AUGUST 13, 2021

QUEEN’S VERTICAL FARMING TEAM

SYSTEM GUIDE

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Executive Summary

In the face of climate change and a growing world population, conventional agricultural practices threaten future global food security. A compelling alternative is vertical farming, a cultivation method that can conserve resources and maximize plant productivity.

Recognizing this emerging industry, the Queen's Vertical Farming Team (QVFT) is designing and building a functional, software-automated aeroponic vertical farm on Queen's University campus. The majority of existing research in this field is conducted by private companies and is thus inaccessible to the public. Through its open-source approach, QVFT aims to democratize vertical farming knowledge and research.

This report demonstrates our progress to date and contains a comprehensive overview of QVFT's aeroponic system, automation subsystem, dynamic software stack, plant science research, and business operations.

QVFT employs an aeroponic cultivation method, in which plants grow without soil and are fed by a nutrient-enriched mist. Crops rest in thin plastic root cups, through which their roots hang into a basin below. Aeroponic vertical farming lends well to automation and can allow for near-complete control over the plant growth environment. The system is broadly divided into five zones: mixing tank, nutrient zone, supply line, growth zone, and return line.

The automation subsystem is an electromechanical feedback control system that automatically maintains optimal growth conditions using interconnected sensors and actuators. These components interact through a logical framework programmed into their Arduino microcontrollers. At the same time, sensor readings are continuously logged by a computer located on-site and uploaded to a website via Ethernet.

The website is really a software stack comprised of a database, back-end, and front-end client. The front-end client will dynamically display real-time data on qvft.ca, which achieves three objectives: (i) Allows for remote monitoring of farm equipment; (ii) Provides a reference for future tuning and improvements; (iii) Creates a public knowledge base to assist other groups with vertical farming research.

1. Introduction

a. Background

A global trend of increasing concern is the diminishing supply of arable land per capita. Due to trends such as climate change, freshwater depletion, and soil degradation, arable land per capita will fall to one-third of the amount available in 1970 by 2050. The unsustainable practices of conventional agriculture exacerbate these issues. In addition, the world population is expected to increase from 7.7 billion (2019) to 9.7 billion (2050). The intersection of these climate and population challenges means that global food security depends on our ability to adapt to increased demand and develop better farming techniques. [1] [2]

Vertical farming is a cultivation practice in which crops are grown in an indoor, climate-controlled facility. This approach is associated with dramatically reduced water consumption (~95%), minimal transportation costs, and massive improvements in per-acre land productivity. Vertical farming can grow nutritious, organic produce in any location, at any time of year. [1] Given these advantages, this technology is projected to become a major contributor to global food production in the coming decades. The vertical farming industry's global market value is projected to grow from $2.23 billion in 2018 to $12.77 billion by 2026, representing a compounded annual growth rate of 24.6%. [3]

b. About QVFT

QVFT is working towards becoming a leader in the university vertical farming space. To achieve this goal, QVFT is designing and building a functional software-automated vertical farm, which will generate a body of publicly available data and research. Our 25 alumni and 13 current members come from diverse academic disciplines and represent all four years of study. *Table 1* introduces the various projects that QVFT will be pursuing over the upcoming school year.

Table 1: Project Descriptions

Project	Goal(s)
Main objective: Aeroponic system	• Design and build a functional prototype of an aeroponic vertical farm
Software stack	• Develop a software interface that allows for remote monitoring of farm equipment and creates a publicly accessible online repository of real-time vertical farming data • [This component will be stored remotely]

Project	Goal(s)
Automation sub-system	• Develop an electromechanical feedback control system that automatically maintains optimal growth conditions using sensors, actuators, and microcontrollers. • Upload real-time sensor readings to the software stack. [This component will physically interact with the aeroponic system]
Plant science research	• Research strategies for optimizing kale productivity within the context of controlled-environment agriculture.
Business operations	• Secure the funding and materials needed to support the other team projects. • Promote QVFT and increase awareness of vertical farming amongst the student community.

2. Aeroponic System

QVFT employs an aeroponic cultivation method, in which plants grow without soil and are fed by a nutrient-enriched mist. Crops rest in thin, plastic root cups, through which their roots hang into a basin below. Aeroponic vertical farming lends well to automation and can allow for near-complete control over the plant growth environment. The system is broadly divided into five zones: mixing tank, nutrient zone, supply line, growth zone, and return line.

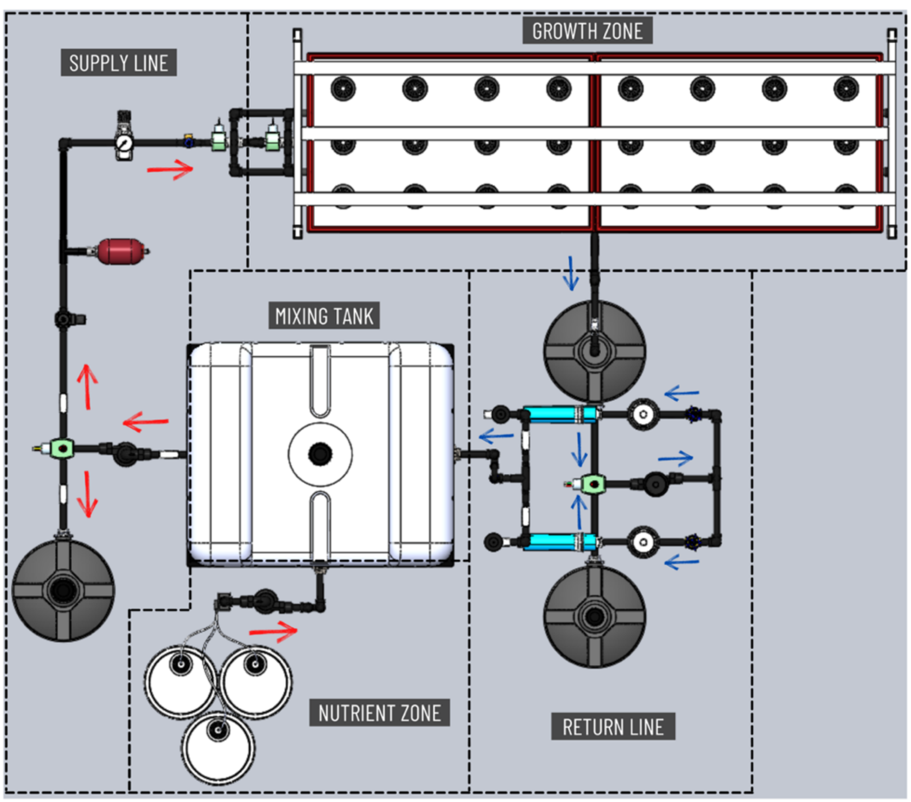

Figure 1: Zones of Aeroponic System

a. Mixing Tank

The mixing tank is the central hub of the farm. Recycled water from the return line is replenished with nutrients from the nutrient zone before being dispensed to the supply line as needed.

b. Nutrient Zone

The nutrient zone replenishes macronutrients and micronutrients consumed by the plants during growth and helps to maintain a consistent, weakly acidic pH. Nutrients A and B (see *Section 5b*) are kept in separate tanks to prevent their dissolved solutes from reacting with each other while in storage. The pH tank contains a mixture to counterbalance the water acidification caused by the reverse osmosis (RO) process performed in the return line (see *Section 2e)*.

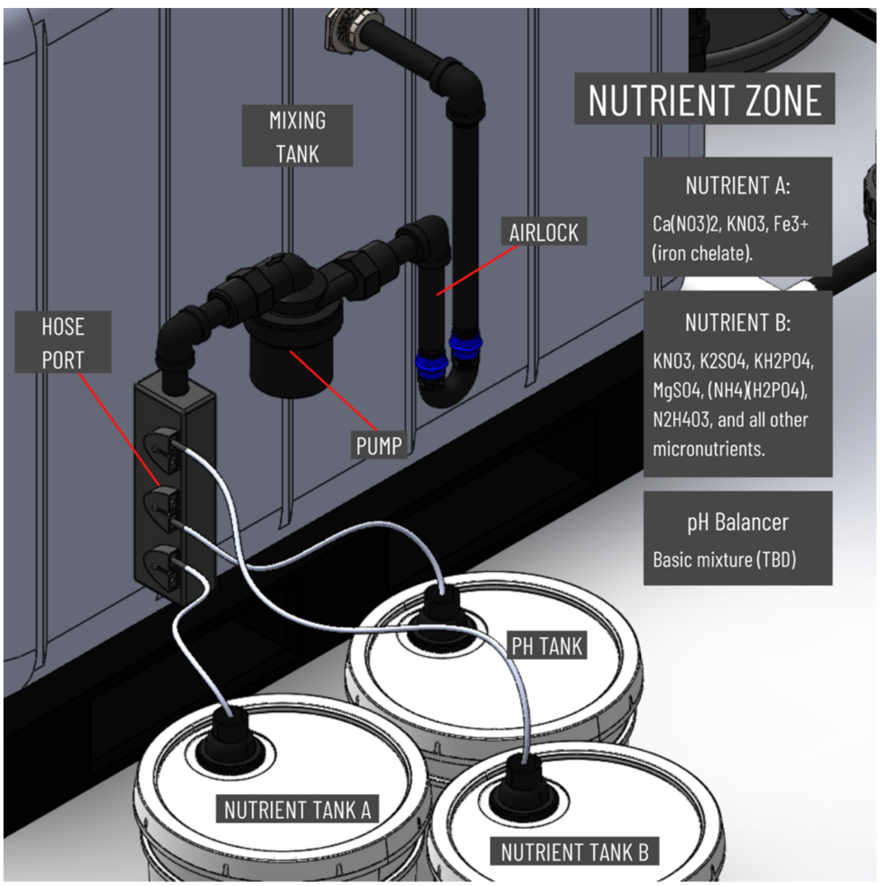

Figure 2: Nutrient Zone CAD Model

c. Supply Line

The supply line transports nutrient-enriched fluid from the mixing tank to four sprinkler lines laid across the two levels of the growth zone.

The 3-way valve normally permits outflow to the growth zone and prevents outflow to the excess water storage tank. However, its orientation can be reversed by the automation subsystem when the mixing tank contains excessive water or must be drained for maintenance (see *Appendix E: Farm Logic Pseudocode*). The valve always permits inflow from the mixing tank.

The supply pump works in concert with a pressure switch, accumulator, and pressure regulator to maintain a consistent 60-120 psi pressure at the sprinklers. The sprinklers require this pressure range to produce the microscopic mist droplet size that allows for rapid nutrient absorption by the plant roots.

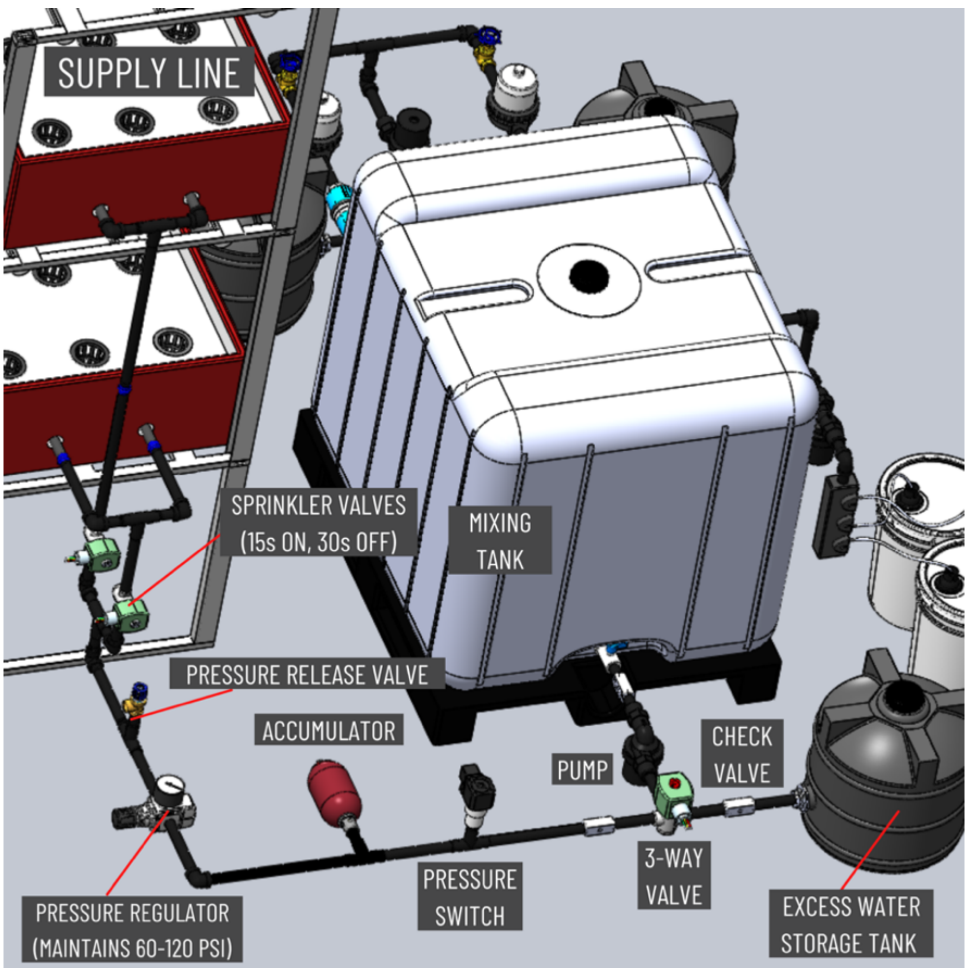

Figure 3: Supply Line CAD Model

Two solenoid valves control the misting cycles for the two levels of plants in the growth zone. Currently, the cycle is planned to be: 15 seconds ON (valves = open) and 30 seconds OFF (valves = closed). The diaphragm accumulator prevents pressure fluctuations between these two modes by storing excess supply line pressure when the solenoids are closed and passively releasing it when they are opened.

