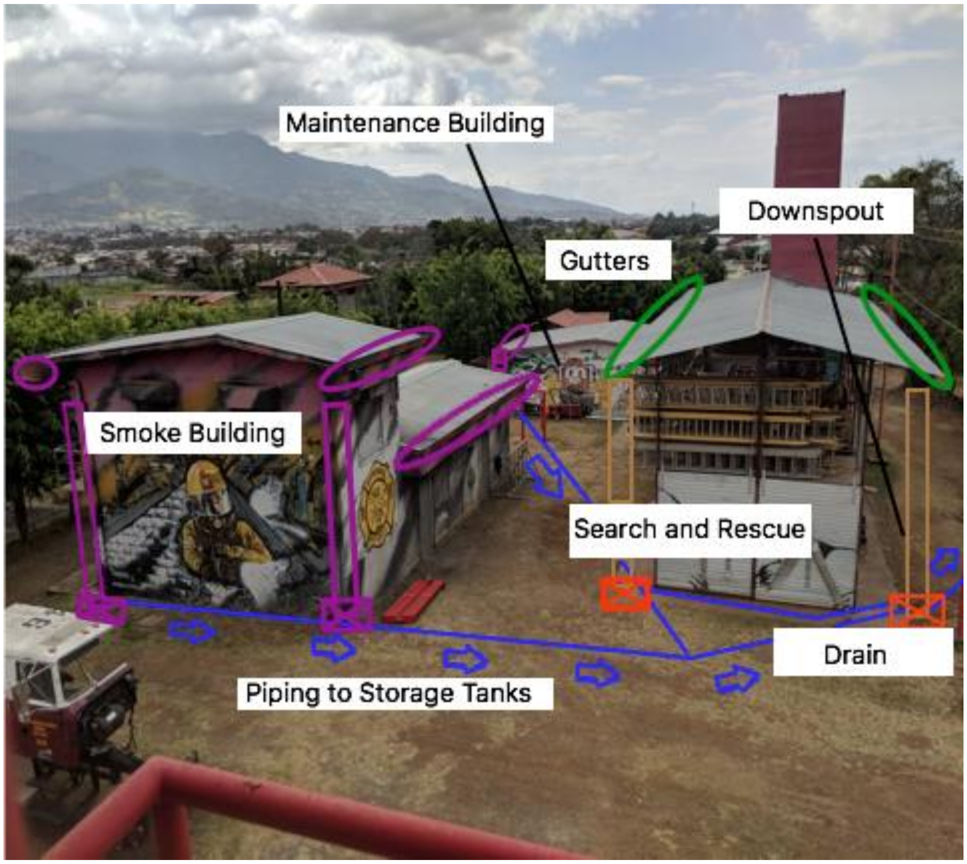


Figure 36: Proposed infrastructure for Smoke Building, Maintenance Building, and Search and Rescue. Purple lines represent preexisting conditions and can be found in Section 4.5 with labeled parts.

New piping (seen in blue in Figure 36 above), needs to be added to direct rainwater from the downspouts to the sediment filter. A total of 36 m piping was calculated for the new infrastructure. This calculation was done without the additional piping from the Maintenance Building as the Bomberos suggested that we try to avoid systems which would require a pump.

## 5.4 Water Recycling System Design-Training Plaza

### 5.4.1 Training Plaza Recycling Design

The picture below shows our suggestion for an improved version of the Academy's current drainage system for collecting runoff water in the Training Plaza area. The design calls for a 0.5 m addition of concrete in a sloped form to the current structure around the Training Plaza. The drain area is covered by a grate/mesh as a preliminary filtration system for large contaminants (Figure 38). This additional structure would redirect all of the water towards the current drains. This design allows the use of the current drains and trough with little extra maintenance required. SolidWorks models of the proposed design can be seen in Figure 37.

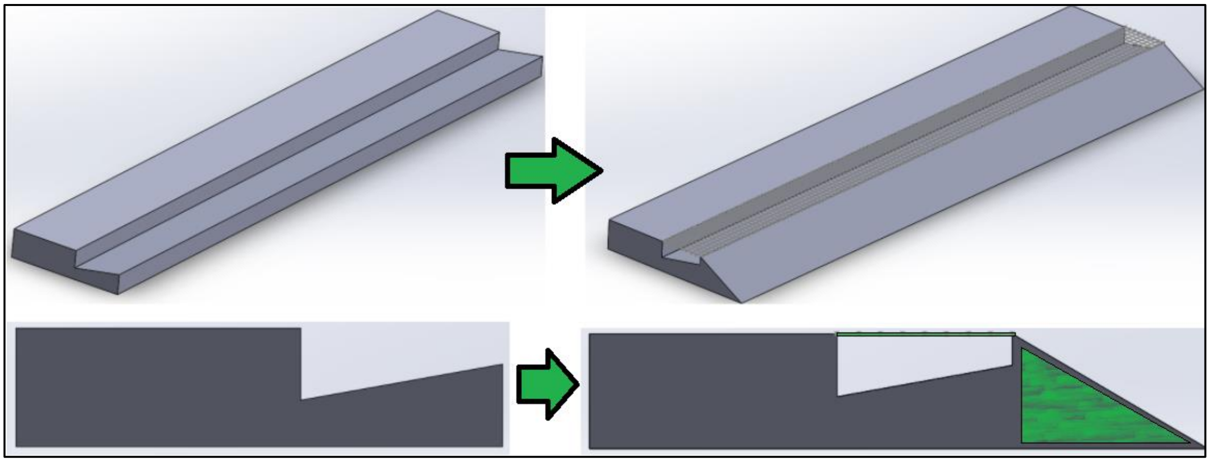


Figure 37: Model of proposed drainage system

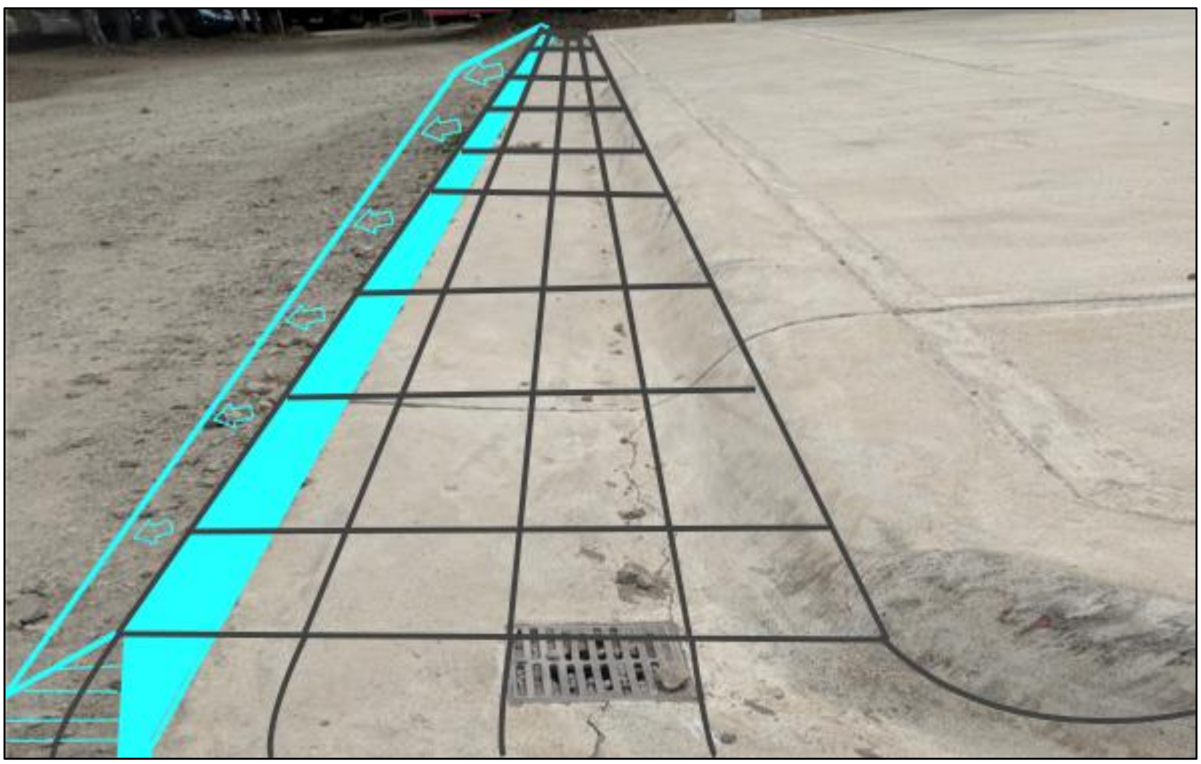


Figure 38: Proposed drainage system with grates

## 5.4.2 Water Conveyance Piping Schematic

Figure 39 shows conceptual drawings of proposed locations for the recycling system and piping network. The dark blue lines demonstrate the proposed piping infrastructure leading to the tank. A total of 30 m of piping is needed for the new infrastructure, with 12 m required for pipes from the lower side of the Training Plaza to the sediment filter, approximately 2 m for piping from the top drain to center drain, and 15.5 m needed for the piping from the center drain to the sediment filter. Water also flows from the pre-existing piping from the Training Tower into this proposed network (Figure 29). Specific pricing, sizing, and material of these pipes can be found in Appendix H.

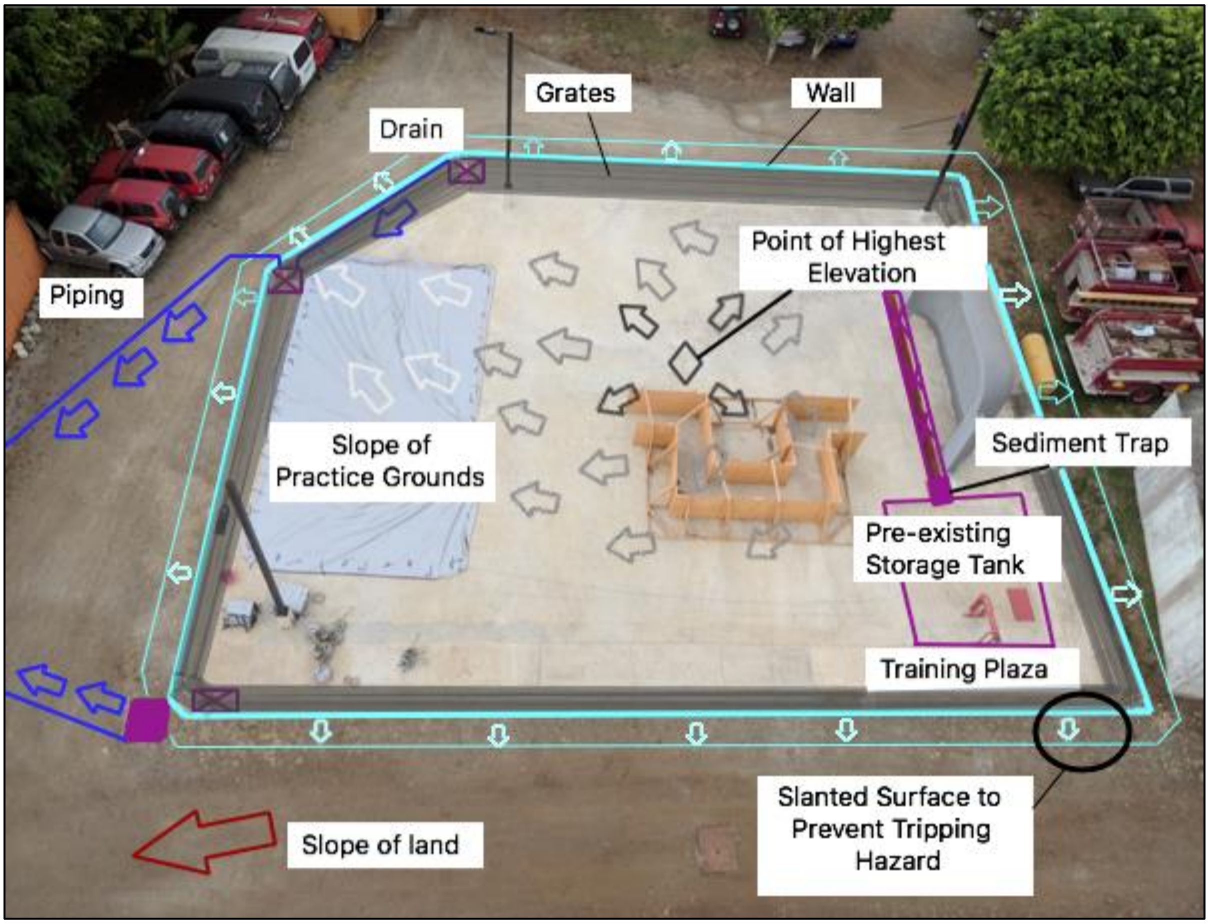



Figure 39: Proposed Training Plaza recycling and piping plan

## 5.5 Material Cost Estimates for Proposed Designs

We used our design proposals with the price information to calculate the approximate costs for each of the designed systems (Table 4). A conversion factor of 565 colones per dollar was used for all calculations. Fully itemized material costs and cost calculation spreadsheets for each of the proposed designs can be seen in Appendix H.

