Urban Farming Interdisciplinary Major Qualifying Project

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Abstract

Flats Mentor Farm (FMF) currently irrigates 7 acres of farmland by pumping well water to holding tanks, from which farmers must fill buckets and carry some distance to their plots to manually water their crops. The project team, in conjunction with representatives from FMF, developed and proposed alternative irrigation methods to replace the existing system, considering various irrigators, filtration systems, and pump designs, and eventually deciding on a MegaNet sprinkler system driven by an unused gasoline-powered pump at FMF, with lay flat line and PVC connections. To simulate the system, the project team built a small-scale prototype simulating irrigation for a 25’ by 25’ plot using a 0.5 hp pump. Difficulties in lay flat line and slip-on PVC connections prevented the prototype from reaching the desired pressure (35 psi). Nevertheless, the irrigation system prototype demonstrated proper MegaNet sprinkler function at low pressure (6 psi). Prototype irrigation system function, despite a proportionally weaker prototyping pump, also suggests proper pump function in the full-scale design.

Results:

- FMF chose the proposed sprinkler irrigation design
- The pump available at the farm would adequately support the farm irrigation needs
- The prototype design was successfully able to transfer water through the system to operate the MegaNet sprinkler; a 0.5 hp pump is able to support a 25’x25’ system.

Authorship

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Pump Requirements	Jasmin
Piping Requirements	Sophia
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AutoCAD Model Design Iterations	Nathan
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1. Introduction

1.1 Client Statement

The Major Qualifying Project (MQP) group received the following statement from the project sponsor, World Farmers: “World Farmers offer mentoring, training, and hands-on assistance when working with each farmer to build the capacity needed to operate individual farming enterprises. We enact our mission through various initiatives, the most prominent of which is the Flats Mentor Farm program. Since 1984, Flats Mentor Farm in Lancaster, Massachusetts has provided the space and infrastructure for small immigrant and refugee farmers to get started. The farmers at Flats Mentor Farm produce over 55 acres of ethnic specialty crops.

The objective of this project is to build an irrigation system for the small scale farmers in a 7-acre segment of the overall farm. The irrigation system would pump water from a nearby river to a water storage tank, and would deliver water at consistent rates to the farmers. Ideally, the irrigation system would be powered from a renewable source such as solar radiation.”

1.2 World Farmers

The Flats Mentor Farm is a 70-acre river bottom parcel of land in Lancaster, Massachusetts. The farm hires and supports small-scale farmers who came to the United States from across the world by allowing them to use the land and provide them with marketing assistance. Flats Mentor Farm employs a manager and a sustainability coordinator to ensure that the farmers can access all the available resources (World Farmers, n.d.c).

1.2.1 World Farmers’ Mission

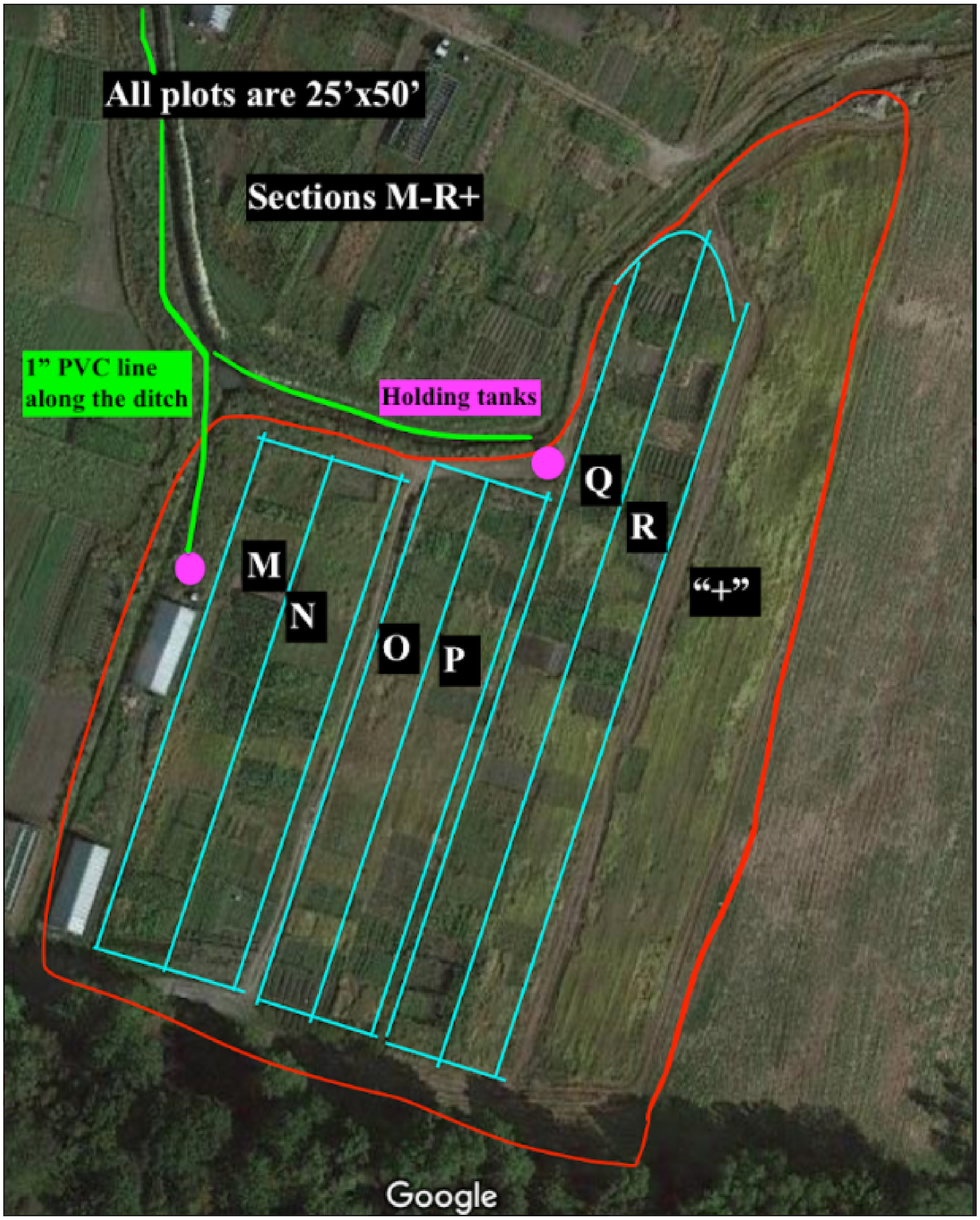
World Farmers creates jobs for refugees and immigrants with agrarian backgrounds, providing sustainable agricultural production and marketing practice experiences. They connect the farmers to retail, wholesale, and farmers' markets in New England, allowing them to preserve their cultural identity while making a living in the United States (World Farmers, n.d.b).

To further assimilate the farmers to the New England lifestyle, the World Farmers' Mentoring Program trains them in agricultural production, marketing, and business development. The program is done in a respectful environment, facilitating cross-cultural learning between the farmers, the staff, and the volunteers (World Farmers, n.d.b).

At Flats Mentor Farm, the farmers grow over 70 different crops, including traditional East African and South Asian vegetables (World Farmers, n.d.a). Seeing as the native climates of these crops differ significantly from Northeast America, the organization trains the farmers in region-appropriate growing practices that will help them support their families while retaining cultural traditions (World Farmers, n.d.b).

1.3 Purpose of This Project

The purpose of this project is to design an irrigation system for World Farmers that can satisfy the watering needs of a 7-acre segment of Flats Mentor Farm. Currently, no irrigation system exists on the farm to provide water to the plots of land on the far east side of the farm. The group must use a pump to direct water from the Nashua River to one or more hydrants, which would then transport water to the crops using a piping and watering system.


All plots are 25’x50’
Sections M-R+
1” PVC line along the ditch
Holding tanks
Q
R
M
N
O
P
“+”
Google

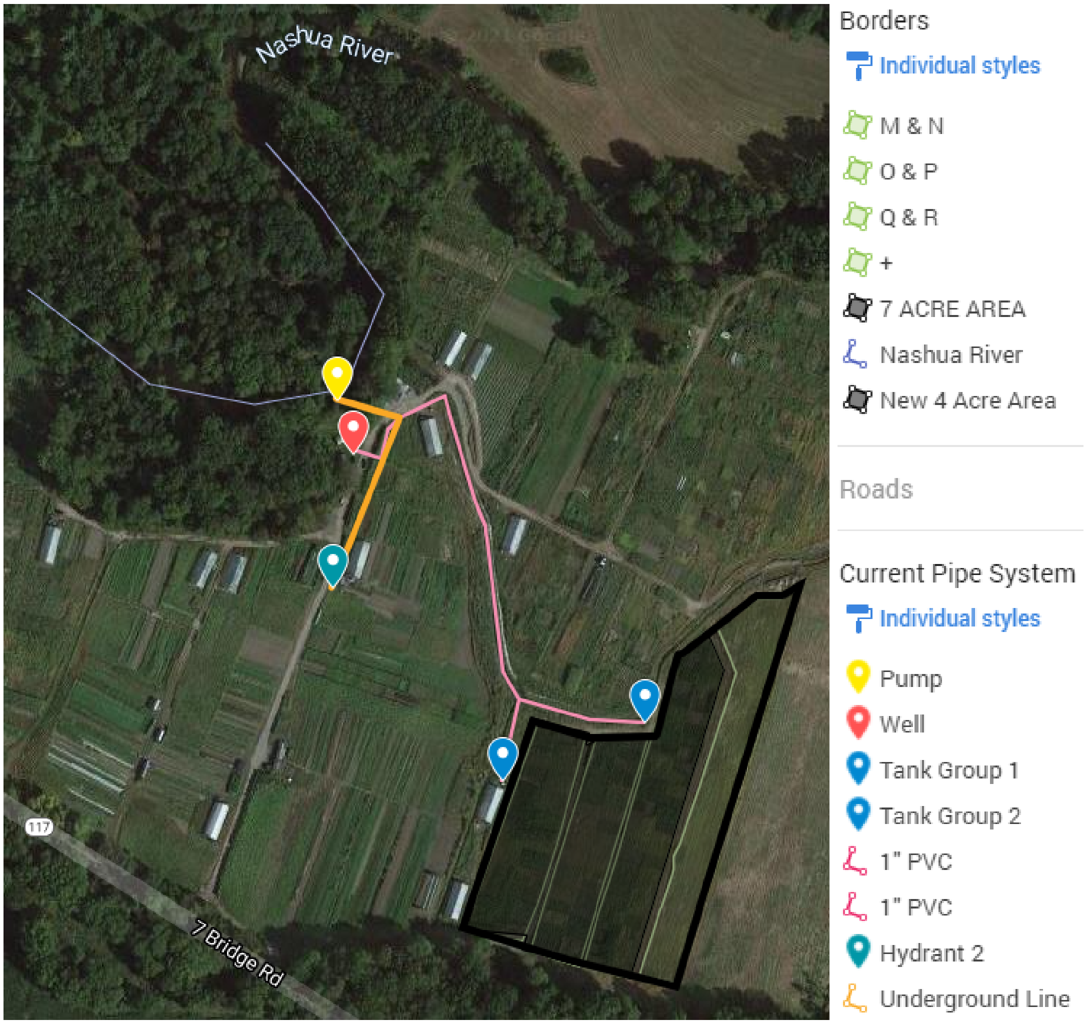


Figure 1a, 1b: The first map was provided by World Farmers and shows a section of Flats Mentor Farm showing the divisions of the seven plot segments, the two large tanks, and the existing PVC line connecting the tanks to the well (a). The second map shows the proximity of the farm to the Nashua River and shows the whole farm. The 4-acre area is outlined in lime green plots labeled M, N, O, P, Q and R within the thick black outline which also includes Plot +(b).

The 7-acre portion of Flats Mentor Farm being discussed has two large holding tanks, one with a 1,500-gallon capacity and the other with 1,000 (Figure 1a). This farm section also has three 270-gallon Intermediate Bulk Container (IBC) tanks. The section is divided into seven segments: M, N, O, P, Q, R, and +. There are 130 family plots 25’ x 50’ in size in total. Between N and O, P and Q, and R and + are 10-foot segments of service road (Figure 1b). Water comes from a well and travels to the holding tanks with 1” PVC lines. The only power source is a generator. The farm also has hydrants, which may be used as a secondary water source. The hydrants connect the pump to the piping to transport the water from the river to the crops. The placement of these features is shown in Figure 1. Farmers have to walk across the property to the holding tanks and carry water to their crops in buckets. This process proves tedious and strenuous, especially since many of the farmers are older.

Much of the watering depends on rainfall. During drought years, World Farmers utilizes a 3” aluminum surface irrigation system to transport water from the nearby river to the plots. This system differs from the holding tanks in that the tanks are used year-round for manual irrigation while the surface irrigation pumps directly from the river. They have found issues with farmers running over these pipes, and they only use them when necessary.

By designing a new irrigation system for Flats Mentor Farm, the MQP team will help the farmers to water their crops more efficiently. Instead of carrying buckets back to their plots, they can have their crops watered automatically. With a sprinkler irrigation system, the water will travel from the river to the farm, watering a wide area of crops quickly without disturbing their orientation.

The goal of this project is to work with World Farmers at Flats Mentor Farm to design a cost-effective irrigation system that spans across the 7-acre farm portion and irrigates the 130 25’ x 50’ family farm plots in the seven segments.

After selecting the most appropriate materials and components (e.g. PVC, aluminum, polyethylene, or vinyl piping), a working prototype will be built to supply the watering needs of one family farm. From there, World Farmers can gather the funding to scale the project up to fulfill the needs of Flats Mentor Farm.

The MQP team will conduct research and perform experiments to optimize the system design over the given land area using a combination of their preexisting equipment and products from outside vendors like Brookdale Fruit Farm and Home Depot.

1.3.1 Objectives of this Study

1. Determining the functional requirements for a farm irrigation system.
2. Designing an irrigation system for a seven-acre segment of Flats Mentor Farm.
3. Building a smaller scale design and prototype that supports one 25’x25’ family farm.

2. Background

2.1 Irrigation Systems

When cultivating crops, many farmers turn to irrigation to meet their water needs. Irrigation is the process of artificially applying water to crops to fulfill their requirements. It can also add nutrients to the artificial water supply for additional benefits. Irrigation ensures that plants receive the necessary water for proper growth, development, and seed germination (Byju, n.d.).

Typical water sources for irrigation include wells, ponds, canals, lakes, and storage tanks. Water is pumped from the source to the crops using piping and some form of emitter, the type depending on the chosen irrigation method. Different crops have different requirements for frequency, time, flow rate, and quantity of water. These factors also depend on the soil type and quality, geographical region, and season (Byju, n.d.).

2.1.1 Types of Irrigation Systems

Figure 2: A channel-based surface irrigation system that distributes water by having it travel from a higher elevation to a lower one (Jamal, 2017b).

There are multiple types of irrigation systems (Kankam, 2017). The first to be discussed is surface irrigation, which involves water distribution through a field using gravitational flow (Figure 2). Soil stores the water in the channels and helps distribute it. It has three stages: Advance, Storage, and Recession. Advance is when the water moves down the soil channel. Storage is when the water ponds at the bottom until it reaches the required depth, and Recession is when the water drains. The main advantage of this type of irrigation is that it's easy to use and requires little capital. Because it uses gravity to move the water, it also has a small energy requirement. However, it varies in availability depending on the soil's elevation, and it is not very efficient. It also requires significant labor to set up, and poor choices can result in the crops not receiving enough water (Jamal, 2017b).

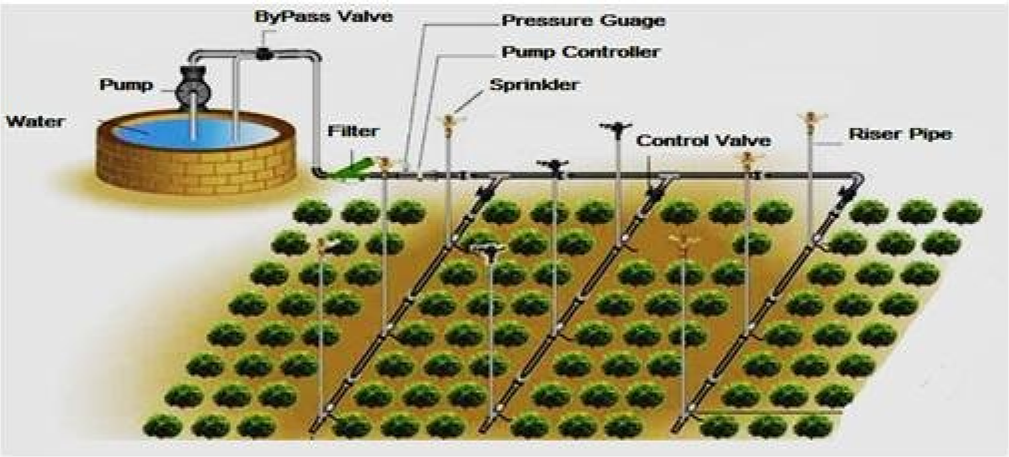


Figure 3: A sprinkler irrigation system drawing water from a well (El-Shimy & Abdo, 2017).