A manual pressure release valve is included to allow an operator to depressurize the supply line before performing maintenance tasks.

Bernoulli's equation and conservation laws were used to determine the pump size and pipe dimensions that would provide the required sprinkler pressure of 60-120 psi. The MATLAB script created to perform these calculations is available in *Appendix D: Supply Line Pump Sizing Calculations*.

d. Growth Zone

The growth zone contains two levels that together hold forty-eight plants. The plants rest in thin, plastic cups which have slots through which their roots can dangle into a plastic growth basin. Mist is emitted from ninety-six sprinkler heads (forty-eight per level), which are oriented at alternating angles to ensure complete mist coverage of the growth basin.

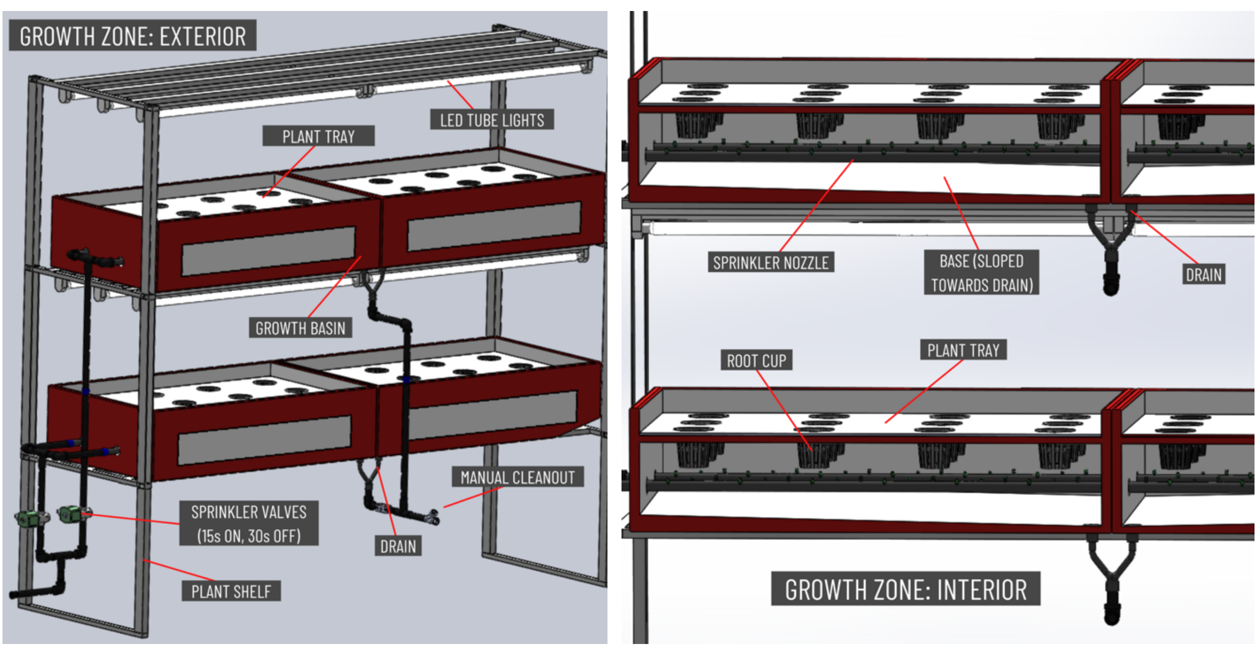

Figure 4: Growth Zone CAD Model

After spraying, the mist collects on the sloped floor of the growth basin and passively trickles through the drain and towards the return line. Compared to the inflow from the supply line, the outbound fluid will be slightly nutrient-depleted and will have lost some volume due to evaporation.

e. Return Line

The vast majority of the mist sprayed in the growth zone can be recollected and recycled by the return line. Outflow from the growth zone is first stored in the farm runoff storage tank. From here, it will be pumped through a series of filters in the return line before finally being expelled to the mixing tank for reuse.

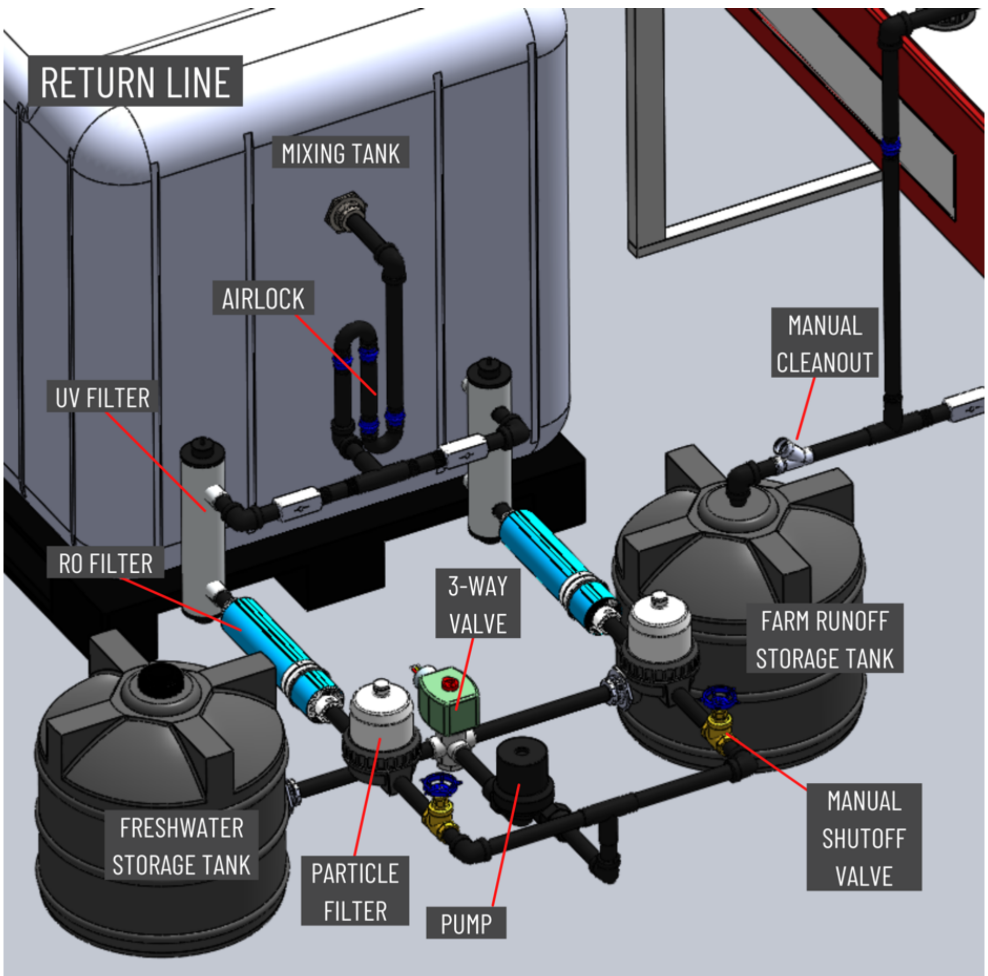

Figure 5: Return Line CAD Model

The 3-way valve normally permits inflow from the farm runoff storage tank and prevents inflow from the freshwater storage. However, its orientation can be reversed by the automation subsystem when extra water is needed in the mixing tank, and there is insufficient fluid available in the farm runoff storage tank (see *Appendix E: Farm Logic Pseudocode*). The valve always permits outflow towards the rest of the return line.

As shown in *Figure 5,* two identical filtration branches are arranged in parallel, each of which can be blocked or unblocked with a manual shutoff valve. In practice, only one filtration branch will be active at a time. The inactive branch serves as a bypass for when the filter components on the main branch are being maintained or replaced. In these situations, the main branch's manual shutoff valve would be closed, and the bypass branch's valve opened, thereby allowing the farm to continue operating without interference. Check valves are strategically placed on either side of the airlock to prevent flow from the main branch from passing backwards down the bypass branch or vice versa.

There is a particle filter, RO filter, and ultraviolet (UV) filter on each filtration branch. The particle filter removes larger sediments from the fluid, while the RO filter eliminates most of the remaining nutrients and the UV filter kills any pathogens.

The mixing tank contains an electrical conductivity (EC) meter, which is a useful tool that can detect the total concentration of solids (i.e., nutrients) dissolved in a fluid. However, it is entirely unable to determine the partial concentrations of individual species which comprise that solute. Given this limitation, all remnant nutrients within the recycled fluid will be stripped in the return line via RO (EC reduced to ~0) before being released to the mixing tank. Doing so will allow for an ideal dose (see *Section 5b*) to be consistently added to the mixing tank by the nutrient zone.

3. Automation Subsystem

The automation subsystem is an electromechanical feedback control system that automatically maintains optimal growth conditions using interconnected sensors (inputs) and actuators (outputs) (see *Appendix A: I/O Components of Automation Subsystem*). These components interact through a logical framework programmed into their Arduino microcontrollers (see *Appendix E: Farm Logic Pseudocode*). At the same time, sensor readings will be continuously logged by a computer located on-site. The computer will reformat the data to be human-readable and then upload it to a website via Ethernet (see *Section 4*).

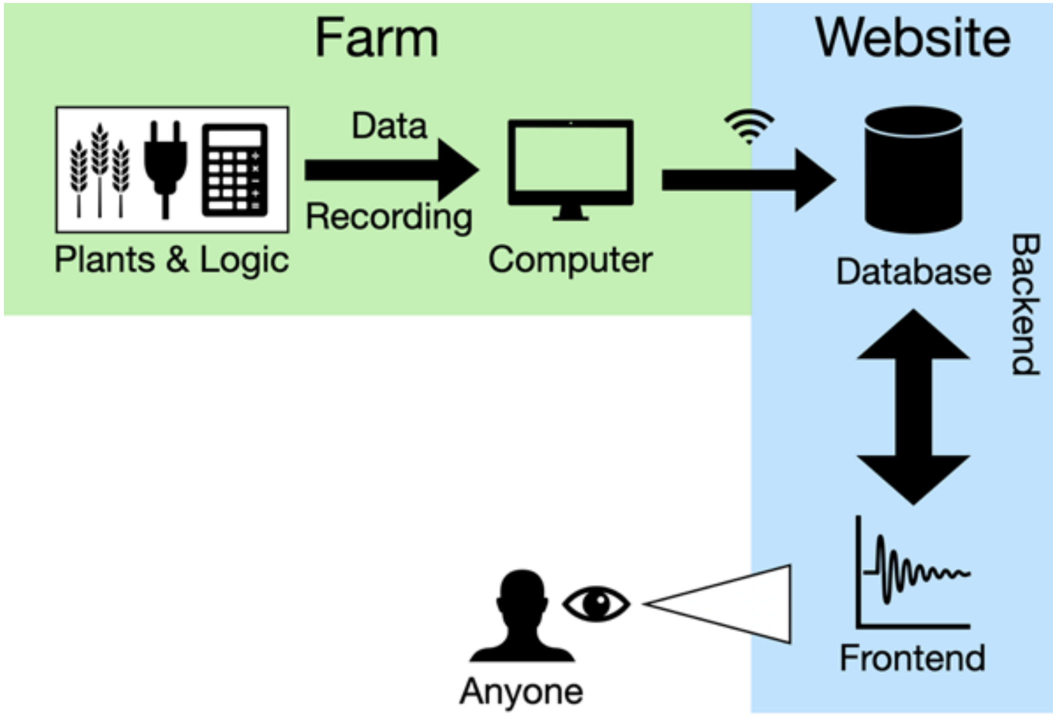

Figure 6: Map of Automation Subsystem (Farm) and Software Stack (Website)

4. Software Stack

The software stack entails the database, back-end, and front-end and ultimately aims to provide a publicly accessible repository of real-time vertical farming data. This repository achieves three objectives: (i) Allows technicians to remotely monitor farm equipment, which improves operations and resource allocation efficiency. (ii) Provides a record for future tuning and improvement of the farm by comparing data to commercial vertical farms and conventional producers. (iii) Creates a public knowledge base to assist other groups with vertical farming research. The majority of vertical farming research is currently conducted by private companies and is thus inaccessible to the public. QVFT's mission is to democratize and advance scientific knowledge in this rapidly developing field.

The lowest level of the stack is a SQL-enabled database, which receives real-time farm data from an Ethernet-enabled computer located on-site (see *Figure 6*). The database architecture corresponds to each element shown in *Appendix A: I/O Components of Automation Subsystem.* It is also flexible enough to accommodate future farm expansion or the addition of multiple farms running simultaneously.