Table 4: Calculated material costs (approximate) for different designs in colones and dollars

| | Colones | Dollars |
|---|---|---|
| Below-Ground Plastic Tank System | **₡7,818,243** | **$13,933.17** |
| Below-Ground Concrete Tank System | **₡1,690,646** | **$3,087.87** |
| Above-Ground Plastic Tank System | **₡7,081,043** | **$12,532.82** |
| Recycling System Design | **₡2,330,515** | **$4,124.80** |
| Rainwater Harvesting System Design | **₡341,800** | **$604.96** |

Important to note when analyzing the numbers, these costs are only for initial materials and do not include installation or maintenance costs (with the exception of an excavation cost). For example, while the below-ground, concrete tank seems cheaper than the other tank system options, the installation costs for this process would be significantly greater than those for the above-ground tank system.

EcoTanks are designed for a 20-year lifetime, thus we extrapolated the prices of our proposed designs over 20-years to provide a cost per year average of the initial material (Table 5). After obtaining the average annual price of water from the facilities managers at the Academy, we were able to complete a rough cost-savings analysis. While the analysis does not include all installation costs, it includes the cost of excavating for the systems.

Table 5: Cost analysis of investment over a 20-year lifespan

| **20-Year Breakdown** | | | | | | |
|---|---|---|---|---|---|---|
| | **Systems with Below-Ground Plastic** | **Systems with Below-Ground Concrete** | **Systems with Above-Ground (Plastic)** | *Labor and construction costs for the below-ground, concrete tank would be much higher than represented only by the material costs | **Average Annual Cost of Water at Academy** | |
| **Total Cost** | | | | | Colones | ₡3,989,537 |
| Colones | ₡10.491.558 | ₡4.362.961 | ₡9.753.358 | | Dollars | $7,061.13 |
| Dollars | $18,567 | $7,722 | $17,263 | | | |
| **Annual cost over 20-year lifetime** | | | | | | |
| Colones | ₡524.528 | ₡1218.148 | ₡487.668 | | | |
| Dollars | $928 | $386 | $863 | | | |
| **Estimated annual cost savings over 20-years** | **Below-Ground Plastic** | **Below-Ground Concrete** | **Above-Ground (Plastic)** | *Actual cost savings would be lower as "Academy water costs" include potable water sanitary water use which would not be replaced by the proposed system | | |
| Colones | ₡3.465.0090 | ₡3.771.388 | ₡3.501.869 | | | |
| Dollars | $6,313 | $6,675 | $6,198 | | | |

We determined that the Academy currently spends a little over $7,000 a year for water. With initial system costs between $7,700 and $18,500, the maximum return on investment for the material costs would be just under 3 years. The annual cost savings for the Academy are around $6,000 with the implementation of any of these systems.

## 5.6 Safety and Maintenance Procedures

For every proposed design we outlined basic procedures for safety, maintenance, and general system upkeep. System longevity depends on consistent maintenance; thus it is important that the Bomberos follow these guidelines. This will ensure them the greatest return on the initial investment by minimizing future replacement costs. Additionally, to uphold the Bomberos' value of "protecting what they love", (lo que amamos) it is pertinent for them to adhere to the safety recommendations. These include cleaning the tank system, sediment filter, rainwater harvesting system infrastructure, and recycling infrastructure to prevent contamination. We also considered safety features within the designs, including ladders that adhere to OSHA standards and appropriately marking tripping hazards. The full safety and maintenance procedures for each proposed design can be found in Appendix J.

# 6.0 Recommendations

Throughout our design process, we discovered an immense capacity to capture rainwater and recycled water on the Academy grounds. Using this information, we created additional design recommendations for rainwater harvesting systems and water recycling systems beyond those requested by the Bomberos so they could fully take advantage of the available water. We additionally provided design recommendations to further prevent contamination of the stored water based on our background research.

## 6.1 Rainwater Harvesting System Recommendations

### 6.1.1 An Additional Rainwater Harvesting System at the Administration Area

Upon analyzing the roofs in the Administration Area of the Academy, we discovered there was 1435m$^2$ of surface area, with pre-existing infrastructure to collect rainwater (Figure 40). Using this roof area and the average rainfall data for San José, we determined that almost a million gallons of rainwater could be captured on an annual basis from the roofs in the Administration Area (See Calculations in Appendix K). To take full advantage of all available water, we recommend the Bomberos implement a rainwater harvesting system and storage tank on these roofs.

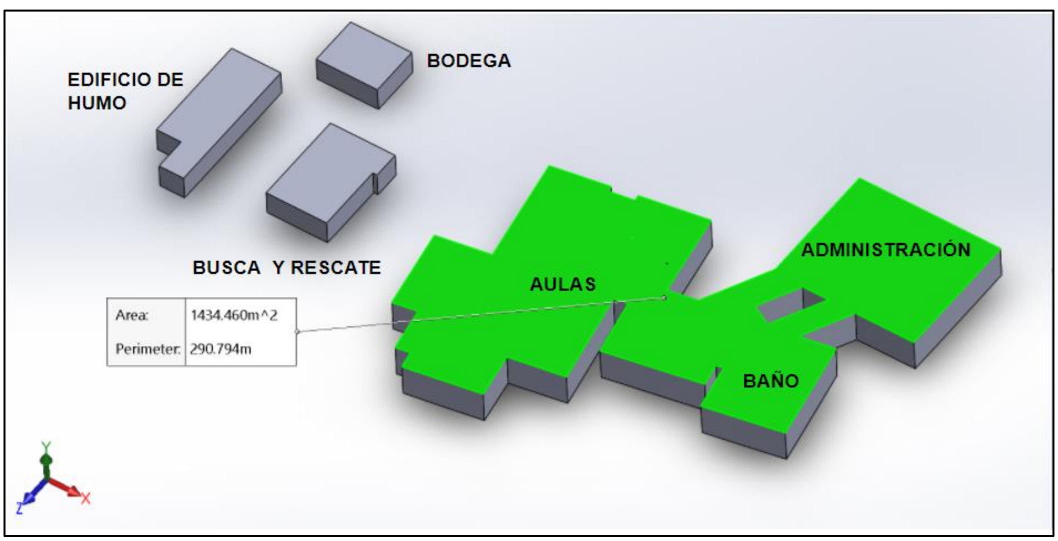



Figure 40: Roof area available from Training grounds (gray) and Administration Building Network (green)

There are numerous possibilities for the use of extra water from a rainwater harvesting tank in the Administration Area. The training schedule at the Academy could be expanded to include more water trainings, or the non-potable water could be used for other purposes including washing floors, fire trucks, sanitary services. Additionally, the excess water could be given to a third party, or returned to the city supply.

We developed general concept designs for three possible tanks to be located downhill from the roofs in an unused area with sufficient space available. These included a design for two below-ground, concrete tanks and one above-ground, cylindrical tank. The general concept designs can be seen in Figure 41 below and more details about location, available space, and design details can be found in Appendix L. The overall tank dimensions and included features in the concept designs are those recommended, although they should only be used as general guidelines and not full designs.

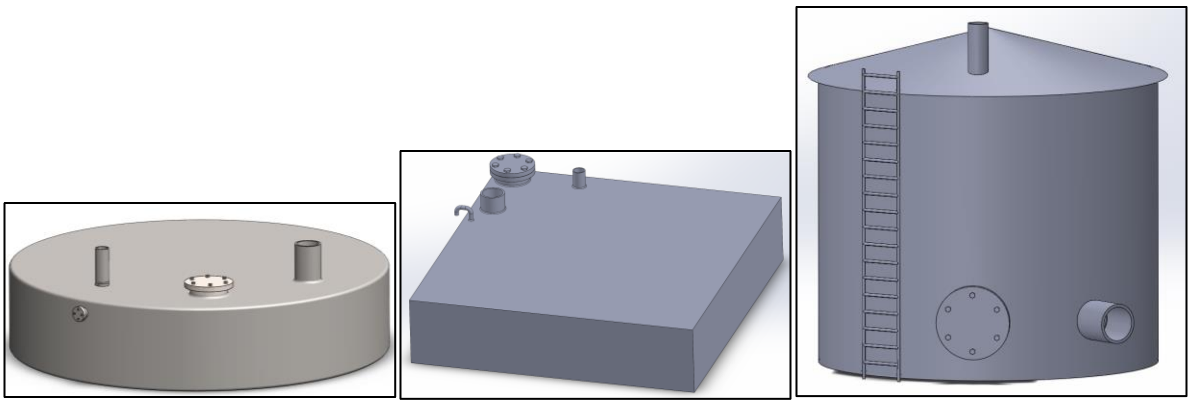


Figure 41: SolidWorks designs for proposed tanks in Administration Area. The left and middle tanks are underground, concrete tanks, and the right tank is an above-ground, metal tank.

A tank in the Administration Area would require a sediment filter for the water before entry. Our recommendation for this would be an above-ground filter directly below the assumed outlet pipes from the existing infrastructure. A concept design for the sediment filter can be seen in Figure 42 with further details in Appendix L. Again, the concept design should be used as a guideline for general features rather than specific dimensions and materials.

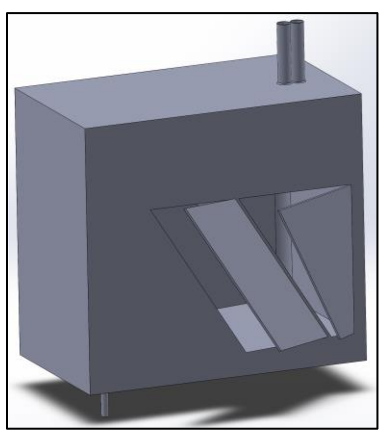


Figure 42: Concept design for proposed sediment filter for rainwater harvesting tank in Administration Area.

### 6.1.2 General Recommendations for Rainwater Harvesting Systems

For every rainwater harvesting system implementation, additional steps should be taken to minimize the number of solids in the tank and contamination in the water. To maintain a closed system, mesh screens should be secured over the end of any inlet or outlet pipe into a tank or any exposed part of the sediment filter. The mesh acts for two purposes; filtering any larger particulates from the water and preventing the entry of outside matter into the water storage supply. The mesh size should be fine enough to prevent the entry of mosquitos and spiders that may come through the inlet pipe and use the tank as a breeding ground. This is a low-cost option to protect the standing water from external contamination.

An additional measure to limit the amount of contamination of water going into the tank is to install gutter leaf screens. These are wire mesh that sit on the tops of the gutters and prevent the entry of different particles. The mesh is often angled away from roof to facilitate cleaning. This system acts as a primary filtration for large contaminants, especially leaves.

## 6.2 Recycling System Recommendations

Another possible design for a recycling system on the Training Plaza from the one proposed in the preceding sections would be excavating around the current drain system and creating a new, more effective system. This would include long sections of grates at the bottom of a slightly-sloped surface to catch as much water as possible. The grates used would be similar to those already in place around the Training Tower, allowing large quantities of water to flow in from any direction. By using these large grates, no extra safety measures would need to be established as the system would be entirely underground and the grates could support human weight. This system would need attentive maintenance as leaves and small rocks could enter through the drains, which would require cleaning a large area.

A possible solution for the Training Tower area would be to modify the surrounding ground material to allow for a better water flow on each side. This modification would involve replacing the current gravel area with concrete. Replacing this section with concrete would allow for much more efficient water flow that is used during training. The concrete would be slightly sloped away from the tower to control the path of the water. Surrounding this new concrete area would be a grate and drain system. This system would trace the perimeter of the concrete and capture the water, which lands on the concrete area independent of the direction it flows during training practices. These drains would all connect underground and flow in a single pipe to the storage tank. Since this entire system is underground, the only possible danger would be a tripping hazard on the drains if the grates are removed.

## 6.3 Additional Recommendations

For training practices that require starting fires, the Bomberos could use propane torches to ignite fires and eliminate water from becoming contaminated. If they wish to continue using diesel and gasoline, they could purchase a PIG Oily Water Filter, as seen in Figure 5. They would set up this filter before water reaches the tank so it could separate out contaminants.

For the Search and Rescue Building, adding fog nets that lead to a drainage system would efficiently recycle the mist expended during training exercises. Although the nets would allow for recycling, the cost for the little quantity of water that would be obtained is probably not worth the investment.

