Chancellor's Honors Program Projects

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Nutrient delievery system for phenotype screening corporation

Lisa D. Zachary
University of Tennessee - Knoxville

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Nutrient Delivery System for Phenotype Screening Corporation

Haley Baker

Meredith Neal

Lisa Zachary

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Background

Phenotype Screening Corporation (PSC) needs an improved system to deliver nutrient solution to individual plants. The current system fails unpredictably, and algae build-up interferes by clogging the exit nozzles. It is important to have reliable nutrient delivery because the accuracy of research done with these plants depends on the system's consistency. The physical setup of the current system is shown below.

The deliverable system will need to maintain a reservoir of a water-nutrient mixture and create a flow such that the mixture will pass through the plants' containers and then into a collection area for recirculation. A filtration component will need to prevent the contamination of the mixture and the build-up of undesirable materials. Requirements for the system include uniform flow to each plant, ease of plant removal and reintroduction to the system, and use of biologically inert materials. Beyond these basic characteristics, integrated controls will need to alert the user to a malfunction. Constraints placed on the project include that the system will not allow metal to come into contact with the mixture and it will not make use of nozzles at the point of delivery to the plant. The challenge is to provide a working nutrient-delivery system that operates within the given constraints.

Work Statement

The objective of the plant nutrient delivery project is to design, fabricate, and implement a new nutrient delivery system for PSC. The successful nutrient delivery system will perform in a reliable, controllable, and simplistic manner.

Design Methodology

The methodology for this capstone design project uses basic steps for developing a product idea. Once the problem is determined, whether it is redesigning or developing a product, operational requirements are determined. The operational requirements lead to design specifications. The design specifications are the baseline for the design alternatives that will then be generated. Design alternatives will then be evaluated and a preliminary design will be chosen. A prototype is then built and tested. If the prototype tests well, the prototype is then put into fabrication. The process is outlined in Figure 1.

Operational Requirements

Operational requirements define the expected functional performance of a redesign or a new product. The requirements can come from a development of a new product or a company's need to improve upon their existing systems. From the operational requirements a list of design specifications are then determined.

Design Specifications

Design specifications are the constraints placed on a design. They identify what the design should accomplish as well as how it should perform. Design specifications can be thought of as the engineering baseline. All concepts will be generated from these specifications. The extent to which the customer is satisfied is based on how well the final design concept fits those specifications.
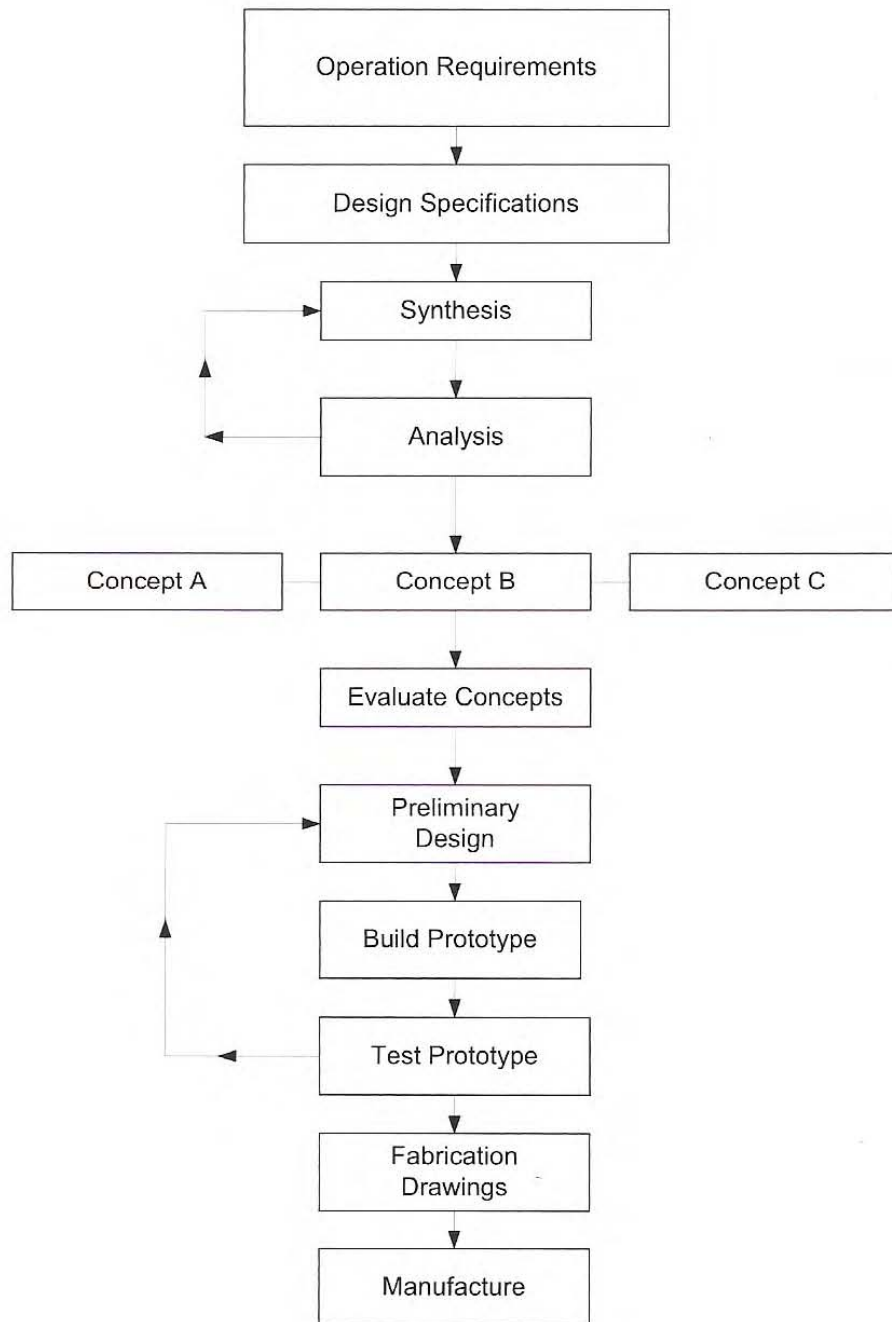
Figure 1
The Project Development Process

Design Alternatives

After the design specifications have been determined the team then will generate design alternatives. Several design alternatives were generated. Through group discussions, ideas were thrown out or put into more consideration. All of the concepts had to meet the design specifications. The ideas were generated through means of researching patents, reference books, speaking with experts in engineering, general brainstorming, and researching existing products on the Internet.

Evaluating Design Alternatives

Since there is no one unique solution when solving a design problem, the method used to evaluate the design alternatives was a numerical method. Important elements to the design along with the constraints of the design were given a numerical weight. Then each concept was graded based on how well the design concept fit that constraint or element. After adding up each weighted element, the concept with the highest score is chosen as the preliminary design.

Preliminary Design of Best Concept

After deciding on a preliminary concept, discussing with the customer is important to ensure the design is what the customer had envisioned. Once the agreement with the customer has been established, it is time to finalize the design. The design concept is expanded by more accurately defining the subsystems, mechanical components, and materials of the design. Calculations are performed and the finalized design is drawn.

Fabrication of Prototype

Once the design is finalized, a prototype can be constructed. The prototype allows for testing to ensure the design will work properly. After the prototype is confirmed to work, the design is again discussed with the customer. If the customer agrees to the design, fabrication of the prototype begins.

Design Specifications

Design specifications are the constraints that must be considered. They identify what the design should accomplish as well as how it should perform. The design specifications below can be thought of as the engineering baseline of the project. The following concepts were generated from these specifications. In order to meet the specific requirements of PSC, the following design specifications are given:

- Reservoir capacity – 5-6 gallons

- Reservoir service – approximately 20 plants

- Solution recirculates

- Individual nutrient solution delivery mechanism

- 30-500 mL per hour of solution to each plant

- User input flow rate

- Easy plant removal

- Constant or intermittent solution delivery

  o Intermittent flow must be controlled by timer/timers

- All plants must have same flow rate within 5%

- 115 VAC power available

- Ability to sense pump failure

- Ease of Maintenance

- Designed for scalability

- Ability to sense delivery failure

- Materials approved by FDA or accepted by the biology community

- Flexible and opaque tubing

- Control system consisting of data acquisition system

- Contaminant prevention

Design Concepts

When creating design concepts, several major aspects of the requirements and restraints were taken into consideration. Universal to the following three designs is a pump, tubing system, branching system, and filter. A pump is needed to provide the mechanical work to move the fluid from the collection reservoir to the plants. The pump must overcome the change in elevation, frictional losses along the tubing, and the pressure emitters located at the end of every tube. In order to deliver fluid from the pump to the plants, a tubing system must be used. This tubing will be opaque to deter algae from forming and flexible to assist in the periodic cleaning. A filter will be added into the system to further assist with the algae prevention. Finally, a branching system will take the mass flow which will be delivered from the pump and separate it into individual flows for each plant. Although the fundamentals of each design are similar, the approach was varied to promote different design concepts while still fulfilling all specifications.

Concept A: Peristaltic Pump

The peristaltic design concept, shown below in Figure 2, consists of a peristaltic pump for each plant delivering the nutrient solution. The solution will be delivered to each plant individually. The excess nutrient solution will then fall back into the reservoir where it is then recycled. A filter will be in the inlet of each pump ensuring no contaminants are delivered to the plants. The pumps will be driven by variable drive motors. A device that will sense whether the motors are drawing current will be in the system to ensure the pumps are running. An alarm system will be activated if the motors are not drawing current.
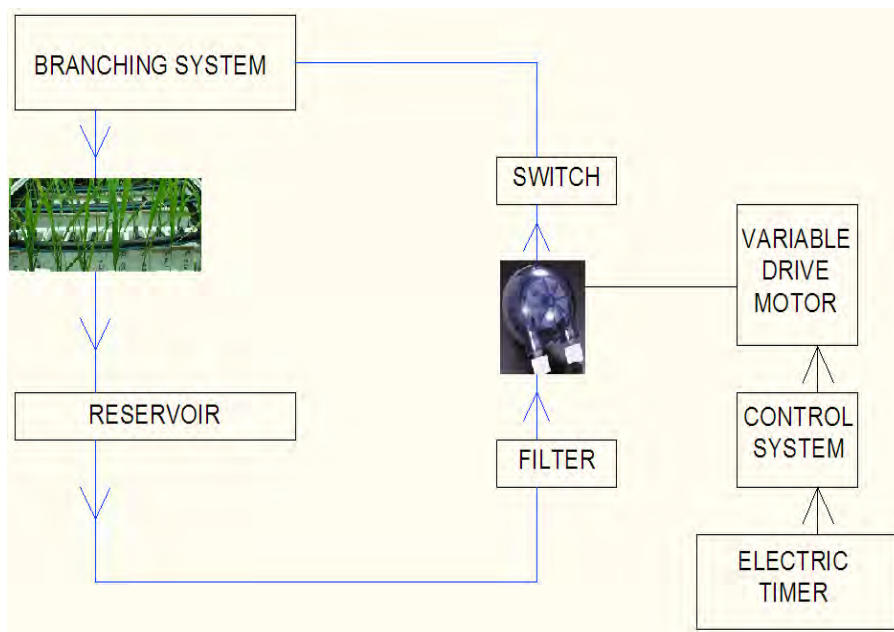
Figure 2: Peristaltic Pump Concept

Concept B: Diaphragm Pump

The next concept utilizes a diaphragm pump to deliver the nutrients. The water is drawn from a collection tank by the diaphragm pump and moved through tubing. The diaphragm pump is ideal because it has the capacity to work with several different types of emitters. Also, the nutrients will come into minimal contact with pump components because only the drum of the pump will touch the fluid. A branching system will be employed to change a mass flow in the manifold tubing to individual flows. The tubes will include valves so that individual flows can be stopped without altering the total flow in the system. As the presence of outside contaminants is a concern, a filter will be used to help keep the nutrient system clean. As with the peristaltic pump concept, a system will be used to monitor the amount of current the pump is drawing. This system will activate an alarm if the motors are not drawing the correct amount of current.