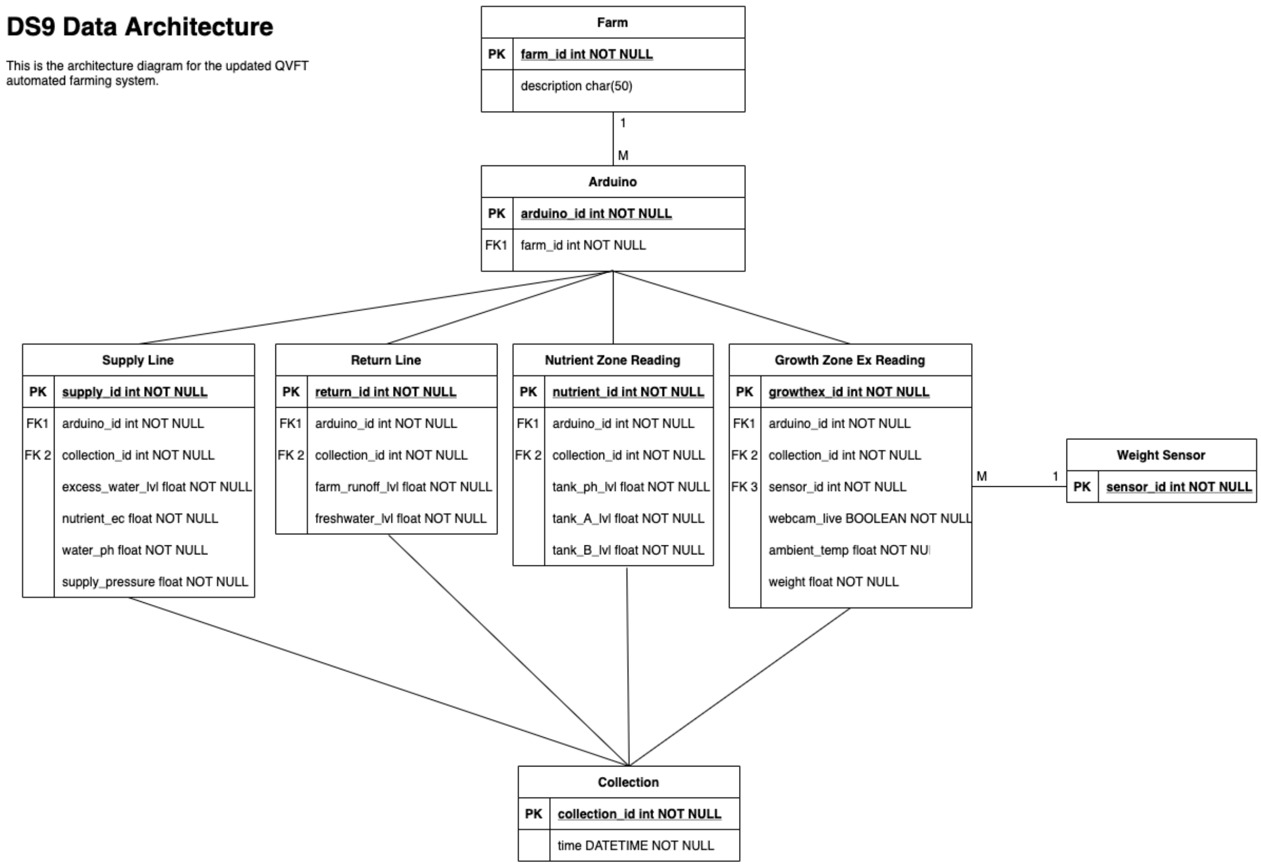

Figure 7: DS9 Database Architecture

The back-end runs through Flask, a Python-based web framework. Flask allows the front-end interface (available through qvft.ca) to display content stored in the database dynamically.

The front-end of the stack has been designed with Bootstrap, an open-source CSS package. Bootstrap allows for the design of websites that scale to multiple resolutions on mobile and desktop. Graphical mock-ups of the Supply Line and Return Line portals are shown below. Further mock-ups of the front-end client are available in *Appendix C: Front-End User Interface Mock-Ups.*

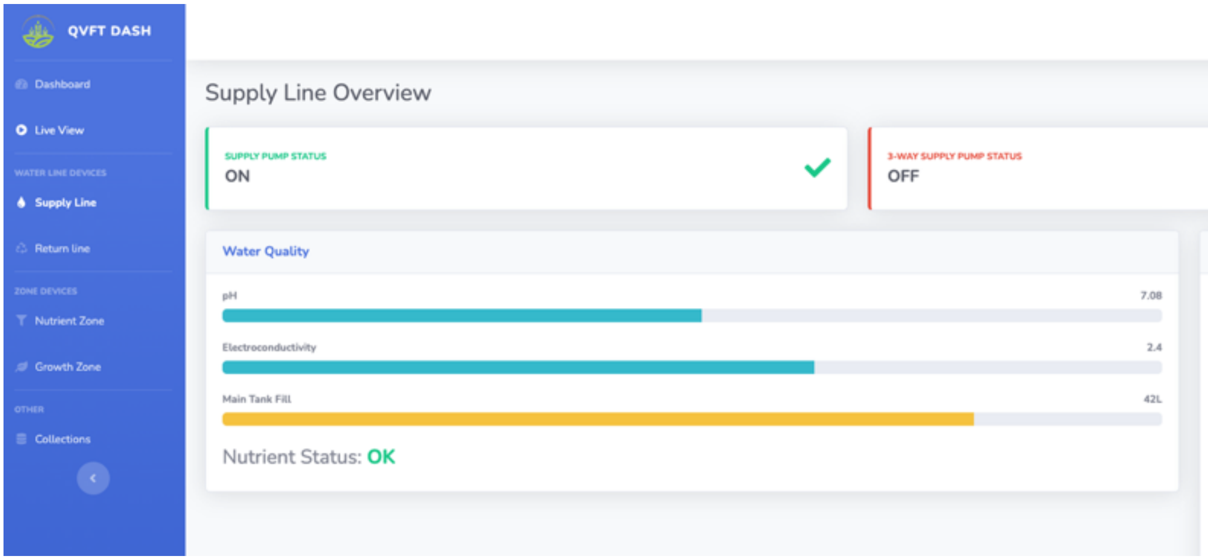

Figure 8: Front-End Mock-Up of Supply Line Portal

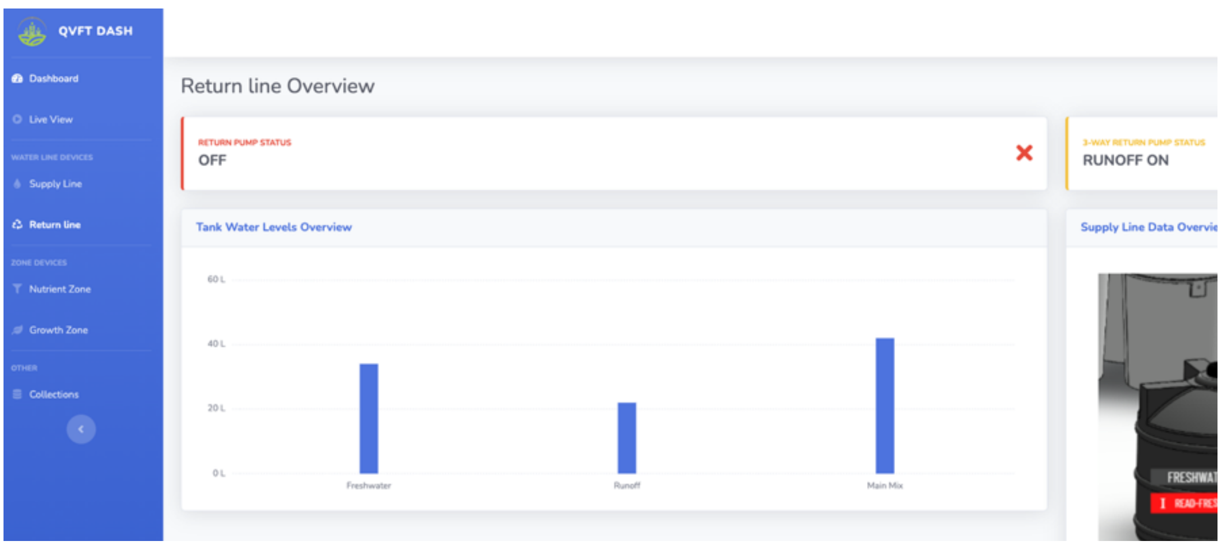

Figure 9: Front-End Mock-Up of Return Line Portal

5. Plant Science Research

a. Crop Selection

In theory, any crop can be cultivated through vertical farming. However, current operations almost exclusively involve small fruits and vegetables such as lettuce, kale, spinach, strawberries, and tomatoes. Leafy greens are popular choices as they meet many of the criteria outlined in *Table 9* (*Appendix F*). [10] Due to its hardiness, adaptability, and existing prevalence in the industry, QVFT will focus solely on the cultivation of kale. [1]

b. Nutrient and pH Requirements for Kale

Precise control of nutrient dosing can significantly improve the yield and speed of plant growth. The three macronutrients that are crucial to all plant life are Nitrogen (N), potassium (K), and phosphorus (P). Micronutrient ratios can be customized to suit the optimal preferences of a particular species. These include calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn), among others. Even within a particular species, the optimal nutrient mixture can vary between different stages of its life cycle.

Table 2 lists the ideal nutrient proportions for leafy greens at various lifecycle stages (ppm). Note that the data reflects optimal conditions under conventional (non-vertical) hydroponic cultivation. While the proportions may change somewhat under aeroponic vertical farming, research in this specific realm is unfortunately scarce.

Cursory research suggests that kale is most productive under slightly acidic conditions (pH of 6-6.5), although further investigation would be beneficial. [5]

Table 2: Optimal Nutrient Mixtures for Leafy Greens at Various Lifecycle Stages

Lifecycle Stage	Optimal Nutrient Proportions [ppm]
Seedling (1-2 weeks) [6]	**N = 140**, P = 40, **K = 210**, Ca = 90, S = 32, Mg = 24, Cl = 89, Fe = 1.00, Mn = 0.25, Zn = 0.13, B = 0.16, Cu = 0.023, **Mo = 0.24**
Juvenile (3-4 weeks) [7]	**N = 165**, P = 40, **K = 250**, Ca = 90, S = 32, Mg = 24, Cl = 89, Fe = 1.00, Mn = 0.25, Zn = 0.13, B = 0.16, Cu = 0.023
Mature (5-6 weeks)	**N = 190**, P = 40, **K = 300**, Ca = 90, S = 32, Mg = 24, Cl = 89, Fe = 1.00, Mn = 0.25, Zn = 0.13, B = 0.16, Cu = 0.023, **Mo = 0.24**

In QVFT’s nutrient zone, nutrients should be separated into three tanks to prevent adverse reactions between compounds while in storage (*Table 3*). [6] The solvent should be distilled water or water that has undergone an RO treatment process. Refer back to *Table 2* for a complete list of nutrients and their proportions.

Table 3: Mixtures for Nutrient Zone Tanks [6]

Name	Nutrients
Nutrient Tank A	KNO_3 (½ of total) , $Ca(NO_3)_2$, Fe^{3+} (iron chelate)
Nutrient Tank B	KNO_3 (½ of total), K_2SO_4, KH_2PO_4, $MgSO_4$, $(NH_4)(H_2PO_4)$, $N_2H_4O_3$, and all other micronutrients
pH Tank	Basic mixture (TBD) to counterbalance the acidic effect of the RO process in the return line.

c. Misting Cycles

Since aeroponic vertical farming lacks an absorbent medium like soil, care must be taken to ensure that plant roots do not dry out while suspended midair. As such, the roots must be misted on a frequent, constant cycle. While scientific research regarding ideal misting cycles is scarce, commercial producers have suggested using a continuous 15-second ON, 30-second OFF cycle.

d. Lighting

The productivity of a particular plant species can be increased by optimizing the intensity, wavelength, and photoperiod of its LED light source.

Light wavelength significantly affects the concentration of primary and secondary metabolites in vegetables. [8] One study of kale found that peak metabolite production occurred at approximately 440 nm and 640 nm in the blue (430-453 nm) and red (642-663 nm) spectral regions, respectively. [9] Another study of Chinese kale in a controlled-environment agriculture context found that an LED red:blue light ratio of 6:3 induced peak nutritional value, whereas 8:3 induced peak physical size, fresh weight, and dry weight.

Chinese kale requires relatively high irradiance intensity to grow effectively. One study reported an optimal daily light integral (DLI) of 47.22 [mol/m^2-day] for Chinese kale. In comparison, the optimal DLI of lettuce and Chinese spinach were 14.51 and 19.90 [mol/m^2-day], respectively. [10] In general, saplings require greater intensity as they are further away from the LED light source. As they grow taller, the intensity requirements decline. [1]

Finally, a study found that an LED photoperiod of 16 hours ON and 8 hours OFF (16/8) produces greater fresh and dry kale yields than 12/12 and 2/1 photoperiods. Leaf length was also 17.1% greater under 16/8 compared to 2/1. [11]

QVFT's farm will employ a 16/8 photocycle and use pulse-width modulation to adjust light intensity throughout the plant growth stages. However, the wavelength of LEDs used on the farm will not be controlled and will depend on the specifications provided by the manufacturer.

e. Harvesting Kale

Kale is known to have a relatively quick growth cycle under conventional (outdoor) growth conditions, with approximately six-week cycles from transplant to harvest. Up to 30% of a kale plant can be partially harvested at once. [12] [13] Leaves should be taken from the bottom to middle of the plant and removed by pulling downwards from the stem. A partial harvest can occur every 6-9 days after some regrowth has occurred. [12]

f. Diagnosing Nutritional Deficiencies and Preventing Pathogens

Regularly monitoring plant health protects the crops and can help indicate broader systemic issues in the vertical farm. A host of nutritional problems can be diagnosed by inspecting the leaves and stems of plants. Nitrogen overload can cause leaves to over-grow and result in weak and broken stems. Potassium deficiency can result in weak stems, drooping leaves, or yellow spots on leaves. Calcium deficiency can cause lower leaves to dry up and turn yellow. [14]

Fungi, parasites, and diseases pose another threat to crops. Fungal growth can result in a brown-tinted stem, yellowed leaves, or spotted leaves, among other effects. The growth basin interiors and return line filtration systems must be regularly maintained to avoid these issues.

6. Business Operations

a. Partnerships

QVFT benefits from a strong partnership network. Some partners offer mentorship and advice, whereas others provide financial donations. We offer three tiers of financial partnerships: Bronze ($100+), Silver ($500+), and Gold ($1,000+). The benefits associated with each tier are listed in *Figure 10* below.

