5-6-2022

Emergency Water Station 3.0 Final Project Report

Winona Menezes
Trinity University

Elyse Reynolds
Trinity University

Robert Swallow
Trinity University

Jacob Thweatt
Trinity University

Emergency Water Station 3.0 Final Project Report

The Emergency Water Station 3.0 Team:
Winona Menezes
Elyse Reynolds
Robert (Bob) Swallow
Jacob Thweatt

May 6, 2022

Executive Summary

The South Texas Human Rights Center (STHRC) tasked our team, The Emergency Water Station 3.0 (3WS), with designing and implementing an emergency water station for migrants and refugees crossing the border between Mexico and Texas. The objectives of this project are to design, build, and test a prototype that can safely provide water to these migrants and refugees while communicating the water amount within the station back to the STHRC without hindrance due to weather or remote location. The following report outlines the features of our complete design, and details the primary functions of the main three subsystems that comprise the design. These subsystems include: the base structure, which holds the water and electronics/communication equipment, the electronics/communication system, which tallies and transmits water jug data to the STHRC, and the power system, which charges the station batteries and powers the electronic components. The final design is evaluated against the project constraints and requirements via subsystem and complete prototype testing.

The design constraints of our project include the allotted time, two full semesters, and a budget of $1200, given to us by the Trinity University Engineering Science department. The fully constructed design must also fit within a standard truck bed (78" x 64") for easy transportation. This constraint was satisfied with the dimensions included in Table 3.1.A of this report. The budget remains under $1200, our team spent exactly $1044.33 this semester on the station design. This project is also completed within the time allotment of two semesters, therefore satisfying all project constraints.

The project requirements for our final design are outlined in Section 3. There are a total of eight requirements that need to be met, including the components that the water station is capable of housing. These components being 18 water gallon jugs, as flagpole, electronics system, as well as half the weight of the average adult human male. (Approx. 300 lbs. total). Our final prototype satisfied each part of this requirement, and had no deformation due to weight. Our design also satisfied the requirement of the operational cost for the communication system, which is $5 per month. Furthermore, we required that the primary components of the electronics/communications subsystem be at least IP55 compliant, as outlined by IEC Code 60529, which contributes to the weather resistance of our design. Each of these components is at least IP55 rated, some being up to IP68 compliant, which adds additional durability to adverse weather which is another requirement. The station must withstand an operational temperature of 20°F - 140°F, and a maximum wind speed of up to 40mph. Based on FEA simulations (seen in Section 3.8) and field tests, the wind speed requirement is satisfied. Although the components that make up our design are all capable of operating within the temperature range, our team was unable to directly test and prove this, as renting time in a 30' tall thermal testing chamber is infeasible. The station also satisfies the requirement to report the total number of one gallon water jugs stored within the device at least once per day, to an accuracy of ±1 gallon jug. Furthermore, the station is required to be visible at night from at least one mile away, which was satisfied by attaching an LED strip to the top of our 25ft flagpole. Lastly, we detail two optional features which were not implemented in the final design: a phone charging system and additional storage compartments for items such as protein powder.

Overall, the Emergency Water Station team has designed, constructed, and implemented a fully functioning prototype. All of our constraints and requirements were met, with the exception of additional lab and field testing for the operational temperature requirement. There are no predicted changes that will be made in the future, but improvements can always be made.

1. Introduction

While crossing the border between Mexico and Texas, migrants and refugees are often subject to high temperatures, leading to critical dehydration and heat exhaustion. To combat this, The South Texas Human Rights Center (STHRC) partnered with the Trinity University Engineering Science Department to implement portable Emergency Water Stations that can be deployed along the Mexico-Texas border.

Our main objective was to iterate on the design of the Emergency Water Station 2.0 and deliver an improved product. The previous teams were largely successful in providing a functional hydration station, but their designs were not without problems. The designs suffered from insufficient base strength, poor weatherproofing, and a costly communication system. Previous designs also suffered from significant drift in the total amount of water recorded by weight sensors, due to the continuous load applied to the weight sensors holding up the weight of a water barrel. Therefore, we identified four main project objectives:

1. Improve the strength of the base structure.
2. Decrease the total cost of transmissions.
3. Improve environmental resistance.
4. Improve the accuracy of the water jug counting mechanism.

The project objectives we focused on were necessary in order to deliver an improved water station that corrected errors that the STHRC identified with the previous water stations. The project requirements agreed upon by the 3WS team and our project advisor/sponsor are as follows:

- The station structure shall be capable of holding the weight of 18 water gallon jugs, flagpole, electronics system, as well as half the weight of the average adult human male (Approx. 300 lbs. total).
- The primary components of the electronic and communication systems shall be IP55 compliant, as outlined by IEC Code 60529.
- The operational cost of the communication system shall cost less than $15 per month.
- The station shall report the total number of one gallon water jugs stored within the device at least once per day, to an accuracy of ±1 gallon jug.
- The station shall be capable of withstanding the adverse weather conditions common to the Mexico-Texas border region (Operational temperature: 20°F - 140°F. Max wind speed: 40 mph).
- The station shall be equipped with a light source for easy visibility at night from at least one mile away.
- The station may include a phone charging system.
- The station may include storage compartments for items such as protein powder.

Looking at our first requirement, it was necessary that the station be capable of holding the weight and strain of all components within and attached to the station. These components being a flagpole, the weight of 18 gallon water jugs, electronics system, and half the weight of the average adult human male (Approx. 300 lbs. total). The additional weight of a person was included due to the uncertainty of whether one will need to stand on the station base in order to remove a jug. Furthermore the primary components of the electronic and communication systems shall be IP55 compliant, as outlined by IEC Code 60529. There are adverse weather conditions at the border throughout the year, and having ingress protection rated components will add durability to our design. This durability aids the requirement that our design must be operational at a temperature range of 20°F - 140°F and a maximum wind speed of 40 mph common to the Mexico-Texas border region. Furthermore, the operational cost of the communications system should fall under $15 per month, based on the satellite communication costs of previous iterations. Since the station must accurately communicate the amount of water remaining in the water station to the STHRC, the station should report the total number of one gallon water jugs stored within the device at least once per day, to an accuracy of ±1 gallon jug. The station must have easy visibility at night so that migrants and refugees can easily locate, and therefore should be equipped with a light source visible from at least one mile away. Additionally, two optional requirements for our design included a phone charging system and storage compartments for items such as protein powder within the station. These two features were implemented in the previous emergency water station design, but our team decided to focus on meeting the four main project objectives identified earlier.

We identified three constraints for this project. These constraints are as follows:

- At least one water station must fit inside the standard truck beds that the STHRC uses for transportation and maintenance, with dimensions of 78” x 64”.
- The total cost of the water station development is limited to the $1200 budget provided by Trinity University and additional funds allocated by our sponsor.
- The time allotted to the project is limited to the Fall 2021 and Spring 2022 academic semesters.

The fully assembled water station must fit inside a standard truck bed that is used by the STHRC with dimensions of 78” x 46”. This is necessary for station transportation and maintenance. Second, the total project cost must remain below $1,200, which was allocated to us by Trinity University. We had no additional funds for this project. Lastly, our time allotted for the project is limited to the Fall of 2021 and Spring of 2022 academic semesters, and we must deliver a fully functioning prototype by the end of the spring semester.

The majority of codes and standards applicable to our design pertain to the communications subsystem and weather resistance of our station. Since our electronics will be exposed to water when it's in the field, IEC Code 60529: Ingress Protection Marking classifies the “degree of protection against solid objects (like body parts, tools and dust grains) and the harmful ingress of water by mechanical casings and electrical enclosures.” for protection against potentially hazardous materials. This is the reason we require our electronics and communications subsystems to be at least IP55 compliant. Furthermore, under Rule 290.44, “All potable water distribution systems including pump stations, mains, and both ground and elevated storage tanks, shall be designed, installed, and constructed in accordance with current American Water Works Association (AWWA) standards with reference to materials to be used and construction procedures to be followed.”

Our design is divided into three subsystems, the base structure, electronics/communications system, and the power system. Looking at the base structure, it contains three ramps which allows the whole station to hold at least 18 gallon water jugs, 6 per ramp. In order for the design to be easily transportable, we chose a plastic, polypropylene, that was less dense and more cost efficient than previous iterations to build the station so that we did not go over budget and or make the design too heavy. Furthermore, the station was simulated in Fusion 360 and Autodesk CFD before construction so that we could test if it could withstand 40mph wind speeds without being knocked over. In order for the station to be visible we included a 25ft flagpole in order to mount an LED so that the station can be visible at night. Overall, the station design functions as intended and meets all design requirements. The next subsystem, the electronics and communications system follows all constraints and requirements outlined above. All of our components are at least IP55 rated, and therefore resistant to any water damage. Looking at the operational cost of the communications, our team implemented the Swarm M138 satellite communication module, which has a monthly operational cost of $5 per month, and it accurately communicates the number of jugs within ±1 left in the station daily to the STHRC. The last subsystem, the power system, is powered by a single solar panel mounted 10ft up our flagpole. It charges two batteries within our electronics box, and is capable of powering the station for 6 days on a full charge. This powers the signal LED, which is visible at night, as well as the station electronics. Even in conditions with minimal sunlight, the power system can reliably sustain station operation. As such, there should be no interruption in transmissions.

2. Overview of the Final Design

Our final design consists of three subsystems: the base structure, power system, and electronics and communications. Each was designed with the intention to iterate on the previous design by addressing the main failure points of each subsystem. The completed station is able to dispense water jugs via a hinged hatch above the bottom of the ramps, with another panel at the back of the ramps for loading new jugs. Each jug at the bottom of the ramps rests on a lever switch which, when released, counts that jug as having been removed from the station, and the tally of jugs in the station is updated accordingly. This design is a significant improvement over the previous iteration of the station, which relied on an unreliable network of load cells to measure the weight of the water jugs and calculate the number of jugs in the station. After refilling the station with water jugs, STHRC volunteers can reset the count via a reset button. This button sets the tally back to 18, the maximum number of jugs the station is expected to hold. We assume that the volunteers will refill the station back to 18 jugs each time; failure to do so will result in an inaccurate tally.

The Swarm M138 satellite communication module is responsible for transmitting the number of jugs currently in the station to the STHRC, as well as sending warnings when the count is low. Transmissions are scheduled at least once per day. Green LEDs at the top of the flagpole are programmed to blink from sunset to sunrise in order to increase station visibility, and are able to be seen with the naked human eye more than one mile away. All power is generated and supplied by a south-facing solar panel mounted on the flagpole. The central electronics are housed within an IP55 compliant box within the station at the base of the flagpole, ensuring that no moisture or dust ingress will penetrate the electronics.

All electrical systems, as well as the water jugs and base of the flagpole, are housed within the base structure subsystem. The station structure is constructed from polypropylene, and has been tested extensively to ensure that it is able to support a weight of up to 300 lbs and can be transported and constructed by volunteers from the STHRC. Additionally, the station prototype has been left on the roof of CSI for multiple weeks to demonstrate weatherproofing capabilities, and Computational Fluid Dynamics (CFD) simulations indicate that the station will withstand winds of up to 40mph without tipping. See §3 for an extensive overview of all testing performed on each subsystem. The following sections will discuss in detail the design and construction of each subsystem.

Figure 2.1.A. Front view of the Emergency Water Station 3.0 device on the roof of the CSI building at Trinity University.

2.1. Water Station Structure Subsystem

The station structure is the basis and framework for the other subsystems, housing all of the components of the power and communications and electronics subsystems. The water station structure was designed to be portable, sturdy enough to withstand harsh weather conditions, and to have a shape optimized for the minimum weight to accomplish the task of reporting water in the station. Of our main objectives, the three which influenced the design of the structure most significantly were: (a) improving the accuracy of water reporting of the station, (b) increasing the strength of the base structure, and (c) improving the weatherproofing of the station. Increasing the strength of the station and improving the weatherproofing of the station were accomplished by simulating the design of the structure during the initial computer-based designs to guarantee that the structure could withstand loads of at least 300 lbs, and not tip over due to winds of up to 40mph. However, it was the desired increase in accuracy of water reporting that had the single most significant impact on the shape of the device, since prior designs of the station structure had been designed around using weight sensors to determine the water station's current water load, and we had chosen a significantly different methodology of water detection: ramps with switches.

The ramp and switch method was developed out of concern about sensor drift in load cell weight sensors which we were made aware of early in the project design phase. Our station was designed around the concept of storing 1-gallon water jugs filled with water on ramps, wherein grabbing a jug from the bottom of each ramp would depress a switch and thus register the removal of water from the station. To hold greater amounts of water than previous water station designs had achieved with barrels filled with 1-gallon jugs, we required our station to hold at least 18 1-gallon jugs on 3 ramps. The final design is actually capable of holding 21 full 1-gallon water jugs at maximum load, since we designed each ramp to hold a maximum of seven jugs instead of six. The design is meant to hold only 18, but a higher number of jugs can be stored if desired.

The structure of the water station has three primary components, the polypropylene main body, 25ft flagpole, and the weight supports to prevent tipping during high wind conditions. Each component was designed to be removable to increase the portability of the design when placed in a truck bed for transportation. We show the completed station schematic in **Figure 2.1.B.** Note that the design is completely shaped around the concept of counting jugs using a ramp and switch methodology.

The main body of the station was constructed by plastic welding parts cut from polypropylene sheets together, and then adding metal hinges for the water loading and unloading sides of the three ramps. The body possesses three ramp sections which are each long enough to hold at least six 1-gallon water jugs of standard dimensions. The top of the ramps has a hatch for loading of jugs, and the bottom of the ramp has a hatch attached to the roof of the body to unload water jugs from. The bottom of the station has four rectangular 'feet' which allow for screwing in the wooden 4x4 beams which act as weight supports to prevent tipping, as well as a pole box for storing the base of the flagpole. The main body of the station (no pole or weight supports) has dimensions which are presented in **Table 2.1.A**., and the full structure dimensions are shown in **Table 2.1.B**.

Table 2.1.A. Dimensions of water station main body.

Measurement	Type	Distance [in]
Water Station Main Body Dimensions	Width	28
	Length	44.52
	Height	29.26

Table 2.1.B. Dimensions of water station structure with flagpole and weight/tipping supports.

Measurement	Type	Distance [in]
Water Station Structure Dimensions	Width (Left to Right)	48
	Length (Front to Back)	44.52
	Height	32.78
	Pole Height	~300

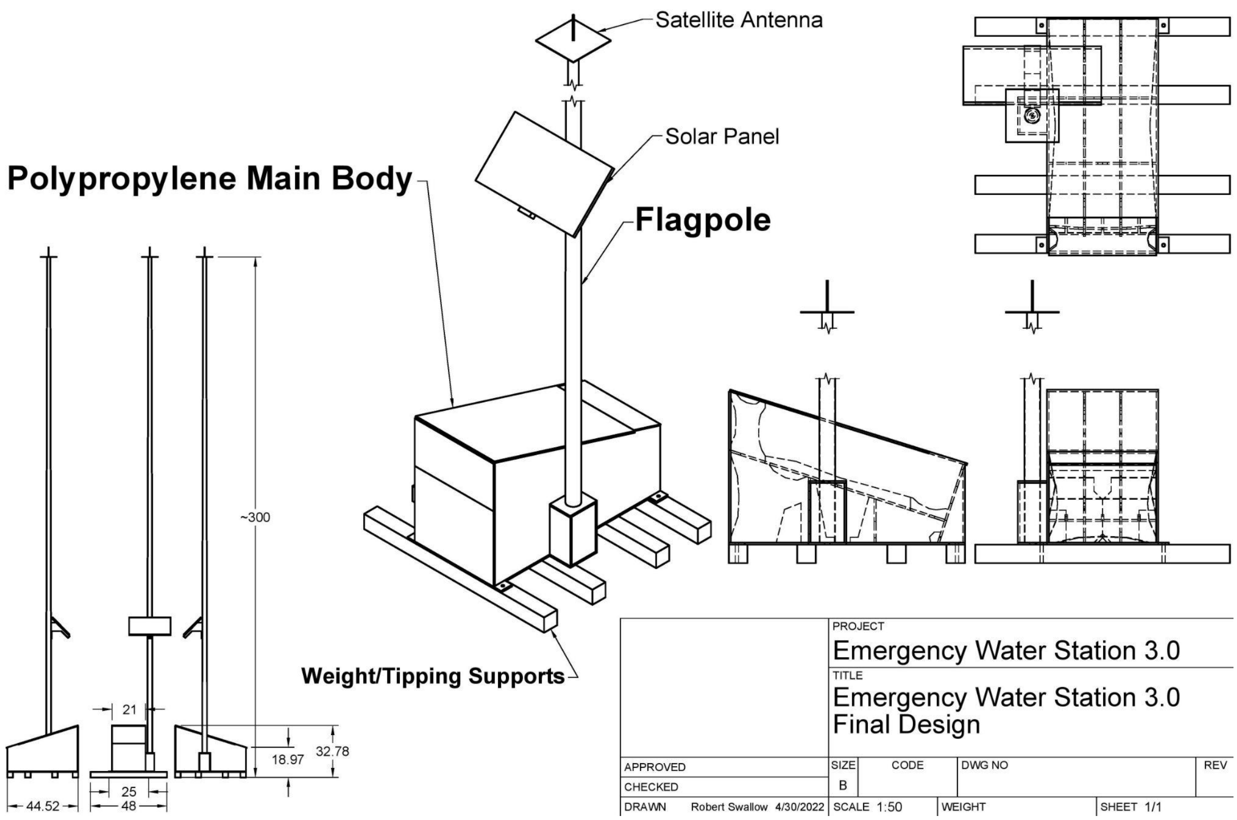

Figure 2.1.B. Emergency Water Station 3.0 Final Design Schematic. Components of the station structure are shown in bold text. The solar panel and satellite antenna are also shown.

The box that the flagpole fits into doubles as the entrance into the device for placing the removable electronics box which carries the electronics and communications subsystem and the batteries for the power subsystem. When the electronics box is inserted through the pole box into the main body, the flagpole then fits through the hole in the top of the pole box.

The flagpole component of the structure is used to provide a location for both the satellite antenna and solar panel, as well as a green LED which flashes at night to make the station's location visible. The flagpole stands approximately 25ft tall with a decreasing diameter between 3in to 2in at the top. Placing the antenna and LED at 25ft above the ground gives our Swarm M138 a superior connection in terms of Received Signal Strength Indicator (RSSI), and the LED a better chance at making the station visible to volunteers and users at night. The flagpole fits inside the flagpole box on the right side of the polypropylene main body, and has wires running through the length of the pole to attach the solar panel, LED, and satellite antenna.

Placing a flagpole on the water station comes with an increase in the horizontal area of our design, meaning greater forces due to wind, and an increase in height of the device which risks lightning strikes. The first concern of higher drag force due to wind was met with the choice to include four 4x4x48 wooden beams with additional weights (sand bags) placed on the four corners of two of the beams. These weight supports provide enough torque to prevent the station from tipping over due to wind. The second concern with the flagpole of lightning strikes was addressed by 3WS planning to use the grounding solution which was previously used by the STHRC to protect the previous water station designs.

Due to our ramp and switch water counting methodology, the Emergency Water Station 3.0 device is significantly taller than its predecessors given the height required to slide down at least six 1-gallon jugs per ramp. This height increase corresponds to an increase in the total area which is susceptible to the effects of drag forces caused by wind, i.e. the station is more at risk of being blown over or damaged by heavy winds due to its shape. Based on Computational Fluid Dynamics simulations of 40mph winds applied to the station model we determined that additional weight supports were necessary to prevent our device from tipping over due to winds. We describe our methodology in running these CFD simulations in §3.8. The weight supports consist of four 4x4x48 wooden beams attached below the main body, with four 60 lbs sand bags placed on top of the four ends of two of the beams.

2.1.1. Relevant Constraints and Requirements

The project constraints relevant to the station structure subsystem are as follows:

- The total cost of the water station development is limited to the $1200 budget provided by Trinity University and additional funds allocated by our sponsor.
- The time allotted to the project is limited to the Fall 2021 and Spring 2022 academic semesters.
- At least one water station must fit inside the standard truck beds that the STHRC uses for transportation and maintenance, with dimensions of 78" x 64".

