Design Report
Harvest Hub Food Racking System

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1. Problem Statement and Objectives

Food should be available, accessible, and adequate for all people. The nutrients available in food transported long distances diminishes with the amount of time spent from harvest to consumption. Transportation costs are significant for locations away from urban areas.There is a need for fresh local produce that is accessible by anyone, even in remote locations. The Harvest Hub aims to satisfy this need with scalable-modular-vertical farming technology. It has the potential to increase the availability of produce in remote, cold, and arid areas with increased yield, yearlong supply, reduced real estate requirements, and minimal transportation. This technology can act in varied capacities; from isolated units in residential and commercial locations, to a part of the produce supply chain integrating into restaurants and grocery retailers.

The primary objective of the Harvest Hub Food Racking System project is to evolve Harvest Hub's current harvesting technology to an optimized, semi-automated and user-friendly version: called HUBTUB 2.0. HUBTUB 2.0 will have centralized irrigation, fertigation systems, built-in sensor technology, and an integrated data collection system. Variables for data collection will include temperature, oxygen and carbon dioxide levels, pH, and lighting/darkness levels to better understand the optimal environments for various crops to grow. This also leads the way for future systems controls and automation capabilities.

2. Product Description

Our HUBTUB 2.0 incorporates some of the original HUBTUB design, with modifications. The original design includes individual fans at the front of each tub to aerate the soil as well as water lines connected to the tub's water towers around the top of the tub. Currently 24 ecofelt pots are used to house the soil and plants in each 4ft x 4ft tub. The soil nutrients and pH are currently tested manually and the temperature is measured from the surrounding room temperature.

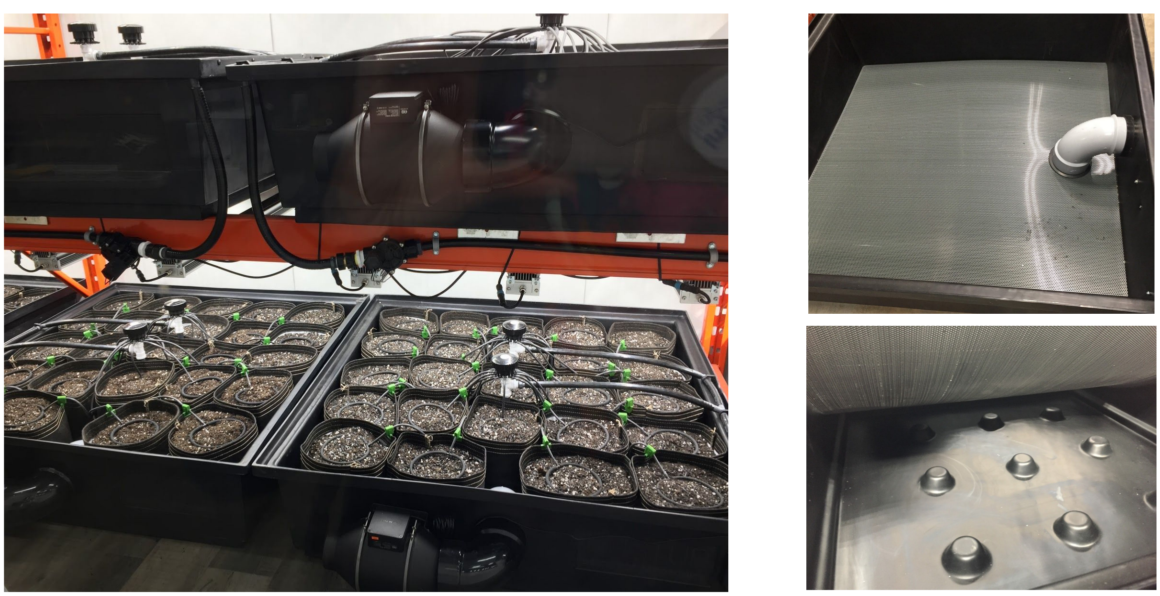


Figure 1. Original HUBTUB with ecofelt pots, individual fans, and water lines connected on the top and front sides (left); mesh layer resting on support pucks to allow airflow underneath the pots (right) [1]

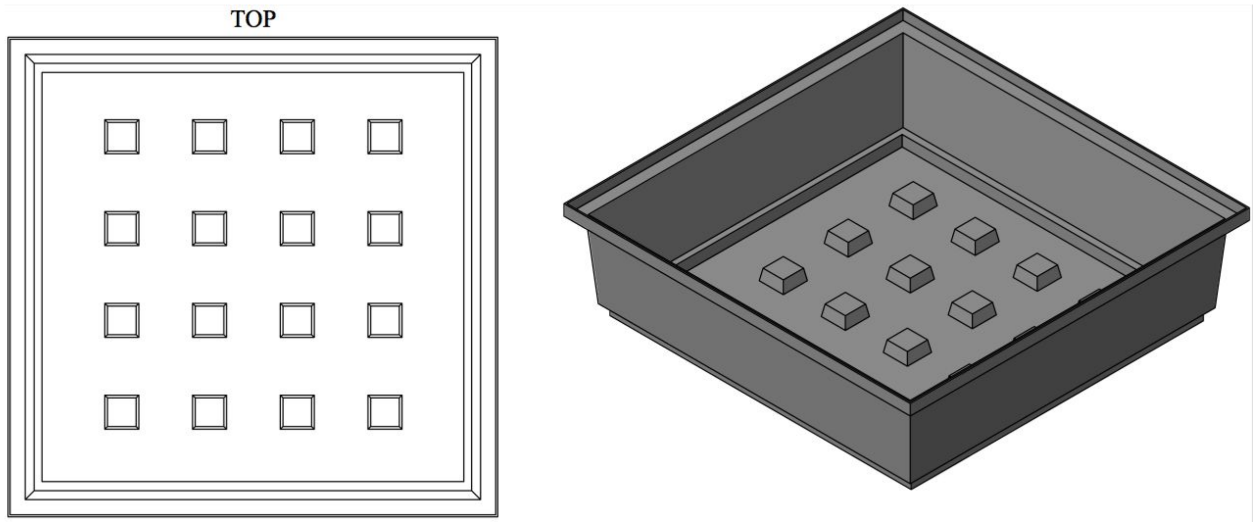


Figure 2. Graphic of the original HUBTUB showing 16 supports pucks

The HUBTUB 2.0 revised design has each tub connected to a central water line on the backside of the tub. Water solenoid valves outfitted in each tub control the flow to the tub. Individual fans per tub will still be used, however, they are smaller and installed at the back of the tub. Aerating the soil and the leaves is an important requirement for optimal plant growth, and therefore was a major factor in the design solutions we created. Rather than using ecofelt for the pots, we have designed resin pots with a mesh bottom to hold the soil and plants. Our design will hold 16 of these new resin grow pots. The overall tub dimensions will remain the same (4ft x 4ft), except that the support pucks will be larger to support the resin pots, eliminating the need for the mesh layer for segregated pots. The mesh was needed to support the ecofelt pots and provide a space underneath for air to flow, and will still be used as an option for the full soil growing scenario. Each of the individual components in the new design are reviewed in detail in the following sections. We have modelled the components for a 12 tub module, which includes two industrial racks back-to-back.

Figure 3. Graphic of 12-tub module

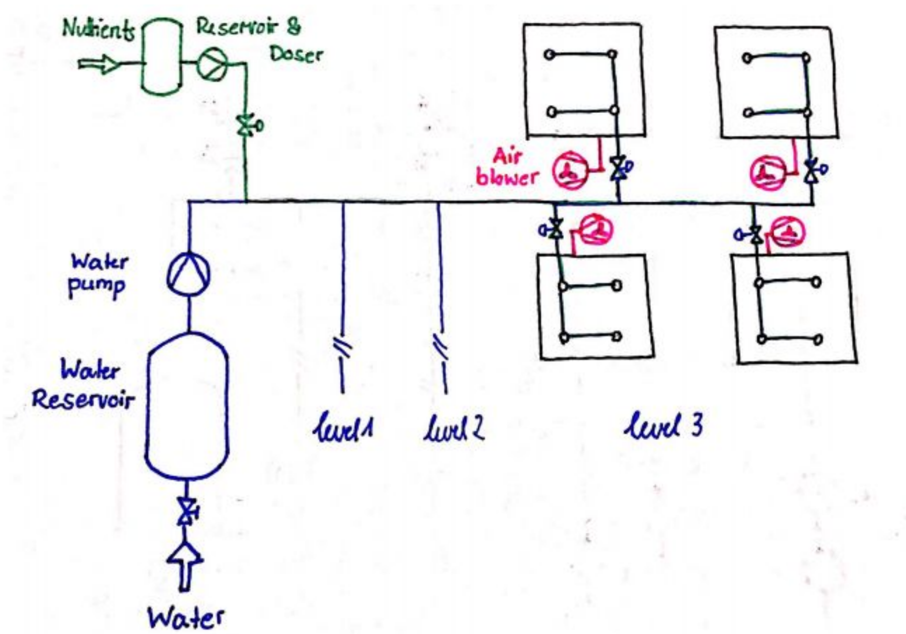


Figure 4.. Schematic overview of the water, air and nutrient systems to a 12 tub module; this shows the details of the 3rd level only, with level 1 and 2 being identical

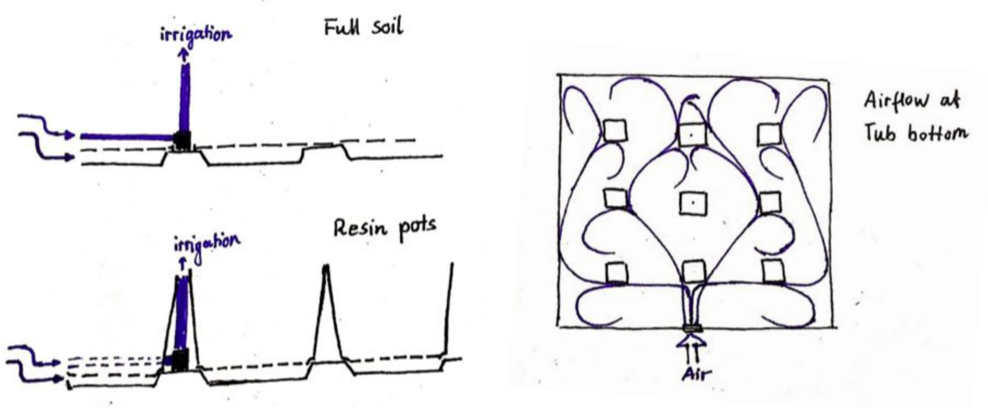


Figure 5. Air distribution in the tub with a full soil solution (upper left) and individual pot solution (lower left); air flow depiction at the bottom of the tub, moving around the support pucks under the pots (right)

Currently there is no sensor technology on board. The irrigation is controlled by the Rain-Bird which allows the user to configure a schedule for watering the plants. The Rain-Bird is to be replaced with a control system that operates the sensors, irrigation and aeration. Temperature, oxygen and carbon dioxide levels, pH, and lighting/darkness cycles data is to be collected. Currently the nutrient levels are measured manually with a soil slurry. Unfortunately, research reveals that real-time nutrient sensors for our purpose are not currently available and we are unable to create sensors within the scope of the project and within our limited time frame. There are a lot of research organizations that have developed nutrient sensors using technology such as optical transducers, electrochemical based nano sensors, radiation sensitive field effect transistors and ion selective electrodes but none are available commercially. The intended monitoring and control system will allow Harvest Hub to collect sensor data, process it, and transmit it via Wi-Fi for local or remote access. The user will be able to visually see their plants, look at sensor data and configure the watering schedule as well.