Another type is sprinkler irrigation, which is when sprinklers water the land in a rain-like manner (Figure 3). The water is distributed through pipes using a pump, and it is sprayed through the air by sprinklers causing it to break apart. This breakage creates an effect similar to rain. Usually, the wetting pattern for the sprinklers is circular, but it's not very uniform. It's suitable for most crops, but it can damage crops with delicate leaves, like lettuce. One pro is that it reduces soil compaction and prevents major damage from the frost. The best advantage is that after its initial installation, it requires very little work to upkeep. However, it requires a relatively high upfront cost, and it’s not very efficient because of evaporation. Additionally, the sprinkler pattern can be blown away by the wind, meaning it’s very vulnerable to the weather. As such, it works best for small backyard gardens (Velez, 2017).

Different types of sprinklers can be used with sprinkler irrigation. One such type are mini gun sprinklers which are portable and can be easily automated. They can cover a large area, and release water at a high pressure. However, they have the highest price out of all sprinklers. Another type is solid set sprinklers, which are immobile, but can be applied over a larger area. They have a smaller optimal pressure and lower flow rate (lower GPM), and they require a lot of maintenance (Byelich, Cook, & Rowley, 2013).

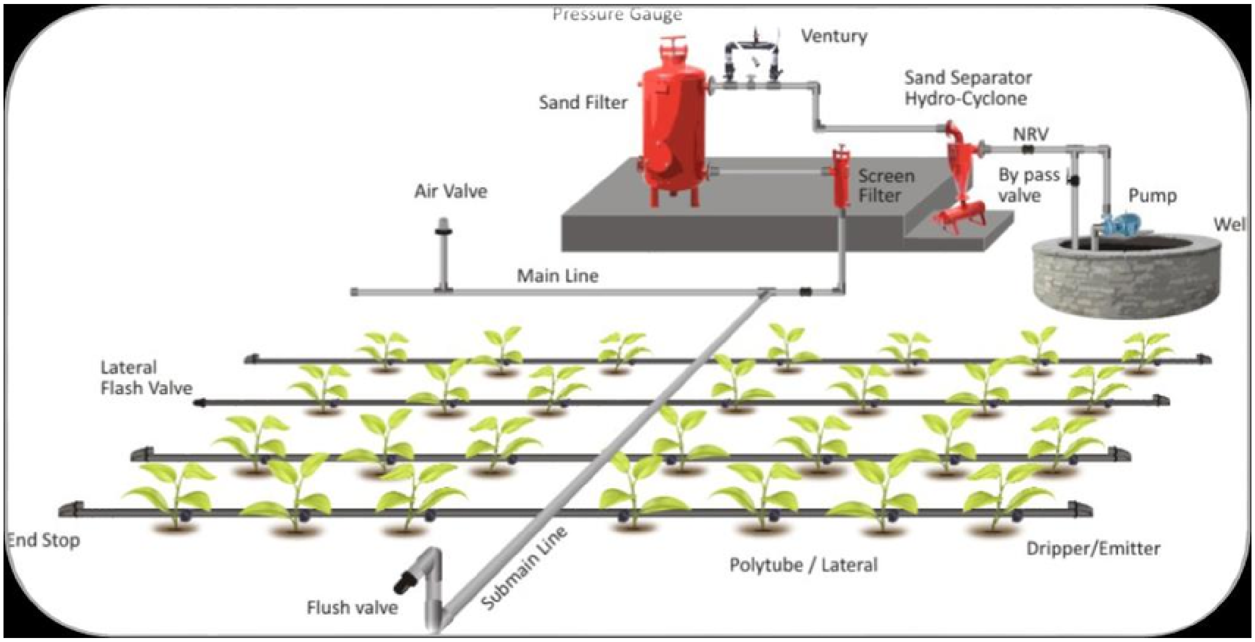


Figure 4: A diagram of a drip irrigation system (Jha, Mali, & Naik, 2015).

An additional type of irrigation is drip irrigation, which works best for rows of crops (Figure 4). It involves installing pipes right above each row and poking holes in them to allow the water to “drip” into the soil, letting the plant absorb the moisture. It can be controlled manually or with a timer, like with Sprinkler Irrigation, and is one of the most efficient irrigation methods in terms of water cost. Because the water drips at soil level to only the desired crops, drip irrigation prevents nearby weeds and wastage from evaporation or wind. However, it is difficult to install, and can lead to roots dying if installed improperly (e.g. overly wide emitter placement). It also has minuscule openings, meaning it can clog up and require drainage. It isn’t good for sprawling crop areas either, since the piping should be straight, and it covers a tiny region. However, as long as one is attentive to its installation and upkeep, drip irrigation works excellently (SF Gate, 2020; “The Pros and Cons of Drip Irrigation,” n.d.).

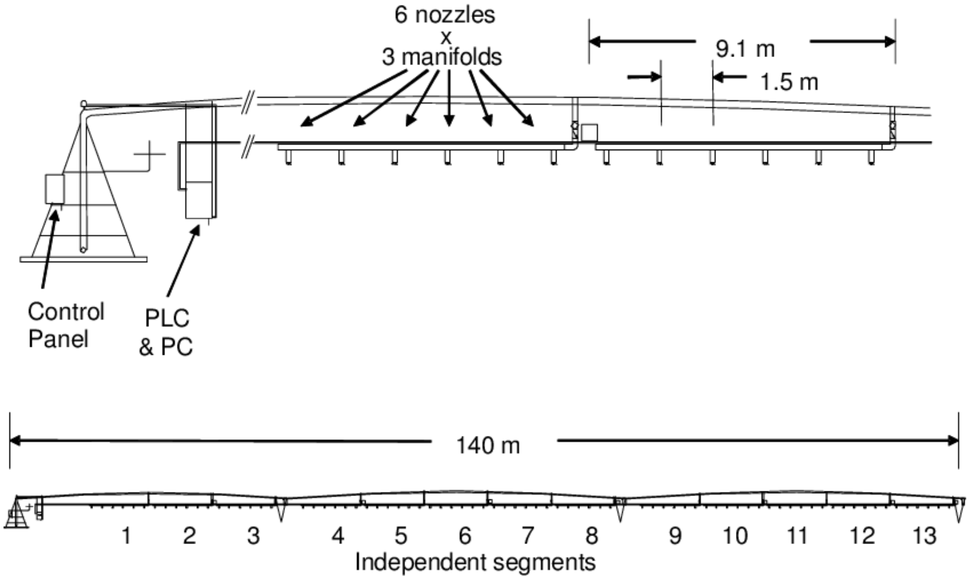


Figure 5: A profile schematic of a pivot irrigation system with 13 segments, with each segment applying 12.5 mm of water at 50% travel velocity (Stone, Sadler, Millen, Evans, Camp, 2006).

Another kind is center pivot irrigation, in which equipment rotates around a pivot and the attached sprinklers water crops (Figure 5). It covers a wide circular area called a crop circle, and it uses water efficiently, causing little runoff. It works best on bigger farmlands and has a low labor cost.

However, the equipment requires upkeep and can permanently deplete groundwater supplies, damaging soil composition in the long run (UN Food and Agriculture Association, 2007).

Figure 6: A woman manually irrigating her crop with a bucket (Ronzio, 2012).

The most labor-intensive type of irrigation is manual irrigation, which involves carrying a water source to the crop (Figure 6). Flats Mentor Farm utilizes manual irrigation, and it is the MQP team's job to design a more suitable system for their farmers' needs. While manual irrigation allows one to choose exactly how much water they want each crop to receive, it is also very time-consuming and laborious (Kankam, 2017). By watering crops manually using buckets, the farmers use more water than they would with an irrigation system. Unless the workers are careful when carrying the water to the crops and avoid over-watering crops, more water is lost along the way than would be lost in an irrigation system (Kankam, 2017).

Figure 7: A raingun used for water gun irrigation (Indiamart, n.d.).

One other type is raingun irrigation, also known as water gun (Figure 7). This micro-irrigation system has a high-performance value, covering an extended water radius with a high volume flow of water ("The Complete Guide to the Raingun," n.d.).

Many raingun irrigation systems have adjustable jet breakers and interchangeable nozzles that one to control the droplet size to water more delicate crops. This feature helps with evenly watering crops. These systems have fewer components than others, lessening the maintenance requirements ("The Complete Guide to the Raingun," n.d.).

Compared to drip irrigation, raingun has a lower cost, has no clogging problem irrespective of water quality, works well with all crop orientations, and needs less maintenance. Raingun irrigation generally saves labor, money, and electricity costs, allows for a wider irrigation coverage, adds nitrogen to the soil, washes away pests, and facilitates the fertilization process ("Rain Gun Irrigation System for Agriculture," 2019).

Water gun irrigation is energy-efficient, durable, inexpensive, and allows for control if it has interchangeable nozzles. It is easy to operate and maintain, and the large land mass covered allows one to install fewer units. However, it does not sprinkle uniformly without extensive control over the nozzles, speeds, and pressure. Also, it is susceptible to evaporation and can be thrown off the trajectory by wind. The initial cost of the gun can be high, and if it breaks, a professional needs to repair it (Titus & Pereira, 2008).

Nonetheless, this irrigation system can easily be raised to cover a greater radius, and it is a definite improvement upon typical manual and sprinkler irrigation. For Flats Mentor Farm, a water gun irrigation system will allow the farmers to plant their crops as they please and have a decent stream of water.

2.1.1 Water Source and Distribution

There are three types of water sources available for irrigation: surface, ground, and public water. For this project, the MQP team will have access to surface water from the Nashua River. When using a river as a water source, the state of Massachusetts requires the filing of a permit with the Department of Environmental Protection if they take more than 100,000 gallons of water per day for three consecutive months or 9 million unregistered gallons over three months (University of Massachusetts Amherst, 2020).

There are some other considerations to keep in mind when pumping from a river. The pumping should not directly affect fish downstream from the site. The best time to pump the water is during high flow to avoid disturbing the ecosystem (Broz, Milholin, & Zulovich, 2017).

Since the water elevation at the river is slightly lower than the farm, the farm requires a pump to transfer water to the crops (Jamal, 2017a). However, the distance between the river and the farms necessitates the use of a powerful pump. If the pump at the farm cannot transfer water to the far east side of the farm, an alternative option would be to pump river water to holding tanks next to the river. A second pump can then be used to move water to the farm plots. However, rather than using a second pump, the tanks can be raised high enough on a concrete foundation to allow gravity to transport the water to the crops.

The total water capacity of the tanks located at the Flats Mentor Farm is approximately 3,310 gallons. These tanks provide enough water for at least one day of irrigation. The limiting factor of the irrigation needs at the farm would be the volumetric capacity of the tanks. These tanks have a relatively small total volumetric capacity, which means the tanks would need frequent refilling and utilization of the primary river pump. If tanks are not used, the limiting factor may be the amount of fuel that the farm is willing to use in one day. (See Appendix A for pump related calculations.)

2.1.1.1 Shallow Wells

An alternative water source for the irrigation system considered was a shallow well. A shallow well is a type of well that derives water from the uppermost saturated aquifer in a specific location. The aquifer's relatively lesser depth means a less powerful pump is required to bring up the water, making shallow wells less costly than deeper wells. This reduced depth also means less filtration by the soil above, so the aquifer is more likely to be contaminated by surface water. Furthermore, the aquifers utilized by shallow wells are more likely to dry up during periods of drought (Environmental Protection Agency, 2019).

There are two primary types of shallow wells: driven and dug/bored. Driven wells require driving a pipe into the ground. They are typically used to reach aquifers 30 to 50 ft below the surface. They are cased continuously, which helps to mitigate contamination of the water compared to dug wells. Bored wells are large diameter holes dug into the ground via shovel or backhoe, and they are cased with stone or brick to prevent collapse. This casing is not continuous, so dug/bored wells have a greater risk of contamination than driven wells, although they are cheaper to make (About Shallow Wells, 2016).

The MQP team considered creating a shallow well for the area of interest on the farm to reduce the water source's distance from the tanks, reducing piping material and costs. The farm regularly tests the local water and has not run into contamination issues, so one of the most significant disadvantages of a shallow well would not apply.

Ultimately, the MQP team dropped the construction plan for a shallow well. The primary reason was that the river should provide all the water necessary for irrigation. The farm was most concerned with reducing the farmers' distance traveled to retrieve water, not lessening the distance to the water source. Another issue with the shallow well was that it would run the risk of drying up during a drought, whereas the river would still provide the necessary water.

2.1.2 Power

Irrigation systems require a power source for pumps to operate. These can be one of three types: gasoline or diesel generators, electric power, or solar-power photovoltaic cell (PV) systems. Each power source type has its benefits and drawbacks.

Conventional gasoline generators use an internal combustion engine to drive the irrigation pump impeller. These generators are coupled to pumps by direct mounting, drive belts, or driveshafts (Yiasoumi, n.d.). Gasoline generators have a lower startup cost than PV systems but require continuous fuel and routine maintenance to function. Those at Flats Mentor Farm would rather use electric or solar power than fuel to power the pumps located at the tanks.

Solar-powered systems use a photovoltaic cell to store energy in a battery, which powers an electric pump. Solar-powered pump systems require other components to function, including:

- A **solar charge controller** to control battery charging and discharge,
- **Cables** to connect components,
- A **water pump timer** to control the pump operation.

Combined with the panel cost, these added components make solar-powered pump systems more expensive than a gasoline-powered pump (Maximum Off Grid, 2020). However, operating costs are near zero, and maintenance is minimal, consisting of only periodic cleaning. On average, a PV cell lasts 15-25 years at above 85% performance as long as it is cleaned when dirty, and can be repaired or replaced under warranty. Solar pump systems also pose less environmental risk than gasoline-powered pumps, with no exhaust or fuel to store or spill (Michigan State University, 2013; Solar Reviews, 2020).

2.1.3 Pumps

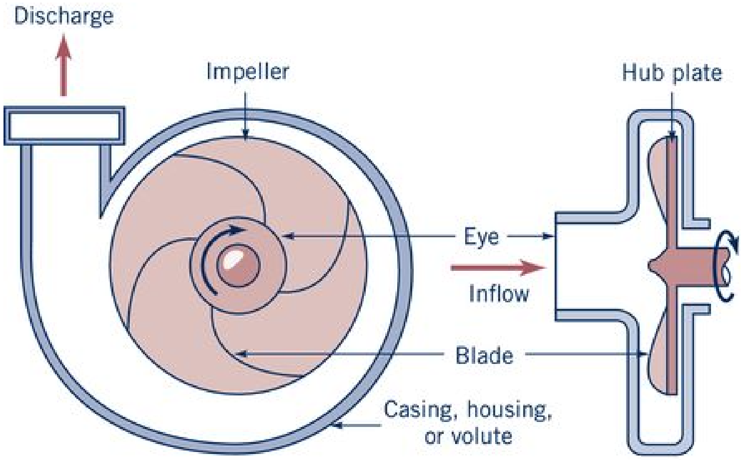


Figure 8: Centrifugal pump (Gerhart, Gerhart, & Hochstein, 2016).

A pump is a device that transforms mechanical energy into hydraulic energy used to move fluids (Gerhart, Gerhart, & Hochstein, 2016). Pumps may fall within four main categories: positive displacement pumps, centrifugal pumps, jet (mixed-flow) pumps, and propeller pumps. The type of pump chosen for a particular application depends on the pressure head (referred to as head) and volumetric flow rate requirements expected to transfer fluid. The head is expressed in pressure units or distance units; volumetric flow rate units are presented as volume over time. Irrigation sites commonly operate centrifugal pumps to transfer water. Centrifugal pumps are turbo-hydraulic pumps, which move fluid by rotating *vanes*—curved chambers on the impeller—or by another fluid (Figure 8). Centrifugal pumps can either work submerged in water or placed on the ground. The pump that World Farmers currently has available at Flats Mentor Farm is a non-submersible, diesel-powered centrifugal pump with adjustable rotational speeds. Centrifugal pumps use the mechanical energy produced by an electric motor to convert velocity to pressure by the use of vanes on a rotating impeller, depicted below.

The pump's impeller has a known thickness and diameter; pumps with larger impeller sizes can produce higher velocities and pressures. Changing the impeller size or changing the rotational speed influences the flow rate.

From the pump efficiency, e_p, and the power input, P_i, the power output of the pump, P_o, can be calculated using Equation 1:

$$P_o = e_p\, P_i \qquad (1)$$

One can also calculate power output at peak efficiency using the specific weight of water, γ (at a given temperature), the pump head (H_p), and the desired flow rate (Q) defined below as Equation 2:

$$P_o = \gamma Q H_p \qquad (2)$$

Knowing the power output and pump efficiency, one can find the input power that the pump requires to operate using Equation 1.

To calculate the pressure head of the pump, H_p, or the distance that the pump is able to move water, the vertical and horizontal distance between the river and the farm land must be determined. Setting the source head, H_S, or river elevation, as the datum point (0 ft), the receiving body head, H_R, or farm elevation, becomes positive. The pump pressure head can be found from Equation 2:

$$H_p = (H_R - H_S) + h_L \qquad (2)$$

The variable h_L signifies the head losses that the pump must overcome. Generally, head loss accounts for the friction of the pipe material that the fluid experiences. Head losses are influenced by the length of the piping and the bends, or elbows, of the design configuration.