The project requirements relevant to the station structure subsystem are as follows:

- The station structure shall be capable of holding the weight of 18 water gallon jugs, flagpole, electronics system, as well as half the weight of the average adult human male. (Approx. 300 lbs. total)
- The station shall be capable of withstanding the adverse weather conditions common to the Mexico-Texas border region. (Operational temperature: 20°F - 140°F. Max wind speed: 40 mph).

The station structure subsystem was designed to meet all the constraints and requirements listed above.

2.1.2. Structure Subsystem Research, Development, and Construction

The shape of the main body of the structure was designed to accommodate the ramp and switch method of water jug counting, but was then modified to optimize the design for lower weight to increase portability and retain strength of the structure. The final design of the main body of the structure was arrived at through shape optimization simulations aimed at reducing material and weight, and structural load simulations aimed at guaranteeing that our device would support at least 300 lbs at maximum load conditions. The software used to optimize the main body of the device was Fusion 360, which uses a technique called Finite Element Analysis (FEA) to compute physical quantities which relate to loads applied to the main body model.

FEA is a tool for solving partial differential equations which lack available analytical solutions. The power of FEA is in that it divides complex domain shapes into smaller elements in order to make approximate solutions take less time and resources to compute. In the case of simulating a structure, FEA takes a computer model of an object, creates a mesh which divides the object into smaller parts called mesh elements, and then approximates the solution to a partial differential equation which governs how the object reacts to load forces. We used Fusion 360's capability to solve shape optimization problems on several of the water station's support structures to reduce their size and weight.

In Fusion 360, shape optimization simulations which are based on FEA can be run which show how critical different parts of a single part are to support a given load. These simulations were then used as a guide to remove excess material from parts. An example of this process is the ramp support structures which were reshaped from solid plastic shown in **Figure 2.1.C**, to the optimized shape in **Figure 2.1.D**. These simulations were able to decrease the overall weight of the station, make manufacturing easier by decreasing the amount of material used, and retain the structure's ability to support weight. Using shape optimization we reduced the weight of our main body design in Fall of 2021 by about 100 lbs. This reduction in weight is important to the portability of the design, since people must be able to safely carry the device to move it. Our metric for reasonable weight carrying is based on the MAC tool, which quantifies the amount of weight that groups of people can carry reasonably [1]. The evaluation of our device's weight is presented in §3.1.

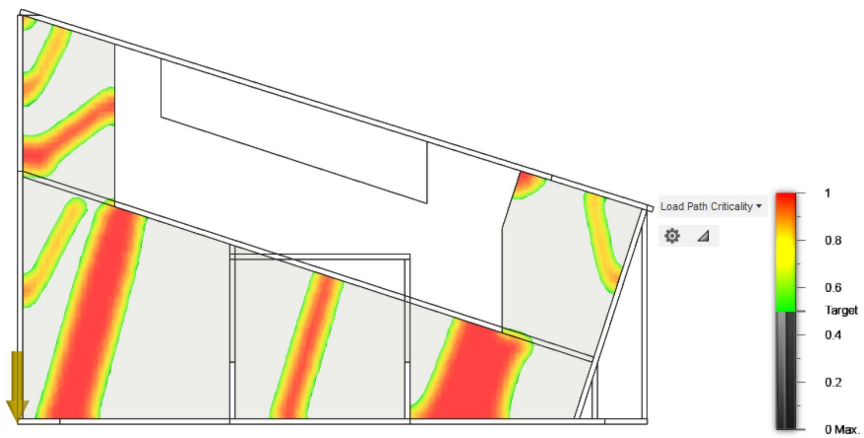

Figure 2.1.C. Results of shape optimization simulation in Fusion 360. Side view of the water station showing the load path criticality of the areas of the ramp support structures. Red corresponds to sections of the ramp structure which are most critical for supporting the load.

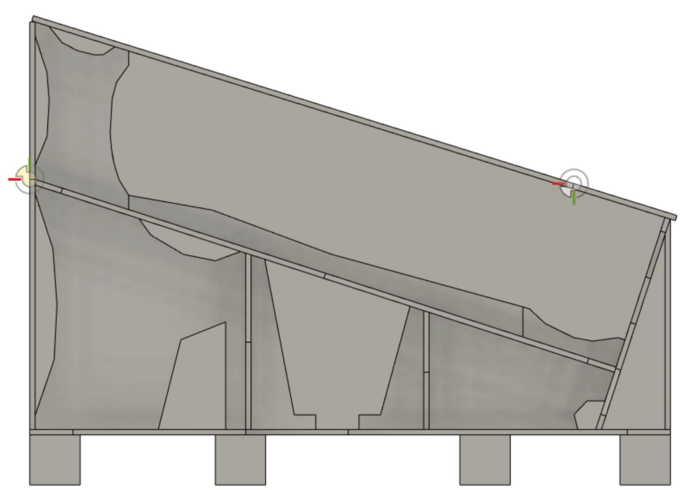

Figure 2.1.D. Side view of the water station with the right side hidden, to show the optimized shape of the ramp support structures. Note that the optimized structure approximately matches the areas of greatest load criticality, with some exceptions.

In total, we optimized each of the six ramp support structures, the ramp itself, the rails which separate the three ramp sections, and the bottom of the ramp. The space in the center of the design which was removed during the shape optimization process from the ramp support structures had the added benefit of being capable of holding the electronics box when the electronics box was slotted through the pole box.

The water station must be capable of supporting the weight of at least 18 water gallon jugs, a flagpole, an electronics system, as well as half the weight of the average adult human male. This weight comes out to approximately 300 lbs, which is significant enough to require both simulation and physical testing to confirm that the computer design can support the weight (prior to actually building the structure) and that the fully constructed main body can hold the weight.

We used FEA simulations in Fusion 360 of maximum load conditions applied to the water station main body structure to verify that the design does not become deformed or damaged by heavy weights placed on the station. These simulations replicated the conditions of applying the weight of 18 water gallon jugs, flagpole, electronics system, as well as half the weight of the average adult human male. Later on these simulations were physically verified by loading our water station with weight that exceeded the required limit without any damage or visible deformation to the structure. The final iteration of these strength simulations is shown in **Figure 2.1.E**, showing that the station is not damaged even under the maximum load conditions of 300lbs.

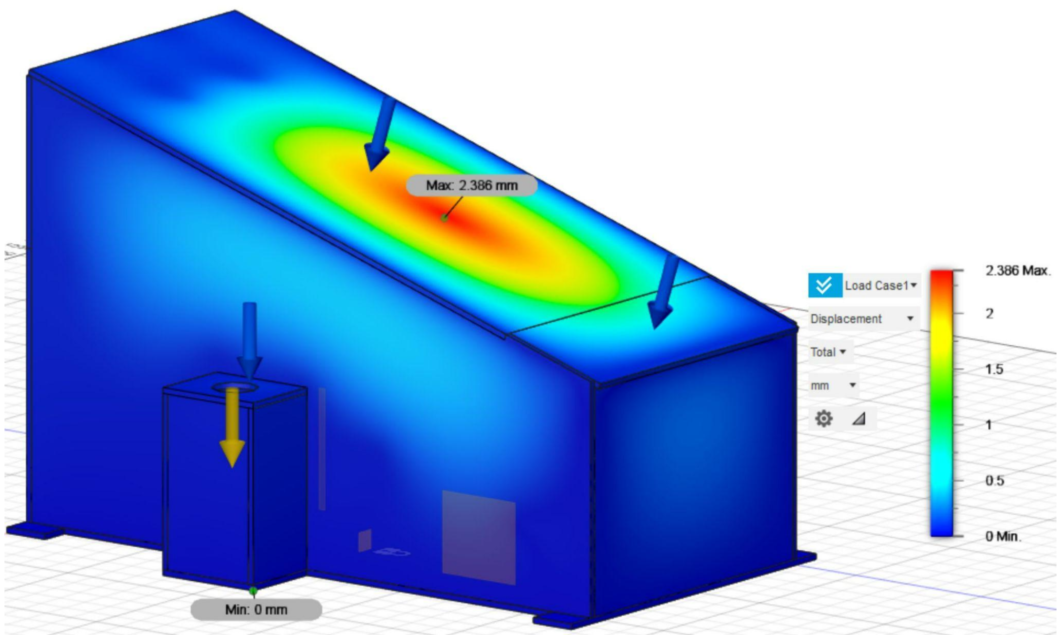

Figure 2.1.E. **Result of final FEA simulation of maximum load applied to the main body.**

The structure of the Emergency Water Station 3.0 was built by cutting out two 96x48 polypropylene sheets of 3/8in thickness into all the parts of the main body, plastic welding the parts together, and then fitting the pole, weight supports, and hinges for all doors into the design. 3WS made extra room in the middle compartment under the ramp for the electronics box to fit into which houses the communications and electronics subsystem plus the batteries of the power subsystem.

The main body assembly was accomplished in the maker space of Trinity University using three key tools, a CNC router for cutting polypropylene into main body components, a plastic welding tool which melts thin strips of polypropylene to run along seams of the body components to plastic weld them together, and a dremel to ensure the fit of parts together. To fit hinges to the loading and unloading doors of the design, drills and impact drivers were used to drive screws into the device. Electronic components such as the switches and reset button of the device were added during the plastic welding process.

The water station will face winds in the Mexico-Texas border region of up to 40mph, and the station structure weight/tipping supports were designed to prevent tipping. Due to the infeasibility of renting time in a wind tunnel for testing of the structure, we decided to perform CFD analysis on the structure to make sure that it would not tip over. To guarantee that the station would not tip over we planned to simulate the water station with no weight/tipping supports, and with the minimum load of water jugs in the station, and therefore we could determine which additional weight supports were required. We then estimated the forces on the station due to a constant 40 mph of wind applied to the design at standard temperature and pressure (20 C and 1 atm of pressure) using drag coefficients for flat plates and cylinders from [2] and [3], to use as comparisons with the CFD simulations of constant 40mph winds applied to the design. Our assumption was that if the station could resist tipping at constant wind speeds of 40mph without tipping then actual wind gusts would not tip the station over.

The water station wind tests were simulated in Autodesk CFD, a software which can be used to solve the Navier-Stokes equation, the fundamental equation of fluid mechanics, for steady state conditions using FEA techniques. The software allowed us to upload a simplified model of the station structure with the main body and flagpole on top of a large rectangular plane which represented the ground. This simplified model was then set to have a volume of air surrounding it, which could have the constant speed of 40 mph in a particular direction applied. We simulated the wind flowing onto the four main directions of the main body, front, back, left and right sides, and then calculated the resulting forces on the water station due to the simulated wind. The forces on the station serve to tip the station over, since they create a torque on the device. The calculations suggested that our design required weight/tipping supports which we designed out of four 4x4x48 beams of wood, where two beams are attached to the main body of the station and have four sandbags each of 60lbs sitting atop the beams. The sandbags' weight prevents the station from tipping over due to their applied torque which is greater than the maximum torque we calculated in our simulations. The full description of this test is provided in §3.8.

The Emergency Water Station 3.0 structure subsystem is not waterproof, but does contain waterproof electronics such as the reset button, ramp switches, and electronics box. We designed the station to allow water to pass through the device and then out holes drilled in the bottom of the main body. Our reasoning was that as long as the electronics were waterproof that the station would continue to function. Our reasoning was shown to be sound when we tested the device during rainy conditions on the roof of the CSI building at Trinity University.

2.2. Water Station Electronics and Communications Subsystem

The electronics and communications subsystem can be further decomposed into two systems: hardware and software. The hardware subsystem is the backbone of the electronics and communications subsystem. It allows the station to measure user input, and facilitates data communication between components within the station and between the station and the STHRC. The software subsystem acts as the brain of the electronics and communications subsystem. It is responsible for storing the water jug tally, flashing the signal LED at night, and scheduling satellite transmissions. These two subsystems work together to monitor and control the complete Emergency Water Station design.

2.2.1. Relevant Constraints and Requirements

The project constraints relevant to the electronics and communications subsystem are as follows:

- The total cost of the water station development is limited to the $1200 budget provided by Trinity University and additional funds allocated by our sponsor.
- The time allotted to the project is limited to the Fall 2021 and Spring 2022 academic semesters.

The project requirements relevant to the electronics and communications subsystem are as follows:

- The primary components of the electronic and communication systems shall be IP55 compliant, as outlined by IEC Code 60529.
- The operational cost of the communication system shall cost less than $15 per month.
- The station shall report the total number of one gallon water jugs stored within the device at least once per day, to an accuracy of ±1 gallon jug.
- The station shall be capable of withstanding the adverse weather conditions common to the Mexico-Texas border region. (Operational temperature: 20°F - 140°F. Max wind speed: 40 mph)
- The station shall be equipped with a light source for easy visibility at night from at least one mile away.

The electronics and communications subsystem was designed to meet all the applicable constraints and requirements listed above.

2.2.2. Electronics & Comm. Subsystem Research, Development, and Construction

The first consideration made during the research and development of the electronics and communications subsystem was with regard to the satellite communication module. Because the hardware and software design of the electronics subsystem is largely built around the satellite communication module, the 3WS team wanted to ensure that the best option was chosen for use in our design. To meet the requirements outlined in §2.2.1, we chose to use the Swarm M138 satellite communication module. This low-power device has an operational temperature range greater than listed in our requirements, and gives us access to the Swarm Satellite Network for water jug tally transmissions [E-5]. To use the Swarm Satellite Network, a monthly fee of $5 is required per M138 modem. This fee meets the operational cost requirement, and allows the station to transmit 720 messages per month, each up to 192 bytes in length.

The next consideration was with regard to the main processing unit within the electronics subsystem. This unit is responsible for keeping track of the water jug tally, flashing the signal LED at night, and scheduling satellite transmissions. The 3WS team chose to use an Arduino MEGA as the main processing unit, as it is a cheap, reliable, and easy to use solution that meets our operational temperature requirements [E-4].

With the satellite modem and main processing unit chosen, work began on designing the hardware system required to power these components and allow communication between the M138 modem, Arduino, and water station I/O. To do this, the 3WS team designed an Arduino shield featuring a voltage regulator, level shifter, I/O terminal blocks and pull down logic, and a power supply decoupler. A top level circuit diagram of the Arduino shield and PCB layout are shown in **Figure 2.2.A** and **Figure 2.2.B**. Full circuit schematics and descriptions of each top level sheet symbol can be found in the Appendix.

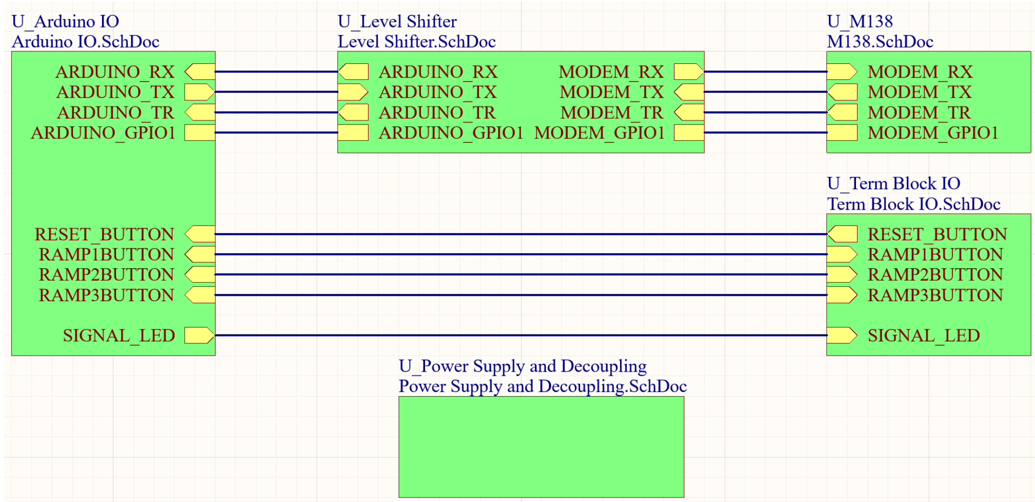

Figure 2.2.A. Top level circuit schematic detailing the high level operation of the Arduino shield.

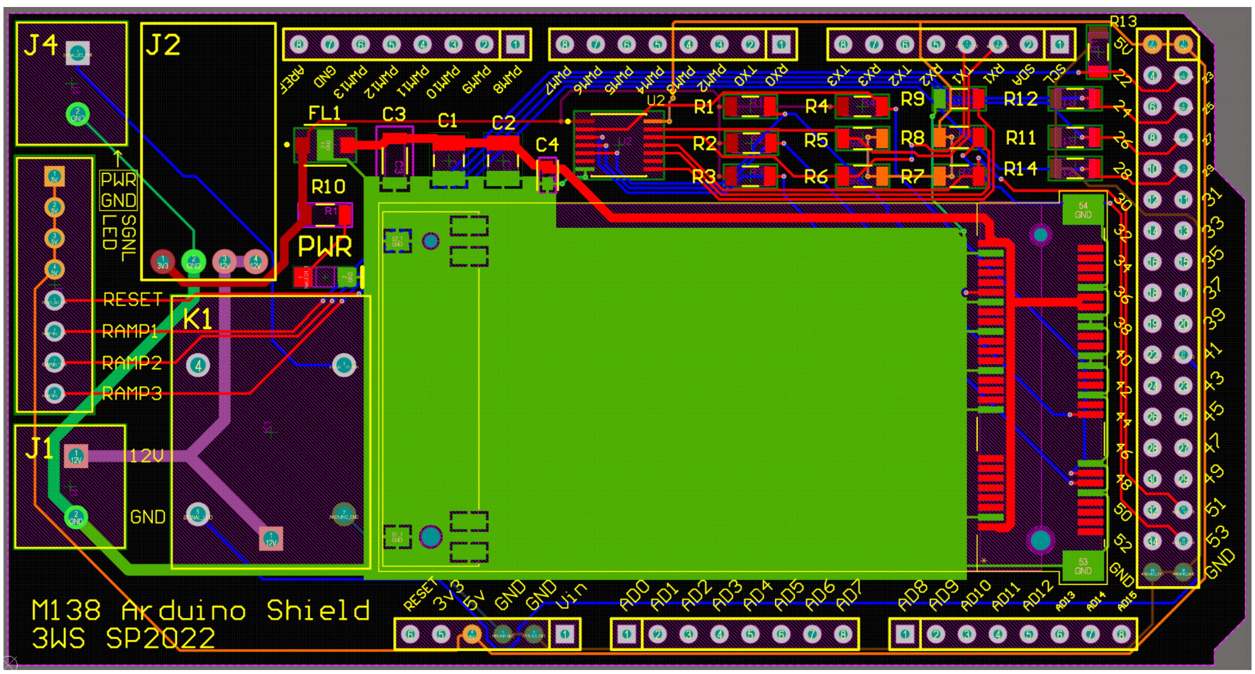

Figure 2.2.B. The PCB layout of the Arduino shield.

The Arduino shield PCB was fabricated by JLCPCB, and the components were hand soldered by the 3WS team in the electronics lab at Trinity University using a fine point soldering iron, and thin solder wire. An image of the completed circuit board is shown in **Figure 2.2.C**.