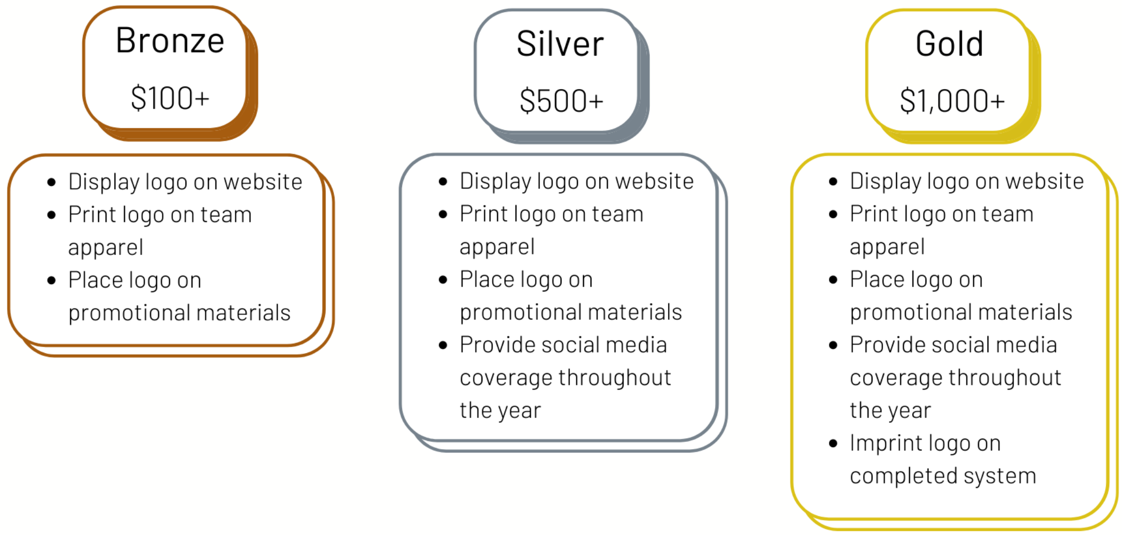

Figure 10: Financial Partnership Tiers

Table 4: List of Partnerships

Name	Description	Type	Degree of Involvement
DDQIC	Start-up incubator at Queen's	Mentorship, Financial (Gold)	• Donated $1,000 to QVFT in Jan. 2021 • Provides extensive engineering advice related to all aspects of the farm's mechanical design
BMA Hydroponics	Kingston-based hydroponic equipment supplier	Financial (Gold)	• Agreed to offer employee pricing on all products (-30%), which will represent >$1,000 in savings
Queen's Arts & Science Student Initiatives Fund	Institutional fund for self-directed projects by students	Financial (Silver)	• Donated $900 to QVFT in Jan. 2020
SIMBL Business Enablement	Consulting firm for start-up founders	Financial (Silver)	• Donated $500 to QVFT in Feb. 2020
ZipGrow Inc.	Supplier of small-scale commercial vertical farms	Mentorship, Semi-Financial	• Provides engineering advice related to the nutrient zone and filtration in the return line • Offered to donate a complete *ZipFarm* to Queen's University through QVFT, which has a market value of $200,500 (paused due to COVID-19)

Name	Description	Type	Degree of Involvement
iGrow	One of the world's most-visited vertical farming news website	Mentorship	• Provides advice and insight into ongoing developments in the vertical farming industry
Aerok Inc.	Aeroponic vertical farming start-up	Mentorship	• Provides engineering advice related to all aspects of the farm's mechanical design • Provides advice and insight into ongoing developments in the vertical farming industry
EngSoc	Student-organization	Affiliate	• QVFT is a ratified organization within EngSoc

b. Community Outreach

QVFT regularly participates in events within the student community. We hosted trade show booths at the 2020 CEEC and QWEC conferences (in-person). In both cases, our booth was among the most popular attractions for attending delegates. We distributed materials, recruited students, and raised awareness of vertical farming. More recently, we participated in the 2021 CEEC and QHBC virtual trade show events.

QVFT also maintains an online presence, with a website (qvft.ca) and social media profiles on LinkedIn and Facebook.

c. Finances & Inventory

QVFT has received $2,400 in combined sponsorship funding to date and requires an additional $5,500 to manufacture the vertical farm prototype on Queen's University campus. See *Appendix B: Budgets and Inventory* for a component-by-component breakdown of planned and incurred costs.

7. Acknowledgements

QVFT’s progress and achievements would not be possible without the important contributions of all past and present members.

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2021-22

Carter Conboy, Chris Molloy, Donal Lynagh, Elissa Wong, Iain Headrick, Joshua Sass-Gregoire, Julia Mackey, Justine Kuczera, Michael Wrana, Patrick Singal, Quantum Hu, Ryan Power, Sebastian Huber-Oikle

8. Contact Information

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Appendix A: I/O Components of Automation Subsystem

