Assignment 8 – End of Documentation Report

Team 2
Water Automation Timing and Efficiency Regulation

Team Members: Jonah Miller, Alejandro Zavala, Francisco Becerril, Hayes Payne

Instructor: Russ Tatro

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Elevator Pitch

A system that monitors and tracks a resident's outdoor water usage to decrease water waste and increase water efficiency.

Executive Summary

An estimated 27 billion gallons of water were being used daily in the residential sector, many states like California were having to find adequate ways to reduce the amount of water the average family household uses. With close to half of the water used on outdoor flora being lost to evaporation, our team has focused on designing a solution that would reduce the amount of water used for residential outdoor flora. Our team designed a product that monitors, documents, and presents the user data on the soil and water usage. The design consisted of 3 different kits: (1) Central Hub, (1) Control kit, and (2) Sensor kits. To assist in the reduction of water, the kits monitor various elements such as the temperature and water volumetric content (VWC) in the soil to determine when the optimal time to water would be. This process allowed the reduction of irrigating water wasted to evaporation, while all being able to be viewed through a Webapp.

The work breakdown structure for our project had been calculated at roughly 964 hours. Where 665 hours were to be dedicated for the Work Packages, and 299 hours were for other assignments related to the project. Each team member was assigned Work Packages based on their expertise, completion of previous packages, and expected workload during the coming week. Our Gantt chart depicted how the 74 Work Packages and 17 assignments were distributed throughout the Fall and Spring semester. Our PERT chart's most critical path added up to 34 weeks and showed wireless communication causing delays and some bottlenecking around the time for integration.

The level of risk that our team encountered during the duration of this project was on average impact level of 2 and probability level of 3. Our biggest risk for the project was malfunctioning code due to broken libraries or difficult to maintain source code. One of our most probable risks for the project continued to be Covid–19. Based upon our risk assessment matrix we saw that our project leaned towards the Risk number of 1.0 (2 impact and 0.5 probability).

By comparing products from companies such as Rachio or Rainbird, our team was able to see what was unique in our product when compared to theirs. The most significant contrast with the other products was what determined the watering cycle. Our device measures the soil VWC at 2 locations, while others use pre-set timers. Another unique aspect of our design was our approach to the remote-control aspect of the design. Our device comes with a web app that would accommodate users on any platform that has access to a web browser.

Our team developed a test plan that outlined the essential tests that needed to be run on our project to determine if we were meeting our design metrics. Each one of our members tested the components of the prototype that they were directly responsible for. The design and testing of the nRF wireless communication network was the most difficult package of our project – consuming 100 hours on design and testing. Ensuring the system reliably gathered the necessary information from the remote kits after integrating Dormant Mode proved troublesome.

ABSTRACT

With fresh water being an indispensable and limited resource; experts agree that close to 50% of all water used in vegetation is lost to evaporation. Team 2 worked on a system that was expected to increase the efficiency of the water used in the outdoor residential sector. The system accomplished this by acting as a self-regulating outdoor water irrigation system using various sensors.

We had a total of 74 work packages with expected start and completion dates. They were estimated to take a total of 10 to 15 hours per package and were divided into sections based on their contribution to the total project: Control kit, Sensor Kit, and the Central Hub. We had also documented 10 major risks that had been predicted to have a potential delay on the project, so we developed mitigation strategies to alleviate the probability and impact of these risks. In our market analysis of our design, we found that there were various other systems that seem parallel to our design; smart sprinklers that use mechanical aspects to efficiently water areas without over watering and smart sprinkler controllers that read weather forecasts to determine future water expectations.

While developing our deployable prototype, tests were performed to assess the performance and functionality of our design. These tests were distributed among team members in accordance with each member's knowledge and experience with each component of our prototype. Each test was selected to improve longevity, functionality, and reliability for our prototype. The tests revealed that our team was able to meet all the desired metrics we had set in the design portion of the project.

Keyword Index

Freshwater, drought, outdoor water, water efficiency, climate change, residential water, water management, water regulation

I. INTRODUCTION

A. Societal Problem

Every year, potable water becomes scarcer. As of September 21, 2021, the USDA stated that 93.9% of California was experiencing severe drought. This is characterized by long and intense fire seasons, inadequate grazing land for cattle, and stressed wildlife. 45.7% of California was under an additional exceptional drought; described with fallow fields, removed orchards, costly fire seasons, and other severe results. [1]

Residential water use was estimated to be 7.7% of the total water use in the United States. California is currently working to encourage urban water suppliers to reduce their allotted water based on the population they support. Starting in 2022, these water suppliers would have a residential water allotment standard to meet based on EPA regulation and guidelines. [2] In order for the Californian population to meet these expectations, we need to adjust our long-term habits now.

The first step in changing our long-term habits is to be aware of them and the impact they have on the environment. Many products have been designed and implemented that address water usage inside the home including efficient shower heads, low-flow toilets, and cost-effective dishwashers. When it came to reducing water usage outside the home, there were fewer solutions. When outdoor watering is concerned, reports state that up to 50% of the water used is wasted to evaporation [3]. This is because most outdoor watering systems only measure the time that the watering system is on instead of the effectiveness of that watering cycle. While all plants require differing levels of water, soil can only absorb and retain a portion of the water.

B. Design Idea

The way we addressed our societal problem was to create an efficient water management tool that would be applicable to the irrigation systems of a residential home. To accomplish this, we focused our design on cost effectiveness, reliability, expandability, and adaptability to various systems and locations within our scope. A central hub provided a user interface that included the capability for a user to monitor the system, adjust the parameters for triggering water cycles, and view their current and previous water use. The control hub gathered all this information from the various sensors that provided it with data concerning the locations they were monitoring, including hose spigots, sprinkler valve controls, and locations in the lawn or garden.

Each sensor to be implemented provided information regarding the relative status of the system: the temperature, relative humidity, soil water saturation, and the amount of water currently being supplied to the setting, if the water was applied through the hose or sprinkler system. These sensors transmitted this data to the hub at a set rate for processing and storage. The central hub processed the data to determine appropriate actions to take, such as triggering the system to immediately water, setting a time to water, or delaying the next planned water cycle. By implementing a connection to weather forecast websites, we included the ability for the system to take future weather patterns into consideration for current watering cycles. For example, if we knew that there was a high probability of rain within the coming days, the system can withhold the usual watering cycle in expectation of water to come. This predicted rainwater would assist in the irrigation of the outside flora and therefore would not be measured by any utility company for the purpose of documenting water use, so the homeowner would benefit greatly if the system planned for this water.

When using wireless communication processes, we considered the efficiency of the various entities in the system. Using power efficient sensors, microcontrollers that specialize in the reduction of energy, and rechargeable power banks that use solar power to generate electrical power for the system, we maximize the life and reliability of our system. Realizing that our team would be using numerous components, our team began designing a work tracker to aid in keeping track of all stages needed to complete our product.

C. Work Breakdown Structure

After our design idea contract was developed, the next step in our project was to develop a work breakdown structure. The work breakdown was projected to take about 1000 hours. It was divided into three sections relating to the three major components in development: a Control kit, Sensor kit, and Central hub. Within each section, there were sub-sections or Work Packages where most have an estimated 15 hours of work. The Work Packages were created based off the measurable metrics developed in the Design Idea Contract. Within the Central hub section, the Work Packages involved the remote data collection from the control and sensor kits, local data collection from the weather API, processing, and storage of that data, sending data to the control and sensor kits, and hosting a user interface for interactions from the user and data display. Both the Control and Sensor kit had power bank, solar panel, microcontroller and RF transmitter and receiver Work Packages, where they differed is that the sensor kit dealt with the temperature & humidity sensor, and soil moisture sensor Work Packages; while the control kit had the water control valve and the water flow sensor Work Packages.

By creating our work breakdown structure, we found where our project had similarities and which of our Work Packages could be worked on in parallel. Seeing how closely our Sensor and Control kits were structured, we had two team members begin the Work Packages for both micro-controllers in the sensor and control kits. We did this since these Work Packages were deemed as the most likely to be the most time-consuming. Another member started at the weather API Work Package, and lastly the EEE team member started on both the solar panel and power bank Work Package. With our team having a general idea of all of our work packages, we then began implementing start and end dates to them.

For a view of the sections and sub-components of the system, reference Appendix D. In-depth descriptions of the components of the project are available in Section V.

D. Project Timeline

A key component in any successful design project is the understanding of timelines, deadlines, and major milestones. To do this, we separated our entire project into separate Work Packages with estimated start dates, estimated end dates, and work hours per package. This process was documented in the previous section of this report. We now take our estimated Work Packages and dates and apply the given data to a timeline to estimate the workload, Work Package distribution, and critical bottlenecks that will limit productivity if not addressed. Our team set out to make a roadmap of where our project was expected to be at a given time.

For our project timeline, we started with making ourselves both a Gantt chart and PERT diagram. These charts allowed us to visualize the estimated schedules and timelines created previously, as well as who was assigned to what packages and when they were estimated to be completed. The PERT diagram outlined how the packages contribute to, and limit, the expected progress and completion of the project. Viewing the Gantt chart, we can see which team member were assigned to the task, what Work Packages they can expect and a projected time frame of how long the Work Package has been given. The timeline was divided based on expected difficulty and took into consideration other student responsibilities. We calculated that each semester had 16 weeks in it, leaving us with 32 weeks for this project. We also had to consider that our winter break while not part of the school year would have to be used to address any issues and try to get ahead on areas where we foresaw possible bottlenecks in the project.

We had to make sure that all the assignments due for this course as well as the other tasks associated between August 2021 to May 2022 in order to have a visual of where we stand in terms of the project. Our team included project milestones such as prototype presentations and signed contracts, some which have already been completed and others which were still being worked on. In terms of the Critical Path, for the first semester all of them lead to the same objective which was to have a working prototype by November 15, and then continue to address any items that might have arisen from the presentation by December 6. As for the second semester the goal will be to take that prototype and design how our final product will be made in order to be used commercially.

E. Risk Assessment

As a team we must always be aware about the dangers posed by working on our project. There were risks to our project and to us, the students, that we need to know about before even starting on any given task. These were dangers to the project that can slow or halt our progress at any point but also situations that can cause injuries to the student. There were also critical paths in our development that required us to be cautious and aware of. If we messed up while on a critical path, it could have drastically delayed our deployment, prevented us to continue, or possibly even having us to redo the whole project from start. Under the subject of risk assessment, we went over our possible risks and how we can mitigate them. We ranked them from the most significant to the least significant and for a visual aide we also create a risk chart labeling all our risks.

A pandemic was still ongoing as we progress in our senior project course and in our deployable project. That means that social distancing was extremely important for our senior project course. We wanted to make sure that no one contracted the virus and therefore require to quarantine for some time. It was one of the main reasons our course was still met virtually, and we only met in person at most twice. Luckily, we had all mostly acclimated to working virtually and we all had hardware to work on our own. Our project was also broken up where each person can work on a part of the project individually and in the end, we can put all our individual parts together.

As for our other critical paths we had five which included the sensor kit, control kit, central hub, wireless communications, and power delivery. Each one was dependent on another therefore when trying to work on any of the five components the risks should be noticed and mitigated. We each had our own components but still were limited to the ones we do have. Any mix-ups could have caused a delay from possibly having to re-order parts that were broken. By noticing these risks, we prevented anything avoidable from happening to our project and to us but there were also risks that exist that can't be avoided. Some of those risks can be one of the numerous unexpected events that can happen like one of us not being able to be part of the team for any reason. These might be unavoidable, but we also had to have them in mind and be prepared for anything.

F. Problem Statement Revision

It was only a matter of time until we had to take serious drastic measures regarding our water consumption. Fresh water levels continued to drop throughout the world, and in the United States several places were already feeling the effects of water scarcity. In many places, the local governments have been required to step in and placed mandates to reduce the amount of water that was once used so freely. With increasing populations and worsening droughts, the need for technology to aid us through these times was ever growing.

In California, we experienced a significant amount of snowfall during major winter storms in December 2021 and January 2022. Even with the snow in the mountains and water in the valley, we still were considered to be in a drought and need to be concerned with our water consumption. In Cape Town, South Africa, they were required to take drastic measures in April 2018 to make sure they did not run completely out of water for their city. We needed to address our issues before it reaches this critical point in California.

We had been required to make minor adjustments to our design, as any development team would. The most notable was the use of our two sensor kits to be used as one unit to obtain a better average reading of a watered area. We needed to consider various factors that we felt could hinder the accuracy of just one sensor kit. The system used various sensors that provided an output to the main hub to determine whether our control kit, which consists of an electronic actuator to either open or close a water ball valve. We had added a weather API as an additional feature that was based upon the zip code the device was in, it considered the weather forecast in its estimation of water usage.

Our team had continually considered our project's marketability. With the help of persisting droughts and with the constant demand of freshwater, we believe this device was the step towards a suitable solution. This device can be seen through two different perspectives, one where it was helping the residents who were having problems with over watering their flora, and the other where it can help those residents who live in an areas water was already scarce and just want to use the correct amount of water. With our revision set for our problem statement, our team was now at a stage where we needed to begin devising how to test our components to ensure reliability.

G. Device Test Plan

Our deployable prototype required a variety of tests in order to ensure the functionality and reliability of our design. These tests were performed for both hardware and software elements using a standard testing procedure developed by our team. Specific names, components used, test description, expected results, and actual results were all tested to determine whether the test passed or failed. Tests were distributed between members based on their previous experience and knowledge of each component of the design. These tests were performed on individual parts of our design to reduce debug time and increase ease of system integration. Failed tests were handled by adjusting the testing procedure or design then retesting until desired results were obtained.

The type of test our team chose were determined by prioritizing what directly affected the Wireless Communication, Soil Moisture Sensors, Solar Panels, Power Bank, Flow Control Valve, Weather API, and the User Interface. Our critical path decided what types of tests we prioritized while planning our testing throughout the duration of the semester. These tests were imperative to ensuring our deployable prototype would meet our measurable metrics.

H. Market Review

The societal problem our team chose was one that was very marketable and was full of other designs that were still trying to alleviate the issue. For devices similar to our design, there were many similar products that can be seen in industries such as industrial farming, where precision watering was essential, especially in areas with ongoing droughts. Our product however was intended from the start to be geared towards residential homeowners with lawns, gardens, or flora. The idea being a smart irrigation system that used sensors to determine when to water.

Our team had researched various companies that make similar products to our prototype. Our findings allowed us to determine the marketability of our product. Our product had some components that were found in other products and other components and features that make it uniquely autonomous and self-sustaining. As opposed to many other systems in the market, our device uses various sensors to measure the soil moisture, local temperature, and relative humidity in the immediate watering area to determine when to water. Some other features, such as a weather API to determine the forecast, an interactive GUI, and solar powered power bank can be seen in other similar products.

By using a SWOT analysis, our team investigated other factors that might affect how our product would fare in the market. One of our biggest advantages was that the market for our product was a growing one so long as populations continue increasing and fresh water supplies continue to decrease. However, some weaknesses such as needing specific condition to operate such as required consistent sun exposure makes our product less appealing to an audience that want a simple, universal solution to their watering needs.

I. Testing Results

It was critically important that we tested our design to prove that it met our stated design metrics. To do this, we divided the labor between the team members based on component and design expertise following the Work Breakdown Structure implemented earlier in our design. Jonah Miller tested the soil moisture sensor, water flow sensor, and the dormant mode programming for the remote kits. Hayes Payne tested the wireless communication network and the temperature and relative humidity sensor. Alejandro Zavala tested the power banks for the remote kits, ball valve, and containers for all the kits and components. Francisco Becerril tested the weather API and web app for the user interface. To ensure that the tests would measure the component's performance while in the system, we would run tests as they were implemented into the containers and system. This applied to many of the sensors, so a schedule was made to ensure that our tests could be completed in a timely fashion while also not severely impacting the remainder of the work to be completed for the system. We split our testing into two major categories: pre and post container implementation. For those components that were predicted to not have changes when it came to the use of the container, we ran those tests first. Once this set of tests were complete, the second category of tests could begin; those that were predicted to be affected when using the containers for the remote kits. With our testing having been completed our team could begin on polishing up the remaining items on the product and finish up our report.

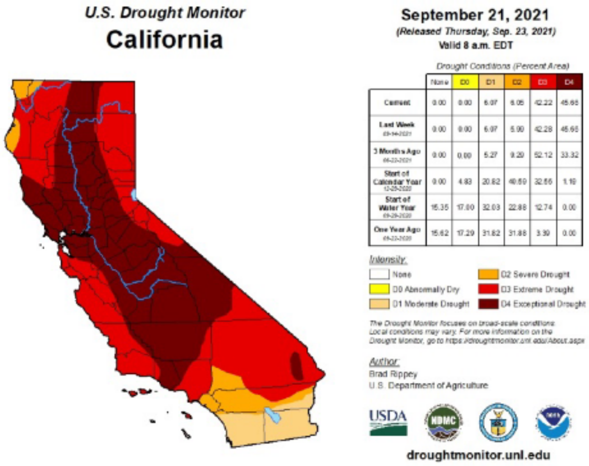
J. End of Documentation

Team W.A.T.E.R set out to create a prototype to help reduce freshwater use to address reoccurring and problematic drought. This senior design guided our team in developing the skills to create this prototype from start to finish. Research, setting appropriate goals, and adaptability were all driving forces to reach the completion of our deployable prototype. Though our team ran into several roadblocks and challenges in the development of our project, we were able to consistently overcome each as they came along. Our team's organization, synergy, and skillsets allowed each of our members to contribute quality design elements to our prototype. All team members worked independently when required and effectively listened to and implemented changes based on team feedback. This feedback loop within our team further refined our implementation quality. Our team managed time effectively to meet deadlines and meet team goals. Each team member demonstrated leadership, independence, quality work, and effective teamwork over the course of senior design. The most difficult part of our project was full system integration. Specifically, the wireless communication between the kits and our central hub proved to be a challenge that took significant effort to overcome. Regardless, our team still faced many obstacles during system integration to meet a quality standard that we were satisfied with. Each team member was required to work continuously throughout the duration of senior design to make our prototype come to fruition. Overall, we were satisfied and proud of our final deployable prototype design.

II. SOCIETAL PROBLEM

A. First Semester Interpretation of the Societal Problem

The battle against climate change has created a necessity for innovation in water management and utilization solutions to address a variety of climate related issues. Climate change has had a significant impact on concerns for water management and utilization. Consequently, one of the most pertinent issues face as of 2021 in the United States is drought. In Figure 1, we see that a substantial portion of California is considered to be in extreme or exceptional drought as of September 21, 2021.[4] The impacts that this drought has had on California supersede basic water availability. Water quality, flood regulation, aquatic species biodiversity, hydropower generation, cultural and recreational activities, irrigation water, and agricultural production were all heavily impacted by drought.[5]



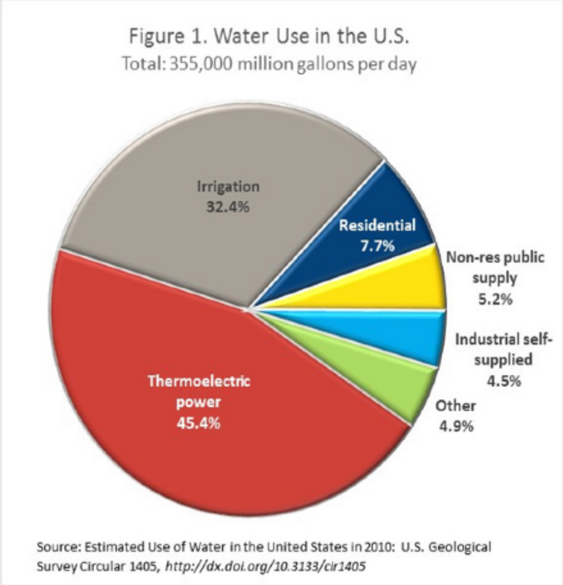
	None	D0	D1	D2	D3	D4
Current	0.00	0.00	6.07	6.05	42.22	45.65
Last Week 09-14-2021	0.00	0.00	6.07	5.99	42.28	45.65
3 Months Ago 06-22-2021	0.00	0.00	5.27	9.29	52.12	33.32
Start of Calendar Year 12-29-2020	0.00	4.83	20.82	40.59	32.56	1.19
Start of Water Year 09-29-2020	15.35	17.00	32.03	22.88	12.74	0.00
One Year Ago 09-22-2020	15.62	17.29	31.82	31.88	3.39	0.00

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information on the Drought Monitor, go to https://droughtmonitor.unl.edu/About.aspx

Fig. 1. U.S. Department of Agriculture[6]

Systems were in place to deal with increased strain on water rescources, but making accurate predictions of the future social, economic, and environmental impacts of these systems is nearly impossible.[7] As a result, increased strain will be placed on water management systems in the future.

A considerable portion of the water use in the United States is utilized for the purpose of irrigating farmland for agriculture and livestock. In 2010, it was was measured that 32.4% of freshwater withdrawls were used for agricultural purposes. Additionally, 7.7% of freshwater withdrawls goes towards meeting residential demand. Of this 7.7%, it is estimated that 30% of the water is used for the purpose of outdoor watering.[8] These claims can also be seen in Figure 2.



Source: Estimated Use of Water in the United States in 2010: U.S. Geological Survey Circular 1405, *http://dx.doi.org/10.3133/cir1405*

Fig. 2. U.S. Geological Survey of Water Utilization[9]

In addition to water strains due to drought, there were other strains on the fresh water supply. In the past 100 years, water demand and utilization has increased significantly. As seen in Figure 3, global fresh water demand for agriculture alone has increased to roughly 4 trillion cubic meters as estimated in 2014.

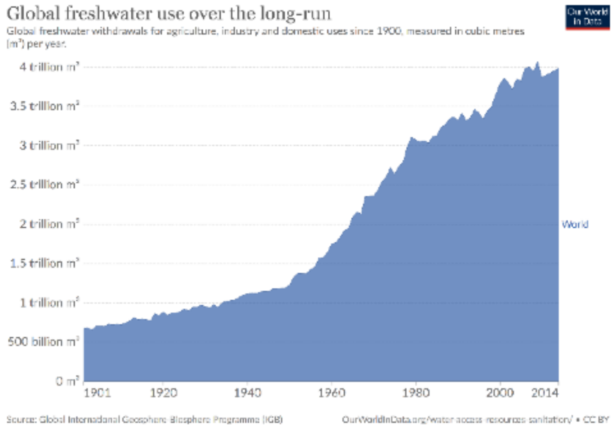


Fig. 3. Global freshwater use over the long run[10]

The rates of water demand for agricultural purposes appear to be a direct result of increased demand of food for a steadily growing population population over the same time interval.[11] Projections concerning increased water demand due to climate change estimate an increase of water withdrawal throughout a significant portion of the United States range from 25% to 50%.[12] With and increase in demand and decrease of the freshwater supply, the United States will continue to struggle to meet demand, let alone prepare for future changes.

While methodoloy, techniques, and technology have improved to help manage water utilization and efficiency, there were still many inefficient methods used throughout the United States that waste considerable amounts of freshwater. Poor agriculture irrigation systems and education on environmental factors contribute to the most common sources of water waste. In residential settings for example, as much as 50% of water used for the purpose of outdoor watering is lost.[13] In 2018, California signed a bill to encourage urban water suppliers to reduce their allotted water based on the population they support. Between 2022 and 2025, these water suppliers will have an indoor water use standard of 55 gallons per person, per day. Afterwards, it will reduce to 50 gallons. [14]An outdoor water standard will also be recommended by October 1, 2021 and implemented June 30, 2022.[15] In order to meet expectations by that time, we need to start adjusting our long-term habits now.