4. Criteria for Product Acceptance

4.1 Deliverables required

A fully re-designed HUBTUB is a required end deliverable of this project, including the design and analysis of the tub, walls, and piping. This encompasses water, air, and nutrient distribution and data collection within the tub. An updated racking system with a pull-out mechanism for human use is another deliverable for the project.

4.1.1 Constraints

1. Size and weight - the growing pots must fit tightly into the tub space to ensure air flow is forced under the pots, providing aeration to the soil.
2. Cost - linked to commercial viability
3. Materials - materials in contact with the soil must be food-grade and non-biodegradable. Rack and support material must be rust-resistant and high-strength.
4. Modular capability - the tubs should be modular and stackable.
5. Scalability - the tub and system should be able to be used at the residential level and also scale up for commercial use.
6. Ergonomic - the tub should be easy and safe to use.
7. Strength - the tub should maintain structural rigidity during use.

All of the design solutions detailed were chosen to meet the constraints listed above.

5. Product Specifications

5.1 Tub design

Our new tub design will maintain the same outer dimensions as the original design (4ft x 4 ft), however, we will include tolerances in our drawings (found in 8.2 Appendix II). There will be fewer (9) support pucks but they will be larger in size to support the corners of the resin pots, eliminating the need for the mesh support layer in the individual pot growing scenario. There will also be a cut out for the quick-connect plate for the air, water, and electrical lines. The tubs are made with UV20 polyurethane.

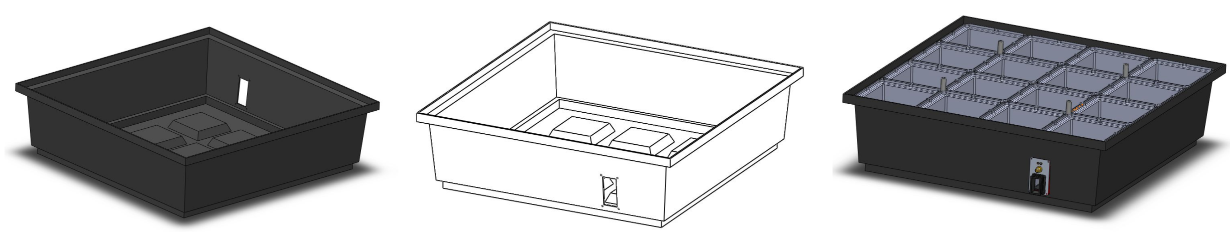


Figure 6. Tub design, showing cut-out for quick connect plate; opaque (left); semi-transparent version showing 9 support pucks (middle); individual pot growing scenario with 16 grow pots (right)

5.2 Pot design

The resin pots we designed will have greater structural rigidity than the original ecofelt pots. Additionally, they will not hold moisture within their walls, which took moisture away from the soil and could also encourage mold and rot. The pots are designed in a way that they will hold a tight seal at the top edges when the tub is fully filled with 16 pots. The food-grade polyethylene terephthalate (PETG) pots will be formed using medium density fibreboard (MDF) molds. The pots need to be made in two separate pieces and then combined using rivets or epoxy. They are a practical solution for decoupling the plants and will prove easier to manufacture and use later in automation.

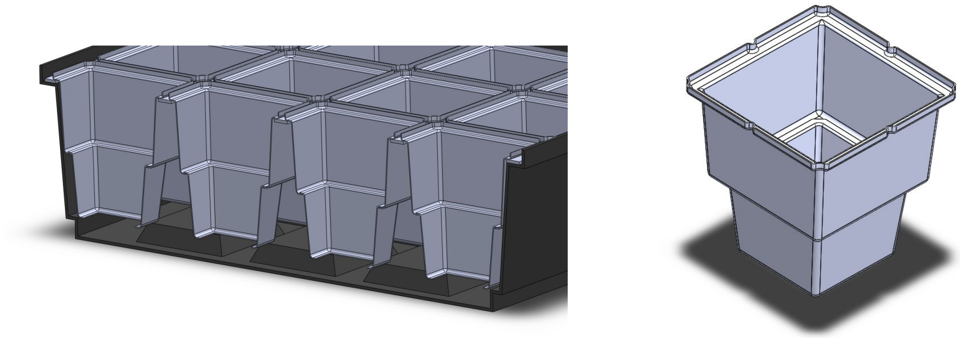


Figure 7. Resin pot design; cut-out view in tub (left) and orthogonal view (right)

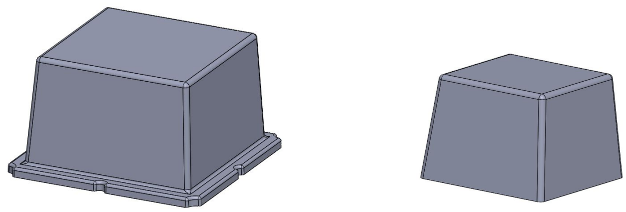


Figure 8. Graphics of molds that will be used for vacuum forming the resin pots; upper portion mold (left); lower portion mold (right)

5.3 Slider

The slider mechanism we designed will not include any moving parts (i.e. no rollers), but instead make use of the inherent friction characteristics of the tub and the cross bars already being used in the racking system. The tub can be slid currently at full load (approximately 500 lbs), over the cross bars. Our design adapts the cross bars with a layer of ultra high molecular weight (UHMW) resin to aid in smooth sliding. Three steel angle bars will be placed for added support, one on either edge of the tub and one in the centre. This helps counter any sagging that could occur due to the weight of the tub and contents. The outer sliders will help guide the tub into the correct positioning for the quick-connection when pushed back.

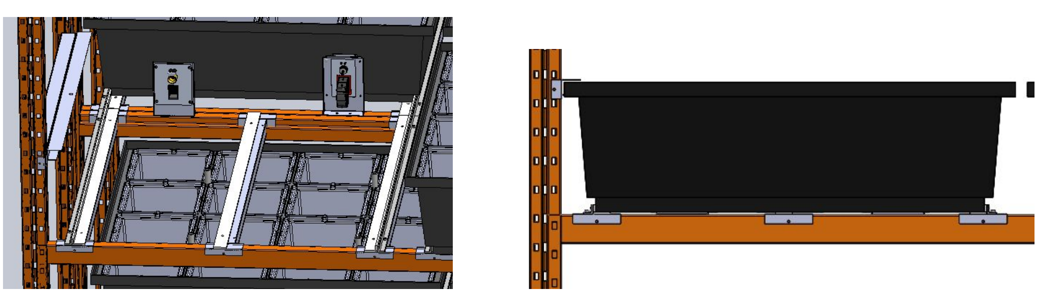


Figure 9. Sliders with the UHMW later (left); front view of the tub on sliders (right)

5.4 Pull-out mechanism (slide support arm)

The design solution that we chose for the pull-out mechanism was a simple one that involved less moving parts (i.e. no rollers) and allows for ease of use. The support arm will enable the user to pull the tub halfway and lock in place for safety, so that the center of mass remains on the rack. This solution proved most efficient to manufacture and use. The steel angle slide supports will connect to the rack and support one side of the tub, preventing the tub from tipping forward when pulled out. Former ideas including a separate support tray were discarded for ergonomic and safety reasons.

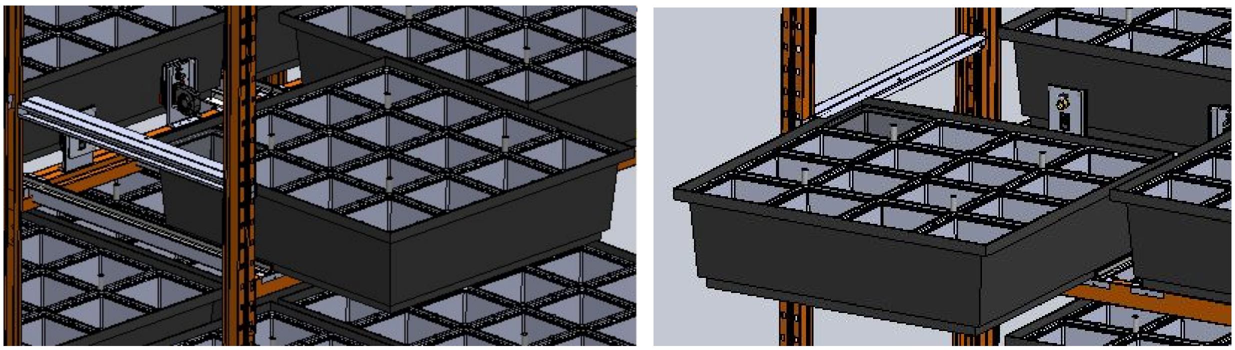


Figure 10. Graphics showing slide support arm

5.5 Quick-connects

Our solution for the water, air, and electrical line connections provides for a sufficiently tight connection for the lines when the tub is placed into its rack location. Flexibility is built into the design, to allow for adequate clearances when the tub is slid into position. Compression springs will be set within tapered electrical contact points that will ensure the connection is made within a certain tolerance level, this resembles the springs used with batteries. The air and water connections will also be tapered to ensure proper fitting within approximately ⅛ of an inch, and oversized holes with foam ring inserts will allow concentric misalignment for the water line. The aluminum plate affixed to the rack will have spring loaded mounts to provide extra misalignment compensation, while the aluminum plate attached to the tub will hold the opposing connections on a solid mount.