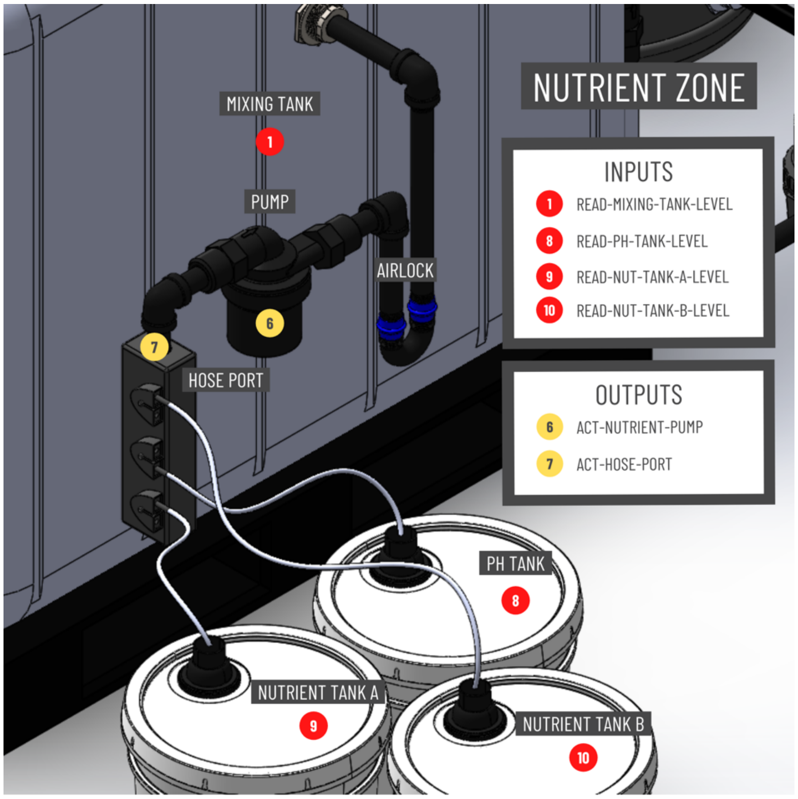

Figure 11: Location of I/O Components in Nutrient Zone CAD Model

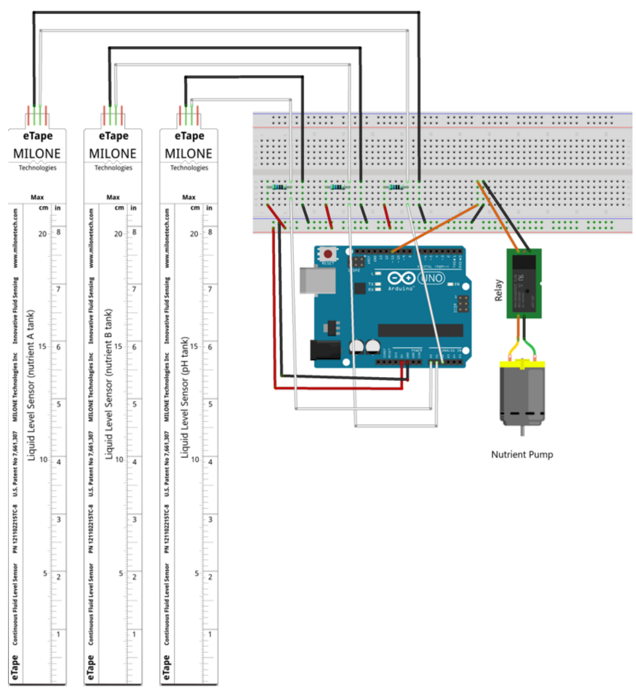

Figure 12: Nutrient Zone Circuit Configuration

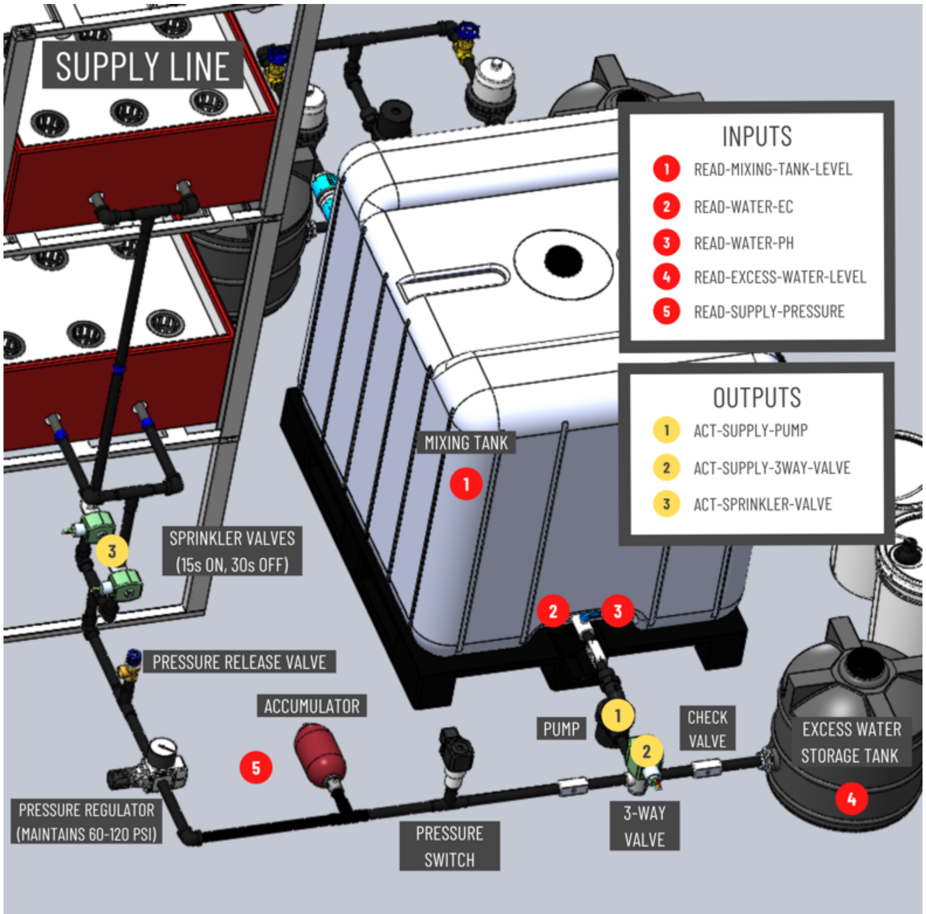

Figure 13: Location of I/O Components in Supply Line CAD Model

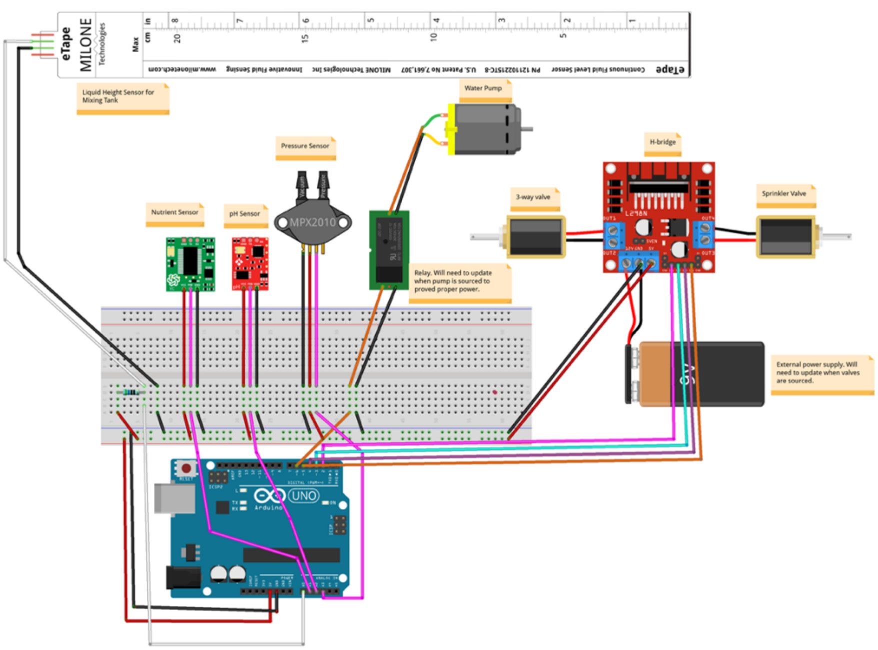

Figure 14: Supply Line Circuit Configuration

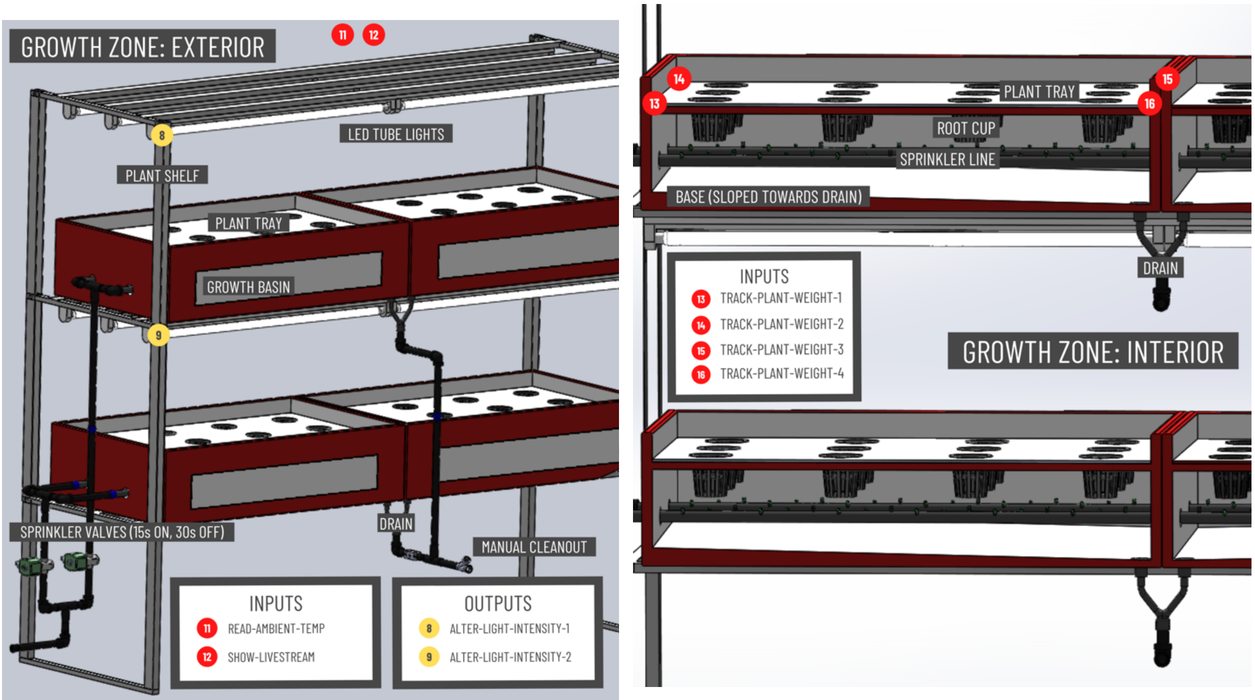

Figure 15: Location of I/O Components in Growth Zone CAD Model

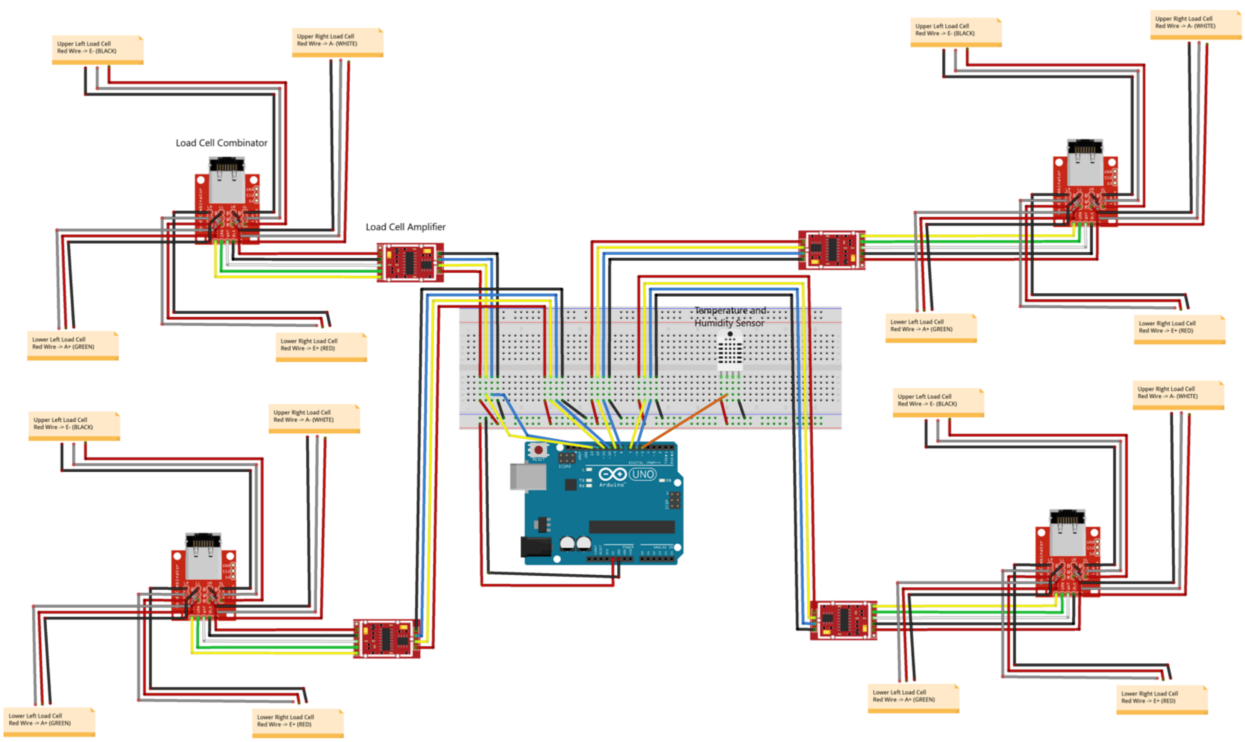

Figure 16: Growth Zone Circuit Configuration

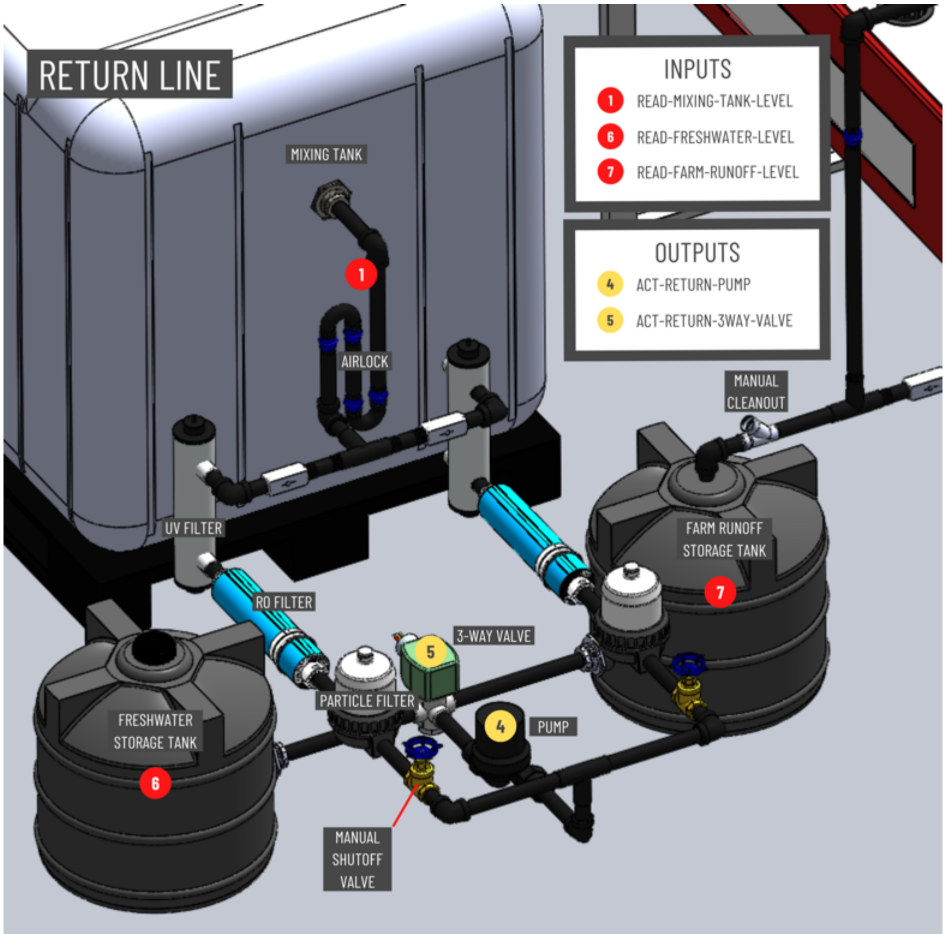

Figure 17: Location of I/O Components in Return Line

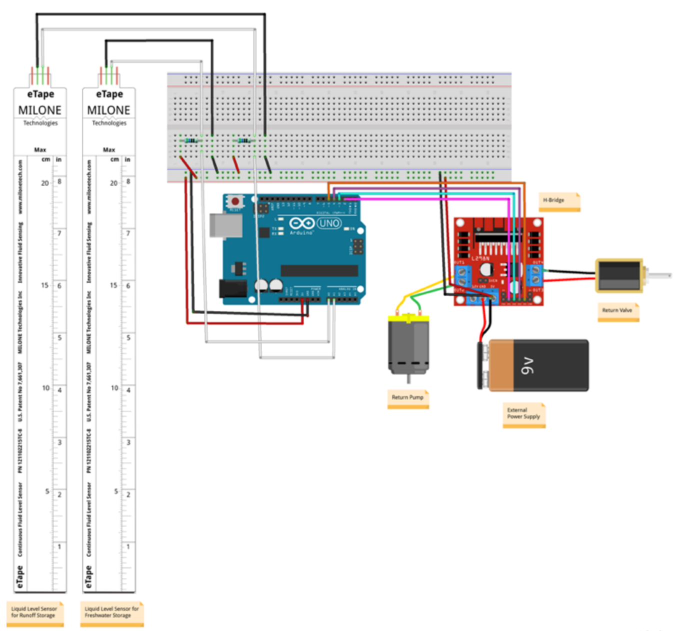

Figure 18: Return Line Circuit Configuration

Table 5: Inputs (Sensors) to the Automation Subsystem

#	ID	Description	Product ID
1	Read-Mixing-Tank-Level	A liquid level sensor ("input") that continuously transmits data to a microcontroller. The microcontroller is pre-programmed with the minimum and maximum acceptable mixing tank liquid levels. If this "input" data is below the minimum threshold, it will execute commands to the pumps and valves in the return line to deposit additional fluid into the mixing tank. These conditions will remain until the readings from "Read-Mixing-Tank-Level" indicate that the liquid levels in the mixing tank have been restored to the maximum threshold. If the liquid level exceeds the maximum threshold, the automation subsystem will command the three-way valve in the supply line to close the branch leading to the growth zone and open the one leading to the excess water storage tank. It will also command the supply line pump to turn on to push the excess fluid towards this tank. These conditions will remain until the readings from "Read-Mixing-Tank-Level" indicate that the liquid levels in the mixing tank have been lowered to the maximum threshold. if this sensor indicates that the fluid levels are not within the ideal range, the other I/O components in the nutrient zone will remain inactive until ideal conditions have been restored.	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)
2	Read-Water-EC	Measures the electrical conductivity (EC) level of the fluid about to enter the supply line through the mixing tank outlet. EC serves as a proxy for the concentration of nutrients within the water.	TDS Sensor/Meter for Arduino: SEN0244 (Datasheet)
3	Read-Water-PH	Measures the pH of the fluid about to enter the supply line through the mixing tank outlet.	pH Meter: SEN0161 or SEN0169 (Datasheet)
4	Read-Excess-Water-Level	Measures the fluid level within the excess water storage tank. Once the fluid level exceeds the specified maximum threshold, an alarm is activated to alert an operator to empty the tank manually. This alarm will take the form of a physical light installed on-site and a digital alarm that can be viewed online through the front-end client.	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)
5	Read-Supply-Pressure	Measures the local pressure midway through the supply line. Since pressure should be between 60 and 120 psi at the sprinkler nozzles, it must be somewhat higher at the point of measurement to account for friction losses, minor losses, and Bernoulli effects.	TBD
6	Read-Freshwater-Level	Measures the fluid level in the freshwater storage tank. Once the fluid level dips below the specified minimum threshold, an alarm is activated to alert an operator to refill the tank manually. This alarm will take the form of a physical light installed on-site and a digital alarm that can be viewed online through the front-end client.	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)
7	Read-Farm-Runoff-Level	Measures the fluid level in the farm runoff storage tank. It is important to ensure that the return line pump is only activated (Act-Return-Pump = ON) if Read-Farm-Runoff-Level is above the minimum specified threshold, which must be physically higher than the pipe that transports fluid from the tank to the pump. Otherwise, air could be sucked into the return line, damaging the pump and reducing its efficiency.	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)

#	ID	Description	Product ID
8	Read-PH-Tank-Level	Measures the fluid level within the pH Tank. If levels are below the specified minimum threshold, an alarm is sent to the front-end to prompt an operator to manually add more of the pH balancing fluid (a base, TBD).	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)
9	Read-Nut-Tank-A-Level	Measures the fluid level within Nutrient Tank A. If levels are below the specified minimum threshold, an alarm is sent to the front-end to prompt an operator to add more of the Nutrient A mixture manually.	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)
10	Read-Nut-Tank-B-Level	Measures the fluid level within Nutrient Tank B. If levels are below the specified minimum threshold, an alarm is sent to the front-end to prompt an operator to add more of the Nutrient B mixture manually.	Continuous Fluid Level Sensor: PN-12110215TC-X (Datasheet)
11	Read-Ambient-Temp	Measures the ambient temperature in the farm room. This data does not affect the actions of any outputs and will be displayed on the front-end client at qvft.ca.	Temp/Humidity Sensor: DHT22 (Datasheet)
12	Show-Livestream	Transmits a live video feed of the crops to the front-end client, which the public can access on qvft.ca. This feature is low-priority and will not be implemented in the short term.	TBD
13, 14, 15, 16	Track-Plant-Weight-1,2,3,4	A piezoelectric pressure sensor is placed under each of the four corners of a plant tray. Together, they measure the combined pressure exerted by the plants and tray. From this, the average mass per plant can be deduced by using basic statics formulas, subtracting the mass of the plant tray, and dividing by the number of plants on that tray.	Load Cell: SEN-10245 (Manual, Datasheet) Load Cell Amplifier: HX711 (Manual, Datasheet)