Using smarter systems and technologies that help minimize these water losses, we were better able to conserve water during times of drought and increased demand. While the technology is still far from perfect, further innovation and improvement were needed to address these major concerns of increasing demand for fresh water.

B. Second Semester Improved Interpretation of the Societal Problem

Over the course of this past semester, our team has developed a greater understanding of the implications and impacts related to water usage. As we have refined our project design, we continued to find additional evidence on the importance of water conservation and usage efficiency. New mandates have been made in California to help with the ongoing issue of meeting freshwater demand, the most recent being passed January 2022. Water scarcity is a growing issue; one that has been a global issue for some time now. This issue will only continue to grow as freshwater demand continues to increase. California is one of several taking big steps in implementing water restrictions. California has passed the Drought Water Conservation Emergency Regulation. This regulation which started on January 18, 2022 is in response to the drought that CA has been in for quite some time now and it hopes that its people will help in the water conservation. It is set to stay active for one year and is implementing acts such as turning off decorative water fountains, using alternatives to clean sidewalks that don't use water, stopping irrigation if there is to be rain in the next two days, and several other measures[16] For those who choose to ignore the mandate, California has added fines to be placed on those who choose to ignore the water crisis.

As water regulation is becoming more of a necessity, water districts across California have begun regulations and restrictions that will continue through the rest of 2022. The Urban Water Management Plan is a document developed every 5 years concerning water usage across the state according to the water districts. The main water district for the Sacramento Region is mandating further conservation mandates for the Sacramento Main District. In the "Urban Water Management Plan", the Sacramento Main district has developed a Water Shortage Contingency Plan with 5 response stages. Once the plan is implemented, each stage applies to both industrial and residential water users and include increased mandatory rationing, and fines for those who do not meet the regulations during that stage. Serious offenders risk the installation of flow restricting devices on their water meters and associated fees.[17]

Recent data from provided by the USDA also suggests that despite the large downpour storms that Northern California receive during the late months in 2021, California is still in a drought as of January 2022.[18] We have learned not only that our project and proposal for our prototype design was initially going to directly contribute to a prevalent societal problem, but as time continues our team has learned that water conservation will continued to be a necessity for the foreseeable future.

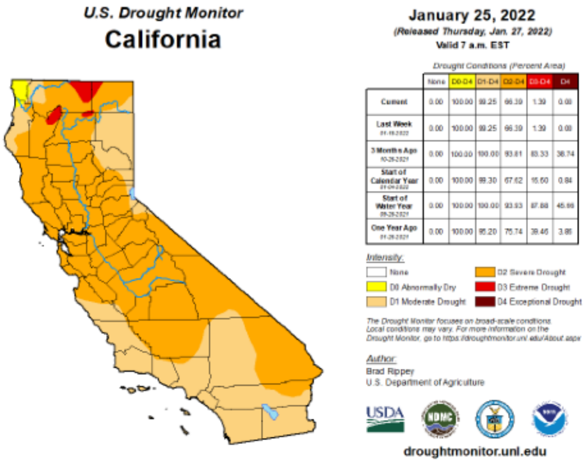


Fig. 4. Updated US Drought Monitor for California, January 25, 2022[19]

Drought and water scarcity were issues not exclusive to California or the United States. In Cape Town, South Africa, there was an event titled "Day Zero". This event was when the city's municipal water supply was predicted run below a critical capacity, at which only water was to be supplied to critical services. Its citizens would be required to line up for their daily allotment of water of 6.6 gallons per person. To delay this event, the city implemented strict regulations, tariffs, and rules regarding water use. They also advertised the predicted remaining days before water was to run out on electronic signs around the city. These actions delayed the "Day Zero" for a full month, and soon after the next rainy season saw the first average rainfall in 4 years.[20] While we were not at this level of extreme situation in California, we can see that this problem plagues people all across the world and they were required to take extreme measures to maintain an adequate level of water.

Not only is this societal problem continuing to develop and become progressively prevalent, but it is also a global issue meaning it's both a qualitative and quantitative issue. Our team has continued to develop and monitor our understanding of the issue with new, pertinent information that has allowed to understand just how important maximizing water efficiency is.

These regulations, and global water shortages have allowed our team to prioritize water conservation as our primary focus. Instead of maintaining and managing several water sources, we have shifted our design to one where a single system regulates the amount of water supplied to a single given area and allows us to maximize the efficiency and also provide information to the homeowner regarding water wastage on that site. This change has been made by using both sensor kits in one watering area to better account for average soil moisture, and potential slope of the focused watering area. This has been the cardinal change our group has made that has progressed and developed with our greater understanding of our societal problem but does not require a change in our project contract or scope as we clarified a part of our original design statement.

The exact form of our deployable prototype includes a control kit that uses Wi-Fi to communicate to a weather API to determine local weather data that would help determine if it is efficient to water during scheduled watering cycles. One control kit that will physically turn a ball valve on and off while giving water volume information back to the central hub over radio frequency modules. Additionally, our two sensor kits use temperature, humidity, and soil moisture sensors which send additional information to the central hub to help determine the watering cycles timing and duration. Each sensor kit is to be encased in a weather resistive casing and equipped with a solar powered power bank to deliver adequate power to its sensors and microcontroller. These sensors gather data which is then communicated to the central hub where the water cycle calculations use all pertinent sensor and weather information to calculate timing and duration of automated watering cycles. The information obtained by the various sensors will also be available for display to the user through a graphical user interface that we will be implementing with the device. This will ultimately help us contribute towards precious water conservation.

III. DESIGN IDEA

A. Design Philosophy

Our design idea sought to aid homeowners in reducing the amount of water used for watering outside flora to combat the amount of water being lost through irrigation. By focusing on the residential sector, our team hoped to provide easy-to-track metrics and a system that would provide much needed aid to areas where water is scarcer. In doing so we hope to potentially lower water bills and meet water restriction standards by increasing the efficiency of current irrigation systems.

The system uses sensors to measure the amount of water being used by irrigation sources, specifically sprinkler systems and hoses. It would use soil moisture sensors to measure the effectiveness of the watering cycles and recommend times and durations that would aim to reduce water waste with the help of air temperature and relative humidity sensors. A weather forecast API would inform the system of upcoming weather patterns for the next day to allow the system to predict whether watering would be necessary. We also implemented solenoid water valves that control the water cycles to maximize soil water retention in our design. moisture. Moisture levels would allow us to determine if the plants around that area would require water by determining if volumetric water content of the surrounding soil were low. Once this value was determined, the system would be able to compare it to other factors such as atmospheric temperature and relative humidity. If and only if temperature was not too high, soil volumetric water content was low, and relative humidity low would the system determine that it was viable to water. Additional parameters such as chance of precipitation would also deterministically affect watering cycles. For example, if there was a low chance of precipitation and all required watering parameters were checked, then the system determines if a section receives its watering cycle. This allows the system to address various locations where the type of flora being watered might desire water at different rates.

Since there was a large amount of data that was used by the system, a log of this information would be recorded and stored. This monitored data produces was logged so that it can be analyzed by the user. This data export was stored in a microSD card in central hub. This data would then be able to be manually transported to another system for assessment. This data included modifications to the system and system data export. Additionally, this data would be converted input into a GUI, so that it can be visualized in graphical form.

Wireless connections between the central hub and remote sensor and control kits would allow the system to be expandable, both in range as well as number of connections. We retain the ability to add more control units, additional sensor locations, and increase the range we were able to communicate at when we were kept wireless. However, it comes at a cost.

The issue concerning using remote sensors and control kits was power drain. When having a system that relies on wireless connectivity between sensors and data logging would need to have a reliable connection that consistently produces the data needed. We were not able to rely on a dedicated power line from the central hub due to the danger of having wires stringing across an open space. Using solar power and a battery bank, we keep the system reliably powered and communicating on a pre-set schedule.

The concern of water usage is a problem that would continue to get worse. Even when our system was applied, there would be a necessity to continue to be diligent in the conservation of water. If we focus our energies on reducing the amount of water, we use by using it more effectively, we would slow our water use. Our system was designed to be used by anyone that wishes to reduce their residential water use and use the water more efficiently.

TABLE I.

MEASURABLE METRICS AND PUNCH LIST

Feature	Measurable Metric
Read Temperature	Read Temperature in a range between 30°F and 90°F ± 1°F
Read Relative Humidity	Read Relative humidity in a range from 20% to 70% ± 3%
Measure Soil Moisture Saturation	Measure and report the moisture of the soil at two separate locations at a depth of 6 in We will measure the Volumetric Water Content (VWC) between 10%-50% ± 1%
Data Transmission	Send and Receive data from various sensors and controllers within the network at a maximum range of 500 ft It would transmit at maximum 0.1 kB every 10 minutes
Solar Power Source and Low Power Consumption	Remote Sensor and Control Kits will have on-board power bank with a capacity of 5,000mAh that is connected to solar power panels The remote Sensor and Control kits will run for 30 days between battery pack changes
Read Flow Rate	Measure the amount of water that is being used by an irrigation system via a pipe or hose between 7GPM and 10 GPM with an acceptable error rate of ± 0.2 GPM It will record data once every 30 seconds at minimum while water is flowing
Control Hose Water Flow	Control the output of water up to 10 GPM from a water hose spigot using a valve that will open or close within 6 seconds
Weather Forecast	An External Weather API will indicate weather patterns for the specified area based on the location of the central hub every hour and next day's forecast once every evening
Data Storage	Store all incoming data from Sensors and API in a file. The system will include a minimum storage of 2GB and expandable to 32GB

B. Specific Design Components

The system would consist of several different component packages. The central hub would be responsible for collecting data and transmitting commands to the various remote sensor and control kits, as well as hosting an interface for API and user interaction. The control kits would communicate with the central hub to measure and control the amount of water being used by the system that the kit is attached to, hose or sprinkler irrigation for example. The sensor kit would measure and report data at various locations within the system's control to the central hub.

The central hub would contain a microcontroller with Wi-Fi support for an external facing interface and a large number of GPIO pins for hardware sensors not initially included with the microcontroller. The Wi-Fi support would allow the central hub to connect to external information sources and host a user interface for the user to make choices regarding the system. The central hub would also be a crucial factor in debugging and controlling the system. It would be powered directly from a DC source because it is crucial for this microcontroller to have consistent uptime. This consistent uptime of the central hub would minimize the risk of lost data or missed watering cycles.

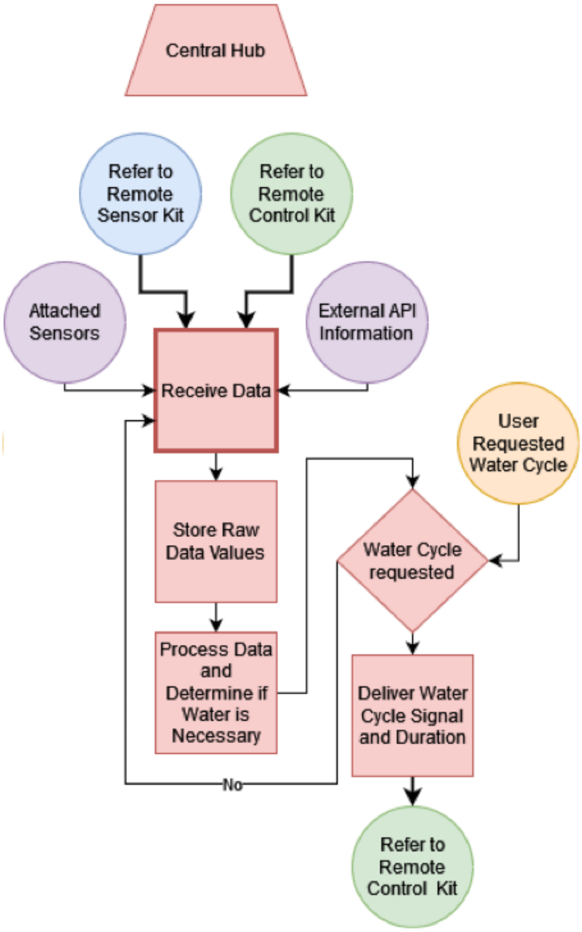


Fig. 5. Graphical Representation of the Control Hub[21]

The control kits would have sensors to monitor the flow of water and would have the ability to turn on or off the system they were attached to. The control aspect of the system is crucial for maximizing water usage efficiency, and the monitoring function of the control kit is key in the reporting aspect of our system. The control kits would also transmit and receive data from the central hub in order to function properly. This would provide the central hub with the data necessary to document the water used by the system and allow for the user to make smart water conservation choices. It would also allow the system the ability to actively manage the water use. With the ability to manually override the control, the user would also be able to water at inopportune times for water consumption. This would be necessary if the user planted additional plants, reseeded their lawns, or other events that require immediate watering.

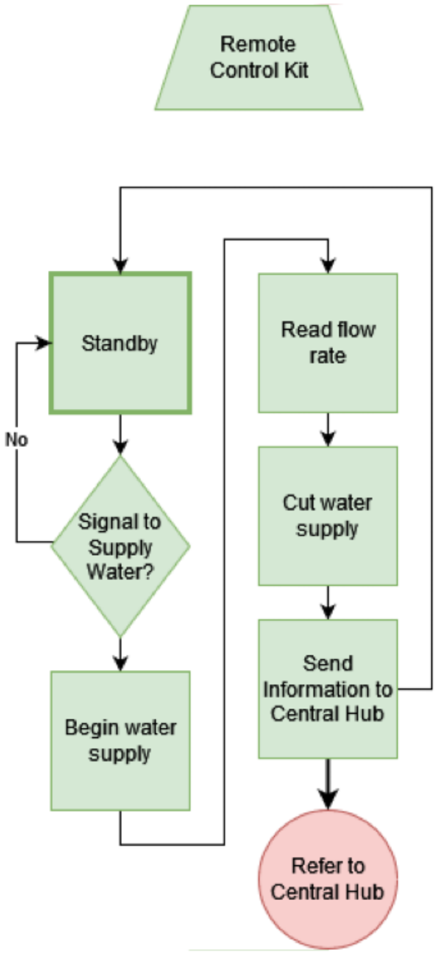


Fig. 6. Graphical Representation of the Control Kit Logic[22]

A main component used in the sensor kit is a soil moisture sensor. This would measure soil saturation at locations within the system's control at various depths. Taking measurements at various depts allow the system to accurately understand how effective the watering cycles are, how much water the soil would retain both short and long term and allow for the growth of plants with deeper root structures. Another sensor included in this kit is a Temperature and Humidity sensor. This would allow the system to measure and record the temperature and relative humidity near the sensor kit. These factors were key in minimizing water loss due to environmental causes such as evaporation. These would be connected to an energy efficient microcontroller with a wireless data transmitter. This data transmitter would output data from the soil sensor to the central hub. The central hub would then be able to use this deterministic data to know if it is an efficient time to water.

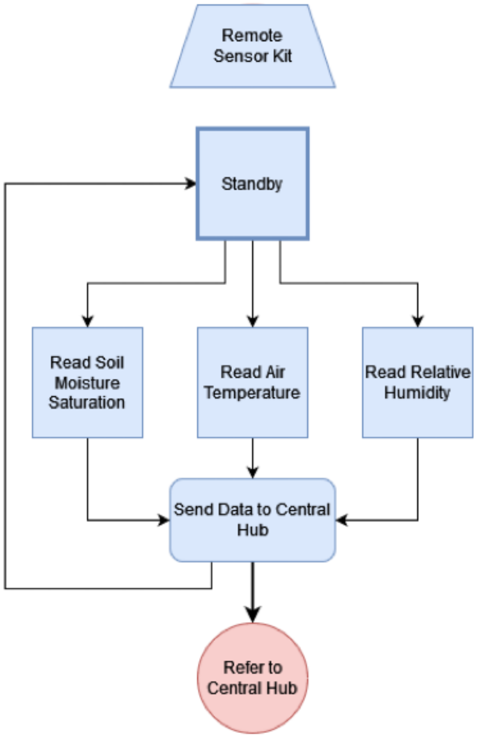


Fig. 7. Graphical Representation of the Sensor Kit Logic[23]

All the remote kits would be powered by voltage regulated rechargeable batteries. Power efficiency is a key part of this component as we aim for longevity between charges of the battery. The rechargeable batteries would be able to be swapped out and recharged at a recharge station that has overcharge protection. This station would allow multiple batteries to be charged at a time to minimize the downtime of the remote sensor kits. This is crucial for the system to run smoothly so that a measurement or water cycle would not be missed.

The primary software to be used in the development of the system would be similar to the C/C++ Raspberry Pi Pico SDK. This program provides the use of libraries that allow for the maximization of the microcontroller as well as the sensors used in each kit. It would also allow us to debug our system at any stage of the development and flash our software to the microcontroller when ready. Languages like C and C++ give us direct control of the hardware presented and allow for significant power drain reductions as available by the sensors and microcontroller.

API's would allow our system to communicate with various weather sites to provide local weather patterns and forecasts. This would work in conjunction with the data from the hardware to determine if a water cycle is needed or if it is not necessary.

All of the data would be logged, stored, and organized using Wi-Fi data transmission for later reference and analysis by the user. It would also be available to the users for processing, extraction from the system, or analysis using a user interface. The user interface would also provide manual overrides to different controlled water supplies that can be triggered by the user at any time.

IV. FUNDING

TABLE II.
ESTIMATED FUNDING AMOUNT AND SOURCES

Source	Estimated Amount ($)	Actual Amount ($)
Jonah Miller	120.00	185.65
Alex Zavala	120.00	251.38
Francisco Becerril	120.00	40.00
Hayes Payne	120.00	170.13
	Total	647.16

V. WORK BREAKDOWN STRUCTURE

To organize our Work Packages and workload, we separated our project into three sections: Control kit, Sensor kit, and Central hub. The sensor kit, section A, involved the measurement of the local air temperature, relative humidity, and soil moisture level at a monitored location. The Work Packages of this section included the Humidity and Temperature sensor reading, Soil moisture sensor reading, RF Communication to and from the central hub, networking the sensor and data communication packages, and power delivery to the system. The control kit, section B, is like the sensor kit, as it uses the RF communication, Pico microcontroller, and power Work Packages. It differs in that it measures and controls the water flow to the monitored flora. Section C deals with the control hub. It involves the user interface, data collection, water cycle calculations, RF communication to the sensor and control kits, and collecting data regarding the future weather patterns. Once all the Work Packages were complete, the system will be running. A visual regarding the Work Packages and components can be found in Appendix D.

It was important to capture responsibilities of projects that were not necessarily parts of the design, but part of the entire process. For Senior Design, this was mostly the assignments and reports required. For the first semester of Senior Design, we have eight assignments required. These assignments cover the steps to the development of the project, including researching a societal problem to address, creating a design idea contract, listing expected milestones, assessing risks associated with the project, and many more.

A. Sensor Kit

1) Humidity and Temperature Sensor

The humidity and temperature sensor, found in Appendix A as A.1, outputs local temperature and humidity data of the surrounding atmosphere. This sensor has no dependencies, and the Work Package only referenced the data collection from the sensor. The other Work Packages that have dependencies on this data were the Pico microcontroller and the RF communication of the microcontroller. These Work Packages require this data to control how often data was captured from the sensor, and how the data was packaged and delivered to the central hub for processing. This Work Package was projected to take 15 hours and was assigned to Hayes Payne. This Work Package required the testing of the sensor output voltages and quantifying the relative humidity and temperature of the surrounding atmosphere. Programming the microcontroller in C was required to receive and parse the data from the sensor as well as control how often it took measurements.

2) Soil Moisture Sensor

The soil moisture sensor, found in Appendix D as A.2, outputs crucial data about the volumetric water content of the soil. This sensor has no dependencies, and the Work Package only references the data collection from the sensor. The Work Packages that were immediately dependent on this information were the microcontroller and RF communication which receive this data for packaging and transmission to the central hub. This package was designed to take about 15 hours of total work and was assigned to Jonah Miller. This package requires testing of the sensor output voltages and quantifying the equivalent volumetric water content percentages. Additionally, programming the Pico microcontroller in C was required to receive and parse the data from the sensor as well as control how often it took measurements. This was one of the first packages to be assigned as we needed the data as the first step required for the data feedback loop of the system.

3) RF Communication with Pico Microcontroller

The RF Communication Work Packages cover the communication between the remote sensor and control kits and the central hub. These components can be seen in Appendix D as A.3 and B.3. RF communication was an integral part of the system as it allows for the kits to wirelessly communicate the gathered data to the central hub. The RF communication occurs at the 433 MHz frequency band, which was a free and unlicensed frequency band that does not require approval from the FCC to use. To separate the workload, this component was divided into two separate packages: microcontroller and central hub communications. This package was designed to take about 20 hours of total work and was assigned to Hayes Payne. The microcontrollers on the sensor and control kits will send packets of data collected from their respective sensors that were gathered at scheduled intervals to the central hub. The central hub was responsible for determining if watering was needed and optimal. Once the central hub receives data, it will send a signal back to the kit stating that it has received the data, if a water cycle has begun, or other necessary system notifications. After the remote kits were given permission to return to dormant mode, they will return to sleep until required to wake up for another reporting cycle.

4) Pico Microcontroller

Microcontrollers were the backbone to the sensor and control kits. They were responsible for the collection of data from the sensors, power delivery to those sensors, communication with the central hub, turning on and off water cycles, and managing the remote kits. We chose two Raspberry Pico's for our microcontrollers as seen in Appendix D as A.4 and B.4.We decided that dealing with the sensors as individual Work Packages and the combination of those packets as well as the power and data management as a separate package allows us to create modular code and have a single Work Package for the sensor and control kits code structure. This package was designed to take about 20 hours of total work and was assigned to Hayes Payne. The microcontroller general code Work Package involves taking the code developed for the sensor, water valve, and RF communication Work Packages and creating the network that combines the modules. This Work Package also involves putting the control and sensor kits in the dormant mode of the microcontrollers to minimize power consumption, identifying the kit via a generated and shared ID number to uniquely identify the control and sensor kits, and localized storage of data on the microcontroller. The Pico Microcontroller programming was reliant on the other packages for the relevant section. For the Sensor kit, it was reliant on the Soil Moisture, Temperature and Humidity, and RF communication Work Packages. For the Control kit, it was reliant on the Water Flow and RF Communication Work Packages. This Work Package was one of the last for the sensor and control kits.

5) Solar Panels

Our power bank will need to be able to be rechargeable, and with our project being outside we decided that the best way to do that was through a photovoltaic system. With many gardens and lawns already primarily positioned to take advantage of the sun, solar panels were deemed to be the best solution to recharging our power bank. We had to do some research on various solar panels to determine which ones could provide the best power to the power bank. We are using a solar panel for the control kit and the sensor kit labeled A.5 and B.5 respectively in Appendix D. This package was designed to take about 10 hours of total work and was assigned to Alejandro Zavala. With our charging panel component being able to take an input of 4 - 6.2 volts, we picked a solar panel that had a rating of 6V and 330mA. When placed in the sun the voltage reached an average of 7 volts. There was some concern if there could be some damage to the charging panel module, so we added to the work structure to dedicate some time to leave the solar panel connected to the charging panel and take measurements and annotations if any damages were noticed on the charging module. The last item of business for the solar panel was to find a location of where we planned on placing the solar panel. We needed to take in factors such as shade from any flora, watering sprinklers, and safety for the panel itself when deciding on where to place the panel. This Work Package can be treated separately from the other packages involving the control and sensor kits. The development of the power components of our design, while crucial to the overall design, was not necessary to the development of the other Work Packages. Due to this fact, this package was developed in parallel to the other packages that have dependencies on it; all the Work Packages associated with the sensor and control kits.