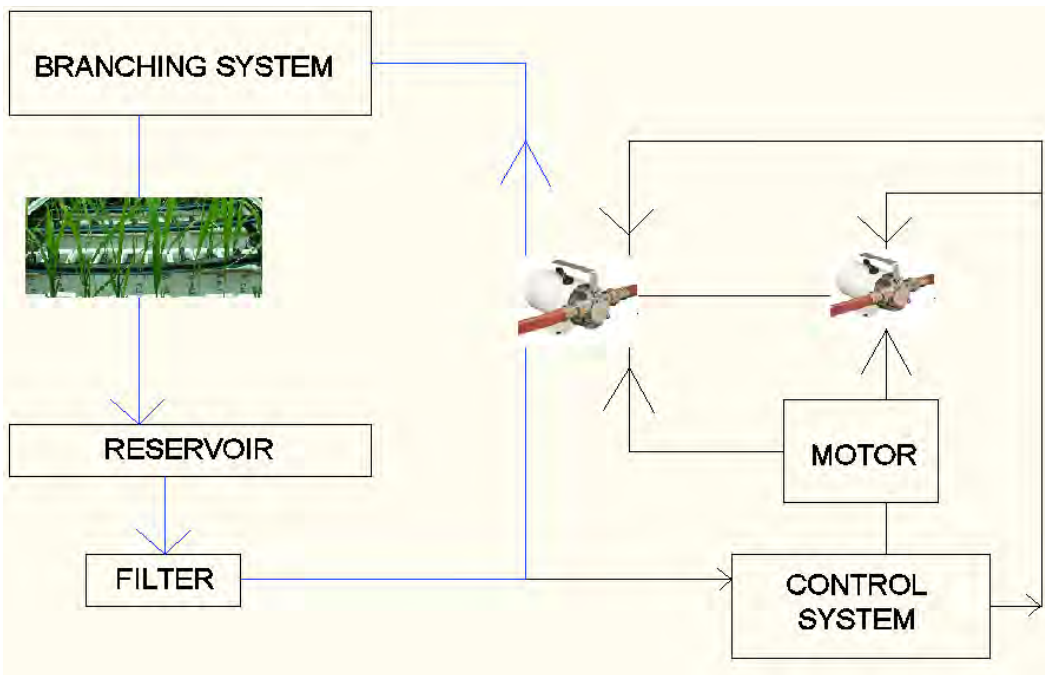**Figure 3: Diaphragm Pump Concept**

Concept C: Gravity Fed

The gravity-fed concept consists of a reservoir, branching system with flow regulators, collection tank, and pump. A schematic of this system is shown in Figure 4. The reservoir is positioned at an elevation above the plants which receive the nutrient solution. Individual flexible tubes carry the solution to each plant. A slider clamp on each tube provides the capability of shutting off the flow entirely for easy plant removal from the system. Shutting off the flow to one plant does not affect the flow delivered to the rest of the plants. The drip-style regulator on each tube is designed after the drip chamber used in intravenous medical applications. This regulator is adjustable which allows the user to set the desired flow rate. The solution passes from the regulator, exits the tube, and is delivered to the substrate in which the plant is housed. A tank positioned beneath the plants collects the nutrient solution in order to recirculate it. A sump pump in the collection tank serves to move the solution back up to the elevated reservoir. Sensors in both the reservoir and collection tank detect when the solution levels either rise too high or drop too low indicating a malfunction in the system. The advantages of this system include the ease of flow adjustment to individual plants and the consistency of gravity to

drive the flow. This system also demonstrates robustness because in the case that the sump pump mechanically fails, the reservoir will still contain solution that can be delivered while the problem with the pump is addressed.
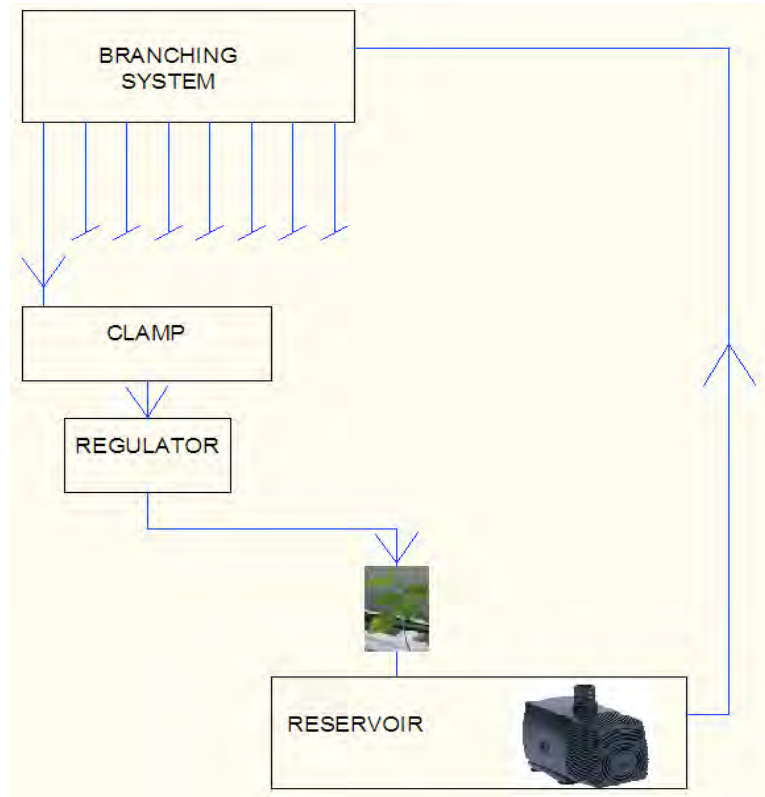
Figure 4: Gravity Fed Concept

Evaluation of Concepts

In order to determine which concept was best, the decision was broken down into several categories: performance, risk, schedule, and cost. These terms are defined as they relate to mechanical design. Performance is the capability of achieving the needed operational characteristics reliably. Risk is the possibility that performance may not be met because of the design approach, absence of testing, or some specific technical consideration. Cost is defined as the estimated cost of the design, including development and manufacturing costs. The performance of the system was determined by rating the ability to vary the flow rate, the reliability, the system's time to replacement, control system, maintenance, and ease of plant removal. Each of these sub-sections is an important requirement of the system. The risk of each system was analyzed. Although the performance of a system

could be very good, if the system depends on unreliable equipment which is difficult to procure and install, the system is not going to be feasible. For these reasons, the risk section addressed the stage of equipment development and the experience of personnel. The availability of the equipment and personnel training were evaluated in the schedule section. Finally, the relative cost of each system was evaluated. In order to keep the project within budget the comparison with competition sub-section was scrutinized in the cost section. The individual sub-sections were tallied to determine which concept would be best. The grading of each concept is displayed below in Table 1.

Table 1 - Design Evaluation

	WEIGHTING	CONCEPT		
	%	A	B	C
PERFORMANCE				
• **Variable Flow Rate**	10	6	5	9
• **Reliability**	10	9	9	8
• **Time to Replacement**	5	4	4	4
• **Control System**	10	9	9	6
• **Maintenance**	5	2	4	4
• **Ease of Plant Removal**	5	5	5	5
	45	35	36	36
RISK				
• **Stage of Equipment Development**	15	14	14	12
• **Experience of Personnel**	10	10	10	10
	25	24	24	22
SCHEDULE				
• **Equipment Availability**	10	8	8	9
• **Personnel Training**	5	5	5	5
	15	13	13	14
COST				
• **Comparison with Competition**	15	9	6	11
TOTAL SCORE	100	81	79	83

Concept Analyses

Analysis of Concept A: Peristaltic Pump

Since the plants will have their own individual pumps, this concept scores high with accuracy, variable flow rate, and reliability. However, it will require a large amount of time to replace the pumps and the maintenance could be difficult. The control system will also have to be quite complex. Equipment development could also be difficult. Although this system would allow for plants to have individual flow rates and the accuracy would be high, the cost of the system would be very expensive. This system was the weakest in the risk, schedule, and cost sections. Mostly for this reason, the peristaltic pump concept will not be the design to continue with.

Analysis of Concept B: Diaphragm Pump

The diaphragm pump design was given relatively high rankings except in the cost section. The diaphragm pump has a long operational life and is reliable. The operational life and reliability were large contributing factors to the pump receiving the highest ranking in risk. However, the diaphragm pump system would be costly because the pump itself is more costly than the other two designs. Although it did not receive the highest ranking, it could be competitive with the gravity-fed system if the cost could be lowered.

Analysis of Concept C: Gravity Fed

The gravity-fed design achieved a higher ranking as compared to the other two designs in the area of performance largely because of the ease with which the flow rate to individual plants can be adjusted. This adjustment creates no effect on the flow rates to other plants. This factor, along with low cost and commercially-available components caused the gravity-fed system to have the highest overall score.

Recommendation

Based on the analysis of each concept described, the option recommended to PSC was the gravity-fed design. Because of its higher score relative to the other two concepts and because of the feasibility of the design, it appears the most desirable for the given situation.

Feedback from PSC

The design concepts were presented to PSC on October 2, 2008. Design specifications were clarified and some additional considerations for the project were given. It was expressed that the desired system will accommodate different size plant containers, allow for easy drainage and disinfecting, and allow for future expandability. The company requested more clarification concerning how the system emitters will come in contact with the plants. PSC also indicated that lower flows than initially indicated should be accommodated (30 mL/hr minimum). Two types of potential system failures were identified. Flow may stop because of (1) pump failure or (2) because of a leak in the reservoir or tubing. The tubing discussed in all three design concepts was clarified to be flexible and opaque. Given these new considerations, a modified constraint list and work statement was delivered to the company following the meeting. With those documents, PSC indicated that the peristaltic design was undesirable primarily because of cost, and the gravity-fed system had potential hazards concerning the elevated reservoir such as placement and user safety. Given this reasoning, the company indicated their approval of the diaphragm pump design concept while also conveying that the use of compressed air in this design was a disadvantage. PSC suggested the use of electric diaphragm pumps instead.

Engineering Design

As outlined in the presentation to PSC, the diaphragm pump design is the system that will be delivered. The following sections describe in detail the nature of the system.