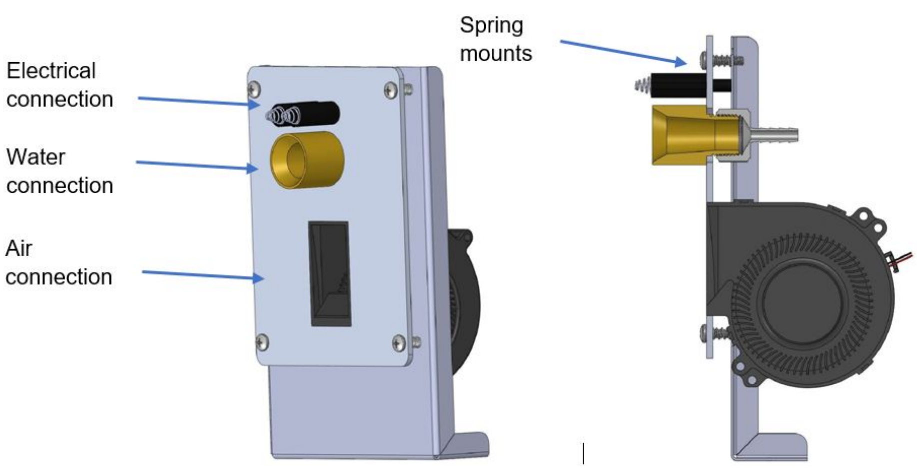


Figure 11. Angled view of one side of the quick-connect mechanism (left); Side view of quick-connect with spring mounts (right)

5.6 Air distribution

The HUBTUB 2.0 will incorporate individual fans per tub. However, we have decided on smaller, centrifugal fans. They are placed at the back of the tub, mounted to the rack via the custom quick-connect plate. This is easier to control, using the Raspberry Pi system, than a centralized air supply. An AC Infinity Cloudline T6 fan is currently in use for airflow for each tub at the farm lab. This fan is made to fit with 6” duct sizes with high airflow (351 CFM) [2] and low static pressure of (300 Pa). It worked well, but the horticultural requirements on airflow are yet to determined. Moving to smaller fans will save on space and costs. We sourced CUI Brushless fans with less flow (54.7 CFM) but higher static pressure (1300.3Pa) [3], which is needed for the back pressure that will be created in the plenum underneath the pots at the bottom of the tub. We made a decision to move away from a centralized air system because of the variations in pressure when not all tubs are being supplied with air would have made the system too complex.

Figure 12. AC Infinity Cloudline T6 fan (left) [2] vs. CUI fan (right) [3]

Table 1. AC Infinity Cloudline T6 fan [2] vs. CUI fan blower specifications [3]

Fan Type	Voltage	Dimensions	CFM	Static Pressure	Cost
AC Infinity Cloudline T6	24VDC	212 x 320 x 200 mm	351 CFM	300 Pa	$197
CUI DC Brushless Fan (CBM-97B)	12VDC	97 x 95 x 33 mm	54.7	1300.3 Pa	$29

5.7 Water distribution and irrigation

The water supply will come from a centralized system that feeds into each tub via supply lines with a solenoid valve in the back of the tub. A Little Giant pump is currently being used for watering in the original HUBTUB system, with a Rain Bird timer and controller. The Little Giant 5 MSP pump has about 14 GPM flow rate [5], at the maximum required height of 15 feet. This is much larger than the 32 GPH flow needed for single-tub watering. We have sourced a smaller (but more powerful) more cost effective pump, that will reach the desired 15 foot height without issues, providing a 10 GPM flow [7]. It also pumps down to a ¼ inch pipe, which is our smallest pipe diameter.

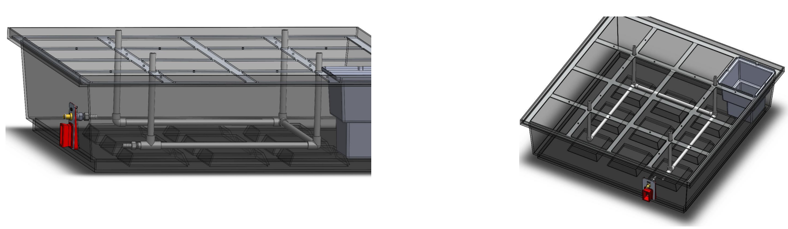


Figure 13. Graphics of piping layout within the tub

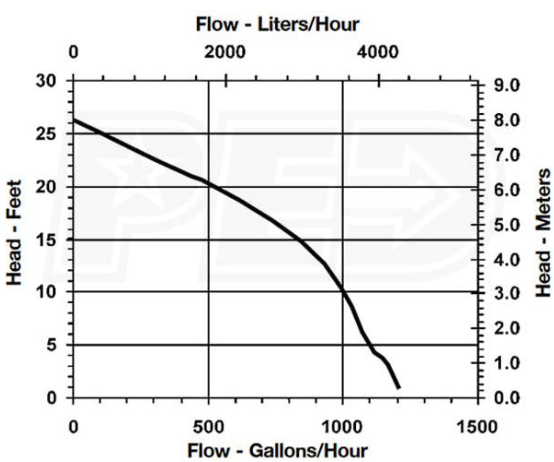
Each tub features 4 water towers and each water tower will hold a 4 outlets dip manifold, as in Figure 13. These emit 2 GPH at an operating pressure of 10 - 50 psi. Drip irrigation is possibly the most efficient watering mode. We advise watering one tub at a time with a smaller sized pump to save on resources.

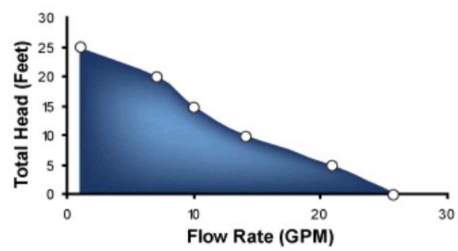
These decisions are based on flow and pressure calculations for a single tub and its supply through the main line. The Continuity Equation, Bernoulli Equation and Friction Equations were applied. They can be found in detail in Appendix III.

Figure 14. Two drip manifold options to test for supplying 4 pots; vertical exit (left) and bent exit [4]

Little Giant

Superior





Performance

HEAD	0'	5'	10'	15'	20'	25'
GPM	26	21	14	10	7	1
GPH	1560	1260	840	600	420	60

Figure 15. Little Giant 5-MSP Series, image (top left), pump curve (bottom left) [5] showing the head versus flow; Superior pump, image (top right), pump curve (bottom right) [6].

Table 2. Little Giant pump vs. Superior Submersible pump specifications.

	Motor	Engine	Pump	Overview	Cost
Little Giant [5]	Voltage: 120 V Running Amps: 5	Continuous Operation Oil-Cooled Horsepower: 0.16 hp	14 Gallons Per Minute @15 ft Outlet Diameter: 1 in Housing Material: Aluminum Impeller Material: Plastic Total Head Lift: 26 ft Submersible	Weight: 9 Pounds Product Length: 9.8in Product Width: 7.3in Product Height: 10.2in	$154.52
Superior [7]	Voltage: 120 VAC Running Amps: 3.6	Continuous Operation Horsepower: 0.20 hp	10 Gallons Per Minute @15 ft Outlet Diameter: 1 ¼ in Housing Material: Thermoplastic Impeller Material: Thermoplastic Total Head Lift: 25 ft Submersible	Weight: 6.7 Pounds Product Length: 5.875in Product Width: 5.375in Product Height: 9.625in	$50.38

5.8 Monitoring and Control System

Implementing a monitoring and control system takes us one step forward in the automation of Harvest Hub. Having a powerful system can allow us to collect and process data from the sensors while controlling the irrigation and aeration of the tubs. Having real-time data of the environmental conditions such as temperature, pH, moisture, etc. of the plants can help the horticulturists determine improvements for the wellbeing of the plants - resulting in higher yields and greater profits.

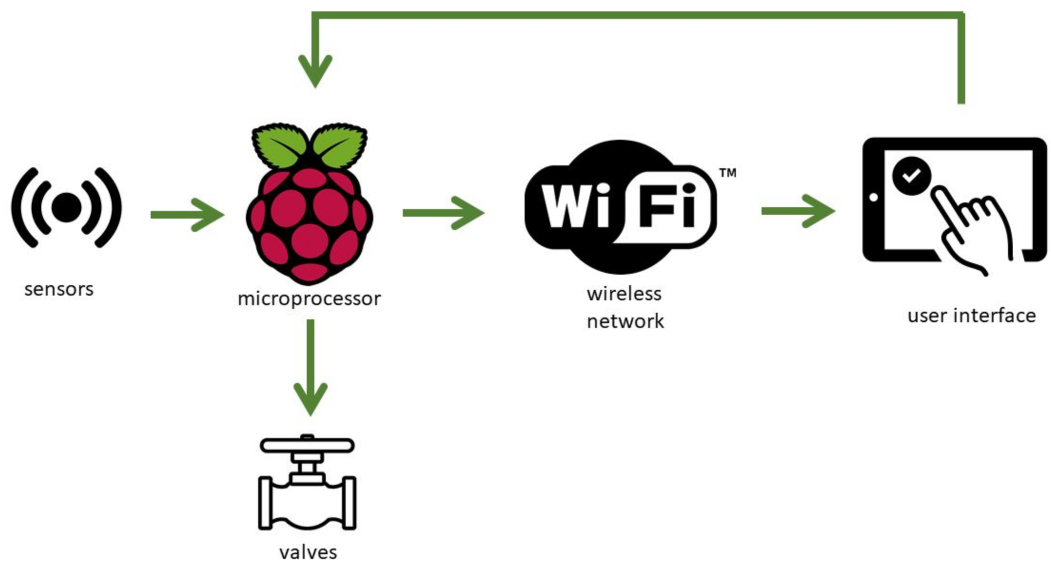


Figure 16. Overview of data collection system

The illustration above describes the data flow for the intended system. The sensors produce analog or digital signals which are received by the Raspberry Pi. This $10 device is the brains of the operation and can receive, collect, and transmit data via wifi or wired connection. The microprocessor is connected to the valve and the blower via wired connection but transmits sensor data and receives commands from the API (application program interface) via wireless network. The API is called hydrosys4 and is an open source software which allows us to view sensor data and configure irrigation schedules. It will be tweaked to suit our needs.