6) Power Bank

Our first task was to determine how these kits were going to be connected. We concluded having wires run throughout one's garden or lawn was impractical, especially when it came time to do any upkeep. For that reason, we chose to be wireless and use RF signals as our means of communications. Since our kits were going to be wireless a battery powered source was absolutely necessary. Therefore, we are using battery banks labeled A.6 and B.6 in Appendix D. Since our microcontrollers were chosen because they already had allowed power consumption while in dormant mode, we had to look into how much amperage our sensors were going to consume while operating. This package was designed to take about 10 hours of total work and was assigned to Alejandro Zavala. From the temperature and humidity using 23 micro amps, the moisture sensor needing 13 mA, and the water flow sensor needing 15 mA. We wanted for the power bank to be able to provide power to the kit for up to 30 days. For this reason, we decided that three 2800 mAh batteries would be more than enough to power the kits for the needed time. A closer estimation will be made once all the components were connected and working. The power bank consists of the battery pack holder, the charging panel module, and the solar panels. The time needed to combine these items could be completed within 1 week; however, the testing itself would need at least 2 weeks in order to find and then adjust any misalignments that could be found. The development of the power components of our design, while crucial to the overall design, is not absolutely necessary to the development of the other Work Packages. Due to this fact, this package was developed in parallel to the other packages that have dependencies on it; all the Work Packages associated with the sensor and control kits.

B. Control Kit

1) Flow Control Valve

The flow control valve, labeled B.1 in Appendix D, has the sole function of turning water flow on or off. This has no dependents, but was controlled by a Pico which determines which state it was in. This state was determined by the data from the soil moisture sensor, humidity and temperature sensor, and weather API data. It only turns on when the system detects watering was required; else its state will be off. This package was assigned to Jonah Miller and was projected to take 10 hours in total. While the mechanism itself was simple, the process behind the valve's state will be determined by programming a simple state machine on the microcontroller. As there were no dependencies, this package was assigned after the sensor programming since its function could be artificially produced for debugging and testing the system.

2) Water Flow Sensor

The water flow sensor, labeled as B.2 in Appendix D, outputs the water flow in gallons per minute. This sensor is crucial in determine the amount of water that is being used for the purpose of watering. This sensor is dependent on the microcontroller to control when it will take measurements of water flow. Moreover, the sensor is dependent on the RF transmission that is responsible for transmitting the data to the central hub. This package was assigned to Jonah Miller and was estimated to take 15 hours of time to complete. The process to complete this package required programming in c to determine when the sensor takes data. Additionally, that data is parsed and sent to the central hub for processing. This is determined by a rate of electric pulses produced by the sensor. The system translates these pulses into an equivalent ratio of gallons per minute. In order get the total, the duration of water flow determines the total amount of water used. This package is crucial in the water management data feedback loop, so it is completed early in the work breakdown structure.

C. Central Hub

1) Weather API

For the weather API, labeled as C.1 in Appendix D, our Work Packages include extracting information from a weather API that was vital to our project. The information extracted from the API will include the current weather and the weather forecast for the upcoming seven days. We were looking for humidity, wind speed, and the chance of rain within the area of where our system was located. This package was designed to take about 10 hours of total work and was assigned to Francisco Becerril. This data will be used in order for our central hub to determine opportune times for allowing our water valve to open. We will be extracting this data as frequently as it's updated by the API or whenever the user requires it. The seven-day forecast will be important for the user to be able to see when they want the system to go off and plan their watering needs at least a week in advance. This package has no dependencies, but the water cycle calculations were dependent on this information. Since the weather API was not dependent on any other part of the project, it was placed into a higher priority than other packages that had dependencies.

2) Data Logging

Data logging, labeled as C.2 in Appendix D, means we will be logging the data from our sensors, the weather API, and our system. The data from the sensors and weather API were meant for the central hub to access to determine if watering should be allowed therefore sending a signal to our water valve allowing it to open. This package was designed to take about 10 hours of total work and was assigned to Francisco Becerril. The data logged will be precisely formatted in a file for further implementation for the user space. System data will also be stored in a separate file for incase the system runs into a problem that we will need to debug. Whenever the system does anything important the process will be stored in a file alongside the time and date of when the process was performed with some system vitals at the time of execution. When we implement a user space, we will also allow the data to be accessed for the user to look over if ever needed. This package was an endpoint and there were no system dependencies on data logging therefore it has less priority than the rest of the packages under section C.

3) User Interface: Data Display

The user interface data display was a visual representation of the data for our system. It is our component C.3 in Appendix D. It has no dependents that affect the functionality of the system. Its sole purpose was to allow the user the ability to quantify the water usage of the system in a simple and easily identifiable manner. This package was designed to take about 10 hours of total work and was assigned to Francisco Becerril. This process of displaying this data was by logging the data from the sensor and control kits as well as the central hub. This data would then be plotted onto an excel spreadsheet and graphed. As this doesn’t directly impact the functionality of the system, this package has a much lower priority than others under Work Packages under section C.

4) User Interface: User Input

Having a user interface where the user can manually override the system allows for a more marketable, and user friendliness. This package has not dependents, so it has lower priority. It falls under component C.4 in Appendix D. Additionally, it was not part of our measurable metrics but was simply a quality-of-life improvement that would be implemented. This package was designed to take about 10 hours of total work and was assigned to Francisco Becerril. The process of creating this package would include the ability for the user to send manual interrupts to the system or override preexisting functionality to whatever the user specified. This ability to manipulate internal system values by an external medium like a computer or phone would be executed entirely via programming it in C and python.

5) Water Cycle Calculations

The water cycle calculations were a crucial aspect to manage the watering cycles. They compare data that was gathered from the weather API such as chance of rain and wind speed to determine with the sensor data from the sensor kit to determine if a watering cycle should be initiated. The component can be seen in Appendix D as C.5. This package was designed to take about 15 hours of total work and was assigned to Jonah Miller. This was completely code driven and takes place internally on the central hub. Based on the incoming data from the sensors and weather API comparisons will directly control the state of the water flow valve. This valve was the dependent on this data, while this data was dependent on both the weather API and the sensor kit data transmission. Since there were quite a few dependencies for this Work Package to function, the weather API and sensor kits sensors and data transmission were assigned first.

6) RF Communication

The RF Transmitter on the central hub was crucial for sending out data to both the control and sensor kits. It is component C.6 in Appendix D. Moreover, it receives incoming data that was used for data logging, and water cycle calculations Work Packages. The RF communication occurs at the 433 MHz frequency band, which was a free and unlicensed frequency band that does not require approval from the FCC to use. This package was designed to take about 10 hours of total work and was assigned to Hayes Payne. This Work Package entails managing data package transmission timings and controlling outgoing signals that determine when the sensor and control kit will time their operations. This was done using custom C libraries that were used to transmit and parse data sent over the RF transmitters into usable data. The entire functionality of the system was dependent on this process as the timing of all data transmission in our feedback loop goes through this Work Package. This Work Package has no dependencies, so the package has highest priority under section C.

D. ASSIGNMENTS

To begin our Senior Design project, we first had to come up with our individual societal problem. For this assignment we had to research a problem that we believed engineering could provide a solution to. We would then need to come together in week 2 to present our idea to our fellow teammates and discuss what our societal problem was and a brief and vague solution to the problem. After presenting our individual problem statement, we had to come together as a group and decide on which societal problem we as a group thought was the best candidate for our group. We took into consideration factors such as possible workloads that the EEE and CPE students could possibly take, which topic currently generated the most found research, and also which topic sounded the most interesting to most of us. Assignment 3 was when our team really bunkered down and hashed out a good portion of the details for our project. The design idea contract needed us to really get into the details of what our design planned on accomplishing and how we planned on making that happen. This was where we clearly wrote out our punch list for the design and committed ourselves to this project. Our fourth assignment was to create a work breakdown structure for our project. For this assignment we had to break down our project into tasks and then make smaller Work Packages where we annotated who would be working on it, the estimated amount of time one would be working on it, and what other portions of the project were dependent on it. The goal was to provide our team with a structured frame that provided us with what deliverables were being expected of us and a timeframe by which to complete it. With this it would require the team to entrust one another for each of us to finish our assigned tasks, and also come forth if a Work Package was going to be delayed. The assignment was the Project timeline. For this portion we created a Gantt chart and a PERT diagram of the anticipated tasks of our project over the period of August 2021 to May 2022. Within this assignment we also showed which teammate was performing the task for each Work Package and a timeline of when a Work Package started and ended. Lastly, we annotated the significant Milestones to our project. Assignment 6 was the project's risk assessment over the entire two semesters. For this assignment we first had to identify the project's critical paths, any potential events and risks that could hinder the completion of a critical path. We then had to come up with mitigation strategies for each one of the risks we had listed before as well as make a risk assessment chart for the most significant risks the team identified. The final assignment for the first semester was the laboratory prototype (technical) review. Assignment 7 asked us to use the design feature set as our guide for the review flow and present the technical details of our prototype. For this portion we had to demonstrate our project’s hardware and software in a system that would include all the functional blocks of our design. The goal of this technical review was to review the design idea and its feature set.

When we developed our Work Packages, we divided our project into three sections: Sensor kit, Control kit, and Central hub. Within these sections, we have a number of Work Packages. Some were unique to the kit, such as the sensors and data collection implementations. Other Work Packages may apply to multiple sections, such as power storage and RF communications. It was important to know what Work Packages can be applied to multiple sections and what were unique to their section. Along with understanding the Work Packages, understanding the dependencies between them was key to avoid any slowdowns. After we divided the Work Packages, we determined which packages were dependent on others. From there, we prioritized them in order to reduce any major bottlenecks in development. We also included Work Packages not directly connected to our product, our Senior Design Assignments. These assignments were a key component to our course, and we need to meet expected deadlines.

VI. PROJECT MILESTONES AND TIMELINE

For our project timeline we marked certain points that our team deemed important checkpoints as well as critical milestones. We divided tasks into 4 sections that were worked on in parallel. These sections were Assignments, Initial Design, Revised Design, and Testing. The assignments span the entirety of both semesters and were worked on in parallel with other tasks. The initial design sections were what we did during the Fall 2021 semester of Senior Design. The revised design took up about 6 weeks of the Spring 2022 Senior Design and was worked on in parallel with testing. The testing category of our project took place over the entire duration of Spring 2021 Senior Design. All packages were broken down into 15-hour increments or fewer except for one labelled “Additional testing” which was miscellaneous testing that will take place the last couple weeks of the Spring, 2022 semester.

Additionally, Senior Design was broken up into different leaders. The first 8 weeks of Fall 2021 Senior Design were led by Jonah Miller, followed by Francisco Becerril for the remainder of the semester. Once the semester was over on December 11, 2021, the leadership transitioned to Alejandro Zavala carrying into the following Spring 2022 semester. His leadership continued through March 15, 2022, where our last and final leader Hayes Payne took over for the rest of Senior Design.

Each package in our timeline included a reference to the work break down structure naming scheme from Appendix D. This naming scheme allowed for simpler organization and referencing on our PERT chart, work breakdown structure, and Gantt charts. Our Gantt chart timeline lists all packages based on this naming scheme along with each Work Package name. Moreover, the dependencies and dependents were all referenced for each package, and assignment. Lastly, the Gantt chart states which team member was assigned to each package as well as the overall amount of time that the package was assumed to take the team.

Further information was broken down into subcategories for each section. These subcategories were broken up into families. A family denotes a package that needed to be broken up into sub packages for them to stay at or under 15 hours to complete. These subcategories were more granular and specify the more specific tasks for that family. For example, our RF transmitters must both transmit and receive, package, and interpret information at both the central hub and kits. Since the package of RF transmission was projected to take 50 hours, we broke it down into central HUB transmission, and kit transmission to keep packages clearer.

In our PERT diagram we can see that our first and only chokepoint comes in when we need to integrate all our components with the microcontrollers. This was a critical step simply because we need to bring in all our Work Packages we have been working on individually and mold each end, so the Work Packages talk to each other. Afterwards we chose what our milestones were going to be and then decided on our longest critical path for the project.

We divided our project into six milestones that were all evenly spaced apart. Our first milestone was November 15 and it the progress demonstration. By this milestone our team should be ready to present our prototype to show where we currently stand in the roadmap. It will also serve as a time for the lab instructors to provide us with any quick feedback. The second Milestone came at us rather quickly on December 10 and by this time our team demonstrated our working laboratory prototype showing all the functionalities of our design idea. After this we got to our third milestone on February 14, 2022. This served as another prototype review, but it concentrated more on establishing a test plan to ensure we were meeting our measurable metrics. Within a month we quickly moved on to our next milestone, and this was where we will be presenting our team's work in a professional meeting. Along with a written report, we showed certain aspects of our project such as technical tasks, features, and components of the system. For our fifth milestone our team had was set April 25 as the day we want to have our design fully integrated and working together properly. This was to step us up to use the rest of our time to focus on minor concerns and mostly address any measurable metric, before arriving to our final milestone on May 13. Our final milestone was to demonstrate a working deployable prototype in the Senior Design Showcase.

Our PERT diagram's longest critical path added up to 34 weeks. Our path starts off with most of the time being used up on the design of the power source and the RF communication system, and then afterwards leaned more towards the reports and assignments for the project. We expect this to happen because we presume that after our Laboratory prototype presentation on December 10, 2021, we will switch from being a fast-paced design process, to conducting test procedures and making test reports.

VII. RISK ASSESSMENT

A. Critical Paths

Our project can be broken into 5 distinct Critical Paths: Sensor Kit, Control Kit, Central Hub, Wireless Communication, and Power Delivery. Each Work Package was designed to contribute to one or multiple Critical Paths. These Critical Paths each had various risks associated with them. Some risks were shared between multiple paths, while some were more specific to a single path. The Sensor Kit Critical Path involved the collection of data remotely. The Sensor Kit is controlled by a microcontroller that is powered via a power bank. Some of the risks associated with the Sensor Kit were environmental damage, issues with the power bank, component failure due to use, malfunctioning code, and limited resource availability due to COVID-19. The Control Kit is responsible for controlling the water delivery and measurement of the system to the environment. Some risks for this critical path were the same as those risks for the Sensor Kit Critical Path: issues with the power bank, component failure, and environmental damage. The next Critical Path is the Central Hub. The Central Hub is responsible for data collection, water cycle calculations, a user interface, and overall system management. Risks associated with the Central Hub include component failure or availability and poor coding practices.

Wireless Communication is another Critical Path initially tied with the Central Hub, Sensor Kit, and Control Kit paths. It had developed into its own Critical Path due to the difficulties and intricacies of the Work Packages. The Central Hub, Control Kit, and Sensor Kit components communicate between each other using wireless communication protocols with their own associated risks. These included poor initial choices in components, component failure, and poor coding practices. The last Critical Path was Power Delivery. The Sensor Kit, Control Kit, and Wireless Communication Packages require steady and reliable power delivery from the power banks. Risks of the Power Delivery Critical Path include environmental damage, component failure, and the rechargeable batteries of the power bank. There were also risks that impact all the Critical Paths. These included the Mental and Physical wellbeing of the team members, mistakes due to the team members being students, development equipment failure, and issues associated with COVID-19 social distancing requirements.

B. Risks and Events

1) Environmental Damage

With our product design meant to be left outside all year round, the risk of environmental damage was one that cannot be overlooked. With temperatures reaching up as high as 115 F and dropping as below zero, the electrical components run the risk of being damaged or not being able to operate in such extreme temperatures. There is also the risk of water damage that can come from rain or moisture in the air. The components will need to be able to withstand heat, water from the rain or sprinklers and also have to deal with any pests that come with having a flora. In order to keep our electrical components safe from the items listed above, our design for our container was of a material that keeps the temperature of the inside at a desirable temperature, while still being able to vent out any heat dissipated from the components. The material is waterproof in order to ensure that the electrical components were safe.

2) Mental and Physical Well-Being

With this course and project being our last before graduation there was a lot at stake that we couldn't afford to mess up. Each individual team member had their own schedule full of classes, work, or family matters that it can be overwhelming to handle everything and put our project at the front of all of our priorities. This can cause mental fatigue and stress and it is not good for our team members to bare. It can lead to disputes and can cause problems in our team dynamics. At the same time each member must take care of themselves physically and hope that no one is dealt a bad card with regards to physical health. To prevent these risks, we must make sure that everyone is doing well mentally and feel support from their teammates while also checking up in each other's physical health for anything that can prevent a team member from completing their duties until the end of the school year.

3) Poor Choice in Components

There were many sensors and physical components that play cardinal rolls in our project. Poor component choice for our project had the potential to bring the project to a halt. As each component that is chosen was essential for the project to work properly, this has the ability to be moderately impactful towards the project's success. One poor choice in components for our project includes choosing potentially unwieldy or unreliable microcontrollers than aren't well suited for the tasks that we created. These microcontrollers were essential for proper function, control, and transmission of data to the rest of our system for proper water cycle control. Additional poor component choices included using components that may draw too much power, draining our power banks too quickly such as our solenoid valve which can draw large amounts of amperage when in use. Other poor component choices may include poor choice in data transmission hardware that is unreliable or lacks range, or poor choices in temperature, humidity, and water flow sensors that don't give accurate enough results to meet our measurable metrics.

There were potential mitigates that we used to reduce the impact these issues have on our project. For example, ordering different alternative components in advance for high-risk high impact components is a way to quickly allow the project to keep moving forward in the event of a poor component choice. Other potential mitigations included using a different approach by using a different component such as a lower power consumption ball valve instead of a solenoid valve that required a lot of power when in use. This would mitigate potential power usage constraint concerns that could inhibit our project measurable metrics for power consumption.

4) Power Distribution Failure

Anytime one deals with power distribution there needs to be a good level of care when dealing with wires and components. Our project used rechargeable batteries, and they ran the risk of potentially starting a fire. The heat that comes with recharging a battery can get very hot if left unattended. In our project, this risk was amplified a bit since our batteries will need to be recharged within a small container enclosing the heat dissipated. To combat this risk our team found a charging panel that we believe to have the best safety procedures for the amount of money we were willing to put into it. Our charging panel, the TP4056, comes with a 4.3 +- 50mV overcharge feature ensuring our batteries were charged to a safe setting, and it also includes a 1A over current protection for the output, which in this case would include the Pico microcontroller. The charging panel also comes with an over-discharge protection and trickle charge in case the batteries ever get too low in voltage.

5) *Component Failure*

Component failure had the potential to prevent our project from meeting the reliability and consistency requirements required for its proper function. Component failure can happen suddenly, and without any misuse or improper care for from the members of our team. As such, these failures can be harder to debug, or find compared to components that were working properly. For the components in our project, potential failures of our components included excess temperature, irregular or improper current and voltage levels, continual use stress, and mechanical stress. Additional concerns arise from the increased likelihood of component failure from cheap parts being used for the prototype. Our group minimized cost as much as possible in ordering parts, and some components lack good quality control. These cheap components have a higher chance of failing short term, in addition to having a shorter overall life cycle.

To reduce the possibility of component failure as much as possible, our team can ensure proper component testing and usage before placing them under load. By following standard component testing procedures in accordance with the manufacturer's datasheet, we can mitigate possible component failure by making sure we were using the components as intended. Furthermore, once our initial prototype is finished, replacing cheap, and unreliable components with more robust, expensive components can help reduce failure rates for components in our project.

6) *Student Errors*

A significant risk for the completion of this project is the fact that we were students. As students, we do not have the complete understanding of the time and monetary requirements to take on a project of our own design. Additionally, we may not understand difficulties associated with these projects. Since we were learning, we need to be able to adapt to these challenges as they arise. A component of this risk has been addressed in a separate section but needs to be addressed here: component destruction. We make mistakes, and it is important that we learn from them. These mistakes may be caught before causing damage, but also may not. To mitigate the impact of these mistakes, we make sure to work closely with Alejandro Zavala, our EEE team member, when it comes to working and applying power to circuits. Our team is very good at being available most of the time to answer any questions as they arise, and each team member has taken on the responsibility to learn as much as they can about various components to answer questions as they come up. Continuing forward, we will make sure that our team members communicate any issues or questions before taking actions.

7) *Development Equipment Failure*

Many of our team members were using equipment to test and develop our project that may not be easily or readily replaceable. Our members were largely working at home on their own personal desktop computers that contain development environments that have been specially catered towards the project. Additional data and project information was stored on these devices which would take time and effort to recover if lost. This was an issue as several of our machines we were working on were well past their life cycle and were overdue for major failures. If this were to happen, it would greatly reduce the efficiency of work and would take time to recover potential lost data, as well as set up new work environments on a different device. Other development equipment that can have a large impact would be cheap testing equipment failure. Several members in our team were using cheap testing equipment such as multimeters and soldering guns. These components failing to work properly can lead to component damage and unreliable testing conditions that can produce undesired results for our system.

There were potential mitigations to reduce the impact that development equipment failures may have on our project. If a team member has a development equipment failure for their workstation, they can contact the university to be lent a temporary replacement machine to work on until they were able to replace their own faulty machine. This will minimize the down time that they were unable to contribute towards the project. Additional precautions can be performed for data loss such as backing up all applicable and pertinent data for the project from our machines to the cloud so it can be accessed upon the event that our machine fails. Additional mitigations for failing test equipment can be mitigated by borrowing other team members' more reliable and expensive test equipment when testing or working with components that were crucial to the project.

8) Resource Availability

A risk that had expanded due to the COVID-19 pandemic is that of resource availability. Since the pandemic, the availability of microcontrollers, sensors, and other components had decreased significantly. For those parts that were still available, the shipping may add significant time delay and costs to the project. For example, when purchasing our microcontrollers, we found that many suppliers did not have stock to sell. For those suppliers that did, they were limiting the number available for orders by a customer. We were able to find one supplier that allowed the purchase of 5 Raspberry Picos in a single order. To mitigate the impact of this risk, we had been proactive in our testing of our components. Whenever we purchased a component, we ordered more than initially expected. For example, we ordered a total of 10 Raspberry Picos when we only were expecting to need 4. Apart from ordering more components than required, we tested those components quickly to determine if they will suit our needs. Multiple team members helped us address concerns about components when they appear and assist with the testing, debugging, and research of replacements if necessary.

9) Malfunctioning Code

Malfunctioning code, whether it's on our part, or because of bad libraries we found that the internet can create big problems for our project. Having code that breaks does not allow us to easily move onto our next tasks and makes our project incomplete. We have to be aware that any code used for the project has to be thoroughly tested and future proofed for versatility use. If we don't have working code, then our project is not complete and that delays any other work that needs to be completed to progress our project forward. Malfunctioning code can easily be prevented by making sure any code we write ourselves makes sense and isn't spaghetti code that gets tangled up and breaks. We will also make sure that in order to mitigate any problems we need verify that any libraries we use for our project work and that they won't break at any point of being demonstrated. Another way we will mitigate our risks is by double checking our code that we will transfer into our micro controllers.