Physical Setup and Layout

Upon receipt of the required components, the system will be assembled. The system will be set up and assembled to undergo a barrage of tests in order to ensure a successful system is delivered to PSC. The set up of the primary system is relatively simplistic. The retaining tank will be outfitted with a liquid level sensing mechanism. This mechanism will be attached to the side of the tank and activated. A hole will be drilled into the side of the tank and tubing will be inserted. A disc filter will be placed in the tubing intakes. The junction will be sealed to ensure the nutrient solution does not leak. The tubing will be connected to the electric diaphragm pump which will be sitting on the ground. Close to the pump is the steady state relay (SSR), which is connected to the pump to ensure that the correct amount of current is being drawn. The output flow from the pump is piped up a meter into the manifold where the flows are separated. After passing the manifold, each tube which carries the flow for an individual plant, is routed to a plant. Initially a modified clamping system was considered to hold the tubes in position near the plant. However, because of the ease of modification of the current system and the complexity of another system, the current system will be used. The nutrient solution drips onto the plant and trickles down into the retaining bin where the system begins again. Another hole will be drilled into the retaining tank for the backup pump's intake. The back-up pump will be in the same vicinity of the diaphragm pump and the SSR. If the system fails, the SSR will send out a signal which will turn on the back-up pump. Like the diaphragm pump, the output flow will be connected to the manifold. In order to ensure plant health, nutrient solution will be ready in the tube so that when the back-up system is turned on, flow will immediately be delivered to the plants.

Operations

Operating the system will be reasonably intuitive for the user and require minimal training. The existing timing system will turn the pumps on and off to allow for intermittent flow. The electric diaphragm pump will pump the nutrient solution through a manifold distributing the solution to each branch. A valve in the branch will provide the

capability of turning on or off the flow to each individual emitter. The emitters will be pressure compensated so that the relatively high flow rate provided by the pump will be scaled back to the appropriate flow rate for the plants. The nutrient solution will then flow down the substrate feeding the roots of the plant. The excess solution will then fall back to the reservoir. If the excess nutrient solution falls too low in the reservoir, the liquid level sensor switch will cause an alarm to sound. If the pump is not drawing current, the solid state relay will switch power to the backup pump, and the valve will allow the backup pump to provide the flow to the manifold and the process will continue. The solution will then flow through a filter before once again traveling to the emitters.

As the existing system is, the components of the system will need to be placed in the cleaning solution as needed. Each component will be able to withstand the acidic cleaning solution used by PSC. The tubing, emitters, filter, and sensor system minus the electrical components can be soaked in the cleaning solution. The electric diaphragm pump along with the backup centrifuge pumps should have the cleaning solution ran through followed by distilled water to clear contaminants.
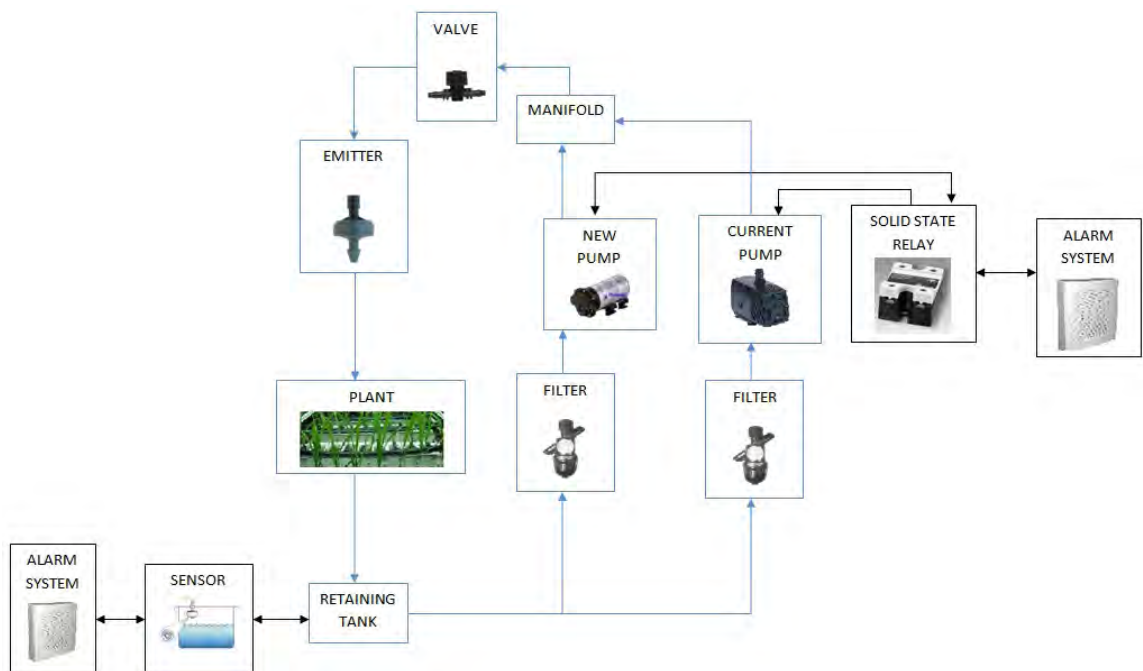

Figure 5: Physical Setup

Pump Selection

The primary concern when sizing the pump is the pressure which needs to be delivered. The pump must produce mechanical work to overcome the losses due to elevation change, viscous forces and the pressure drop across the nozzle. Pump sizing begins with Bernoulli's fundamental governing equation where p is the pressure in pascals, γ the specific weight in kg/m³, g the acceleration due to gravity in m/s², V the velocity in m/s and z the elevation in meters.

$$\frac{p_1}{\gamma} + \frac{1}{2g}V_1^2 + z_1 = \frac{p_2}{\gamma} + \frac{1}{2g}V_2^2 + z_2 \qquad (1)$$

Equation 1 models a stream line and does not take into consideration the pressure losses through the system. Modifying Bernoulli's equation to account for losses renders Equation 2.

$$\frac{p_1}{\gamma} + \frac{1}{2g}V_1^2 + z_1 = \frac{p_2}{\gamma} + \frac{1}{2g}V_2^2 + z_2 + h_L \qquad (2)$$

The elevation datum is set at stage 1, yielding an elevation of zero. At stage 2, the velocity of the fluid is assumed to be negligible because it is dripping. The pressure at stage 2 is atmospheric.

$$\frac{p_1}{\gamma} + \frac{1}{2g}V_1^2 = z_2 + h_L \qquad (3)$$

In order to size the pump, the pressure at stage 1 must be determined. The pressure calculations will be made with both the highest and lowest specified flow rates. Using the relationships for viscous flows in pipes, the velocity is determined by the pressure drop, diameter, dynamic viscosity and length of piping.

$$V = \frac{\Delta p D^2}{32 \mu l} \qquad (4)$$

The length of pipe is assumed to be two meters. (See Appendix for detailed calculations.)

Sensing

Liquid level sensing will ensure that the nutrient solution is not escaping the system. For example, in the case where tubing comes loose or breaks and begins to leak, the system will fail to deliver the nutrient solution to the plants. The liquid level sensing will audibly notify the user with an alarm that the levels in the tank are not acceptable.

An internal float switch will be used. The switch will be made of polypropylene and will therefore not contaminate the nutrient solution as a metal would. The liquid level switch will be in circuit with a power source and an alarm. When the level is above the appropriate position the buoy on the sensor will be afloat and will keep the switch open. While the switch is open, the alarm will not sound. However, when the level drops below the appropriate level, the buoy will sink and close the switch causing the alarm to sound. The alarm may be wired to multiple liquid sensors for efficiency.

A scaled schematic is shown in Figure 6 and a visual representation of the sensor in operation is shown in Figure 7.
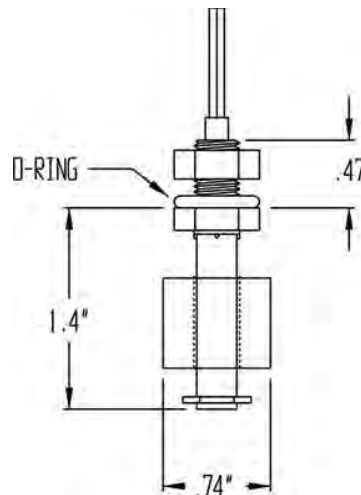

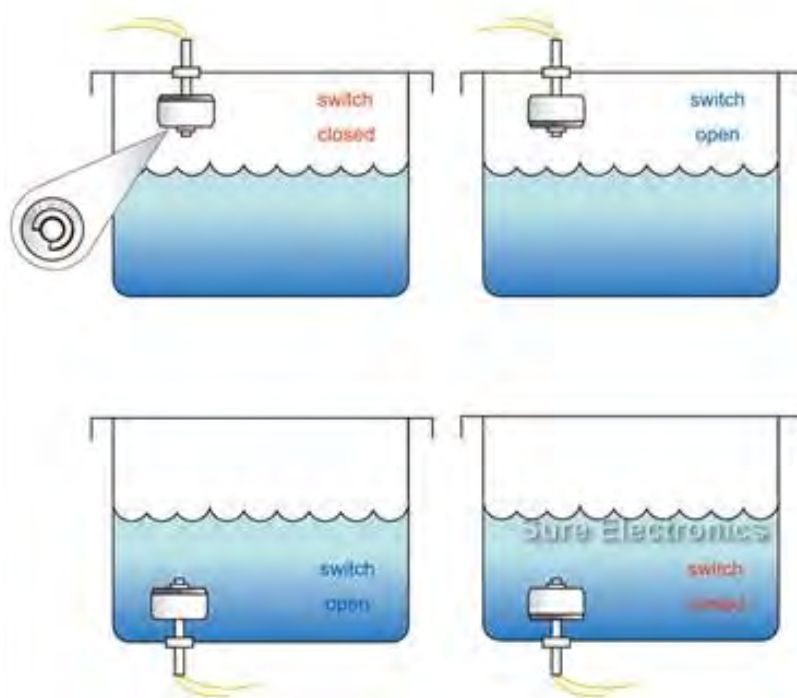**Figure 6 – Scaled Schematic of Sensor**