When finding values related to the head of a pipe, K refers to the loss coefficient, g refers to the gravitational constant (9.81 m/s^2), and Q refers to the volumetric flow rate of the fluid in the pipe. The loss of fluid along a pipe in head terms is represented in Equation 3:

$$\Delta h = \frac{KQ^2}{2g} \qquad (3)$$

To maintain the flow Q and raise it against gravitational force from the reservoir height difference ΔZ, energy E must be supplied in head terms as:

$$E = \Delta Z + \frac{KQ^2}{2g} = H \qquad (4)$$

The system loss coefficient K in Equation 4 can be written in terms of the entry loss and friction loss of the suction pipe h_s and the losses due to bends, friction loss and exit loss h_d. If the system is altered (such as closing a valve) the K will change. Thus the total head loss can be written as in Equation 5:

$$H = \Delta Z + h_s + h_d \quad (5)$$

For rotodynamic pumps, the generated head is a function of discharge. When they operate in conjugation with pipe systems, the head from the pump equals the system energy requirement of the flow rate because they share volumes, as seen in Equation 6:

$$H = D = \Delta Z + \frac{KQ^2}{2g} \quad (6)$$

The solution is the intersection of the pump and the system characteristic, or operating point. This point is where the pump and system operate at the same rate. The process of choosing the correct pump is known as pump matching. The point on the system that corresponds to the required flow rate is the duty requirement, which means the operating point must correspond with it. This requirement means that different operating points can be chosen depending on the selected pump.

To operate the pump available at the farm, the inlet goes into the river. The pump inlet pipe should have a filter fixed to its base and float at least one foot above the river bottom to minimize the amount of sediment that enters. Debris entering the pump can damage or reduce the lifespan of the pump. The river's depth varies throughout the year and has an estimated minimum depth of three ft. The pump motor must then be filled with fuel and turned on by an employee to generate the pump. A sprinkler irrigation system will then irrigate each farm plot.

2.1.4 Filtration System

Pumped water, especially from surface water sources (vs. wells and municipal sources), must be filtered before irrigating crops. Filtration systems remove larger suspended solids and certain organic materials such as algae and mold but will not remove microorganisms (e.g., bacteria, protozoa, plankton). Filtration arrangements will consist of a primary filtration method, often followed by a second filter for materials not separated by the first stage. Commonly used filters include:

1. **Media Filters** - These separate suspended material by forcing water through a container filled with sharp-edged media, usually gravel or sand, and excel at removing organic material. These filters should be followed by a secondary filter to prevent media leakage into the irrigation system (Netafim, 2015).
2. **Screen Filters** - These pass water through a metal screen/net to trap inorganic matter but do not reliably filter slimy organic matter. Screen filters are commonly used as secondary filters when drawing from surface water sources. (Netafim, 2015).
3. **Disk Filters** - These share characteristics of screen and media filters, employing a stack of abrasive mesh disks. Disk filters have greater filtering surface area and can handle higher flow rates compared to screen filters (Netafim, 2015).
4. **Conical Filters -** The conical cone strainer is another common mechanical filter used within a pipeline. In this application, it will filter debris from the Nashua River that passes through the foot valve of the pump. It is normally placed between two connecting pipeline flanges after the pump, and should be cleaned or replaced frequently. The orientation of the conical strainer can be flipped horizontally. It is recommended to orient the strainer so that the flow and particles are pushed toward the outer edges where the strainer is strongest. The standard size of the holes on the strainer is 0.0625 inches, and it could operate with an additional material of a smaller perforations size called mesh attached to the strainer. It is recommended to use 40 mesh for filtering river water, which has a perforation size of 0.016 inches. With smaller strainer perforations, the fluid

experiences more friction and a larger pressure drop ("Introduction to Permanent and Temporary Strainer Types," 2019).

5. **Centrifugal Filters** - Also known as "hydrocyclone sand separators," these are cone-shaped vessels that use centrifugal force to remove larger inorganic matter (less than 50 microns). Since these neither separate inorganic matter nor pass water through a physical barrier, they need a secondary filter, usually a media filter (Netafim, 2015; Stryker, n.d.a).

Filtration system choices will depend on the chosen water source. In Flats Mentor Farm, drawing from the Nashua River will likely require multiple filter types because it is a surface water source. On the other hand, drawing from a well with frequent water testing may only need a single filter type. Each filter produces a drop in pressure. Pressure drop can be calculated or interpreted graphically. Pressure drop depends on the flow rate of the system and the dimensions for that specific strainer model. To calculate the change in pressure due to a strainer, use Equation 7:

$$\Delta P = \left[\frac{Q}{C_v}\right]^2 \qquad (7)$$

ΔP is the pressure change, Q is flow rate, and C_v is the flow coefficient. The flow coefficient is specific to a particular strainer model and is obtained from the manufacturer. Alternatively, the manufacturer can provide a graph that relates flow rate and pressure loss given a particular strainer (with known diameter and perforation size). If the system has additional mesh lining, then multiply the calculated pressure drop by a correction factor to find the final pressure drop.

2.1.5 Piping

Irrigation systems require pipes that transport the water from a source to its destination. Piping can vary by its material and its diameter. For irrigation, the two most common piping materials are white PVC (polyvinyl chloride) and black pipe (polyethylene) (Smith, 2018). When selecting piping, the factors to consider are the volumetric flow rate of water in the pipe, the density and velocity of water, the elevation change throughout the piping, the pipe's roughness, and friction factors affecting head (pressure) loss. These factors affect the pipe's pressure, diameter, Reynolds Number, and the total head required.

Below are the equations to determine the proper piping for the irrigation system. Equation 8 finds the diameter (D_{pipe}) of the pipe using the water's volumetric flow rate (Q) and velocity (v).

$$D_{pipe} = \sqrt{\frac{4Q}{\pi v}} \tag{8}$$

Equation 9 determines the Reynolds number (Re) using the water's density (ρ), the velocity (v), the pipe diameter (D_{pipe}), and the dynamic viscosity (μ).

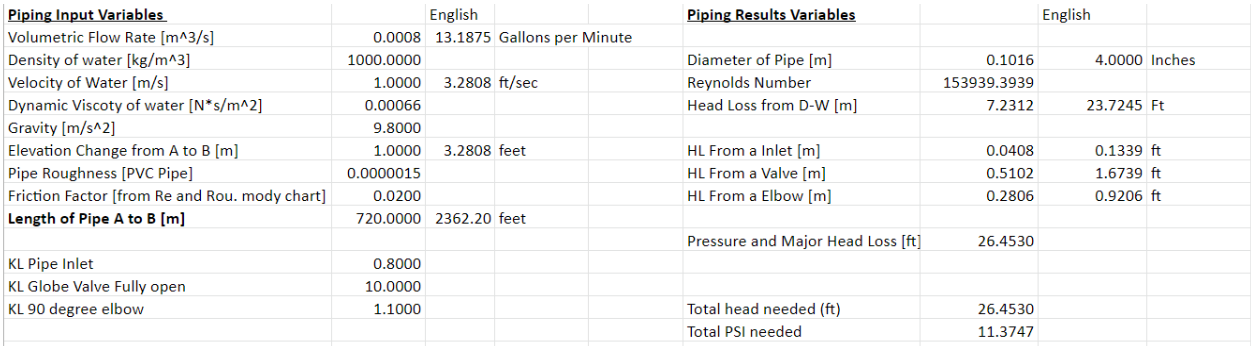
$$Re = \frac{\rho v D_{pipe}}{\mu} \tag{9}$$

Equation 10 calculates the pressure drop (Δp) using the friction factor (f), density (ρ), velocity (v), pipe diameter (D_{pipe}), and pipe length (L).

$$\Delta p = f(\rho)(v/2)(1/D_{pipe})(L) \tag{10}$$

Lastly, Equation 11 gives the major head loss ($h_{L,major}$) due to friction using the friction factor (f), pipe length (L), pipe diameter (D_{pipe}), velocity (v), and gravity (g). Equation 11 is known as the Darcy-Weisbach equation.

$$h_{L,major} = \frac{f*L*v^{2}}{2*g*D_{pipe}} \tag{11}$$



Piping Input Variables		English		**Piping Results Variables**		English	
Volumetric Flow Rate [m^3/s]	0.0008	13.1875	Gallons per Minute				
Density of water [kg/m^3]	1000.0000			Diameter of Pipe [m]	0.1016	4.0000	Inches
Velocity of Water [m/s]	1.0000	3.2808	ft/sec	Reynolds Number	153939.3939		
Dynamic Viscoty of water [N*s/m^2]	0.00066			Head Loss from D-W [m]	7.2312	23.7245	Ft
Gravity [m/s^2]	9.8000						
Elevation Change from A to B [m]	1.0000	3.2808	feet	HL From a Inlet [m]	0.0408	0.1339	ft
Pipe Roughness [PVC Pipe]	0.0000015			HL From a Valve [m]	0.5102	1.6739	ft
Friction Factor [from Re and Rou. mody chart]	0.0200			HL From a Elbow [m]	0.2806	0.9206	ft
Length of Pipe A to B [m]	720.0000	2362.20	feet				
				Pressure and Major Head Loss [ft]	26.4530		
KL Pipe Inlet	0.8000						
KL Globe Valve Fully open	10.0000						
KL 90 degree elbow	1.1000			Total head needed (ft)	26.4530		
				Total PSI needed	11.3747		

Figure 9. Sample calculation from piping variable calculator.

The piping selection affects the total head needed, which then affects the pump choice. The pump selection also comes from the volumetric flow rate required. The MQP team made a piping variable calculator, which takes the various input variables for piping and calculates the resulting values. Below is a sample calculation from the calculator as seen in Figure 9.

Besides the actual piping, the two other most important components are fittings and valves, which control the pressure, temperature, and flow rate of the transmitted fluid. Fittings connect different sections of pipe in different ways. The pressure of the piping affects the types of fitting an irrigation system will have. With water conservation becoming more concerning, low-pressure systems are gaining popularity. Some typical fittings are elbows (creates a turn in the pipe), adapter (adapts one type of connection to another), and couplers (a straight fitting that connects two sections). Other types of fittings are caps (close off one end), crosses (connects four sections of pipe), tees (connects one pipe to two others), and valves. Valves are fittings that have on/off functionality. The most common valve is a ball valve with a quarter-turn handle. Another prominent type of valve is a pressure control valve, which controls the pressure of the fluid.

2.1.5.1 Water Hammer Effect

The water hammer effect occurs when the liquid pressure is turned on and off too quickly. When at a full capacity, the water flows evenly. Water hammer causes the water to produce a loud, thumping sound. Factors that affect it include valve closure rate, pipe size, and water pressure ("The Effects of Water Hammer," n.d.). Abruptly closing the valve, long pipes, and a pressure higher than what the pipe can handle can cause the water hammer effect (Madens, 2019).

One way to mathematically observe the water hammer effect is through the one-dimensional wave equation (Equation 12). It can predict the maximum line pressures and disturbance propagation times in a water distribution system with sudden valve closures (Choon, Aik, Aik, & Hin, 2012).

$$\Delta P = \rho a \Delta v \tag{12}$$

ΔP is the pressure rise due to the water hammer in N/m^2, ρ is the liquid density in kg/m^3, a is the impulse wave velocity in m/s, and Δv is the pipeline liquid velocity change. Water in pipes experience impulse waves from a sudden increase in pressure and decrease in flow rate. Other forms of the equation, such as Equation 13, utilize the water column's pressure increase (H) in terms of meters and gravity (g) in m/s^2 (Choon et. al, 2012).

$$\Delta H = a \Delta v / g \tag{13}$$

These equations assume that the friction losses are smaller than the static pressure, there is single phase flow, there are no dissolved gases in the fluid, and the fluid velocity change occurs faster than the critical time. The speed of the pressure waves, as seen in Equation 14, depends on density (ρ), elasticity modulus of the pipe material (E), elasticity modulus of the liquid (k), pipe diameter (D), wall thickness (e), and a constant assumed to equal one (C_1) (Choon et. al, 2012).

$$a = \sqrt{\frac{1}{(\frac{\rho}{k}+\frac{DC_1}{Ee})}} \tag{14}$$

Pressure waves that produce the water hammer effect come from non-normal operations. These include opening and closing the valves too quickly, turning the pump on and off too fast, or suddenly changing the pump's rotational speed. Other parameters influencing the attenuation, shape, and factors including pipe pressure, velocity flow, wall material, blockage, leakage, friction, and cavitations (Choon et. al, 2012).

Opting for a high-pressure capacity pipe will prevent water hammer from occurring. Additional parts like a water hammer arrestor, pulsation dampener, pressure snubber, or surge suppressor offer pressure control (DirectMaterial, 2019). Adding one of these parts can decrease the flow velocity of the liquid or increase the moment of inertia of the pump. Installing a flywheel to the rotating axis of the driving motor prevents the rotational speed from sharply reducing. Installing a bypass pipe with a non-return valve will prevent sudden pressure reduction. Surge tanks in the piping system can suppress pressure waves by storing liquid in the tanks as pipe pressure increases, preventing rapid velocity changes. Pressure control and vacuum valves reduce water hammer by bringing the pressure back to normal (Choon et. al, 2012).

2.2 Farming in Massachusetts

Agriculture has been a vital part of Massachusetts since its first settlers came and grew crops to feed themselves. Today there are 7,241 farms in Massachusetts that encompass 491,653 acres. Farms in Massachusetts tend to be family orientated. Family farms account for 94.2% of farms (Inglis, 2017). Vegetable farms account for 13% of all farms (University of Massachusetts

Amherst, 2020a). In recent years CSAs (Community Supported Agriculture) have become very popular as more people want to support their local communities and be more environmentally friendly. The COVID-19 pandemic has led to a surge in demand for locally grown fruits and vegetables (Greenberg, 2020).

2.2.1 Irrigation on Massachusetts Farms

To see what other vegetable farms in Massachusetts use for irrigation, the MQP team reached out to 30 farms, asking about their irrigation use and power sources. The farms that do use irrigation either use a drip or sprinkler system. The power sources were pumps that were powered using either electricity or diesel. One farmer, Ted Painter from Shelburne Farm, spoke of the challenges that farmers face when it comes to irrigation. While solar power is a good option for many farms, farmers often lack the funds for that transition. The main barrier to expanding irrigation systems is the high cost of wells. Drilling companies charge for wells by the foot, and many do not have the technology to predict the depth before drilling, which makes the cost of a well unknown for many farmers. This uncertainty makes well installations challenging to work into a budget. While it costs a lot to install a well, piping system, and drip lines, maintaining an irrigation system is much cheaper.

2.3 Irrigation System Standards

Water used for irrigating crops needs to follow various standards to avoid damaging the crops or rendering them unsafe for human consumption. The water’s pH should ideally be 5.0-7.0, and its alkalinity should be between 0 to 100 ppm Calcium Carbonate (30-60 is ideal for most plants). The salt levels are critical in irrigation water. Furthermore, the salinity levels (measured by the Electrical Conductivity of the water) in irrigation water should be no higher than 1.5 mS/cm (without water-soluble fertilizer added).

Concerning elements, Calcium in water should be within 40-100 ppm, and Magnesium should be within 30-50 ppm. Sodium should be less than 40 ppm, and Chloride should be less than 140 ppm. Potassium, Nitrate, Ammonium, and Phosphate are indicators of possible contamination of a water source. Therefore, water becomes unusable if it has more than 5 ppm of any of them. Iron should be below 0.3 mg/L for micro-irrigation to mitigate clogging, and levels beyond that can also damage plant foliage. Likewise, Manganese compounds should be below 0.05 mg/L in water to avoid crop damage and irrigation clogging. Fluoride should be below 0.75 ppm. Finally, while one could use water with Sulfate levels below 50 ppm, they should add supplemental Sulfate to the crops because it is essential for plant growth (University of Massachusetts Amherst, 2015).

3. Project Design

3.1 Functional Requirements

When designing an irrigation system, many factors must be considered. Two major components of any complex system are its functional requirements and design parameters, both of which need to be determined early on in the design process. In terms of irrigation, Flats Mentor Farm will have to consider the farmers' needs. The amount of water farmers need and the types of crops they grow may change from season to season, so a versatile system that meets these needs will best fit their farm. A modular approach will also be more usable by the rest of the farm. One way to begin the process of creating a system is through Axiomatic Design.

3.2 Axiomatic Design

To determine the functional requirements of the irrigation system, an axiomatic design matrix was created. This matrix compares the functional requirements to the design parameters to determine the best design to meet World Farmers' needs (Suh, 2001).

The MQP team began by listing the first level functional requirements (FR) and their design parameters (DP). This process resulted in the first level matrix in Equation 14.

- FR_1 = transport water from river to plots
- DP_1 = piping and emitters
- FR_2 = power pump
- DP_2 = generator

$$\begin{bmatrix} FR_1 \\ FR_2 \end{bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{bmatrix} DP_1 \\ DP_2 \end{bmatrix} \tag{14}$$

Then, the process of decomposing them into the second level functional requirements and design parameters began.