10) Social Distancing

An additional major risk was that of socially distancing due to the COVID-19 pandemic. There were significant health concerns when it came to meeting in-person for our projects. CSUS had developed strategies to mitigate the risks associated with COVID-19. There were many ways we could have lowed our risk of exposure to COVID-19, but the "Risk Mitigation Triad"[24] mentioned 3 specific categories: Distance, Disinfect, and Face Covering.

According to the Division of Administration and Business Affairs' Risk Management website, while on campus, we needed to follow the guidelines outlined. To meet physical distancing guidelines, we were to make sure that we maintain 6 feet of space between people for all activities, follow circulation paths in areas of high foot traffic, avoid group or gathering spaces, accept new temporary maximum capacities for each room, and follow posted guidelines for circulation. To assist with the physical distancing requirements, CSUS installed plastic panels in areas that cannot meet physical distancing, adjusted seating arrangements to meet 6-foot requirements, closed or converted meeting and study rooms that do not meet social distancing standards, employed monitors to assist in queueing lines and monitoring spacing requirements, and developed new signage for individuals to follow while on campus. It was critical that we followed these guidelines for physical distancing both on and off campus to ensure our safety.

Some additional ways that CSUS had ensured our safety while on campus included distributing hand sanitizer to each employee on campus, installed hand sanitizer stations at multiple locations within each building and in some classrooms. CSUS also had protocols to sanitize commonly used areas based on usage, limiting the usage of campus space, providing PPE such as gloves and face masks if requested. On the topic of face coverings, they were to be worn by all individuals whenever indoors with others, outdoors of people were visibly present at any distance, following CDC and DPH guidelines when it came to face covering usage, and assessing if additional face covering requirements were necessary during activities. Gloves may be required if multiple people were to touch the same object without disinfection, but normally they were not needed nor recommended.

In order to reduce our risk of exposure to COVID-19, our team did the following whenever meeting in-person, both on and off campus. First, we performed COVID-19 self-assessments before meeting in person. If we found that we may have been exposed to COVID-19, we did not expect that person to meet in person, and the remainder of the team adjusted meeting expectations as well as assist in the exposed team member's interactions with the meeting such as a video call to show progress and work. It was recommended that the team member exposed get a COVID-19 test as soon as possible and report to the team leader and instructor if positive. Second, we maintained 6 feet of distance whenever possible. If this was not possible, we limited our contact between team members. Third, we always wore CDC and DPH approved face coverings while meeting. Additional masks would be provided if necessary, during in person meetings. Fourth, we reduced the number of objects we shared while meeting in person. Instead of handling the same microcontrollers and sensors, we could show our teammates how to wire them using our own in demonstration. We expected that following our four strategies when we meet, we will significantly reduce our risk of exposure to COVID-19.

C. Ranking of Risks

In determining the Risk Level associated with the risks listed previously, it was determined that Faulty Code and Poor Coding Practices is the greatest risk to our project. The next highest risk is similar, poor choices in project components. The third highest risk is that of student error. This risk encapsulates several issues; destroying components and incorrect assumptions to name two. Fourth is the damage to our system from the environment. This was the highest external risk that we need to overcome. Fifth was another external risk, the failure of components in their use. COVID-19 has had significant impacts on the world these past two years. For our project, it contributes to the risks in various ways. The first way COVID-19 contributed to our project's risks was our sixth highest risk of failure: that of the concerns for Social Distancing and the difficulties in meeting in person for development. The seventh risk was that of the failure of the power delivery system and power bank. Our eighth risk was that to our team members; their mental and physical well-being. The nineth highest risk was also from COVID-19, the availability of sensors and other resources. The lowest risk to our project listed was that of Development Equipment Failure.

D. Risk Chart

TABLE III.
RISK IMPACT CHART[25]

Probability					
0.9	**10** *0.9*	**6** *1.8*	*2.7*	**9** *3.6*	*4.5*
0.7	*0 .7*	*1.4*	*2.1*	*2.8*	*3.5*
0.5	*0 .5*	**5** *1.0*	**1** *1.5*	**3** *2.0*	*2.5*
0.3	**2** *0.3*	**4** *0.6*	*0.9*	*1.2*	*1.5*
0.1	**7** *0.1*	**8** *0.2*	*0.3*	*0.4*	*0.5*
	1	**2**	**3**	**4**	**5**

Impact

Legend

Package Reference Number

(Risk Impact)

VIII. DEPLOYABLE PROTOTYPE STATUS

A. Planned Testing

We set out to provide our device with quantifiable test results on how our prototype should be performing. These results provided the team, to an extent if we were meeting the desired design idea, we set forth to accomplish. Our team divided the workload based on the work packages that each team member had previously overseen up until this point. The format of our test plan sheet was as follows, each item would have its own unique Test ID, followed by a Test Description, Expected Results, Actual Results, which team member oversaw the testing, and finally whether that test passed or failed according to our measurable metrics.

Our test were determined based on what we considered essential for each kit in our prototype to ensure the longevity and success of our device. They consisted of both software and hardware, where the software testing will be conducted using test-benches on Micro python. As for the hardware testing, they required different types of equipment based on the test that needs to be conducted. Throughout this year each team member had their own section of the project where they were the subject matter expert of the group, this member also be in charge of providing the test procedures and eventually the test reports.

We determined that to make sure that each component was tested thoroughly, we should test them individually. We developed three to five tests for each component listed in the Work Breakdown Structure: Humidity and Temperature Sensor, Soil Moisture Sensor, Wireless Communication, Solar Panels, Power Banks, Flow Control Valve, Water Flow Sensor, Weather API, Data Logging, and the User Interface. The most critical components to be tested were the Wireless Communication, Solar Panels, Power Bank, Flow Control Valve, Weather API, and the User Interface.

1) NRF-24L01

For the wireless communication tests, we tested 3 main parameters: communication over long distances, communication through partial or full cover, and systemwide communications. In the Design Idea Contract, we stated that our system would be able to reliably communicate at a maximum range of 500 ft. The component we selected had 2 parameters that we were able to adjust to confirm this distance: the data rate and output power. Each parameter had 3 settings that we can adjust to. A concern was that as we increase the data rate and output power, it increased the power consumption of the component. We needed to find a balance between power consumption and reliable communication. The next parameter for the wireless communication was communicating through partial or full cover. A major concern of our project was waterproofing and outdoor reliability, as our project was designed to be in a yard. We needed to determine the ability or reliability of our communications through various levels of cover to determine whether they were available as materials to work with. In addition to testing the reliability while covered, we needed to determine how well wireless communication worked around corners. Finally, the last parameter needed to be tested was the communication style. The NRF components act like walkie-talkies. They could either transmit or receive data at any one time. To communicate in a network, there were two possible options. We could have either communicated to all devices within one channel, or each device could have had its own channel. Both options had their benefits and downsides; they also had their own distinct developmental processes. This was the most important test to perform with the wireless communication components.

2) AHT20 Temperature and Humidity sensor

The Temperature and Humidity component, while vital to the project, did not have software components that allowed us to modify the accuracy, reliability, or power consumption as much as the wireless components. The main factors we tested relied on how well the component performed in an outdoor environment. The first test was determining if we needed to expose part of the AHT20 to obtain accurate readings of the humidity and temperature near the sensor kit. We planned on housing the kits in weather resistant housings to protect the components and increase the life of the product. We needed to confirm that this housing would not interfere with the readings from the AHT20. If it was to interfere, we needed to determine what modifications needed to take place with the housing to make our prototype met our specifications. The next test for the AHT20 was determining if there needed to be a delay between measuring the relative humidity and temperature. Since we were taking these measurements so infrequently, there should not be an issue. We planned to take a series of measurements within a given timeframe and average out the measurements to alleviate any fluctuations in measurements. This test allowed us to determine the minimum time that the sensor kit will be active during any cycle. The final test for our AHT20 sensors was also associated with the component's exposure; what were the short- and long-term concerns when the AHT20 was outside, both directly and indirectly in the sun? We expected that there would be no serious concerns as they pertained to the component's performance in an outdoor environment, but we needed to be able to confirm this.

3) Vegetronix VH400 Soil Moisture sensor

For our soil moisture testing we measured the input and output voltage of the sensor. The output voltage needed to be tested to see that it was in accordance with the piecewise function used to determine the volumetric water content in the soil. The voltage outputs should range between 0.0 to 3.0 with a +- 2% error. A voltage reading of 0V would indicate that the soil is very dry, while a reading of 3V indicated a very saturated soil. As for the input voltage of the soil moisture sensor, it will be connected to the microcontroller which outputs 3.3V and the sensor itself has a wide operational range from 3.3V to 20V.

4) Raspberry Pi Pico Microcontroller

A critical portion of our project was ensuring that our microcontroller was able to enter and exit Dormant mode. During Dormant Mode, the microcontroller was able to cut power to all attached components and even itself, leaving only the necessary portion to be able to exit this state. This manner which will allowed our device to be able to meet our power bank's goal of up to 30 days of operation. Dormant mode allowed our amperage consumption to be lowered to an exceptionally low idle of 2.0 mA. We implemented into the code a timed interval where a team member needed to verify that they measure a drop from 80mA to 2.0mA, and then again rise from 2.0mA to 80mA.

5) Digiten G¾" Water Flow Sensor

One aspect of our project was to be able to demonstrate the water usage that is being used by our device. In order to accomplish this feature, we added a water flow sensor to the control kit. We need to be able to ensure that the water readings that will be sent to the GUI were being projected within a certain margin of error. To test our water flow sensor, our test put 5 gallons of water through the sensor across a range of angles from 30 to 60 degrees. We believed that the flow sensor should produce results that were within a 3% error.

6) Power Bank Kit

Our Power bank, being the heart of the project, was all controlled by our TP4056 charging board. It was what directed the power received from the solar panels into the batteries, while also directing the power from batteries to the microcontroller. Our testing involved measuring the voltage output from the batteries to the charging board, and then measuring the voltage from the charging board to the microcontroller. We expected the measurements to have a range from 3.3 to 4.2V with a +-0.1V, depending on the charge level of the batteries. For our test for the solar panels, we needed to test them in a sunny open area. The expected result for this test was to see an increase in the voltage potential in the batteries then from the beginning of the test. The batteries were 1.2V but the datasheet shows that they can go up to 1.4V.

7) ABS IP65 Junction Box

Our containers for each of the kits must endure the harshest test from the rest of the components. The container was expected to stay outside, where it needed to endure UV rays, summer heat, winter weather and most importantly be water resistant. For this test we needed to place the container in temperatures that will range from -32F to 100F and verify that it can withstand those temperatures without any degradation to the box. Another test we planned on conducting is a shock and vibration test once we have been able to glue the components inside the box. Our box test included dropping it from a height of 2 feet and verifying that the components inside have not moved.

8) Weather API

The testing for the weather API our team had implemented into our prototype was one that will be testing accuracy. The purpose of our weather API was to determine if in the next couple days there were any forecasted rainfalls. As we know the weather is often a quick and ever changing, so we tested if the API can update the system with any weather updates that may occur. Our test for the API involved testing its location accuracy and the accuracy of the weather based on the location. For this weather API the accuracy of the location used was an entire zip code, so we tested that it is able to find the correct zip code on its own. The other test required us to measure the weather information it is receiving and verify that information to ensure that there was dramatic variations.

B. Testing Results

For our testing schedule, we decided to maintain the assigned components and designs as was described in the Work Breakdown Structure earlier in this report. When determining the necessary tests and the procedures on how to distribute the work between team members and over the testing period, we learned that we could separate the tests into two major categories. This distinction arose during conversations on how we were to deploy our system. We knew that each remote kit would be required to withstand various weather conditions. To ensure that our system would work, we discussed the implementation of cases for each kit. This then led to the determination of what components would be affected by the implementation of these cases, and which tests were not going to be affected. For our components that were determined to be affected using a case around or remote kits, we knew that these needed to be tested later in the schedule compared to the tests that were determined that the case would not affect their performance. The components that we believed would be affected by the implementation of the cases were the AHT20 Temperature and Relative Humidity sensor and the nRF24L01 Wireless communication modules. Regarding these components, we determined that some tests would be able to be ran before the implementation and testing of the cases.

9) Test Performer: Jonah Miller

As stated previously, Jonah Miller was responsible for testing the Dormant Mode functionality of the Pi Pico Microcontrollers, soil moisture sensor measurements, and control kit component logic. It was important that aspects of these components were to be tested early on, as many elements of the prototype were dependent on their proper functionality. Jonah was selected to lead out the portion of this testing since his computer engineering knowledge allowed for understanding the code logic working in conjunction with the hardware.

Jonah's first test was to measure the volumetric water content output from the soil moisture sensor. These measurements were validated through expected values provided by the manufacturer in the form of a piecewise function. These tests were conducted from February 7th – February 14th. The analog voltage from the sensor was converted into digital voltage from a conversion factor, then modified by factors provided by the manufacturer for each interval in the piecewise function. Measurements were taken from 15-30% moisture saturation. The reason for this range is that loamy soils tend to be fully saturated at 30% and typically only go as low as 15% in the climate our prototype would be used in. The expected values at intervals every 5% saturation were as expected compared to the provided values from the manufacturer.

Next, he tested the Dormant Mode functionality of the Pi Pico's in the remote kits. The testing and validation of the Dormant Mode is essential for drastically reducing overall power consumption of the kit and meeting our metric for kit stability and power consumption. These tests were conducted from February 28th – March 7th. The procedure for validating the functionality of dormant mode started by flashing the program onto the microcontrollers. After this he measured the current consumed by the microcontroller using a multimeter. The resting power consumption of the microcontrollers was reduced from 100mW down to around 13mW. We were anticipating an ideal reduction down to 9.9mW, however these results were still expected as nothing ever reaches ideal circumstances. The 13mW consumption measured is within allowable tolerances for our design and device.

The next sent of testing involved the accuracy of the flow measurement of the hall sensor. These tests were conducted from February 21st – 28th. Typical household water pressures were measure at a maximum of around 8-10 gallons per minute. Our sensor is stated to measure a maximum flow rate capacity of 15 gallons per minute. It was found that the installation angle of the flow sensor directly affected the accuracy of the measurements. This determination led to the development of coefficients that would allow us to modify the measured values to accurately capture the flow rate. Measurements were taken at 0, 30°, 45°, 60°, and 90°. The developed coefficients for each angle that were developed were 1.08, 1.03, 0.97, 0.94, and 0.91 respectively. Using the hall sensor and the coefficients developed, we found that the component met our required metrics within our stated tolerances.

The last set of testing involved the logic of the ball valve on the control kit. The ball valve tests took place from March 7th – March 14th. The valve logic is determined solely by the code but uses physical relays to properly distribute power to the ball valve. While testing the logic, the physical connections were simultaneously validated to be working correctly. By using artificial values and setting flags for all possible conditions, Jonah was able to validate the ball valve opening and closing during all possible scenarios. The logic was reliable 100% of the time as always acted as expected. However, occasionally, the physical wiring that delivered power to and from the relays acted a bit unpredictably. To solve this concern, we implemented soldered connections to and from all our components and the microcontroller on the remote kits.

10) Test Performer: Alejandro Zavala

For Alejandro, much of his testing revolved around the measurement of voltage inputs and outputs for the Power kit. He was responsible for validating that our chosen components were supplied with enough power now that our device was fully integrated with all the necessary hardware components. Alejandro was to lead this portion of the tests since he was the one that was chosen to assemble the containers, with insight and instruction from the rest of the team, with all the hardware components for the remote kits. This also led to the ability to run the tests that were determined to require the full assembly of the kits and cases.

A set of tests ran by Alejandro were regarding the Power Bank kit and were conducted between March 18 - March 27. He was to measure the power bank's battery output voltage, power bank charging board output voltage, and finally power bank solar panel to battery voltage. For the battery output test, we were expecting a reading of 3.7V +-0.3V that would go as an input to the charging board. He conducted this test using a multimeter and found that all 3 kits an average battery output voltage at 3.81V. This voltage supply was enough to run the microcontroller and many of the components, as some required additional step-up voltages. Each battery case came with an ON/OFF switch to cut the power if needed. Alejandro was able to test all 6 cases with only one case needing to be changed since it had a faulty switch. The only other discrepancy he encountered during this test is that the battery terminal connectors inside the packs needed adjusting for some of the batteries to make contact. These concerns were addressed soon after testing and confirmed to solve the issue.

The next test concerned the measure of the voltage from the charging board to the Pico microcontroller. The microcontroller has an input range of 1.8-5.5V, and our charging board does not boost the voltage measured at the battery packs. Since our previous test had shown most battery packs output an average of 3.81V, Alejandro knew he could expect the same value to be seen as the output from the charging board. An issue that he found regarding the charging boards was with 2 of the charging boards, the measured output was not at the expected value. One of the charging boards was measuring an output of 2.4V, and another charging board wasn’t giving a proper reading, measuring values in the mV range. In both situations, Alejandro was able to exchange the charging boards for new ones determined this solved the issues found. Upon further inspection, one of the charging boards had visible damages on the negative terminal. As for the other charging boar, he was unable to find any visible damage, and could not conclude why it was outputting 2.4V instead of 3.8V. In the end he was able to obtain all 3 kits to output the correct voltage from the charging board to the microcontroller.

The final power bank test concerned the solar panel output to the battery. This test involved the validation that the charging board was limiting the power kit charging at 4.2V delivered from the solar panels. The output from the solar panels was measured at 7V to the charging board and the batteries themselves have an operational range of between 2.7V and 4.2V. Due to unfavorable weather conditions during the timeframe that Alejandro was conducting these tests, he was unable to find a day with continuous and consistent sunlight. The battery packs reached a maximum of 4.083V at the end of the day and would revert to a lower voltage the next day to about 3.991V. We believe this test was a failure because we were not able to identify if the charging board cuts off the charging at 4.2V.

Testing the ball valve performance, it was necessary to measure the time the actuator needed to fully switch between states. While the ball valve data sheet says it can achieve this in 4 seconds our measurable metric has it set to complete it in under 7 seconds. With the ball valve needing a minimum input of 9V, our voltage step up is powered directly by the batteries instead of the microcontroller. This is mainly because of the microcontroller’s inability to output the sufficient current to make our 7 second time limit. Each kit has two battery packs in parallel, each containing three 1.2V batteries in series. These batteries were NiMH and have the capability to output high quantities of current if needed. Measuring the current draw from the ball valve with a multimeter, it showed a consumption of about 60mA for just over 5 seconds. This test was repeated 20 times - 10 for opening and 10 for closing the valve. Our design using relays to control the power delivery from the battery packs, and signals from the microcontroller allow us to reliably control the movement of the ball valve in our system.

The final test performed for the kits involved testing the reliability and durability of the cases and remote kits. The shock and vibration test were designed to determine the ability of the test items to withstand impacts to the case without significant internal damage that would limit or otherwise affect our remote kits adversely. The test was run by Alejandro by dropping the container kits from a height of 2 feet onto a grassy area, the expected height and deployment area of our sensor kits. This test was conducted several times; Alejandro making slight adjustments to the remote kit cases he saw concerning issues. This adjustment involved the addition of Styrofoam to weakened area. This testing saw an overall improvement in components and wires staying in place during these tests.

A test that was initially discussed and planned, but ultimately dropped from the testing schedule of the tests that Alejandro was to conduct determined to not be necessary and too risky for the survival of the components at this stage of development. The test would allow us to determine how the container was affected by exposure to consistent outdoor temperature and weather. The test would determine two aspects of our design; how the exterior temperature affected the inside of the box and if the box was able to evenly circulate the heat dissipated by the components inside the box. This was a very important safety test that would help us determine if the components would be fine during extreme weather conditions. The reason we were not able to conduct this test was because the containers had already been integrated with all the components. Our major concern involved of placing our developed remote kits at risk with extreme temperatures. It was determined too high of a risk for us at this stage of the product development.

11) Test Performer: Hayes Payne

The testing of the Wireless communication network and AHT20 Temperature and Humidity sensor was assigned to Hayes. He was the team's expert when it came to these components, as was assigned in the Work Breakdown Structure. We decided to continue with this division of labor, as it was better to have each team member assigned to test the components they worked with during the development of our prototype. To test each component and verify that it was within our stated measurable metrics, several tests were designed, approved, and performed on a schedule to meet the given timeline without significantly impacting the other work necessary for the system and design.

For the wireless communication network, four tests were designed to ensure that our system would meet our stated metrics as well as perform as expected. They were the Angle, Cover, Channel Switching, and CRC/ACK tests. When we began testing our design as a team, we soon found that we could combine our tests. The first critical tests dealt with the messaging techniques of the system. The nRF24L01 components have built-in acknowledgement messaging system, in which it confirms when messages were received by target device. Another messaging technique of our system was to manually generate the acknowledgement messages by returning messages that were sent from a source by the destination device. Testing began with using the component's built-in service. Between two devices, this technique worked excellent. When applied to the larger network, the technique began to break down. Ultimately, we were required to modify both messaging techniques and applying both to our system. When a message is sent from a remote kit to the Central Hub, the automatic acknowledgement of the system tells the sending component to stop sending multiple copies of the same message. The remote kit will then wait for a response by the Central Hub regarding system information. This tells the remote kit that the message was received properly by the Central Hub, as the acknowledgement and the secondary message combined provides enough information to determine that the system works properly.

The next test of the wireless communication network involved covering the components in a case. RF type components need to be uncovered, and our initial components we chose had an antenna built onto the PCB. This was a concern, as our remote kits would be exposed to the elements during their normal use, and we had need for a weatherproof design. A solution to this concern was found by purchasing and using a version of the nRF24L01 component that had an external antenna, that could be fed through the component case. This component used all the same structure as the previous component, so no additional modifications were needed.

The final test of the wireless communication network was that of the range of the test. A measurable metric of our system is that it performs at a maximum range of five-hundred feet. To test this, we needed to perform the remainder of the wireless communication network tests to make sure that we had the system working at the near completed state. Once we were at this point, we found a location that had an open distance that was sufficient for our testing purposes. Using two component kits, we wrote a program that would send a message every thirty seconds and notify when the message was received or if it was lost. We increased the distance between the kits until we reached our required range. We found that when the kits were closer together, the messages were received quicker and more reliably. The further we went, the longer the messages took to receive and send. The components still worked as expected, and the messages heard were correct. This confirmed that the system met our measurable metric as expected and designed for this requirement.

The AHT20 testing involved 3 tests: Polling Rate Accuracy, Exposure, and Case testing. For the polling rate accuracy test involved determining the minimum polling rate for our sensor kits. To perform this test, we wrote a simple test bench to measure the factors of Temperature and Relative humidity in a temperature-controlled room. The system would query for the values from the component at increments of ten seconds, thirty seconds, one minute, ten minutes, and thirty minutes. Once the code was written and the test was set up, the test could be run, printing out values to a screen and file for analysis. After the test concluded, we were able to analyze the data. We determined that when we measured the values at ten and thirty second intervals, the values would incrementally increase at an average of 0.08 degrees Fahrenheit per poll. With a one-minute interval, this value dropped to 0.02 degrees Fahrenheit per poll. This value is well within our allowable tolerances, but to reduce the number of messages in our wireless network, we determined that a minimum of one minute interval would be enough resolution for our system to produce usable data.

The next test was a combination of the Exposure test and the Case testing. In our development of our system, we initially had designs on modifications to the sensor kit cases. One of the modifications regarded the AHT20 and its ability to accurately collect data in the environment that our product would be used in. We determined that it would be necessary to limit the airflow and exposure of our components to ensure that the entire system would work correctly. The accuracy testing regarding the amount of exposure as well as the effectiveness of a case would therefore be combined. Our testing involved running the sensor kit outside to determine the effect of the case. To perform this test, we had one sensor kit with no case running simultaneous to a sensor kit in a case. We ran both systems at a polling rate of five minutes. After an hour of running, we compared the two results, and found that there was no significant difference between the two measurements that would adversely affect the performance of the system.