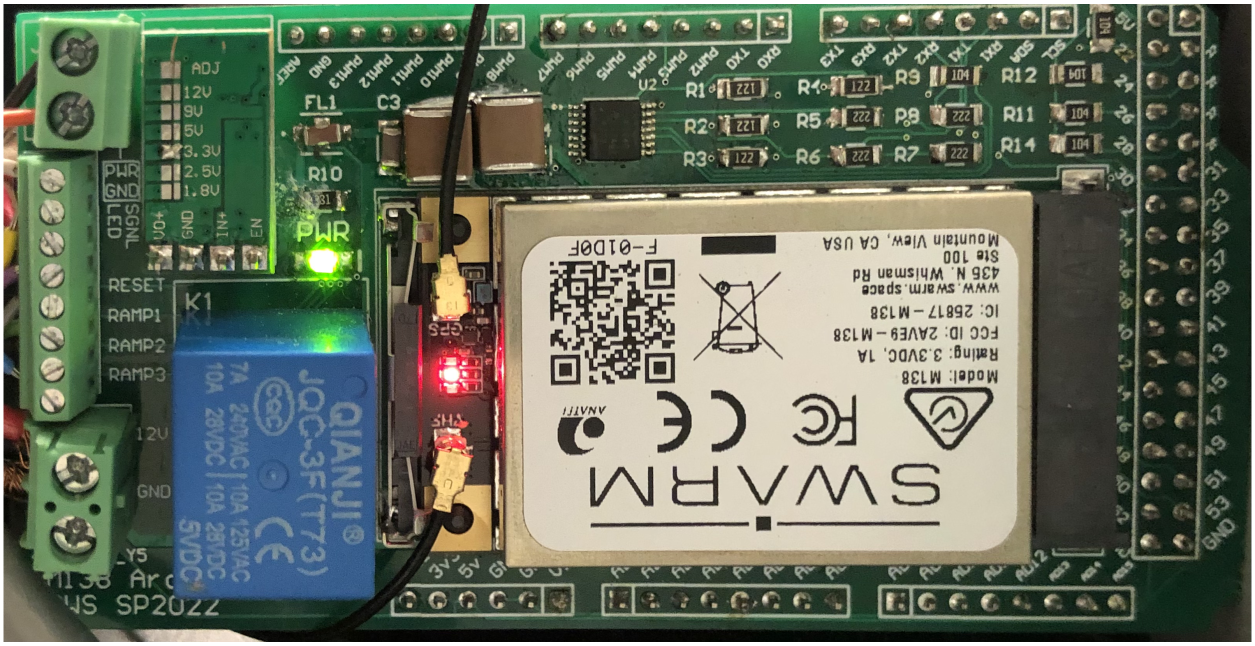

Figure 2.2.C. The complete Arduino shield, populated by the M138 modem.

To house the main electronics and shield them from the elements, 3WS utilized an IP68 rated electronics enclosure produced by Gratury. The Arduino, M138 modem shield, solar charge controller, and station batteries are located in this electronics housing. To pass I/O cables in and out of the housing, holes were drilled in the sides of the box and passed through IP68 rated cable glands to maintain ingress protection. These I/O cables are terminated in IP68 rated cable connectors to allow easy connection and disconnection to the buttons and solar panel attached to the station. Using these connectors enables the electronics housing to be completely removed from the station for assembly and debugging. **Figure 2.2.D** shows the fully assembled electronics housing.

Figure 2.2.D. The inside of the electronics housing.

While the hardware makes communication between the Arduino, M138 modem, and station I/O possible, the software ultimately controls these processes. The water station software was programmed in the Arduino IDE. A flow chart of the main loop is shown in **Figure 2.2.E**.

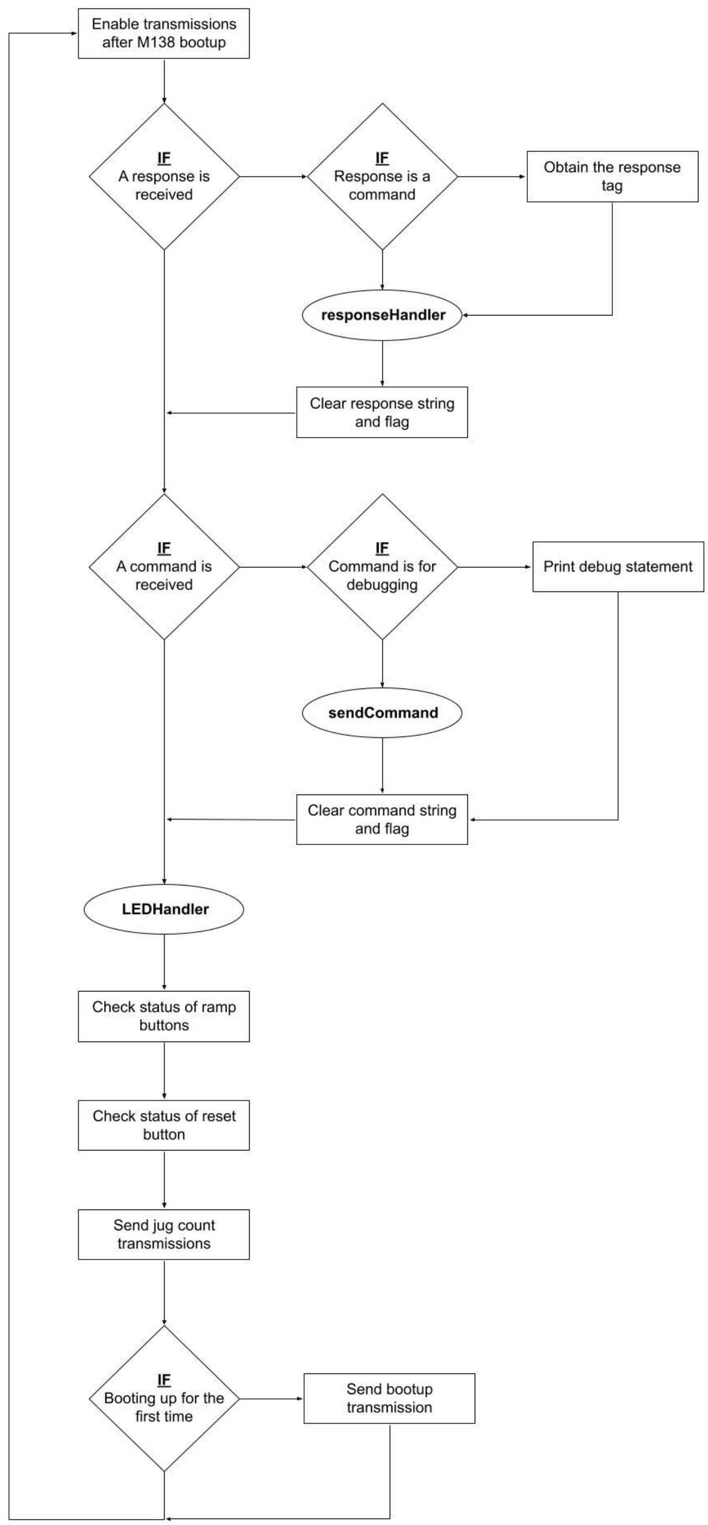

Figure 2.2.E. A flow chart showing the main software loop.

Communication between the Arduino and the M138 modem is handled using UART serial communication. Response messages from the M138 modem to the Arduino are handled by the response handler. This handler reads the serial data sent by the M138, converts the data to a string, then analyzes these strings for useful data. The response handler is ultimately responsible for setting variables like the latitude and longitude coordinates of the station, the current date and time, and other transmission flags. Command messages from the Arduino to the M138 are handled by the command handler. These commands can be date/time requests, satellite transmission commands, or various debugging commands. Before sending commands to the M138, each command has a unique NMEA checksum attached to the end of the string. This checksum is calculated by exclusive-oring each byte of the string together.

The LED handler is responsible for flashing the LED at night. This function dynamically calculates the sunrise and sunset at the water station's geospatial location each day using GPS position data and the date/time stamp provided by the M138's GPS connection. Between sunset and sunrise, this function flashes the signal LED at a frequency of 1Hz. This is shown in **Figure 2.2.F**.

Figure 2.2.F. View of the LED blinking on and off at night.

The button handlers are responsible for monitoring and debouncing the ramp switches and the reset button, and updating the number of water jugs stored in the station. When any ramp switch is unpressed, the water jug tally is reduced by one. No action occurs when a ramp switch is pressed. When the reset button is pressed, the water jug tally is reset to 18, all the transmission flags are reset, and a reset message is queued for satellite transmission.

Finally, the warning handler is responsible for monitoring the water jug tally and queueing warning messages for satellite transmission. Additionally, the warning handler queues a satellite transmission containing the current water jug tally each day at 11PM CST.

To successfully send and receive satellite transmissions, the Swarm M138 satellite modem requires an antenna ground plane removed from any vertical obstructions. For the ground plane, 3WS used a 1’ x 1’ x ¼” aluminum plate, in accordance with the Swarm design guidelines [4]. This antenna ground plane is secured to the top of the flagpole, far above the ground and likely above any potential vertical obstructions that would exist in the field.

The signal LED is also secured to the top of the flagpole. 3WS selected a green LED strip rated for outdoor use (IP68 ingress protection, and within operational temperature requirement). 3WS chose a green LED to distinguish the signal light from starlight, and to differentiate from the red, white, and blue lights often used by police and other emergency services. **Figure 2.2.G** shows the antenna ground plane and signal LED attached to the top of the flagpole.

Figure 2.2.G. View of the top of the Emergency Water Station 3.0 pole, where the LED strip has been coiled below the satellite antenna ground plane.

The ramp switches and reset button used in the station are all IP68 rated snap action lever switches, with operational temperature ranges consistent with the project requirements. These are secured to the station using custom designed 3D printed mounts made of a high temperature plastic to prevent deformation due to heat exposure in the field. These mounts are shown in **Figure 2.2.H**.

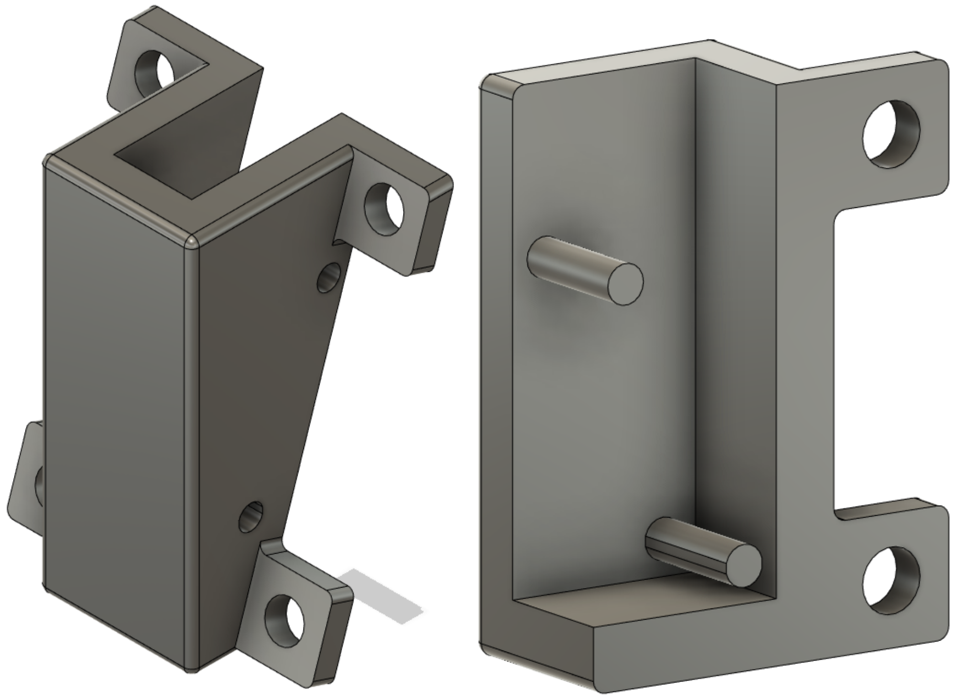

Figure 2.2.H. Switch mounts used to secure the ramp switches and reset button to the station base.

2.3. Water Station Power Subsystem

The Emergency Water Station power subsystem is responsible for collecting and providing power to the electronics that monitor and control the station. This power is collected via a 30 watt solar panel mounted on the flagpole, and is stored in two, 12 volt 10 amp-hour lithium iron phosphate batteries connected in parallel.

2.3.1. Relevant Constraints and Requirements

The project constraints relevant to the power subsystem are as follows:

- The total cost of the water station development is limited to the $1200 budget provided by Trinity University and additional funds allocated by our sponsor.
- The time allotted to the project is limited to the Fall 2021 and Spring 2022 academic semesters.

The project requirements relevant to the power subsystem are as follows:

- The primary components of the electronic and communication systems shall be IP55 compliant, as outlined by IEC Code 60529.
- The station shall be capable of withstanding the adverse weather conditions common to the Mexico-Texas border region. (Operational temperature: 20°F - 140°F. Max wind speed: 40 mph)

The power subsystem was designed to meet all the applicable constraints and requirements listed above.

2.3.2. Power Subsystem Research, Development, and Construction

Most components of the power subsystem were salvaged from the previous design iteration of the Emergency Water Station project. The 3WS team chose to reuse the 30 watt solar panel, solar charge controller, and lithium iron phosphate batteries of an Emergency Water Station 2.0 that was retrieved from the field during the Fall 2021 semester. These components have been proven to work in the field, and allowed the team to reallocate around $400 in the budget towards other aspects of the project. A diagram showing the layout of the power subsystem is shown in **Figure 2.3.A**.

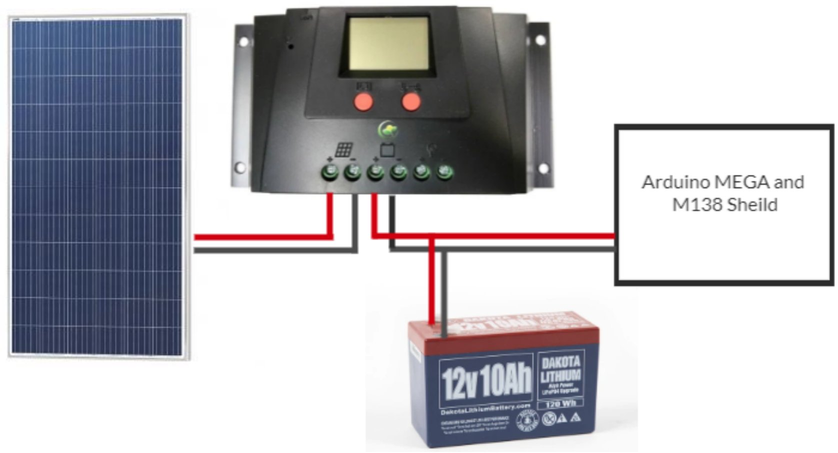

Figure 2.3.A. Diagram of the power subsystem connections.

As the solar panel collects energy during the day, it is fed through the solar charge controller to provide a steady, safe current and voltage output to the batteries. This steady power output is what ultimately charges the batteries. Without the solar charge controller, the voltage and current generated by the solar panel would vary wildly (from ~2 to ~35 volts, at ~0.01 to ~1.5 amps) and could potentially damage the batteries, causing at best, reduced lifespan, and at worst, violent electrical fires. Additionally, the station electronics are connected directly to the batteries, as per the recommendation of the solar charge controller manufacturer [E-3].

Two 12 volt, 10 amp-hour lithium iron phosphate batteries are used to store the power generated by the solar panel and supply power to the station at night. These two batteries are connected in parallel to double their capacity, resulting in a total station power capacity of 240 watt-hours. Upon taking power measurements of the fully constructed electronics and communications subsystem, 3WS found the station to draw 1.674 watts, averaged over the course of a full day of operation. Using **Equation 2.3.A**, the total operational time of the station was calculated, assuming initially fully charged batteries and no power collection from the solar panel.

$$Operational\ Time = \frac{240\ watts*hour}{1.674\ watts} * \frac{1\ day}{24\ hours} = 5.97\ days \qquad \textbf{(2.3.A)}$$

As shown in the calculation, the power subsystem is capable of powering the electronics for just under six days, assuming no power generation from the solar panel. The 3WS team believes this is ample capacity for normal station operation, and provides an excellent buffer in the case of long periods with little to no sunlight.

To generate power for the station, the power subsystem uses a 30 watt solar panel mounted on the flagpole via duct clamps. The 30 watt rating details that, in direct sunlight, the solar panel is capable of generating 30 watts of power. While this rating is likely accurate, the 3WS team opted to assume far less efficient solar collection in direct sunlight as an extra safety factor. As such, the solar panel was only considered to output 25 watts in direct sunlight during design calculations. This underestimation ensured that the power system was designed to function in efficiency conditions far worse than are actually realized in the station once deployed. Assuming a 25 watt output in direct sunlight and using the measured average station power draw of 1.674 watts, the total number of hours in direct sunlight needed to compensate for one day of station operation was calculated to be 1.6 hours, as shown in **Equation 2.3.B**.

$$Direct\ Sunlight\ Hours = \frac{1.674\ watts * 24\ hours}{25\ watts} = 1.6\ hours \qquad \textbf{(2.3.A)}$$

Note that this is 1.6 hours of *direct* sunlight to compensate for one day of operation. While the 3WS team believes that experiencing at least 1.6 hours of direct sunlight per day is easily achievable in the Mexico-Texas border region, it is important to note that the solar panel is still capable of generating significant amounts of power without direct sunlight (due to cloud cover, fog, rain, etc.) [5]. Because of this, we are confident that the station power system can sustainably collect and distribute power to the water station in many different weather conditions.

To further maximize the number of hours of sunlight exposure, the solar panel is oriented to face south. This is the ideal orientation for solar panels in the northern hemisphere, and will further increase the amount of power generated by the power subsystem [6].

All connectors utilized in the power subsystem are rated for IP68 ingress protection, in accordance with the ingress protection project requirement. All components used in the power subsystem are rated for use within the operational temperature range requirement [E-1] - [E-3].

2.4. Comparison of Emergency Water Station 3.0 to Prior Water Station Designs

Previous iterations of the Emergency Water Station, while functional, were not without issues. 3WS was able to resolve many of these issues with our final design, most notably the inaccuracy of the jug-counting system and the shortcomings of the satellite communication module. Extensive modifications were implemented in order to address these failure points and provide a more robust, reliable system of counting jugs and relaying this information via satellite communication. These changes are detailed in the following subsections.

2.4.1. Comparison of Load Cells to Lever Switches

In order to measure the amount of water in the station, the Emergency Water Station 2.0 design relied on a series of FC2231 load cells to measure the total weight of the water and calculate the number of jugs present [7]. In addition to being sensitive to fluctuations in temperature and humidity, 3WS discovered a major flaw in the use of these sensors: load cells are highly sensitive to sensor creep. Load cell sensors calculate weight by measuring the deformation and subsequent recovery of the load cell as an item is placed on top of the sensor. While they are useful for periodic applications of weight, a continuous load applied over an extended period of time will cause the sensor to experience creep to a degree that the measurements effectively become unusable [8], as was discovered by the STHRC after extended field use.

To address this issue, 3WS made the decision to switch from a load cell-based measuring system to one based on snap action lever switches. These switches operate well within the operating ranges of temperature and humidity required by our station, and therefore will not experience fluctuations in accuracy as a result of a change in weather. Additionally, these simple sensors only output either a digital ON or OFF signal, thereby entirely eliminating the issue of sensor creep. Complex calculations and monitoring of weather conditions are also now unnecessary, thus reducing power consumption, cost, and complexity of the electrical schematic. Fewer potential failure points and a dramatic increase in longevity of the jug counting system establish confidence that the switch from load cells to lever switches represents a major improvement in the quality of our design.

2.4.2. Comparison of Rockblock to Swarm M138

Both the Emergency Water Station 2.0 and 3WS rely on satellite communication to transmit information from the station to the volunteers at the STHRC. However, while the previous design utilized a RockBlock 6903 satcomm module, 3WS has implemented the Swarm M138. The RockBlock communicates via the Iridium satellite array for a line rental fee of $15 per month, with an additional cost for each byte of data sent. Idle power usage was low at 34 mA, but very high during transmissions at 1.3 A [9]. The module was also prohibitively expensive at $260, and required an additional Raspberry Pi to transfer data sent by the RockBlock to the BlueHost website [7].

For comparison, the Swarm M138 costs only $120 and charges $5 per month to transmit 750 data packets up to 192 bytes each, far exceeding the requirements of our project and representing a significant decrease in both the monthly cost and one-time purchase of the device. Idle power consumption is even lower at only 23 mA, and 850 mA during transmissions [4], the duration of which are much shorter than that of the RockBlock. It also does not require the use of a Raspberry Pi, and communicates with the central microcontroller, an Arduino MEGA, via a custom Arduino Shield PCB. This simplified electrical configuration and reduced cost represents another significant improvement over the design of the Emergency Water Station 2.0.

3. Design Evaluation

Here, we define the project constraints and requirements that were established in the Water Station 3.0 Updated Project Proposal, describe the tests used to evaluate the design's adherence to the constraints and requirements, and discuss the results. Each constraint and requirement is outlined, then followed by a description of the related tests and results.