Second Level Functional Requirements:

- FR_{11} = transport clean water
- FR_{12} = transport enough water at specific times
- FR_{21} = efficiently supply power
- FR_{22} = provide low-cost energy

Second Level Design Parameters:

- DP_{11} = filtration system attached to pump
- DP_{12} = user controller interface to turn on/off pump when needed
- DP_{21} = sufficient horsepower
- DP_{22} = low-cost, fuel-efficient generator able to run at full load most of the time

The decomposition of FR_1 and FR_2 resulted in decoupled matrices (Equation 15 and Equation 16).

$$\begin{bmatrix} FR_{11} \\ FR_{12} \end{bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{bmatrix} DP_{11} \\ DP_{12} \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} FR_{21} \\ FR_{22} \end{bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{bmatrix} DP_{21} \\ DP_{22} \end{bmatrix} \tag{16}$$

The final axiomatic design matrix features all second level functional requirements and design parameters (Equation 17).

$$\begin{bmatrix} FR_{11} \\ FR_{12} \\ FR_{21} \\ FR_{22} \end{bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{bmatrix} DP_{11} \\ DP_{12} \\ DP_{21} \\ DP_{22} \end{bmatrix} \tag{17}$$

Using Equation 15, the MQP team would use a pump with a user controller interface to turn the pump on and off and control the speeds. It would have a filtration system to transport clean water from the river to the crops. Equation 16 indicates the need for a powerful and efficient power source. While more costly in the long run, a diesel generator would effectively supply the necessary power to run the pump. World Farmers currently has a high-power pump that functions using a diesel generator. It is not feasible to convert the system to solar power without purchasing all new materials, so instead the system will be designed using the current pump and diesel generator because they meet the functional requirements.

3.3 Optimization

To optimize the irrigation system, the MQP team decided to work on saving water by creating a linear equation to model the total profit in MATLAB. There are three components of the linear model used to optimize the irrigation system. The total area of the farm segment in concern is roughly 28,328 square meters, or 304,920 square feet.

One way to avoid this loss is by applying linear programming to maximize the profit generated from the crop (or crops) while minimizing water used for irrigation to satisfy the crops' water needs without compromising the other plots on the farm. In this optimization, the total profit for the crop was optimized.

Nationally, the cost of irrigation for water when pumping from an onsite water source is about \$15 per acre, or \$15/43560 square feet. (Agricultural Resources, n.d.c) Additionally, depending on how deep the water needs to go when being irrigated, the cost to pump water from the nearby river is estimated to be \$0.08/mm. (OECD, 2010) This means the total cost for the water is about \$1.20/(mm*acre).

The three main crops being looked at are collard greens, amaranth, and kale. There should only be one kale plant per square foot, and kale seeds sell for roughly \$3.65 per 1,000 seeds. (Harris Seeds, n.d.c) Therefore, the production price for kale is \$0.00365 per square foot.

A good yield for kale per acre based off results from New England is roughly 2000 pounds (University of Vermont, n.d.c), and fresh kale sells for $2.88 per pound based on data collected from Massachusetts in 2016. This means that the gain for kale is $5760 per acre. Similarly, there should only be one collard green per square foot, and collard seeds sell for roughly $4.75 per 100 seeds. (Johnny's Selected Seeds, n.d.c) Therefore, the production price for collard greens is $0.0475 per square foot. A good yield for collard greens per acre based off results from New England is roughly 2000 pounds (University of Vermont, n.d.c), and the collard greens sell for about $2.63 per pound. This means that the gain for collard greens is $5260 per acre. Amaranth seeds cost roughly $4.00 per acre, and it sells for roughly $0.40 per pound. The yield for amaranth per acre is 800 pounds, so that means when planted in this farm's area, there will be a gain of $320 per acre. (Iowa State, n.d.c)

The first is the decision variables, which are the components of the model that can be edited to come up with the optimal solution of the model. Production cost is determined by human labor, cost of planting, and seed cost. One of these decision variables is the amount of area taken up by a crop. The MQP team can ask about the crops grown around the farm, and then choose how they are distributed throughout the area to maximize profit. However, the farm wants a minimum of 10000 square feet worth of each crop. One of the most important decision variables to look at is the crop water requirements (CWR) are defined as the amount of water needed to meet the water consumed by the crop through evapotranspiration. The crop water requirements for kale are between 12.5 mm to 30 mm. (Gardening Know How, 2019). The crop water requirements for collard greens are similarly also between 25 mm to 30 mm. (Bonnie Plants, n.d.c) Finally, the crop water requirements for amaranth are between 5 mm to 15 mm. (West Coast Seeds, 2021)

The objective function is what is needed to do to minimize the cost of irrigating the crop. This will be optimized by adjusting the above decision variables as well as the constants that affect them. Here is the objective function:

$$\text{CropProfit} = (Sc * Ac) - (Ac * Pc) - (Wc * Ac * CWR) \tag{18}$$

Ac = Area of crop

Pc = Production cost of crop

Wc = irrigation cost

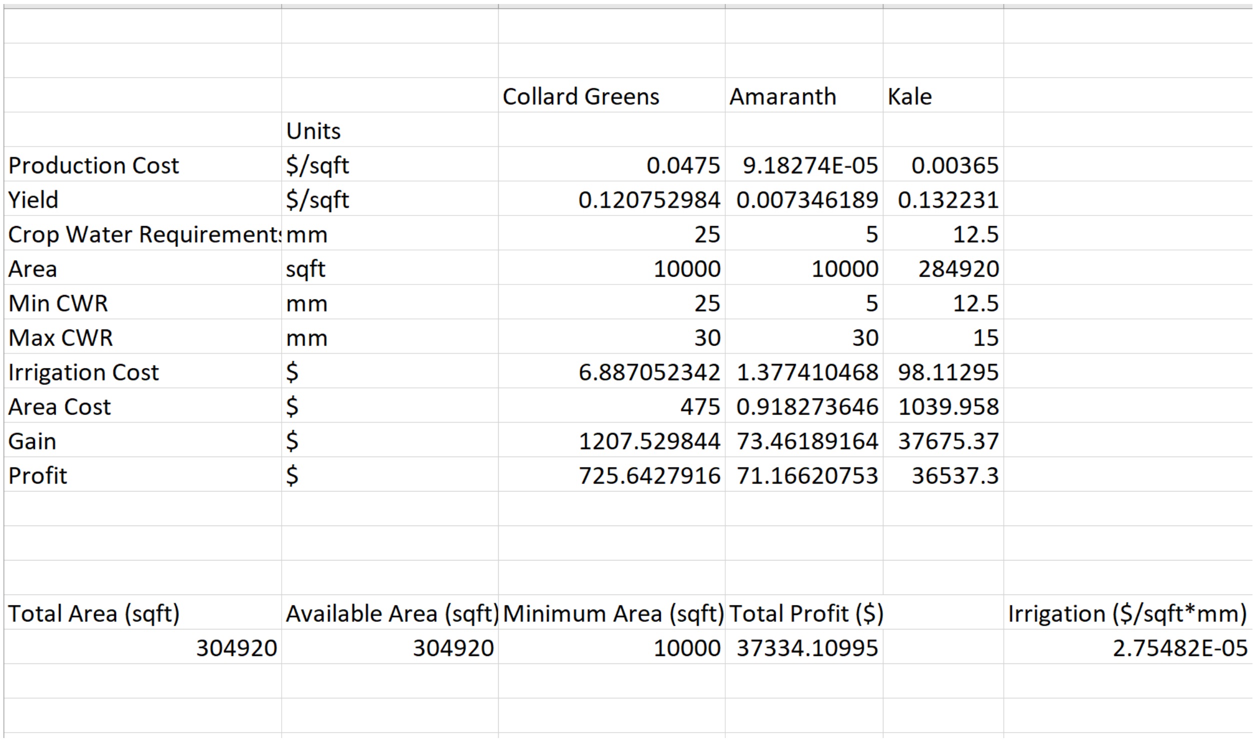
Sc = Sale Price of Crop

The constraints are what the objective function is subjected to and affect how much the decision variables can be changed. One of the constraints is that the total amount of water used in one year must not surpass the amount available from the water source, V. Another one of the constraints is that the area for the crop must not be larger than the total area for the farm, TA. Additionally, the farm wants at least 10000 square feet worth of each crop being looked at. The final set of constraints is the CWR, which must be set between a minimum value and a maximum value for each crop. For this, it is always best that the CWR is as low as possible.

$$A(i) \leq TA \tag{19}$$

$$CWR(i) * A(i) \leq V \tag{20}$$

$$Ac(i) \geq 10000 \tag{21}$$



	Units	Collard Greens	Amaranth	Kale
Production Cost	$/sqft	0.0475	9.18274E-05	0.00365
Yield	$/sqft	0.120752984	0.007346189	0.132231
Crop Water Requirement	mm	25	5	12.5
Area	sqft	10000	10000	284920
Min CWR	mm	25	5	12.5
Max CWR	mm	30	30	15
Irrigation Cost	$	6.887052342	1.377410468	98.11295
Area Cost	$	475	0.918273646	1039.958
Gain	$	1207.529844	73.46189164	37675.37
Profit	$	725.6427916	71.16620753	36537.3

Total Area (sqft)	Available Area (sqft)	Minimum Area (sqft)	Total Profit ($)		Irrigation ($/sqft*mm)
304920	304920	10000	37334.10995		2.75482E-05

Figure 10: Optimal crop and irrigation distribution

Overall, it seems that for the greatest optimization (Figure 10), the crop that should be prioritized the most is Kale. This crop cost the least to produce compared to its selling price, and thus it has the highest margin of profit of all the crops. Additionally, it doesn't cost much to irrigate, and it has a large year round availability.

The MQP team also thought up several options for further optimization of the cost of the system when it is being constructed. One option for reducing the design cost is decreasing the diameter of the red layflat. Brookdale Fruit Farm's updated design includes 4" red layflat, but the MQP team suggested using either 2" or 3" instead. The 4" red layflat costs $796 per roll, whereas the 3" costs $600 and the 2" costs $300. There were concerns about the pressure being increased by reducing the layflat diameter. The pressure can be tested using the prototype, which could prove the viability of reducing the diameter. Replacing the 4" layflat with 3" would decrease the design price by $392 or 7.21%, whereas using the 2” would reduce it by $992 or 19.99%.

Another option the MQP team considered was reducing the number of sprinklers, necessitating an increased distance between each sprinkler. However, World Farmers rejected this alteration because it reduces the already limited land area irrigated by the system. Reducing the number of sprinklers would require more money spent on other watering systems to compensate for the reduced irrigation.

3.4 Required Irrigation Rate

To find the irrigation rate required for crops, the team used Equation 21. They first found the historic evapotranspiration (ET) value, which is the amount of water needed by irrigation. An online calculator from Rain Master Control Systems was used, where the maximum value was 0.15 inches per day during the summer (“Historic ET By Zip Code,” 2012). This value was multiplied by the plant factor (PF), which considers the amount of water that different plants need. Because each family farm has varying crop species and counts, the average water intake value of 0.5 was used. The result was then multiplied by the area in square ft. The size was estimated to be seven acres, which equals 304,920 square ft. To get the values into gallons, this was multiplied by the factor 0.62. This was then divided by the irrigation efficiency, which was assumed to be 0.75. Drip irrigation systems generally have a 90% efficiency, so the calculation will go with IE = 0.90 (“How Much Water”, n.d.).

$$\frac{ET*PF*SF*0.62}{IE} = \frac{(0.15)(0.5)(304920)(0.62)}{0.75} = 18,905.04\text{GPD} \quad (22)$$

This value is far below the 100,000 gallons per day (GPD) required for a permit. If a drip irrigation system with a 90% efficiency is used, it would deliver 15,754.2 gallons per day.

3.5 Pump Requirements

The centrifugal pump available at Flats Mentor Farm will be utilized to transfer water from the Nashua River to the farm plots. Currently, farmers pump water from an on-site well to several tanks; the pump will be moved to transport water from the Nashua River to the farm area. Those at the farm have previously operated this pump from the river to transfer water to a 4-inch hydrant closer to the farm plots of interest. Using a foot valve on the suction hose of the pump to filter debris from the river, the pump can successfully supply water to each of the hydrants. The goal of the project is to design an irrigation system on the farm using the existing pump. First, the project group must confirm the pump capabilities to irrigate the 7-acre farm. Using pump characteristic curves provided by the pump manufacturer, Rainbow Irrigation Company, allows for graphical analysis of the pump's capabilities. Self-producing characteristic curves of a pump from raw data would risk damaging the pump.

The pressure head and volumetric flow rate compose a pump performance curve, or H-Q curve.

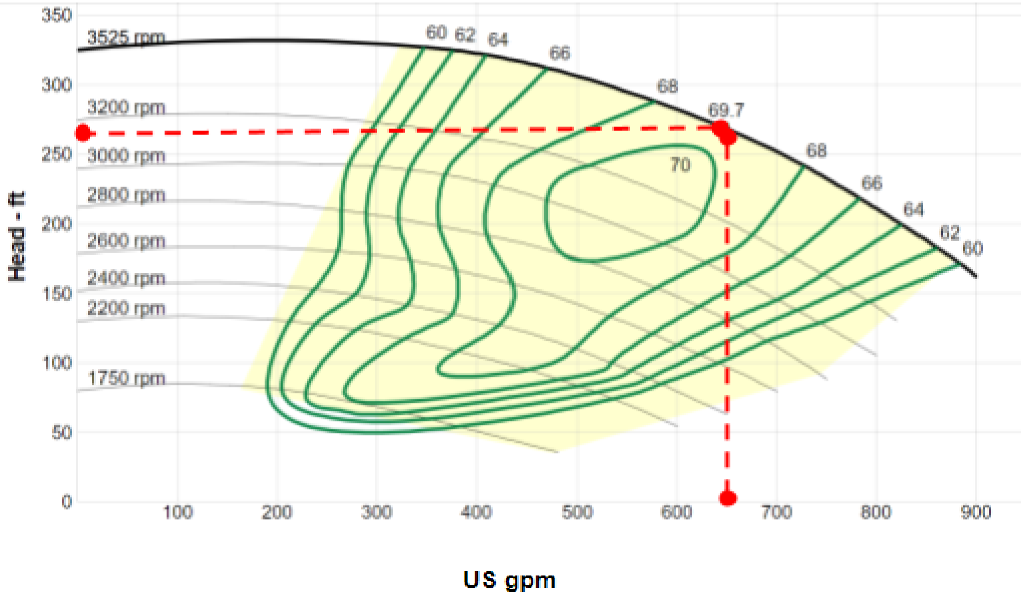


Figure 11: Head flow rate characteristic curve.

This characteristic curve illustrates that as the head decreases, the flow increases (Figure 11). At a given head and flow rate, the pump would achieve a specific efficiency. Figure 10 also shows that this specific pump model has a peak efficiency of 69.7%, at which it has a volumetric flow rate of 650 GPM and head of 268 ft. Ideally, the pump should work at peak efficiency to minimize the amount of fuel the pump requires. These measures are the optimal head and flow rate at which the pump should ideally operate. The efficiency of the pump should exceed 60% efficiency. With the characteristic data relating power and flow rate below, one can find the amount of power necessary to operate the pump at optimal efficiency.

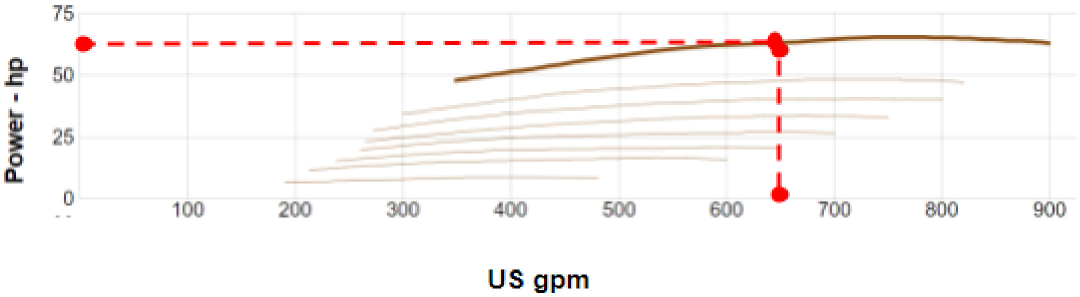


Figure 12: Power flow rate characteristic curve.

Figure 12 illustrates that this pump requires an input power of 63.2hp to operate at 650 GPM and optimal efficiency. The efficiency, head, flow rate, and power values depend on the pump impeller speed (3525 rpm) and its dimensions. The pumped fluid is assumed to be pure water at 68℉.

To confirm that this pump model meets this project's needs, it was vital to determine the necessary head and flow rate to irrigate the farm. The pump must overcome the pressure head loss between the pump and the farm area. The pressure head must also overpower any head losses throughout the system, including losses due to friction of the pipe material and bends in the system. The actual flow rate used to water a farm will depend on its size and the irrigation method utilized. Using Equation 21, the flow rate of water for a 7-acre farm was estimated to be around 18,905 GPD (“How Much Water,” n.d.), assuming utilization of a sprinkler irrigation system. Alternatively, the desired flow rate could be estimated from the number of crops planted at the farm and daily watering needs of each plant. However, the number of crops per farm plot and the types of crops vary widely.

The pump at the farm is able to reach a maximum rotational speed of 3525 rpm and an estimated maximum flow rate of 900 GPM. Converting the head to pressure shows that the minimum pressure is 78 psi and the maximum is 142 psi at 3525 rpm. However, the pump does not need to operate at 3525 rpm, and it should be decreased. It is recommended that the pump operate near the middle of the pump capabilities between 2200-2500 rpm, 200-400 GPM, and 130-150 ft (300-347 psi). Reducing the pump rotational speed would decrease the output pressure, which can be adjusted manually via a throttle on the pump engine.