Figure 7 – Sensor in Operation

Back-up System

The backup system will be comprised of a solid state relay (SSR), pump, liquid level
system switch, and alarm system. The SSR is an electronic switch which uses a control
signal to activate a light-emitting diode which in turn activates a photo-sensitive diode.
The SSR operates using the electrical circuit shown in Figure 8. A schematic of the
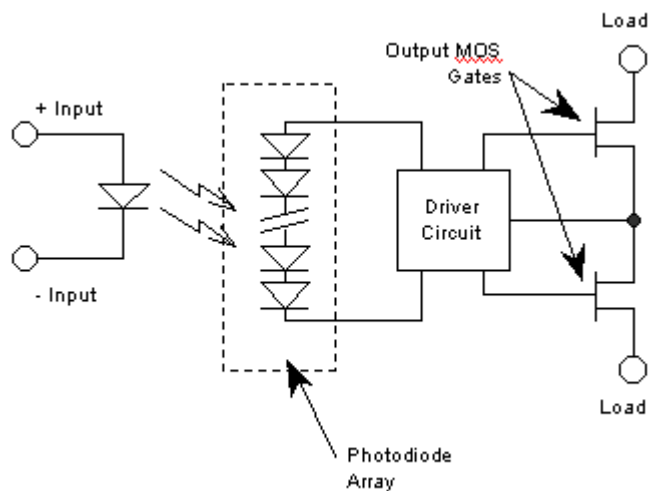electrical components involved in the system is shown in Figure 9.
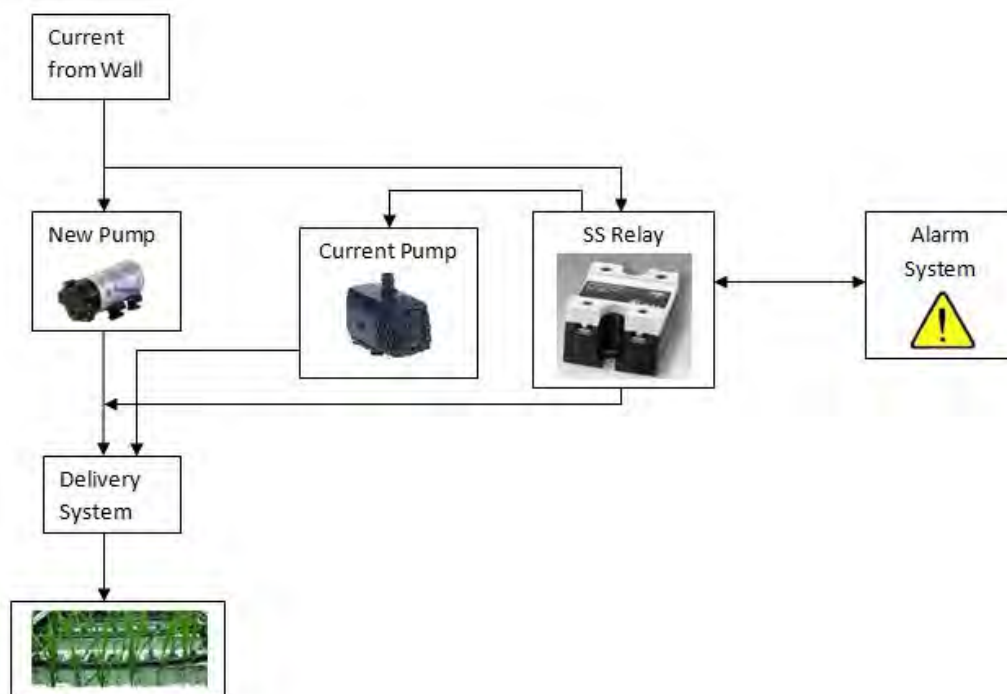

Figure 8 – Workings of SSR

Figure 9 – Electrical Components Schematic

As seen in Figure 9, The SSR will be connected to both sides of the diaphragm pump. If the pump fails, it will quit drawing current. At this point, the SSR will detect the drop in current and activate. When the current drops under the amount required by the pump, the SSR will send a signal to the connected to alarm system. The alarm system will notify the user of failure.

Adaptability

The system will have the ability to adapt to changing conditions. The system will allow for a variety of conditions to be tested. For instance, the temperature of the nutrient solution can be brought down to below freezing, while not affecting pump function or the liquid level sensor switch. Both components can withstand very low temperatures and very high temperatures without losing function. The pump can function up to a maximum temperature of 170°F. The liquid level sensor can function between -40°F to 194°F.

In addition, the system can grow to accommodate a larger number of plants. While the

backup system and the sensing mechanism may not be as useful on the small scope of six simulated environments and a maximum of about 240 plants, a situation involving thousands of plants will create greater difficulty for noticing when there has been a failure. The alarm from the sensing system will direct the individual to the particular environment that is losing its nutrient solution. Also, while one may notice a failed pump fairly quickly at PSC's current number of simulated environments, on the large scope of thousands of plants it will be difficult to notice a failed pump. The backup system will allow the user to avoid killing plants from failed pumps.

The system will allow for different size plants and components. The manifolds will be placed on the sides of the containers allowing for full growth of the plants. The system will use the same type of tubing that is currently in use for flexibility and ease of cleaning. The system will ensure a sufficient amount of tubing to allow for large containers.

Design Testing

After acquiring the system components (see Parts List, Appendix), a prototype of the system will be built and tested to ensure desirable performance and compliance within the given constraints. The system will be constructed as previously specified. It will be a replica of the system to be used by PSC; however, the prototype will not involve actual plants nor will it be subjected to sun lamps which are utilized in the actual application. Also, since the current timing system possessed by PSC is to be used in the new design, new timers will not be purchased. To simulate the on-off intervals created by the timing system, our prototype will be manually run based on the same time intervals. The current system at PSC runs for 30 seconds and shuts off for 4 minutes and 30 seconds. This constitutes one cycle of 5 minutes, and 12 cycles are completed each hour. This intermittent flow will be recreated with the prototype. The water used in the prototype will be collected from each emitter to measure the actual flow rate of the liquid to each plant. The flow from each emitter will be compared to every other emitter to determine if the flow is remaining approximately (within 5%) constant down the line. This test will be

performed with 0.5 gph emitters as well as with the 1 gph emitters with a cycle of 15 seconds on and 4 minutes and 45 seconds off to complete one cycle. The most accurate method in terms of solution delivery amounts can be determined from this test. Next, it is necessary to determine the system's response to a failure. As specified by PSC in response to the design concepts presentation, two system failure types are of primary concern. The problem of "no flow" would indicate a pump failure. This scenario will be reconstructed. Breaking the power source to the pump will cause it to "fail." The prototype's back-up system will sense that current is no longer being drawn by the pump, and the reserve pump will begin running in place of the primary pump. If there is a break in the tubing or a leakage of any sort, the water level in the reservoir will begin to decrease. Rerouting the water as it comes out of the emitters to another tank will recreate this situation. The successful system will alert the user to this problem by means of the liquid level sensors located in the reservoir. Throughout the course of these experiments, the behavior of the system will be compared between tests to determine reliability. Moreover, based on the apparent robustness of components, the approximate work life will be estimated.
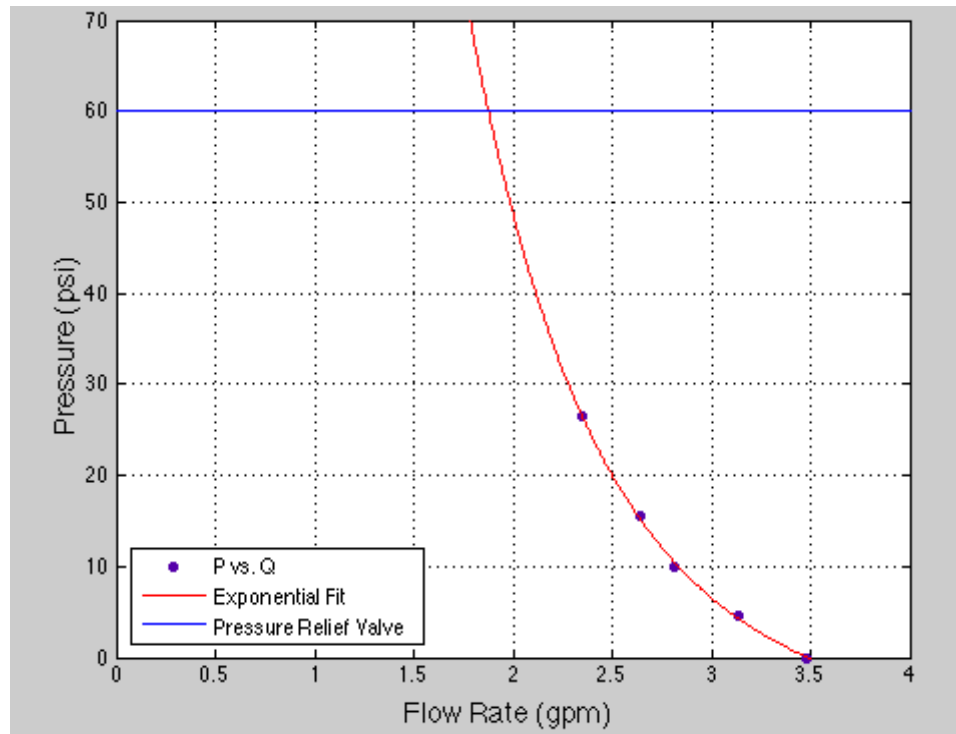
Positive Displacement Pump Performance

Figure 10 – Pressure vs. Flow Rate: Experimental Data

Testing Procedure

To experimentally determine the pump's performance curve, the flow rate and simultaneous pressure in the tubing were observed. It should be noted that during initial testing, the filter was incorporated into the system at the pump inlet. The flow rate was accurately measured by filling a container to a specified volume (2 L) and recording the time required to pump this much liquid. The pressure was measured with a gauge teed into the line in which the fluid was flowing. A ball valve at the fluid outlet was adjusted to restrict the flow. Three trials were performed at each pressure reading to ensure accuracy. An exponential curve of the form shown in Equation 5 was fitted to the data where *a, b, c,* and *d* are constant coefficients.

$$ae^{(bx)}+ce^{(dx)} \qquad\qquad (5)$$

Pump Type

The pump tested was a positive-displacement pump (PDP) which forces the fluid along by volume changes. A cavity which cyclicly opens and closes allows the fluid to flow in through the inlet and it is then squeezed through an outlet. Specifically, this was a diaphragm PDP. An advantage of using this type of pump is that the viscosity of the fluid which is being pumped has no effect on pump performance [1]. For this design's specific application, however, the viscosity will not change and is known to be essentially that of water. PDPs do not require priming like other types of pumps which adds an element of user-friendliness. Figure 10 shows the performance of the pump in terms of pressure and flow rate. The pump is fitted with a pressure relief valve so that complete shutoff is prevented from occurring. If this were to happen, damage would likely be caused to the pump. PDPs generate nearly constant flow rate; as shown in Figure 10, a flow rate change of only 1.7 gpm is the result of a 60 psi (180 ft) pressure differential. This is consistent with the known behavior of PDP pumps. As shown in Figure 11, the relative performance is dramatically different for the PDP and dynamic pumps [1]. The pump specifications indicate that the pump operates at 60 psi and 3.2 gpm. This is approximately consistent with the experimentally obtained data.
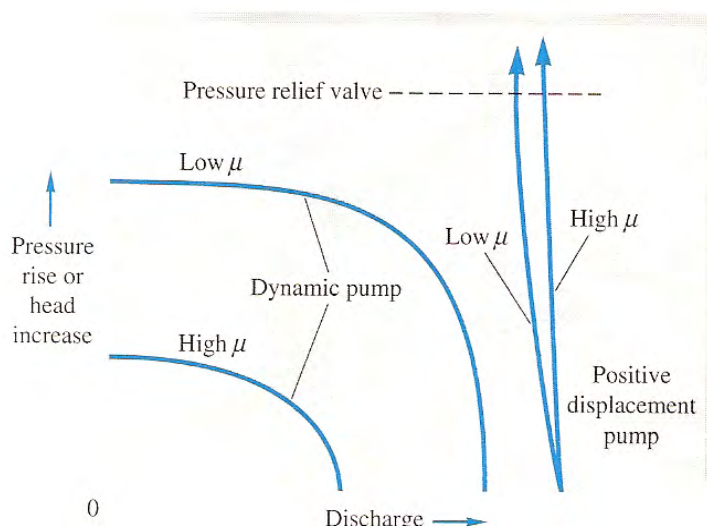
Figure 11 – Performance of PDP and Dynamic Pumps

System Demand

The system demand curve was developed by breaking down the system into three sections. The first section was the piping that led from the reservoir to the tee where the 1/2" tubing is split into two manifolds. The second portion considered the manifold itself, and the third section analyzed the 1/4" branches. Bernoulli's equation with an additional term for viscous effects was applied to each section to determine the amount of pressure required to overcome the losses. The losses come from elevation change, velocity change, the viscous effects, friction, and minor losses associated with elbows, tees, and branches.