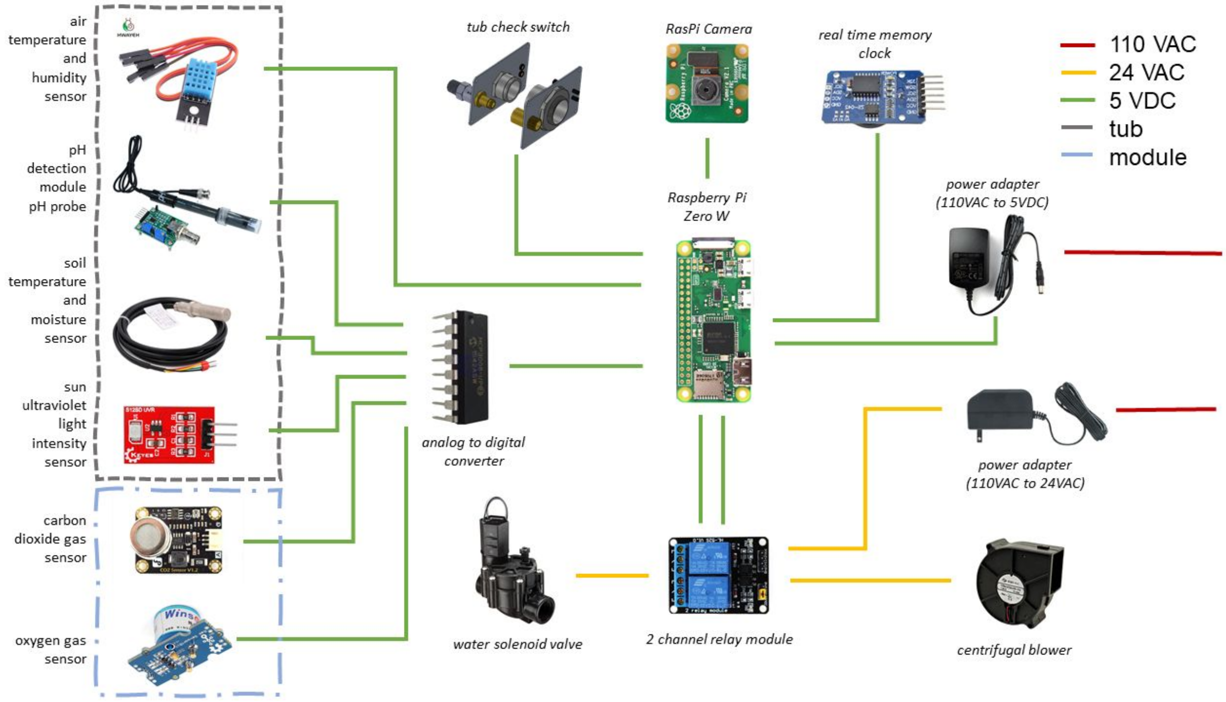


Figure 17. Electronics diagram

All the electronics above make possible the application described above. This system for one tub, with the exception of oxygen and carbon dioxide sensors, which will be installed for the entire enclosure (12 tubs). The electronics can be mounted on the tub itself, on the rack or split in between. The electronics will be in a weather proof container to protect it from the moisture in the air.

An overview of the electronic configuration is as follows: The circuit is designed to operate on 110 North American standard AC voltage. There are two power inputs, one is decreased to 24 VAC for the valves and blowers and the other is rectified to 5V for the microprocessor and sensors.

Utilizing a relay allows us to send signals to a high voltage AC device from a low voltage DC signal from the Raspberry pi. The raspberry pi will be able to control (limited to power on/power off) the water solenoid valve and the centrifugal blower. Their schedule will be configured using hydrosys4.

The sensor suit contains air temperature and humidity sensor, pH sensor, soil temperature and moisture sensor, sunlight intensity sensor, carbon dioxide sensor and oxygen gas sensor. These parameters will allow the horticulturist to further optimize plant growth by increasing or decreasing the parameter of interest. Due to the cost of gas sensors ($110) and the relatively stable nature of gas sensors across all tubs we decided to have one carbon dioxide and one oxygen sensor for one enclosure (12 tubs). This would save us $1,210 per module at the expense of not having individual oxygen and carbon dioxide concentration data. A camera is also connected letting the user view their plants remotely.

The raspberry pi is connected to two other important components to ensure safe control of the system. The first is a tub safety check switch. The tub safety check ensures the tub is in place in case its watering time and the water solenoid valves turn on. If the tub is not in place the valves will not turn on. The second integral safety feature is a real time clock module. Once updated the clock remembers the time the raspberry pi refers to when scheduling. Without the real time clock, if the raspberry were to be powered off for whatever reason, the microprocessor will lose all track of time. This means that the schedule would have no time values to reference the configured schedule and result in potentially distorting the watering times and ultimately watering at random intervals. To prevent this the real time clock has been installed which contains a personal battery in the scenario all power is lost.

The hardware required to run Hydrosys4 is minimal in that it only requires a raspberry pi zero and an SD card to install the program. Hydrosys4 has eleven overall functions that we will tweak to better fit our needs. Of these eleven functions the precise irrigation timing, auto irrigation, sensor data collecting, remote access and automation functions of the program will be utilized.

6. Plan for Winter Term

6.1 Design stages

Throughout the project, we have been and will continue to follow the engineering design process outlined in Figure 18. In order to begin the project, we met with the sponsor to identify their needs and what constraints applied to our design. Following this, we researched different aspects of the food racking system from the racking to the sensors. We brainstormed possible design solutions that would help solve our problem statement and worked with the Harvest Hub to select the optimal solution. Before the end of the fall semester, we aim to have our engineering drawings and bills of materials ready to submit so that we may begin procurement and manufacturing in the new year in the winter semester. After our prototype is completed we will evaluate the operations and make any necessary revisions and improvement, time permitting.

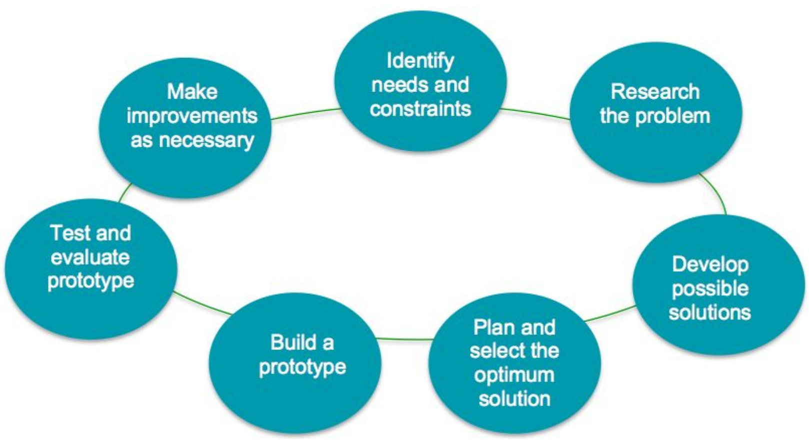


Figure 18. Overview of our engineering design process [8]

Timeline	December 2019- January 2020	January 2020	February 2020	March 2020
Stage	Procurement	Manufacturing	Assembly	Testing and Improvements

Figure 19. Timeline for the Winter semester plan, from prototype building to testing and improvements.

6.2 Design software

SolidWorks is our tool of choice for visualizing the design of the tub and racking system. It will also help us with our bill of materials and work orders to be submitted mid-December 2019. Following the work order submission will be the manufacturing phase, which we hope to start in January 2020.

For the monitoring and control system, several softwares will be utilized. First and foremost the illustrative diagram (Figure 17) will have to be transformed into a detailed circuit design. A detailed circuit design will include the pin configuration, the power and data lines, and intermediary components. This will be created using Scheme-It. The software would allow us to make professional circuit diagrams which could potentially be simulated in CircuitLab. This virtual simulation step is not necessary but would ensure correct current and voltages are being supplied and that there are no short-circuits in the design.

6.3 Manufacturing

Our goal for the winter semester starting in January 2020 is to procure all of our required materials and begin manufacturing. For those components that require fabrication, Table 3 outlines the manufacturing process that we will follow. We have elected to modify an original tub rather than creating a mold and having a new tub made. This decision was made to save on time and costs. The pots will be fabricated using thermoforming equipment with molds made using a wood CNC mill. The sliders and slide support arms will be fabricated with a band saw and drilling and fastening tools. The quick-connects for the water will be turned with a lathe. The electrical and fan connections will be done using 3D printing. All equipment is available at the University of Calgary Machine Shop and Maker Multiplex. Special considerations must be made for safety while fabricating the component parts. Concurrent with the manufacturing phase will be the programming controls and hardware phase.

Table 3. Overview of Manufacturing Design Process

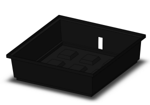
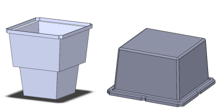
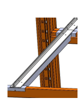
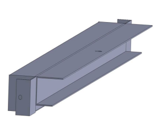
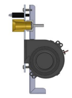
Component	Manufacturing Process
Tub 	Roll molding - changed support puck design Hot knifing - cut-out for the quick-connect plate
Pots 	CNC milling: MDF molds Thermoforming - body of polymer pots (2 parts) Hot knifing - holes for mesh base
Slider 	Drilling and fastening - UHMW layer to the cross bars for the sliding mechanism
Slide support 	Band sawing - cut extrusions to size Drilling and fastening- creating holes for fastening slider material

Table 3 (continued). Overview of Manufacturing Design Process

Component	Manufacturing Process
Quick-connect (water) 	Lathe turning - brass quick connects for water
Electrical connections 	3D printing
Fan connector 	3D printing

6.4 Programming controls and hardware

The programing for the monitoring and control system will be performed using Python. The open source software code will be taken from GitHub and adjusted for our needs.

The detailed circuit design will help with the physical circuit wiring and assembly. The electronic assembly and soldering will take place in the Makerspace.

6.5 Assembly and installation

We will make use of the Harvest Hub farm lab space to integrate all of our mechanical components and install the sensors, water, air, and electrical lines. The first step is adapting the original tub with the new support pucks and installing the quick-connect plate along with the water, air, and electrical lines. The sensors can be installed in a designated sampling pot. We will affix the slider cross bars and slide support arm to the racking unit so that it will be ready for the tub when it is complete. This step can be done before, during, or after the tub components are assembled. Following the component installations will be the product testing phase.