# 7.0 Conclusion

The goal of this project was to increase water sustainability by maximizing water collection and reuse at the firefighter training Academy in San José. We created possible schematics and designs for rainwater harvesting and water recycling systems using the current infrastructure at the Academy. These designs were based on an understanding of the Bomberos' training water practices and similar systems around the world. We developed an approximate cost estimate for each proposed design to aid the Bomberos in choosing which design would best meet the needs of the Academy. Our design proposals included a below-ground plastic tank system with an approximate cost of $13,900, an above-ground plastic tank system at $12,500, a below-ground concrete tank at $3,000, a below-ground sediment filter costing $375, a water recycling system for the Training Plaza costing $4,100, and rainwater harvesting infrastructure costing $600. Additionally, for each design component we created safety and maintenance features and recommendations for Academy personnel.

In developing an understanding of water use at the Academy, both our team and the Bomberos were surprised at the immense available surface area for rainwater collection. We found that the capacity of rainwater that can be collected from the roof areas around the training grounds was more than six times that of water used in a typical year of training. Rainwater harvesting combined with water recycling further increases this value of excess water. Our designs developed throughout the project were limited not by rainwater availability, but by physical space available on the Academy grounds and the high costs of water storage tanks. Recommendations for future expansion of this project are outlined throughout the report. If the financial means of the Bomberos changes in the future, they can take full advantage of the available rainwater and expand their water-use at the Academy.

Initially we were given a broad scope for our project with the goal of increasing water for training through rainwater harvesting and water recycling methods. We decided to design systems in the area of the Administration buildings and in the Training Areas to fully take advantage of all available rainwater collection surfaces and provide the Bomberos with the opportunity to expand water use during training. During our project process, the Bomberos asked us to scale down our project and focus designs to only the Training Areas for cost purposes. Throughout the process, we learned an important lesson in engineering consulting; that the designs must be feasible for the client both in terms of function and cost. While starting the process with creative ideas can be beneficial, the ultimate goal is to produce useful and realistic designs. The Bomberos were instrumental in helping us narrow the project scope to elevate its feasibility for implementation at the Academy.

Finances for the implementation of the project project depend on varying factors in each of the designs. Due to this, our recommended systems are only feasible for the Bomberos to implement if they have an available budget. Implementing the systems on their campus in the future would be challenging without sufficient funds. The water both from rainfall and reuse purposes is free, as opposed to a commodity that the Bomberos currently pay for. The designs in this proposal are cost effective, yielding an average return on investment time of 3 years. Although the initial material costs are high, it is important to keep in mind the return on investment when choosing a system design. A more detailed breakdown of the return on investment details can be found in Section 5.5.

While ideally our work leads to a system where 100% of the water needs of the Academy is met by rainfall and recycled sources, we understand that our proposal of rainwater and recycled water may yield a supplementary water source, especially due to the limitations of storage space on the grounds and costs. High water demand for different training practices, proper maintenance upkeep, and annual variation in rain patterns contribute to the effectiveness of our designs.

With an implemented, sustainable water system as proposed in our designs, the Academy should be able to meet its water needs for trainings and potentially expand training practices. With changing climate patterns and growing water scarcity around the world, we see a potential for similar projects in other fire departments or facilities with high water use. While visiting the fire station in Pacayas, we discovered the directors were interested in a similar water storage system. This interest stems from the high quantity of annual rainfall that is currently unused and the tensions created between the community and firefighters when they use municipal, potable water supplies during trainings. While many of the general recommendations can be applied to individual stations, specific designs or qualitative analysis varies by location dependent on rainfall patterns, training facilities, and training activities. Although specific for the San José training Academy, we hope the general recommendations and detailed procedures can be used to undertake future projects.

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# Appendix A: Descriptive Outline of Academy and Structures

There are a number of structures on the Academy used for training. A Search and Rescue Building is used for trainings where firefighters learn to save people in complex scenarios and includes a labyrinth. To the side of the Search and Rescue Building is the Smoke Building where firefighters learn how to navigate in heavy smoke. The Smoke Building is outfitted already with gutters, pipes, and drains (Figures A.1-A.4).

| | |
|---|---|
|  |  |
| **Figure A.1:** Search and Rescue | **Figure A.2:** Smoke Building |
|  |  |
| **Figure A.3:** Underside of rafters Search and Rescue | **Figure A.4:** Drainage system for Smoke Building |

Beyond these buildings, the main functions on the Academy include the Concrete Training Pad (Figure A.5), where firefighters learn proper equipment use, especially related to hoses. The main structure on the Academy grounds is the seven-story tower used to simulate fires and rescues in tall buildings with fixed sprinkler systems. Most of the water used in training is expended in these areas. In the far corner of the Training Plaza, there is a 4,000L water storage tank, but the ground slopes in the direction opposite from the drain in this area (Figure A.6). There is a drain on each side of the bottom of the tower, but the over collection area is not sloped in any direction.

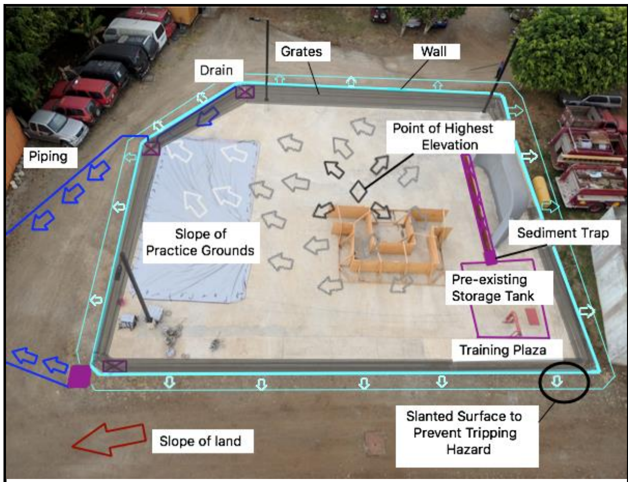



**Figure A.5:** Concrete Training Pad with arrows in direction of slight slope of pad

**Figure A.6:** Drain from wall into small tank on training pad

The lack of drainage infrastructure can be seen below where water runoff from training has carved a path through the Academy grounds (Figure A.7).

**Figure A.7:** Runoff pathway created by the water from the training areas

Figure A.8 below shows the proposed location for the tank by the project manager at the Academy.

**Figure A.8:** Possible tank location (as suggested by Allan)

The Training Tower (Figure A.9) is one of the most water costly aspect of the Academy training facility. The tower has a “fixed system” where a sprinkler system attaches to a fire truck during trainings (Figure A.10).


**Figure A.9:** Training Tower

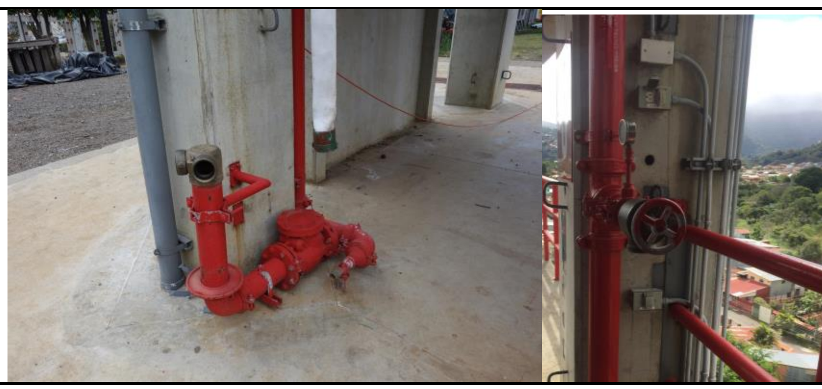


**Figure A.10:** Water Inlet and Piping System for Tower

**Figure A.11:** Original Sediment Traps Underneath Concrete Training Pad

# Appendix B: Detailed Notes and Observations from Massachusetts Fire Academy

December 5, 2017
Stow, MA
Information gathered from: Mr. Joseph Klucznik-Deputy Director
James DiRico-Director of Capital Asset Management
Frederic Corazzini-Deputy Director of Capital Asset Management

Current Water Supply:

- The Stow facility pulls water from free from a reservoir across the street from the facility
- The Springfield training facility pays to receive water from the city domestic water supply

Tanks:

- The Stow facility has a 44,000 gallon concrete water tank
- The Springfield facility has two, 20,000 gallon fiberglass tanks
  - Tank is anchored to a concrete pad
- Any metal components of the tanks are made of black iron and cast iron Victaulic couplings

Treatment:

- Not purified, but treated
  - Removes some solid contaminants (straw)
  - Removes some of the smell
- Water used for training is treated with an electrostatic treatment system to remove bacteria in the system
  - Dolphin Systems WaterCare product used for treatment
- A series of sediment grates with holes of decreasing size filter out solids from water before tank (Stow)
  - Use a settling tank to collect
- Use a weir to collect large debris in Springfield
  - Collect straw and large particles

General Maintenance:

- Water must be exchanged now and again due to particulate buildup
- Water is flushed and completely replaced every 5 weeks (Stow) or 10 weeks (Springfield)
- Sumps, reservoirs, and tanks are emptied and washed down once a year

Water Reclamation System:

- 75-80% training water reclaimed
- Water lands on asphalt and flows to drains located around the campus
- Water is used in gas school for vapor protection and suppression (protect from exposures)
- Water is used in equipment testing to teach proper equipment handling technique
- On burn building: scuppers collect water which cascades down the building to drains in the yard
    - Often get clogged with straw (Figure B.1-B.2)

**Figure B.1:** Scuppers on burn building clogged with straw used to simulate fire situations at the Massachusetts Fire Academy (image by Kelly Vodola)

**Figure B.2:** Scuppers on burn building clogged with straw used to simulate fire situations at the Massachusetts Fire Academy (image by Kelly Vodola)

- Whole campus is on a slight slope leading to the drains (Figure B.3)


**Figure B.3:** Image showing the slight slope down from the burn building simulator to the main drains on the campus (image taken by Joe Klucznik)

- There are specific reclamation points around campus
    - Often get clogged with straw (Figure B.4)

**Figure B.4:** Examples of drains clogged with straw and leaves used for burn material to simulate fires during training at the Massachusetts Fire Academy Scuppers on burn building clogged with straw used to simulate fire situations at the Massachusetts Fire Academy (images by Kelly Vodola)

- Facilities need 2-3 weeks/year shut down for cleaning operations and maintenance

Other Suppression Techniques

- Dry chemical extinguishers are used for some fires
    - Used in a separate location so chemicals don't get into water

Burn Details

- Propane sometimes used as fuel
- Straw and wood pallets used for relatively clean burning
- No paints or contaminants are used to make sure smoke isn't toxic
- Natural gas sometimes used as fuel
- Burn building, dumpster prop, car props filled with straw for simulations (Figure B.5)
- Smaller props include motors, mailboxes
- Simulations used to teach proper methods and safety
- Burn building materials of construction limit what you can burn in the building


**Figure B.5:** Images of props used in burn simulations at Stow Academy. Burn building (left), dumpster (top right) and a prop car (bottom right) (images taken by Kelly Vodola)

MFA Programs

- Career Recruit Program
    - 5 days/week
    - 72 people
    - 10 week-long program
    - Runs all year
- Call Volunteer Program
    - 2 nights/week and weekends
    - 6 programs/year
    - 15 weeks long/program
- MA has around 12,000 full time firefighters, 13,000 volunteer firefighters

# Appendix C: Interview Questions for Project Stakeholders

**Goals:**

- ★ Understand wants and needs for water recycling system
- ★ Make system comfortable and understandable (gauge their level of technical knowledge?)
- ★ Determine how a system would affect trainings
- ★ Ensure they are able and willing to maintain a system

**Director (Ronny LaTouche)**

- What is your title at the Academy?
- What is your role/relation to the training Academy?
- How do you feel about Costa Rica's water use?
- What is your standpoint on sustainability?
    - Do you think water sustainability is a high priority for the Bomberos?
- Do you have any tentative ideas already in place for either the rainwater harvesting system or water recycling system?
- Do you already have materials or supplies that you wanted to use?
- How much water do you think the Academy uses on a typical training day?
- How often do you have to ship in trucks of water? How much water comes on each truck?
- Where is the best place for a storage tank? Where would it be least invasive?
- Who would maintain a rainwater harvesting and recycling system?
    - Have on hand information about how much maintenance is generally required:
        - First-flush devices: After rainfall, contaminated water must be drained either manually or automatically from the device.
        - Someone will need to evaluate gutters, downspouts, and first- flush devices once a year for sediment and debris content and remove the contaminants if any are present
        - Sediment traps must be cleaned (after an extended period of time- try to give concrete answer like once a month)
- What concerns would you have with keeping water stored for long periods of time?
- How willing are you to pause training to install a recycling system?
        - Plan on having an estimate of how long it could take from local civil engineers or past projects

**Facility Manager**

- What is your title at the Academy?
- What is your role/relation to the training Academy?
- How do you feel about Costa Rica's water use?
- What is your standpoint on sustainability?
    - Do you think water sustainability is a high priority for the Bomberos?
- Do you have any tentative ideas already in place for either the rainwater harvesting system or water recycling system?