Viscous losses are present because there is a shear layer or boundary layer near the tubing wall. At the wall boundary, the velocity of the fluid is zero; this is known as the no-slip condition [1]. The viscous losses were calculated with the Hagen-Poiseuille solution to the Navier-Stokes equation for incompressible flow in a straight circular pipe.

The detailed engineering calculations are shown in the Appendix. For all three sections of the system, the flow was determined to be laminar since the Reynolds number never exceeded 2300 which is the generally accepted transition value from laminar to turbulent flow.

Figure 12 shows the performance curve with the imposed demand curve of the system. This is for a system consisting of 8 feet of 1/2" diameter tubing and 20 branches of 1 foot lengths of 1/4" tubing. The optimal operating point for the pump would then be at the intersection of the performance and demand curves. This would result in a flow rate of 2.94 gpm and a pressure of 7.84 psi. The problem arises when the drip emitters are added to the system. The emitters will operate at pressures of 5 psi or greater (with a limit at approximately 50 psi), but the flow rate is regulated depending on its specifications. For this specific situation, 1 gph emitters were used. This is equivalent to 0.0157 gpm and for 20 emitters, this is a total flow rate of 0.333 gpm. This restricted flow rate would demand the pump to operate at a pressure far higher than its pressure relief valve level of 60 psi.

This caused the observable shaking and failure of the system. Pressures exceeded that which the fittings and pump could withstand.
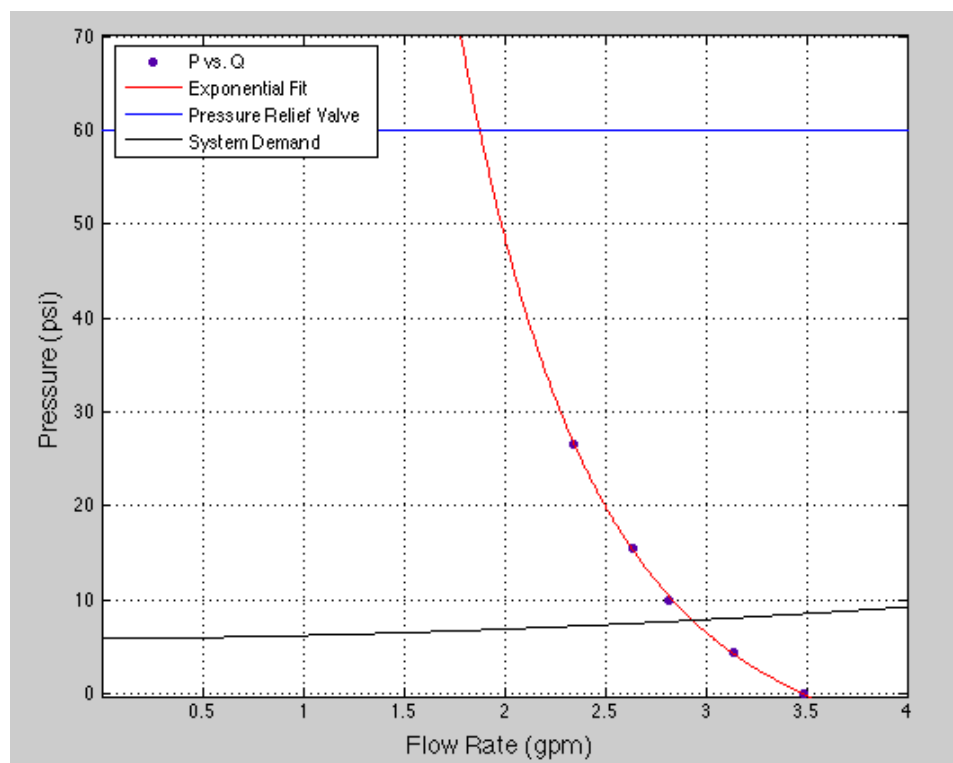

Figure 12 – Performance Curve With System Demand Curve

From the engineering analysis (see Appendix), it was also determined that the pressure loss for each additional branch was 0.00561 psi. For each additional foot of 1/2" tubing manifold, the pressure loss was 0.00289 psi.

Impeller Pump Performance

Another possibility for pumping is the impeller pump. An impeller pump is a centrifugal pump which uses blades to drive a fluid radially outward. They are capable of running at high speeds and can be used to highly increase the speed of the water exiting the system. Many impeller pumps are versatile and are capable of pumping mixtures of water and another material. These pumps operate over a wide speed range, from less than 30 to more than 3000 RPM. Also important, they do not clog easily.

These qualities would make further research into an impeller pump beneficial. According

to Johnson Pump, many of their pumps are able to deliver fluids at the rates required as seen in Figure 13. Because of the large operating range it is possible that there would no longer be a need for pressure emitters. It would simplify the system if the emitters could be eliminated as well as remove another opportunity for part of the system to clog or fail.
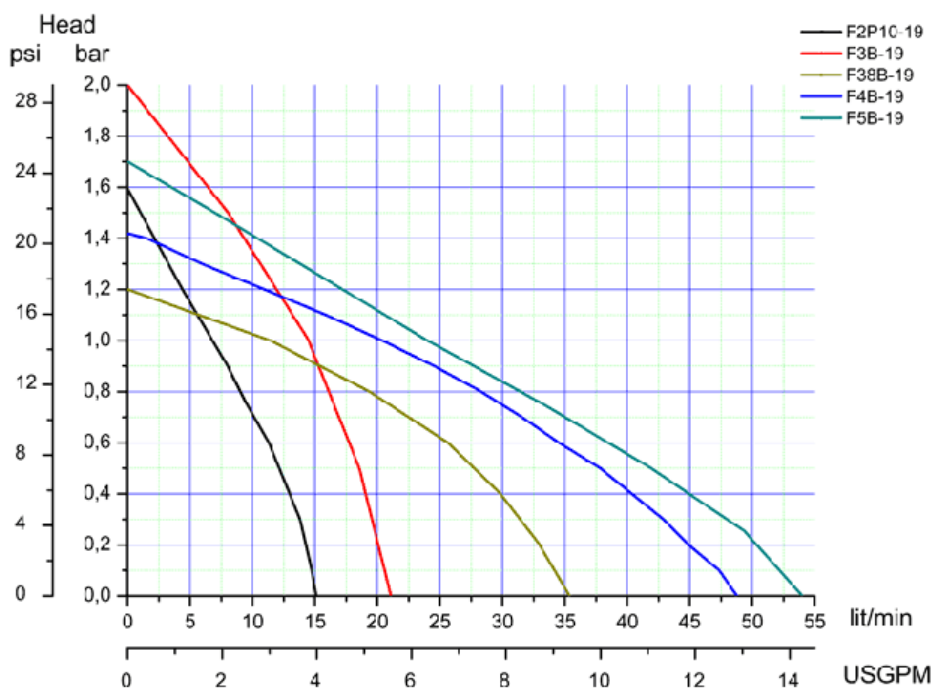

Figure 13 - Capacity Curve for Impeller Pump

If there is a strong desire to eliminate the pressure emitters, it is suggested that further consideration be given to peristaltic pumps. If the pressure emitters are to stay, the peristaltic pump will not be able to overcome the emitters. However, the impeller pump would be able deliver the necessary head. Impeller pumps would add to scalability because they are so capable of delivering high flow rates and pressures. Instead of being forced to have individual pumps per system, just one impeller pump would be able to deliver the necessary head to multiple systems. While this would prove problematic if the pump failed, risking multiple systems, with the alarm systems in place it would not be risky. The main problem with impeller pumps is that most of the moving parts which would come into contact with the fluid are metal. While there are some plastic and Teflon impeller pumps, they are much more expensive than the other options.

From actual experimental testing of the impeller pump currently in operation at PSC, the performance curve shown in Figure 14 was obtained.
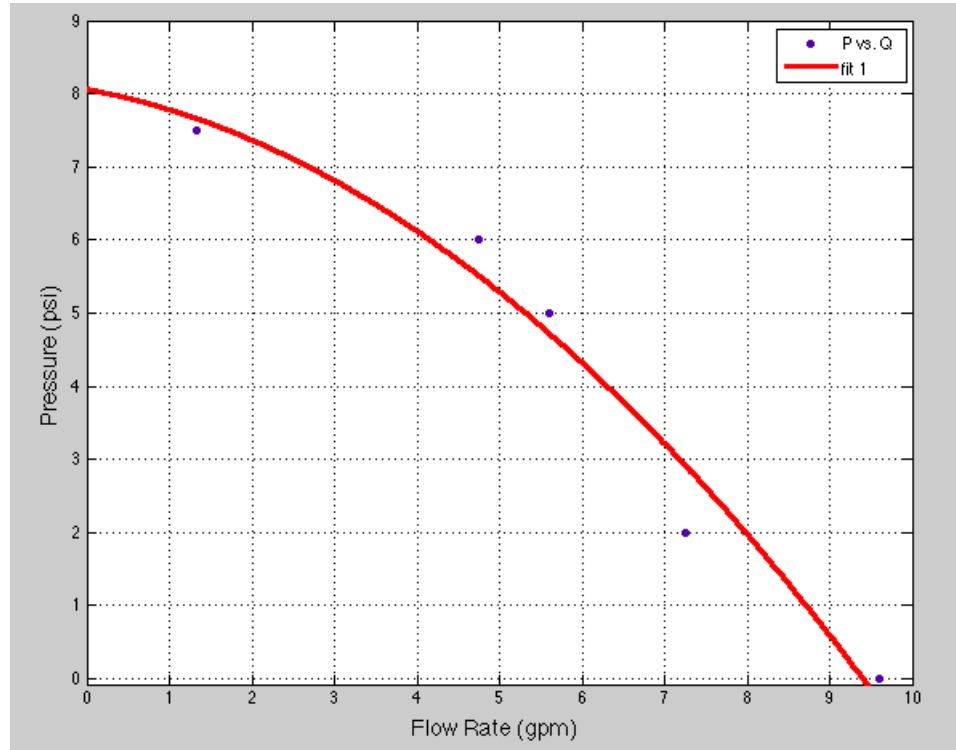