Table 6: Outputs (Controls) from the Automation Subsystem

#	ID	Description	Product ID
1	Act-Supply-Pump	Sends an electrical signal to turn the supply pump ON. By default, the pump is OFF whenever no signal is being sent.	TBD (actuator attached to pump)
2	Act-Supply-3Way-Valve	Sends an electrical signal to open the branch leading to the excess water storage tank and close the one leading to the growth zone. By default, the reverse orientation is true whenever no signal is being sent. The branch coming from the mixing tank is always open.	TBD (actuator attached to 3-way solenoid valve)
3	Act-Sprinkler-Valve	Sends an electrical signal to close the solenoid valves for 30 seconds. By default, the solenoid valves are open whenever no signal is being sent. The default state is held for 15 seconds. This cycle repeats continuously, resulting in 30-second gaps between 15-second misting cycles.	TBD (actuator attached to solenoid valve)
4	Act-Return-Pump	Sends an electrical signal to turn the return pump ON. By default, the pump is OFF whenever no signal is being sent.	TBD (actuator attached to pump)

#	ID	Description	Product ID
5	Act-Return-3Way-Valve	Sends an electrical signal to open the branch from the freshwater storage tank and close the one from the farm runoff storage tank. By default, the reverse orientation is true whenever no signal is being sent. The branch leading to the rest of the return line is always open.	TBD (actuator attached to 3-way solenoid valve)
6	Act-Nutrient-Pump	This output is not adequately depicted in *Figure 11*. Instead of a single large pump, two peristaltic pumps will be attached directly to the hose port: one which controls the flow of a fixed ratio of nutrients A and B, and another which controls the flow of the pH balancing fluid. Their ON/OFF status depends on the supply-line inputs “Read-Water-EC” and “Read-Water-PH”, respectively. For example, if EC levels are outside the specified ideal range, then “Act-Nutrient-Pump” commands the pump to turn ON and dispense fluid from the three buckets. The pump turns OFF once “Read-Water-EC” registers that EC levels have returned to the ideal range.	TBD (actuator attached to pump)
7	Act-Hose-Port	This feature is shown in the CAD model but is no longer relevant and can be ignored.	N/A
8	Alter-Light-Intensity-1	Modulates the intensity of the LED tubes on the lower level of the growth zone.	TBD
9	Alter-Light-Intensity-2	Modulates the intensity of the LED tubes on the upper level of the growth zone.	TBD

Appendix B: Budgets and Inventory

Table 7: Historical Budget

LINE #	ITEM	Specifics	Unit Price	Qty.	Sub-total	Budget
Revenue						
		Sponsorship, Donations, and Grants				
00001	SIMBL Business Enablement	External donation	$ 500.00	1	$ 500.00	$ 500.00
00002	Faculty of Arts and Science Student Initiatives Fu	University grant	$ 900.00	1	$ 900.00	$ 900.00
00003	DDQIC	Fall sponsorship [Funds not yet accepted]	$ 1,000.00	1	$ 1,000.00	$ 1,000.00
Total Sponsorship, Donations, and Grants						**$ 1,400.00**
		Internal Reimbursements from Members				
00004	Team Sweaters	Member reimbursement for Standard Sweater	$ 35.00	7	$ 245.00	$ 245.00
00005	Team Sweaters	Member reimbursement for Embroidered Sweater	$ 41.00	5	$ 205.00	$ 205.00
00006	Loan	Loan from Patrick to help pay for sweaters (repaid when Artsci grant funds arrived)	$ 40.00	1	$ 40.00	$ 40.00
00007	RBC	Reversed service fee	$ 5.00	1	$ 5.00	$ 5.00
00008	RBC	Reversed service fee	$ 4.50	1	$ 4.50	$ 4.50
Total Internal Reimbursements from Members						**$ 499.50**
TOTAL REVENUE						$ 1,899.50
Expenses						
		Business Operations				
00009	Shoppers Drug Mart	Postage stamps for mailing sponsorship package to potential sponsors	$ 3.38	1	$ 3.38	$ 3.38
00010	RBC	Paper statement with images fee	$ 4.50	3	$ 13.50	$ 13.50
00011	RBC	Monthly banking fee	$ 5.00	3	$ 15.00	$ 15.00
00012	AMS Publishing	3 nametags for use at CEEC trade show, printed at P&CC	$ 8.76	1	$ 8.76	$ 8.76
00013	AMS Publishing	Colour prints of QVFT proposal from P&CC	$ 14.47	1	$ 14.47	$ 14.47
00014	Namecheap.com	Cost of QVFT's domain name (11.98/year, with rates increasing after year 1). Netlify server is linked to this.	$ 16.35	1	$ 16.35	$ 16.35
00015	AMS Publishing	Colour prints of QVFT proposal from P&CC	$ 17.94	1	$ 17.94	$ 17.94
00016	Michelle Ye	Headshots	$ 10.00	9	$ 90.00	$ 90.00
00017	AMS Publishing	Posters and other promotional material for CEEC trade show, printed at P&CC	$ 21.75	1	$ 21.75	$ 21.75
00018	AMS Publishing	Colour prints of sponsorship package booklets from P&CC	$ 29.50	1	$ 29.50	$ 29.50
00019	Michelle Ye	Headshots (discounted rate; 30/four people)	$ 7.50	4	$ 30.00	$ 30.00
00020	Team Sweaters	Sweater money sent back to Spencer	$ 35.00	1	$ 35.00	$ 35.00
00021	Milan Parmar @ Upwork	QVFT logo made through Upwork.com	$ 50.10	1	$ 50.10	$ 50.10
00022	Refreshments for Team Social	24 bottles of Smirnoff Ice	$ 56.00	1	$ 56.00	$ 56.00
00023	Service Ontario IBSA	Registration of Varsity Greens as a business	$ 60.00	1	$ 60.00	$ 60.00
00024	Refreshments for Team Social	24 tall cans of Hey Yall	$ 68.40	1	$ 68.40	$ 68.40
00025	Campus Equipment Outfitters	Embroidered sweaters	$ 41.00	5	$ 205.00	$ 205.00
00026	Campus Equipment Outfitters	Unembroidered sweaters	$ 35.00	8	$ 280.00	$ 280.00
Total Business Operations						**$ 1,015.15**
		Aeroponic System				
00027	Root cups		FREE	~24		
Total Aeroponic System						**$ -**
		Automation System & Software Stack				
00028	Qkits	Tax	$0.62	1	$ 0.62	$ 0.62
00029	10 cm MF jumper cable	Qkits - 40 Pin Male to Female Jumper Cable 10 CM	$2.26	1	$ 2.26	$ 2.26
00030	20 cm MM jumper cable	Qkits - 40 Pin Male to Male Jumper Cable 20 CM	$2.52	1	$ 2.52	$ 2.52
00031	20 cm MF jumper cable	Qkits - 40 Pin Male to Female Jumper Cable 20 CM	$2.52	1	$ 2.52	$ 2.52
00032	10 cm MM jumper cable	Qkits - 40 Pin Male to Male Jumper Cable 10 CM	$1.94	2	$ 3.88	$ 3.88
00033	General parts and supplies	Qkits	$4.50	1	$ 4.50	$ 4.50
00034	Toggle switch	Qkits - DPDT ON-OFF-ON 15A/125V AC	$5.48	1	$ 5.48	$ 5.48
00035	Mini LED board	Qkits - Traffic Light LED Display	$2.95	2	$ 5.90	$ 5.90
00036	Breadboard	RobotShop - Full-Size Bare Breadboard (830 Tie Point)	$7.93	1	$ 7.93	$ 7.93
00037	Load cell	RobotShop- 5 kg Micro Load Cell	$9.35	1	$ 9.35	$ 9.35
00038	Temp/humidity sensor	Qkits - DHT22	$10.26	1	$ 10.26	$ 10.26
00039	Load cell amplifier	RobotShop - HX711	$13.31	1	$ 13.31	$ 13.31
00040	Assorted resistors (100 ohms to 100K ohms)	Qkits - Set of 610 Resistors (E-12 Series)	$15.42	1	$ 15.42	$ 15.42
00041	RobotShop	HST	$15.68	1	$ 15.68	$ 15.68
00042	QKits	Tax	$16.28	1	$ 16.28	$ 16.28
00043	Analog TDS (EC/nutrient) sensor	RobotShop - Gravity Analog TDS Sensor/Meter for Arduino	$18.20	1	$ 18.20	$ 18.20
00044	Breadboard	Qkits - 1260 Point Bread Board	$23.16	1	$ 23.16	$ 23.16
00045	Arduino Nano	RobotShop - Arduino Nano 33 IOT Microcontroller with Headers	$32.43	1	$ 32.43	$ 32.43
00046	pH meter	RobotShop - Gravity Analog pH Meter Kit	$39.33	1	$ 39.33	$ 39.33
00047	Multimeter	Qkits - 3 1/2 Digit Multi Meter 20A	$54.12	1	$ 54.12	$ 54.12
Total Automation System & Software Stack						**$ 283.15**
		Plant Science Research				
00048	Custom Hydro Nutrients	Magnesium sulfate 1lb	$ 4.62	1	$ 4.62	$ 4.62
00049	Custom Hydro Nutrients	Calcium nitrate 1lb	$ 6.60	1	$ 6.60	$ 6.60
00050	Custom Hydro Nutrients	Soluble trace element mix 8oz	$ 7.52	1	$ 7.52	$ 7.52
00051	Custom Hydro Nutrients	Potassium chloride 1lb	$ 10.23	1	$ 10.23	$ 10.23
00052	Custom Hydro Nutrients	ICL PeaK MKP 1lb	$ 11.88	1	$ 11.88	$ 11.88
00053	Custom Hydro Nutrients	Shipping	$ 45.13	1	$ 45.13	$ 45.13
Total Plant Science						**$ 85.98**
TOTAL EXPENSES						$ 1,384.28
		SUMMARY				
Total Revenue						**$ 1,899.50**
Total Expenses						**$ 1,384.28**
Net Surplus						**$ 515.22**

Table 8: Future Budget (Estimated, Excludes Sales Tax)

LINE #	ITEM	Specifics	Unit Price	Qty.	Sub-total	Budget
Revenue						
		Sponsorship, Donations, and Grants				
Total Sponsorship, Donations, and Grants						$ -
TOTAL REVENUE						$ -
Expenses						
		Business Operations				
Total Business & Administration						$ -
		Aeroponic System				
00001	1/2" clear tubing	USA Sealing Tubing,Clear,1/2 in Inside Dia.	$ 3.28	3	$ 9.84	$ 9.84
00002	1/8" ID rubber tubing	length	$ 14.60	1	$ 14.60	$ 14.60
00003	2-way solenoid valve + actuators	Alcon 05EZ009A2-1JIA Solenoid Valve	$ 48.12	2	$ 96.24	$ 96.24
00004	2" pipe coupling (rough estimate of qty.)	Eastman 2 in. x 2 in. PVC DWV Flexible Coupling	$ 4.67	10	$ 46.70	$ 46.70
00005	2" PVC elbow joint	Home Depot Charlotte Pipe 2 in. PVC Schedule. 40 90-Degree S x S Elbow Fitting	$ 3.53	22	$ 77.66	$ 77.66
00006	2" PVC Piping (385" altogether in CAD model)	Xirtec white PVC SCH40 plain.end pipe, 2 in. x 10 ft	$ 25.99	4	$103.96	$ 103.96
00007	2" PVC U-bend	Waterwau PVC U-Bend - 2" Slip x 2" Slip	$ 14.19	2	$ 28.38	$ 28.38
00008	3-way solenoid valve	Tameson TP-DA 1/4" 3/2 Way NC Brass FKM 0-2bar 12V DC	$ 55.10	2	$110.20	$ 110.20
00009	3/4" PVC Piping (384" of sprinkler line in CAD model)	Xirtec white PVC SCH40 plain.end pipe, 3/4 in. x 10 ft.	$ 13.99	4	$ 55.96	$ 55.96
00010	30 gallon plastic drum	Very rough estimate	$ 88.00	3	$264.00	$ 264.00
00011	Accumulator tank	SEAFLO Pre-Pressurized Accumulator Tank SFAT-075-125-01	$ 65.01	1	$ 65.01	$ 65.01
00012	Analog pressure gauge	Baker 421AVND-300 Pressure Gauge, 0-300 PSI	$ 37.40	1	$ 37.40	$ 37.40
00013	Check valves	American Valve P32S 2" PVC in-Line Check Socket Schedule 40, 2-Inch	$ 23.61	5	$118.05	$ 118.05
00014	Custom-made growth basin built from CAD model	Very rough estimate	$ 60.00	4	$240.00	$ 240.00
00015	Digital pressure sensor	Robotshop Water Pressure Sensor G1/4 1.2MPa	$ 16.54	1	$ 16.54	$ 16.54
00016	Full-spectrum LED tubes (price is special deal arranged with manufacturer)	Jointech LED T8 Tube Plant Light - 32W Full Spectra		8	$400.00	$ 400.00
00017	General hardware	Very rough estimate	$100.00	1	$100.00	$ 100.00
00018	IBC Tank (For mixing tank)	330 Gallon Reconditioned IBC Tote (IBC Tanks)	$ 222.99	1	$222.99	$ 222.99
00019	Manual cleanout w/ plug	Mueller Industries Clean Out Tee, W/ Plug, 2 in, PVC, WH	$ 11.36	1	$ 11.36	$ 11.36
00020	Manual shutoff valve (2-way_	Boshart Canada 2 inch PVC FPT x FPT Molded-in-Place Compact Ball Valve (2-Pack)	$ 31.20	2	$ 62.40	$ 62.40
00021	Misting nozzle kit	Kalolary 50-pack	$ 42.74	1	$ 42.74	$ 42.74
00022	Particle filter	HydroLogic Small Boy Sediment Carbon Filter 1 GPM	$164.99	2	$329.98	$ 329.98
00023	Peristaltic pump	ZipGrow Peristaltic Pump – Single (300mL/min)	$ 174.95	2	$349.90	$ 349.90
00024	Plastic pail lid	Standard Lid	$ 2.45	3	$ 7.35	$ 7.35
00025	Pumps	Seaflo 12V 100PSI Self-Priming Diaphragm Pump, 1.3 GPM	$ 44.99	3	$134.97	$ 134.97
00026	Reverse osmosis filter	Stealth-RO™ Reverse Osmosis Filter	$239.99	2	$479.98	$ 479.98
00027	Rona All-Purpose Round Pail		$ 3.97	3	$ 11.91	$ 11.91
00028	Sprinkler nozzles	Antelco 0.36 mm micro spray jet (100 pack)	$ 57.70	1	$ 57.70	$ 57.70
00029	Tee joint	Rona 2-in PVC Tee	$ 6.89	6	$ 41.34	$ 41.34
00030	Tools	Very rough estimate	$100.00	1	$100.00	$ 100.00
00031	UV filter	GrowoniX UV Steriliation for EX100-GX400	$ 216.44	2	$432.88	$ 432.88
Total Mechanical						$3,526.50
		Automation System & Software Stack				
00032	Arduino 21V power supplies	Very rough estimate	$ 15.00	4	$ 60.00	$ 60.00
00033	Continuous fluid level sensor	PN-12110215TC-X	$59.95	7	$419.65	$ 419.65
Total Systems Automation						$ 479.65
		Plant Science Research				
Total Plant Science						$ -
TOTAL EXPENSES						$4,006.15
		SUMMARY				
Total Revenue						$ -
Total Expenses						$4,006.15
Net Surplus						-$4,006.15