6.6 Product testing

After successfully completing the manufacturing, programming, and installations, we will move onto product controls and testing. We will visit the Harvest Hub farm lab to test the data collection systems, water, air, and electrical lines, valve operations, and sliding mechanism. The sliding mechanism will be tested for functionality, for fit with the quick-connect plate, and for safety. The slide support should stop the tub from being pulled more than halfway and should stop the tub from tipping forward. The valves will be assessed for leaks and to ensure that air, water, and electricity are flowing as expected. Finally, the data collection system will be tested for adequate data recording. During this phase, if any components are not working properly, we will make improvements and revisions as necessary.

7. Roles and Responsibilities

Table 4. Summary of Team Roles and Responsibilities

Team member	Fall term	Winter term	Overall accountability
Raahem Sheikh	Research: sensors and electronics for data collection (temperature, oxygen, CO_2, soil nutrients, pH, lighting cycles) Design: Monitoring and control system schematic, sensor schematics Electronic parts specifications and cost analysis BOMs, Work orders	Procurement of electronics and sensor components Electronics installation and operation Control and testing: Data collection Valve operations	Draftsman, fabricator Component: Sensors
Krishneel Singh	Research: sensors and electronics for data collection (temperature, oxygen, CO_2, soil nutrients, pH, lighting cycles) Design: Monitoring and control system schematic, sensor schematics Electronic parts specifications and cost analysis BOMs, Work orders	Procurement of electronics and sensor components Electronics installation and operation Control and testing: Data collection Valve operations	Draftsman, fabricator Component: Sensors
Charisse Dominski	Research: vertical farming, sensors, quick-connects, pull-out mechanism Design: CAD for pull-out mechanism (support arm) Support arm stress calculations and materials analysis Cost analysis BOMs, Work orders	Procurement of raw materials for support arm (steel, bolts) Fabrication: Support arm, assist with tub, pots, slider, quick-connects Testing: Sliding test	Writer and Designer Component: Pull-out mechanism (support arm)
Anna M. Baecke	Research: vertical farming, pumps, water lines, air circulation systems Design: Water system Air flow system Thermodynamic calculations Cost analysis, parts specifications BOMs, Work orders	Procurement of pump, fan, piping Installation and operations Control and Testing: Water and air controls and feedback Data collection	Theoretical Analyst Components: Water systems Air flow
Elliott Hewson	Research: slider mechanism, quick-connects, materials Design: CAD for tub, pots, slider mechanism, quick-connects Friction and load calculations Parts specifications, cost analysis BOMs, Work orders	Procurement of raw materials for tub, pucks, pots, slider, quick-connects Fabrication Testing: Sliding test Load bearing test	Designer, draftsman, fabricator Components: Tub Pots Slider Quick-connects

8. Appendix

8.1 Appendix I - Bill of Materials

Table 5. Bill of materials for mechanical components

Harvest HUB Mechanical Design BOM					
Per 1 Tub				**Final Total:**	$291.69
Item	Supplier	Quantity	Cost/per	Currency	Total
					$0.00
Connections Panel Tub					$0.00
Brass Check Valve	Mcmaster Carr/Home Depot	1	17.71	USD	$17.71
206 O ring	Mcmaster Carr	1	0.188	USD	$0.19
Custom Electrical Contacts (3D Printed)	Makerspace	2			$0.00
10-24 Locknut	Mcmaster Carr	4	0.0331	USD	$0.13
Screws 10-24 .75"	Mcmaster Carr	4	0.0553	USD	$0.22
10-24 Locknut	Mcmaster Carr	4	0.0331	USD	$0.13
Brass Hose Barbed Fitting	Mcmaster Carr/Home Depot	1	4.275	USD	$4.28
Brass Bar Stock 1.5" Diameter	Stores	2	2.81		$5.62
1/8 Aluminum Plate (8"x4")	Stores or Direct from Manufacturer	1	1.5		$1.50
8-32 Screw	Mcmaster Carr	4	0.159		$0.64
Connections Panel Rack					$0.00
0.25" 0.2" id Compression Spring	Mcmaster Carr	4	0.430833333	USD	$1.72
10-24 Locknut	Mcmaster Carr	4	0.0331	USD	$0.13
Screws 10-24 .75"	Mcmaster Carr	4	0.0553	USD	$0.22
1/8 Aluminum Plate (8"x4")	Stores or Direct from Manufacturer	1	1.5		$1.50
Galvinized Steel Plate (7"x11")	Stores/ Mcmaster Carr	1	3.08		$3.08
Custom Electrical Contacts (3D Printed)	Makerspace	2			$0.00
Brass Bar Stock 1.5" Diameter	Stores	2			$0.00
Electric Fan	Digikey	1	28.78		$28.78
1/4 20 Screws 1 in length	Stores/ Mcmaster Carr	2	0.2548		$0.51
Brass Hose Barbed Fitting	Mcmaster Carr	1	4.275	USD	$4.28
Solenoid valve	irrigationdirect.ca	1	25.5		$25.50
Tub Structure					$0.00
Aluminum sheet 14 GA 4'x4'	Stores or Direct from Manufacturer	1	50		$50.00
polyehthelene Foam Sheet	Stores/ Mcmaster Carr	1	18.06		$18.06
Adhesive (TBD)					$0.00
					$0.00
					$0.00
Slider Guides					$0.00
Steel angle extrusion	Stores/ Mcmaster Carr	2	21.28		$42.56
Teflon or UHMW	Stores/ Mcmaster Carr	5	8		$40.00
1/4 20 Screws 1 in length	Stores/ Mcmaster Carr	6	0.2548		$1.53
					$0.00
Pots					$0.00
PETG Sheets	Industrial Paints and Platics	2	3.75		$7.50
MDF Sheets (1 time Molds)	Home Depot				$0.00
Rivets 1/8in	Stores/ Mcmaster Carr	4			$0.00
					$0.00
Tub Water					$0.00
Plastic Barbed Tube Fitting	Mcmaster Carr\Home Depot	2	0.924		$1.85
Tee Connector, 1/2 in Pipe	Mcmaster Carr\Home Depot	1	3.38		$3.38
Side-Outlet Elbow Connectors	Mcmaster Carr\Home Depot	3	1.65		$4.95
PVC Pipe 1/2in	Home Depot\Stores	10	0.948		$9.48
Vinyl Tubing 1/2 in	Home Depot\Stores	1	0.768		$0.77
Hose Clamps	Home depot	2	1.24		$2.48
4 outlet drip manifolds	irrigationdirect.ca	4	3.25		$13.00

Table 6. Bill of materials for electronics

BILL OF MATERIALS - ENGG 501 - HARVEST HUB - 2019

THE HARVESTHUB
FARM•EAT•LEARN

		NAME
PRODUCT NAME	TUB TECH	
APPROVED BY		Raahem Sheikh
DATE OF APPROVAL		Krishneel Singh
PART COUNT	18	
TOTAL COST (USD)	$ 241.45	

PART NUMBER	PART	WEBPAGE DESCRIPTION	QUANTITY	SUPPLIER/LINK	UNIT COST (USD)	UNIT COST (CAD)	AMOUNT
01	Soil Temperature and Humidity Sensor	Soil Temperature And Humidity Sensor FS200-SHT10 I2C interface Metal surface for DIY Greenhouse flower nursery lawn SR003 (SHT10)	1	ALI EXPRESS	$ 8.70	$ 11.48	$ 11.48
02	Liquid pH Sensor	Liquid PH Value Detection Regulator Sensor Module Monitoring Control Meter Tester + BNC PH Electrode	1	ALI EXPRESS	$ 9.53	$ 12.58	$ 12.58
03	Sunlight Ultraviolet Light Intensity Sensor	KEYES CJMCU-GUVA-S12SD Sunlight Ultraviolet Light Intensity Sensor for Arduino	1	ALI EXPRESS	$ 2.19	$ 2.89	$ 2.89
04	O_2 Gas Sensor	Grove O² Gas Sensor	1	ROBOT SHOP	$ 54.90	$ 72.47	$ 72.47
05	CO_2 Gas Sensor	CO2 Sensor Arduino Compatible	1	ROBOT SHOP	$ 55.95	$ 73.85	$ 73.85
06	Ambient Temperature and Humidity Sensor	Digital Temperature and Humidity Sensor DHT11 DHT22 AM2302B AM2301 AM2320 Temperature and Humidity Sensor For Arduino AM2302	1	ALI EXPRESS	$ 3.20	$ 4.22	$ 4.22
07	Camera	CSI interface OV5647 1080P video 5MP Raspberry Pi Camera Module with 16cm flex cable	1	ALI EXPRESS	$ 9.00	$ 11.88	$ 11.88
08	Rasberry Pi Zero Microprocessor	Raspberry Pi Zero W (Wireless)	1	CANA KIT	$ 10.00	$ 13.20	$ 13.20
09	Relay	2 channel relay module	1	ALI EXPRESS	$ 1.25	$ 1.65	$ 1.65
10	Rasberry Pi Zero Power Supply	Raspberry Pi 3 Power Adapter 5V 3A DC Power Supply 100V ~ 240 V EU US UK AU Power Charger Micro USB Port for RPI 3	1	ALI EXPRESS	$ 3.02	$ 3.99	$ 3.99
12	Analog to Digital Converter	1PCS MCP3008 DIP16 MCP3008-I/P DIP-16 DIP	2	ALI EXPRESS	$ 1.67	$ 2.20	$ 4.41
13	Serpentine Tube	(Dia 8MM 400MM) led gooseneck led flexible holder lamp M8+M10 Chrome/Black Iron Hose universal soft pipe Metal serpentine tubes	2	ALI EXPRESS	$ 5.52	$ 7.29	$ 14.57
14	16 GB SD Card	SanDisk A1 Memory Card 256GB 200GB 128GB 64GB 98MB/S 32GB 16GB Micro sd card Class10 UHS-1 flash card Memory Microsd TF/SD Card	1	ALI EXPRESS	$ 2.40	$ 3.17	$ 3.17
15	SD Card adapter	High speed card reader USB 3.0 micro sd card reader micro sd adapter brand usb 3.0 card reader quality top sd card reader	1	ALI EXPRESS	$ 1.92	$ 2.53	$ 2.53
16	Enclosure	Electrical ABS weatherproof project junction box IP68 transparent plastic enclosures 175*175*100mm 200*150*75mm 200*150*100mm	1	ALI EXPRESS	$ 5.56	$ 7.34	$ 7.34
17	Real Time Clock	Precision DS3231 Real Time Clock Module RTC DS3231 3.3V/5V with Battery for Raspberry Pi for arduino DIY Kit	1	ALI EXPRESS	$ 0.92	$ 1.21	$ 1.21
		TOTAL PARTS	18			TOTAL (CAD)	$ 241.46