- Do we already have materials or supplies that you wanted to use?
- How much water do you think the Academy uses on a typical training day?
- How often do you have to ship in trucks of water and how much comes on each?
- Where is the best place for a storage tank, where would it be least invasive?
- Who would maintain a rainwater harvesting and recycling system?
    - Have on hand information about how much maintenance is generally required:
        - First-flush devices:After rainfall, contaminated water must be drained either manually or automatically from the device.
        - Someone will need to evaluate gutters, downspouts, and first- flush devices once a year for sediment and debris content and remove the contaminants if any are present
        - Sediment traps must be cleaned (after an extended period of time- try to give concrete answer like once a month)
- Which training activities require the most water?
- What concerns would you have with keeping water stored for long periods of time?
- What are the different ways you use water during trainings?
- What type of materials do you use in burn simulations?
- What infrastructure is already in place to drain the water from training activities?
- How willing are you to pause training to install a recycling system?
        - Plan on having an estimate of how long it could take from local civil engineers or past projects

**Training operations director**

- What is your title at the Academy?
- What is your role/relation to the training Academy?
- How do you feel about Costa Rica's water use?
- What is your standpoint on sustainability?
    - Do you think water sustainability is a high priority for the Bomberos?
- Do you have any tentative ideas already in place for either the rainwater harvesting system or water recycling system?
- Do we already have materials or supplies that you wanted to use?
- How often do firefighters train? Is there a schedule?
    - How many firefighters per training?
    - How long are trainings?
- How much water do you think the Academy uses on a typical training day?
- How severe is the lack of water at the Academy?
    - Can you remember a time when trainings were cancelled because of lack of water?
- How often do you have to ship in trucks of water and how much comes on each?
- Which training activities require the most water?
- Who would maintain a rainwater harvesting and recycling system?
    - Have on hand information about how much maintenance is generally required:

        - First-flush devices: After rainfall, contaminated water must be drained either manually or automatically from the device.
        - Someone will need to evaluate gutters, downspouts, and first- flush devices once a year for sediment and debris content and remove the contaminants if any are present
        - Sediment traps must be cleaned (after an extended period of time- try to give concrete answer like once a month)
- What type of materials do you use in burn simulations?
- How willing are you to pause training and install a recycling system?

**Station chiefs at nearby stations**

- What is your title at the Academy?
- What is your role?
- How do you feel about Costa Rica's water use?
- What is your standpoint on sustainability?
    - Do you think water sustainability is a high priority for the Bomberos?
- Where do you get your water from? Costs associated?
- What effect does bringing water to the training Academy have on your station?
- How is it decided when you will bring water to the training Academy?
- How much water do you think the training Academy uses on a typical training day?
- How often do you have to ship in trucks of water and how much comes on each?

**Firefighters who undergo trainings**

- What is your title at the Academy?
- What is your role at the training Academy?
- How do you feel about Costa Rica's water use?
- What is your standpoint on sustainability?
    - Do you think water sustainability is a high priority for the Bomberos?
- How much water do you think the Academy uses on a typical training day?
- How severe is the lack of water at the Academy?
    - Can you remember a time when trainings were cancelled because of lack of water?
- Are there any training exercises involving water that you do not think are very beneficial?
- What are the different ways you use water during trainings?

# Appendix D: Interview Notes from Interviews with Various Bomberos Personnel and Stakeholders

**Director of the National Training Academy- Don Ronny LaTouche**

- What is your title in the Academy?
  - Director of the Academy
- How do you feel about water use in Costa Rica?
  - We waste a lot of water
- What is your point of view of sustainability in relation to water and use of water? Do you think using water sustainably is a high priority for the Bomberos?
  - We have a poor use of water, we always use potable water for everything, even tasks that don't need clean water
  - We should use residual/recycled water-not potable for those tasks
  - Yes, water use and sustainability are a high priority for us because we supply water for all of our activities
  - We use water in all of our activities and are always thinking about its use and understand it better
- We know you already presented us ideas about our project, but do you have any other additional ideas or thoughts for a possible system?
  - The red tank is connected to a water well and 2 hydrants now with non-potable water that didn't have before (when first designed the project)
  - Now we have a sprinkler system in the Administration Area
- How much water would you estimate the Bomberos use in one typical training session?
  - 10,000 gallons on a typical day of training
- How frequently do you have to bring fire trucks for training and how much water do they bring?
  - Need 5 trucks - each one has 1,500 gallons
- What worries would you have with storing water for long periods of time?
  - If it is in a closed tank, there aren't many concerns, but if it is an open tank, there would be a lot more problems
  - Also need separation system for combustible contaminants
- Would you be opposed to pausing training to install a recycling system?
  - We can stop/pause training activities for establishing system

**Main Takeaways**

- Potable water is used for all activities, even where non-potable/recycled water could be used
- Because the Bomberos use water-especially in high quantities, they have a greater understanding/appreciation for responsible water use

**Allan Rodriguez-Training Operations director**

- What is your position/Title?
  - Coordinates classes in charge de classroom area
  - Our project manager
  - Was firefighter then operations director then at Academy
- How do you feel about water use in CR?
  - Is very responsible (in cost or coverage?)

- Water in CR is very cheap
- Not a question of cost
- $2/month in most areas
- People don't understand value water, only use and use
- People learn is water is renewable resource and inexhaustible (what they learn in school)
- Is important for people to understand its importance

- What is your point of view on sustainability of water and the use of water?
  - Point of view in our work: Water is an element required for work-best method to put out fires
  - Study of types of fires etc. should be a study of how to best use water responsibly
  - You have to have an awareness of water use
- Is sustainable water use a priority for the Bomberos?
  - Yes for Bomberos and all of country
- Do you have ideas about a system?
  - Recollect water in jet practice field
  - Have a well that pumps water from hydrant to tank at bottom of Academy
  - Before hydrant and other tank, had to use other units to bring water to tank (big red one)
    - Want something similar up top
- Are there materials you want us to use?
  - No, only think of 3 B's, bueno, bonito, y barato. (Translated: good, beautiful, and cheap)
- Training of Firefighters
  - There is annual agenda
  - Some courses use more water than others
  - Fixed system (tower) use more water—4 this year Sistema de fija contra los incencios
  - Hose trainings use water all day
  - Fire simulations use lots of water
  - Search and rescue trainings use some water
  - 24 firefighters/course
  - 2-5 dias/curso
  - 3,000 gallons of water per day of typical training
- Is there a water shortage?
  - In cities, access to water is not a problem
  - River in Cartago
  - Central distribution system in town (Tuia madre)
  - Bigger problem in rural areas
- What size trucks are used transport water around for trainings?
  - 1,000 gallons/truck
  - In fixed system, trainings for rapid response, search and rescue require trucks and lots of water
- Who would be in charge of maintenance?
  - Campus (blue shirt people)
  - Here every day for maintenance
  - Campus, facilidades (buildings), administration, business services (4 areas of academia)
- What do you use to simulate fires?
  - Use wood, gas (1 gallon), and 2 gallons of diesel
  - In all parts
  - Almost never in the tower

    - Usually in search and rescue
    - Usually use smoke machine
- Are you willing to pause training to install a system?
    - Yes-will pause training to build (also have new building in process of construction)
    - We can do a general calculation for cost of systems

**Main Takeaways**

- Interest stems not necessarily from money or need but from personal opinions about sustainable water use
    - Conserve potable water supplies
- People are beginning to realize how important water is
- Costa Rica has wide access to water in the urban areas
- Mostly looking for system right around training grounds
- There are people in place to maintain a system
- Safety for a system is also important and a consideration for redesign

## Norman Chang

### Sub-director of the National Fire Academy

- How do you feel about water use in Costa Rica?
    - CR has lots of water
    - Still learning how to use water, save water, reuse water, use filtration systems, use water in best way
        - But this is not new, we have many years that we have been doing RWH, filtration etc.
    - RWH, purification
    - Uses water well
    - Country that uses a lot of water, wer learning to recycle a lot more and use more systems that purify water better and filter water, thinks it's pretty good at recycling
- What is your point of view on sustainability with water use?
    - Water is a limited resource, need to keep in mind that is limited and need to reuse it
    - It is more about awareness about the water and sustainability for future generations
    - It is not just about water, but other resources as well
    - It is all about awareness
    - There are many groups in Costa Rica that work in areas of sustainability--for example: Earth university
    - Also courses about recycling, reuse of resources in
    - In Academy use Blue Flag recycling program (mucho reciclaje)
        - Is about reuse of resources in the Academy
        - Trash cans with lots of different recycling
        - Do not just for the Bomberos but for the civilians who take courses at the Academy so they can learn about the program and recycling
    - Limited recycling water, they are aware of the water use and want to recycle, but not just water, want to work on making people learn to recycle more. Bandera azul is a program at the Academy that teaches recycling. There are trash cans here that are regular trash or recycling. Everyone the Academy takes this, but I think other people do too who aren't affiliated.
- How much water do you think you use on a normal day of training?

    - Amount of water used on a day of training depends on the day
    - ”Estaciones de trabajo”=training exercises very diverse
    - Use the most: Mangueras / tendidos, chorros
    - Also use the most: simulaciones de incendio
    - One tank 6,000-7,000L and one much larger tank that can fill 12 trucks with water
    - Missing systems that can bring lots of water to other places (distribution system)
    - Missing a (network= “Red”) of hydrants (want 5-6 hydrants on campus to transfer water from one place to another)
- Do you have any ideas for a system?
    - I am a Civil engineer and have a lot of ideas
    - Most simple collect water from most important roofs (administration, classrooms, complex of bathrooms the bathroom complex, the storage building) -- all of these systems together will make a large collection area
    - 3 zones most important for project:
        - Zona de chorros
        - New building-would be interesting to estimate new building roof size to see how much water they could get from that area
        - New parking area to see if system could be expanded when the new areas are constructed. (can fit 100 cars)
        - The water is not potable, it needs filtration, but it is a lot of water
- What do you think about multiple tanks around the facility?
    - Two tanks would be ok
    - It is important to identify measurements and specifications of the tank
    - If tank is above-ground, have to think of how the water will enter the tank--may have to use pump
    - Have to be careful because the training campus is still developing
    - An underground tank would be better because is out of the way of any future developments
    - Underground tank is more expensive, have to be careful with the underground pipes so they don’t interfere with others
    - Concrete, plastic, fiberglass tanks all possible. Concrete would be the most strong
    - There are reinforced plastic tanks for underground
    - Makes slope of water easier and is out of the way
- Where does the Academy currently get water?
    - Water utility for San José is called Acueductos y Ancantallriados (AyA)
    - Public business
    - Some others throughout CR
    - Others are asadas-administrators (smaller) of water outside of San José
    - For potable water
    - 30,000-35,000 colones for a year for a normal family of 4-6 people
- Use far road for access for trucks with main road

**Main Takeaways**

- Wants us to design for new developments and take those into account
- Distribution network: Wants fire hydrants to be part of plan

- Use Gravity rather than a pump, and a tank underground
- Use of largest roofs for catchment would be most effective: Storage / administrative building
- This Academy serves as flagship for other companies in terms of renewability
  - Blue Flag program

**<u>Cartago (Class A fire station- larger, more urban)</u>**

**Chief:** Wilberth Figueroa Fernández

- Station background and throughs on the project:
  - We wash it [the station and the trucks] every day and the water bill is very high
  - Academy doesn't have any water storage
  - There are 8-9 full time firefighters at the Cartago station
  - There are a lot of smaller stations that would benefit from a similar project
- What is your title at the Academy? What is your role?
  - Station chief (25 years working at station)
  - Other station chief-Ronny? Rojas
- What is your relationship with the Academy?
  - We are students, some of us are instructors
  - We visit at least 2-3 times per year for training
    i. Some trainings are not in the Academy
- How do you feel about water use in Costa Rica? As a Bombero and as a citizen?
  - We take advantage of our water resources a lot, but we need to do more to save it, it is a resource we have a lot of but we need to save more
  - It is not well rationed
  - We are missing some responsibility in water use
  - Another factor is that the cost of water is so low, there aren't meters or it doesn't even matter how much water one uses because it is so cheap
  - There it is 2,000 colones/mes [3.50 USD], other places, 15,000 colones/year
- What is your point of view about sustainability as it relates to water and the use of water?
  - We are missing a culture, education, technology, fiscalizacion, we are missing a number of things in order to create a sustainable system
  - We are missing a culture like in Europe where people have more awareness of water use
  - If water cost more, people would care more/pay more attention to their use
- Do you think saving water is a high priority for the Bomberos?
  - The problem is not only from the firefighters, but for all of the population
- Where do you get your water for the station?
  - Water comes from springs in the mountains to tanks run by the city and the asados, (local water administration groups) have their own sources
  - The water for training at the Academy comes from other stations closer to the Academy- only if they don't have water for the trainings
  - If we have a practice here in our zone, we have to provide our own water
  - Right now the water practices are minimized because causes a lack of water in the city, which causes tensions and problems
    - Cannot practice locally because there is not enough water for this in the streets
    - More than anything, you need to understand "it is treated, potable water" after practice, the water is wasted into the river
    - Because of this, we mostly have to go to the Academy for any trainings that require water

        - We can do dry practices with hoses and other equipment but we cannot practice putting out fires
    - If want to use water outside of city, have to have a report for the municipality

- What would be your estimate for the amount of water you use on typical training days at the Academy?
    - Hose practices require less water, the tower uses a lot of water
    - Actual amount of water used is very difficult to determine because it depends on the training
    - There are administrative and operative courses
        - Practices in the Tower, Search and Rescue Building, have a course with extinguishers to practice putting out little fires
    - There is a tank on the Academy grounds, but there is not a way to fill it
        - If there is no water, they have to send bomberos and a truck to go get some

**Main Takeaways**

- The problem of water use is not just ours, but part of the whole population
- There are some contentious relationships between fire stations and the local populations that prevent trainings with water outside of the Academy
- Each full-time, salaried firefighter has to attend 2-3 scheduled trainings at the Academy each year
- Many of the trainings in the Academy also do not involve water or only require very small amounts of water
- Water is so prevalent and not well-rationed because it is very cheap. There is not really an established culture for people to have an awareness of water use or importance.