12) Test Performer: Francisco Becerril

The final set of tests were designed and ran by Francisco Becerril. He was tasked with testing the web app running on the raspberry pi, the raspberry pi ability to run for long periods of time, and any software related to the web app, database, and file storage on the raspberry pi. These components all revolve around our raspberry pi hub where we host our web app. They were crucial since the web app is our only way of having a user interface. Francisco was the person working on these components so naturally he had the most knowledge of testing cases for the components.

For the first set of tests, Francisco needed to ensure the accuracy of the weather data retrieved by the weatherbit API was accurate. It was necessary to prove that the weather API was stating temperatures within 5 degrees of the outside temperature to not adversely affect our water cycle calculations. This data is being retrieved from local weather agencies that report the weather. The data gathered is used in the user interface for a general reference of what weather might be like in the upcoming days or hours. Between February 28th and March 1st, Francisco took multiple attempts of cross verifying the data retrieved by the API with outside temperatures using a general-purpose thermostat. Comparing the temperatures between 10 AM and 2PM, Francisco compared the temperatures every hour getting four samples for each day. We measured a 2.25-to-3-degree Fahrenheit average difference from the reported data we retrieved from the API for each day. This result was within what we expected and although the retrieved temperatures aren't exact, they were still within our tolerances for our system.

The next test completed by Francisco was to test for any data corruption when writing into files. This is a concept in computer science that is talked about extensively. When we write in our information to a file or memory location, we want to make sure another program or process is not currently at the same memory location. This can cause corruption and make our data completely unreadable. In the week of March 7th- 13th, Francisco took it upon himself to see what were the ways that our data can be corrupted. For our project we were writing into csv files to store data that we retrieve from the API and any component information we want to store. At the same time, we might be reading the data for our web app and reading mid writing can cause displaying of corrupt data. This is our biggest concern. After running two programs one reading a file while the other writes into the file, Francisco came across this problem of corruption. With the implementation of software locks, we can open the file and lock it before we start writing into it, similarly if a file is locked then we must wait before reading from that same file. Like any software we might come across more issues but for the time being we have a solution that will deter corruption.

On our Web App, we implemented the use of a virtual button that sends a signal to the Raspberry Pi. We want to make sure that the virtual button, or web app call from user to Raspberry Pi won't put too much stress on the Pi if pressed too much and make sure that it won't physically damage any component. The virtual button can only be pressed as fast as someone can click on it but at the same time someone could create a program that could send the signal equivalent to the button to the Pi causing it to have to handle and compute for each time the button is pressed. Francisco spent the week of March 14th-15th to determine how impactful this would be on the Pi and test ways to prevent it. From simply pressing the button or refreshing our web page as quickly as possible we could see some stress on the CPU of our Pi. This caused for major security concerns so the solution Francisco came up with was restricting who could try to access and send requests to the Raspberry Pi. Francisco started to implement a database on the Pi to hold important values but also to hold credentials for accounts registered to access the web app. Also preventing the web app from being able to be reached from the wide world internet we reduced the risk of the PI being targeted. This result reassured us that our web app would be safe and was not as susceptible to attacks.

Finally, Francisco also tested was to see if the Raspberry Pi Hub would run for long periods of time. The other components in our prototype were battery powered and would be running on for weeks on end. The Raspberry Pi as a product is designed to run for long amounts of time, it could possibly even outlive the SD card it uses for the Operating System. One of the main concerns is providing proper power to the Pi with a 15-Watt DC power supply. So, with the correct power adapter I ran left the Pi running for on and off working on the Web App from March 21st – 28th. With only one interruption when I accidentally turned off the system. The Raspberry Pi was able to achieve and uptime of almost 6 days without any issues. Even when it relied on Wi-Fi, if its connection was disrupted for a bit, the Pi was able to get back online. This is the most important result, we can work on the Pi remotely and if the WI-FI is available, the Pi will continue to stay online.

IX. MARKETABILITY FORECAST

A. Who is the Consumer?

With increasing limitations on water usage, there has been a demand of alternative lawn options. There is also a movement to automate as much of a household as possible. Smart outlets, thermostats, locks, sprinkler heads, and other watering systems were commonly found in home improvement stores. With the increasing availability of these options, we believe that this market will only be expanding. While demand for traditional lawns may decrease, we predict that there will be an increasing demand for watering in specific amounts for gardening foods or minimal amounts of flora. This product will have a positive impact on society. Increasing the effectiveness of watering will allow people to continue to have the lawns or gardens they wish, within certain expectations. Using Google Trends, a service provided by Google, we were able to view the popularity of searches using their engine. This allows us to determine the popularity of a product without having to do significant market research. The graph below indicates what Google was able to provide for us.

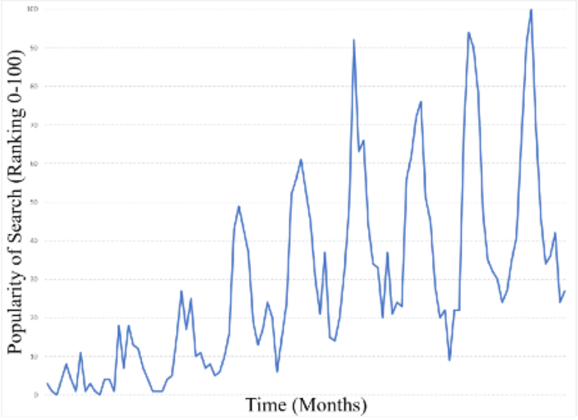


Fig. 8. Google Trends Analysis[26]

It indicates that the popularity of searching the phrase “Smart Sprinkler Controller”, which is a parallel category to our product. This shows the increasing popularity of this search, starting in January 2013 to January 2022. We can see a significant cyclical increase in popularity of this search, hitting its peak around the first week of June. We also see the popularity of this search increasing over time, which also supports our statement that our product and similar products were becoming more popular.

There were two major conventions of smart irrigation systems, ones that use pre-installed sprinkler systems and those that use faucets. Either way, a majority of these systems use timers to determine the necessary water cycles for the plants. With systems that use pre-installed sprinkler systems, they manage several different zones. Faucet based systems still generally use timers, and can water only one zone, unless it also has a splitter. Our system provides the necessary amount of water from a faucet source but uses a measure of the water in the soil at the watering location to determine if additional water is necessary. Like other systems, our system reads the weather forecast to predict future rainfall. Another aspect of our system deals with reporting water usage. Smart sprinkler systems do not have the ability to directly measure the amount of water. Our system directly measures the output of water from the faucet, allowing a homeowner to know how much water they were using when running the water cycle similar to some other faucet systems. A concern of these other faucet system is the length of time between charges or battery swaps. Our system addresses this concern with the minimal passive power usage, larger power capacity, and solar panels to recharge the power pack during the day.

B. Product Competitive Environment

Our device more closely falls under a smart sprinkler system, with an emphasis on water conservation. Our team understands that, with the combination of regular droughts and increasing populations, that devices like ours will be necessary for the residential house should they wish to have any outdoor flora requiring regular watering. While the simplest solution may be tearing out one's lawn and replacing it with drought-tolerant landscape, there will be situations where that solution is not a real possibility.

Many companies that produce similar products include in their mission statements phrases such as water conservation, overwatering, and smart watering. These companies understand that the way we approach irrigation needs to change and have increased development of Smart irrigation systems. Smart irrigation systems were those that use data collected concerning various flora to develop watering schedules that run automatically to meet specific landscape needs in order to improve outdoor water use efficiencies. For many of these companies, their products address the concern around making water sustainable while giving the user a more hands off approach to their lawns. While there were still multiple products and options that run based off a basic timer, some of the newest products allow for the user to set the watering schedule to their liking from the convenience of their phone.

C. Competitor's Products

From information gathered in multiple reports the landscape irrigation system market is growing alongside the conscious observation in water conservation needs. Most irrigation systems do not include components such as sensors to monitor real time humidity levels or soil moisture. Some of the current competitors for our prototype were Banyan Water Inc., Galcon Bakarim Agricultural Cooperative Society Ltd., GREEN ELECTRONICS LLC, Hunter Industries Inc, HydroPoint Data Systems Inc., Netafim Ltd., Rachio Inc., Rain Bird Corp., The, Toro Co., and Weathermatic. Some smart systems have an API similar to ours that monitors weather conditions. Some also manage multiple water source at once. However, those that use sensors were rarer and have a significant cost associated. One possibility for why all these companies have not moved onto using more sensors to create a "smart" irrigation system is because it might cost too much or maybe the demand isn't there however, the smart irrigation market is predicted to grow.

D. SWOT Analysis

Our prototype has a competitive advantage in that it is design to save as much water as possible compared to competitors. Using soil moisture, temperature, and humidity sensors in conjunction with a weather API our prototype fills a gap in the residential sector of smart watering systems. Most competitors have smart timing and weather forecast predictions to help time when is best to water, and for what duration. However, these systems do not measure soil moisture directly to improve water cycle duration accuracy and reduce potential overwatering.

Since water conservation continues to be an issue into the foreseeable future, the need for systems like our prototype will increase the expected longevity of our systems lifecycle since the societal problem only continues to become increasingly relevant. As such, we would expect to have an increase in demand from our target audience over time for the foreseeable future.

Under the supervision and developed senior design program by California State University – Sacramento our team has had a robust launchpad for the direction and development of our prototype. Our team is comprised of computer and electrical engineers that specialize in C and Python programming, as well as circuit analysis and verification. The skillsets of our team synergize allowing for a robust prototype design that encompasses a detail-oriented industry standard approach.

Our prototype has been designed using well documented, reliable, efficient microcontrollers. These Raspberry Pi Pico microcontrollers have allowed our prototype to utilize C and python programming languages in order to develop the ability to work with highly supported and versatile programming languages. Additionally, our central hub performs quite well as it has an excellent Wi-Fi chip with a reliable consistent connection and a fully working Linux based operating system that allows us to run a webpage, weather API, and log data with relative ease.

Our system falls short in multiple use cases. We were limited to specific environments, ranges, weather conditions, soil types, and suitable installment cases. These were a direct result of our hardware and component choices. The radio frequency modules were line of sight which limits a variety of use cases. Additionally, the battery packs we have chosen for power banks, as well as the solar panel and its mount require specific types of soil, and access to direct sunlight in order to function adequately. These design choices limit the use cases for our prototype.

Our project has been limited to less-than-optimal monetary resources solely provided by the team members. This has directly impacted design decisions and component choice such as a simple hall effect flow meter which doesn't have optimal accuracy.

The Covid-19 pandemic has limited our ability to meet in person for most of the prototype development. This has limited the teams access the school facilitates and resources as well as helpful equipment that would have helped expedite our development of the prototype design which may have a negative effect on the quality of the product.

The prototype can be improved with much more power efficient microcontrollers, using custom made tailored PCB designed specifically for our use case. A custom PCB would increase longevity and reliability of each of the sensor and control kits that determine the watering cycle by drastically reducing power consumption using it only for necessary processes and control of the system. Additionally, the prototype could benefit from higher capacity, compact power banks that were optimized for efficient power consumption.

The expandability of the prototype has a large amount of potential as it could easily be made modular. Additional radio frequency hubs could be added that handle up to six more sensor kits would allow for a large amount of expansion that could cover a much larger area. The skill set required to create custom PCBs, and additional hubs to handle a power efficient large volume system is well within the skill set of our team members.

This area expansion and efficient expanded design would allow for the potential of expanding from the residential sector to the larger and higher requirement industrial sector. The lowered power consumption, increase in reliability, among other potential improvements would allow the design to expand its target audience to other branches.

Additionally, water conservation mandates throughout California during 2022 that were expected to extent into 2023 and beyond would increase the ability for our product to be relevant and expand the number of consumers that would have reason to use it in the residential sectors as warnings, and even fines can be prevented from conserving water using our design.

If there is an over average abundance of rain that replenishes the areas of the United States that were currently in a drought for a considerable period, our project would likely be redundant or not worth using to our targeted audience. This would likely be exacerbated by current water conservation mandates being lifted, created even less requisites for people to be incentivized to use a water conserving system. An aspect that many competing products that were currently on the market excel at were reliability, and convenient, simple installment. This is a great quality that is greatly desirable to most consumers. Our design requires several kits to be installed and or mounted as opposed to a simple or singular unit that is directly installed to a spigot. Our prototype may not be as intuitive or user friendly as some on the market.

Additionally, many products on the market have an appealing and aesthetic appearance with high quality materials. Our design would require an overhaul of materials and physical presentation in order to be appealing to a typical consumer in our target audience. This would require quite a large amount of resources and design work that would potentially drastically increase the cost of design and producing the product. Since our prototype is design is dependent on solar panels to supply power to the system for extended periods of time, areas that don’t get adequate sun exposure would decrease our products reliability and deter many consumers from using it if they didn’t want to be bothered with the idea of having to worry about where to properly place it for their specific application.

X. CONCLUSION

A. Societal Problem

It is a fact that water is a scarce resource that we need to ration. Even reducing waste of water anywhere would benefit fighting against droughts. California, we suffer from wildfires, lack of grazing land for cattle, and stressed wildlife. Therefore, we were looking into solutions to increase residential water efficiency, including the 50% of water that was wasted due to evaporation. Climate change has created concerns for water management and utilization due to an increase demand of food and potable water for human consumption. In addition to the humanitarian concerns of drought, there were also environmental concerns including decreasing water quality and species biodiversity. With many inefficient methods of water management, we had developed a system that monitored and tracked a resident's outdoor water usage to decrease water waste and increase water efficiency.

B. Design Idea

To tackle this societal problem the system designed would maintain water efficiency and be both energy efficient and reliable. There were many more water conserving measures that should be taken to preserve freshwater resources, yet this design would reliably reduce residential water consumption while maintaining current landscaping practices. Using soil moisture sensors, combined with temperature, relative humidity, and a weather API, our system would reduce overwater. This was accomplished by comparing the volumetric water content of the soil, atmospheric temperature, relative humidity, and an assortment of values from the weather API to determine when and how much to water during the next watering cycle. from each of these sensors with predetermined metrics that result in efficient watering management from our system. These sensors were remote and transmit their data wirelessly to a central hub for processing.

These remote kits were essential for the system as they allowed for an expanded range for the system to cover. Additionally, the wireless aspect of the sensor mean that they must be powered by a solar powered power banks to provide consistent power to the remote sensors. These power banks contain rechargeable batteries that charge faster than they discharge from the provided solar energy. This was possible as the sensor kits that control the sensors were designed with high power efficiency by going into dormancy when not in use. Because of this, the power banks would always meet the power demand of the sensors. This was essential as it allows them to be able to provide data reliably to the central hub whenever required.

Additional control sensor kits were used to communicate the water flow of the system with the central hub. This was accomplished by using water flow sensors that give a voltage output depending on the volume of water that was flowing. This was important as it allows the system to determine the amount of water it was consuming, which was a crucial metric in reducing water waste. Moreover, the water flow would be able to be started or terminated automatically by the system using solenoid valves. This allowed for automatic control of the flow of water determined allowing for dynamic control based on the data coming from the other sensors.

The design idea our team provided would help combat the issue in our societal problem. With many more measures being taken to conserve freshwater resources, our design looked to help the residential households lower their outside water output used on their flora. The design harped three main concerns for the development of the system: reliability, longevity, and adaptability. This system would also be modular and expandable to allow for an increased number of sensing and watering locations. Since each watering location had its own distinct watering needs and may be independent from other locations, it would require its own control and sensor components. This would allow the overall system to be dynamically sized according to the needs of the user and use water according to the greatest needs.

C. Work Breakdown Structure

Once our design idea was complete, additional organization was needed to maintain the project to distribute the work between the team. To do so, we created a work breakdown structure to organize workflow into different Work Packages of equal size. In creating the work break down structure, we broke up the project into three primary sections: the Control kits, Sensor kits, and Central Hub. The individual Work Packages can be distributed between these component sections to create the entire system. Our central hub Work Packages were distributed to Francisco and categorizing them into dependencies and dependents. The Work Packages that were core to the system (e.g., sensor data collections, remote communication, remote power) were considered the highest priority since they had the most Work Packages relying or dependent on them and would also have the fewest dependencies, or Work Packages that they relied on. Our project had a total of 74 Work Packages, totaling an estimated 964 hours of work to finish the packages. The Work Packages were partitioned between the team members with an estimated 15-hour work total to complete the assigned task where each team member was taking on around 4 packages each. This allowed deadlines to be more easily met as well as more flexibility in future changes to the work breakdown structure, as necessary.

The sensor kit section contained the Work Packages that were required for data collection of soil and atmospheric information as well as the transmission to the central hub. The various sensors from the sensor kit were imperative to the data feedback loop for water management. The data feedback loop involves the collection of data to determine if watering was necessary, and if watering was necessary, it notifies the central when enough water was delivered to the area the sensor was measuring and stops the water cycle. This made the distribution of the sensors and sensor kit components to the team members a crucial task. Another Work Package for the sensor kit involved the programming of the microcontrollers to connect the data collection of the sensors, control the frequency of data collection, manage the power usage of the sensor kits, and the delivery of the data to the central hub. It was determined that the microcontrollers would be programmed in the C programming language to allow for the close manipulation of the data to produce results that we can read and use easily. This also allows us to verify that our sensors would produce quantifiable measurements to meet our measurable metrics. The sensor kit was broken down into six Work Packages and distributed to our team members based on their respective abilities.

The control kit Work Packages involved controlling the flow of water as well as the measurement of the water that passes through the system. The measurement of water flow was read via a sensor as a voltage and then converted to the gallons per minute value by the control kit's microcontroller. This required a conversion equation that was calculated on the microcontroller. This value was then sent over wireless communication to be processed by the central hub. The water flow control valve requires the programming of a state machine to control whether water was flowing or not at any given time. The control kit had six packages as well. Many of these Work Packages can be shared with the sensor kit section, so we were able to reduce the total amount of Work Packages and time.

The control and sensor kits were powered via a rechargeable solar-powered power bank. The power bank was designed to take advantage of the placement of the sensor kits in gardens and lawn that were in direct sunlight. The control kits would also be in direct sunlight but near the home. Powering our kits with a rechargeable power bank avoided the necessity of physical wiring to power and data to and from the sensor and control kits however this does introduce the requirement for the remote transmission of data. A Work Package regarding power involves the use of solar panels to charge a set power bank. This involved testing the output of the panels under various circumstances, determining the output, and regulating that output in a useful way to increase the longevity of the system. Another Work Package for power involved the use of high capacitance batteries to allow the system to meet both longevity of the remote system and meet the voltage requirements of the sensor and control kits. Since both the control and sensor kits required power to operate, these power related Work Packages were a high priority for completion as they had no dependents and many dependencies. However, since much of the testing and development of the system was done while connected to a stationary power source, it allowed an increased amount of testing to assure that the system would meet requirements of power drain.

The central hub section contained a duplicate Work Package with the control and sensor kits, but most were unique in their development and execution in the system. The duplicate Work Package included the transmission and receival of data transmission. The unique Work Packages involved the processing of the data provided by the remote kits, a user interface for the display and communication with a user, and long-term data storage. Much of the data feedback loop, sensor kit, and control kits were dependent on the transmission of data and control signals to function properly, so the data transmission Work Package took a high priority in regard to other Work Packages under the central hub. The data transmission Work Package of the control hub worked synchronously with the Work Packages of data transmission of the control and sensor kits, so it was crucial that it was completed in a timely manner. Data processing was another important Work Package as it included the processing of incoming data to be compared with set values to determine if the flora required watering and if conditions were appropriate for a watering cycle. The data was parsed into readable files in order to be extrapolated by differing programs for the data processing and user interface Work Packages in the central hub section. This was the simplest way to store and communicate data between the Work Packages for data processing, user control, and data storage within the central hub section. The data storage Work Package, while allowing the interaction between Work Packages in the central hub section, had a low priority as the data processing and user interface Work Packages could use sample data generated by a team member.

Ultimately, the decision to break the project into different sections that were then portioned into smaller Work Packages of time was crucial to meet the various deadlines and assess the progress of the project and team on a weekly basis. It also allowed the even distribution of work between each member, complementing their strengths to allow for expedited progress and increased.

D. Project Timeline

Our work breakdown structure lead into the development of our timeline where several milestones in our senior design project were created. These included group assignments and several important dates. Amongst them the biggest were the lab prototype, the midterm progress review, and the end of project documentation. The lab prototype milestone was when we would have a majority of our components producing results that aligned to the Design Idea Contract. The midterm progress review was another milestone in which we presented our current status of our project to our Project Supervisor for review and discussion. The final milestone in our project was the End of Project Documentation, at which our project and report were fully complete and met our stated requirements as listed in Section B of this report.

In order to see this through, we would need a way to keep our bearing throughout the year. The Work Breakdown Structure laid the foundation to the timeline by dividing the work into separate Work Packages and Work Package Families. We had taken the information provided in that section and applied that in two visual formats: a Gantt chart and PERT diagram. With the Gantt chart and PERT diagram our team was able to divide the 57 Work Packages and 17 Senior Design Assignments across the two semesters of Senior Design and place a designated teammate to accomplish the task. Each Work Package had an estimated start and end date. Each Work Package was averaged to take 10 to 15 hours. The Senior Design Assignments were separated differently, as all the team members were required to work on these, so the estimated time was significantly larger than other Work Packages. The Gantt Chart did not indicate any delays or bottlenecks that the project may have. The PERT Diagram allowed us to track the progress, necessary Work Packages, and expected completion dates of the project Work Packages. It also highlighted the Critical Path and showcased the Work Packages that were estimated to take the longest and potentially hold up the project. With these two visuals in mind, nothing was set in stone, and we understand that this was an iterative process that requires our team to provide honest feedback in order to get the most from them. We also input key milestones that we set to accomplish throughout the project's lifespan. With the upcoming milestone being the prototype due on November 15, we had to ensure that the team remained on track to finish the design as scheduled.

E. Risk Assessment

With each design implementation there were a set of risks which could have slowed down, set back, or created limitations for our project. Using risk assessment with reference to our critical path allowed our team to develop the most pertinent risks and mitigation strategies to minimize risk potential and impact. Environmental component damage, malfunctioning code, poor choice in components, and student errors have the highest risk impact with respect to our critical path from our PERT chart referenced in Appendix E. Our team created a risk assessment chart that weighs our risk impact based on the probability and total impact the issue would have on our project. The risk was determined in total time it would take the group to recover under the event it occurred.

Our team had assessed a total of 10 primary risks for our project. The risks include environmental damage, poor choice in components, rechargeable battery power, component failure, development equipment failure, malfunctioning code, computer engineers and student errors, mental and physical health, resource availability, and COVID-19. These risks were what were determined to have the highest risk impact for our 5 critical paths. Our critical paths were as follows, sensor kit, control kit, central hub, data transmission, and remote power. Each one of the critical paths had been all interdependent on one another to produce the continual feedback loop required to produce an efficient watering cycle and meet our measurable metrics.