Appendix C: Front-End User Interface Mock-Ups

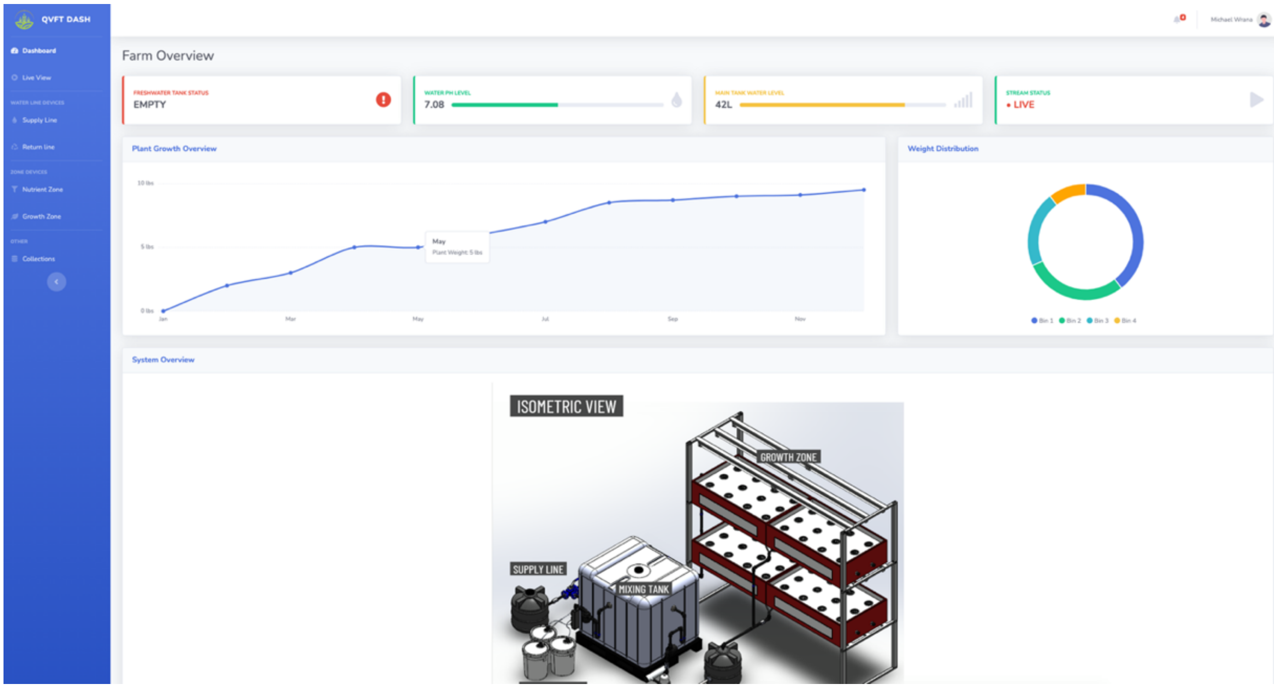

Figure 19: Front-End Mock-Up of Overall Farm Portal

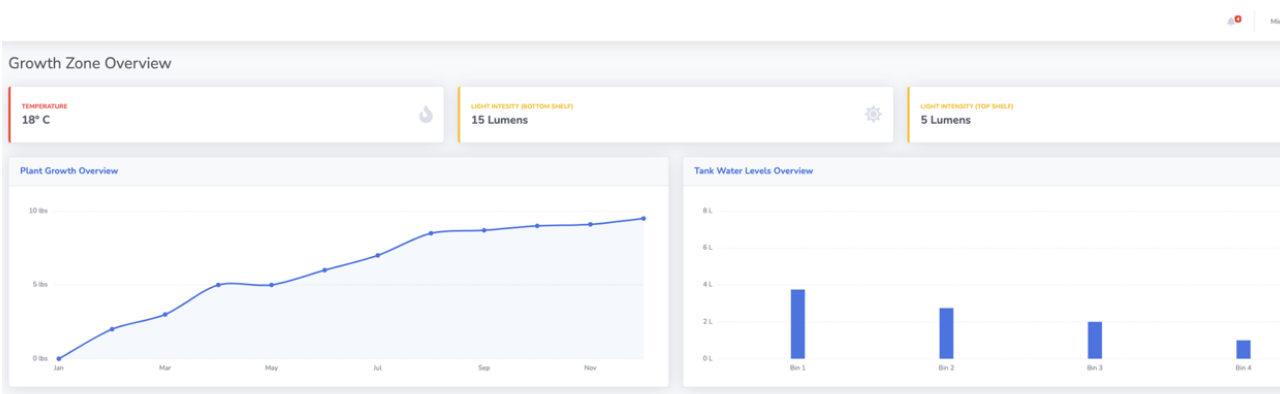

Figure 20: Front-End Mock-Up of Growth Zone Portal

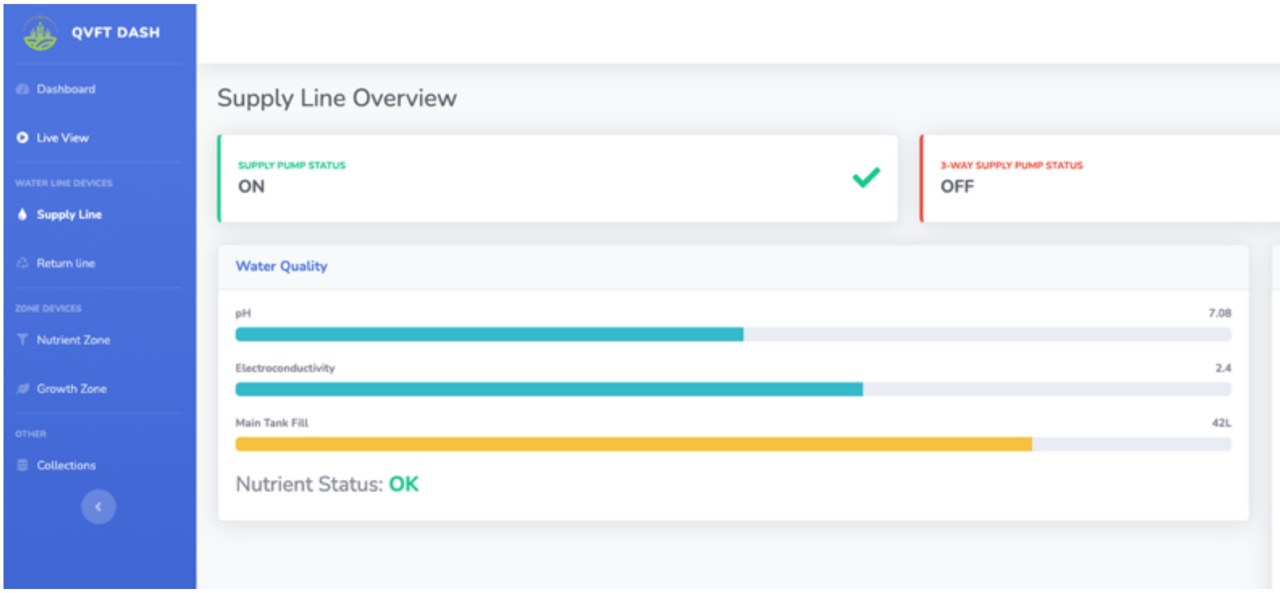

Figure 21: Front-End Mock-Up of Supply Line Portal

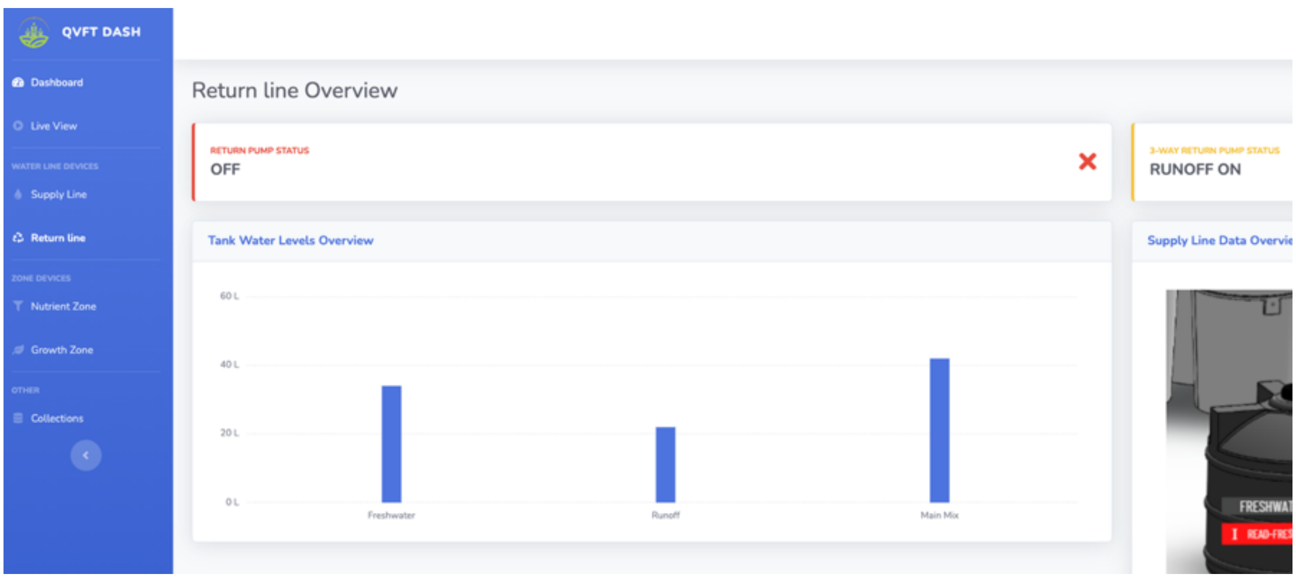

Figure 22: Front-End Mock-Up of Return Line Portal

Appendix D: Supply Line Pump Sizing Calculations

```
% Supply Line Pump Sizing Calculations

% Constants
g = 9.81; % [m/s^2] acc. of gravity
rho = 997; % [kg/m^3] water density @ room temp.
P1 = 0; % [Pa] gauge pressure inside mixing tank @ point 1

mu = 0.0009; % [add units] dynamic visc. of water at room temp

% Part 1. ADJUSTABLE PARAMETERS
n_sprinklers = 40; % from CAD, arbitrarily chosen
L = (21+21+9+15+3+18+6+6+3+3)/39.3701; % [m] Pipe length from point 1 to 2
Z1 = 0.5; % [m] fluid height within mixing tank; this value was guessed
Z2 = 0.63; % [m] height of point 2 based on CAD model; needs an update?
    % Z2 = Z3 always
e = 0.0045e-3; % [m] surface roughness of wrought iron (note: "e-3" means "x10^-3")
D = (60.3-2*3.91)*10^-3; % [m] inner diam. of nominal 2" (50mm) pipe
D = 0.051;
A = pi/4*(D^2); % [m2]
K_elbow_90deg = 0.75;
K_check_valve = 2;
K_tee_joint = 1; % guessed, need more info
K_threeway = 1; % guessed, need more info
K_l = K_elbow_90deg*2 + K_check_valve*2 + K_tee_joint + K_threeway*1;
K_l = 10;
% ^ Minor loss coefficient (K_l):

%% Part 1. Analyze between Point 2 and Point 3

% 1. Determine P, Q at sprinkler line based on other datasheet specs provided
Psprinkler = 50e3; % [Pa] sprinkler discharge pressure from datasheet
Dsprinkler = 0.36e-3; % [m] diameter of sprinkler orifice from datasheet
Asprinkler = pi/4*(Dsprinkler^2); % [m2] sprinkler orifice area
Qsprinkler = 13/3600/1000; % [m3/s] converted from L/hour rating on datasheet
% ^ flow rate per ONE sprinkler
Q2 = Qsprinkler*n_sprinklers; % Total flow rate out of system
V2 = Q2/A;
P2 = Psprinkler; % Assuming constant pressure throughout sprinkler line

% 2. Calculate pump head needed via Bernoulli from point 1 to 2
Re2 = rho*V2*D/mu; % [-] Reynolds # @ pt 2, used to approx. fric. factor
f = (1/(-2*log10((e/D)/3.7-2.51/Re2*...
    (1.8*log10(((e/D)/3.7)^1.11+6.9/Re2)))))^2;
hpump = P2/(rho*g) + Z2 - Z1 + V2^2/(2*g)*(1+K_l+f*L/D); % [m]

% 3. So far our calcs have assumed that the sprinklers are always on.
% How about when they're off? Flow rate would be 0. So let's simulate
% the system performance between these two boundary conditions.

Qactual = linspace(0,Q2);
hsys = P2/(rho*g) + Z2 - Z1 + (1+K_l+f*L/D)*(8/(pi^2*D^4*g)).*Qactual.^2;
close all
subplot(2,2,1)
plot(Qactual*3600000/60, hsys);
hold on
xlab = xlabel('Flow Rate [L/min]');
ylab = ylabel('System Head [m]');
title('Supply Pump Performance Curve (Metric)')
```

```
subplot(2,2,2)
plot(Qactual*15850.323141, hsys*3.28084);
hold on
xlab = xlabel('Flow Rate [GPM]');
ylab = ylabel('System Head [ft]');
title('Supply Pump Performance Curve (Imperial)')
subplot(2,2,3)
plot(Qactual*3600, hsys);
hold on
xlab = xlabel('Flow Rate [m3/h]');
ylab = ylabel('System Head [m]');
title('Supply Pump Performance Curve (Metric)')


% 5. Prevent Cavitation in Pump
% Net-Positive Suction Head (NPSH) available @ Pump
Patm = 101325; %[Pa] Suction line pressure (assume equal to P @ point 1)
Pvapour = 2338.8; % [Pa] pressure at which water becomes vapour @ 20degC
Lsuction = 6/39.3701;
Zpump = 0; %[m]
K_l_suction = K_check_valve*1;
hfpump = V2^2/(2*g)*(f*Lsuction/D); % roughly assume Vsuction is same as V2
hmpump = V2^2/(2*g)*K_l_suction;
NPSH_avail = (Patm - Pvapour)/(rho*g)+Z1-Zpump - V2^2/(2*g) - hfpump - hmpump; % [m]

% 6. DESIGN CONSTRAINT: NPSH_avail must be > NPSH_required
% NPSH_required is obtained from manufacturer's datasheet
% We still need to figure this part out
```

Appendix E: Farm Logic Pseudocode

```
%% FARM LOGIC MODEL (Pseudocode)
% 'FALSE' is default condition for all control points
% 'FALSE' means signal/current = OFF
% 'TRUE' means signal/current = ON

%% CONSTANTS (TBD BY MECH AND PLANT SCIENCE TEAMS)
mixing_tank_level_min = ; % [m] minimum allowable water height in mixing tank
mixing_tank_level_max = ; % [m] max allowable water height
farm_runoff_level_min = ; % [m] min allowable water height in farm runoff tank
farm_runoff_level_max = ; % [m] max allowable water height
freshwater_level_min = ; % [m] min allowable water height in freshwater tank
excess_water_level_max = ; % [m] max allow. water height in excess water tank
nutrient_tank_level_min = % [m] min. allow. height in nutrient/pH buckets

sprinkler_time_ON = 15; % [seconds] duration of each plant spraying
sprinkler_time_OFF = 30; % [seconds] rest time between each spraying

supply_pressure_min = 60*6895; % [PSI converted to Pa] min allow. in line
supply_pressure_max = 120*6895; % [Pa] max allow. in supply line

water_ec_min = ; % [-] min. allow. EC (nutrient content) in mixing tank
water_ec_max = ; % [-] max. allow. EC

water_PH_min = ; % [-] min. PH allowed in mixing tank

optim_light_intensity_1 = ; % optimal value for plants growing on top shelf
optim_light_intensity_2 = ; % optim. val. for plants on bottom shelf
% these optimal values will changes as the kale plants progress through
% their life cycles

%% 1. SUPPLY LINE

% 1a. Sprinkler Valve ON/OFF Cycle
% This cycle repeats continuously and independently from rest of system
ACTUATE_SPRINKLER_VALVE = TRUE; % opens up valve (signal/current = ON)
runtime = sprinkler_time_ON;
ACTUATE_SPRINKLER_VALVE = FALSE; % closes false (signal/current = OFF)
runtime = sprinkler_time_OFF;

% 1b. Maintain Supply Line Pressure
if READ_SUPPLY_PRESSURE < supply_pressure_min
% insufficient pressure at initial condition
    while READ_SUPPLY_PRESSURE < supply_pressure_max
    % pressure in line is too low to properly spray plants
    ACTUATE_SUPPLY_PUMP = TRUE;
    % pump adds extra pressure since outflow is constrained @ sprinklers
    % pump turns OFF once we've reached the max allowed supply pressure
    end
else
    do nothing
    % the line pressure is within the acceptable range
    % the accumulator maintains the pressure to some degree while pump=OFF
end

% 1c. Manual Emptying of Excess Water Tank
if READ_EXCESS_WATER_LEVEL > excess_water_level_max
    sprintf('Please empty excess water storage tank')
end
```

```matlab
%% 2. RETURN LINE

% 2a. Recycle Water from Farm Runoff Storage to Mixing Tank
if READ_FARM_RUNOFF_LEVEL >= farm_runoff_level_max
    % only empty the runoff tank when it is full
    while READ_FARM_RUNOFF_LEVEL >= farm_runoff_level_min
        ACTUATE_RETURN_PUMP = TRUE; % drains the runoff tank
    end
else
    do nothing
end

% 2b. Manual Refilling of Freshwater Tank
if READ_FRESHWATER_LEVEL < freshwater_level_min
    sprintf('Please refill freshwater storage tank')
end

%% 3. NUTRIENT ZONE

% 3a. Send Manual Refill Notifications
if READ_NUTRIENT_TANK_A_LEVEL < nutrient_tank_level_min