3.6 Piping Requirements

The design will require piping from the hydrants to the farm plots. The piping will be required to sustain a minimal pressure and flow rate to the sprinklers. To calculate the pressure loss in the pipe, the Darcy-Weisbach Major Head Loss Equation (Equation 11) was used. This equation calculates the major head losses along a given length of pipe for an incompressible fluid. For an estimated pipe length of 2,362 ft, which was the longest pipe distance in the first proposed design, it was calculated that the total pressure drop would be 23 ft of head or 11 psi. This means that for the sprinklers to have their minimum pressure, the pump would need to be run at least 11 psi above the minimum pressure of the sprinklers.

The material of the pipe would be required to withstand a minimal 35 psi compression above ground and a minimal 100 psi fluid pressure (the max psi of the current pump is 100 psi). The pipe should also be UV resistant. The material could be PVC, aluminum, flatline, or FlexNet. The piping will also require hose connectors, known as camlocks.

3.7 Cavitation and Net Positive Suction Head (NPSH)

In irrigation piping, a phenomenon known as *cavitation* can occur. Low-pressure areas below the water's vapor pressure can cause small bubbles of water vapor to form and collapse, sending shockwaves through the system damaging parts such as pump impellers or valves.

A piping system's potential for cavitation is based on the Net Positive Suction Head (NPSH), measured in head-feet. The NPSH is the difference between suction pressure and vapor pressure at the pump's suction nozzle. Cavitation is calculated from required and available NPSH: NPSHr and NPSHa, respectively. (Pumps & Systems, 2016). If NPSHa is greater than NPSHr, cavitation will not occur. Required NPSH is specified in pump performance curves; Flats Mentor Farm's pump curve is shown below in Figure 12:

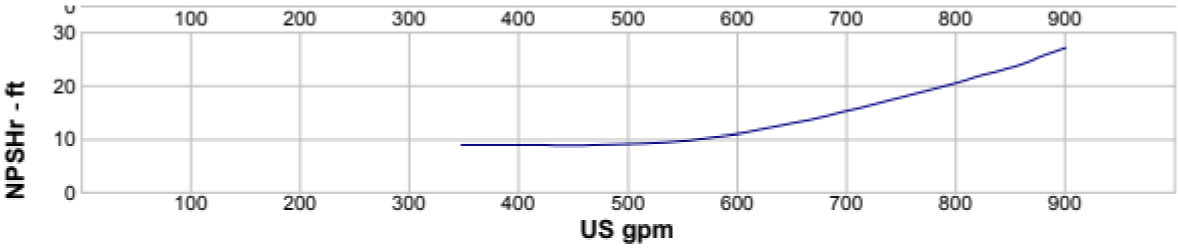


Figure 13: FMF Rainbow pump curve (US GPM vs. NPSHr in ft.)

Required NPSH for the FMF pump ranges from approximately 9-28 psi. The absolute NPSH of the system can be calculated using the following equation:

$$NPSHa = A - V + S - F \quad (23)$$

In the above equation to calculate NPSHa, (A) is absolute pressure, (V) is vapor pressure, (S) is static head, and (F) is friction head. Assuming atmospheric absolute pressure, 293.15 K water temperature, 12 ft maximum static head, and knowing that 1 KPa = 2.9883 feet-head:

$$NPSHa = 33.7985 - 0.08031 + 12 - 14.2190 = 30.78 \text{ (ft. head)}$$

$$30.78 > 28\ (ft.\ head) \rightarrow NPSHa > NPSHr$$

In the proposed FMF irrigation system, the available NPSH is greater than the required NPSH. Additionally, since Equation 20 was calculated using the absolute minimum NPSHa and maximum NPSHr value, cavitation is highly unlikely to occur.

4. Project Approach

4.1 Design Iterations

Those at Flats Mentor Farm initially requested the project group to pump water from the river to the existing tanks at the farm. In order to utilize the tanks, they would need to be lifted to allow gravity to transfer the fluid. Alternatively, each tank or tank group would need a pump to irrigate the farm via a sprinkler system. Figure 14 shows an illustration of the tank group locations with Flats Mentor Farm's initial design suggestions.

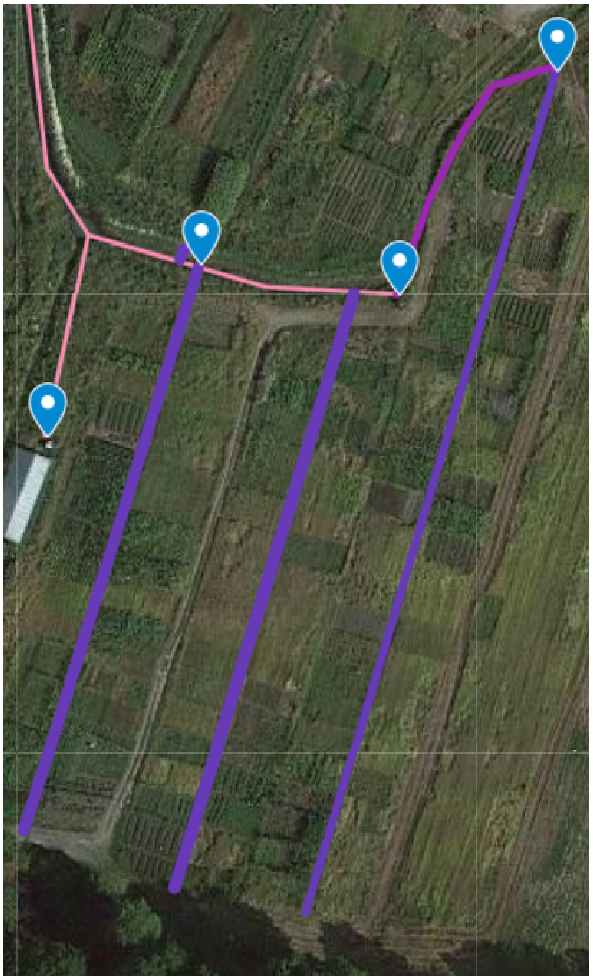


Figure 14: Flats Mentor Farm Suggested Irrigation System Using Tanks

It has been concluded and agreed upon that the implementation of holding tanks is not the most efficient option to support the irrigation needs of the farm; the project group would need to purchase several pumps for each tank group, increasing the total cost, and the pump that the farm currently has available is powerful enough to transfer water to the far east side farm plots with the proper piping configuration. Also, with the above design, farmers and staff would not need to operate the pump as frequently to refill the tanks. Instead, one pump from the Nashua River will directly irrigate the farm through a sprinkler system without the use of tanks.

4.1.1 The MQP Team's First Design

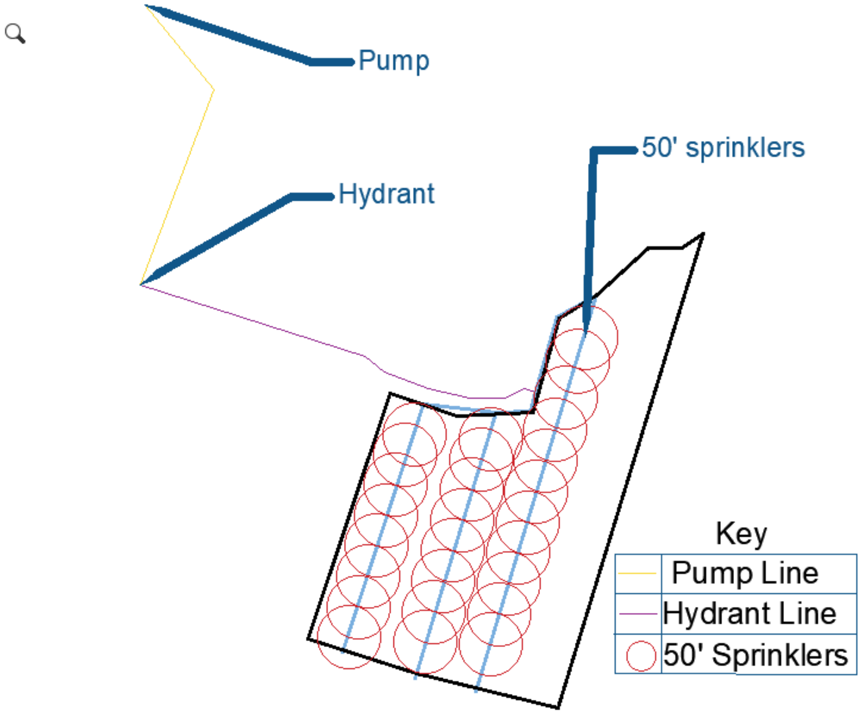


Figure 15: Original design with 24 50-foot radius sprinklers represented by red circles. The yellow line is the 6" diameter underground aluminum pipe connecting the pump to the hydrant and the purple line is the 4" diameter layflat connecting the hydrant to the sprinkler system. The blue lines have the sprinklers attached and go in between every other section.

Based on both existing constraints provided by World Farmers and relevant variables determined in the project's design phase, an irrigation system was designed (Figure 15). The limitations and relevant variables include piping specifications, spray radii of sprinklers, and required operational pressure. Through the consideration of these variables and constraints, a preliminary irrigation system design was developed.

In this design, several materials met the piping qualifications, but 1-¼" 26 SDR PVC was chosen as the material because it was the most cost-efficient of the initially researched materials. This piping's pressure rating, 160 psi, would fall within the limitations of the existing Rainbow Irrigation Systems pump.

The area of interest includes 130 plots that are 25' by 50' (Figure 1b). Piping would run parallel to different sections, or rows of plots, within the area. It was concluded that a sprinkler irrigation system would meet the needs of the farm because of its low-maintenance, wide coverage, and ease of installation. Since the plots are 25-ft wide, the sprinklers would go in between sections M and N, O and P, and Q and R. The sprinklers would have a 50-foot radius and would be placed every 50 ft along the PVC line. The sprinklers would need to operate at 71.1 psi to meet their maximum radius of 59 ft. This system was found to be the most efficient in terms of cost as it reduces the number of sprinklers required to reach every plot (Figure 11). Despite this, it was found some issues in the approach as the sprinklers' coverage would fail to reach some plots' corners.

The existing pump on the farm operates at a range of pressures which falls within the pressure requirements for both the piping (maximum of 160 psi) and Irrigation King's ¾" Brass Impact 59-foot radius sprinklers (maximum radius achieved at 71.1 psi).

With these considerations, a decision was made. The MQP team's first design featured 1-¼" 26 SDR PVC pipes, ¾" Brass Impact 59-foot radius sprinklers, and used the existing pump which would meet the pressure requirements for operation of the system.

4.1.2 Brookdale Fruit Farm's First Design

Along with the project group's first design, World Farmers contacted its irrigation equipment supplier, Brookdale Fruit Farm, to develop its irrigation system design (Figure 16).

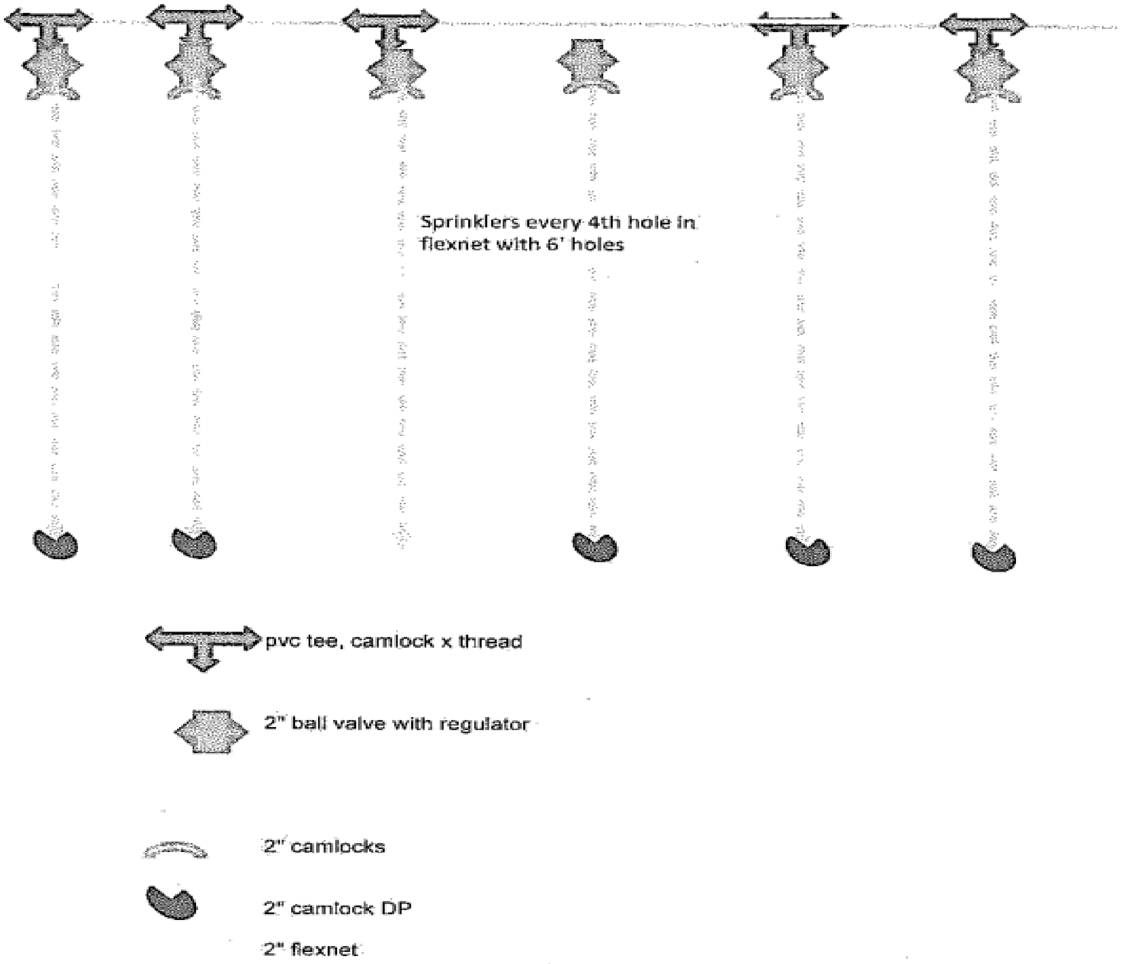


Figure 16: Brookdale Fruit Farm's first design iteration.

The first Brookdale design introduces different piping materials: layflat main line (Figure 22) attached to FlexNet laterals with elevated sprinklers attached to every 4th hole (or every 24 ft) (Appendix C), secured with a Type DP camlock and an end cap. FlexNet is highly durable, leak-proof, lighter and more flexible than conventional piping materials, and can be laid down and rolled up more easily than a layflat line.

Camlocks are aluminum fittings that are used to secure piping together and minimize any leaks within the system (Appendix C). Camlocks that are barbed at one end are designed to fit into flexible piping, such as FlexNet and layflat, while other camlocks are designed with a male thread to connect to a female threaded fitting such as PVC tees and other aluminum fittings. These camlocks are able to couple to each other by a male-female latching design — female camlocks latch onto the male indented camlocks. It is recommended to apply teflon tape or liquid to the threads to better secure the camlocks with attaching fittings.

However, FlexNet introduces difficulties due to its 36 psi max and higher cost per unit length. Its 36 psi maximum requires twice as many lines (seven instead of three laterals at the widest point) as the MQP team's original design (Figure 14), which doubles the cost of the already expensive piping. Brookdale's irrigation system design was itemized and quoted at $10,417, far exceeding the project operating budget (Appendix D). World Farmers rejected the initial Brookdale proposal for this reason, but FlexNet and camlocks would remain in later designs.

4.1.3 Brookdale Fruit Farm's Updated Design

Brookdale Fruit Farm's original design was severely over budget.