This design adheres to all constraints and requirements, and therefore achieves our primary objectives for the project: improving the strength of the base structure, decreasing the cost of communications, improving weatherproofing, and ultimately improving the accuracy of reporting current water content in the station.

Project Constraints

3.1. Size and Portability Constraint

At least one water station must fit inside the standard truck beds that the STHRC uses for transportation and maintenance, with dimensions of 78" x 64".

3.1.1. Size and Portability Test

3WS tested whether the station structure can fit within a 78" x 64" truck bed, while also being portable enough to be loaded and unloaded from a truck.

3.1.1.1. Test Objectives

1. To determine if the station structure physically fits within a 78" x 64" space.
2. To determine if the station can be loaded and unloaded into a truck bed by a group of people.

3.1.1.2. Features Evaluated

The Size Test evaluated whether or not the design meets our design constraint on the size of the device, and also whether or not the water station is portable enough to be set up by volunteers in the Mexico-Texas border region.

3.1.1.3. Test Scope

The test involved measuring the physical size of the device with a measuring tool (a tape measure), and lifting the device with multiple group members to test whether the device could be loaded into a truck bed.

3.1.1.4. Test Plan

The first part of the test consisted of measuring the dimensions of the water station to determine if it fits within a 78" x 64" space. The second part of the test consisted of having 3WS members attempt to lift and lower the device on the ground to see if loading the water station into a truck is feasible.

3.1.1.5. Acceptance Criteria

The device was considered of the appropriate size and portability, if the dimensions are such that the station fits within a 78" x 64" area, and if it is able to be lifted and lowered to the height of a truck bed by less than or equal to four volunteers.

3.1.1.6. Test Results

The water station structure described in §2.2 was constructed to test its fit within the required 78" x 64" area. The measured water station structure dimensions are compared with the required area in **Table 3.1.A**. With the addition of the wooden 4x4 beams meant to stabilize the design and raise it above the mud, the dimensions are larger in the width dimension from the dimensions in the Full Prototype Test Report. If desired however, the wooden beams may be removed from the station, and reattached later. Additionally the five sections of the 25' aluminum pole were measured to verify that the pole (when disassembled) fits within the truck bed. When compared to the maximum truck bed area which is allowed for the water station fit, the water station can be placed into the space.

Table 3.1.A. Dimensions of water station structure compared with required truck bed dimensions.

Measurement	Type	Distance [in]	Comments
Water Station Dimensions	Width (Left-Right)	48	48" with wooden 4x4 beams, 28" with pole box
	Length (Front-Back)	44.52	Decrease from fall semester design length of 48'
	Height	29.26	Decrease from fall semester design height of 30.5'
	Pole Section Height (Max)	56.38	5 pole segments
Truck Bed Dimensions	Width	64	Width (Left-Right) of structure and pole sections fit within a standard truck bed
	Length	78	Length (Front-Back) of structure and pole sections fit within a standard truck bed

Our water station structure was capable of being lifted and lowered by two members of 3WS when we installed the structure onto the roof of the Center for Sciences and Innovation building at Trinity

University for the weatherproofing test (§3.8). We attribute the ability to lift the design to the lighter structure design than our prototype design from Fall 2021. The water station structure is lighter than our fall semester structure design by over 100 lbs, due to several factors: (1) change of materials from HDPE to polypropylene, (2) decrease in the thickness of the plastic from half-inch to 3/8ths-inch, and (3) shape optimization simulations which were used to design the support structures of the device.

We decreased the plastic-only weight of the structure from 192 lbs (Fall 2021 prototype design) to 87 lbs, which is a significant improvement towards ease of loading and unloading from a truck bed by STHRC volunteers. **Table 3.1.B** shows the weight of our current design, and compares the current weight of the fully assembled design with maximum safe carrying loads. We assume an additional weight of ~15 lbs added by the electronics, and any miscellaneous parts which cannot be removed. The weight of the total device (without the pole and sand bags) is approximately 102 lbs. According to the MAC tool [1], the weight of the water station structure, without the pole and sand bags attached, may be carried safely (with moderate risk) by two to three volunteers. Two members of 3WS were able to safely raise, carry, and lower the weight of the station without the pole or sand bags attached.

Table 3.1.B. Comparison of total weight of station designs with the maximum weight that can be reasonably carried by several people.

Category	Weight [lbs]
Water Station 3.0 Preliminary Design HDPE (0.5 inch thick)	192
Water Station 3.0 Final Design - Polypropylene (0.375 inch thick)	87
Water Station 3.0 Final Design - Approximate Total Weight (structure + electronics, without pole or sand bags)	~102
Max Weight Carried by Two People [1] Low Risk	77
Max Weight Carried by Three People [1] Low Risk	121
Max Weight Carried by Two People [1] Medium Risk	77-143
Max Weight Carried by Three People [1] Medium Risk	121-209

3.1.1.7. Evaluation

Our water station dimensions fit within the required truck bed space of 78” x 64”, and the weight of the station may be carried with moderate risk by two or three volunteers. Based on these two results, our Emergency Water Station 3.0 device successfully meets the size and portability constraint on the station.

3.2. Budget Constraint

The total cost of the water station development is limited to the $1200 budget provided by Trinity University and additional funds allocated by our sponsor.

3.2.1. Budget Constraint Evaluation

The total cost of the project was **$1,044.33**, which is under the $1200 budget. We did not ask for or receive any additional funding from our sponsor. The satellite communications costs of $5 per month will be covered by Trinity University. Based on these facts, our budget constraint was satisfied.

3.3. Time Constraint

The time allotted to the project is limited to the Fall 2021 and Spring 2022 academic semesters.

3.3.1. Time Constraint Evaluation

The project was completed during the Spring 2022 academic semester. Our completion of the Emergency Water Station 3.0 final design during the Spring 2022 semester guarantees that we successfully met our time constraint.

Project Requirements

3.4. Storage and Weight Support Requirement

The station structure shall be capable of holding the weight of 18 water gallon jugs, flagpole, electronics system, as well as half the weight of the average adult human male. (Approx. 300 lbs. total).

3.4.1. Storage Test

3WS demonstrated that the station structure has the capacity to hold 18 full 1-gallon water jugs.

3.4.1.1. Test Objectives

To determine if the Emergency Water Station 3.0 device can store 18 full 1-gallon jugs.

3.4.1.2. Features Evaluated

3WS aimed to determine the maximum number of water jugs which can be stored in the station, which should be at least 18.

3.4.1.3. Test Scope

During the physical portion of the Weather Proofing tests in §3.8, 3WS set up the station on the roof of the CSI building at Trinity University, and loaded water jugs into the station. The maximum number of water jugs was determined by how many were able to fit into the device on the three ramps.

3.4.1.4. Test Plan

The test was conducted by setting up the water station, and then sequentially loading jugs into the top of each of the three ramps and determining the total number of jugs which are able to be loaded.

3.4.1.5. Acceptance Criteria

If the total number of 1-gallon jugs that the device can hold was greater than or equal to 18, then we considered our device to meet the capacity portion of the Storage and Weight Support requirement. All doors must be able to close at the end of the test, and all 1-gallon jugs must be able to slide down the ramp in order to be counted.

3.4.1.6. Test Results

3WS loaded 1-gallon jugs into the water station structure until 1-gallon jugs could not be added onto any of the three ramps. The Emergency Water Station 3.0 device can hold **21 full 1-gallon jugs** on its three ramps, with all doors closed. We tested that each gallon jug was able to slide down each ramp as well to guarantee that all 21 jugs could be counted using our switch method. Both the top and bottom doors to the device were closed while all 21 jugs were loaded.

These results matched our calculations and measurements of the length of the ramp and dimensions of water jugs shown in **Table 3.4.C**. Note that the 42.37" ramp structure allows for 7.06 jugs per ramp, matching the 21 jugs loaded during the physical test.

Table 3.4.C. Measurements of the fit of 1-gallon jugs onto ramps.

Measurement	Type	[in]	Comments
1-Gallon Jug	Side Length	6.00	
	Height	9.75	
Ramp Dimensions	Side Length	6.50	Fits one gallon water jugs without allowing for rotation
	Total Length	42.37	Fits more than 6, 1-gallon water jugs (42.37/6.00 = 7.06 per ramp)
	Min. Height	10.75	Fits the height of 1-gallon water jugs

3.4.1.7. Evaluation

3WS recorded that our water station may hold a maximum of 21 full 1-gallon water jugs. The Water Jug Capacity test is considered successful since the 18 minimum number of jugs to fit in the device was confirmed, and all 1-gallon water jugs slide down the ramps to be counted by the switches.

3.4.2. Weight Support Test

3WS demonstrated that the station structure can withstand the full weight of all necessary components, water storage, and human interaction without any significant deformation to the structure.

3.4.2.1. Test Objectives

1. To determine via simulation that the station design does not deform when subject to a load of 300 lbs. distributed over the water storage ramp, and top of the structure.
2. To verify that the completed station does not significantly deform during maximum load conditions.

3.4.2.2. Features Evaluated

The ability of the station to withstand, without significant deformation, the maximum loading conditions expected of our design: 300 lbs.

3.4.2.3. Test Scope

We used Autodesk Fusion 360 to perform simulations of loading conditions on our updated station structure design, and verified those simulations by loading the completed physical station structure with weight.

3.4.2.4. Test Plan

The Weight Support test consisted of two parts, the FEA simulations, and the physical tests. The simulations consist of Fusion 360 FEA simulations of loading conditions applied to the structure model distributed over the top of the device and the water storage ramp. The physical tests consisted of loading the station with all 18 water gallon jugs, and then loading the station with the maximum load conditions of ~300 lbs. After loading the station 3WS then inspected the station structure for any visible signs of deformation.

3.4.2.5. Acceptance Criteria

The Weight Support test was considered successful if both the station structure simulations and physical tests produce negligible amounts of displacement on the station structure during maximum load conditions. We consider less than 0.5 cm of displacement in any part of the structure due to loading conditions as a negligible amount. Less than 0.5 cm of displacement was considered not visible displacement in our physical tests of the completed water station.

3.4.2.6. Test Results

3WS completed both the simulation and physical testing of the station structure's ability to hold the proscribed weight of 300 lbs. The new final design prioritizes decreasing the weight of the device for better portability without sacrificing structural integrity.

The final water station structure was designed in Fusion 360 to withstand the load of 300 lbs. distributed evenly over the three ramps and the top of the device. The FEA simulations in Fusion 360 of static loads applied to the design resulted in minimal displacement and strain on the structure. The static stress simulation of the maximum loading condition is shown in **Figure 3.4.A**. Note that 120 lbf was placed over the top facing structures of the design, and 180 lbf over the three ramps (larger than 18 1-gallon water jugs weight).

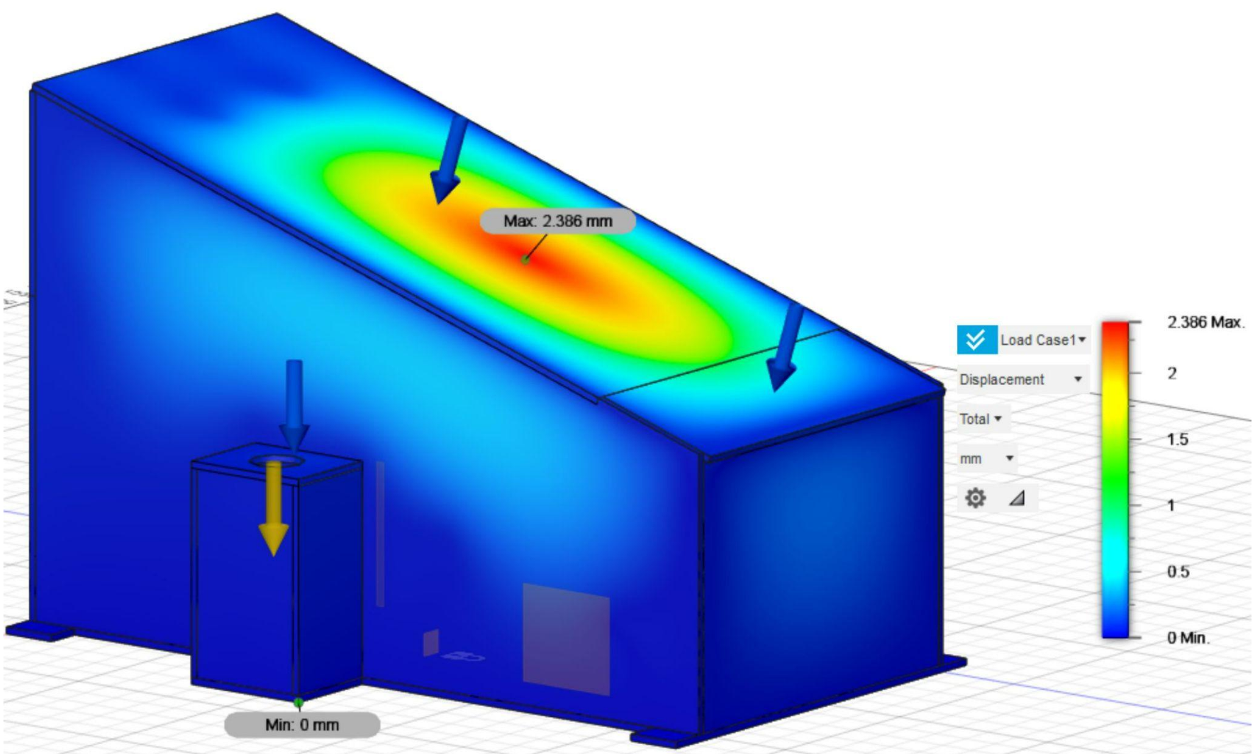

Figure 3.4.A. Result of FEA simulation of maximum load applied to the water station. The maximum displacement occurs at the top face, where the least support structures are present.

The simulations yielded displacement magnitudes less than 3mm. **Tables 3.4.A** and **3.4.B** show the results of static loads of gravity only, and gravity plus 300 lbs. applied to the station structure. Fusion 360 indicated that the design is over-engineered due to the high minimum required safety factor.

Table 3.4.A. Results of FEA simulation of station design under load of gravity.

Category	Data	Comments
Maximum Strain	0.002	Indicates that the design does not experience any significant deformation
Maximum Displacement [mm]	2.4	Indicates that the design will not experience permanent deformation
Safety Factor Minimum	11.25	The device is over-engineered according to Fusion 360 safety factor criterion

Table 3.4.B. Results of FEA simulation of station design under maximum load conditions.

Category	Data	Comments
Maximum Strain	1.8E-4	Indicates that the design does not experience any significant deformation
Maximum Displacement [mm]	0.2	Indicates that the design will not experience permanent deformation
Safety Factor Minimum	15	The device is over-engineered according to Fusion 360 safety factor criterion

During the storage capacity tests of §3.4.1, 3WS determined that the station can withstand the weight of 21 full 1-gallon water jugs (~210 lbs), plus the weight of the pole and electronics plus the full weight of a human male (150 lbs) without any visible deformation to the structure. This load is equivalent to greater than 300lbs weight support requirement which was simulated in **Figure 3.4.A**.

3.4.2.7. Evaluation

Since the water station structure was confirmed to only experience negligible or non-visible displacement under the maximum load conditions of **greater than 300 lbs**, our weight support requirement was satisfied.

3.5. Electronics Ingress Protection Requirement

The primary components of the electronic and communication systems shall be IP55 compliant, as outlined by IEC Code 60529.

3.5.1. Ingress Protection Test

3.5.1.1. Test Overview

Ingress Protection Test: This test demonstrated the water and dust ingress protection capabilities of the electronics housing.

3.5.1.2. Objectives

The Ingress Protection Test determined if the electronics housing possesses ingress protection capabilities that are compliant with the IP55 ingress protection rating outlined in IEC Code 60529.

3.5.1.3. Features Evaluated

This test evaluated the ingress protection capabilities of the electronics housing, and ensured that the electronics system is compliant with the IP55 ingress protection requirements outlined in IEC Code 60529.

3.5.1.4. Test Scope

This test followed the procedures for ingress protection testing outlined in IEC Code 60529. To evaluate the water ingress protection of the electronics housing, water jets were projected by a ¼ inch nozzle against the electronics box from all directions for three minutes. To evaluate the dust ingress protection of the electronics housing, the electronics housing was placed outside and exposed to dirt, sand, wind, and other debris for a 24 hour period.

3.5.1.5. Test Plan

The water ingress protection portion of this test required a source of water (a garden hose was used), a ¼ inch nozzle attachment, and a timer. The electronics housing was sealed, sprayed with the water jet for three minutes and rotated into a new position every 30 seconds, then unsealed and examined for water ingress.

The dust ingress protection portion of the test required an outside location exposed to the elements that the electronics housing was placed in for a 24 hour period. The electronics housing was sealed, placed in the location for 24 hours, then unsealed and examined for dust and debris ingress.

In both of these tests, the electronics system was not present in the electronics housing. This should not have altered the results of the test, as the housing completely sealed the electronics from the exterior. In the dust ingress protection test, a 24 hour period with fair weather conditions (absent of rain or heavy winds) was chosen to evaluate the electronics housing. The electronics housing will ultimately be placed inside the base station structure, and so will be shielded from elements such as heavy rain and wind.

The data collected in this test was the amount of water and dust that are contained in the electronics housing following completion of the testing procedures.

3.5.1.6. Acceptance Criteria

The ingress protection test was considered successful if the amount of water and dust contained in the electronics housing following the testing procedures was compliant with the IP55 ingress protection requirements outlined in IEC Code 60529. According to the code, a device is IP55 compliant if water and dust do not enter in sufficient quantities to cause harm to the system following the testing procedures. To this end, less than one milliliter of water and one milliliter of dust was allowed to enter the electronics housing to be considered compliant with the IP55 rating.

3.5.1.7. Test Results

The water ingress protection test was conducted as outlined above with the use of a garden hose. The electronics housing was unsealed and examined after the water test, and there was no sign of water ingress into the housing.

The dust ingress protection test was conducted as outlined above. The electronics housing was left outdoors in the elements under fair weather conditions for a 24 hour period, and then unsealed. No dirt was found inside the electronics housing.

3.5.1.8. Evaluation

These tests confirmed that the electronics housing is at least IP55 compliant, as outlined by IEC Code 60529, and should have no water or dust ingress during field deployment.

3.6. Operational Cost Requirement

The operational cost of the communication system shall cost less than $15 per month.

3.6.1. Operational Cost Requirement Evaluation

The cost of our satellite communications system is $5 per month. Therefore, this requirement is satisfied.

3.7. Daily Water Reporting Requirement

The station shall report the total number of one gallon water jugs stored within the device at least once per day, to an accuracy of ±1 gallon jug.

3.7.1. Data Transmission Test

3.7.1.1. Test Overview

<u>Data Transmission Test:</u> This test demonstrated the satellite communication capabilities of the Emergency Water Station.

3.7.1.2. Objectives

The Data Transmission Test determined if the Emergency Water Station could successfully transmit water jug tally data using the satellite communication module.

3.7.1.3. Features Evaluated

This test evaluated the ability of the Emergency Water Station to report water jug tally data at least once per day.

3.7.1.4. Test Scope

This test was performed in the lab, rather than in the field. According to data provided by the Swarm Satellite Network, there should be no difference in transmission quality or success rate based on the geographic location of the satellite communication module.

3.7.1.5. Test Plan

The Data Transmission Test required the Swarm M138 satellite communication module, a functioning breakout board, an interfacing Arduino, and activation of the M138 module on the Swarm Satellite Network. Additionally, a computer with an internet connection was used to verify the success of a transmission.

To run this test, an integer value representing the water jug tally was sent to the satellite communication module via the Arduino, flagged for transmission, then sent to the Swarm backend servers upon contacting the next available satellite. This process was repeated once per day for three days

This test assumed that the transmission signal quality did not change depending on geographic location, and that the signal quality will not be degraded once the satellite communication module is placed into the base station structure. Additionally, this test assumed that only integer data will be transmitted to the Swarm backend servers.

The data collected in this test was the success or failure of the data transmission.

3.7.1.6. Acceptance Criteria

The Data Transmission Test was considered successful if the satellite communication module can successfully send integer data to the Swarm backend servers once per day for three days.