Component weathering and external damage had been a specific technical risk that requires testing of protective construction materials that house and protect our vulnerable components from external weathering such as rain, sun exposure, and pests. Other assessed broad technical risks for our project include component failure and resource availability. These risks were mitigated by proper testing and practice in compliance with the component manufacturer and standard university safety practices before implementing any new design into our project. If a component were to fail, replacing that resource could be difficult in the allotted time frame dictated by our critical path.

Our team assessed the most impactful risk to our team was having malfunctioning code. Debugging can be a lengthy process and figuring where the problem lies would take many hours. Furthermore, the likelihood of it happening was very high as we continually run into the issue on bi-weekly basis. Our primary mitigation for this was allotting around 60 hours of scheduled time in addressing these specific issues, as we developed our risk assessment.

Furthermore, systemic risks that were unavoidable such as COVID-19 could impede progress for team members. Practicing social distancing in compliance with the university, federal, and state pandemic guidelines has created specific challenges and strains on our project. Mitigating COVID-19 risks included practicing social distancing, wearing masks when on campus or meeting together, and following standard CDC and university guidelines. Our team had gone out of our way to make sure that these guidelines were followed, as each member had worked on their respective project delegations remotely throughout the duration of the project.

F. Problem Statement Revision

After our risk analysis, our team had continued to expand our prototype based on updated, new pertinent information regarding our societal problem. New regulations and mandates for California to combat drought and help preserve fresh water sources were continuing to take place into 2022. Increased demand for freshwater is not only a local issue in California, but it continued to be a pressing issue throughout the United States and other parts of the world.

Our initial assessment of the societal problem was not far off as far as what we currently know. However, more recent updated data had demonstrated that the issue was only getting worse and would continue to do so into the foreseeable future. By assessing current drought data, and increased freshwater demand charts our team has gained a definitive understanding about the societal problem. As such, our team made some priority changes to our prototype that maximize water efficiency over broad usage.

As demand on freshwater resources continues to rise, and persisting drought continue to exacerbate the lack of supply, our team has shifted our priorities for our prototype. In order to maximize water use efficiency, we have narrowed the scope of our design from multi locational, to maximizing water usage at a single watering location. We had done this by shifting both our sensor kits to read the data from one watering location. This allowed us to help better estimate appropriate watering levels when a watering location has factors affecting watering a larger area, as well as taking multiple data points to get a better average soil moisture level for a given location. As a result, our prototype would be able to use a more accurate and minimal amount of water.

G. Device Test Plan

Refocusing our design based on our revised problem statement, our team determined being able to test every detail of a device might be something that might get done out in industry, for our project, because of time and inexperience we determined tests for the major components of our device. The tests were based on our Work Breakdown Structure and include Humidity and Temperature Sensor, Soil Moisture Sensor, Wireless Communication, Solar Panels, Power Banks, Flow Control Valve, Water Flow Sensor, Weather API, Data Logging, and the User Interface.

Each component had their own personalized test. For example, our wireless communication would have tests that see how well it does with switching channels between other NRFs, we would also measure the range as well as how it does with surfaces that might block the line of sight. On the other hand, something like our kit container case just needed tests that check how well it does to protect the inside from external forces.

An important portion of an engineer's job was to validate the device that they were working on. This was done by first finding the key areas that would need to undergo testing. The test procedures that our team came up with for our device fully incorporated every aspect of the device. Our test procedures included the test description followed by what our team expected each test result would produce. Based on these results our team evaluated which items meet our desired metrics and for those that were not, we need to see what can be done. A failed test procedure did not necessarily spell out a failed project, but we as a team would need to address if that portion was able to be fixed and how critical it is to our measurable metric table.

H. Market Review

The market analysis performed regarding our design has been extremely insightful. We have an increased understanding that the market for products like ours was consistently increasing and demand was expected to continue to do so. We were using technologies that have been used in industrial agriculture and applying to the residential sector; monitoring water usage for watering outdoor flora, adjusting watering cycles based on weather forecasts, and actively determining watering cycles based on data collected regarding soil moisture. Comparing our prototype to products available in the market currently, we have strengths that would allow us to excel in the market, but also weaknesses in our design that, if addressed, would increase our performance. Our main strength involves our sensors. Using active monitoring of the watering site, we can determine that we were not overwatering the flora. Inadvertently, we also can determine how well the system was applying the water. Comparing our design to competitors, we were able to adapt the length of our watering cycle based off the needs of the area. Most competitors use timers and calculations based on the type of flora to be watered, but not the actual application of that water. Some weaknesses of our design involve the limited scope of our prototype; the environment, watering area, range of the communication, and installment cases. In an actual product development, we would address these and rework our design to be more applicable. Since we were limited in our time, development schedule, and experience, we would address these weaknesses as possible, but progress with our current design.

I. Testing Results

Regardless of our limited time and experience our team developed our testing results. When designing a project there were many factors that need to be tested to ensure that everything was executing according to design specifications. From our original test procedures, that our team had written out earlier in the semester, our team was able to provide test reports for many of them. Each team member was assigned their tests based on their design expertise for the project. The tests conducted can be split into two time frames: before container assembly and after completion of container assembly. Tests surrounding the GUI didn't have any dependencies and could have been done in either phase. While others were dependent on the completion of the container and could not begin until then. These tests were mostly there to gauge how the container itself would be affecting the components. For our communication, we had to see if range and line of sight was going to suffer; there was also a matter of how the AHT20 Temperature sensor measurements were going to be affected by being inside the enclosure.

Our team originally wrote test procedures for 25 tests. From those 25, our team combined some of them since they were very similar, and were only unable to perform 1 of the tests due to an elevated risk factor. Overall our device testing results were a success and we were able to verify that our prototype was ready for the final stages. Most importantly all of our features were able to meet their measurable metric.

J. End of Project Documentation

Ultimately, team W.A.T.E.R was the name our team came up with ultimately for our prototype design. Senior design was a productive and beneficial learning experience for each of our team members. Some of the learning outcomes of senior design for our team members were skills such as leadership, time management, project integration, and effective team communication. Each team member quickly found their respective niche for our prototype design based on their interest and general skill sets. Our team had three computer engineering major and one electrical engineer. Effective research, setting appropriate goals, and adaptability were all driving forces to reach the completion of our deployable prototype. Often our team ran into obstacle or roadblocks, but we were able to always find solutions, work arounds, or alternatives to keep the project moving forward. Though our team members worked effectively and independently they were able to work together and keep the entire team informed.

Additionally, each member was very receptive to team feedback and adjusted their implementation or design accordingly. Overall, our team worked very synergistically, and we all learned and developed invaluable skills that will assist us going into industry. Our team remained highly organized, and goal oriented throughout the duration of the project. We always met deadlines well in advance to give ourselves time to increase the quality of each step of the project. The most difficult process for our team was system integration. We had to work hard continuously throughout the entire duration of senior design to create a quality design that our team was happy with. This report documents the research, work, design, mitigations, and limitations of our design in its entirety.

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GLOSSARY

- **API -** *Application Programming Interface*
    - Intermediary software that allows communication between multiple applications.
- **Climate Change**
    - The regional changes in typical climate patterns.
- **Drought**
    - An extended period of atypically low rainfall, resulting in reduced water availability.
- **EPA -** *Environmental Protection Agency*
    - A federal government executive independent U.S. agency tasked with environmental protection.
- **Flash** – *Flash memory*
- **GPIO** – *General Purpose Input/Output*
    - A general component of hardware that allows for programmable input or output connections to a system.
- **GUI** – *Graphical User Interface*
- **I2C** – *Inter-Integrated Circuit*
    - A serial protocol which connects external devices to our programmable microcontrollers.
- **Libraries**
    - A collection of files, programs, and code is used as reference by the programs code.
- **Microcontroller**
    - A small computer that contains a CPU, memory, and programmable input and output.
- **SDK** - *Software Development Kit*
    - A software set for developers of a specific platform.
- **USDA** - *United States Department of Agriculture*
    - The federal executive department is responsible for developing and executing federal laws related to farming, forestry, rural economic development, and food.
- **Water Withdrawal -** Fresh water that is taken and transported from surface water or ground water sources

Appendix A. Hardware

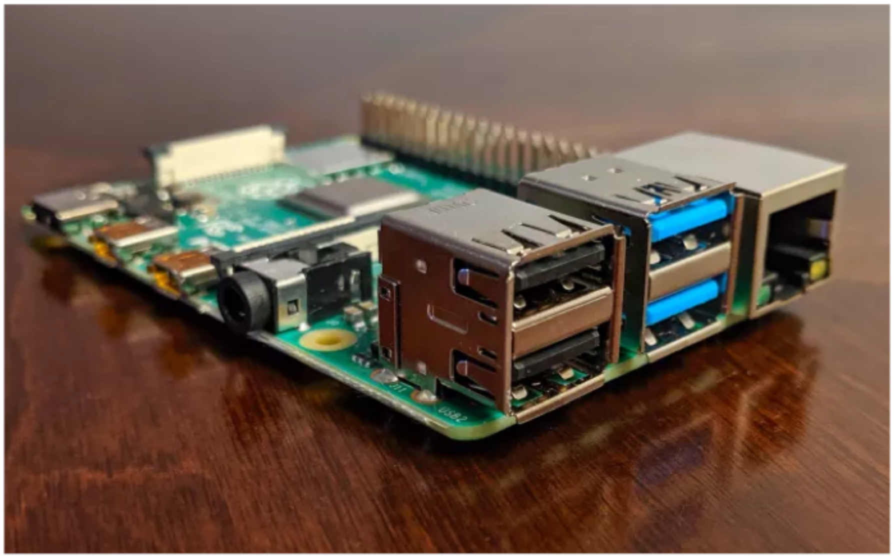


Fig. 9. Raspberry Pi 4 for our Central Hub[27]

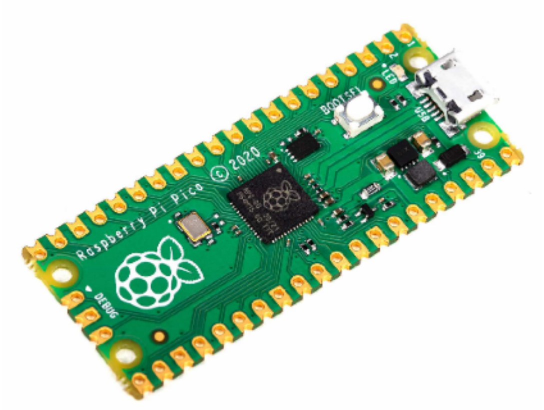


Fig. 10. Raspberry Pi Pico Microcontroller for our Sensor and Control Kits[28]

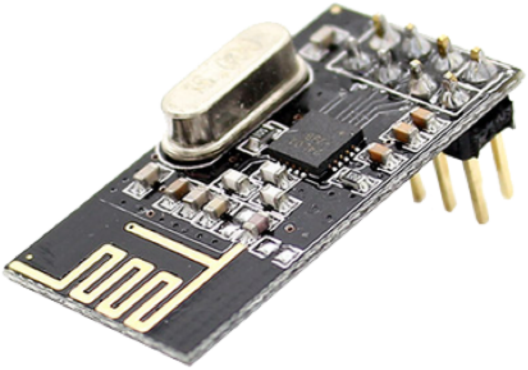


Fig. 11. nRF24L01 Wireless Communication Module[29]

Fig. 12. Vegetronix Capacitive Soil Moisture Sensor for the Sensor Kit[30]

Fig. 13. AHT20 Temperature and Relative Humidity Sensor for the Sensor Kit[31]

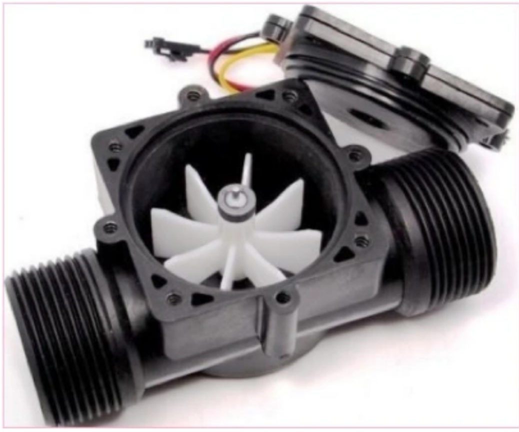


Fig. 14. Hall Effect Water Flow Sensor for the Control Kit[32]

Fig. 15. Nickle-Metal Hydride Batteries for the Battery Packs[33]

Fig. 16. 2W Solar Panel[34]

Fig. 17. Weatherproof Container for individual kits[35]

Fig. 18. Deployed Control Kit[36]

Fig. 19. Deployed Sensor Kit[37]

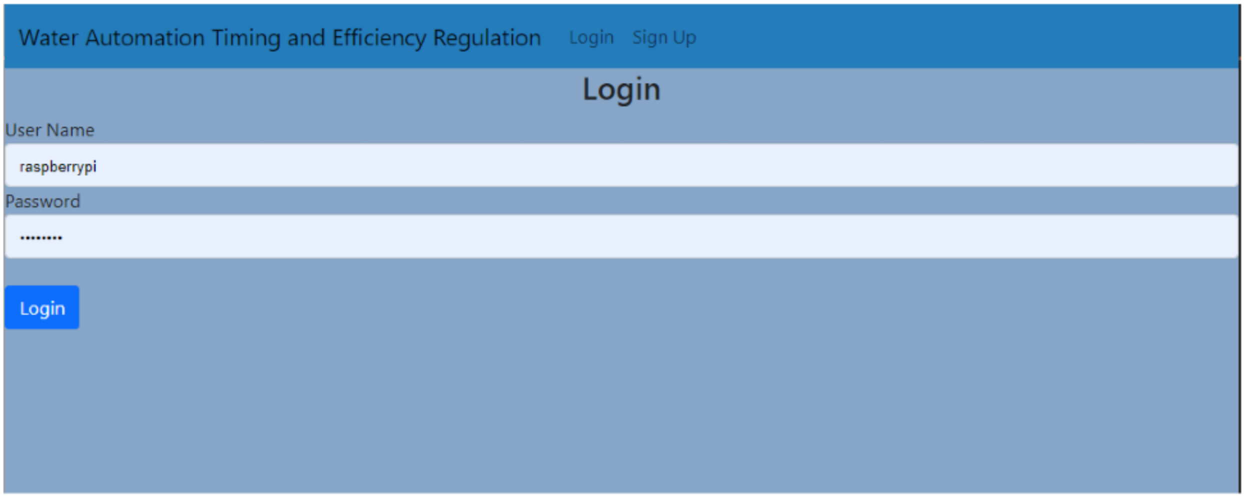
Appendix B. Software

Fig. 20. Software Used: Python Programming Language[38]

Fig. 21. Software Used: Flask[39]

Fig. 22. Software Used: SQLite[40]

Fig. 23. Software Used: WeatherBit.io[41]

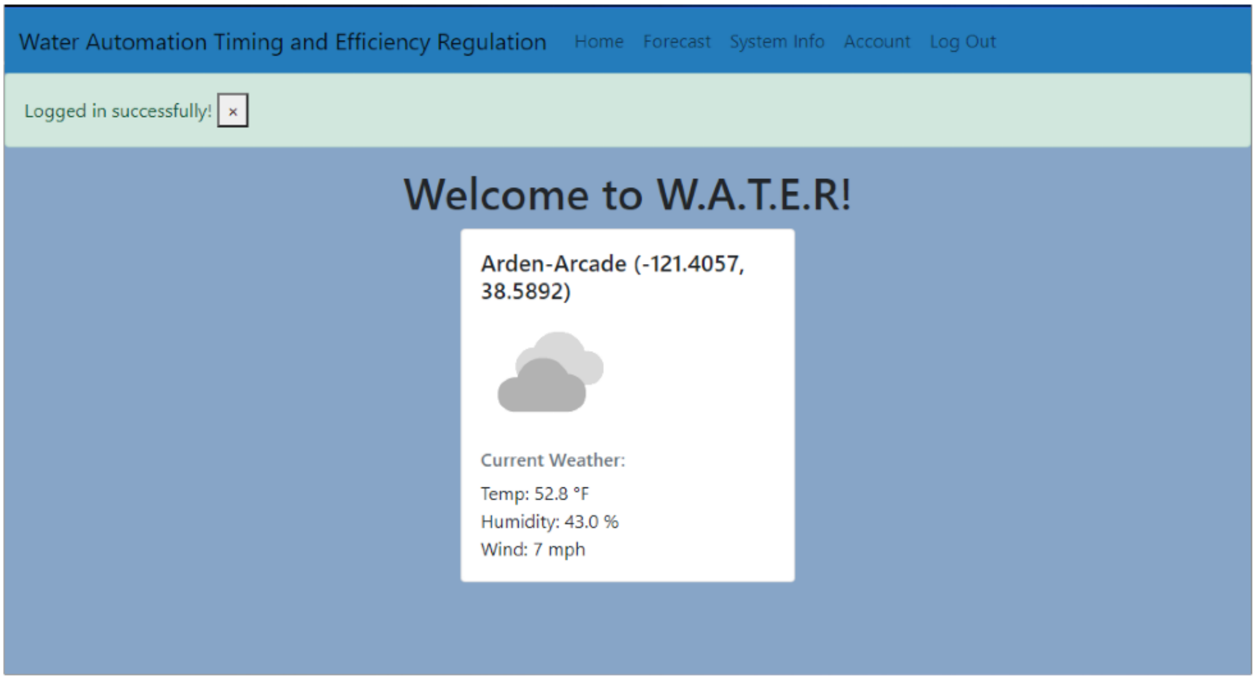


User Name: raspberrypi

Password: ••••••••

Fig. 24. Web App: Login Screen[42]

Fig. 25. Web App: Sign Up Screen[43]



Logged in successfully!

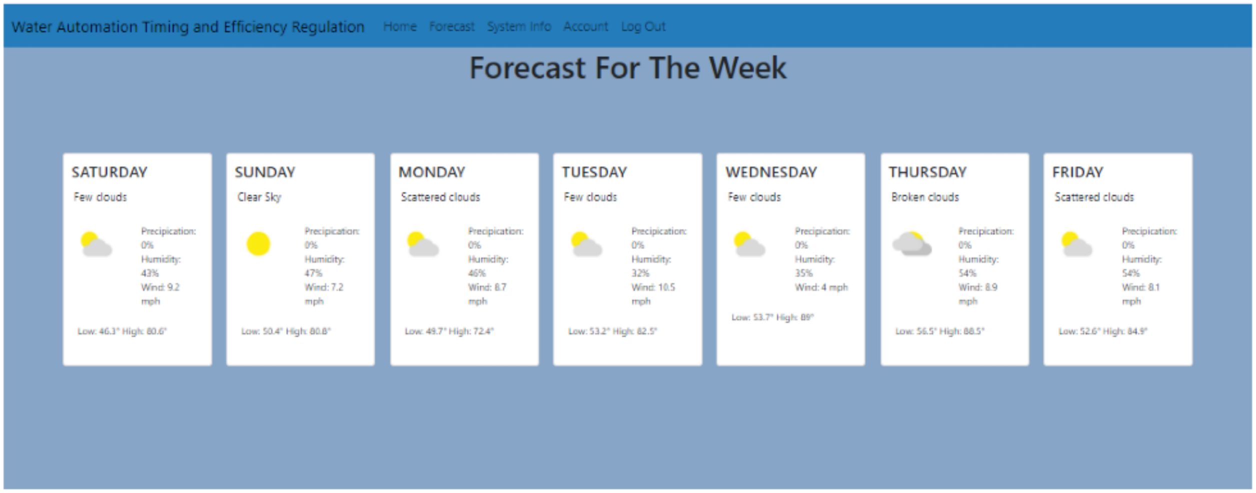
Welcome to W.A.T.E.R!

Arden-Arcade (-121.4057, 38.5892)

Current Weather:

Temp: 52.8 °F
Humidity: 43.0 %
Wind: 7 mph

Fig. 26. Web App: Home Screen[44]



Forecast For The Week

SATURDAY
Few clouds
Precipitation: 0%
Humidity: 43%
Wind: 9.2 mph
Low: 46.3° High: 80.6°

SUNDAY
Clear Sky
Precipitation: 0%
Humidity: 47%
Wind: 7.2 mph
Low: 50.4° High: 80.8°

MONDAY
Scattered clouds
Precipitation: 0%
Humidity: 46%
Wind: 8.7 mph
Low: 49.7° High: 72.4°

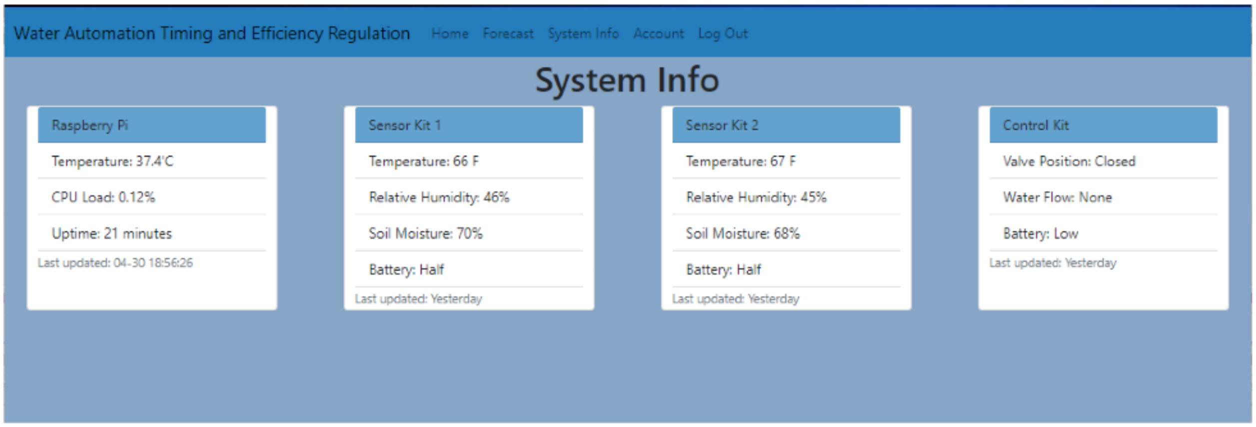
TUESDAY
Few clouds
Precipitation: 0%
Humidity: 32%
Wind: 10.5 mph
Low: 53.2° High: 82.5°

WEDNESDAY
Few clouds
Precipitation: 0%
Humidity: 35%
Wind: 4 mph
Low: 53.7° High: 89°

THURSDAY
Broken clouds
Precipitation: 0%
Humidity: 54%
Wind: 8.9 mph
Low: 56.5° High: 88.5°

FRIDAY
Scattered clouds
Precipitation: 0%
Humidity: 54%
Wind: 8.1 mph
Low: 52.6° High: 84.9°

Fig. 27. Web App: Weekly Forecast[45]