8.2 Appendix II - Design Drawings

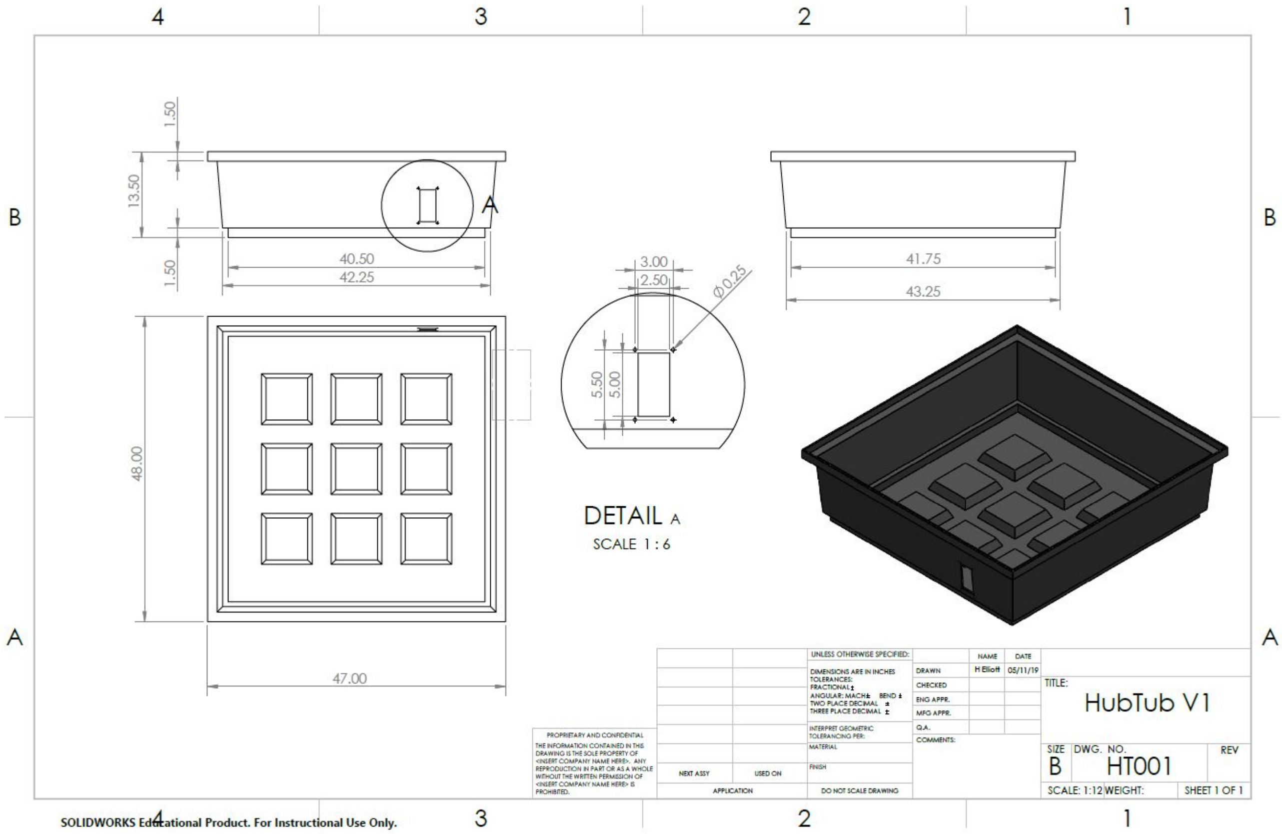


Figure 20. CAD drawing of the new tub design, showing the quick-connect cut-out and 9 support puck layout.

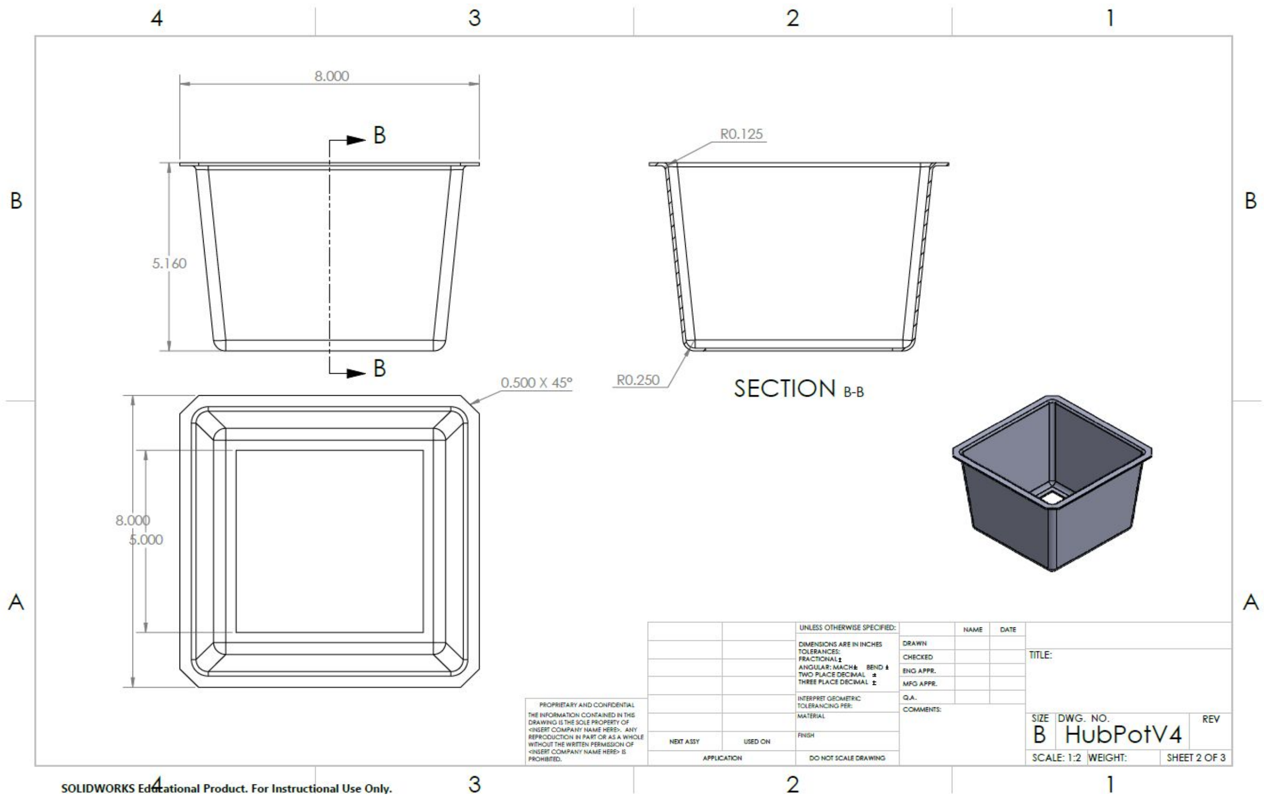


Figure 21. CAD drawing of the lower half of the new resin pots.

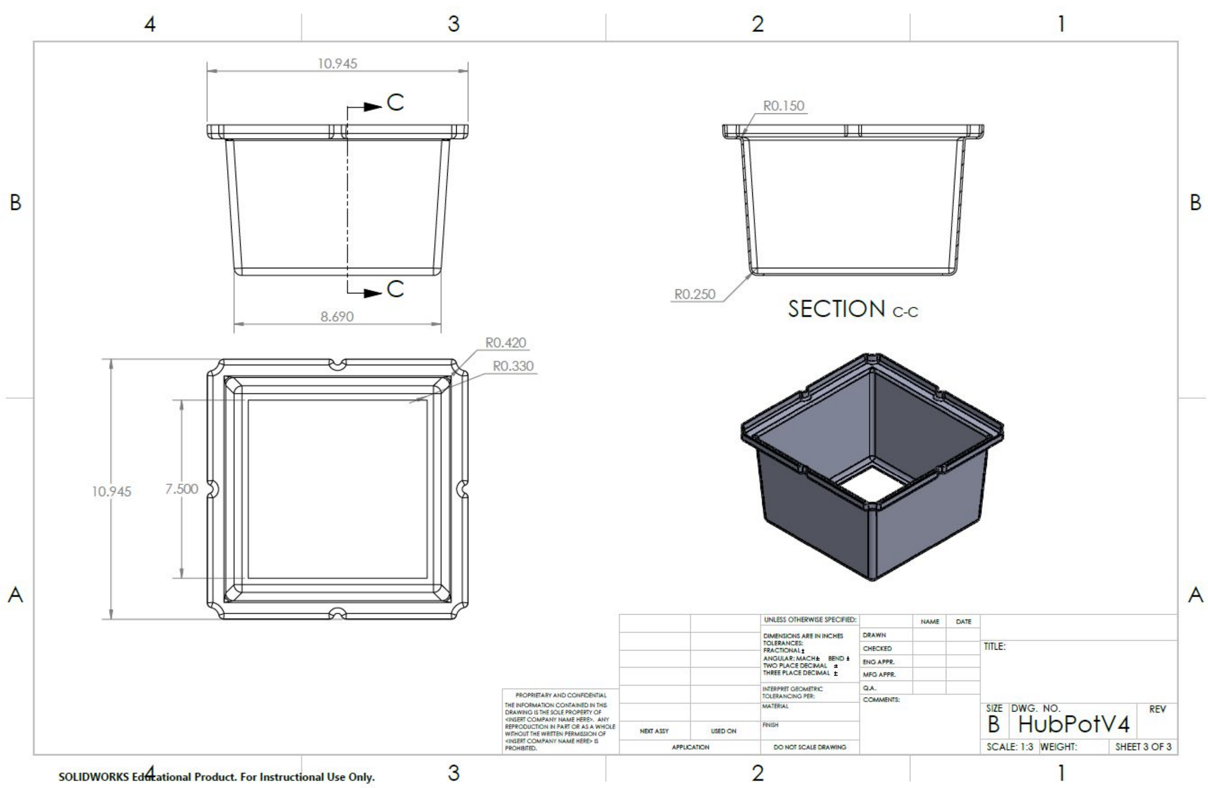


Figure 22. CAD drawing of the upper half of the new resin pots.