Figure 14 – Performance Curve for Impeller Pump

In Figure 15, the system demand and hydraulic horsepower curves have been superimposed on to the performance curve graph. It can be concluded from Figure 15 that although the impeller pump operates as desired, it actually provides more pumping power than is necessary for the given system. Economically speaking, a smaller, less expensive pump could be employed which would provide the needed pressure at its most efficient operating point. Even if a higher flow rate was used such as 2.3 gpm which marks the intersection of the pump performance and system demand curves, the pump still would not be operating as efficiently as possible.
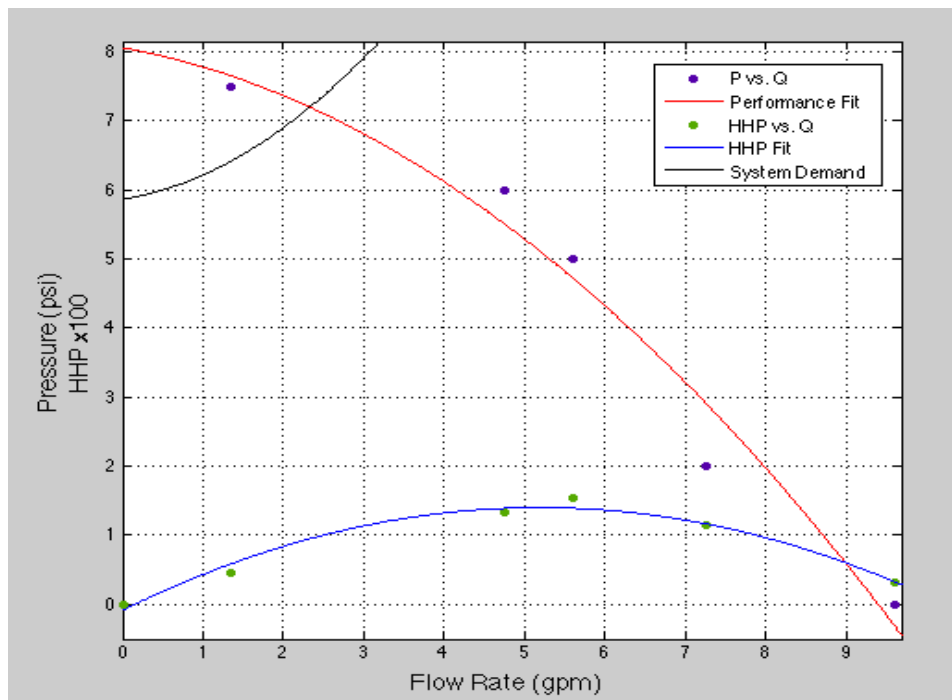
Figure 15 – Impeller Performance, System Demand, HHP

It should be noted that in Figure 15, the units on the vertical axis when considering the HHP curve is horsepower x (10^{-2}).

Filter

The filter suggested in the design was tested and still recommended for implementation in actual system use. The filter is an Arkal 3/4" Filtap; it is 100 micron or 140 mesh. Because it was implemented at the inlet of the pump, the head loss across the pump can be neglected in the overall system design. In the case of centrifugal pumps, there is no inlet tubing on which to implement the filter. In this case, the filter must be positioned at the outlet. In order to determine the effect that this would have on the downstream system, additional testing was done on the PDP without the filter. Although it is beneficial to place the filter at the pump inlet to prevent particulate matter from entering the pump and causing failure, placement at the outlet is acceptable for impeller pumps without fear of clogging and failure because impeller pumps are even capable of moving sludge. The only concern is that particulate matter should not reach the plants and interfere with the experimentation. Therefore, a filter at the pump outlet will prevent this from happening. Filter specifications instruct the user to not subject the device to

pressures greater than 140 psi. For pumps like the diaphragm pump, the filter is at the fluid entrance to the pump which is open to the atmosphere, the danger of surpassing this pressure limit is not a consideration. For the impeller case where the filter is placed at the outlet, the greatest pressure reached is approximately 7 psi; once again, there is no danger of the 140 psi limit being surpassed. The filter was integrated into the system using two Mister Landscaper hose fittings which connect 1/2" tubing to 3/4" male fittings.
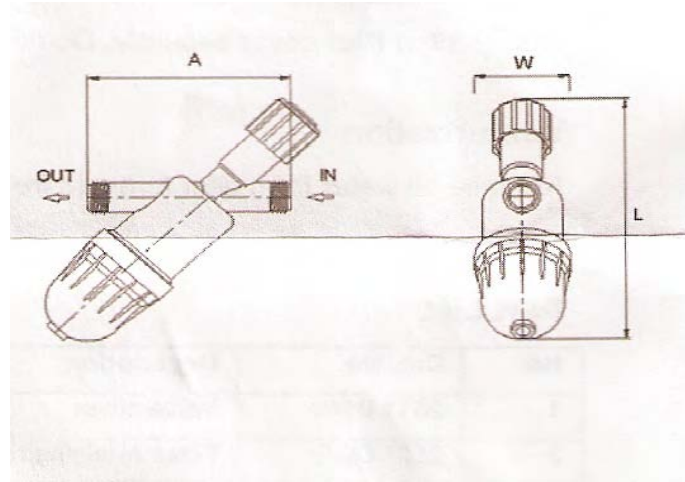

Figure 16 – Filter Dimensions

As shown in Figure 16, the distance between the connections *A* is 15.5 cm, the width *W* is 7.4 cm, and the length *L* is 21 cm. The entire filter is plastic which was considered in filter selection because it is important for the fluid to avoid contact with any metals. The materials are also resistant to degradation from exposure to chemicals. The filter element is cylindrical and consists of grooved discs compressed together on a spine. If desired, other filtration grade discs are available to operate in the same filter housing.

Table 2 - Filter Parts

No.	Part	Material
1	Valve Cover	PC
2	Filtap retaining ring	ACETAL
3	Valve stem	PP
4	Tap o-ring	EPDM
5	Filter body	PB.T
6	Cover o-ring	NITRILE
7	Spine ring	PP
8	Spine tightening ring	PP
9	Filter spine	PP
10	Disc set	PP
11	Filter tightening spring	S.S
12	Filter cover	PB.T
13	Filter element	
14	Filter body complex	
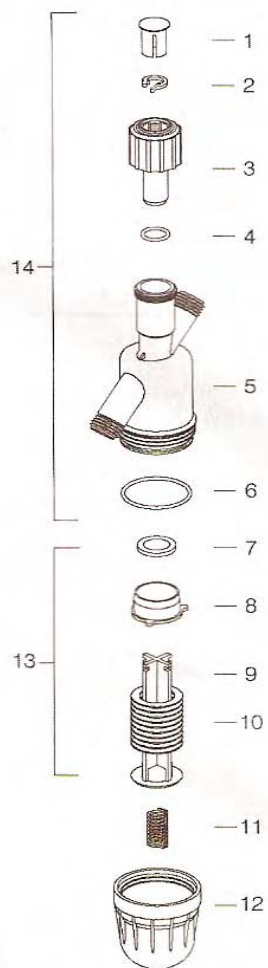
Materials

SS – Stainless Steel

PP – Polypropylene

PB.T – Polybutylen Terephthalate

PC - Polycarbonat

Figure 17 – Filter: Exploded View

Figure 17 and Table 2 detail the filter parts and materials. To clean or replace the filter discs, the cover at the bottom of the filter is simply unscrewed, the filter element is removed, and the tightening ring is moved to the end of the spine. The discs can then be cleaned with a water jet. Reassembly is the reverse process.

It was expected that the presence of the filter would make no difference on the performance of the pump given that the filter's valve is left in the fully open position so as to not restrict flow to the inlet of the pump. To ensure that this assumption was correct, the same testing as outlined above was repeated without the filter in the system. The results of that testing are compared to the original testing in Figure 18. Using the same scale in each figure, it can be concluded that for a given pressure, the flow rate is nearly identical. Therefore, it is expected that the filter can be integrated into the impeller pump system at the outlet with minimal changes to system performance.
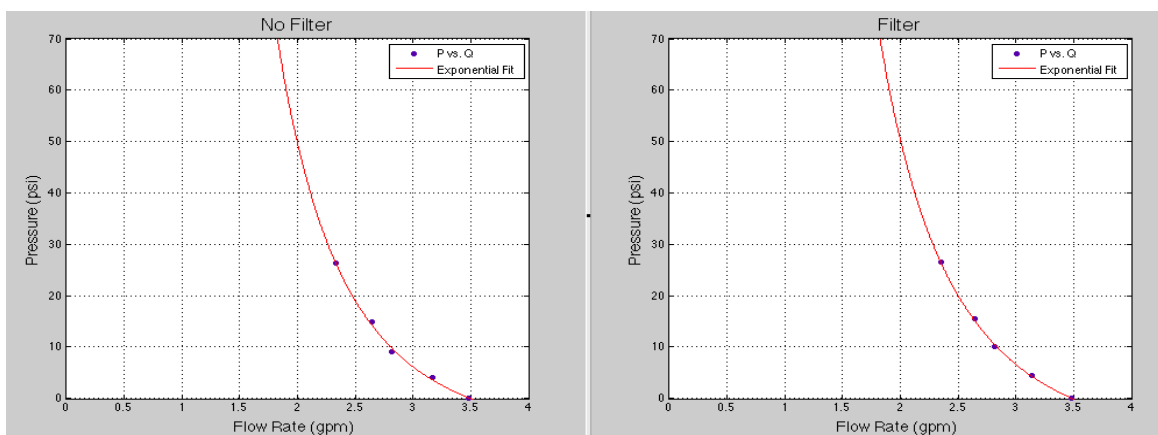

Figure 18 – Comparison of Pump Performance Curves: Filter vs. No Filter

Also, the filter specifications indicated that the maximum flow rate through the filter is 18 gpm which is well above the maximum flow rate capacity of the filter. Future users should be cautioned that it is important to ensure that the valve on the filter is fully opened during operation. If not, it could lead to smaller deliverable flow rates than expected. However, it was also observed during testing with the PDP that without the filter that particulate matter in the fluid caused the pump to sputter creating differences in pressure and flow rate. Therefore, it is important to include a filter in the system to

prevent pump malfunction or, in the case of the impeller pump, to purify unwanted materials before delivering it to the plants.

Tubing System Performance

The tubing system devised is highly similar to the one already in place. When the water leaves the containment bin at the bottom of the stand, it passes through a filter. Next entering the pump, the fluid then moves to a T where it is split to two symmetrical ½ in tubes. Twelve holes were punched equidistantly and fittings installed and connected to ¼ in tubes. These tubes are connected to flow regulators, and eventually to the emitters. In order to better move plants, the flow regulators are added. These regulators allow for an individual flow to be turned on or off, instead of having to turn on or off the entire system.

Alarm Device Performance

The alarm system including the liquid level switch component will allow for scalability. While the current system is manageable without having detection of the level of the tanks, the liquid level switch allows for thousands of plants to be manageable at one time. The switch will alert the user of leak detection and status of liquid level. The switch is easy to use as well. The float on the switch will float with the nutrient solution while the solution maintains the appropriate level and keep the circuit open. Once the nutrient solutions falls below the adequate level, the float will drop and close the circuit to the alarm. This mechanism allows the user to be notified that there is a leak in the nutrient delivery system or that more nutrient solution should be added to the reservoirs.
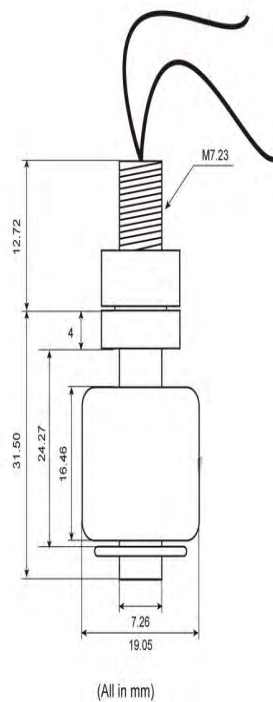
Figure 19 – Schematic and Image of Liquid Level Switch

The liquid level float switch is of simple construction. The switch is made of inert materials. Figure 19 above shows the dimensions of the switch. The switch has a max switching voltage of 100 volts and max switching current of 0.5 A. The max load current is 1.0 A and the max contact resistance is 100 mΩ. The switch can be subjected to a temperature range of -10°C to 85°C. The total weight of the switch is approximately 20 grams.