## Cartago Firefighters

- What is your title at the Academy? What is your role?
    - William Rojas-Captain
    - Ricardo Herrito- Operator
    - There are sergeants, captains, and operators
    - Sargent, operative
    - Enter in the fires
- What is your relationship to the Academy?
    - we are students at Academy
    - ONLY allowed to take 2 courses per year within each position category
    - 2-3 times a year go to train at the Academy because some trainings are not at Academy
    - The Academy gives us the opportunity to train and better ourselves as firefighters
        i. Become more professional firefighters
        ii. Courses for each type of position
        iii. 15 courses in total
    - When you take all the courses for your position, you go back and recertify in the other courses
    - Academy gives us the ability to train and to captivate water
    - Compliment knowledge as Bomberos
    - We have to have a profile as Bomberos
    - The Academy gives us a list of courses that we can choose 2/year for us to take
    - Become more professional
    - Types of courses specific for the type of firefighter or position they are that they can

choose and recertify after they take all in each category

- How do you feel about Costa Rica's water use?
    - When I was in school, (30-40 years ago), I learned that resources were renewable (trees were nonrenewable)
    - Lamentably, the people don't care about the problems they are causing in the environment (cut down trees, trash in rivers, use of water)
    - "Thank god" it is changing- kids are learning about water conservation, environmental conservation
    - Much more recycling
    - Kids are much more conscious, 17-year-old make parents recycle
    - I try to conserve water, don't use plastic bags in supermarket, not throw trash in the river, recycle
    - 20-years and younger have awareness about water conservation
    - 40+ harder for them to learn and change ways, don't understand about water use and conservation
    - Firefighters had a lot of floods and landslides and they told people (this is what happens when you cut down trees)
    - New pop. has a consciousness, in general yes (young people) and no about CR pop. in general because different ages
    - There are institutions and projects to reforest and replant areas

Ricardo:

- There are older sustainability organizations, but interest has become greater in recent times
- There are a lot of reforestation projects, including by the state-run electricity utility
    - Sustainability is a government effort as well as on the level of the general population
    - In Cartago there's a prestigious technical university that works on environmental projects and has sustainability projects (green campus and recycling)

- Do you think water sustainability is a high priority for the Bomberos?
    - As institution, we learn to not waste water because it is important to have when needed in emergencies
    - Unfortunately spend a mountain of water in training
    - We are taking steps as an institution and the people have more awareness
- How much water do you think the Academy uses on a typical training day?
    - 1 inch diameter of a faucet 1 minute=6 gallons of water pass through
    - Estimate 500 gallons to wash Bomberos→ 100 gallons de agua every day… every day wash 4 trucks
    - This amount of water is very relative because in one building on one block, there are 12-25 people here and that is more than usual--> water use for this block is going to be higher
- Are there any training exercises involving water that you think are very beneficial?
    - Ricardo: the last parts of training (dry movements)
    - William: Practicing the use of water in general
    - Level tests don't use water (level of firefighters)
    - Prohibit water for end of level tests for Bomberos

    - **A lot of the practices nowadays are done without water because it is taking it from the city water supply**
    - "The monitor" (100-150 gallons/minute?) use very infrequently, only use them for big fires, only if necessary
    - Usually use hose lines 100 gallons/min
    - 2.5" 250 gallons/minute
    - Usually for fires
    - Can put out fires with a blanket-like tool
- Where would be the best place at the Academy for a tank that would be out of the way?
    - Always below (subterranean)
    - Ricardo: the Academy has an advantage of having a huge area, use the most amount of space that you can to collect highest amount of water, close to each building so the gutters can go into the tank
    - The buildings are relatively far from training area
    - Sistemas fijos contra los incendios (cursos) in the tower, the units have to feed the dry tubes but if they could be filled from the tank, it would be better

**Main Takeaways**

- They have dry practices because the townspeople don't like when they take so much water from the city water supply (only use it in emergencies)
- Cartago spends water to wash all 4 trucks every day even though they've gone through conflicts with townspeople
- Perspective from when they were younger has changed (what was taught in school about water use) and the new generation is more environmentally conscious
- Had a lot of knowledge about the different sustainability-related projects in the area
- Equipment Use: "The monitor" (100-150 gallons/minute?) use very infrequently, only use them for big fires, only if necessary
- Enjoy taking training courses to become more professional- find them very important

**<u>Pacayas Station- (rural, smaller, Class C station)</u>**

- Names and titles and thoughts on projects
    - Don Ramirez (Station Chief)—Oscar (operational firefighter)
    - Would be good to have project because it rains a lot but we don't take advantage of it
    - Participants of courses and has opportunity to be an instructor (part of course is effective use of water as well)
    - Every day there is more conflict between the neighborhoods and the firefighters because they use all of the water
    - We don't take advantage of rainwater here in Costa Rica- and here we have a lot of rain in the country
- What is your relation to the Academy?
    - We are students as firefighters
    - We take courses there
    - Don Ramirez is an instructor, part of his course is the use of water in fighting fires
- What are your thoughts on the use of water in Costa Rica?
    - Every day is more difficult to use water to fight fires and to be firefighters in areas with communities
    - It is a theme not discussed enough in Costa Rica
    - We must have a conscience as a population to use less water
    - We waste a lot in our houses

        - We wash everything, vehicles, houses, we spend a lot although we have arrived at a point where we need to conserve more
    - The population in cities especially is growing and we won't recognize the importance of water until the point where we don't have enough to use
        - In Guanacaste especially there are lots of tourist resorts that use a lot of water and it causes a lot of conflicts about water use
        - Conflicts with the police about who has control of the water-controlled by those with money (hotels etc.)
        - Pueblo de Coco is another example (Isla de Coco?)
- What is your view on sustainability as it relates to water and the use of water?
    - There is much more population, people in charge don't care about the forests, they only care about the money
    - Nowadays there is less rain, everyday is getting warmer
- Do you think water sustainability is a high priority for the Bomberos?
    - Think that water conservation is a high priority of the firefighters
    - Without water, their job will become very difficult
    - In some stations they have larger trucks to bring water to fires where they don't or can't have hydrants and this will be worse in the future, it will not be easy to get water
- Where do you get water for this station now?
    - Get city water—potable water
    - Sometimes can get water from rivers and ponds, but usually from the potable water supply in the communities and afterwards you cannot drink it because it is contaminated
    - Have a plan for stations as well for water use and recycling and recollection?
    - Don't pay for water but don't have water to practice and it is fundamental for us to be able to train and practice with water
    - Can use water from the rivers to practice, but cannot use water from the city
    - It is difficult to train without water because we don't know the weight of filled hoses etc. without using water
    - People in agricultural regions (like Pacayas) don't see practices as beneficial, only as a way that the firefighters are using/spending their water

- About how much water do you use to practice?
    - Cannot use water to practice except from the rivers
    - Use very little fire in practices
    - There are no good ways to practice
- What are the training activities in the Academy that use water that are the most helpful?
    - Practicing fire in high buildings (the tower)
    - They still use very little water in practices
    - Water is not just for ourselves, it's for everyone but there's no other way to practice
- Where on the campus should a large water tank be placed that would be out of the way of firefighters during training?
    - Where the tank should be located depends on the placement of the roofs
    - Place where the bricks are-use the workshop roof to collect the most water
- Other thoughts and notes:
    - Both RWH and recycling of water would be the most important
    - Might be interesting to also have some RWH for potable purposes
    - Can use recycled water also to bath and for sanitary services
    - Fog harvesting is very prevalent in this region

Notes from Don Ramirez:

- I have 18 years with the Bomberos and always learned that you have to care for and conserve water but now there's much more spending the water—no one is interested or thinks about conserving the water
- The most important thing is that "it is potable water"
- The agriculture here has a great effect on the water use
- The government doesn't have interest in caring for the water
- People in general wash everything
- Now that there's less water, we don't spend as much but on the coasts, there are greater problems because they use lots
- Water is all public here—never has been privatized
- People don't have an awareness about water use because it doesn't interest them-it's not important
- The city doesn't close off pipes when no longer in use, everything is always open
- Why are you doing a project at the Academy? There are many more countries where there are greater water difficulties and even in Costa Rica other areas where there is a greater need

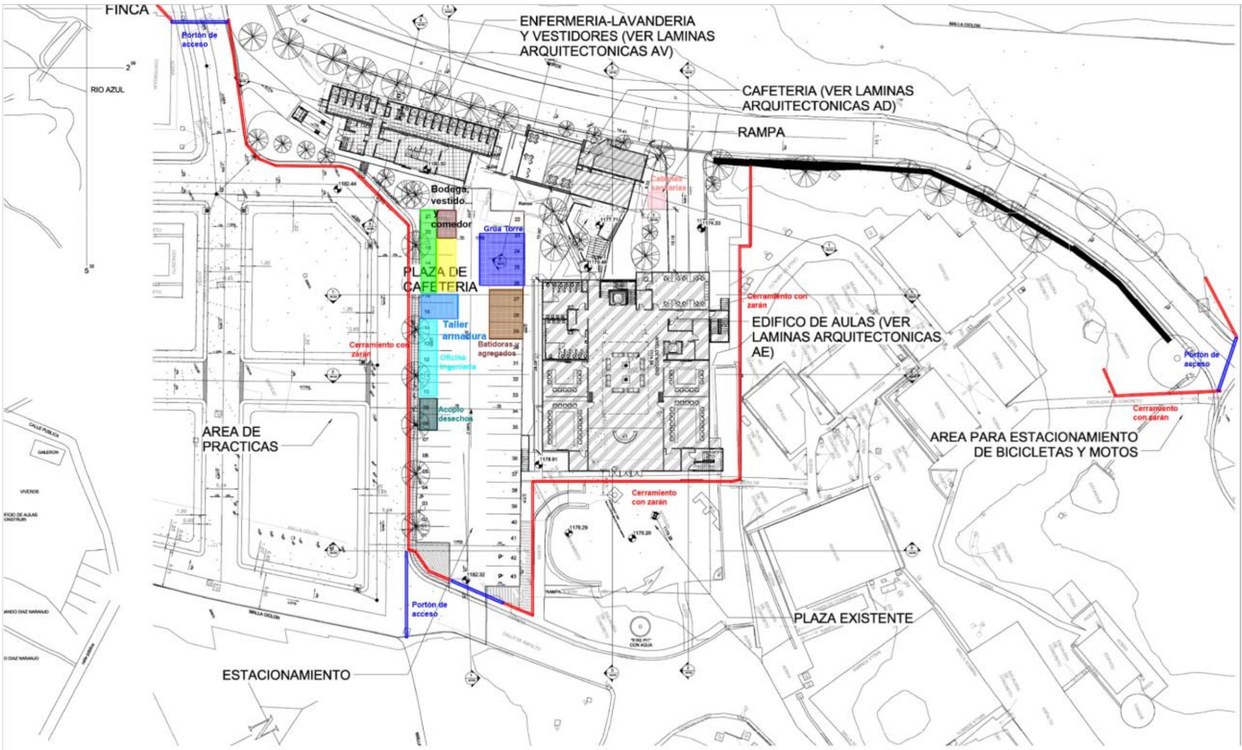
**Estarlin-volunteer firefighter**

- In rural zones, there are mostly only volunteer firefighters
- Most of the training he has he gets here instead of Academy because has other jobs
- The perspective about sustainability is a little much here, there are lots of projects, other countries don't have the same projects and regulations
- We use a lot of water, the water use for us is excessive, we need to find more strategies and different work plans to change the amount of water that we use
- We have to have a greater awareness of our use of water

**Main Takeaways:**

- Water recycling/conserving needs to be better taught to the Costa Rican population since so much is being wasted.
- A RWH system and water recycling would be helpful at local fire stations as well. Hoping the project expands to those and to other countries.
- The RWH systems are extremely useful especially in the mountains to help reduce water waste.
- Certain locations can greatly benefit from water harvesting systems since their environments can give tons of rain.
- People only think about money and power and not about the environment.
- The Academy greatly benefits firefighters since the students can use water to train, making it a more realistic simulation.