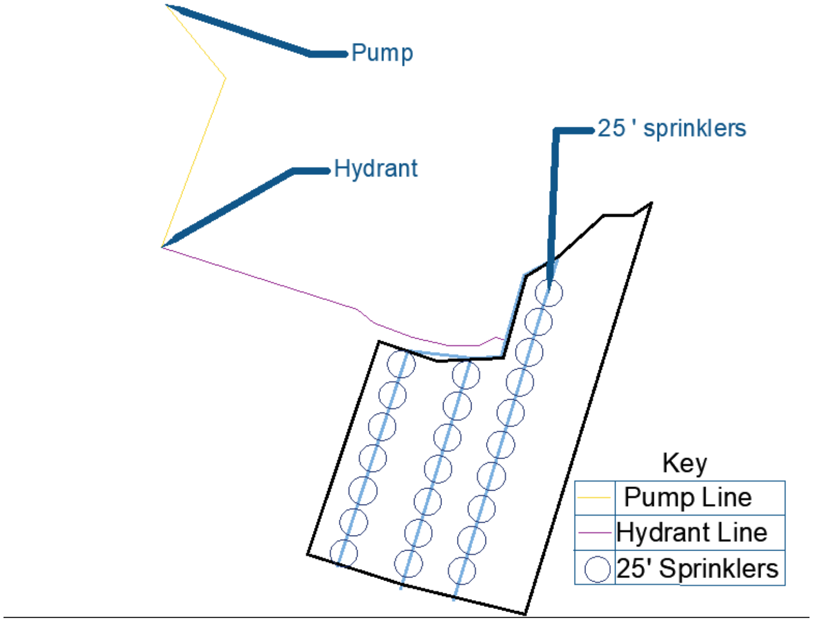
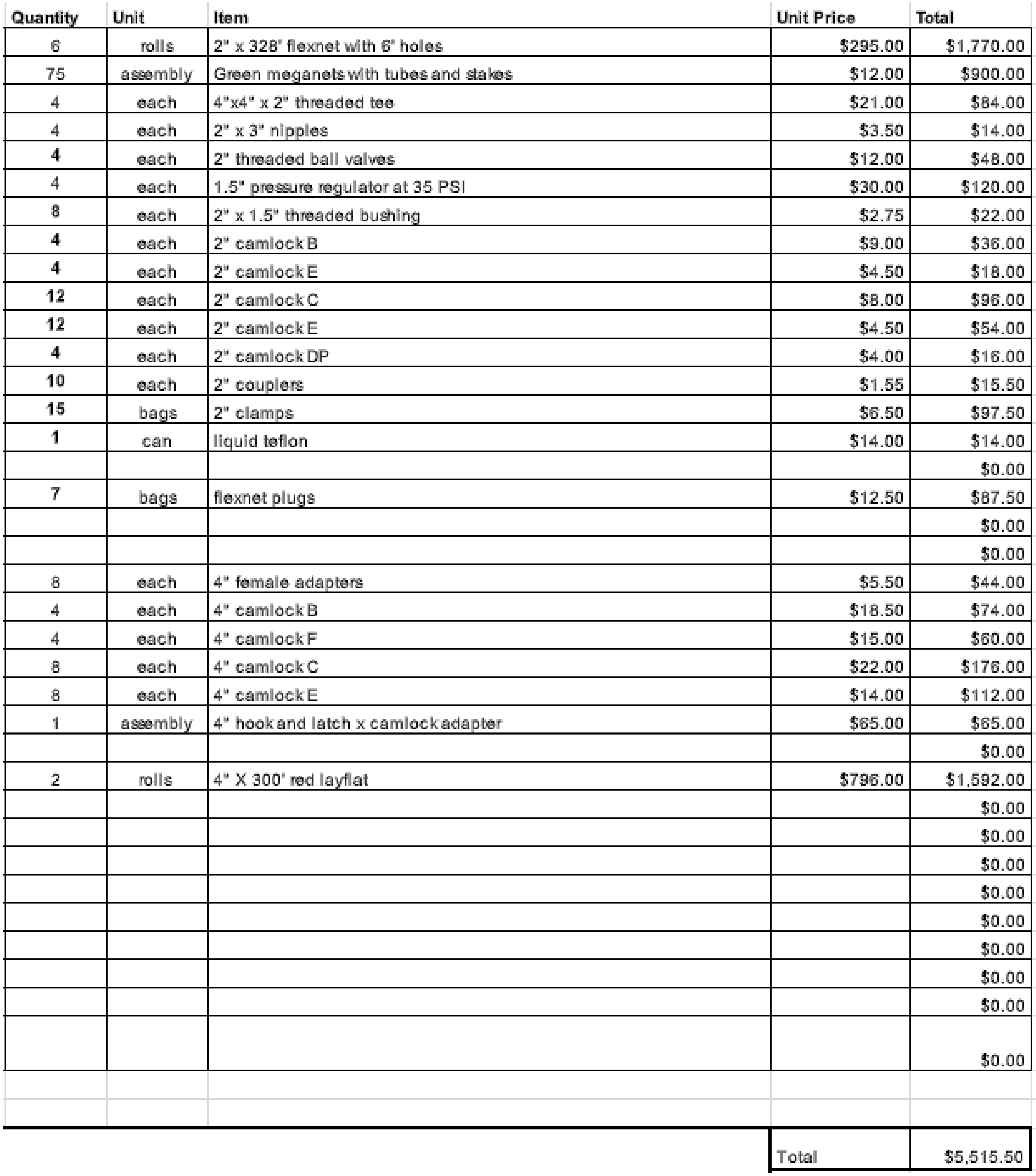


Figure 17: Brookdale Fruit Farm's redesign

Working with World Farmers, Brookdale created a scaled-down version of their design that was much cheaper than the original design since it uses six rolls of FlexNet instead of the previously used 14 (Figure 17). The updated design still used all of the features that they intended to use in the original design: a layflat line attached to FlexNet intervals with sprinklers attached every 24 ft secured with camlocks. It also reduced the number of rows of FlexNet from 14 to Y and the number of sprinkler assemblies from 225 to 75.



Quantity	Unit	Item	Unit Price	Total
6	rolls	2" x 328' flexnet with 6' holes	$295.00	$1,770.00
75	assembly	Green meganets with tubes and stakes	$12.00	$900.00
4	each	4"x4" x 2" threaded tee	$21.00	$84.00
4	each	2" x 3" nipples	$3.50	$14.00
4	each	2" threaded ball valves	$12.00	$48.00
4	each	1.5" pressure regulator at 35 PSI	$30.00	$120.00
8	each	2" x 1.5" threaded bushing	$2.75	$22.00
4	each	2" camlock B	$9.00	$36.00
4	each	2" camlock E	$4.50	$18.00
12	each	2" camlock C	$8.00	$96.00
12	each	2" camlock E	$4.50	$54.00
4	each	2" camlock DP	$4.00	$16.00
10	each	2" couplers	$1.55	$15.50
15	bags	2" clamps	$6.50	$97.50
1	can	liquid teflon	$14.00	$14.00
				$0.00
7	bags	flexnet plugs	$12.50	$87.50
				$0.00
				$0.00
8	each	4" female adapters	$5.50	$44.00
4	each	4" camlock B	$18.50	$74.00
4	each	4" camlock F	$15.00	$60.00
8	each	4" camlock C	$22.00	$176.00
8	each	4" camlock E	$14.00	$112.00
1	assembly	4" hook and latch x camlock adapter	$65.00	$65.00
				$0.00
2	rolls	4" X 300' red layflat	$796.00	$1,592.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
				$0.00
			Total	$5,515.50

Figure 18: Updated cost after reducing the number of sprinklers and lines.

Decreasing the FlexNet lines scaled down the quantities for each of the other items on the original quote, reducing the final cost from $10,417 to $5,515 (Figure 18).

5. Prototype

5.1 Prototype Design

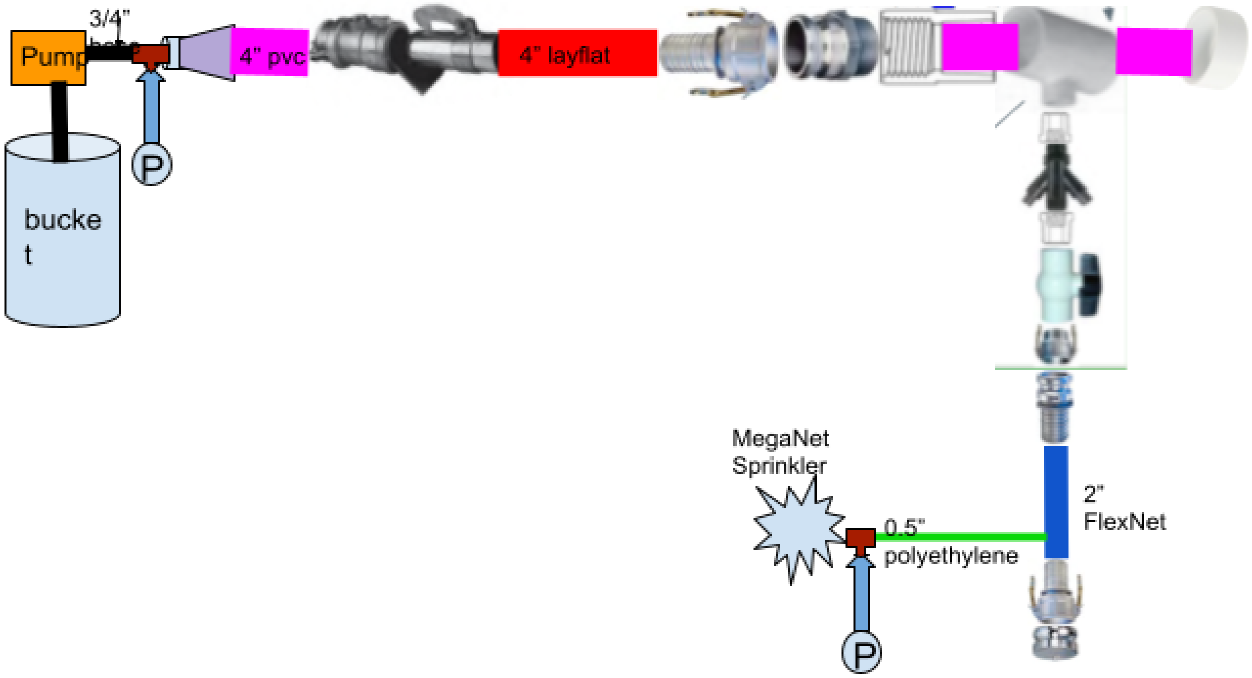


Figure 19: Prototype Design

The prototype design (Figure 19) is a scaled-down version of the actual system that will be implemented on the farm. It takes up approximately 25’ x 25’ and will replicate the water provided to one family farm (25’ x 50’). The system begins with water being drawn out from a tank by a pump connected by a hose. The pump has a ¾” inlet and outlet, and it connects to a ¾” hose, a PVC reducer, a hook-latch, and then to the 4” layflat. After 25’ of layflat, the system encounters a 90 degree bend. It uses a 4” Camlock C, 4” Camlock F, a thread-slip coupler, and a threaded tee with a cap on the 4” outlet. The 2” outlet that creates the bend has a threaded bushing, a pressure regulator, and another threaded bushing attached. It then goes into a PVC valve, which has a 2” Camlock B and a 2” Camlock E. From there, it connects to a 25’ segment of FlexNet. The end has a 2” Camlock C and a 2” Camlock DP. Attached 3’ from the end is a MegaNet sprinkler assembly. The pressure gauges are represented by P in Figure 29.

5.2 Prototype Tests

5.2.1 MegaNet Water Output

In order to best understand how long crops will need to be watered with the MegaNet sprinklers, it is necessary to know the MegaNet’s volumetric output of water over a given area. With this information, the farm can determine the crop which needs the least watering and determine how long it takes to water that crop. The farm can then set the sprinklers to stay on for that length of time to avoid overwatering any of the crops. To test how much water is sprinkled onto a given area, a 5 inch diameter measuring cup with a 4.5 cup volume will be placed within the range of the sprinkler of the prototype (Figure 29). The sprinkler will be turned on, and a timer app on a smartphone will be started. Once the measuring cup is filled up, the timer will be stopped and the sprinkler will be turned off. With the full measuring cup, dividing the volume by the amount of time elapsed will give the volumetric output over the area encompassed by the cup.

5.2.2 Design Efficiency

For the prototype design to work most efficiently, the system must not have any leaks in the piping material or at the connections. Leaks can be prevented by using the proper fixtures that have been confirmed to withstand the working pressure range of the design. According to the manufacturer, the 4-inch layflat piping can withstand up to 125 psi, and its material is protected against consistent exposure to UV light and various weather conditions. The FlexNet piping works at a maximum pressure of 36.2 psi. In order to reduce the pressure and prevent the FlexNet from bursting, a pressure reducer fitting will be attached before the FlexNet piping. To increase the lifespan of the piping material it can be stored indoors during winter seasons. It is also recommended that the material and size of threaded fittings be compatible. For example, a PVC female thread should be paired with a PVC male thread; pairing metal and PVC threads together risks cracking the PVC material. Along with thread diameter size, it is important to note the number of threads per inch (TIP) and shape (e.g. straight or tapered) of the thread in order to pair them properly. To reduce leaks at paired fittings, Teflon tape or liquid can be applied to seal the space between each pairing. For the design to work efficiently, the MQP group will also confirm the pressure regulator reduces pressure to 35 psi and the MegaNet sprinkler outputs a total water volume of 1.54 GPM. Lastly, the group will confirm that the pressure drop across the system is no more than 2 psi through the 50 ft of piping including camlock fittings.

5.2.3 Pressure Loss Over Entire System

In order to determine the pressure loss over the entire system, two pressure gauges will be used. One will be placed after the pump and the other will be placed right before the sprinkler. From the Darcy-Weisbach equation (Equation 11), the pressure loss in the system is estimated to be 1.5 ft or 0.65 psi. The measurement of each gauge will be checked 5-10 times.

5.2.4 Total Flow Rate Following the Sprinkler

To test the flow rate following the sprinkler, two pressure gauges will be used. One will go after the sprinkler and the other will go after the pump. With readings from the pressure gauges, equation 24 will be used to calculate flow rate. In this equation q is flow rate (ft^3/s), A_C is the area ratio, P_1 and P_2 (psi), ρ is the fluid density ($slug/ft^3$), D_2 is the nozzle inner diameter (ft), D_1 is the upstream and downstream pipe diameter (ft), and d is the diameter ratio (Frank, 2017). This will be measured and calculated 5-10 times using Equation 24.

$$q=A_C(\pi/4)D_2^2[2(P_1-P_2)/\rho(1-d^4)]^{1/2} \qquad (24)$$

5.2.5 How Can this be Scaled to the Farm?

Pressure calculations for the prototype scale (50 ft of piping consisting of 25 ft layflat line and 25ft FlexNet can be expanded to a full-scale irrigation system at the Flats. The head loss in the current prototype can be used to infer the head loss expected in the larger system, which then determines the pump pressure required to function. Head loss calculations for the larger system are calculated based on the head loss induced by piping length and per connector (e.g. tees, inlets, bends). The head loss of the full-scale system will determine the pump pressure required to function.

6. Mini Guide for Farmers

Upon consulting with a local vendor of irrigation supplies, Brookdale Fruit Farms, World Farmers concluded that this design was outdated. Most commercial and private farms moved away from the use of 50-foot radius sprinklers with aluminum lines to a system using FlexNet, detailed in section 4.2. However, Jessy Gill, Worcester Polytechnic Institute’s correspondent at World Farmers, liked the MQP team’s original design and requested to formulate it into a mini guide.

The mini guide's purpose is to explain how the farmers could implement the original design into their plots. While World Farmers would not supply them with the means to do so, they could purchase the equipment themselves to create the irrigation system. A step-by-step guide to installing the system was provided, with product recommendations and a guide to tank sizing. It was also detailed how to convert the design into one suitable for drip irrigation. The mini guide is available in Appendix B.

Appendix A: Calculations

From the pump efficiency, e_p, and the power input, P_i, the power output of the pump, P_o, can be calculated using the following equation:

$$P_o = e_p\, P_i$$

$$P_o = 0.697(63.2\text{hp})$$

$$P_o = 44.05\text{hp}$$

Power output can be calculated at peak efficiency using the specific weight of water (at a given temperature), the pump head, and the desired flow rate, as shown below.

$$P_o = \gamma Q H_p$$

$$P_o = 62.3\text{lb/ft}^3(1.45\text{ft}^3\text{/s})(268\text{ft})$$

$$P_o = 24180\ \text{ft} \cdot \text{lb/s}$$

$$P_o = 44.0\text{hp}$$

The mini guide shows pumps used at each tank location. The tanks pump output power required for Section M can be calculated as follows.

$$P_o = \gamma Q H_p$$

$$P_o = 62.3\text{lb/ft}^3(0.0147\text{ft}^3\text{/s})(56.4\text{ft})$$

$$P_o = 51.7\text{ft} \cdot \text{lb/s}$$

$$P_o = 0.0939\text{hp}$$

$$P_o \cong 70.0\text{W}$$

The input power that the tanks pump requires to operate can now be found using the following formula, assuming the pump is operating at 65% efficiency.

$$P_i = e_p / P_o$$

$$P_i = 0.65/70.0\text{W}$$

$$P_i \cong 108\text{W}$$

Setting the source head (tanks elevation), H_S, as the datum point (0 ft), the farm elevation, H_R, becomes -5. The pump pressure head comes from:

H_P = Pump Head;

H_S = Source Head;

H_R = Receiving Body Head;

h_L = Head Losses

$$H_p = (H_R - H_S) + h_L$$

$$H_p = (-5 - 0) + 56.4$$

$$H_p = 51.4 \text{ ft}$$

Alternatively, if the tank pumps from the bottom instead of the top, the difference in elevation (H_R - H_S) equals 0 ft, and the pump head equals the head losses of 56.4 ft.

Appendix B: A Farmer's Tank Irrigation Mini Guide

In consideration of those at World Farmers Flats Mentor Farm located in Massachusetts, the MQP group created this Mini Guide to assist farmers in developing their own sustainable irrigation system.

To use a given water holding tank, you will likely need to operate a pump with hoses or piping to transfer water. In place of a pump, you could use gravity and PVC piping to irrigate your land, which will be discussed in the final section of this guide. This guide lists essential steps and questions to help you design a tank-pump irrigation system that adequately suits your specific needs.

1. Estimate your watering needs

a. How many plants are you watering?

The amount of needed water can be found by counting the total number of crops and multiplying it by 0.6 gal (2 liters), the average amount of water a full-size plant needs in 1 day.