The switch is in circuit with a simple alarm. The alarm can handle a voltage of up to 12 volts. Through applying different voltages the pitch and volume of the alarm can be controlled. Through varies test and using the principals of Ohms law it was discovered that the best voltage to use for the alarming system would be 6 volts. The alarm is powered by a simple battery pack holding 4 AAA batteries. The battery pack has an on off switch, hence the alarm system can be turned off when cleaning the system. The battery pack and alarm system have been attached to plexiglass sheet that has been bent to allow the alarm to hang on the outside of the reservoir as shown in Figure 20. The switch will also be fixed to a plexiglass sheet that has been bent with suction cups that

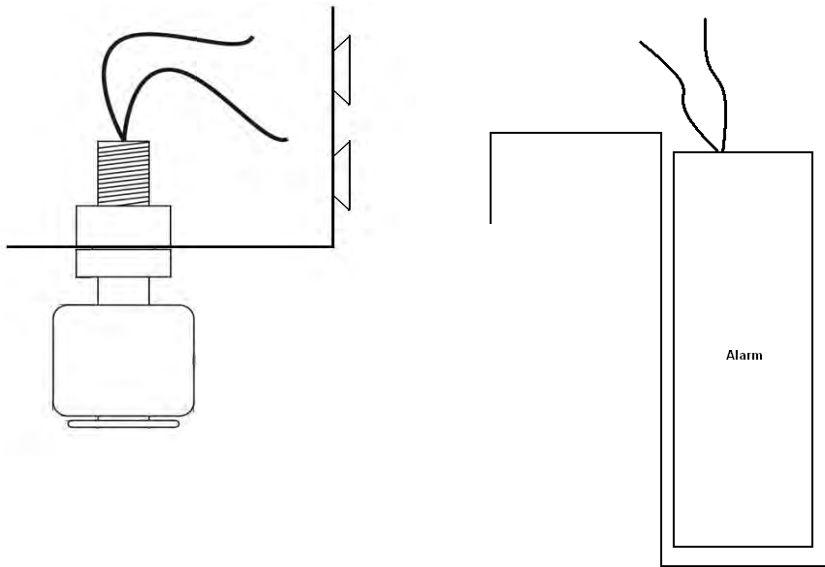allow the switch to be placed at the appropriate levels.

Figure 20 – Liquid Level Switch and Alarm Installation

Appendix

Project Planning

The project planning is done using Microsoft Project. The displays of both the table and Gantt Chart are below in Table 3 and Figures 21 and 22.

Table 3: Project Planning Table

|	ⓘ	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	✓	Assinment of Project	0 days	Thu 8/28/08	Thu 8/28/08		
2	✓	Initial Meeting and Brainstorming	1 day	Mon 9/1/08	Mon 9/1/08	1	All
3	✓ 🗒	Work Statement	3 days	Tue 9/2/08	Thu 9/4/08	2	All
4	✓	IV Drip Brainstorming	3 days	Thu 9/4/08	Mon 9/8/08	2	All
5	✓	Constraints Received	2 days	Wed 9/10/08	Thu 9/11/08		Haley
6	✓	Project Paper – Section I	30 days	Mon 9/15/08	Fri 10/24/08		All
7	✓	Flow Diagram	1 day	Thu 9/11/08	Thu 9/11/08		Lisa
8	✓	Alternative Control System	10 days	Mon 9/15/08	Fri 9/26/08	5	All
9	✓	Peristaltic Pump Research	6 days	Thu 9/18/08	Thu 9/25/08	5	Haley
10	✓	Diaphragm Peristaltic Pump Res	6 days	Thu 9/18/08	Thu 9/25/08	5	Meredith
11	✓	Gravity Fed System Research	6 days	Thu 9/18/08	Thu 9/25/08	5	Lisa
12	✓	Control Research	3 days	Mon 9/22/08	Wed 9/24/08		All
13	✓	Drawings Created	3 days	Wed 9/24/08	Fri 9/26/08	8,9,10,11	Meredith
14	✓	PowerPoint for Presentation I	2 days	Mon 9/29/08	Tue 9/30/08	13	All
15	✓	Preparation for Presentation I	3 days	Mon 9/29/08	Wed 10/1/08	14	All
16	✓	Presentation I	0 days	Thu 10/2/08	Thu 10/2/08	15	All
17	✓	Feedback from PSC	0 days	Thu 10/2/08	Thu 10/2/08		
18	✓	Project Paper - Section II	10 days	Thu 10/30/08	Wed 11/12/08	6	All
19	✓	Modified Work Statement	2 days	Mon 10/6/08	Tue 10/7/08	17	Lisa
20	✓	Revise Proposal	5 days	Mon 10/6/08	Fri 10/10/08	17	All
21	✓	Delivery of Revised Proposal	0 days	Tue 10/14/08	Tue 10/14/08	20	
22	✓	Selection of Diaphragm Pump C	0 days	Wed 10/22/08	Wed 10/22/08		
23	✓	Parts List I	2 days	Mon 10/27/08	Tue 10/28/08		Meredith
24	✓	Methodology	3 days	Mon 10/27/08	Wed 10/29/08		Haley
25	✓	Irrigation Research	2 days	Tue 11/4/08	Wed 11/5/08		Lisa
26	✓	On-Site Meeting	0 days	Wed 10/15/08	Wed 10/15/08		All
27	▥	Project Paper - Section III	7 days	Thu 11/20/08	Sun 11/30/08	18,23,24,25	All
28	▥	PowerPoint for Presentation II	1 day	Mon 12/1/08	Mon 12/1/08	27	All
29	▥	Preparation for Presentation II	2 days	Tue 12/2/08	Wed 12/3/08	28	All
30	▥	Presentation II	0 days	Wed 12/3/08	Wed 12/3/08	28,29	All
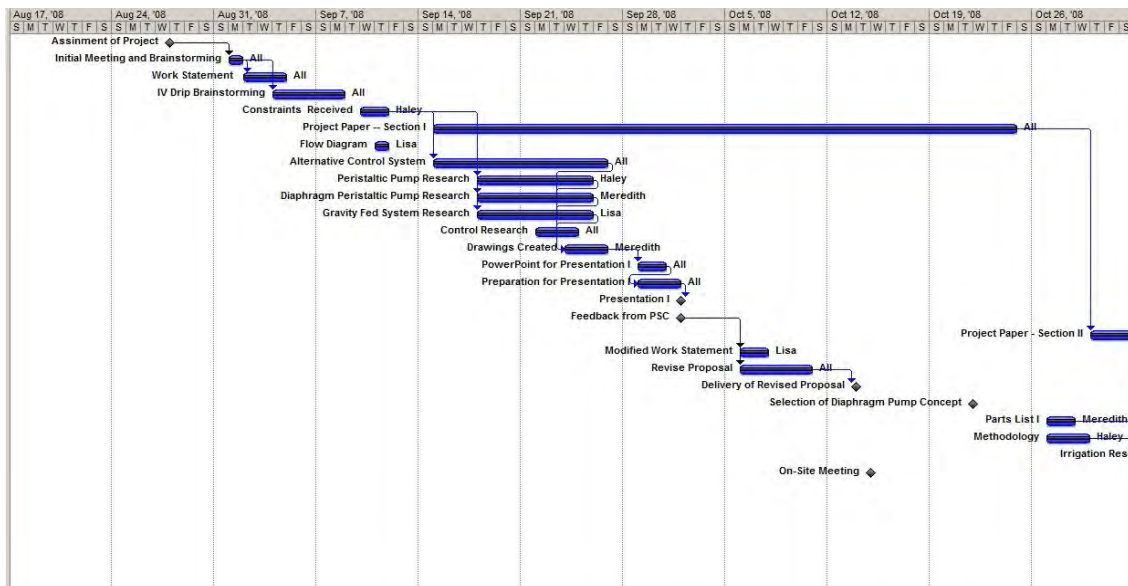
Figure 21: Gantt Chart August to October
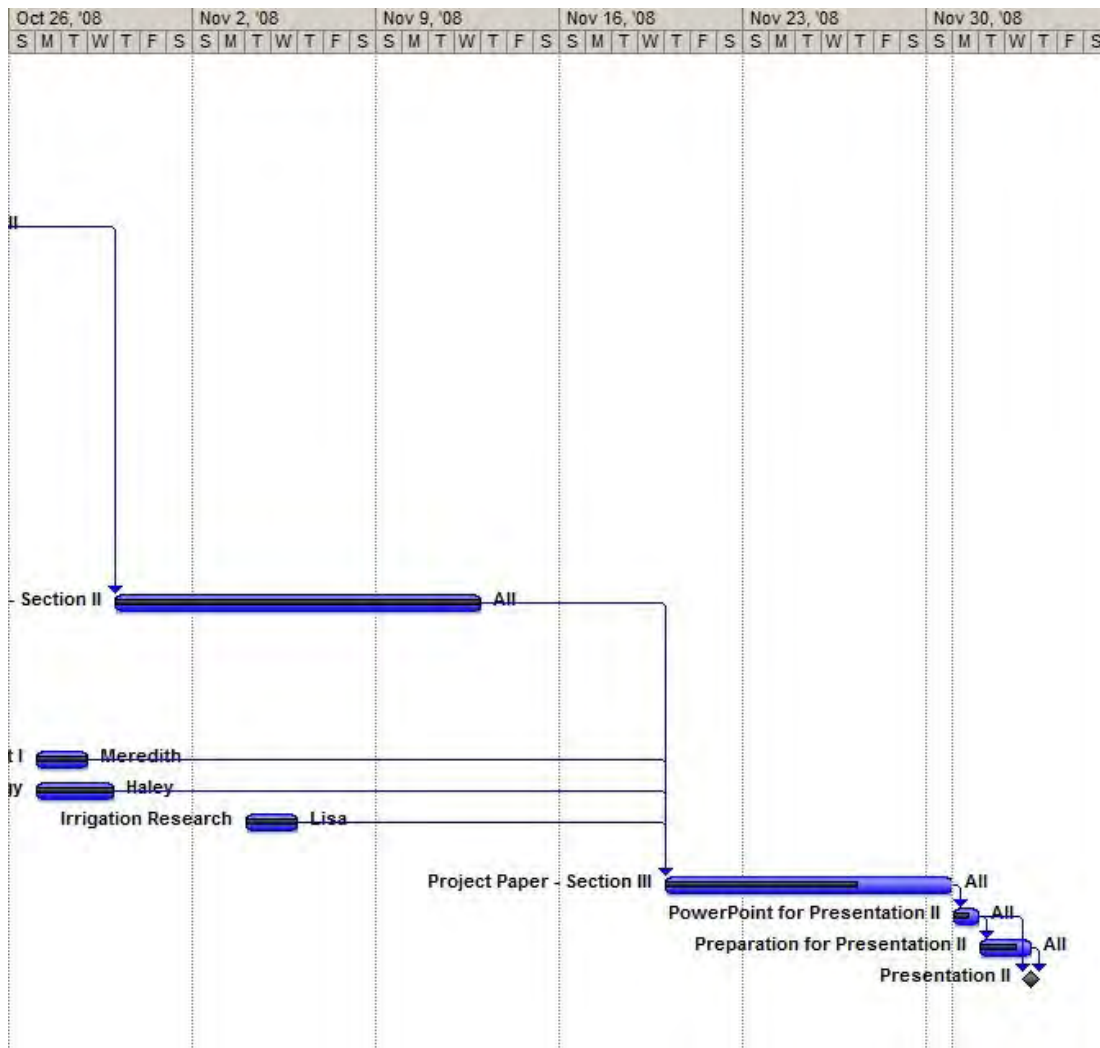
Figure 22: Gantt Chart October to December

Engineering Calculations

Pump Sizing

In order to properly size the pump, the pressure required of the pump must be determined. Taking into consideration the given specifications, the following derivation was performed. Also, because the amounts of nutrients in the solution are so small, the properties of the solution are assumed to be the same as water.