# Appendix E: AutoCAD Diagram of Current Academy Infrastructure




AG100 - PLANTA DE CONJUNTO (36% of Scale); Takeoff in Active Area: All Areas; Arquitectural Bomberos; 2-22-2017 22-45-30; 12/01/2018 03:55

# Appendix F: First Design Iteration for Training Grounds Storage Tank

Figure F.1 below shows the design drawing for the first iteration of the tank on the Training Grounds. This concrete tank of 16,500 gallon water volume capacity, has sizing of 10 meters long by 4m wide, with two different depths of 1.5 m on one side and 2 m on the other. The variation in depth creates a slope that naturally causes water to flow through the system. The entire tank rests at a 3 degree slope towards the West side of the Academy to facilitate water flow towards the outlet and facilitate easy access for trucks to connect to the water outlet port. The tank additionally has an overflow pipe to prevent the tank from overfilling its capacity. The overflow pipe is lower than the inlet and must have a small hole at the highest point along it to prevent a siphoning effect. The outflow and overflow pipes should have a net covering on the end to prevent entry of bugs into the system.

The tank has three compartments divided by screens. The first compartment has a mesh screen with 10-30 mm holes to filter out medium to large sediment, such as leaves. The second compartment is bound by a screen with 15-500 micron holes to trap finer particles and filter them from the water. Both of the screens are on sliding fixtures so they can be pulled out to allow the leaf and sediment buildup to be flushed from the tank. The third compartment was the main storage place for the clean water. Each compartment had a steel cover, which would have a handle with a lock. A series of metal rungs provided access into the first two tank sections to allow proper personnel to clean.

The doors contain locks and in order to clean the maintenance team can slide out the two sediment filters. The inside edges of the tank are rounded to facilitate cleaning and minimize sediment buildup along the tank edges. The outflow pipe on the tank sits as an extension to the rounded tank edges to easily release water and flush out sediment from the tank.

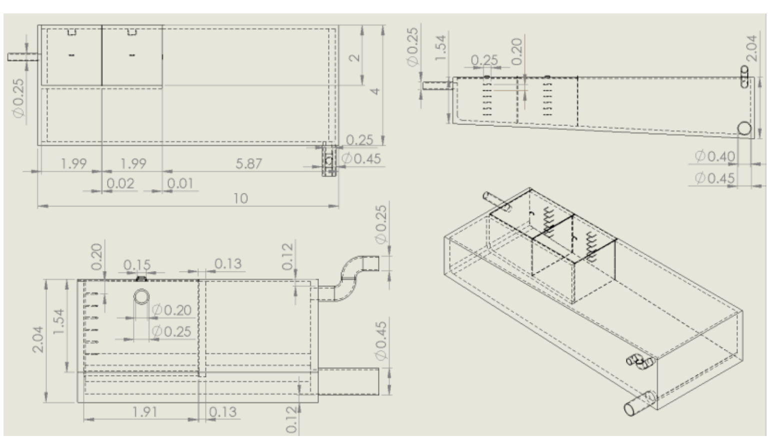



**Figure F.1:** Dimensioned SolidWorks drawings for the first iteration of training grounds tank.

# Appendix G: Price Estimates from Costa Rican Vendors

INPREFA S.A. Pricing Quote for Prefabricated Concrete Blocks. Transportation and installation costs are included in the breakdown.

Prefacasa
CONSTRUCTORA Y CONSULTORA

**Constructora y Consultora PREFACASA, S.A.**

**1 Km al Sur de la entrada principal del Parque Industrial, Tejar de El Guarco, Cartago.**

**Cédula Jurídica: 3-101-33007527**

**Cartago,** 20-02-2018

**Cotización N°: 10331**

**Señor (es):**

**Atención:** Alan Rodriguez. C06319

**Cédula:**

**TEL/FAX:** 8716 6009

**EMAIL:** arodriguez@bomberos.go.cr

**Dirección:**

**Presente:**
Estimados Señores:

A nombre de mi representada INPREFA S.A. en respuesta a su solicitud le presentamos la siguiente oferta:

Las principales características del material son:

- Columnas de concreto reforzado 12x12cm, resistencia del concreto fć=250kg/cm2, con una longitud de 3.20m.
- Baldosas de concreto reforzado de 4cm de espesor x 50cm de altura y longitud variable, resistencia del concreto fć=250kg/cm2.
- Sistema sismo resistente.

Descripción de la oferta

Cotización de material prefabricado para una tapia de 16m lineales (en 2,50ml de altura libre), contemplando baldosas lisas de 2,00mX0,50m.

Para instalar en la localidad de San Antonio de Desamparados.

Desglose el material

07 columnas tipo C 3,20m
02 columna tipo E 3,20m
40 baldosas lisas de 0.50mx2.00m

* La instalación ser realizará en el trazo según los puntos topográficos brindados por el cliente, incluye realización de fundaciones (excavaciòn para cada columna), realizaciòn del concreto, instalación de columnas, instalación de baldosas.

**DESCRIPCIÓN DE LA OFERTA**

| Código | Descripción | Cant. | P.TOTAL |
|---|---|---|---|
| COT-001 | 16m Tapia en 2,50m de altura libre utilizando baldosa lisa 2,00mX0,50m | 1,00 | 400.000,00 |

Tel.: 2573- 6767 Fax 2573-5558/2573- Tel. Quebrador JyM: 2716-7969 Apartado Postal 700-7050,

"Empresa legalmente inscrita en el Colegio Federado de Ingenieros y Arquitectos de Costa Rica. Regis

Website: **ventas@inprefa.com**

**Constructora y Consultora PREFACASA, S.A.**

**1 Km al Sur de la entrada principal del Parque Industrial, Tejar de El Guarco, Cartago.**

**Cédula Jurídica: 3-101-33007527**

| | | | |
|---|---|---|---|
| PR-SR.00007 | Transporte a San Antonio Desamparados | 1,00 | 80.000,00 |
| PR-SR.00001 | Instalación paredes incluye agregados arena, piedra, cemento y mano de ol | 1,00 | 225.000,00 |

| | |
|---|---|
| **Total de la Oferta:** | 705.000,00 |

**Disponibilidad:** SEGÚN PROGRAMACIÓN
**Vigencia:** 20-marzo-2018
**Forma de Pago:** Efectivo 0d
**Vendedor:** Daniela Moya

- El material tiene un peso bruto aproximado de 110 quintales.

Nota: Para iniciar la instalación de la tapia es necesario que el terreno se encuentre en óptimas condiciones con accesos seguros para ingreso de camiones, así como también es importante que cuente con los respectivos permisos de construcción y puntos de topografia. Incluye mano de obra, materiales agregados como: arena, piedra cuartilla, cemento, madera para niveletas, clavos, etc.
Cuentas Corrientes:

- Banco Nacional Costa Rica: 100-01-075-007677-8 ( Constructora y Consultora PREFACASA)

Lugar: San Antonio de Desamparados.
Información para programación y coordinación de pedidos: Teléfono 2573-6767, E-mail: ventas@inprefa.com, inpventas1@inprefa.com, inpventas2@inprefa.com,
inprecepcion@inprefa.com.
Observaciones:

- Se recomienda no realizar cortes en la columna para modificar la altura de la misma.
- El precio cotizado No incluye el impuesto de ventas y costo de transporte.
- Los agregados utilizados en la producción de concreto son de primera calidad extraídos del Río Parismina, Guácimo—Limón y procesados por nuestra compañía Quebrador JYM S.A Teléfono: 2716-5858, www.quebradoresjym.com.
- El cliente debe suministrar accesos seguros al sitio de la obra.
- Los precios pueden variar según la inspección que realice el Ingeniero al terreno.
- Para iniciar la construcción de la tapia es necesario que el terreno se encuentre en condiciones óptimas para construir, contando con el servicio de agua, así como con los respectivos permisos de construcción.
- Se requiere que el material tenga una adecuada manipulación durante el proceso constructivo.

Ing. Juan Carlos Guzmán B.

EcoTank Plastic Water Storage Tank Pricing Quote

la casa del TANQUE
*Los especialistas en tanques*

**LA CASA DEL TANQUE S.A.**
Cédula Jurídica: 3101191210
Teléfono: 22273722 - Fax: 22265218

| | | | | |
|---|---|---|---|---|
| **Cliente** | TALON BOIE | | **FECHA** | **13/02/2018** |
| **Atención** | CLIENTE DE CONTADO | | **Nº cotización** | ***41536*** |
| **Teléfonos** | . - Fax | | **Cotizador** | KARLA VANESSA VALVERDE SA |

| Cantidad | Código | Descripción | I.V.A | Precio Unitario | Precio Total |
|---|---|---|---|---|---|
| 1.00 | 01-022000 | TANQUE INDUSTRIAL ECOTANK 22000 LTS NEGRO ESTANDAR | N | 1,878,138.78 | 1,878,138.78 |

| Monto en Letras | | |
|---|---|---|
| Dos millones ciento veintidos mil doscientos noventa y seis colones con 82/100 | **Subtotal** | 1,878,138.78 |
| | **Descuento** | 0.00 |
| | **I.V.** | 244,158.04 |
| | **Total** | 2,122,296.82 |

**Condiciones**

**Plazo de entrega:** 1 DIA( Salvo Imprevistos o Previa Venta)
**Validez de la oferta:** 8 DIAS.
**Plazo de pago:** 0 DIAS.
**Forma de pago:** C O N T A D O
Precios Sujetos a Cambio sin Previo Aviso

**Observaciones**

**Aprobación por parte del cliente**

**Fecha:**
**Aprobado por:**
**Cargo:**
**Firma:**

Amco Concrete Pricing Quote for Below-Ground, Concrete Tank

AMERICA CONCRETOS S.A
De Materiales El Lagar, 125 m
Este, San Joaquin de Flores
Teléfono: 2509-9870

Fecha: 20/02/2018
Hora: 10:25:23 am
Cotización: COT-2018-0378

Señor(a): TALON BOIE

**Cliente:** CUERPO DE BOMBEROS

**Dirección:** DESAMPARADOS

**Cotización**

Atendiendo su amable solicitud, América Concretos se permite cotizar el suministro de concreto premezclado para su proyecto de construcción.

| Código | Cant | Descripción | Precio Unitario | Monto Total |
|---|---|---|---|---|
| CF350D28H | 11.00 | PT CONCRETO FINO 350 KG/CM 28D | ¢90,025.24 | ¢990,277.61 |
| CN105D28H | 17.00 | PT CONCRETO NORMAL 105 KG/CM 28D | ¢66,139.37 | ¢1,124,369.37 |
| SERV-B | 28.00 | SERVICIO BOMBEO DE CONCRETO (VOLUMEN MAYOR A 16 MTS) | ¢10,000.00 | ¢280,000.00 |

| | |
|---|---|
| Total mercadería: | **¢2,394,646.98** |
| Impuesto de ventas: | ¢274,904.11 |
| **Total General:** | ¢2,669,551.09 |

**Condiciones**

**Observaciones:**

En Caso de que la administración tributaria disponga el cobro de impuesto de ventas sobre los servicios y el transporte, dicho cobro será asumido por el cliente y cualquier impuesto adicional decretado por el Gobierno y que no esté en esta cotización

**Notas:** Después de tiempo de descarga de 60 minutos máximo por viaje, se cobra 35000 colones por hora de atraso, además de 700 colones por litro de plastificante.

**Forma de pago:** Se cancela por adelantado

**Cuentas de Banco:**

Cta. BANCO NACIONAL # 100-01-045-000729-6 a nombre de América Concretos, S.A.
Cta. COSTA RICA # 001-0282556-2 a nombre de América Concretos, S.A.
Cta. SCOTIABANK # 13000371400 a nombre de América Concretos, S.A.
Cta. BAC San José # 913040168 a nombre de América Concretos, S.A.