3.7.1.7. Test Results

The Data Transmission Test was performed as outlined above, and three days of successful transmissions were recorded from April 1st through April 3rd. A screenshot of the Swarm message report is shown in **Figure 3.2.A**.

	22253020	0x01d0f	Apr 3, 2022 16:10	35
	22180069	0x01d0f	Apr 2, 2022 13:22	35
	22127834 Acknowledged	0x01d0f	Apr 1, 2022 16:27	35

Figure 3.2.A. A screenshot of the Swarm transmission message reports, showing three successful transmissions from April 1st through April 3rd.

3.7.1.8. Evaluation

These results confirm the functionality of the Swarm M138 satellite communication module, therefore showing that the design is capable of reporting the water jug tally at least once per day.

3.7.2. Water Jug Tally Test

3.7.2.1. Test Overview

<u>Water Jug Tally Test:</u> This test demonstrated the accuracy of the water jug tally system.

3.7.2.2. Objectives

The Water Jug Tally test determined if the Emergency Water Station accurately tracked the water jug tally during expected operation.

3.7.2.3. Features Evaluated

This test evaluated the accuracy of the water jug tally kept by the Emergency Water Station.

3.7.2.4. Test Scope

This test was performed for several different tally conditions to ensure accuracy. The initial and final number of water jug removals was varied to ensure confidence that the Emergency Water Station accurately tallies the number of water jugs in any count condition.

3.7.2.5. Test Plan

This test required 18 water jugs, interactions from a user, and the final Emergency Water Station design.

To run this test, the station was fully loaded and a set initial quantity of water jugs was removed. Following this, a user fully loaded the station, then reset the tally using the station reset button. Finally, a set final quantity of water jugs was removed from the station, and the water jug tally was recorded.

This test assumed that operators removing the water jugs would not interfere with the water jug sliding, manually press the water jug tally switches, or partially remove and replace a water jug. Additionally, this test assumed that the user refilling the station knew how to interface with the reset system, and that the user fully filled the water station before pressing the reset button.

The data collected in the Water Jug Tally Test was the final water jug tally stored at the end of the testing procedure.

3.7.2.6. *Acceptance Criteria*

The Water Jug Tally Test was considered successful if the water jug tally was consistently within ±1 jug of the actual number of water jugs contained in the station after the final set of water jug removals.

3.7.2.7. *Test Results*

Six different iterations of the Water Jug Tally Test were conducted using the final station. In the tests, 3, 6, 9, 12, and 15 jugs were removed in the initial and final sets. The results of these tests are shown in **Table 3.7.A**.

Table 3.7.A. Water Jug Tally Test Results.

Test Number	Initial Number Removed	Final Number Removed	Expected Tally	Final Tally
Test 1	3	3	15	15
Test 2	6	6	12	12
Test 3	9	9	9	9
Test 4	12	12	6	6
Test 5	15	15	3	3

3.7.2.8. *Evaluation*

As seen in **Table 3.7.A**, the final tallies were identical to the actual number of water jugs in all tests. This demonstrates that the Emergency Water Station can maintain a tally of the number of water jugs held in the station, accurate to ±1 gallon jug.

3.8. Weather-Proofing Requirement

The station shall be capable of withstanding the adverse weather conditions common to the Mexico-Texas border region. (Operational temperature: 20°F - 140°F. Max wind speed: 40 mph).

3.8.1. Wind Stability CFD Simulations Test

3WS tested that our station structure does not tip over or become damaged by exposure to 40 mph winds.

3.8.1.1. *Test Objectives*

1. To determine the force required to tip over the device under different load conditions to determine the minimum force required.
2. To determine the force caused by applying 40 mph winds on the station structure.
3. To determine whether or not the station is likely to tip over due to the application of 40 mph winds.

3.8.1.2. *Features Evaluated*

This test evaluated the stability of our design when a 40 mph wind is applied to the station structure.

3.8.1.3. *Test Scope*

This test consisted of calculating the minimum tipping force of the station structure, by calculating the force applied by 40 mph winds on the station structure (computed via *Autodesk CFD* simulations, or wind force equivalent calculations). The 40 mph winds were assumed to be at steady state conditions in the simulations.

3.8.1.4. *Assumptions*

We require the Emergency Water Station 3.0 device to not tip over during wind speeds of 40 mph applied horizontally to the design. Wind gusts in the Mexico-Texas border region last for less than 20 seconds;

therefore if the station is simulated to prevent tipping from steady state 40 mph winds, we assume that the station will not tip over to 40 mph wind gusts in reality. Any additional weight that is calculated to prevent the station from tipping over will automatically be more weight than is necessary to prevent tipping, since steady state 40 mph winds would cause tipping more readily than gusts which will actually occur. We considered the drag force on the solar panel to be negligible.

3.8.1.5. Test Plan

Due to the infeasibility of renting out time in a large wind tunnel with the physical water station structure, we use wind force simulations using CFD, and equivalent forces on areas due to wind, to determine the force on the structure from 40 mph winds. These simulations solve a modified form of the Navier-Stokes equation, for steady state 40 mph winds applied to a model of the station.

3.8.1.6. Acceptance Criteria

The Wind Stability CFD Simulation test is considered successful if the station simulation results indicate that the force caused by 40 mph winds applied to the station is less than the force required to tip over the station structure, or that the station will not tip over if additional weight is added to the station to counteract the tipping moment.

3.8.1.7. Test Results

The station structure is meant to withstand 40 mph wind forces without tipping over. This was tested by calculating the drag force on the station (plastic components only) via theoretical drag force calculations, and by simulation in Autodesk CFD. These calculations provided forces and force radii to calculate the moments about the edge of the device just prior to tipping. Our calculations show that the water station requires additional support weight placed on the feet of the device to prevent tipping during high winds. We estimate that four 44 lbs sand bags placed on wooden beams of 40 inch length under the device will stabilize the design when subjected to 40 mph steady state wind speeds applied horizontally to the device.

The theoretical calculations of each drag force on the water station were performed using **Equation 3.8.A**, which requires the density of air at STP ρ, velocity of the air v, drag coefficient c_D, and the frontal area of the water station part A_F. The total drag force is assumed to be the sum of the components in **Equation 3.8.B.** Each of these parameters is provided in **Tables 3.8.4.A** and **3.1.8.B.** The drag coefficients of the station sides and pole were estimated using values found from nasa.gov [2], and an empirical relation for c_D of a cylinder from [3] using the Reynolds number calculated in **Equation 3.8.C**.

$$F_D = \frac{1}{2}\rho v^2 c_D A_F \quad \textbf{(3.8.A)}$$

$$F_D = F_{D,\,Base} + F_{D,\,Pole} \quad \textbf{(3.8.B)}$$

$$Re = \frac{vD}{\nu} \quad \textbf{(3.8.C)}$$

Table 3.8.A. Parameters used for theoretical drag force calculations.

Category	Value	Units	Comments
v	40 17.9	[mph] [m/s]	Max wind speeds
D	2.5 0.06	[in] [m]	Average diameter of pole
ν	1.460E-5 1.5723E-4	[m^2/s] [ft^2/s]	Kinematic Viscosity of air
Re	7E4	[-]	Corresponds to a cylinder c_D = 1.19 [3]

ρ	1.225 0.077	[kg/m^3] [lb/ft^3]	Air pressure at STP

Table 3.8.B. Additional parameters used for theoretical drag force calculations.

Category	Approx. 3D Shape	c_D [-]	Approx. Normal Area	A_F [in^2]	Center of Area Height [in]	Comments
Station Front	Rectangle	1.28	Rectangle	673	14.6	c_D from [2]
Station Back	Rectangle	1.28	Rectangle	673	14.6	c_D from [2]
Station Sides	Rectangle	1.28	Trapezoid	984	11.2	c_D from [2]
Pole	Cylinder	1.19	Trapezoid	810	151.2	c_D from [3] Eq. 10, center of area of trapezoid h = 27ft a = 2 in b = 3 in

The parameters in **Tables 3.8.A** and **3.8.B** were used to calculate the theoretical drag force on the whole station structure, yielding the results in the second column of **Table 3.8.C**.

The CFD simulations in Autodesk CFD were performed with a simplified model of the water station, with a ground plane to simulate the station sitting in an open field. Air speeds in four directions were applied to the design, yielding four different horizontal forces along the axis of air flow. Drag forces were calculated by taking the forces on each surface area of the model and summing them together. The resulting forces and height distances to the origin are provided in columns 3 and 4 of **Table 3.8.C**. A view of the simulation results for the Front facing wind flow is shown in **Figure 3.8.A**.

Table 3.8.C. Comparison of theoretical drag force calculations with drag force calculated via CFD simulation of 40 mph winds applied to the front, back, pole side, and flat side.

Category	Horizontal Force Theoretical [lbf]	Horizontal Force CFD Result [lbf]	Radius to Origin CFD Result [in]	Comments
Front	52.0	49.3	110	Theoretical forces are uniformly higher than CFD results due to the drag coefficients not taking into account the decrease in wind speed due to the ground
Back	52.0	44.8	119	
Pole Side	63.3	50.6	107	
Flat Side	63.3	51.6	113	

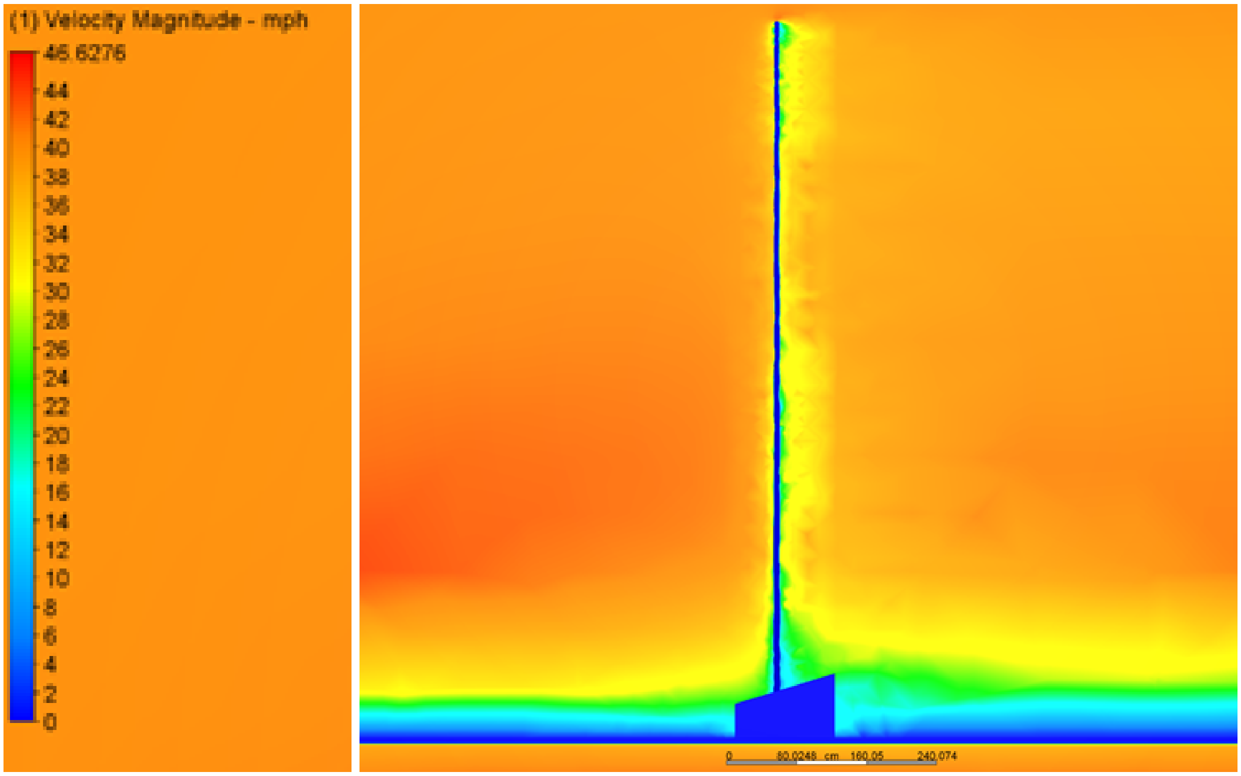

Figure 3.8.A. Water Station 3.0 CFD Simulation results for winds pointed at the front of the station. The speed of the air flow is shown where orange corresponds to faster local wind speeds, and blue tinted for lower wind speeds. The blue horizontal line is the cross section of the rectangular plane which represents the ground.

Table 3.8.C indicates that the CFD simulations predict a uniformly lower estimate for the drag forces on the water station, therefore the CFD results were used for the tipping calculations, since our theoretical drag forces did not take into account the effect of the slowdown of air near the ground. The primary purpose for calculating the theoretical drag forces was to establish that the CFD simulations were producing accurate data around the same magnitude as theoretical estimates. Since each CFD force is within ~12 lbf of the theoretical estimate, we consider our simulations to be good estimates.

We assume that tipping will not occur when the sum of the stabilizing moments due to the weight of the station and any additional supports about an edge is greater than the magnitude of the moments from any drag forces on the station or the pole. This assumption is shown in **Equation 3.8.D**, where tipping moments are considered to be negative, and stabilizing moments are positive about the axis parallel to the edge of the device. The tipping moments consist of a drag force due to the 40 mph winds applied to the station, and a height corresponding to the center of force on the device, in **Equation 3.8.E**. Stabilizing moments consist of the weight of the device applied at a distance of half the corresponding width of the device, and any additional weight added to the device multiplied by the width of the device.

$$0 \leq \sum M_{edge} = - M_{Tipping} + M_{Stabilizing} \quad \textbf{(3.8.D)}$$

$$M_{Tipping} = F_D * r_{center\ height} \quad \textbf{(3.8.E)}$$

$$M_{Stabilizing} = W_{Device,\,Min.} * r_{width}/2 + F_{Additional} * r_{width} \quad \textbf{(3.8.F)}$$

Solving for $F_{Additional}$ from **Equation 3.8.F** yields **3.8.G**, which is the additional force required to be placed on the opposite side edge of the device to prevent tipping.

$$F_{Additional\ Required} = \frac{1}{r_{width}}(M_{Tipping} - W_{Device,\,Min.} * r_{width}/2) \quad \textbf{(3.8.G)}$$

Table 3.1.4.D. Calculation of required additional weight force: $F_{Additional}$ to prevent the station from tipping over based on the CFD forces for each condition in Table 3.1.4.C.

Category	r_{width} [in]	$M_{Tipping}$ [lbf*in]	Weight of Station Moment =102 lbf *0.5*r_{width} [lbf*in]	Required $F_{Additional}$ [lbf]	Required $F_{Additional}$ r_{width} = 40 [in]	Comments
Front	44.52	5423	2270	71	N/A	Achievable with sandbags placed on wooden planks
Back	44.52	5331	2270	69	N/A	
Pole Side	25	5414	1275	166	85	
Flat Side	25	5521	1275	170	87	

The results of **Table 3.8.D** show that the water station would tip over (without any additional weight support) since $F_{Additional}$ is positive. According to columns 5 and 6 of **Table 3.8.D**, the water station requires a minimum of 87 lbs of additional weight placed on the end of 40 inch long wooden planks which can be placed under the structure in line with the feet of the base. These wooden planks serve an additional purpose of allowing the design to sit above the dirt and muddy conditions in the field. 3WS already possesses cinder blocks and remaining budget to purchase additional weight supports and 40 inch wooden planks to put under the device. We are confident that with the addition of these weight supports, that the design will not tip over under 40 mph wind conditions, assuming that the station is empty of any water gallon jugs.

3.8.1.8. Evaluation

The Wind Stability CFD Simulations test was successful in determining what additional weight supports are required to prevent the station from tipping over during steady state 40 mph wind conditions. Four supports of 87/2 = 43.5 lbs placed at the four corners of the design on two 40 inch long wooden planks attached parallel on the front and back of the bottom of the design will prevent tipping. The final design uses four 60 lbs sand bags located on 48 inch length wooden 4x4 beams for additional safety factor.

3.8.2. Wind Stability and Weatherproofing Field Test

3WS tested that our station structure does not tip over or become damaged by exposure to San Antonio weather conditions.

3.8.2.1. Test Objectives

To determine whether or not the station is likely to tip over due to weather conditions applied to the station on the 5th floor roof of the CSI building at Trinity University.

3.8.2.2. Features Evaluated

This test evaluated the stability and durability of our design when exposed to the outside (wind + rain).

3.8.2.3. Test Scope

3WS set up the Emergency Water Station 3.0 device on the fifth floor roof of CSI at Trinity University. This setup is shown in **Figure 3.8.B**.

Figure 3.8.B. Emergency Water Station 3.0 device installed on the fifth floor roof of CSI for the Wind Stability and Weatherproofing Field Test. Note that we grounded the station using a wire attached to CSI railing which was grounded.

3.8.2.4. Test Plan

3WS set up the emergency water station on the fifth floor roof of the CSI building at Trinity University. We then left the station on the roof starting on 4/13/2022. During the test we periodically checked to see if there was any damage or tipping occurring on the station, or if any of the electronics were damaged by wind or rain. We knew that the forecast for the next several weeks included high winds and rain, which were good tests of the stability and durability of the station. 3WS also grounded the station with wire attached to CSI.

3.8.2.5. Acceptance Criteria

We consider that the station passes the Wind Stability and Weatherproofing Field Test if the station does not tip over, become damaged, or cease to operate by exposure to weather conditions on the roof of the CSI building at Trinity University.

3.8.2.6. Test Results

The water station was able to survive up on the roof of CSI for more than seven days as of this report's completion. No visible or detectable damage, deformation, or cease of function was observed over the time period. We show the view of the station (included at the beginning of the report) of the station after a week of testing, during which two of the seven days had rain, and at least 3 days had wind gusts of 20mph or more.

Figure 3.8.C. Front view of the Emergency Water Station 3.0 device on 4/27/2022, after 7 days on the roof of the CSI building.

3.8.2.7. Evaluation

Since our station was able to withstand the weather conditions of San Antonio on top of the fifth floor of the CSI building without tipping over, becoming damaged, or ceasing to transmit or register jug withdrawals, we consider the device to pass the Wind Stability and Weatherproofing Field Test.

3.8.3. Operational Temperature Range Evaluation

Due to the infeasibility of renting time in a large thermal cycling chamber with the fully constructed water station, we were unable to complete direct testing of the operational temperature range. Instead, the operational temperature range requirement was used as a guideline for purchasing the construction materials and electronics components that comprise the station design. Datasheets listing the operational temperature ranges of all the construction materials and electronics components used in the final design can be found in the bibliography [M-1], [M-2], [E-1] - [E-27].

Because all the components used in the final design are rated to operate within the specified temperature range, we consider the temperature aspect of the Weatherproofing Requirement to be satisfied.

3.9. Night Visibility Requirement

The station shall be equipped with a light source for easy visibility at night from at least one mile away.

3.9.1. LED Visibility Test

3.9.1.1. Test Overview

<u>LED Visibility Test:</u> This test demonstrated that the LED which will be placed at the top of the flagpole is visible at night from a mile away.

3.9.1.2. Objectives

1. Ensure that the device has a visible indicator of its location at night.
2. Ensure that the visibility of the LED is sufficient to be able to see the device from a distance of one mile.

3.9.1.3. Features Evaluated

The visibility of the signal LED was evaluated.

3.9.1.4. Test Scope

The average human eye can detect a candle flame from at least 1.6 miles away [10]. With this fact, the LED was proven to be visible from at least one mile away by ensuring its luminous intensity was greater than that of a candle flame (about 1 candela).

This test assumed clear visibility conditions (no fog, no obstructions).

3.9.1.5. Test Plan

This test required an ammeter, as well as knowledge of how to convert output power to luminous intensity.

To run this test, the current draw of the powered signal LED was measured with an ammeter. With this value, the LED output power and luminous intensity was calculated and compared to the luminous intensity of a candle flame (about 1 candela).

The data collected during this test was the current draw of the LED signal light.

3.9.1.6. Acceptance Criteria

The LED visibility test was considered successful if the luminous intensity of the signal LED was greater than one candela.