Ex: Say you have 12 crops on your plot. To calculate the amount of water needed, $12 * 0.6 = 7.2$ gallons per day, or 24 liters.

b. What is the size of your land?

For larger areas, multiply the length and width of your land, then divide it by 4 ft^2 (assuming plants are 2 ft apart). Multiply this value by 0.6 gallons (2 liters).

Ex: A plot of land that is 25 by 50 ft has an area of 1,250 square ft and an estimated 312 plants, which require 187 gallons (709 liters) of water daily.

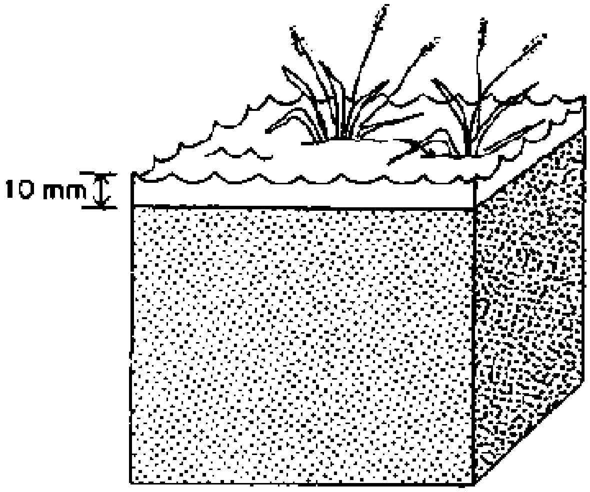


Figure A: 10 mm/day water volume per area (Crop Water Needs, n.d.)

2. Acquire the appropriate tank and measure its dimensions.

Common tank volumes include the following: 50, 100, 200, 500, 1000, 3000, and 5000 gallons. These water storage tanks are also referred to as Intermediate Bulk Containers (IBC). Your tank should hold enough water for at least 1 day of crop watering needs. A farm plot which requires 187 gallons of water per day should utilize a 200 gallon tank.

Take note of the height of your tank and the location of the water outlet on the tank. Some tanks have the outlet close to the bottom while others have an opening on the top.

Figure B: Various water tank sizes

Tank Recommendations:

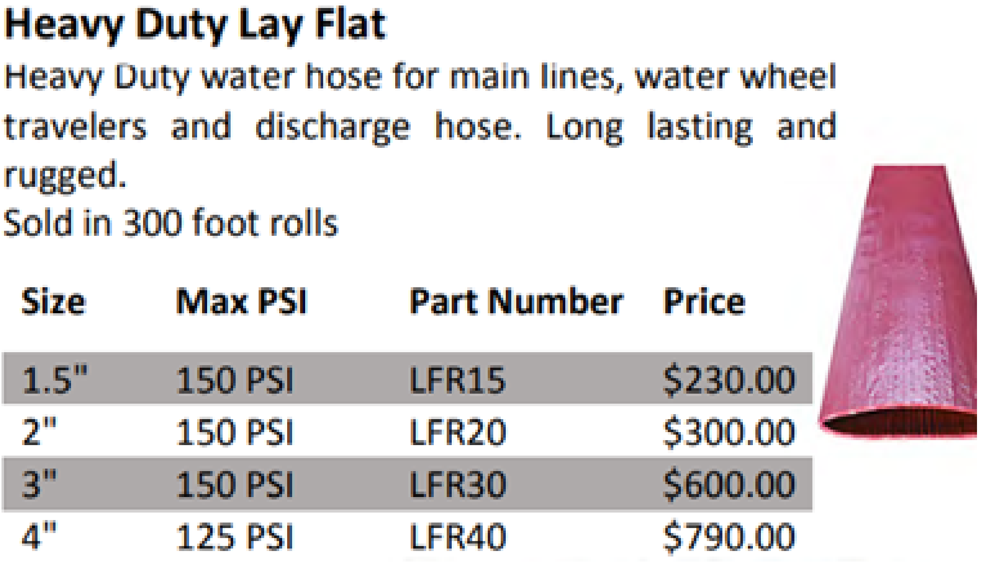
- UV-resistant Polyethylene Tanks with both inlet and outlet
- Firm base or foundation to keep it from falling or bursting at the bottom
- A submersible pump should be placed a few inches from the bottom of the tank to avoid sludge entering the pump

NOTE: Check the diameter of the inlet and outlet carefully! Make sure they match your piping from the pump and the piping to the crops.

3. Estimate the distance between your tank and farm and connect your pump and farm land with hose

The distance from your tank and farm land is approximately the length of your hose or piping. The further away your farm is from your tank, the more hose or piping you need and the more powerful the pump will need to be. The hose should be able to withstand the appropriate amount of pressure your pump discharges. For example, if your pump has a pressure output of 80 psi, it is essential that the hose is able to withstand such pressure. You can utilize a garden hose or layflat lines to transfer water. Below is a common layflat product used to transfer water for irrigation purposes.

Distributed by Brookdale Fruit Farm (Hollis, NH)



Heavy Duty Lay Flat

Heavy Duty water hose for main lines, water wheel travelers and discharge hose. Long lasting and rugged.
Sold in 300 foot rolls

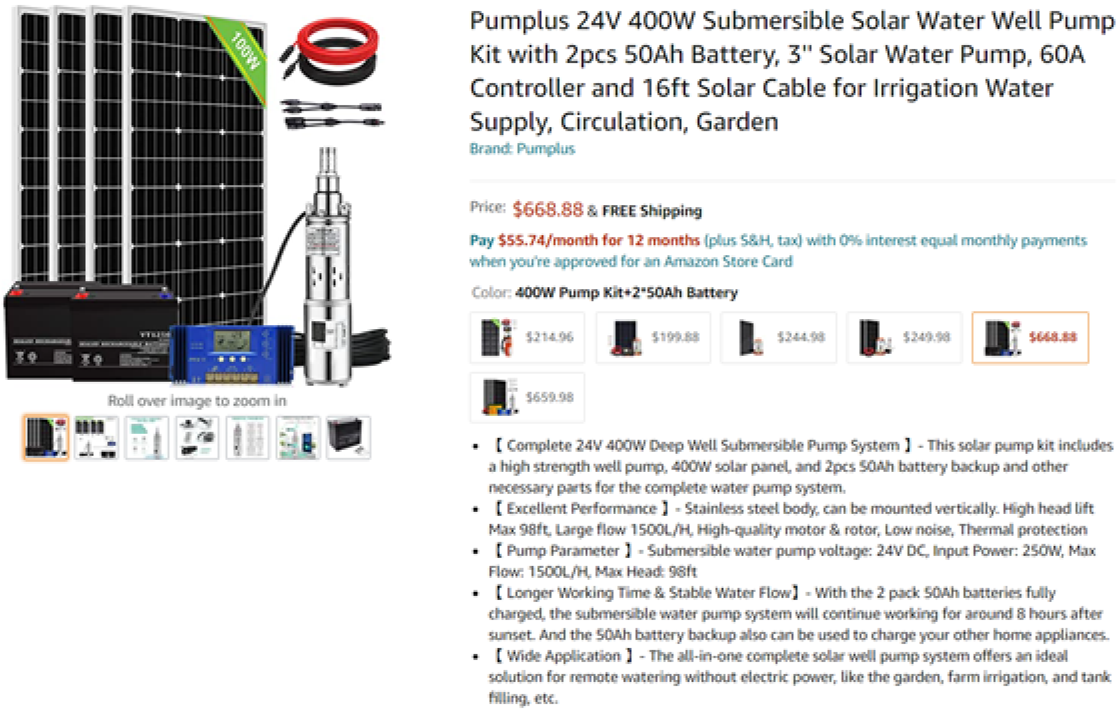
Size	Max PSI	Part Number	Price
1.5"	150 PSI	LFR15	$230.00
2"	150 PSI	LFR20	$300.00
3"	150 PSI	LFR30	$600.00
4"	125 PSI	LFR40	$790.00

Figure C: Layflat Specifications

4. Choose your pump and power source

The pump you choose should be powerful enough to provide enough pressure at the outlet of your hose. The pressure required for a standard size garden hose (⅝ inches in diameter), is 30 psi (207 kPa). The longer your hose, the more pressure the pump must output to move water through the length of your hose. In order for a sprinkler system to work properly, the pump should output a minimum of 30 psi. This typically requires a pump that is 0.5 hp. Two common power sources for a small pump are AC electric power and solar power. To use AC power, simply plug the pump into a nearby wall outlet. For a solar-powered pump system, it is recommended that you purchase an all-inclusive kit that includes the solar panel, solar-powered pump, and cables, as shown below.

Distributed by Amazon



Pumplus 24V 400W Submersible Solar Water Well Pump Kit with 2pcs 50Ah Battery, 3" Solar Water Pump, 60A Controller and 16ft Solar Cable for Irrigation Water Supply, Circulation, Garden

Brand: Pumplus

Price: $668.88 & **FREE Shipping**

Pay $55.74/month for 12 months (plus S&H, tax) with 0% interest equal monthly payments when you're approved for an Amazon Store Card

Color: **400W Pump Kit+2*50Ah Battery**

$214.96 $199.88 $244.98 $249.98 $668.88 $659.98

- 【Complete 24V 400W Deep Well Submersible Pump System】- This solar pump kit includes a high strength well pump, 400W solar panel, and 2pcs 50Ah battery backup and other necessary parts for the complete water pump system.
- 【Excellent Performance】- Stainless steel body, can be mounted vertically. High head lift Max 98ft, Large flow 1500L/H, High-quality motor & rotor, Low noise, Thermal protection
- 【Pump Parameter】- Submersible water pump voltage: 24V DC, Input Power: 250W, Max Flow: 1500L/H, Max Head: 98ft
- 【Longer Working Time & Stable Water Flow】- With the 2 pack 50Ah batteries fully charged, the submersible water pump system will continue working for around 8 hours after sunset. And the 50Ah battery backup also can be used to charge your other home appliances.
- 【Wide Application】- The all-in-one complete solar well pump system offers an ideal solution for remote watering without electric power, like the garden, farm irrigation, and tank filling, etc.

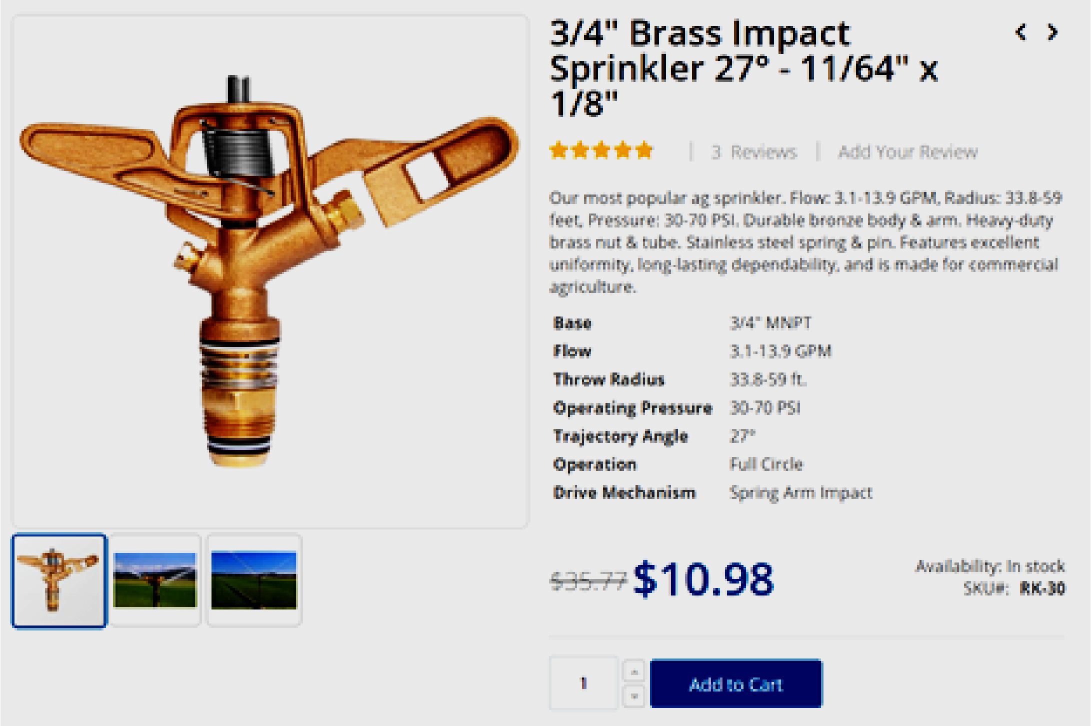
Figure D: Solar Powered Pump Kit

Benefits:

- Comes with solar panels, solar battery, and water pump
- Designed for irrigation
- 250 W would suit the 50-foot radius sprinklers
- Flow rate: 6.6 GPM (gallons per minute)

5. Choose your watering method

There are several ways to directly water your crops: you can manually water each plant with your garden hose, use sprinklers, or establish a drip irrigation system. This guide will focus primarily on the sprinkler system method. Two important factors to consider when choosing a sprinkler is the flow rate and radius of the water flow. The output volumetric flow of a sprinkler can range from 2-13 gallons per minute and its radius can range from 20-30 ft. Below are two comparable sprinklers sold by IrrigationKing that can efficiently water your crop area.



3/4" Brass Impact Sprinkler 27° - 11/64" x 1/8"

★★★★★

Our most popular ag sprinkler. Flow: 3.1-13.9 GPM, Radius: 33.8-59 feet, Pressure: 30-70 PSI. Durable bronze body & arm. Heavy-duty brass nut & tube. Stainless steel spring & pin. Features excellent uniformity, long-lasting dependability, and is made for commercial agriculture.

Base	3/4" MNPT
Flow	3.1-13.9 GPM
Throw Radius	33.8-59 ft.
Operating Pressure	30-70 PSI
Trajectory Angle	27°
Operation	Full Circle
Drive Mechanism	Spring Arm Impact

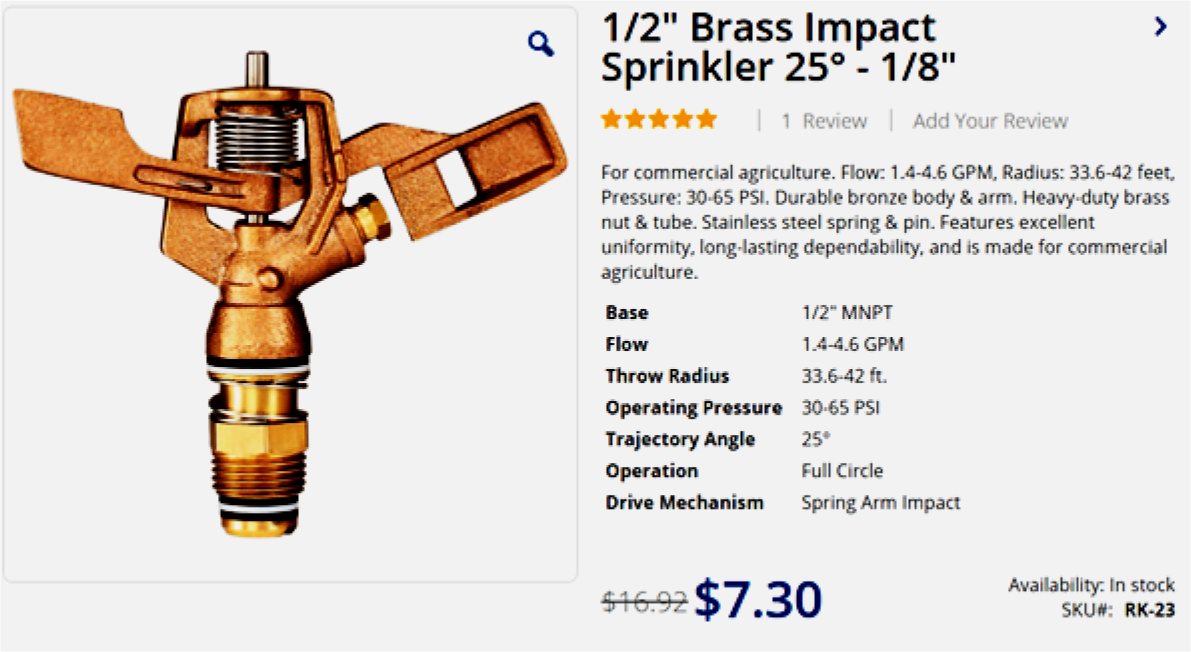
~~$35.77~~ $10.98

Availability: In stock
SKU#: **RK-30**

Benefits:

- Up to 59 foot radius so it will cover the entirety of the plot
- Dual jets for more coverage
- Corrosion resistant
- Full circle rotation

- Using the 250 Watt pump kit would create a 50 foot radius



1/2" Brass Impact Sprinkler 25° - 1/8"

★★★★★ | 1 Review | Add Your Review

For commercial agriculture. Flow: 1.4-4.6 GPM, Radius: 33.6-42 feet, Pressure: 30-65 PSI. Durable bronze body & arm. Heavy-duty brass nut & tube. Stainless steel spring & pin. Features excellent uniformity, long-lasting dependability, and is made for commercial agriculture.