Teléfono: (506)2509-98-98 * Fax: (506)2432-5530
E-mail: ventas@amco.co.cr * P.O. Box 1370-3000 Heredia - Costa Rica

Quote from Cristol Rejillas for Specialized Grating (because of the cost, grating material from El Lagar was used in the cost estimates instead)

**COTIZACION**
**No. 93517 Rev. 1**

Fecha Cotización: 26 - feb - 2018
Cotizacion Vigente Hasta: 31 - mar - 2018

**ESTRUCTURAS Y PISOS PANAMA S.A. - RUC: 155600520-2-2015 DV 91**
Oficinas: Calle 73 Este - Barrio Carrasquilla
Ph Sunshine By The Park / Of. 26-C - Ciudad de Panamá
**PBX:** (507) 203 4387 - **Mov. Phone:** (507) 6909 7622

**AMAUTA 9 S.A.S. - ACEROS ANDERI - NIT: 900.500.233-1**
Oficinas: Cra. 74 No. 7 B 11 CA 27 - Bogotá D.C., Colombia
**PBX:** (571) 359 2936 - **Mov. Phone:** (57) 317 678 5312

CRISOL® Rejillas
*Su Bienestar, Nuestra Felicidad.*
ACEROS ANDERI AMAUTA 9 S.A.S. NIT: 900.500.233-1

| | | | |
|---|---|---|---|
| NIT: | **1TALONBOIE** | Ciudad: | SAN JOSE (CDS) |
| Cliente: | **WORCESTER POTECHNIC INSTITUTE** | | |
| Contacto: | **TALON BOIE** | | |
| Teléfonos: | (506) 8719-3349 | | |
| E-mail: | iqpbomberos@wpi.edu | | |

Asesor Comercial: LUZ STELLA SOLANO
Celular: (507) 6262 7562 - Correo Electrónico: luz@rejillascrisol.com

**DESCRIPCION Y ESPECIFICACIONES TECNICAS GENERALES DE LOS PRODUCTOS COTIZADOS**

AMAUTA 9 S.A.S. - ACEROS ANDERI coloca a su consideración la siguiente oferta de Rejillas Industriales y Estructuras Metálicas en Acero ASTM A-36. Fabricadas de acuerdo a las Normas americanas ANSI NAAMM MBG 531-09 7ma. Edición para tráfico peatonal (Platina portante con una altura máxima de 2.1/2" y un espesor máximo de 3/16") y a las normas americanas ANSI NAAMM MBG 532-09 5ta. Edición para tráfico vehicular (Platina portante con una altura máxima de 5" y un espesor mínimo de 1/4" y máximo de 3/8"). Soldadura aplicada bajo proceso MIG norma AWS A5.18, WS 82.0.035", Icontec 2632,ASME SFA5.18. Galvanizado por inmersión en caliente de acuerdo a las Normas Colombianas NTC 3320 y NTC 2076 homologadas de las Normas Internacionales ASTM-A-123 y ASTM-A-153.

**Nota:** **AMAUTA 9 S.A.S. - ACEROS ANDERI** Inicia a contar el tiempo para la entrega de los productos aquí cotizados, desde el día que se cumplen todas las condiciones comerciales que se enumeran a continuación:

1.- Se recibe del cliente la Orden de Compra o el Contrato firmado por ambas partes.
2.- El cliente aprueba los planos y/o medidas de los productos a fabricar de la Orden o el Contrato.
3.- Se recibe del cliente el soporte de la consignación o transferencia del pago.

| Ítem | Producto | Tipo | Material | Cantidad | U/M | Portante | | | Amarre | | | Tipo de Dentado o Descripción Estructura | Acabado | Precio Unitario (US$) | Valor Total Cotización (US$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Altura | Espesor | Longitud en mm. | Altura o Fijación | Espesor | Longitud en mm. | | | | |
| 1 | REJILLAS | T-30x100 | A36 | **90** | Un | 2" | 1/4" | **550** | 1" | 1/4" | **1000** | LISAS | GALVANIZADO | $ 224,67 | $ 20.220,30 |
| 2 | REJILLAS | T-30x100 | A36 | **1** | Un | 2" | 1/4" | **550** | 1" | 1/4" | **750** | LISAS | GALVANIZADO | $ 173,20 | $ 173,20 |

# Appendix H: Cost Calculations for Proposed Designs

| BELOW-GROUND DESIGN | | | | Plastic | | Concrete | | Notes Justification |
|---|---|---|---|---|---|---|---|---|
| | Description | Quantity | Vendor | Colones | Dollars | Colones | Dollars | |
| ***Tanks*** | | | | | | | | |
| **Concrete Tank** | 8.25m x 4m x 2m (w/tax) | 1 | Amco | | | ₡1,103,960 | $1,954 | |
| **Rebar Support (Parilla#4)** | 6m sections | 20 | EPA | | | ₡59,900 | $106.02 | |
| **Plastic Tank** | 22,000L (w/tax) | 3 | EcoTank | ₡6,366,890 | $11,268.83 | | | |
| **Excavation** | Cost per hour | 4 | | ₡217,200 | $480.00 | ₡217,200 | $480.00 | |
| ***Concrete*** | | | | | | | | |
| **Foundation** | 3.26mx10.26mx0.13m premix 105kg/cm^3 resistance | total | Amco | ₡287,586 | $509.00 | n/a | n/a | |
| **Underground Walls** | 2@10mx3mx0.13m 2@3mx3.76mx0.13m Prefabricated | total | El Lagar | ₡520,000 | $920.35 | n/a | n/a | Prefabricated concrete blocks cheaper than making walls from mix |
| ***Sediment Filter*** | | | | | | | | |
| **Concrete** | 4mx1mx1.5m premix 350kg/cm^3 resistance | total | Amco | ₡212,134 | $375.46 | ₡212,134 | $375.46 | |
| ***Piping*** | | | | | | | | |
| **Tank Connections and Outflow/Overflow Piping** | 4" PVC, 6m section | 1 | El Lagar | ₡18,000 | $31.86 | ₡18,000 | $31.86 | |
| ***Piping Accessories*** | | | | | | | | |
| **2" pvc Ball Valve** | Before sediment filter | 2 | El Lagar | ₡5,882 | $10.41 | ₡5,882 | $10.41 | |
| **4" pvc Ball Valve Mid Quality** | Between-tank connections (PVC) | 2 | El Lagar | ₡116,980 | $207.04 | n/a | n/a | Valves not easily accessible thus higher quality needed |
| **4" pvc Ball Valve High Quality** | Tank outflow control (PVC) | 1 | El Lagar | ₡73,570 | $130.21 | ₡73,570 | $130.21 | |
| ***Pumps*** | | | | n/a | n/a | n/a | n/a | |
| **Total** | | | | ₡7,818,243 | **$13,933.17** | **₡1,690,646** | **$3,087.87** | |

| ABOVE-GROUND DESIGN | | | | | |
|---|---|---|---|---|---|
| | **Description** | **Quantity** | **Vendor** | **Colones** | **Dollars** |
| ***Tanks*** | | | | | |
| **Plastic Tank** | 22,000L (price includes taxes) | 3 | EcoTank | ₡6,366,890 | $11,268.83 |
| ***Concrete*** | | | | | |
| **Foundation** | 3.26mx10.26mx0.13m From mixed concrete 105kg/cm^3 resistance | total | Amco | ₡287,586 | $509.00 |
| ***Sediment Filter*** | | | | | |
| **Concrete** | 4mx1mx1.5m (=2.35m^3)from premixed concrete 350kg/cm^3 resistance | total | Amco | ₡212,134 | $375.46 |
| ***Piping*** | | | | | |
| **Tank Connections and Outflow/Overflow Piping** | 4" PVC, 6m section | 1 | El Lagar | ₡18,000 | $31.86 |
| ***Piping Accessories*** | | | | | |
| **2" PVC Ball Valve** | Before sediment filter | 2 | El Lagar | ₡5,882 | $10.41 |
| **4" pvc Ball Valve Mid Quality** | Between-tank connections (PVC) | 2 | El Lagar | ₡116,980 | $207.04 |
| **4" pvc Ball Valve High Quality** | Tank outflow control (PVC) | 1 | El Lagar | ₡73,570 | $130.21 |
| ***Pumps*** | | | | | |
| **2.5 hp Jet** | To get water into tanks (DAB pump with 2 year warranty) | 1 | EPA | ₡295,000 | $522.12 |
| **Total** | | | | **₡7,081,043** | **$12,532.82** |

| Recycling System Design | | | | | |
|---|---|---|---|---|---|
| | Description | Quantity | Vendor | Colones | Dollars |
| ***Concrete*** | | | | | |
| **Added Curved Surface** | 2m^3 From mixed concrete 105kg/cm^3 resistance" | total | Amco | ₡132,279 | $234.12 |
| ***Piping*** | | | | | |
| **2" Pressurized** | 3m sections | 10 | El Lagar | ₡160,600 | $284.25 |
| ***Grates*** | | | | | |
| **Heavy #2006070** | 4'x8' | | E Lagar | | |
| **Heavy #2006021** | 4'x8' | | El Lagar | | |
| **Crisol Rejilla** | 91m perimeter x 1.829 m^2 | total | Crisol Rejilla | | |
| **Total** | | | | **₡292,879** | **$518.37** |

| Rainwater Harvesting System Design | | | | | |
|---|---|---|---|---|---|
| | Description | Quantity | Vendor | Colones | Dollars |
| ***Gutter Infrastructure*** | | | | | |
| **Gutters** | 3m sections, 'Lisa Alto' gutter | 12 | El Lagar | ₡199,800 | $353.63 |
| **Downspouts** | 5cm Diameter, 3m sections | 3 | El Lagar | ₡26,535 | $46.96 |
| ***Piping*** | | | | | |
| **Conveyance Piping** | "2"" Diameter 6m sections | 6 | El Lagar | ₡96,360 | $170.55 |
| ***Grates*** | | | | | |
| **Downspout Protection** | Grate for Downspout | 1 | El Lagar | ₡19,105 | $33.81 |
| **Total** | | | | **₡341,800** | **$604.96** |

# Appendix I: Sediment Filter Sizing Rationale

## Specific Calculations for Sediment Filter Capacity

The sediment filter was initially designed on a conceptual basis within the limitations of the available area on the training grounds. We determined that the largest possible length for the sediment filter was 4m based on the available area. The sediment filter functions on the mechanical principle of gravity, with dense particles physically falling through the water to settle at the bottom of the tank. When the particles have a density greater than water, they will naturally settle out in a time-dependent manner. On a conceptual level, the longer the water remains in the sediment tank, the more particles will settle out. For this reason, we used the fully-available length to maximize the retention time of the water in the tank. After creating this design, we calculated the size of particles a sediment filter with this capacity could remove with some general assumptions.

The approximate retention time of water in the sediment filter was calculated based on an assumption of a maximum water entry flow rate of 1m/s. The total distance the water must travel between the inlet and outlet tubes in the sediment filter was calculated to be 3.4m, as the water must navigate around two arms in the sediment filter (See Figure 35). From these, we determined that the approximate minimum retention time in the sediment filter (at a maximum entry flow of 1m/s) is 3.4s

$$\frac{3.4m}{1m/s} = 3.4s$$

The designed sediment filter has an effective settling height of 1.0m. From this, we calculated the minimum settling velocity ($v_s$) for a particle that will be removed by the filter.

$$\frac{1m}{3.4s} = 0.30m/s$$

$$v_s = 0.30m/s$$

The density of the largest particle that can be settled, which is needed to show the separation ability for this designed sediment filter, can be calculated from the formula for settling velocity.

$$v_s = \frac{g(\rho_s - \rho_w)d}{18\mu}$$

ρ: density of solid (s) and density of water (w)

d: diameter of solid—assumed to be 1mm
μ: dynamic viscosity of water
g: gravity

$$0.30m/s = \frac{9.8m/s^2 \left(\boldsymbol{\rho_s} - \frac{1000kg}{m^3}\right)(0.001m)^2}{18(8.9 * 10^{-4}\ Pa\ s)}$$

$$\boldsymbol{\rho_s} = \frac{1485kg}{m^3}$$

# Appendix J: Safety and Maintenance Guidelines and Procedures

Table of Contents:



## **Rainwater Harvesting System:**

- Clean gutters and downspouts two times a month, and before and after large storms.
- Inspect the gutter connections to the roofs once a year to ensure that they are well. connected.

## **Water Storage Tank:**

*First Iteration:*

- Each of the lids on the tank have a lock attaching them to the ground. These locks can only be opened by a key that resides within either the facility building or the administration building.
- The sediment filters can be removed to make cleaning the interior of the tank very simple.
- Below each door of the tank are rungs that act as a ladder to allow ease of access and ease of exit during maintenance. The dimensions of the rungs follow OSHA standard for trestle ladders.
- The tank is completely submerged, eliminating any possibility of a tripping hazard for the tank. The only tripping hazard that remains are the doors to the tank, which would be colored either black and yellow or red, drawing attention to itself so surrounding people are be aware.
- Label the tank with “non-potable water” on the side.
- Mark tank with “Caution: Confined Space” on manhole.
- Include a valve on the water inlet pipe to enable shut-off of water flow to the tank.
- Inspect overflow system and pressure relief ventilation yearly for proper function.
- Completely empty, wash, and clean out the tank once a year to flush out sediment and prevent bacterial buildup. (Chlorine can be used to kill any bacteria).