Equations Used

$$A = \frac{\pi}{4} D^2$$

$$V = \frac{Q}{A}$$

$$Re_D = \frac{\rho V D}{\mu}$$

$$\Delta P_{viscous} = \frac{8 \mu L Q}{\pi R^4}$$

$$f_{lam} = \frac{64}{Re_D}$$

$$h_{friction} = f_{lam} \frac{L V^2}{2 D g}$$

$$\Delta P_{head} = \rho g h_{friction}$$

$$h_{minor} = \frac{V^r}{2 g} \sum K$$

$$\Delta P_{minor} = \rho g h_{minor}$$

Table 4: Specified Parameters

Given Units	Si Units
Q = 20 gph	Q = 2.0820e-05 m³/s
D₁ = 0.5" D₂ = 0.25"	D₁ = 0.0127 m D₂ = 0.0063 m

Water Properties

Density: $\rho = 998 \frac{kg}{m^3}$

Dynamic Viscosity: $\mu = 0.001003 \frac{N-s}{m^2}$

Derivation of Required Pressure:

$$\Delta P = \rho g (h_2 - h_1) + \frac{\rho \left(V_2^2 - V_1^2 \right)}{2} + \Delta P_{viscous} + \Delta P_{friction} + \Delta P_{minor}$$

Section 1: From Reservoir to Dividing Tee

$L = 2 \, ft$

$D = D_1$

$h_2 - h_1 = 1 \, ft$

$\sum K = K_{(tee, line)} + K_{elbow} = 2.2721$

$Re_D = 2076.9$

$\Delta P = 0.445 \, psi$

Section 2: Manifold (2 branches)

$L = 3 \, ft$

$D = D_1$

$h_2 - h_1 = 0 \, ft$

$\sum K = K_{(tee, branch)} = 1.193$

$Re_D = 1038.4$

$\Delta P = 0.0203 \, psi$

Section 3: 1/4" Lines (20 branches)

$L = 1 \, ft$

$D = D_2$

$h_2 - h_1 = 1 \, ft$

$\sum K = 0$

$Re_D = 207.69$

$\Delta P = 0.4791 \, psi$

Laminar flow in a pipe is defined as any Reynolds number less than 2,300. Therefore, the flow is defined as laminar. The relationship between frictional losses in a pipe and the Reynolds number is laminar.

Often, the viscous term in Bernoulli's equation is neglected because of its small contribution. The term comes from the Hagen-Poiseuille relation which is given by Equation 6 where v_z represents the velocity of the flow in the axial direction of the pipe, mu is the fluid's viscosity, and R is the pipe's radius. For the low flow rates considered in this specific system, laminar flow is assumed which makes the Hagen-Poiseuille relation applicable.

$$v_z = \left(\frac{-dp}{dz} \right) \frac{R^2}{4\mu} \tag{6}$$

The phrase "fully developed" implies that the region under consideration is at a sufficient distance from the entrance such that the flow is purely axial. In terms of flow rate and pressure drop, Equation 6 can be rewritten as Equation 7. Here, L is the length of the pipe through which the fluid flows.

$$Q = \frac{\pi R^\varepsilon \Delta P}{\Lambda \mu L} \tag{7}$$

Parts List

Part	Quantity	Company	Part/Model number	Cost/unit	Total Cost
Liquid Level Switch	1	Innovative Components	LS-209	$15.75	$15.75
Alarm	1	T-Tronics Inc.	TTI-S-441	$7.99	$7.99
12V 5AH Battery	1	BatteryASAP.com	UB1250F1	$14.25	$14.25
Wire	1 - 90 ft pack	Radio Shack	278-1221	$6.99	$6.99
Pump	1	Aquatec Electric Diaphragm Pumps	8841-2J03-B421	$210.00	$210.00
0.5 gph emitter	20	Drip Works USA - Brand: Woodpecker PC (Netafim)	DNJR12	$0.32	$6.30
1.0 gph emitter	20	Drip Works USA - Brand: Woodpecker PC (Netafim)	DNJR1	$0.32	$6.30
Filter	1	Drip Works USA - Brand: Arkal	AV34	$28.80	$28.80
3/4" Tubing Adapter	2	Hardware and Tools - Brand: Rain Drip	R326CT	$3.78	$7.56
1/4" Support Stakes	2 - 10 pack	Lowe's - Brand: Mister Landscaper	MLT-DST	$6.13	$12.26
1/4" Tubing	2 - 100 ft. pack	Brand: Mister Landscaper	MLT-B100B	$23.45	$46.90
Solid State Relay	1	Sords Electric		$21.60	$21.60
1/4" Vinyl Couplers	2 - 15 pack	Mister Landscaper	MLT-BXB	$5.45	$10.90
1/4" Barbed Valve	3 - 10 pack	Hardware and Tools - Brand: Rain Drip	612010B	$10.49	$31.47
Allotment for add'l electrical supplies				$20.00	$20.00
				TOTAL	$447.07

Vendor Pictures and Information

Woodpecker Jr. PC (Netafim)
http://www.dripworksusa.com/store/pcdrippers.php
The DNJR12, DNJR1 and DNJR2 pressure compensating emitters are versatile emitters that can be used in landscapes, greenhouses, orchards or backyard gardens. One unique aspect of this emitter is that it won't begin to emit water until it reaches 5 PSI. This is great for greenhouses or systems that need to pressurize before any of the emitters start to work. This stops the problem in greenhouses where the first plants in the system get over-watered before the last plants have reached saturation. The output of the Woodpecker Jr. is extremely consistent. They can be used with the DNPCAP (above) and the 4 way splitter (DMPCA or DMASS. 1/4" inlet and outlet. (Note that the DNPCAP will fit on this emitter but the loop on the cap will not fit between the emitter and the tubing as it does with the Woodpecker emitter.) Pressure range of 7-50 psi.

Mister Landscaper 1/4" Support Stakes For Vinyl
http://www.lowes.com/lowes/lkn?action=productDetail&productId=8839-1029-MLT-DST&lpage=none
The support stake is used to hold the 1/4" poly tubing in place allows you to form the poly tubing to any landscape design desired.

3/4 Tubing Adapter #R326CT by Rain Drip
http://www.hardwareandtools.com/invt/u526616?ref=gbase
3/4" Pipe Thread Tubing Adapter, Connects 1/4" Tubing To 3/4" Male Pipe Thread, Washer Included.

Arkal Filter with Valve (Y TYPE)
http://www.dripworksusa.com/store/dskfilter.php
This is the same 3/4" disc filter as above* but has a built in valve to shut off the water flow and to allow for easy cleaning. Uses the same replacement disc set as the 3/4" Arkal filter above. Maximum pressure is 140 PSI.

*"Filter above":
Arkal Disc Filter (Y TYPE)
This is one of the finest disc filters on the market.   If you have organic matter (algae) in your water supply this may be the answer! The stacked discs in the Arkal filter are more durable and easier to clean than screens or cartridges, but the disc must be removed from the filter body for cleaning. The 3/4" Arkal is not available in 200 mesh. Maximum pressure is 140 PSI.

Sensor Switch

Liquid level sensor -   http://www.liquidlevel.com/products_switches_standard_vt_LS-209.asp

Polypropylene | LS-209

Plastics are ideal in highly corrosive water and chemical applications were metallic units are not desired. Economical pricing makes plastic the material of choice for the OEM.

Part #	Reed Switch	Dry State	Price	Buy Now
LS-209	50 watt; 220v/1.5A	N.O.*	$15.75	BUY ▶

max

* The dry state can be changed from Normally Open to Normally Closed by inverting the float.

N.O.: Normally Open
N.C.: Normally Closed

Operating Temp	Maximum Pressure	Float Spec. Gravity
-40°F to 194°F	25 PSI	.80
Thread	**Float**	**Lead Wires**
M8x1.25	.74" diameter	22 AWG PVC 19"

Quantity Discounts	
Quantity	**Package Discount**
5-24	10%
25-99	20%
100 and up	30%

Alarm

http://www.tti-plus.com/15-Watt-Piezo-Dynamic-Dual-Tone-Siren-p/tti-s-441.htm

Our Price: $7.99
15 watt Dual Tone Siren, Piezo Dynamic Technology, 110 db
Product Features
Features/Specifications:
- New Patented Piezo Dynamic Technology
- 15 watt Dual Tone Siren
- 100 MA (+/- 10%)
- 110 db (+/- 3db)
- 6-12 volt DC operation
- High impact ABS housing
- Weather resistant, suitable for indoor/outdoor use
- New low-profile design 4 1/4" x 1 1/4" (106mm x 30mm)

Tubing

http://misterlandscaper.stores.yahoo.net/ml100blaccon1.html

(MLT–B100B)   100 Ft. Boxed Coil – 1/4" Black Connector Vinyl

This Box of black 1/4" Vinyl Tubing is used primarily to run Drippers and Dripper Stakes either directly from an outdoor faucet or from the 1/2" Poly Tubing. It is conveniently packaged in an easy to use pull through box. This Product is perfect for extending your Drip Irrigation system or your Micro sprinker irrigation system to all parts of your garden. (Each 100 Foot Box Sold Individually)

Availability: Usually ships in 5-7 business days.

MLT-B100B   **$23.45**

¼" Vinyl Couplers

http://misterlandscaper.stores.yahoo.net/mlsmal14barx.html

(MLT–BXB)   1/4" Vinyl Couplers

The 1/4" Vinyl Couplers are an excellent tool for expanding a Drip Irrigation System. You can use them to connect two pieces of the 1/4" Vinyl Tubing, attach the Vinyl to the 1/2" Poly Tubing, or to repair a cut in the Vinyl. (15 Couplers Per Bag)

Availability: Usually ships in 5-7 business days.

MLT-BXB **$5.45**

10Pk 1/4 Barbed Valve
Hardwaretools.com

Product Description

10 Pack, 1/4`` Barbed Valve, Adjusts, Balances Or Shuts Off Water Flow To Watering Circuits, Zones Or Plants, For Use With 1/4``, .160``.

Product Details
  Price From: $10.49
 Manufacturer: Rain Drip Inc 1
Model Number: 612010B
 UPC Number: 018171120106

Bibliography

1. White, Frank M. *Fluid Mechanics*. 6th ed. McGraw Hill. Boston, 2008. pp. 751-752.