    sprintf('Please refill Nutrient Tank A')
elseif READ_NUTRIENT_TANK_B_LEVEL < nutrient_tank_level_min
    sprintf('Please refill Nutrient Tank B')
elseif READ_PH_TANK_LEVEL < nutrient_tank_level_min
    sprintf('Please refill PH Tank')
end

%% 4. GROWTH ZONE

% 4a. Track the Average Plant Weight in Real-Time
average_weight = 0.25*(TRACK_PLANT_WEIGHT_1 + TRACK_PLANT_WEIGHT_2 ...
    + TRACK_PLANT_WEIGHT_3 + TRACK_PLANT_WEIGHT_4);
% record this data in our records as it updates in real time

% 4b. Control the Light Intensity
% Not sure how to write this part, since control isn't Boolean
ALTER_LIGHT_INTENSITY_1 = optim_light_intensity_1;
ALTER_LIGHT_INTENSITY_2 = optim_light_intensity_2;

% 4c. Passively Record Ambient Data
READ_AMBIENT_TEMP
SHOW_WEBCAM_LIVESTREAM

%% 5. MIXING TANK (INVOLVES SUPPLY/RETURN LINES AND NUTRIENT ZONE)

% 5a. Maintain Acceptable Mixing Tank Water Levels
if READ_MIXING_TANK_LEVEL < mixing_tank_level_min % mixing tank needs more water!
    % Farm runoff storage is our 1st and preferred choice for additional
    % water over the freshwater storage tank
    if READ_FARM_RUNOFF_LEVEL > farm_runoff_level_min
        ACTUATE_RETURN_PUMP = TRUE;
        % Shut off pump once 'if' statement stops being true
        % Probably need a while loop here
    % Freshwater is needed if there is insufficient recycled water
    % (farm runoff) available
    elseif READ_FRESHWATER_LEVEL > freshwater_level_min
```

```
        % now shut off runoff branch and open freshwater branch
        ACTUATE_RETURN_3WAY_VALVE = TRUE;
        delay = 5; % seconds
        ACTUATE_RETURN_PUMP = TRUE;
    % 'Else' is reached when there is still not enough water in the
    % mixing tank, but there is also insufficient refill water in the
    % farm runoff and freshwater storage tanks. Thus we need to
    % manually add more water to the freshwater storage tank
    else
        sprintf('Please refill freshwater storage tank');
    end
elseif READ_MIXING_TANK_LEVEL > mixing_tank_level_max % too much water!
    if READ_EXCESS_WATER_LEVEL < excess_water_level_max % excess tank has room
        % now shut off sprinkler branch and open excess water branch
        ACTUATE_SUPPLY_3WAY_VALVE = TRUE;
        delay = 5; % seconds
        ACTUATE_SUPPLY_PUMP = TRUE; % eject mxg tank water to excess tank
    else % excess tank is full; can't accept any more water
        sprintf('Please empty excess water storage tank');
        do nothing
    end
else % the mixing tank level is within acceptable range
    do nothing
end

% 5b. Maintain Acceptable Mixing Tank EC (Nutrient) Levels
% Mech team still need to figure out how hose port will work
% For now, use SELECT_HOSE_PORT_X and SELECT_HOSE_PORT_Y as simplifications
if READ_WATER_EC < water_EC_min % water needs more nutrients!
    SELECT_HOSE_PORT_X = TRUE; % nutrient A,B ports = OPEN, pH port = CLOSED
    delay = 5; % [seconds]
    ACTUATE_NUTRIENT_PUMP = TRUE;
    % Shut off pump once 'if' statement stops being true
    % Probably need a while loop here
elseif READ_WATER_EC > water_EC_max % too much nutrition, must dilute!
   if READ_FRESHWATER_LEVEL > freshwater_level_min
        ACTUATE_RETURN_3WAY_VALVE = TRUE;
        delay = 5; % seconds
        ACTUATE_RETURN_PUMP = TRUE;
        % freshwater is pumped from return line until the nutrients in
        % the mixing tank are sufficiently diluted
        % Shut off pump once the EC becomes acceptable (use while loop?)
   else
       sprintf('Please refill freshwater storage tank');
       do nothing
   end
else
    do nothing
    % Mixing Tank EC (nutrient) levels are in the acceptable range
end

% 5c. Maintain Acceptable Mixing Tank PH Levels
if READ_WATER_PH < water_PH_min % water is too acidic, add some base!
    SELECT_HOSE_PORT_Y = TRUE; % nutrient A,B ports = CLOSED, pH port = OPEN
    delay = 5; % [seconds]
    ACTUATE_NUTRIENT_PUMP = TRUE;
    % Shut off pump once 'if' statement stops being true
    % Probably need a while loop here

    else
        do nothing
        % water PH is in the acceptable range above the minimum threshold
    end
```

Appendix F: Crop Selection for Vertical Farming

Table 9: Commercial Suitability Factors of Crops [10]

Factor	Description
Growth Cycle	As vertical farming is a cost-intensive food production process, crops that have a short growth cycle are preferred.
Harvestable Yield	Plants with high harvestable yield (e.g., kale, lettuce, Swiss chard) are preferred as they minimize the amount of energy wasted on unusable parts of the crop. Examples of plants with low harvestable yield include tomatoes, blueberries, and blackberries.
Stature	Plants of shorter stature require less spacing between growth layers, meaning greater productivity within a fixed indoor space. Horizontal spacing will account for the expected width of the plants at maturity.
Seasonal Demand Variability	Vertical farms can be optimized specifically for crops with year-round demand as they eliminate the need for crop rotation. Consistent demand and crop specialization lend well to increased productivity, profitability, and automation. Watermelon, however, is an example of a crop that experiences seasonal demand variation, possibly due to the noticeable quality differences between seasons. If able to deliver consistently high-quality watermelons year-round, vertical farming could perhaps have a competitive edge (and experience elevated demand) outside the summertime.
Geographic Growth Range	Certain crops such as wild blueberries require precise soil and climatic conditions, resulting in a limited geographic growth range. Other examples include tropical fruits and coffee beans, which must be imported by those in northern climates year-round. As vertical farming makes geographic constraints irrelevant, it could potentially produce such crops locally and offer a fresher, tastier, more sustainable product.
Automation Compatibility	Crops conducive to automation can minimize labour demand.
Perishability	Highly perishable crops grown through conventional methods often have a brief shelf life, as time is required to transport from farm to market. By operating within or around cities, vertical farming can deliver produce sooner to consumers and have a distinct advantage in this area.
Market Value	As vertical farming is not yet an economy of scale, food production is inevitably costlier than the conventional alternative. Crops which already demand premium pricing such as baby lettuce are better suited to vertical farming given the present realities of the industry.
Potential for Added Value	Vertical farming is able to grow crops of potentially higher quality than that of traditional agriculture through CEA controls and optimization. Organic by design, these crops may also have improved texture, colour, flavour, and shelf life. As a result, crops selected for cultivation should be those which present the greatest opportunity for improvement on the existing industry standard.