*Final Iteration:*

Above-Ground Plastic:

- The lids attached to each of the three tanks should be locked with padlocks. The locks can only be opened by a key that resides within either the facility building or the Administration Building.
- There is an air flow pipe on each tank to prevent bursting when the tank is filled with water. This also acts as ventilation for any maintenance workers who would be cleaning the tanks.
- The tanks should be brightly colored to prevent any collisions with vehicles on the road next to the location of the tanks.
- Label the tank with “non-potable water” in a visible manner.
- Mark each tank with “Caution: Confined Space” on manholes.
- Include a valve on the water inlet pipe to enable shut-off of water flow to the tank.
- Inspect overflow system and pressure relief ventilation yearly for proper function.
- Consider adding a dual pump system in case of pump malfunction or necessary maintenance.
- Completely empty, wash, and clean out the tank once a year to flush out sediment and prevent bacterial buildup. (Chlorine can be used to kill any bacteria).

Below-Ground Plastic:

- The lids attached to each of the three tanks should be locked with padlocks. The locks can only be opened by a key that resides within either the facility building or the Administration Building.
- There is an air flow pipe on each tank to prevent bursting when the tank is filled with water. This also acts as ventilation for any maintenance workers who would be cleaning the tanks.
- Since the tanks would be protruding from the ground by half of a meter, there is an immediate tripping hazard. This should be prevented by making the tanks a vibrant color to raise awareness.
- Label the tank with “non-potable water” in a visible manner.
- Mark each tank with “Caution: Confined Space” on manholes.
- Include a valve on the water inlet pipe to enable shut-off of water flow to the tank.
- Inspect overflow system and pressure relief ventilation yearly for proper function.
- Completely empty, wash, and clean out the tank once a year to flush out sediment and prevent bacterial buildup. (Chlorine can be used to kill any bacteria).

Below-Ground Concrete:

- The lid on the tank has a lock attaching it to the ground. This lock can only be opened by a key that resides within either the facility building or the administration building.

- There is an air flow pipe on each tank to prevent bursting when the tank is filled with water. This also acts as ventilation for any maintenance workers who would be cleaning the tanks.
- Below the door of the tank are rungs that act as a ladder to allow ease of access and ease of exit during maintenance. The dimensions of the rungs follow OSHA standard for trestle ladders.
- The tank itself is completely submerged, eliminating any possibility of a tripping hazard for the tank. The only tripping hazard that remains are the doors to the tank, which would be colored either black and yellow or red, drawing attention to itself so surrounding people are aware.
- Label the tank with “non-potable water” in a visible manner.
- Mark each tank with “Caution: Confined Space” on manholes.
- Include a valve on the water inlet pipe to enable shut-off of water flow to the tank.
- Inspect overflow system and pressure relief ventilation yearly for proper function
- Completely empty, wash, and clean out the tank once a year to flush out sediment and prevent bacterial buildup. (Chlorine can be used to kill any bacteria).

## Sediment Filter:

- The sediment Filter has three lids attached to the top, one for each section of the structure. These entrances should be locked down with a padlock and can only be accessed with a key that is located in either the facility building or the Administration Building.
- The stagnant water on the bottom of the tank should be cleaned out and replaced every rainfall to avoid water contamination.
- The sediment and floating particles collected in the sediment filter should be cleaned out after every rainfall to allow for clean and flowing water.
- Below each door of the tank are rungs that act as a ladder to allow ease of access and ease of exit during maintenance. The dimensions of the rungs follow OSHA standard for trestle ladders.

## Improved Training Plaza Recycling System:

- The added lip on the end is as a tripping hazard. To avoid this, a sloped cement section should be added that allows for a gradual increase in elevation that can be easily walked on. In addition, the lip would be colored differently to raise awareness to the sloped area.
- There should also be a grate added to the top of the drain to prevent foot injuries and possible additional tripping.
- These grates would need to be cleaned out every month to allow for a continuous flow of water.

Ensure all designs of tanks are up to OSHA standards for safety of employees. Specifically, confined space requirements are upheld by having acceptable entry conditions for authorized entrants. The confined space should be large enough for employees to perform assigned work and is not designed for continuous occupancy of employee (United States Department of Labor).

# Appendix K: Water Use Model for Administration Area

| Month (at end) | Rainfall Data (mm) | Rainwater Volume (L) | Rainwater Volume (gal) | Water Used per Month (L) | Water Used per Month (gal) | Total Volume in Tank (L) | Total Volume in Tank (gal) |
|---|---|---|---|---|---|---|---|
| Jan | 124.1 | 142368 | 37614 | 0 | 0 | 142368 | 37614 |
| Feb | 76.9 | 88220 | 23308 | 0 | 0 | 230587 | 60921 |
| Mar | 79.4 | 91088 | 24065 | 54504 | 14400 | 267171 | 70587 |
| Apr | 134.8 | 154643 | 40857 | 54504 | 14400 | 367309 | 97043 |
| May | 309.5 | 355058 | 93807 | 81756 | 21600 | 640612 | 169250 |
| Jun | 341.2 | 391425 | 103415 | 54504 | 14400 | 977532 | 258265 |
| Jul | 338.9 | 388786 | 102718 | 81756 | 21600 | 1284563 | 339382 |
| Aug | 336.2 | 385689 | 101899 | 54504 | 14400 | 1615747 | 426882 |
| Sept | 354.6 | 406797 | 107476 | 90840 | 24000 | 1931704 | 510358 |
| Oct | 409.4 | 469664 | 124086 | 54504 | 14400 | 2346864 | 620043 |
| Nov | 289.2 | 331770 | 87654 | 81756 | 21600 | 2596878 | 686097 |
| Dec | 202.8 | 232652 | 61467 | 63588 | 16800 | 2765942 | 730764 |
| **Total** | | 3438158 | **908364** | | | | |

| | |
|---|---|
| **Surface Area (m^2)** | 1434 |
| **Approximated Efficiency** | 0.8 |
| **Effective Surface Area (m^2)** | 1147.2 |

# Appendix L: Administration Area Rainwater Harvesting Design Details

Figure K.1 below shows the current area available for a possible Administration Tank. The useable surface area is approximately 585 m^2, but all tank designs would only require less than 14 % of this space. The leftover space could be developed during future projects or continue being used as overflow parking.

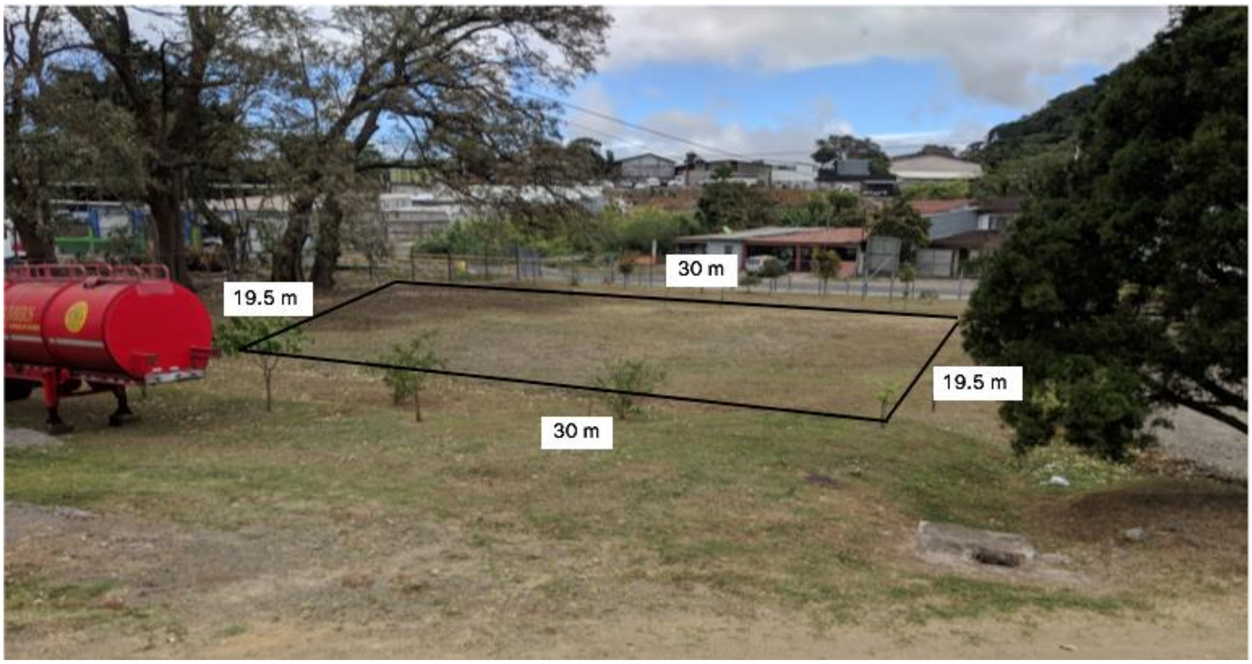


Figure K.1: Proposed location for storage tank behind Administration Buildings

<u>Tank Design Choices</u>

For the Administration Tank, three designs were determined feasible to properly utilize the area available. These designs include a cylindrical below-ground tank, a cylindrical above-ground tank, and a rectangular below-ground tank. All three would require an above-ground sediment tank filter beforehand and would be used for rainwater storage. Different attributes of each design are compared below.

Table K.1: Comparison between three possible designs for tanks for rainwater harvesting system in Administration Building area

| | Cylindrical Below-ground | Cylindrical Above-ground | Rectangular Below-ground |
|---|---|---|---|
| Total Volume (m^3) | 157 | 155.5 | 153 |
| Dimensions | H: 2m D:10m | H: 5.5m D:6m | W:9m L: 8.5m D: 2m |
| Surface Area of Base (m^2) | 79 | 28.3 | 76.5 |
| % Area Used of Available | 13.5 | 5 | 13.1 |
| Type of Material | Concrete | Stainless Steel | Concrete |

The letters "H," "D," "L," and "W" refer to height, diameter, length, and width. The cylindrical, above-ground tank uses the least amount of surface area, which allows the Bomberos to use the land plot for other purposes. But the tank is also high, which can be a safety hazard, require expensive pumps, and is aesthetically unattractive. Using these basic components the Bomberos can determine important aspects and possibly install a similar design to one of these models in the future.

Sediment Filter Design Choice for Administration Area

The sediment tank for the administration system tank would use the current pipe infrastructure and natural slope of the Academy to filter water before the rainwater tank in place for the Admin System (Figure K.2-K.3). The volume observed as feasible for a sediment tank, following the layout of the land, was 7.5m^3, or 2 m in height, 2.5 m in length, and 1.5 m in width. The pipes protruding from the concrete wall in the image above would carry water from the Admin System roofs and feed directly into this sediment trap.


Figure K.2: Proposed location for sediment filter for Administration Area rainwater harvesting tank system

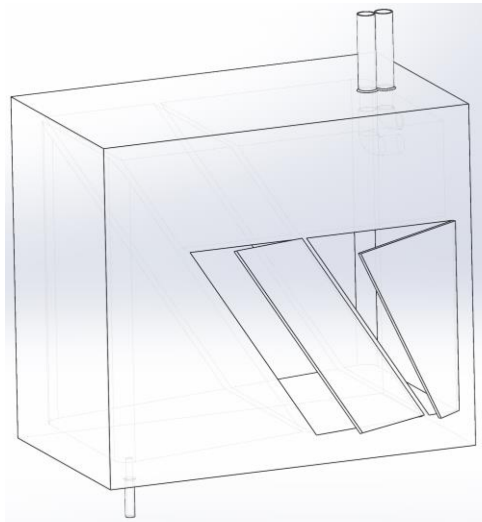


Figure K.3: Drawing for designed sediment filter in Administration Area

The conceptual design for the sediment tank is concrete with walls of 0.127 meters (5 inches) thickness. For ease of cleaning, the sediment filter is above-ground. The inlet pipe at the top of the tank is bent at a 90 degree angle so the water flows horizontally. This design choice slows down the stream of water so that sediment at the bottom of the tank is not agitated and incoming sediment has a chance to settle. The curved inlet also prevents mesh screens from wearing down too quickly. The sediment tank involves two, fixed-mesh screen filters. The filter closer to the inlet should be a mesh screen with holes of 10-30mm to filter out larger organic matter. The second filter would remove finer particles, thus the spaces should be 15-500 micrometers. The material for the mesh screens should be either stainless steel or plastic. Steel does not wear down easily and can handle very high water pressure, but plastic is less corrosive, cheaper, and flexible. The outlet is at the bottom of the tank and acts as a drain to direct clean water underneath the road and to the storage tank.

For maintenance and safety upkeep, the sediment filters would need to be cleaned regularly. Access for cleaning is provided with the opening doors, which would allow personnel to enter the tank and clean off the screens when needed.