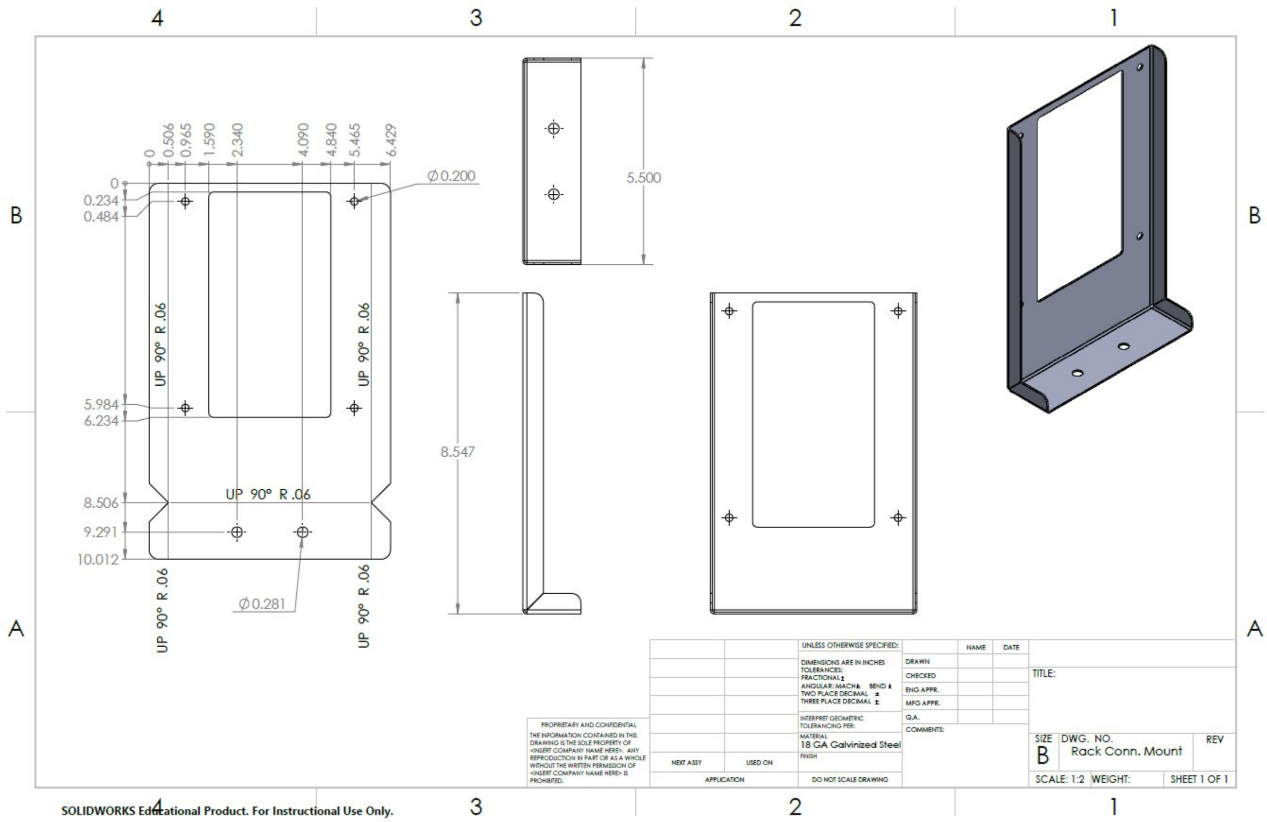


Figure 23. CAD drawing of the quick-connect plate.

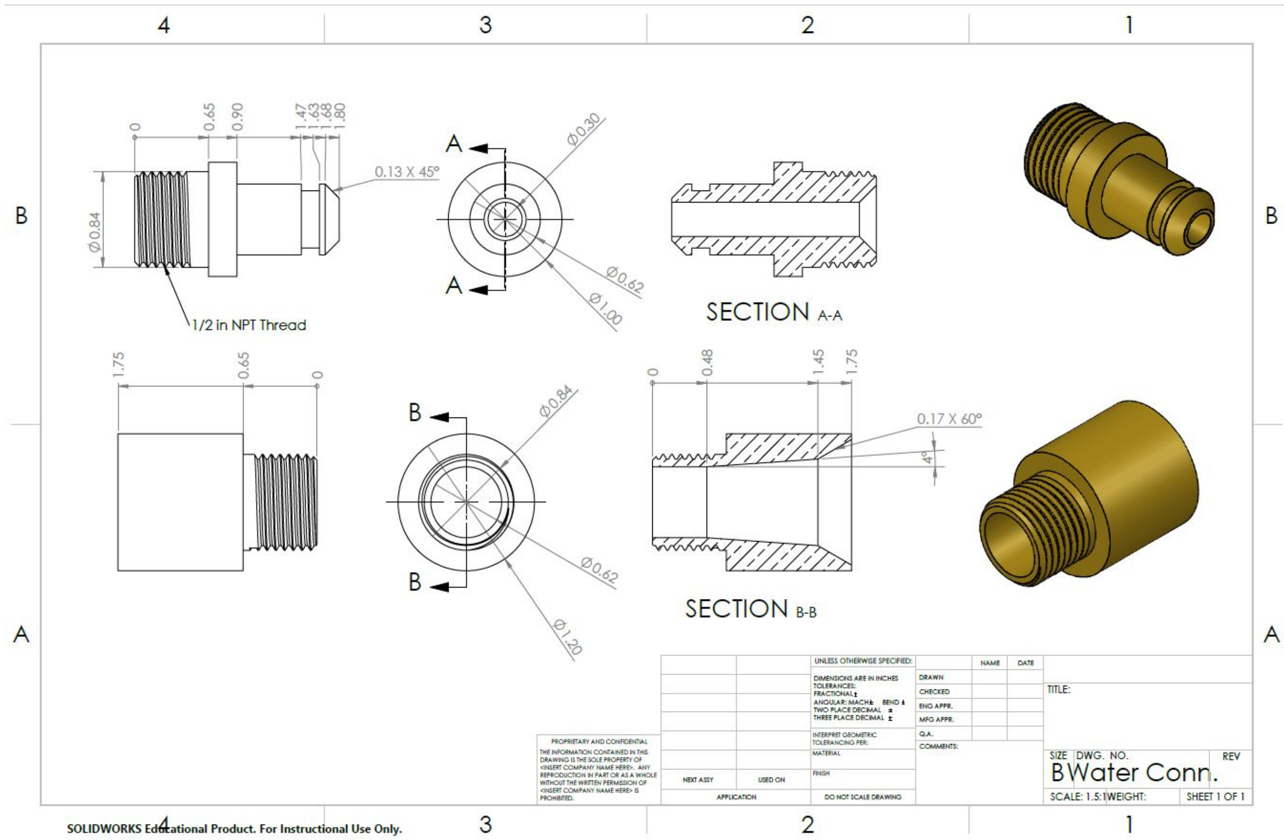


Figure 24. CAD drawing of the water connection.

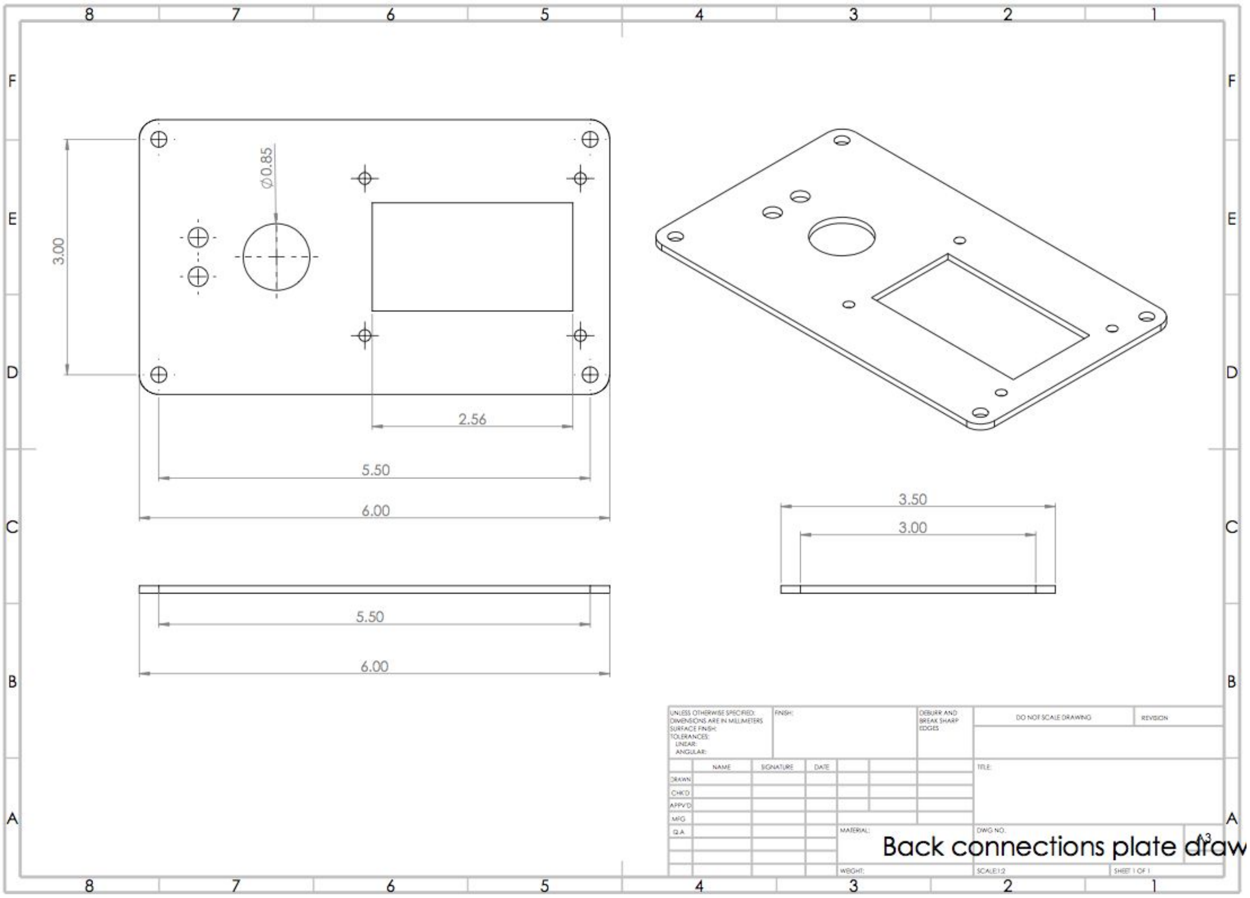


Figure 25. CAD drawing of the back-side connections plate.