3.9.1.7. Test Results

The signal LED current draw was measured to be 110 milliamps. Using this measurement, alongside the nominal voltage of the signal LED (12V), the output power was calculated to be 1.32 watts. Assuming the average luminous efficacy of green LEDs is 80 lumens per watt, the luminous intensity of the signal LED (in candela) was calculated using **Equation 3.9.A** [11].

$$I_v = \frac{Luminous\ Efficacy * Watts\ Used}{4\pi} = \frac{80 * 1.32}{4\pi} = 8.4\ cd \quad \textbf{(3.9.A)}$$

3.9.1.8. Evaluation

The luminous intensity was found to be 8.4 candela, over eight times greater than the 1 candela threshold required in the acceptance criteria. Therefore, the signal LED is proven to be visible from at least one mile away, meeting the Night Visibility Requirement.

3.10. Phone Charging Optional Feature

The station may include a phone charging system.

3.10.1. Optional Feature Results and Feasibility Evaluation

We did not include a phone charging system in the station, since we decided to prioritize the completion and testing of all other features of the design associated with our constraints and requirements. This decision to not include a phone charger was agreed on by all members of 3WS and our Sponsor/Advisor Dr. Aminian.

Our power system tests do show that adding a phone charger would be a reasonable addition to the station, given that the two batteries included in the electronics subsystem were calculated to far exceed support of 1 day of continuous operation without any additional charge supplied by the solar panels. Charging a phone from zero battery to full would require only a fraction of the charge of one of our two batteries. We are confident that a phone charging system could draw energy from the main power subsystem of the station without depleting the station's batteries.

3.11. Storage Compartments Optional Feature

The station may include storage compartments for items such as protein powder.

3.11.1. Optional Feature Results and Feasibility Evaluation

We did not include an additional storage compartment in the station, since we decided to prioritize the completion and testing of all other features of the design associated with our constraints and requirements. This decision to not include a storage compartment was agreed on by all members of 3WS and our Sponsor/Advisor Dr. Aminian.

The station base structure has ample room for several additional storage compartments which could be added by removing plastic material from the sides of the design and creating a door with metal hinges. **Figure 3.11.A** shows how the inside of the station has considerable room for additional storage compartments. To waterproof the compartments, one could use a copy of the electronics box which we purchased for the electronics subsystem.

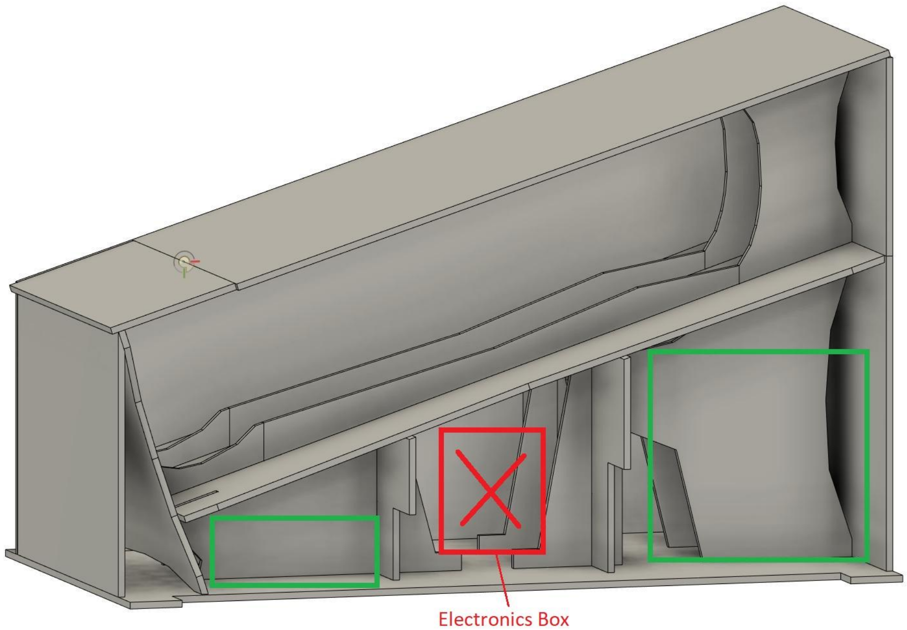

Figure 3.11.A. View of the station base structure with the left wall removed to show the areas marked in green which are available for conversion into additional compartments for items such as protein powder.

3.12. Additional Evaluations

This subsection details additional design evaluations that are independent of the project constraints and requirements. Although independent, we find these evaluations to be helpful in proving the success of the overall station design.

3.12.1. Sustainable Operation Test

3.12.1.1. Test Overview

Sustainable Operation Test: This test demonstrated that the power system was able to reliably supply energy to the electronics system over multiple days of uninterrupted operation.

3.12.1.2. Objectives

This test determined if the Emergency Water Station was able continue sustainable operation using only solar power to generate and deliver power to the electronics.

3.12.1.3. Features Evaluated

This test evaluated the ability of the Emergency Water Station to operate in remote locations disconnected from the power grid.

3.12.1.4. Test Scope

The Sustainable Operation Test was conducted using the fully constructed water station during a two week period with varied weather conditions. The station experienced conditions from clear and sunny to powerful thunderstorms.

The station electronics were operated as if placed in the field at the border. The solar panel was oriented south to maximize the amount of solar radiation incident on the panel. This setup ensured an accurate simulation of the expected operation and orientation of the Emergency Water Station once deployed in the field.

3.12.1.5. Test Plan

This test required an outside location free from shade and vertical obstructions (such as buildings and trees) where the complete station was placed for two weeks. We utilized the roof of the Center for Sciences and Innovation as this location. This test also required a multimeter to measure battery voltage for charge calculations.

To run this test, the station batteries were charged to full capacity, connected to the electronics and power system, and the station was operated for two weeks with no power/electronics system interventions. Throughout the test, battery voltage measurements were taken at 10 AM and 8 PM each day. At the end of the testing period, the battery voltage was measured compared to the initial value.

The data collected during this test consisted of battery voltage measurements.

3.12.1.6. Acceptance Criteria

The Sustainable Operation Test was considered successful if the battery output voltage remained above 13.15 volts (~40% charge) throughout the entire testing period [12].

3.12.1.7. Test Results

The Sustainable Operation Test began on April 13th, 2022, and was completed on April 25, 2022. During the testing period, it rained for three days, and was very cloudy for five consecutive days. All other days were partly cloudy or clear. A plot detailing the voltage measurements taken each day is shown in **Figure 3.12.A**.

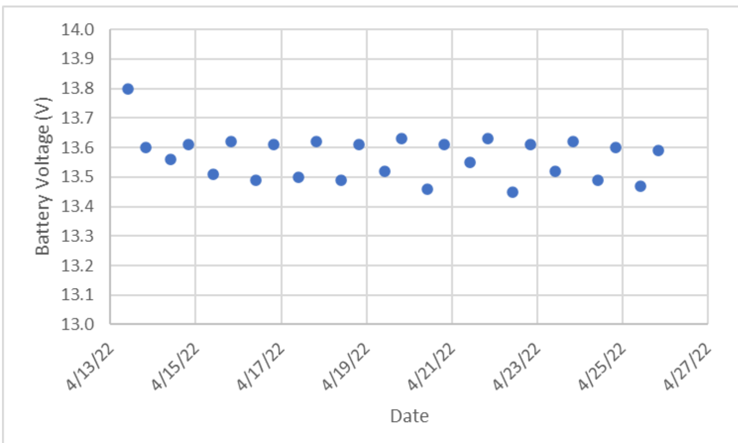

Figure 3.12.A. Plot showing the station battery voltage over the two week testing period.

Initially, the battery was charged to 13.8 volts. As seen in **Figure 3.12.A**, this initial charge quickly depleted and the battery voltage began steady oscillation around 13.55 volts. This oscillation is expected as the battery charges throughout the day and discharges throughout the night. Throughout the testing period, the lowest voltage measurement recorded was 13.45 volts. This measurement was taken after a long period of dark, stormy cloud cover. The highest measurement recorded was 13.63 volts, on a day with clear and sunny skies.

3.12.1.8. Evaluation

Because the lowest voltage measurement recorded was 13.45 volts, 0.3 volts greater than the acceptance criteria voltage, we are confident that the Emergency Water Station will operate sustainably when placed in the field. Additionally, the wide range of operating conditions experienced during the testing period demonstrates the resilience of the power system, and proves its ability to reliably power the station in many different weather conditions.

4. Conclusions

The Emergency Water Station 3.0 device meets all project constraints and requirements, addressing all four of our main project objectives as well; guaranteeing the strength of the station structure, and its weatherproofing, reducing the cost per month of the device to operate, and improving the accuracy of water reporting using a ramp and switch method. The project was completed on time, and under our $1200 budget, and has been successfully field tested on the roof of the CSI building at Trinity.

Our water station has a nominal maximum capacity of 18 full 1-gallon jugs, but supports up to 21 on the three ramps at absolute maximum capacity. The station was tested to support the weight of: 21 full 1-gallon jugs, the weight of one adult male, a flagpole with a solar panel, and all electronics without visible deformation or tipping over. After more than a week on the roof of CSI the device did not tip over, become damaged, or cease to function due to the winds or rains which occurred during the field tests. All the while the communications electronics dutifully reported the water jugs that were in the station during its daily satellite transmissions and refill warnings. The station remained self-sustaining on its own power due to the solar panel and batteries. The green LED switched on and off all throughout the nights of the tests signaling its location, and was visible clearly due to its location atop the flagpole. We are pleased to report that the testing of our device to guarantee that it met all constraints and requirements was a success.

4.1. Next Steps and Recommendations

We did not implement the two optional features of a phone charger or extra compartments for storing items such as protein powder, but we are confident that these features could be implemented. We are confident in the feasibility of these features because of our sustainable operations test proving that our device has ample power to spare for a phone charger, and the main body of the device has open spaces underneath the ramp for extra storage compartments.

One potential change that could be made to the electronics and communications subsystem relates to the main processing unit used in the design. In the current design, an Arduino MEGA is used as the brain of the water station. We chose this system because we had several spare units available to us from previous water station projects. The Arduino MEGA is a 5V logic system, and is the most power hungry device in the main Arduino ecosystem. To improve the power consumption and simplify the circuitry of the electronics system, this main processing unit could be replaced by a 3.3V system, such as the Raspberry Pi Pico. This switch would drastically reduce the amount of power used by the electronics system, and would allow the level shifting component of the hardware circuitry to be removed. Although this would simplify the design and reduce power consumption, the 3WS team does not find this change to be necessary, as we have demonstrated full functionality of this design and showed our power subsystem to generate and store significantly more power than required for sustainable operation.

4.2. Potential Pitfalls and Alternatives

Our 3.0 iteration of the water station project uses switches and a reset button to register the unloading and loading of water jugs into the design. When a number of jugs are added to the station which does not set the total number of jugs in the station to 18 exactly, then the counter in the electronics and communication subsystem will register the incorrect number of jugs. Also picking up a jug and immediately placing it back down on the switch without allowing the other jugs to slide down will register a jug taken away in error. The station registering one less jug than it actually holds in error is in the favor of more jugs in the station, which favors the safety of those who would use the station, since it could cause the station to be refilled early. In testing we always knew to reload the station to 18 jugs exactly and always to fully take out a jug if it had been lifted, but these are potential problems only for a volunteer who does not understand how to properly reset the load of jugs. If not reset correctly, the device could hold less jugs than it registers, making the station susceptible to not being reloaded before it becomes empty.

Another potential pitfall to the performance of the project could come about due to the lack of waterproofing of the main station body, since we only required that the main electronics which could actually be damaged by water or dirt over a short period of time. It is possible, although unlikely, that if enough dirt were to enter into the design the waterproof switches on the bottom of each ramp could become blocked by debris. To fix this potential problem, we advise that the switches and reset button of the device are periodically checked and any dirt wiped off. Previous water stations also suffered from dirt buildup on the weight sensing load cells, and comparatively, waterproof switches have a much better chance of not becoming blocked or their function interrupted by dirt.

4.3. Acknowledgements

3WS has been successful in creating the most recent iteration of the Emergency Water Station in large part due to the help of our Advisor/Sponsor Dr. Mehran Aminian. His guidance and understanding throughout the challenges we faced during the project helped to ensure the project's successes and completion.

We would also like to thank the many members of the Trinity faculty and staff who helped to support our project. We would like to thank our Senior Design Administrator Dr. Darin George for his efforts to support our team and the other senior project teams. Without Dr. George's efforts, all of our senior design projects would not have been possible.

3WS would like to thank our contact with the STHRC, Eddie Canales for his assistance, advice, and for meeting with us to discuss our project. The information he provided, along with the previous Emergency Water Station 2.0 device, were key in developing our strategy to improve the station to meet our main project objectives.

5. Appendices

5.1. Emergency Water Station 3.0 User Manual (Setup + Operation + Safety + Materials)

Table of Contents for User Manual

The Emergency Water Station 3.0 is a device which stores water contained in 1-gallon jugs. The device transmits the amount of water remaining in the station once a day via satellite to an online database. Volunteers can use the station transmissions to determine when to refill the station. This user manual includes instructions on how to set up the water station, how to operate the station once it has been set up, how to avoid safety hazards, and which materials were used in the construction of the station.

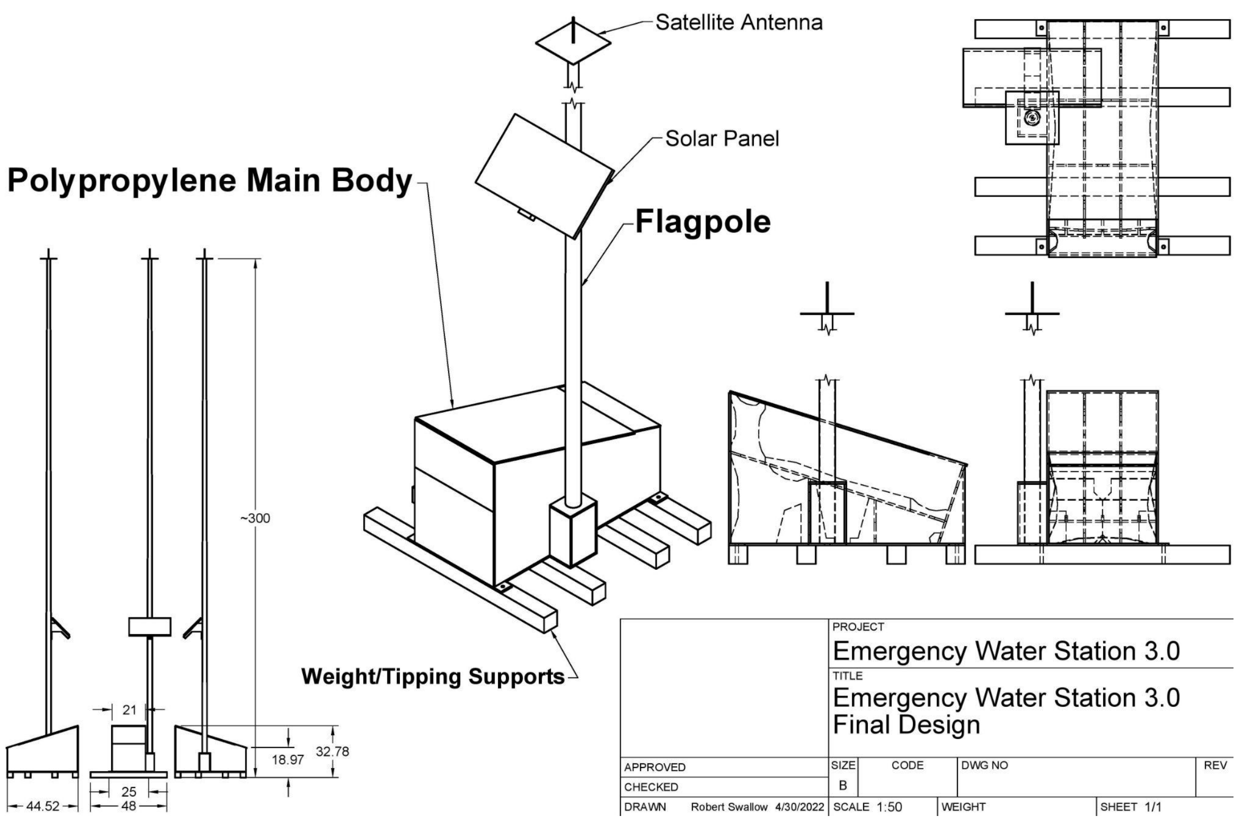

Figure 5.1.A. Emergency Water Station 3.0 Final Design Schematic.

5.1.1. Emergency Water Station 3.0 Setup

The water station consists of four components which all fit together to form the fully set up device:

1. The main body of the water station
   - constructed from durable white polypropylene plastic
   - plastic welded together by melting polypropylene strips into the seams of 3/8ths inch thick pieces
   - three ramps which store 18 1-gallon water jugs
   - opening for loading jugs at the top of the back of the station
   - opening for unloading jugs at the top of the front of the station
   - each ramp has a switch at the bottom to register when jugs have been taken
   - a reset button which resets the total count of water jugs to 18
2. The flagpole
   - aluminum
   - satellite antenna on top
   - green LED at the top of the pole for making the station visible at night
   - solar panel approximately ~9 ft up the pole
   - must be grounded to prevent damage from lightning strikes
3. The electronics box
   - fits into the door of the pole box, and sits underneath the middle of the station ramp structure
   - contains an arduino with a Swarm M138 satellite transmission device
   - waterproof box which connects to the reset button, switches, solar panel, green LED, and satellite antenna
4. The weight/tipping supports
   - four 4x4x48 wooden beams which sit underneath the main body of the water station
   - two of the four 4x4s are attached to the main body using bolts and nuts
   - used to prevent tipping, raise the device above the ground
   - four sand bags should be placed on the top of the two connected 4x4s to prevent tipping of the station up to 40mph winds

With all four components in separate pieces, the setup process can begin:

1. Lay out the four 4x4x48 wooden beams of the weight/tipping supports parallel to each other on the ground and lower the main body of the water station on top of the wooden beams. Attach the two beams at the four corners of the main body structure using bolts through attachment holes fastened with nuts.
2. Place four 60lbs sand bags on the four corners of the weight/tipping supports.
3. Open the pole box of the main body of the station structure (located on the right side of the device)
4. Open the electronics box and reconnect the batteries to turn on the arduino, and then close the electronics box.
5. Place the electronics box inside the station through the hole in the pole box, while connecting the wires which correspond to the solar panel, satellite antenna and switches/reset button
6. Assemble the flagpole by fitting each aluminum part into one another. This process also involves attaching the solar panel and feeding the solar panel cables, green LED cable, and satellite antenna cable up the flagpole to attach to their respective electronic device.
7. Raise the flagpole and slot it through the pole box's top hole
8. Secure the flagpole by tightening the metal bracing ring on the station's side, and ground the flagpole using a lightning grounding system

9. For the first four minutes since the bootup of the electronics system the device will not be operational, after four minutes the device will queue a bootup message to be transmitted via satellite, and will then register any ramp switches or reset button presses
10. 18 1-gallon water jugs may be loaded into the design by opening up the top of the three ramps on the back of the station. Jugs which are loaded are meant to slide to the bottom so that other jugs can be loaded in the same location. Note that the station can support up to 21 jugs (7 per ramp), but we recommend limiting the station to 18 maximum (6 per ramp).

5.1.2. Emergency Water Station 3.0 Operation

The following outlines how to safely operate the Emergency Water Station 3.0:

1. Filling and resetting the station:
    - The station is designed to be loaded at the rear end of the station (the top of the ramp), and have jugs removed at the bottom of the ramp.
    - The station itself is programmed to count up to 18 jugs (6 per ramp). When loading the ramp, it is recommended not to exceed this number of jugs.
        - Note: If more or less jugs are loaded outside of the recommended number, the count via the daily transmission will be incorrect.
    - To load the station, slide the jugs down the ramp until each ramp is filled, 6 per ramp. Confirm that all jugs are upright to ensure they can easily be removed from the bottom door.
    - Once the station is fully loaded with water jugs, press the red reset button once. This button is located on the inside of the station, to the right of the loading door.
    - The loading door has a locking mechanism, and if desired, a lock can be attached to prevent anyone else from accessing the back of the station.
        - The same locking mechanism can also be found on the flagpole box.
2. Accessing the transmissions:
    - The daily transmission is sent out at 11PM CST. This transmission includes the number of jugs remaining in the station at that time. Additional warning messages will be sent when the station has 10, 5, 2, 1, and 0, jug(s) remaining.
    - These transmissions can be seen on the Swarm website: bumblebee.hive.swarm.space
    - After logging in, the dashboard will automatically show, this can be seen in **Figure 5.1.2.A** below.