System Info

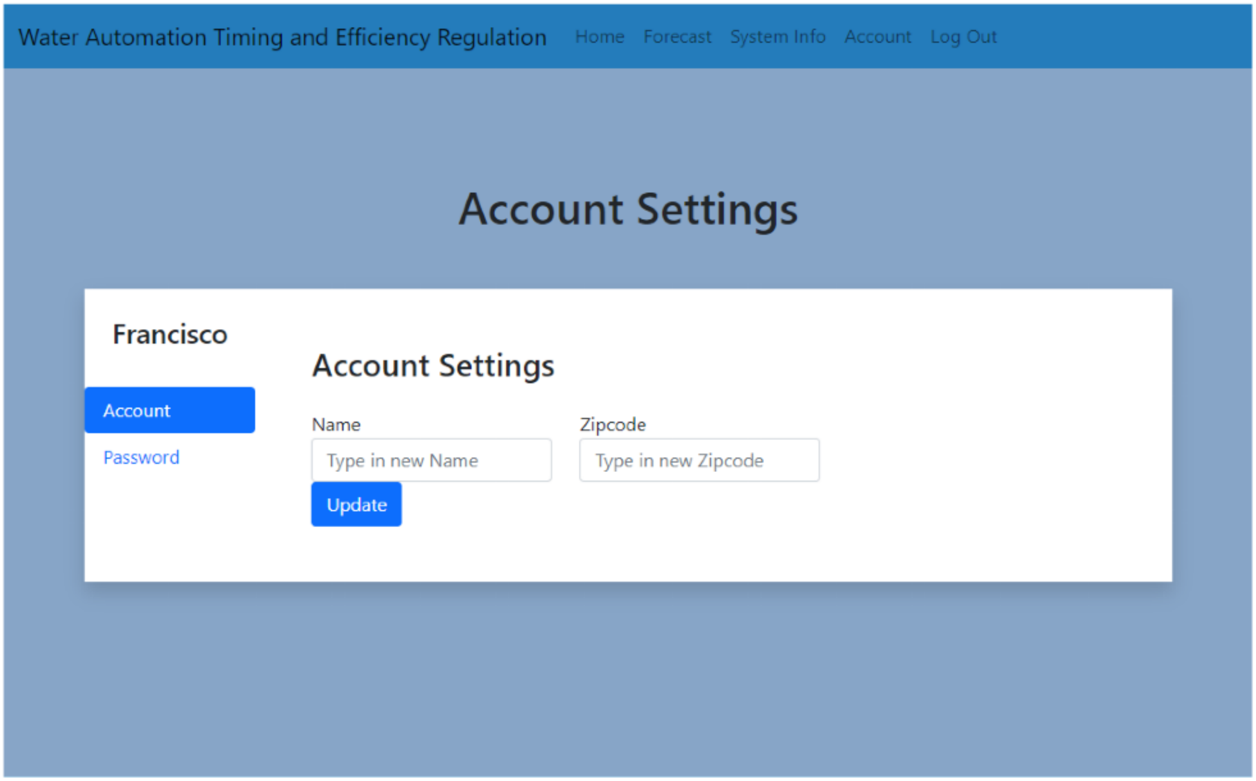
Raspberry Pi
Temperature: 37.4'C
CPU Load: 0.12%
Uptime: 21 minutes
Last updated: 04-30 18:56:26

Sensor Kit 1
Temperature: 66 F
Relative Humidity: 46%
Soil Moisture: 70%
Battery: Half
Last updated: Yesterday

Sensor Kit 2
Temperature: 67 F
Relative Humidity: 45%
Soil Moisture: 68%
Battery: Half
Last updated: Yesterday

Control Kit
Valve Position: Closed
Water Flow: None
Battery: Low
Last updated: Yesterday

Fig. 28. Web App: System Info[46]



Account Settings

Francisco

Account Settings

Name
Type in new Name

Zipcode
Type in new Zipcode

Fig. 29. Web App: Account Settings[47]

Appendix C. Mechanical Aspects

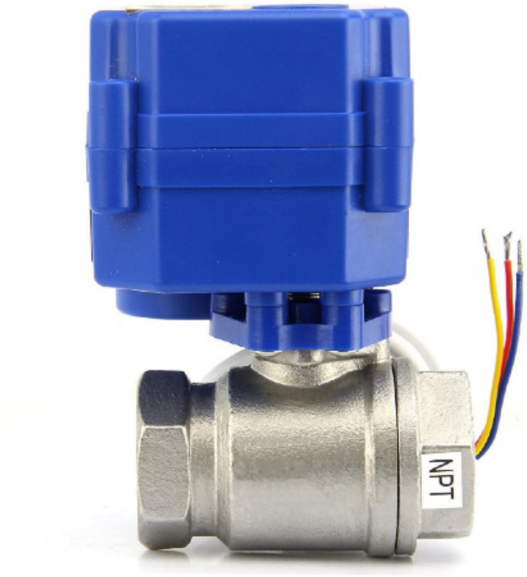


Fig. 30. Mechanically Turning Water Ball Valve[48]

Appendix D. Work Breakdown Structure

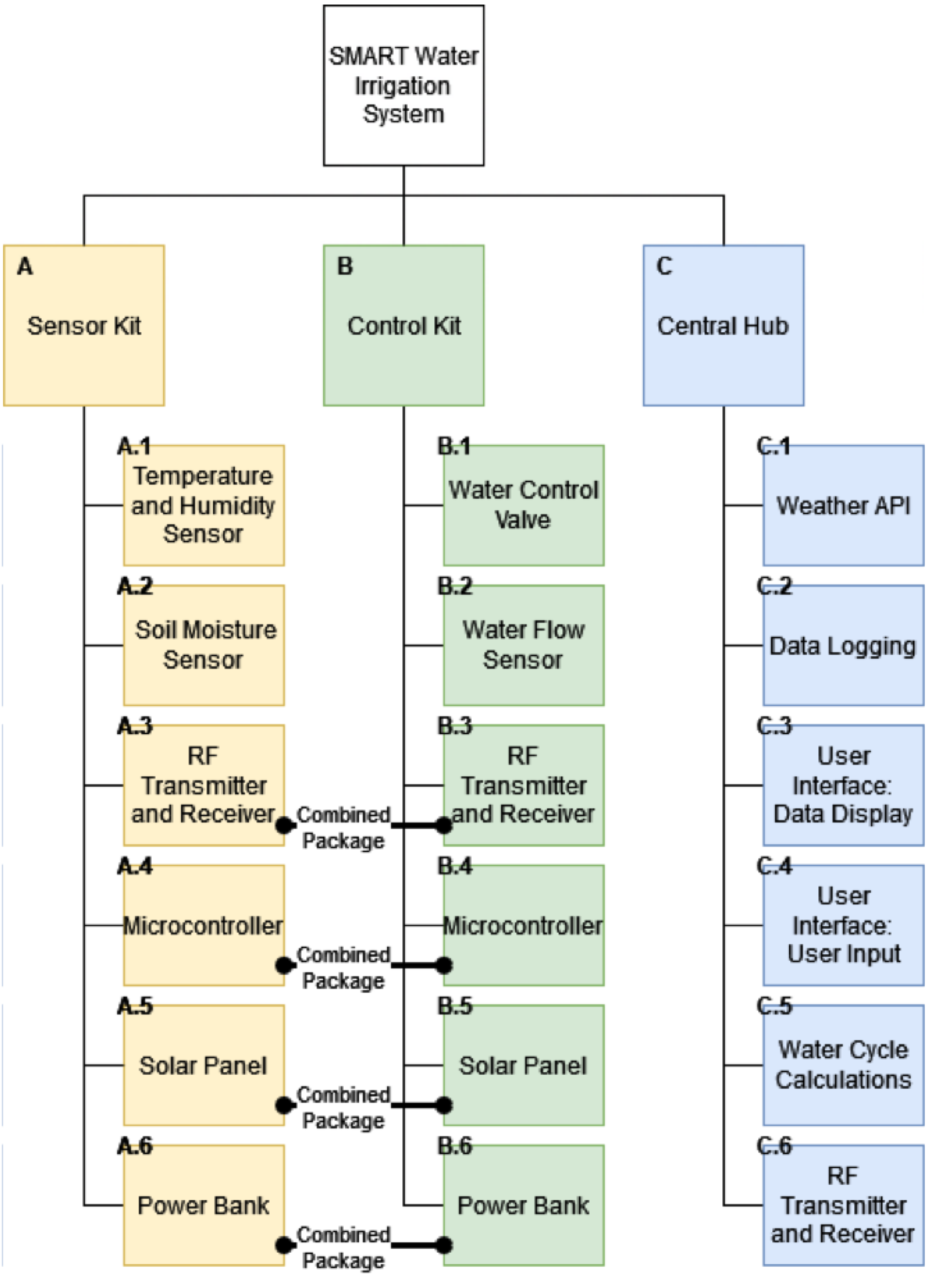


Fig. 31. A diagram depicting how the components contribute to the project in total[49]

TABLE IV.
WORK BREAKDOWN STRUCTURE ASSIGNMENTS

Work Package Family	**Work Package Reference**	**Work Package**	**Actual Start Date**	**Actual End Date**	**Actual Hours**	**Assigned Student**
Humidity and Temperature Sensor	A.1	Humidity and Temperature Sensor	10/18/21	11/6/21	20	Hayes Payne
Humidity and Temperature Sensor	A.1.1	Data Collection from Sensor	10/18/21	11/6/21	10	Hayes Payne
Humidity and Temperature Sensor	A.1.2	Power Consumption of Sensor	10/18/21	11/6/21	10	Alex Zavala
Soil Moisture Sensor	A.2.1	Data Collection from Sensor	10/18/21	11/1/21	15	Jonah Miller
Soil Moisture Sensor	A.2.2	Power delivery to sensor	10/18/21	11/1/21	5	Jonah Miller
RF Communication on Pico	A.3.1, B.3.1	RF Transmission coding	10/26/21	11/8/21	20	Hayes Payne
RF Communication on Pico	A.3.2, B.3.2	RF Receival coding	10/26/21	11/8/21	15	Hayes Payne
RF Communication on Pico	A.3.3, B.3.3	Testing RF communication	10/26/21	11/10/21	20	Hayes Payne
Solar Panels	A.5, B.5	Solar Panels	10/18/21	10/25/21	10	Alex Zavala
Power Bank	A.6.1, B.6.1	Power Bank Charging	10/18/21	10/25/21	13	Alex Zavala
Power Bank	A.6.2, B.6.2	Power Delivery to system	10/25/21	11/19/21	13	Alex Zavala
Pico Microcontroller	A4.1, B.4.1	Dormant Mode Programming	11/1/21	11/18/21	30	Hayes Payne & Jonah Miller
Pico Microcontroller	A4.2, B.4.2	SDK set up and debugging	11/1/21	11/10/21	20	Hayes Payne & Jonah Miller
Flow Control Valve	B.1	Flow Control Valve	10/18/21	11/19/21	20	Jonah Miller & Alex Zavala
Water Flow Sensor	B.2	Water Flow Sensor	10/25/21	11/8/21	15	Jonah Miller

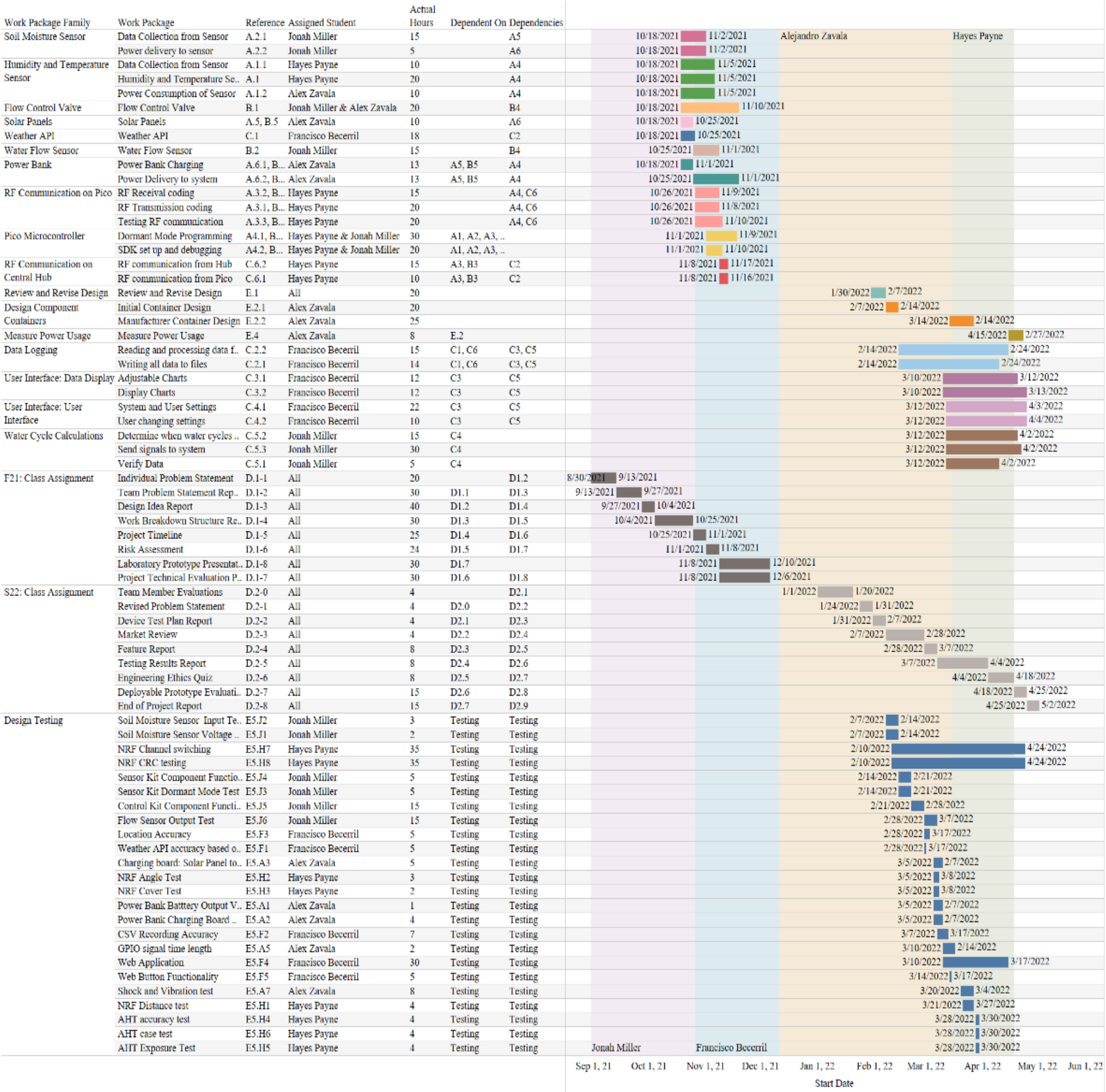
Weather API	C.1	Weather API	10/18/21	10/26/21	18	Francisco Becerril
Data Logging	C.2.1	Writing all data to files	2/14/22	4/10/22	14	Francisco Becerril
Data Logging	C.2.2	Reading and processing data for calculations	2/14/22	4/15/22	15	Francisco Becerril
User Interface: Data Display	C.3.1	Adjustable Charts	3/10/22	4/20/22	12	Francisco Becerril
User Interface: Data Display	C.3.2	Display Charts	3/10/22	4/25/22	12	Francisco Becerril
User Interface: User Interface	C.4.1	System and User Settings	3/12/22	4/25/22	22	Francisco Becerril
User Interface: User Interface	C.4.2	User changing settings	3/12/22	4/25/22	10	Francisco Becerril
Water Cycle Calculations	C.5.1	Verify Data	3/12/22	4/10/22	5	Jonah Miller
Water Cycle Calculations	C.5.2	Determine when water cycles were needed	3/12/22	4/20/22	15	Jonah Miller
Water Cycle Calculations	C.5.3	Send signals to system	3/12/22	4/22/22	30	Jonah Miller
RF Communication on Central Hub	C.6.1	RF communication from Pico	11/8/21	11/13/21	10	Hayes Payne
RF Communication on Central Hub	C.6.2	RF communication from Hub	11/8/21	11/13/21	15	Hayes Payne
F21: Class Assignment	D.1-1	Individual Problem Statement	8/30/21	9/13/21	20	All
F21: Class Assignment	D.1-2	Team Problem Statement Report	9/13/21	9/27/21	30	All
F21: Class Assignment	D.1-3	Design Idea Report	9/27/21	10/4/21	40	All
F21: Class Assignment	D.1-4	Work Breakdown Structure Report	10/4/21	10/25/21	30	All
F21: Class Assignment	D.1-5	Project Timeline	10/25/21	11/1/21	25	All
F21: Class Assignment	D.1-6	Risk Assessment	11/1/21	11/8/21	24	All
F21: Class Assignment	D.1-7	Project Technical	11/8/21	12/6/21	30	All

		Evaluation Presentation				
F21: Class Assignment	D.1-8	Laboratory Prototype Presentation	11/8/21	12/6/21	30	All
S22: Class Assignment	D.2-0	Team Member Evaluations	1/1/22	1/20/22	4	All
S22: Class Assignment	D.2-1	Revised Problem Statement	1/24/22	1/31/22	4	All
S22: Class Assignment	D.2-2	Device Test Plan Report	1/31/22	2/7/22	4	All
S22: Class Assignment	D.2-3	Market Review	2/7/22	2/28/22	4	All
S22: Class Assignment	D.2-4	Feature Report	2/28/22	3/7/22	8	All
S22: Class Assignment	D.2-5	Testing Results Report	3/7/22	4/4/22	8	All
S22: Class Assignment	D.2-6	Engineering Ethics Quiz	4/4/22	4/18/22	8	All
S22: Class Assignment	D.2-7	Deployable Prototype Evaluation	4/18/22	4/25/22	15	All
S22: Class Assignment	D.2-8	End of Project Report	4/25/22	5/2/22	15	All
Review and Revise Design	E.1	Review and Revise Design	1/30/22	2/7/22	20	All
Design Component Containers	E.2.1	Initial Container Design	2/7/22	2/14/22	20	Alex Zavala
Design Component Containers	E.2.2	Manufacturer Container Design	3/14/22	3/27/22	25	Alex Zavala
Measure Heat Production	E.3	Measure Heat Production	n/a	n/a	0	Alex Zavala
Measure Power Usage	E.4	Measure Power Usage	4/15/22	4/23/22	8	Alex Zavala
Design Testing	E5.J1	Soil Moisture Sensor Voltage Output Test	2/7/22	2/14/22	2	Jonah Miller
Design Testing	E5.J2	Soil Moisture Sensor Input Test	2/7/22	2/14/22	3	Jonah Miller
Design Testing	E5.J3	Sensor Kit Dormant Mode Test	2/14/22	2/21/22	5	Jonah Miller
Design Testing	E5.J4	Sensor Kit Component	2/14/22	2/21/22	5	Jonah Miller

		Functionality Test				
Design Testing	E5.J5	Control Kit Component Functionality Test	2/21/22	2/28/22	15	Jonah Miller
Design Testing	E5.J6	Flow Sensor Output Test	2/28/22	3/7/22	15	Jonah Miller
Design Testing	E5.H1	NRF Distance test	3/21/22	3/27/22	4	Hayes Payne
Design Testing	E5.H2	NRF Angle Test	3/5/22	3/8/22	3	Hayes Payne
Design Testing	E5.H3	NRF Cover Test	3/5/22	3/8/22	2	Hayes Payne
Design Testing	E5.H4	AHT accuracy test	3/28/22	3/30/22	4	Hayes Payne
Design Testing	E5.H5	AHT Exposure Test	3/28/22	3/30/22	4	Hayes Payne
Design Testing	E5.H6	AHT case test	3/28/22	3/30/22	4	Hayes Payne
Design Testing	E5.H7	NRF Channel switching	2/10/22	4/24/22	20	Hayes Payne
Design Testing	E5.H8	NRF CRC testing	2/10/22	4/24/22	20	Hayes Payne
Design Testing	E5.A1	Power Bank Batttery Output Voltage Test	3/5/22	3/10/22	1	Alex Zavala
Design Testing	E5.A2	Power Bank Charging Board Output Voltage Test	3/5/22	3/10/22	4	Alex Zavala
Design Testing	E5.A3	Charging board: Solar Panel to battery	3/5/22	3/10/22	5	Alex Zavala
Design Testing	E5.A5	GPIO signal time length	3/10/22	3/17/22	2	Alex Zavala
Design Testing	E5.A6	Kit Container temperature test	n/a	n/a	0	Alex Zavala
Design Testing	E5.A7	Shock and Vibration test	3/20/22	3/27/22	8	Alex Zavala
Design Testing	E5.F1	Weather API accuracy based on location	2/28/22	3/1/22	5	Francisco Becerril
Design Testing	E5.F2	CSV Recording Accuracy	3/7/22	3/13/22	7	Francisco Becerril

Design Testing	E5.F3	Location Accuracy	2/28/22	3/3/22	5	Francisco Becerril
Design Testing	E5.F4	Web Application	3/10/22	4/15/22	30	Francisco Becerril
Design Testing	E5.F5	Web Button Functionality	3/14/22	3/15/22	5	Francisco Becerril