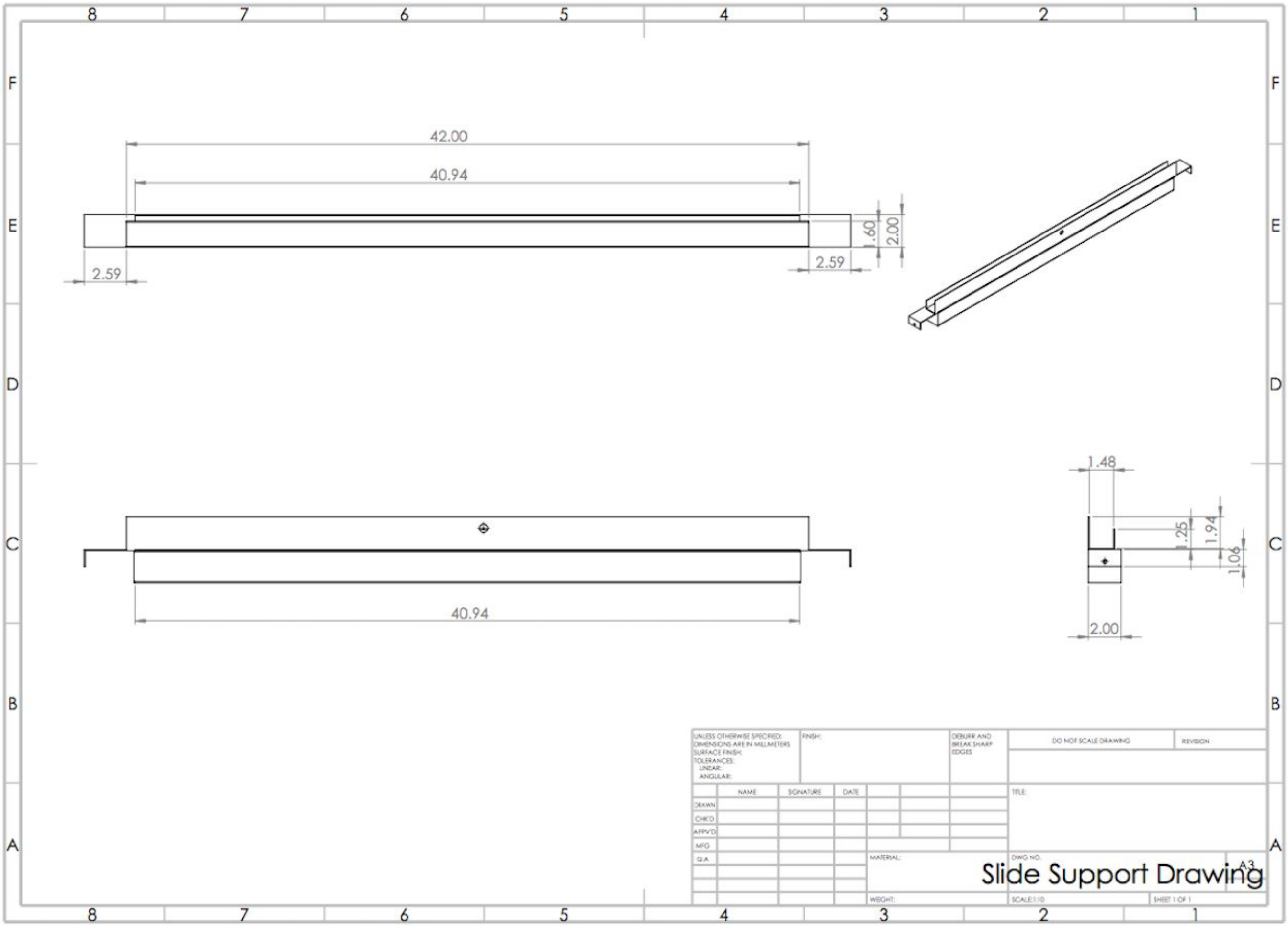


Figure 26. CAD drawing of the pull-out slide support arm

8.3 Appendix III - Process Calculations

<table>
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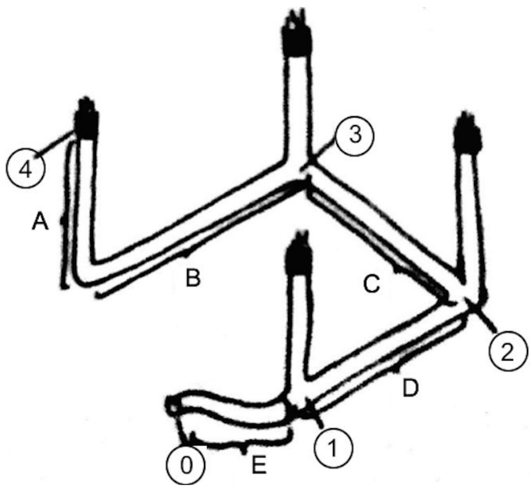

Figure 27. Figure of tub flow reference points
</td>
<td>
Tub flow reference points for calculations:

4) 4-outlet drip manifold, outlet ¼ inch, 2 GPH, at 10-50 psi

0) tub entrance (at connector plate), pipes ½ inch

A) Water Tower

B), C), D) Horizontal connection lines

E) Tub entrance connection line
</td>
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</table>

Flow Rates and velocities

Backwards calculation, from drip outlets to tub entrance
Using continuity equation

Point		Size [inch]	Flow [GPH]	Flow [m³/h]	velocity [m/s]
4	Outlet Barb	0,25	2	0,007570824	0,066439066
	Input	0,5	8	0,030283294	0,066439066
3	ongoing	0,5	8	0,030283294	0,066439066
	to tower	0,5	8	0,030283294	0,066439066
	input	0,5	16	0,060566589	0,132878132
2	to tower	0,5	8	0,030283294	0,066439066
	ongoing	0,5	16	0,060566589	0,132878132
	input	0,5	24	0,090849883	0,199317197
1	to tower	0,5	8	0,030283294	0,066439066
	ongoing	0,5	24	0,090849883	0,199317197
	input	0,5	32	0,121133177	0,265756263
0	output	0,5	32	0,121133177	0,265756263
	input	0,5	32	0,121133177	0,265756263

1 tub supply: pump has to offer 32 GPH
*12 tub supply watering all at once: pump has to give 12*32 GPH = 384 GPH*
-> for lower pump requirements, better don't water them all at once!

Pressure requirements
4 outlet drip manifolds (Operating pressure at input 10 - 50 psi / 0,7-3,5 bar)

Rigid PVC Pipe	Sandrauhigkeit ks [m]	0,000007 (roughness ε)	
	Diameter D	0,0127 m	
Reynolds Number	Re=ρ*u*d/η	ρ... density, kg/m³	1000
Friction Factor	λ=64/Re (laminar)	u... velocity	
	or ks/D + Moody Diagram	d...characteristic length	D
pressure loss coeffict.	ζ=λ*l/d	η... viscosity, dynamic, mPa/s	1,3
pressure lost	Δp=ρ*g*h + ρ/2*u²*Σ(ζ)		

A) Tower	[inch]	Re	ks/D	λ	ζ
Length	15	649,058566	laminar	0,098604353	2,958130592
corner		reference: https://www.schweizer-fn.de/ze			1,2
Δ height	15				
Δp_tower	**3746,7873 Pa**				

B) Line	[inch]	Re	ks/D	λ	ζ
Length	20	649,058566	laminar	0,098604353	3,944174122
seperation		reference: https://www.schweizer-fn.de/ze			2
Δ height	0				
Δp_B	**13,1192365 Pa**				

C) Line	[inch]	Re	ks/D	λ	ζ
Length	20	1298,11713	laminar	0,049302177	1,972087061
seperation		reference: https://www.schweizer-fn.de/ze			2
Δheight	0				
Δp_C	**35,066772**	**Pa**			

D) Line	[inch]	Re	ks/D	λ	ζ
Length	20	1947,1757	laminar	0,032868118	1,314724707
seperation		reference: https://www.schweizer-fn.de/ze			2
Δ height	0				
Δp_D	**65,8426063**	**Pa**			

Vinyl Tubing		Sandrauhigkeit ks [m]		0,000005 (roughness ε)	
		Diameter D		0,0127 m	
E) Line	[inch]	Re	ks/D	λ	ζ
Length	15	2596,23426	0,000393701	0,05	1,5
connection		reference: https://www.schweizer-fn.de/ze			0,5
Δ height	-6				
Δp_E	**-1406,761**	**Pa**			

Total pressure lost within the tub to reach the furthest outlet is the sum of lines A to E

Δp_tub	**2454,05491**	**Pa**
	0,35593059	psi

Main system: pressure requirements for a tub on third level, furthest from the pump
-> Pressure losts due to flow in pipe, corners etc.
-> pressure lost due to height

Main Line	[inch]	Re	ks/D	λ	ζ
Length	200	1298,11713	laminar	0,049302177	9,860435305
corners		https://www.schweizer-fn.de/zeta/rohrbog			0,25
valve		https://www.schweizer-fn.de/berechnung/			1
Δ height	150				
Δp_main	**37401,1733**	**Pa**			
	5,4245818	psi			

Total Pressure Lost Δp_total = Δp_tub + Δp_main

Δp_total = 39855,22824 Pa

5,780512386 psi

Pump

Single tub watering GPH 32 pump outlet max. 50 psi (keep all drippers safe)

50 psi - 6 psi is still enough for highest tub

9. References

[1] Harvest Hub Farm Lab. (2019, October). Photographs, Calgary. Used with permission.

[2] CLOUDLINE T6, Quiet Inline Duct Fan System with Temperature and Humidity Controller, 6-Inch. (n.d.). Retrieved December 3, 2019, from https://www.acinfinity.com/component-cooling/inline-duct-fan-systems/cloudline-t6-quiet-inline-duct-fan-system-with-temperature-and-humidity-controller-6-inch/.

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[6]. (n.d.). Retrieved December 8, 2019, from https://www.superiorpump.com/products/utility/91250.html.

[7] Superior Pump 1/5 HP Submersible Thermoplastic Utility Pump-91025. (n.d.). Retrieved December 8, 2019, from https://www.homedepot.com/p/Superior-Pump-1-5-HP-Submersible-Thermoplastic-Utility-Pump-91025/204605930.

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