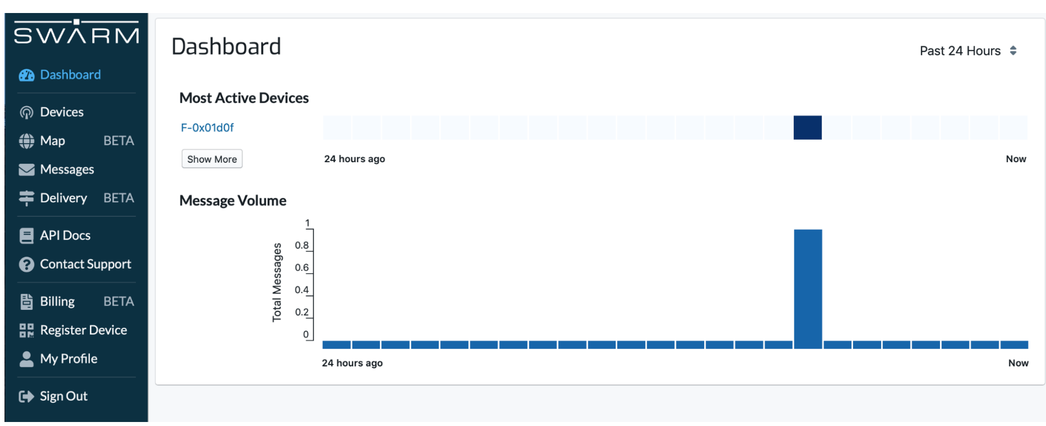

Figure 5.1.2.A. Dashboard of Swarm Website

- The main dashboard shows the active device, our Swarm tile, and the number of messages received in the past 24 hours.

- In order to locate the recent transmission messages, go to the left column and click on the "messages" tab under the Swarm logo. This will display all transmission messages that have been sent by the station, including the date, time, and size. Seen in **Figure 5.1.2.B.** below.

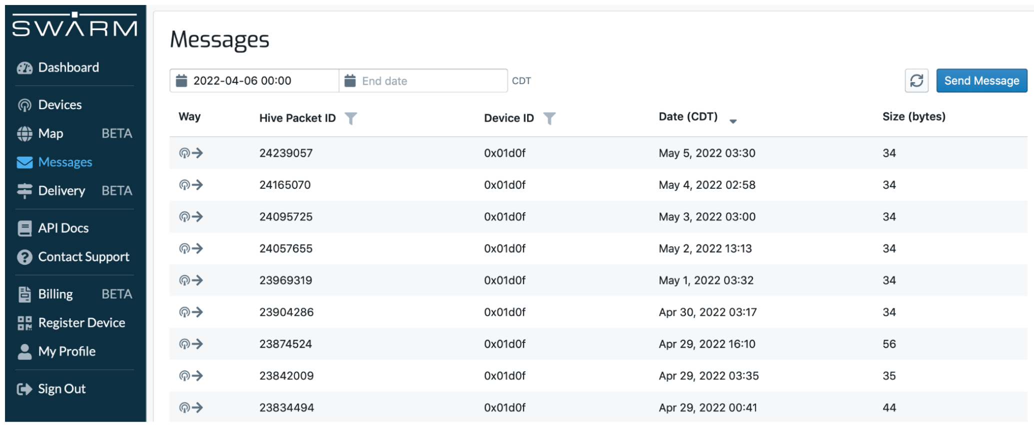

Figure 5.1.2.B. Swarm Transmission Messages

- By clicking on a specific message, or hive packet, the message text can be viewed. This contains the number of jugs remaining in the station at the time of transmission. For example, by clicking on the message with the Hive Packet ID 24239057, **Figure 5.1.2.C.** will pop up on the left hand side of the message list.

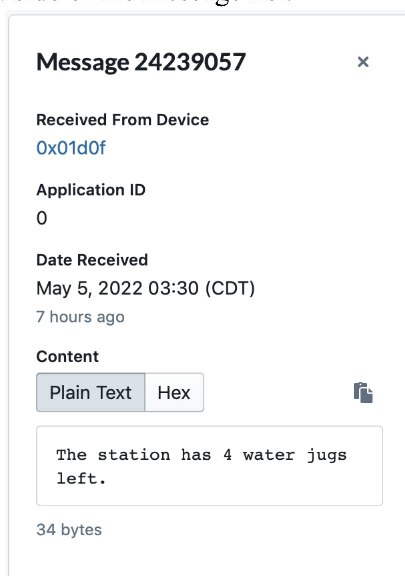

Figure 5.1.2.C. Swarm Transmission Message Text

- More detailed instructions on receiving and viewing the daily transmission will be included in a separate manual shared directly with the STHRC.

3. Additional notes:
   - The water station itself is not waterproof, only the electronics box and electronic components within it. Therefore, it is likely that small amounts of water and debris may collect inside the station, but this will have no negative effect on the functionality of the station.

    - Drainage holes are drilled into the base of the main station compartment and flagpole box to prevent water from pooling inside.
  - If any issues arise with the function of the station or its transmissions, contact the Trinity University Engineering Science Department, 210-999-7511.

5.1.3. Emergency Water Station 3.0 Safety

There are three significant safety concerns which must be understood in order to use the Emergency Water Station 3.0 device safely:

1. The station's 25ft pole presents a risk of lightning strikes to the user during a thunderstorm. The device must be properly grounded, and avoided by anyone during any times where thunder is occurring or could occur.
2. The station and pole are heavy enough to present the risk of contusion, laceration, and abrasion of a person's body if not handled properly. Take care to lift and lower the station slowly and methodically to prevent crushing of any body parts, and prevent any parts of the station dropping on a body part.
3. The 25ft pole and 4x4 wooden beams must be attached as tightly as possible to the device using the attachment point on the pole, and the four included nut/bolt pairs for the beams. Failure to secure these parts tightly could result in the pole or station tipping over and potentially hurting a user.

5.1.4. Emergency Water Station 3.0 Materials

Table 5.1.4.A. Materials used to Construct Station Housing.

IEEE	Part	Description	Manufacturer	Supplier Link
[M-1]	2x Polypropylene sheet	3/8X48X96, Natural	Regal Plastics	Regal Plastics
[M-2]	Polypropylene oval welding rod	5/32" Natural	United States Plastic Corp.	US Plastics
	Broad utility hinge	2-1/2 in Zinc-plated	Everbilt	Home Depot
	Flag Pole	27 ft telescoping flagpole	Ameritex Flag	Ameritex Flag
	Door Pull	4- 7/8 in Zinc-plated	Everbilt	Home Depot
	Fixed Staple Safety Hasp	2-1/2 in. Satin Brass	Everbilt	Home Depot
	Heavy Duty Strap Hinge	4 in Zinc-Plated	Everbilt	Home Depot
	Worm Gear Clamp	6 in Galvanized Steel	Everbilt	Home Depot
	4x 4x4 Wood Beam	3.5X3.5X48	N/A	Home Depot
	4x Sand Bag	60 lbs	Quikrete	Home Depot

Table 5.1.4.B. Materials Used to Construct Power System.

IEEE	Part	Description	Manufacturer	Supplier Link
[E-1]	Lithium Battery	12V 10Ah	Dakota Lithium	Amazon
[E-2]	Solar Panel	30 watt, 12V compact	Renogy	Amazon
[E-3]	Solar Charge Controller	12V/24V, 20A	Bioenno	Bioenno Power

Table 5.1.4.C. Materials used to Construct Electronics/Communications.

IEEE	Part	Description	Manufacturer	Supplier Link
[E-4]	Arduino Mega	2560	Arduino	Arduino
[E-5]	Swarm Modem	M138	Swarm	Swarm
[E-6]	Switch Snap Action	SPDT 5A, 125V	Omron Electronics Inc.	Digikey
[E-7]	Board Terminal Block	8 Position Wire	Phoenix Contact	Digikey
[E-8]	Board Terminal Block	2 Position Wire	Phoenix Contact	Digikey
[E-9]	Chip Resistor	330kOhms 1/4W 1206	Stackpole Electronics Inc.	Digikey
[E-10]	Chip Resistor	100kOhms 1/4W 1206	Stackpole Electronics Inc.	Digikey
[E-11]	Chip Resistor	2.2kOhms 1/4W 1206	Stackpole Electronics Inc.	Digikey
[E-12]	Chip Resistor	1.2kOhms 1/4W 1207	Stackpole Electronics Inc.	Digikey
[E-13]	Receptacle Connector	8 position	Samtec Inc.	Digikey
[E-14]	Connector Header	4 position	WURTH ELECTRONICS INC	Digikey
[E-15]	Receptacle Connector	36 Position	Samtec Inc.	Digikey
[E-16]	Receptacle Connector	6 Position	Samtec Inc.	Digikey
[E-17]	Ceramic Capacitor	100 µF, 16V	TDK Corp.	Digikey
[E-18]	Ceramic Capacitor	10 µF, 16V	TDK Corp.	Digikey
[E-19]	Ceramic Capacitor	0.1 µF, 16V	TDK Corp.	Digikey
[E-20]	Feed Through Capacitor	1 µF, 100V	TDK Corp.	Digikey
[E-21]	Board Terminal Block	2 Position	Phoenix Contact	Digikey
[E-22]	Board Terminal Block	6 Position	On Shore Technology Inc.	Digikey
[E-23]	Chip Resistor	1/4 W, 0 Ohms	Stackpole	Digikey

			Electronics Inc.	
[E-24]	LED	Green 571nm	Lite-On Inc.	Digikey
[E-25]	Receptacle Connector	8 position circular	Souriau-Sunbank by Eaton	Digikey
[E-26]	Relay SPDT	24VDC Coil Through Hole	Panasonic	Digikey
[E-27]	Voltage Level Translator	100MHz	Texas Instruments	Digikey

5.2. Additional Project Images and Test Information

5.2.1. Water Station Structure Schematics and Pictures

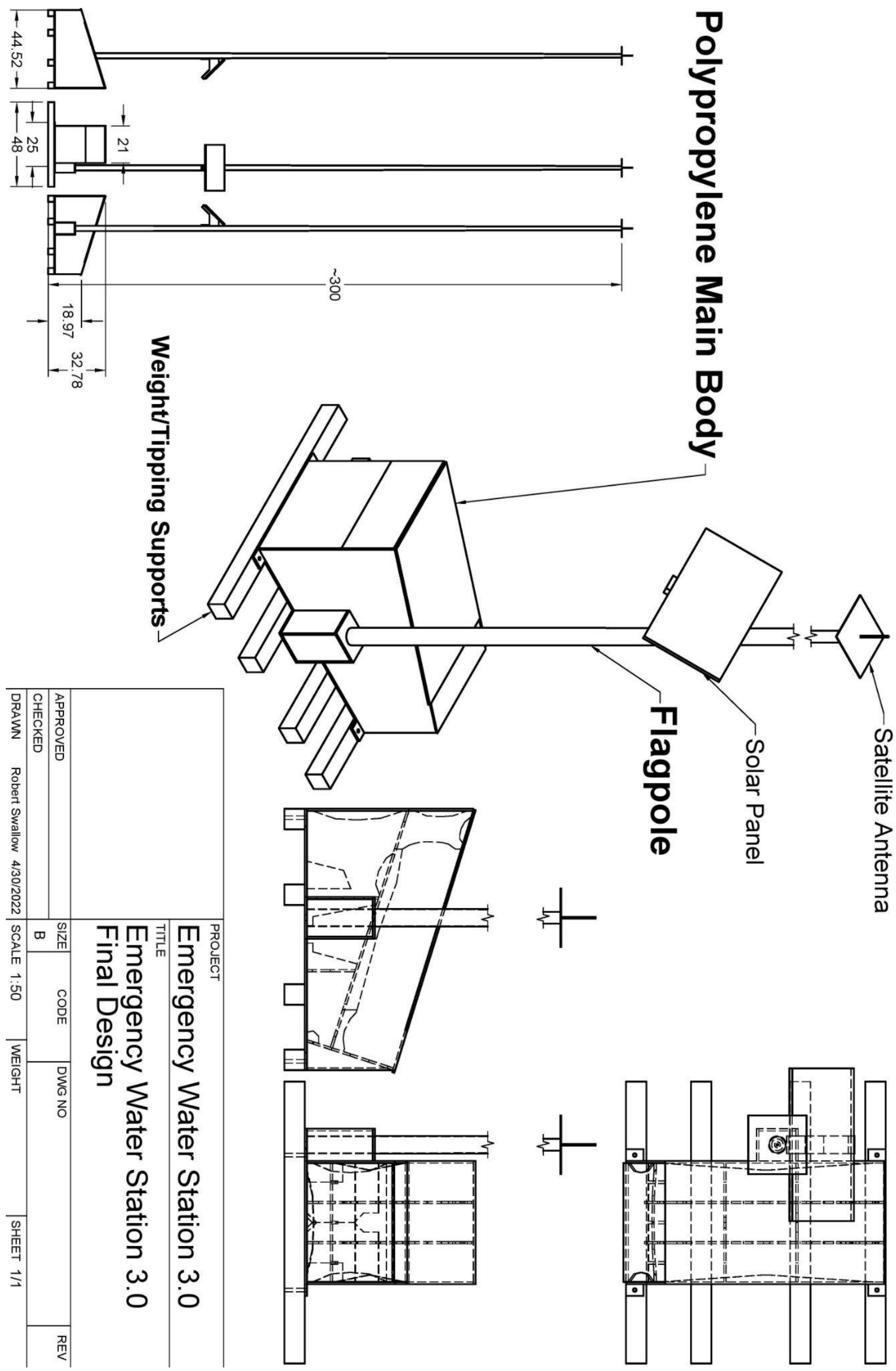

Figure 5.2.1.A. Emergency Water Station 3.0 Final Design Schematic.

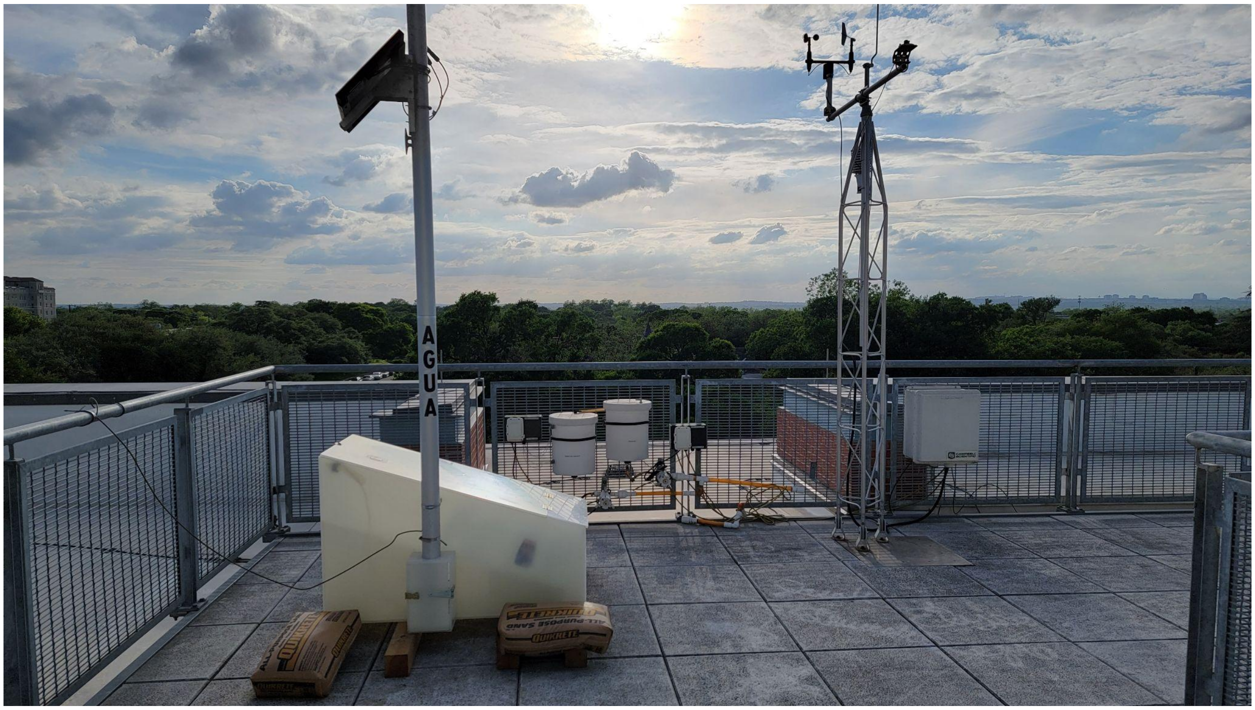

Figure 5.2.1.B. Emergency Water Station 3.0 on the CSI building roof.

Figure 5.2.1.C. Emergency Water Station 3.0 opening for water jug withdrawals.

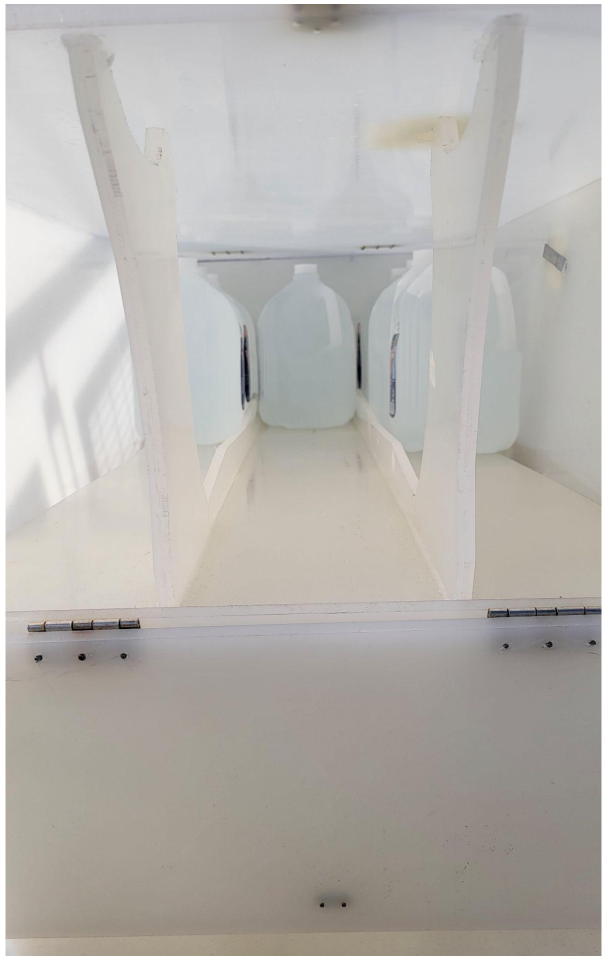

Figure 5.2.1.C. Emergency Water Station 3.0 view of the top of the three ramps. This image shows the design at half capacity, i.e. 9 full 1-gallon water jugs.