Appendix E. Timeline Charts and PERT Diagrams



Work Package Family	Work Package	Reference	Assigned Student	Actual Hours	Dependent On	Dependencies		
Soil Moisture Sensor	Data Collection from Sensor	A.2.1	Jonah Miller	15		A5	10/18/2021	11/2/2021
	Power delivery to sensor	A.2.2	Jonah Miller	5		A6	10/18/2021	11/2/2021
Humidity and Temperature Sensor	Data Collection from Sensor	A.1.1	Hayes Payne	10		A4	10/18/2021	11/5/2021
	Humidity and Temperature Se..	A.1	Hayes Payne	20		A4	10/18/2021	11/5/2021
	Power Consumption of Sensor	A.1.2	Alex Zavala	10		A4	10/18/2021	11/5/2021
Flow Control Valve	Flow Control Valve	B.1	Jonah Miller & Alex Zavala	20		B4	10/18/2021	11/10/2021
Solar Panels	Solar Panels	A.5, B.5	Alex Zavala	10		A6	10/18/2021	10/25/2021
Weather API	Weather API	C.1	Francisco Becerril	18		C2	10/18/2021	10/25/2021
Water Flow Sensor	Water Flow Sensor	B.2	Jonah Miller	15		B4	10/25/2021	11/1/2021
Power Bank	Power Bank Charging	A.6.1, B...	Alex Zavala	13	A5, B5	A4	10/18/2021	11/1/2021
	Power Delivery to system	A.6.2, B...	Alex Zavala	13	A5, B5	A4	10/25/2021	11/1/2021
RF Communication on Pico	RF Receival coding	A.3.2, B...	Hayes Payne	15		A4, C6	10/26/2021	11/9/2021
	RF Transmission coding	A.3.1, B...	Hayes Payne	20		A4, C6	10/26/2021	11/8/2021
	Testing RF communication	A.3.3, B...	Hayes Payne	20		A4, C6	10/26/2021	11/10/2021
Pico Microcontroller	Dormant Mode Programming	A4.1, B...	Hayes Payne & Jonah Miller	30	A1, A2, A3, ..		11/1/2021	11/9/2021
	SDK set up and debugging	A4.2, B...	Hayes Payne & Jonah Miller	20	A1, A2, A3, ..		11/1/2021	11/10/2021
RF Communication on Central Hub	RF communication from Hub	C.6.2	Hayes Payne	15	A3, B3	C2	11/8/2021	11/17/2021
	RF communication from Pico	C.6.1	Hayes Payne	10	A3, B3	C2	11/8/2021	11/16/2021
Review and Revise Design	Review and Revise Design	E.1	All	20			1/30/2022	2/7/2022
Design Component Containers	Initial Container Design	E.2.1	Alex Zavala	20			2/7/2022	2/14/2022
	Manufacturer Container Design	E.2.2	Alex Zavala	25			3/14/2022	2/14/2022
Measure Power Usage	Measure Power Usage	E.4	Alex Zavala	8	E.2		4/15/2022	2/27/2022
Data Logging	Reading and processing data f..	C.2.2	Francisco Becerril	15	C1, C6	C3, C5	2/14/2022	2/24/2022
	Writing all data to files	C.2.1	Francisco Becerril	14	C1, C6	C3, C5	2/14/2022	2/24/2022
User Interface: Data Display	Adjustable Charts	C.3.1	Francisco Becerril	12	C3	C5	3/10/2022	3/12/2022
	Display Charts	C.3.2	Francisco Becerril	12	C3	C5	3/10/2022	3/13/2022
User Interface: User Interface	System and User Settings	C.4.1	Francisco Becerril	22	C3	C5	3/12/2022	4/3/2022
	User changing settings	C.4.2	Francisco Becerril	10	C3	C5	3/12/2022	4/4/2022
Water Cycle Calculations	Determine when water cycles ..	C.5.2	Jonah Miller	15	C4		3/12/2022	4/2/2022
	Send signals to system	C.5.3	Jonah Miller	30	C4		3/12/2022	4/2/2022
	Verify Data	C.5.1	Jonah Miller	5	C4		3/12/2022	4/2/2022
F21: Class Assignment	Individual Problem Statement	D.1-1	All	20		D1.2	8/30/2021	9/13/2021
	Team Problem Statement Rep..	D.1-2	All	30	D1.1	D1.3	9/13/2021	9/27/2021
	Design Idea Report	D.1-3	All	40	D1.2	D1.4	9/27/2021	10/4/2021
	Work Breakdown Structure Re..	D.1-4	All	30	D1.3	D1.5	10/4/2021	10/25/2021
	Project Timeline	D.1-5	All	25	D1.4	D1.6	10/25/2021	11/1/2021
	Risk Assessment	D.1-6	All	24	D1.5	D1.7	11/1/2021	11/8/2021
	Laboratory Prototype Presentat..	D.1-8	All	30	D1.7		11/8/2021	12/10/2021
	Project Technical Evaluation P..	D.1-7	All	30	D1.6	D1.8	11/8/2021	12/6/2021
S22: Class Assignment	Team Member Evaluations	D.2-0	All	4		D2.1	1/1/2022	1/20/2022
	Revised Problem Statement	D.2-1	All	4	D2.0	D2.2	1/24/2022	1/31/2022
	Device Test Plan Report	D.2-2	All	4	D2.1	D2.3	1/31/2022	2/7/2022
	Market Review	D.2-3	All	4	D2.2	D2.4	2/7/2022	2/28/2022
	Feature Report	D.2-4	All	8	D2.3	D2.5	2/28/2022	3/7/2022
	Testing Results Report	D.2-5	All	8	D2.4	D2.6	3/7/2022	4/4/2022
	Engineering Ethics Quiz	D.2-6	All	8	D2.5	D2.7	4/4/2022	4/18/2022
	Deployable Prototype Evaluati..	D.2-7	All	15	D2.6	D2.8	4/18/2022	4/25/2022
	End of Project Report	D.2-8	All	15	D2.7	D2.9	4/25/2022	5/2/2022
Design Testing	Soil Moisture Sensor Input Te..	E5.J2	Jonah Miller	3	Testing	Testing	2/7/2022	2/14/2022
	Soil Moisture Sensor Voltage ..	E5.J1	Jonah Miller	2	Testing	Testing	2/7/2022	2/14/2022
	NRF Channel switching	E5.H7	Hayes Payne	35	Testing	Testing	2/10/2022	4/24/2022
	NRF CRC testing	E5.H8	Hayes Payne	35	Testing	Testing	2/10/2022	4/24/2022
	Sensor Kit Component Functio..	E5.J4	Jonah Miller	5	Testing	Testing	2/14/2022	2/21/2022
	Sensor Kit Dormant Mode Test	E5.J3	Jonah Miller	5	Testing	Testing	2/14/2022	2/21/2022
	Control Kit Component Functi..	E5.J5	Jonah Miller	15	Testing	Testing	2/21/2022	2/28/2022
	Flow Sensor Output Test	E5.J6	Jonah Miller	15	Testing	Testing	2/28/2022	3/7/2022
	Location Accuracy	E5.F3	Francisco Becerril	5	Testing	Testing	2/28/2022	3/17/2022
	Weather API accuracy based o..	E5.F1	Francisco Becerril	5	Testing	Testing	2/28/2022	3/17/2022
	Charging board: Solar Panel to..	E5.A3	Alex Zavala	5	Testing	Testing	3/5/2022	2/7/2022
	NRF Angle Test	E5.H2	Hayes Payne	3	Testing	Testing	3/5/2022	3/8/2022
	NRF Cover Test	E5.H3	Hayes Payne	2	Testing	Testing	3/5/2022	3/8/2022
	Power Bank Battery Output V..	E5.A1	Alex Zavala	1	Testing	Testing	3/5/2022	2/7/2022
	Power Bank Charging Board ..	E5.A2	Alex Zavala	4	Testing	Testing	3/5/2022	2/7/2022
	CSV Recording Accuracy	E5.F2	Francisco Becerril	7	Testing	Testing	3/7/2022	3/17/2022
	GPIO signal time length	E5.A5	Alex Zavala	2	Testing	Testing	3/10/2022	2/14/2022
	Web Application	E5.F4	Francisco Becerril	30	Testing	Testing	3/10/2022	3/17/2022
	Web Button Functionality	E5.F5	Francisco Becerril	5	Testing	Testing	3/14/2022	3/17/2022
	Shock and Vibration test	E5.A7	Alex Zavala	8	Testing	Testing	3/20/2022	3/4/2022
	NRF Distance test	E5.H1	Hayes Payne	4	Testing	Testing	3/21/2022	3/27/2022
	AHT accuracy test	E5.H4	Hayes Payne	4	Testing	Testing	3/28/2022	3/30/2022
	AHT case test	E5.H6	Hayes Payne	4	Testing	Testing	3/28/2022	3/30/2022
	AHT Exposure Test	E5.H5	Hayes Payne	4	Testing	Testing	3/28/2022	3/30/2022

Fig. 32. Gantt Chart Timeline [50]

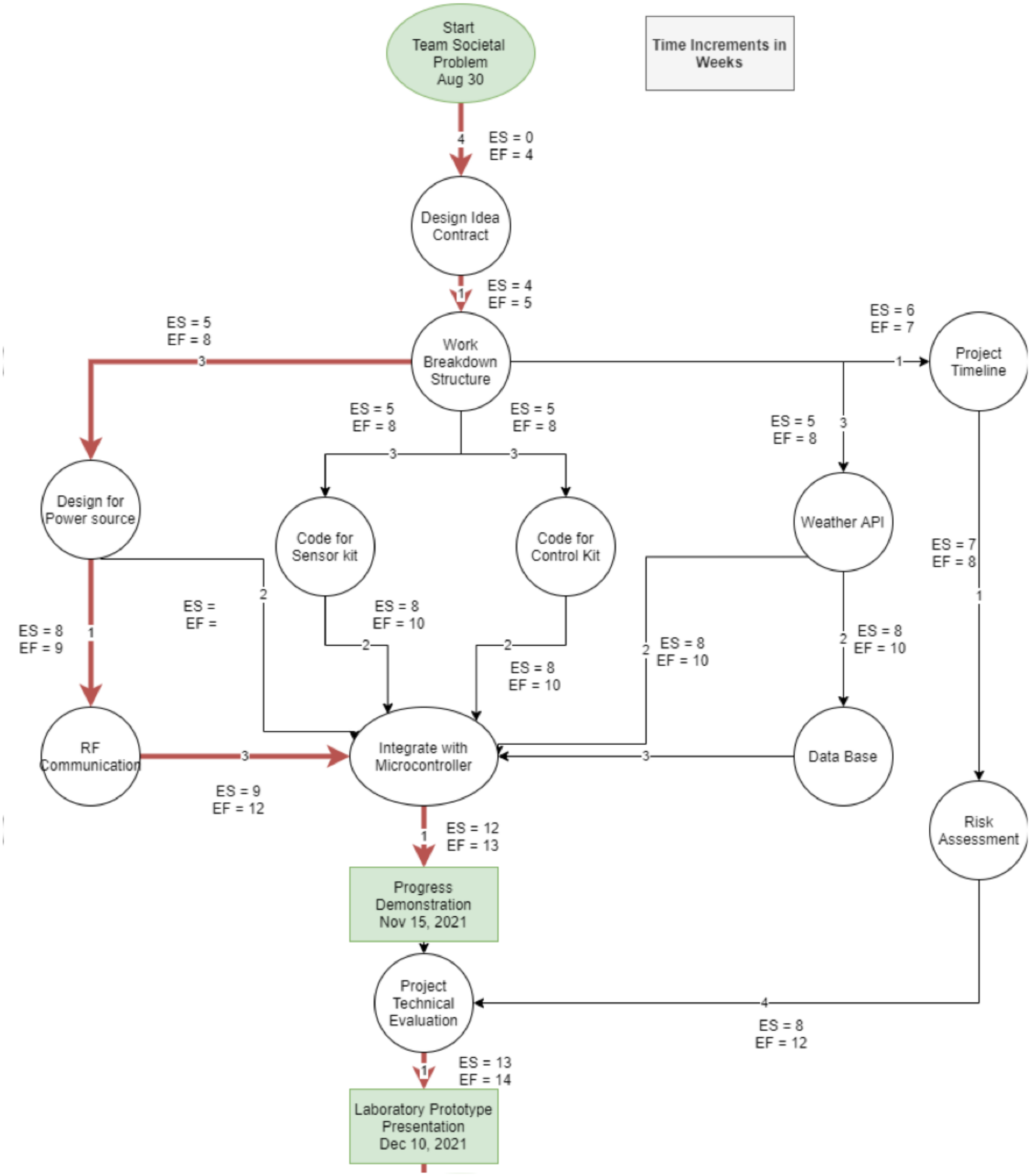


Fig. 33. PERT Diagram part 1 [51]

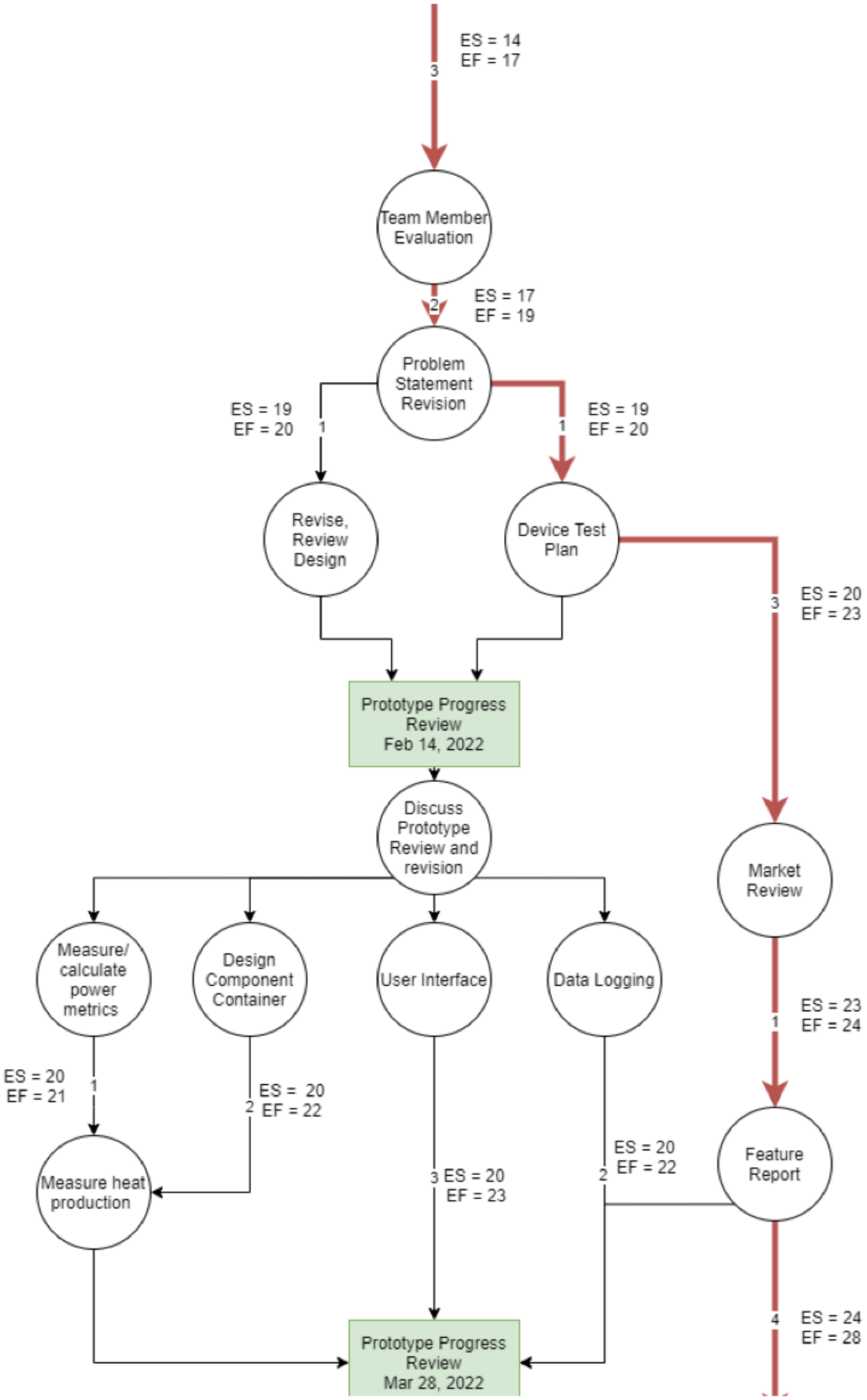


Fig. 34. PERT Diagram part 2 [52]

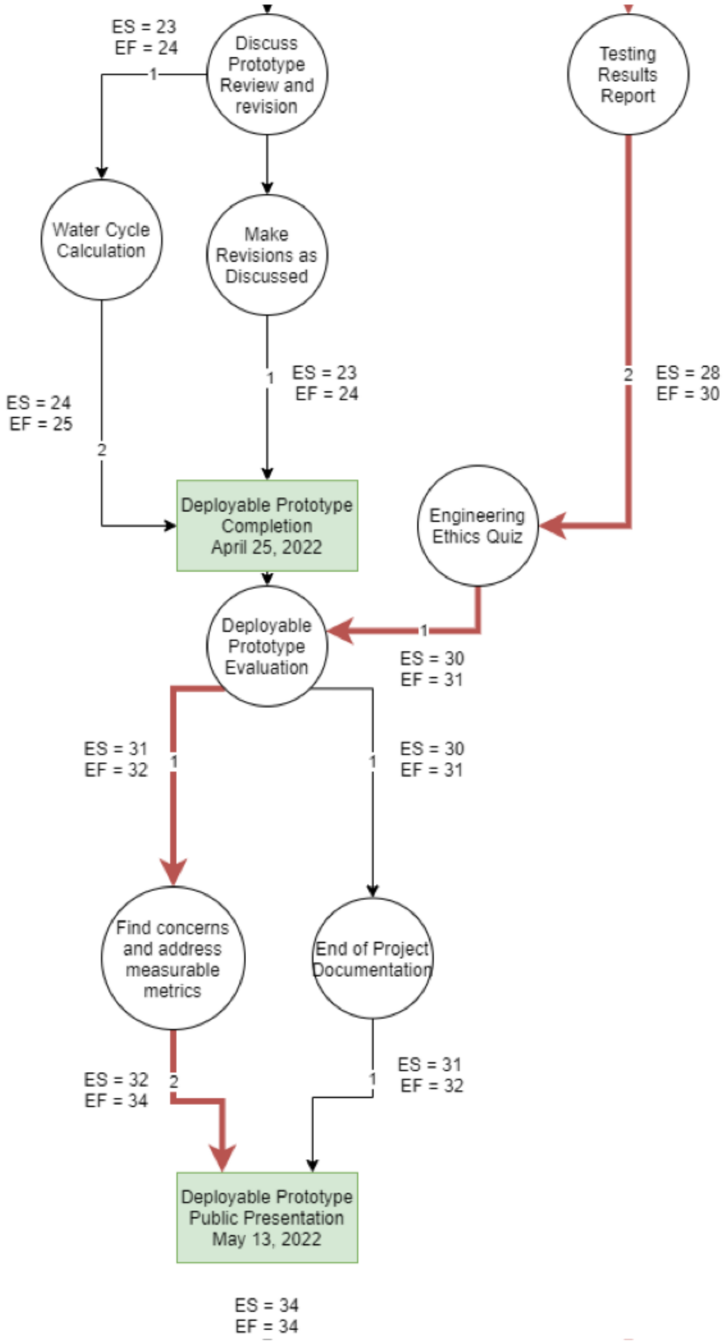


Fig. 35. PERT Diagram part 3 [53]

Appendix F. Resumes

Hayes Payne

Education

Bachelor of Science, Computer Engineering — Expected Spring 2022
California State University, Sacramento — GPA 3.52

Associate of Science, Mathematics — Awarded December 2018
Folsom Lake College — G.P.A 3.11

Projects

Project W.A.T.E.R. — Spring 2022

My team and I developed a system to manage the water delivery to residential lawns and gardens. I focused on designing and creating the RF Wireless Communication Network to communicate between four remote microcontrollers and components.

Simulating a Vending Machine — Fall 2019

I simulated a Vending Machine using Verilog and a FPGA that was able to accept various amounts of currency and only deliver a product when there were enough available funds.

Building a functioning 3-axis robot — Spring 2019

Using a project outline, I built a functioning 3-axis Master-Slave robot. I designed and manufactured the frame and platform of the system using various tools at my disposal.

Simple AI robots — Fall 2018

I designed a program that would randomly generate robots that would search a virtual board for batteries.

Work Experience

Allegation Inquiry Management Section, Office Technician — 2019 – 2022

I work with management to develop the AIMS database to document all relevant information within the Section. I have monitored and manage the development of an additional system to handle the increased workload and new business practice. I also develop and manage reports concerning information within the AIM system using Tableau and Microsoft Excel.

Los Rios Community College District, Makerspace Facilitator — 2018 - 2019

I developed educational programs that involved the use and understanding of various machinery. I also worked with the different campus organizations to involve students in our lab to increase awareness and funding of our workshop.

Knowledge and Skills

Autodesk Fusion 360 and Meshmixer, Microsoft Office Suite, Adobe Illustrator, OMAX Layout and Make, Ultimaker Cura, Formlabs PreForm, C++, C, Verilog, Leading instructional workshops, machining, managing a lab environment, managing a farm of 3D printers, mastering machinery and instructing others in its use, working with supervisors remotely, and handling medical and security emergencies.

Jonah Miller

Education

Bachelor of Science, Computer Engineering Expected Spring 2022

California State University - Sacramento - Sacramento, CA

3.4 Cumulative GPA | 3.7 CSUS GPA | Expected Graduation May 2022

Member of ACM Club

Relevant Coursework Completed

Computer Networking Fundamentals, Advance Computer Organization, Advanced Logic Design, Computer Interfacing, Electronics, Network Analysis, Signals and Systems, Probability of Random Signals, Data Structures and Algorithms, Embedded System Design, CMOS and Digital VLSI Design, Computer Hardware System Design.

Vice President of FLC++

Responsible for managing coordinated gatherings for club members to meet and discuss future events.

Assisted club president in designing coding tournaments for students.

Projects

16-bit CPU Design

I co-developed design alternatives for arithmetic functions, CPU internal architecture, instruction set, instruction cycle, I/O, memory.

Front Door Security System

I co-developed, locking system using sensors and a microcontroller with status changes to the system sent to user via a SMS API.

Work Experience

Certified Personal Trainer Oct 2018 - Present

Snap Fitness, Placerville, CA

I specialized in communication with clients to determine goals and performed client assessments. Also, I maintained files detailing personal fitness regimens, records and contracts in newly implemented system to keep all client information current.

Construction Worker Aug 2016 - Jul 2017

Turnbull Construction, Placerville, CA

I performed installations of new structures, updated systems and replaced worn components to bring buildings up to current codes. I also worked independently in fast-paced environment while meeting productivity and quality expectations.

Knowledge and Skills

C, C++, Verilog, VHDL, Python, GitHub, Microsoft Office Suite, PSPICE, Work Ethic, Collaboration and Communication

Francisco Becerril

Education

Bachelor of Science, Computer Engineering Expected Spring 2022
Math Minor
California State University, Sacramento, California
Associate of Math and Science Awarded May 2015
Contra Costa College, San Pablo, California

Projects

Water Management Senior Project Fall 2021-May 2022

Collaborated in a team to engineer some prototype to help fight a societal problem determined by us. Focusing on outdoor water waste, we developed an automated smart water management system. My responsibilities included handling API weather info for our system and creating a web application to handle our needs.

JAVA Object Oriented Game Spring 2022

As part of my object-oriented graphics course, I am being tasked with developing a working game on an emulator using Java as our primary language. This course revolves around proper programming, documenting, and refactoring.

OS Infinite Fall 2021

Used knowledge from previous courses like threading, concurrency, parallelism, CPU scheduling, and inter process communication to develop an operating system with a small team, for our Operating Systems Pragmatics course.

Work Experience

SSD Technical Intern | Solidigm January 2022 – Present

Being part of the Customer Acceleration Team for clients, my responsibilities include helping our Application Engineers with remanufacturing SSDs for client use. I'm also given a great opportunity to network and extend out to other teams and provide any help with other projects.

ASSOCIATE | IN-N-OUT MARCH 2016 - Present

Utilized excellent customer service, leadership, communication, and teamwork skills daily to provide our picture-perfect products to our customers. Training manager leading shift teams to run our business as smoothly as possible, also helped smoothly launch a new store in Stockton, CA.

Knowledge and Skills

Office Suite Programs (Advanced) | Java/C++/C/Python/Ruby/Assembly (Proficient) | Windows and macOS (Advanced) | UNIX/LINUX (Proficient) | FPGA Work (Proficient) | Some Work on MATLAB and NI Multisim | Verilog/VHDL Experienced | CMOS VSLI Design/ Cadence Knowledge | Git Knowledgeable

Alejandro Zavala

Education

Bachelor of Science, Electronic & Electrical Engineering Expected May 2022
California State University, Sacramento GPA 3.89

Protective Service Specialist July 1, 2017
United Services Military Apprenticeship Program

Projects

Water Automation Timing and Efficiency (WATER) Fall 2021-Present

Oversaw the power design aspect for my Senior Design Project. Had to ensure all components could maintain power for 30 days off a homemade power bank that would also be able to be recharged by solar panels.

Amplifier Circuits Lab Spring 2021

Designed an amplifier circuit and simulated the output using Pspice.

Assembled inverting and non-inverting op-amp circuits and manipulated the output signal by changing component values.

Work Experience

Siemens System Engineer May 2022 – Present

Worked directly under the Project Manager for the Light Rail Vehicles. Aided with items such as monthly reports, and correspondence between Siemens and the customer.

Siemens Project Manager Internship May 2021 – May 2022

Worked directly under the Project Manager for the Light Rail Vehicles. Aided with items such as monthly reports, and correspondence between Siemens and the customer.

Marine Security Guard April 2015 – August 2018
Marine Corps Embassy Security Group

Provided internal security to US Embassies primarily using equipment such as CCTV, electronic latches, & broadcasting system

Utilities / Engineer, Combat Logistics Battalion 11 June 2012 – April 2015
In charge of setting basic utility functions, establishing perimeters

Knowledge and Skills

Bilingual, team player, Microsoft Office Suite, PSPICE