5.2.2. Arduino Shield Circuit Schematics

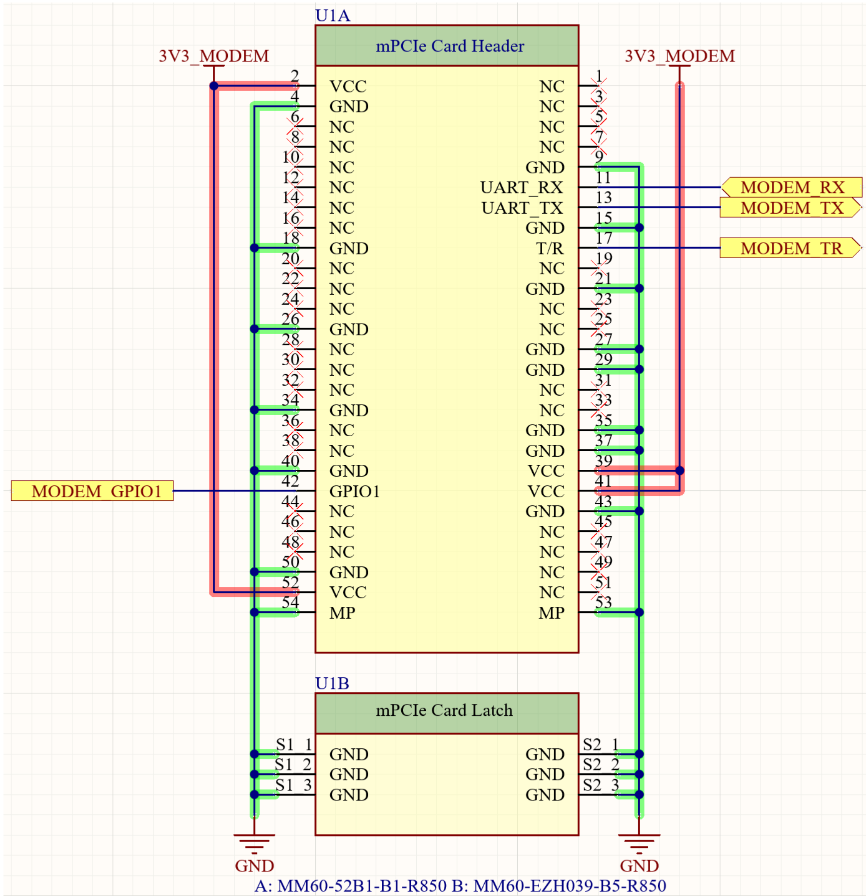

Figure 5.2.2.A. Circuit schematic detailing the M138 mPCIe connector pinouts.

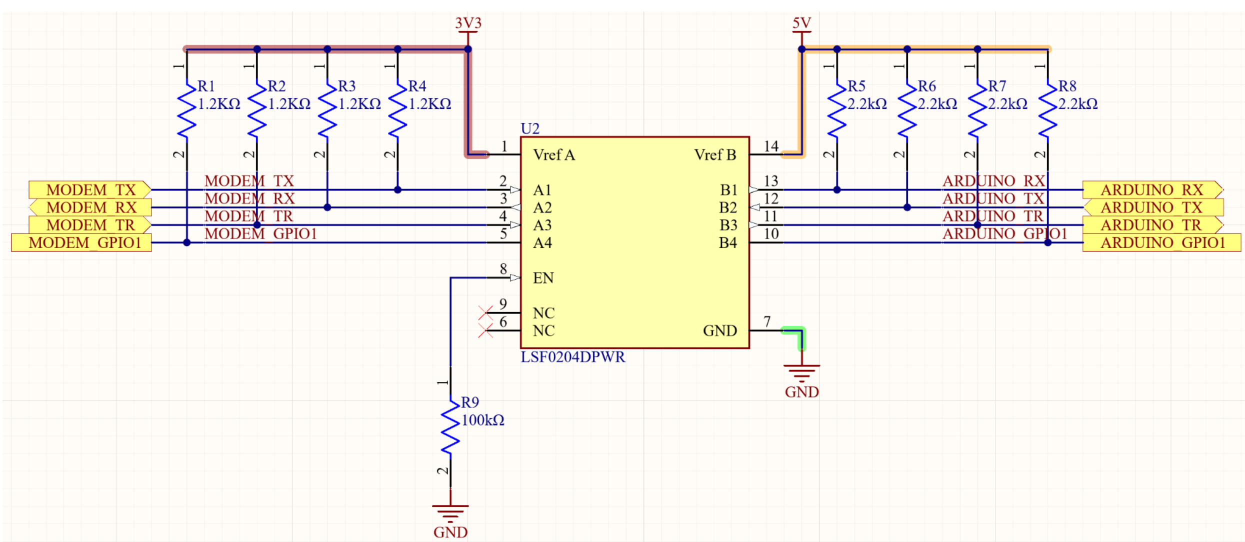

Figure 5.2.2.B. Circuit schematic detailing the level shifter pinouts. This level shifter is required to allow the 5V Arduino MEGA and 3.3V M138 modem to communicate with one another.

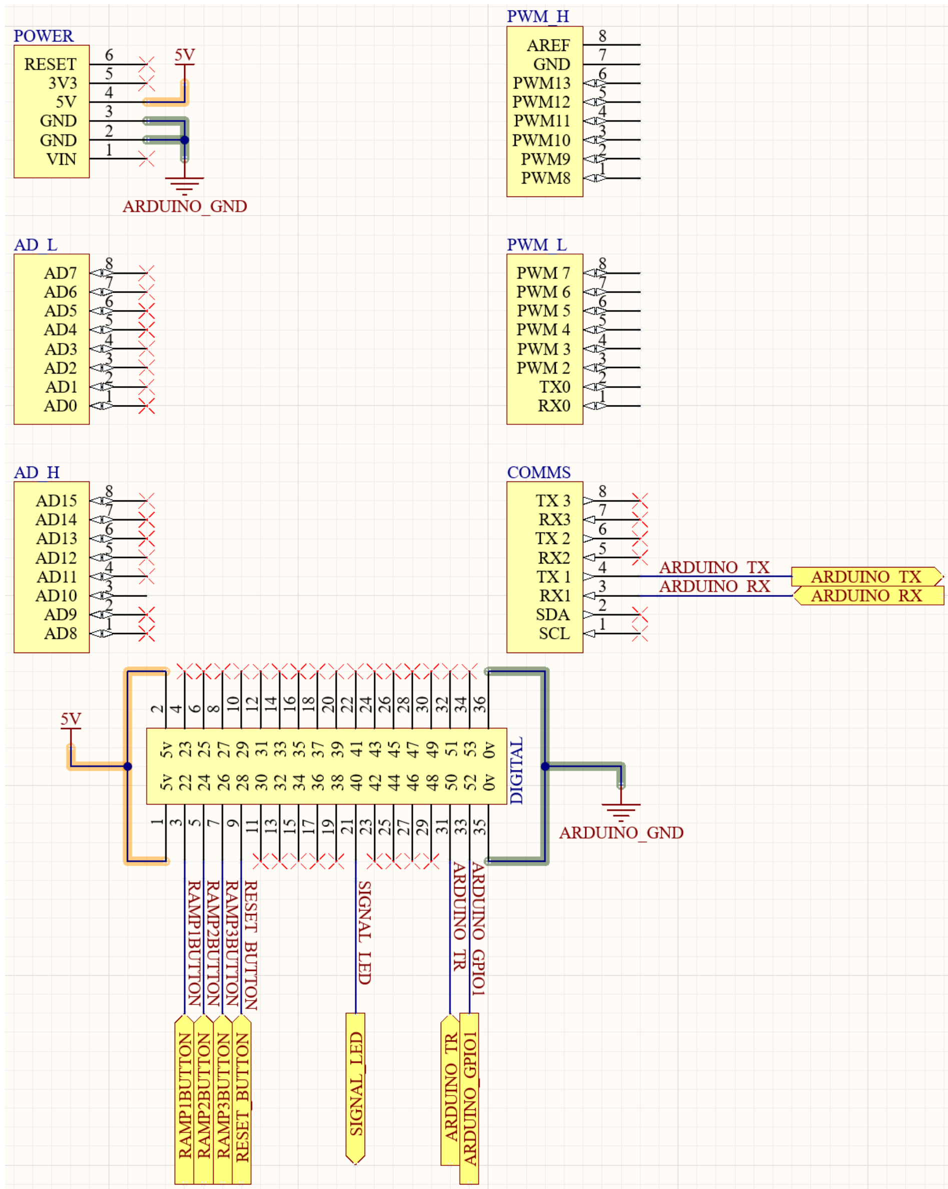

Figure 5.2.2.C. Circuit schematic detailing the Arduino MEGA pinouts.

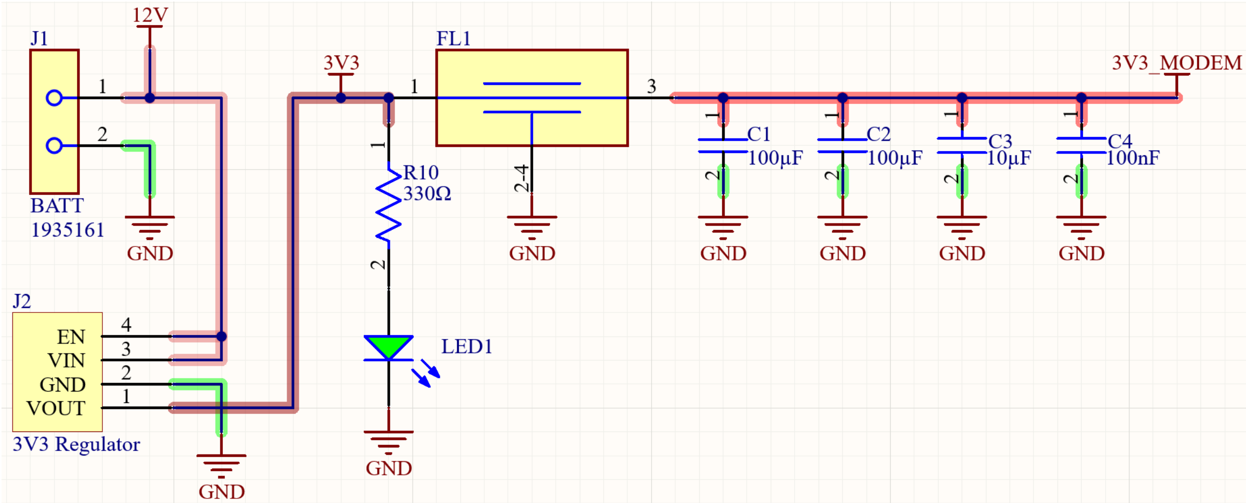

Figure 5.2.2.D. Circuit schematic detailing the voltage regulation (J2) and decoupling circuit. The voltage regulator converts the 12V to 14V battery output to a stable 3.3V output for use by the M138 modem and level shifter. The decoupling circuit was implemented using design recommendations from Swarm [4].

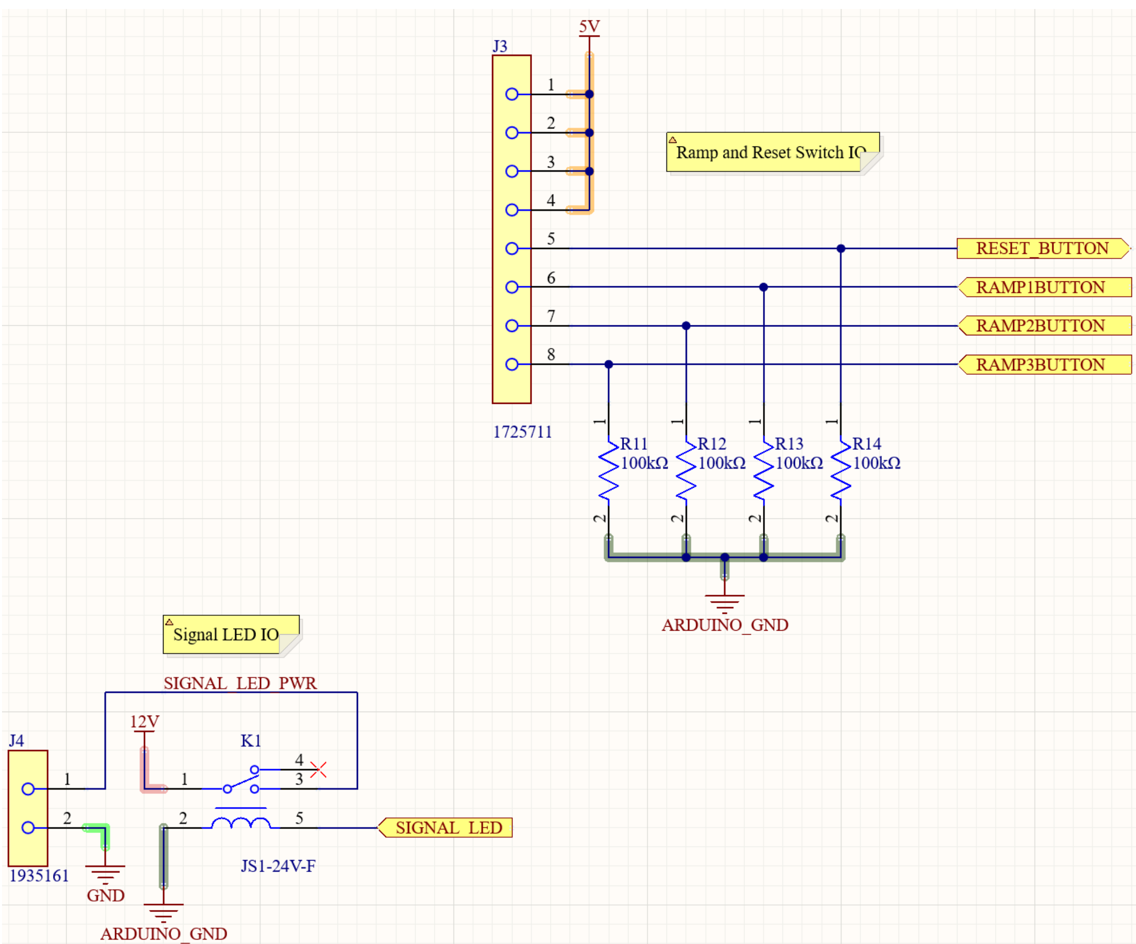

Figure 5.2.2.E. Circuit schematic detailing the term block pinouts for the ramp switches, reset button, and signal LED.

6. Bibliography

6.1. Research References

[1] “Manual Handling Assessment Charts (the MAC tool).” *Health and Safety Executive*. 2018 https://www.hse.gov.uk/pubns/indg383.pdf

[2] “Shape Effects on Drag” NASA. Ed. Nancy Hall. 2021. https://www.grc.nasa.gov/WWW/k-12/airplane/shaped.html

[3] T. Baracu, R. Bosneagu “Numerical analysis of the flow around a cylinder for the perspective of correlations of the drag coefficient of the ship’s hulls” Scientific Bulletin of Naval Academy. 2019. https://www.anmb.ro/buletinstiintific/buletine/2019_Issue2/01_MES/256.pdf

[4] “Swarm M138 Modem Product Manual,” Swarm Technologies, Inc., San Francisco, Feb. 2022. [Online]. Available: https://swarm.space/wp-content/uploads/2022/04/SwarmM138-Modem-Product-Manual.pdf

[5] “Falfurrias Climate, Weather By Month, Average Temperature (Texas, United States),” Weather Spark. https://weatherspark.com/y/7089/Average-Weather-in-Falfurrias-Texas-United-States-Year-Round [Accessed: 29-Apr-2022].

[6] “Best Direction To Put Your Solar Panels | Vivint Solar Learning Center,” vivint.Solar. https://www.vivintsolar.com/learning-center/best-direction-for-solar-panels [Accessed: 29-Apr-2022].

[7] Dahlinger, D., Farrell, S., Granzino, B., Johnson, T., Kusima, K., Kutach, C., Richter, N., Righes, G., Rodriguez, J., Williams, E., *Emergency Water Station Final Design Report*. Mehran Aminian, 1 May 2019.

[8] “Creep, Drift and Your Load Cell,” Adam Equipment USA, Aug. 02, 2021. https://www.adamequipment.com/aeblog/creep-and-drift [Accessed: 29-Apr-2022].

[9] “Iridium 9603 SBD Transceiver Developer’s Guide,” Iridium Everywhere, Aug. 2014. [Online]. Available: https://cdn.sparkfun.com/assets/6/8/6/6/d/DEV_Iridium_9603-9603N_Developers_Guide__v2.2__1_.pdf

[10] K. Krisciunas and D. Carona, “At What Distance Can the Human Eye Detect a Candle Flame?,” arXiv, Jul. 2015, doi: https://doi.org/10.48550/arXiv.1507.06270.

[11] Alhassan, A. I., Farrell, R. M., Saifaddin, B., Mughal, A., Wu, F., DenBaars, S. P., Nakamura, S., and Speck, J. S., “High Luminous Efficacy Green Light-Emitting Diodes with AlGaN Cap Layer,” Optics Express, 24(16), p. 17868. 2016.

[12] A. Beale, “LiFePO4 Battery Voltage Charts (12V, 24V & 48V),” Footprint Hero, May 03, 2022. https://footprinthero.com/lifepo4-battery-voltage-charts [Accessed: 29-Apr-2022].

6.2. Materials and Electronics References

[M-1] Regal Plastics. (n.d.). *Polypropylene sheets*. Polypropylene Sheets. Retrieved May 4, 2022, from https://www.regal-plastics.com/polypropylene/

[M-2] “5/32 natural polypropylene oval welding rod (approximately 133' per lb. coil),” *U.S. Plastic Corp.* [Online]. Available: https://www.usplastic.com/catalog/item.aspx?itemid=40283. [Accessed: 04-May-2022].

[E-1] A. Jay, “Dakota Lithium 12V 10ah battery,” *Dakota Lithium Batteries*. [Online]. Available: https://dakotalithium.com/product/dakota-lithium-12v-10ah-battery/. [Accessed: 29-Apr-2022].

[E-2] Renogy, “30W Monocrystalline Solar Panel,” RNG-30D-SS datasheet, June. 2018.

[E-3] Bioenno Power, “Bioenno Power SC-122420JUD CC/CV Series User Manual.”

[E-4] Arduino, "Arduino® MEGA 2560 Rev3," A000067 datasheet, Sep. 2020 [Revised Apr. 2022].

[E-5] Swarm, “Swarm M138 modem,” *Swarm Technologies*, 14-Apr-2022. [Online]. Available: https://swarm.space/swarm-m138-modem/. [Accessed: 29-Apr-2022].

[E-6] Omron Corp., "Sealed Miniature Basic Switch Conforms to IP67," C095-E1-08 datasheet.

[E-7] Phoenix Contact, "MPT 0,5/ 8-2,54," 17257112 datasheet, Feb. 2010.

[E-8] Phoenix Contact, "PCB terminal block - PT 1,5/ 2-5,0-H," 1935161 datasheet, Aug. 2015.

[E-9][E-10][E-11][E-12] Stackpole Electronics, Inc., "RMCF / RMCP Series," datasheet, [Revised Jan. 2022].

[E-13] Samtec, "Thorugh-Hole 0.25" Sq. Post Socket," F-219 datasheet, [Revised Feb. 2021].

[E-14] “61300411121,” DigiKey. [Online]. Available: https://www.digikey.com/en/products/detail/w%C3%BCrth-elektronik/61300411121/4846827?s=N4IgTCBcDaIOwGYwFoCsCCMdkDkAiIAugL5A. [Accessed: 29-Apr-2022].

[E-15][E-16] Samtec, "Thorugh-Hole 0.25" Sq. Post Socket," F-219 datasheet, [Revised Feb. 2021].

[E-17][E-18][E-19] TDK, "MULTILAYER CERAMIC CHIP CAPACITORS," 20211027 datasheet, Oct. 2021.

[E-20] TDK, "3-terminal filters," 20190115 datasheet, Jan. 2019.

[E-21] Phoenix Contact, "PCB terminal block - PT 1,5/ 2-5,0-H," 1935161 datasheet, Aug. 2015.

[E-22] “OSTVN06A150,” *DigiKey*. [Online]. Available: https://www.digikey.com/en/products/detail/on-shore-technology-inc/OSTVN06A150/1588866?s=N4IgTCBcDaIKIBECMAGArANjQWgHIJAF0BfIA. [Accessed: 29-Apr-2022].

[E-23] Stackpole Electronics, Inc., "RMCF / RMCP Series," datasheet, [Revised Jan. 2022].

[E-24] Lite-On Inc., "SMD LED," DS22-2000-256 datasheet, Dec. 2014.

[E-25] Souriau, "SMD LED," 8D013M08BN datasheet, Oct. 2016.

[E-26] Panasonic, "Cubic type,1 Form A/1 Form C 10 A, Power relays," ASCTB186E datasheet, Mar. 2020.

[E-27] Texas Instruments, " LSF0204x 4-Bits Bidirectional Multi-Voltage Level Translator for Open-Drain and Push-Pull Application," SLVSCP5H datasheet, Jul. 2014 [Revised 2021].