Base	1/2" MNPT
Flow	1.4-4.6 GPM
Throw Radius	33.6-42 ft.
Operating Pressure	30-65 PSI
Trajectory Angle	25°
Operation	Full Circle
Drive Mechanism	Spring Arm Impact

~~$16.92~~ $7.30

Availability: In stock
SKU#: **RK-23**

Benefits:

- Corrosion resistant
- Single jet of water
- Designed for agriculture
- Using the 120 Watt pump would create a 40 foot radius

With the above information, you can determine the amount of time it would take your pump to irrigate your farm land given the following assumptions:

- 50 foot radius sprinklers
- Pump power of 250 Watts
- Flow rate = 6.6 GPM

Table 1: Time of Pump Operation

Tank Size	**Time to Empty Tank**
275 gallon tank	42 minutes
500 gallon tank	76 minutes
1000 gallon tank	152 minutes
1500 gallon tank	227 minutes

To determine the time to empty for your tank, divide the capacity in gallons by the pump's flow rate in gallons per minute (GPM). You can use an online calculator to convert the units (e.g. L/h) into GPM or whichever units you prefer.

10 Steps to Install Your System:

1. Place the pump by the tanks (or inside the tank if pump is submersible)
2. Attach the solar panels (and solar battery if applicable) as instructed by the pump manufacturer

NOTE: You may be able to connect the existing pump to your tank if permitted.

3. Connect the pump to the hydrant using piping
4. Use piping to connect the hydrant to each of the tanks and the tanks to each other. This piping system will transport water from the river to the hydrant to the tanks.
5. Turn off the pump **GRADUALLY** once the tanks have been filled to avoid overfilling them and prevent water hammer from occurring

6. Connect piping to the tank outlet that is long enough to reach the desired plot
7. Make sure the piping has holes the desired distance apart and attach sprinklers to the openings
8. Install a submersible solar-powered pump at the bottom of each tank as per the manufacturer’s instructions
9. Turn the pump on for the duration you wish to water the crops or until the tank is nearly empty.

NOTE: Using the pump with unfiltered water risks damaging the pump.

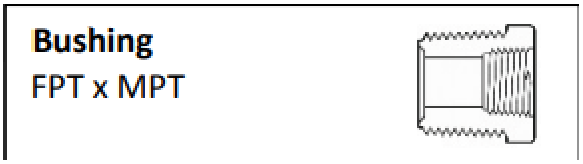
10. To use a drip irrigation system, attach a “soaker hose” to the pump and extend it throughout your farm plot

Appendix C: Components of the Irrigation System

FlexNet lines and MegaNet sprinklers.

1 ½" 2 tip
Regulator
PR-15...$30.00
GPM: 7-40
Regulation PSI
12, 15, 20, 25, 30,
35, 43, 50, 65

Pressure Regulator

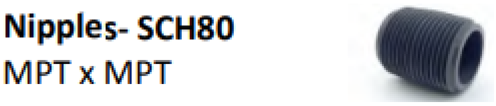


Bushing
FPT x MPT

Threaded Bushing

Flexnet Plug

FlexNet Plug



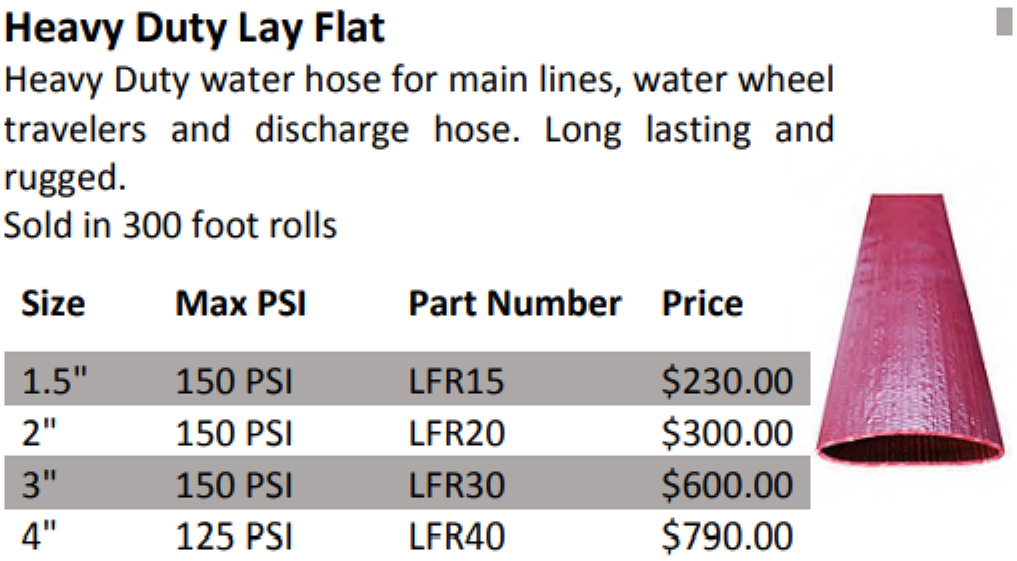
Nipples- SCH80
MPT x MPT

Nipple

Threaded Ball Valve

Clamp on Hook Latch Set
Repair run over pipe
2 inch......$45.00
3 inch......$58.00
4 inch......$71.00

Hook and Latch x Camlock Adapter



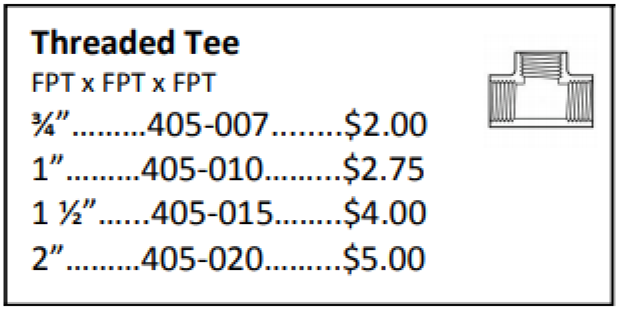
Heavy Duty Lay Flat

Heavy Duty water hose for main lines, water wheel travelers and discharge hose. Long lasting and rugged.

Sold in 300 foot rolls

Size	Max PSI	Part Number	Price
1.5"	150 PSI	LFR15	$230.00
2"	150 PSI	LFR20	$300.00
3"	150 PSI	LFR30	$600.00
4"	125 PSI	LFR40	$790.00

Layflat

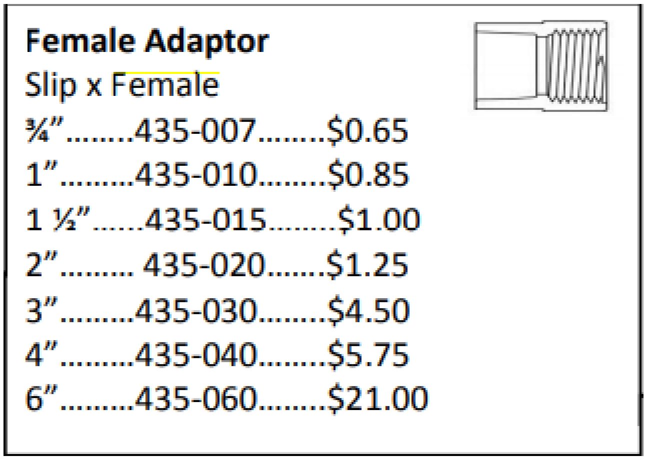


Threaded Tee

FPT x FPT x FPT

¾”.........405-007........$2.00
1”.........405-010.........$2.75
1 ½”......405-015........$4.00
2”.........405-020.........$5.00

Threaded Tee

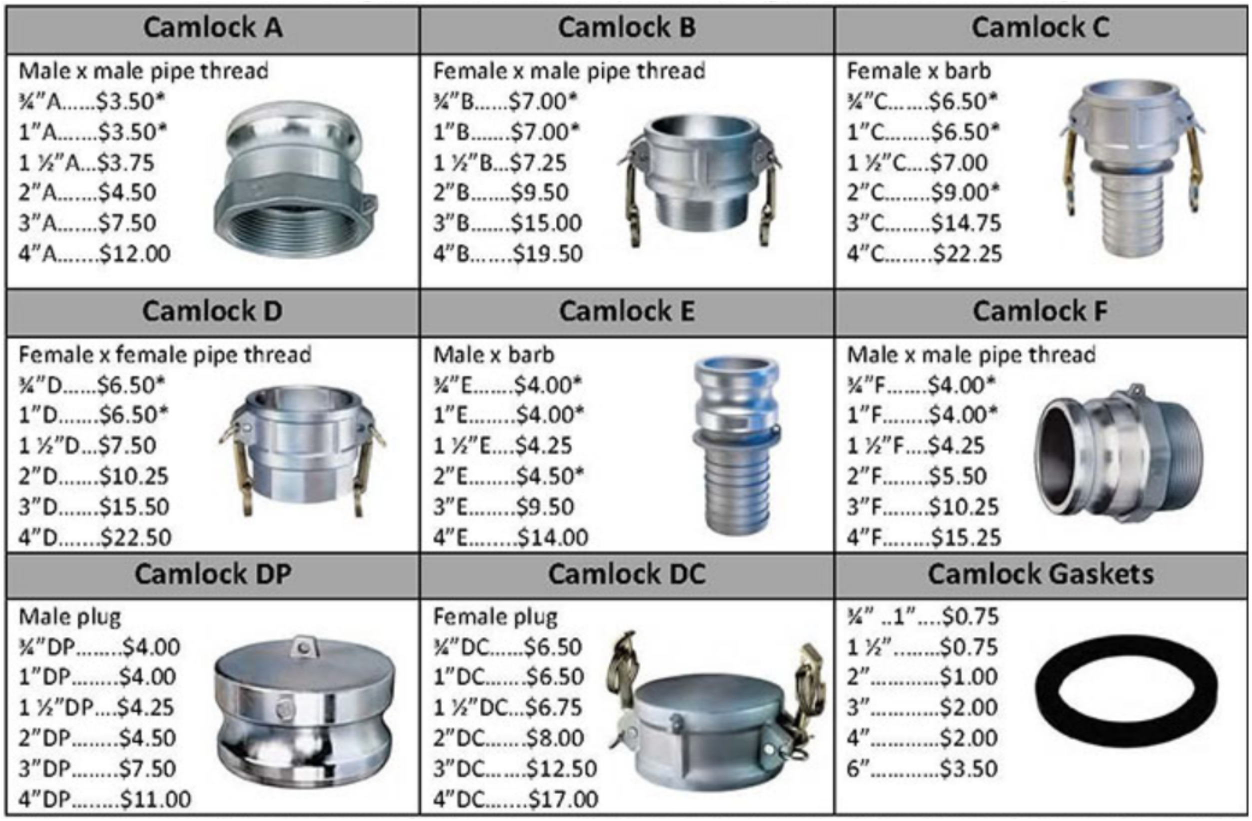


Female Adaptor

Slip x Female

¾”........435-007........$0.65
1”.........435-010........$0.85
1 ½”......435-015........$1.00
2”......... 435-020.......$1.25
3”.........435-030........$4.50
4”.........435-040........$5.75
6”.........435-060........$21.00

Female Adapter



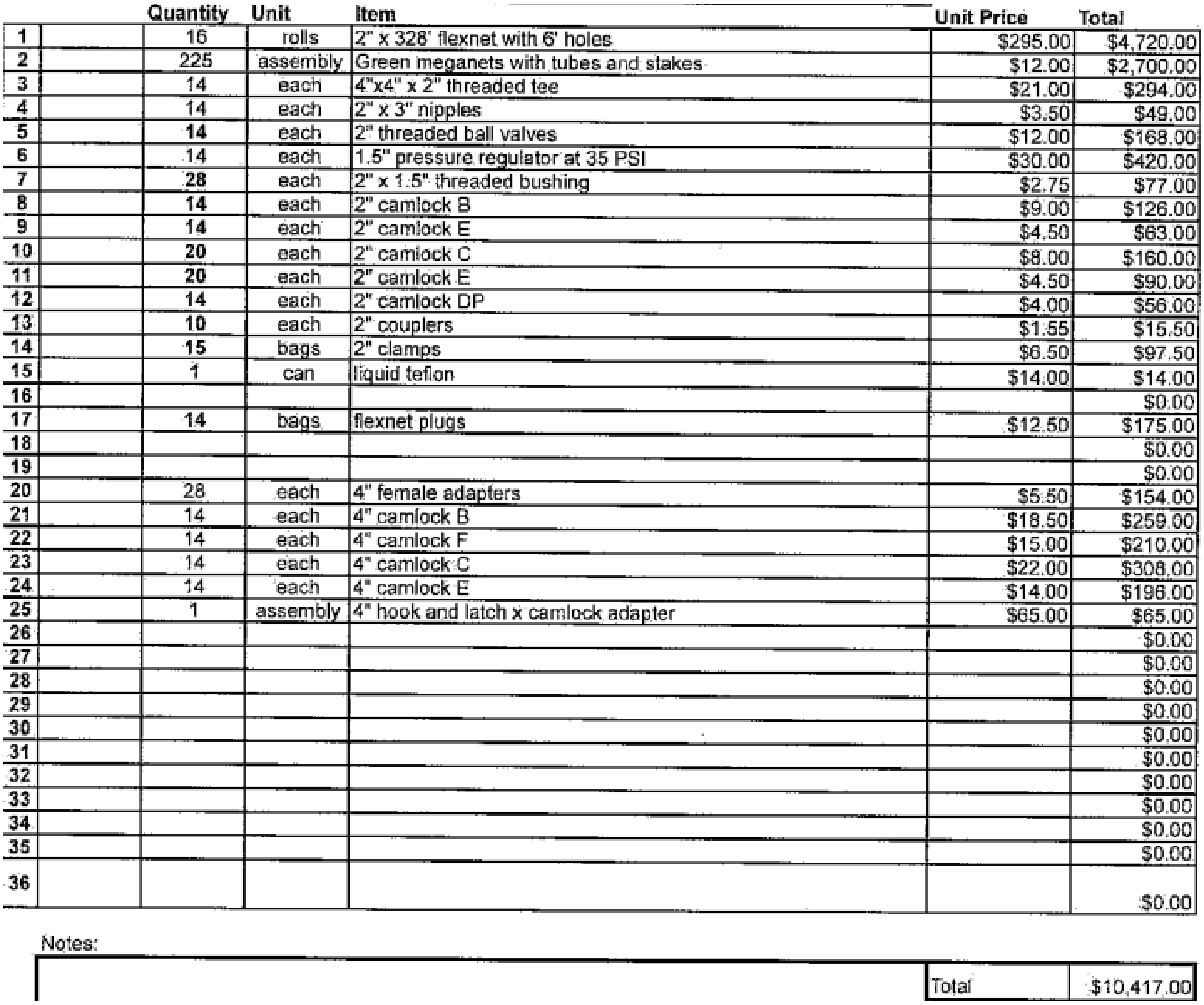
Camlock A	Camlock B	Camlock C
Male x male pipe thread	Female x male pipe thread	Female x barb
¾"A......$3.50*	¾"B......$7.00*	¾"C.......$6.50*
1"A.......$3.50*	1"B.......$7.00*	1"C........$6.50*
1 ½"A...$3.75	1 ½"B...$7.25	1 ½"C....$7.00
2"A.......$4.50	2"B.......$9.50	2"C........$9.00*
3"A.......$7.50	3"B.......$15.00	3"C........$14.75
4"A.......$12.00	4"B.......$19.50	4"C........$22.25

Camlock D	Camlock E	Camlock F
Female x female pipe thread	Male x barb	Male x male pipe thread
¾"D......$6.50*	¾"E.......$4.00*	¾"F.......$4.00*
1"D.......$6.50*	1"E........$4.00*	1"F........$4.00*
1 ½"D...$7.50	1 ½"E....$4.25	1 ½"F....$4.25
2"D.......$10.25	2"E........$4.50*	2"F........$5.50
3"D.......$15.50	3"E........$9.50	3"F........$10.25
4"D.......$22.50	4"E........$14.00	4"F........$15.25

Camlock DP	Camlock DC	Camlock Gaskets
Male plug	Female plug	¾" ..1"....$0.75
¾"DP........$4.00	¾"DC......$6.50	1 ½"........$0.75
1"DP........$4.00	1"DC.......$6.50	2"............$1.00
1 ½"DP....$4.25	1 ½"DC...$6.75	3"............$2.00
2"DP........$4.50	2"DC.......$8.00	4"............$2.00
3"DP........$7.50	3"DC.......$12.50	6"............$3.50
4"DP........$11.00	4"DC.......$17.00	

Standard Camlock Types

Appendix D: Brookdale Fruit Farm Quote for First Design



		Quantity	Unit	Item	Unit Price	Total
1		16	rolls	2" x 328' flexnet with 6' holes	$295.00	$4,720.00
2		225	assembly	Green meganets with tubes and stakes	$12.00	$2,700.00
3		14	each	4"x4" x 2" threaded tee	$21.00	$294.00
4		14	each	2" x 3" nipples	$3.50	$49.00
5		14	each	2" threaded ball valves	$12.00	$168.00
6		14	each	1.5" pressure regulator at 35 PSI	$30.00	$420.00
7		28	each	2" x 1.5" threaded bushing	$2.75	$77.00
8		14	each	2" camlock B	$9.00	$126.00
9		14	each	2" camlock E	$4.50	$63.00
10		20	each	2" camlock C	$8.00	$160.00
11		20	each	2" camlock E	$4.50	$90.00
12		14	each	2" camlock DP	$4.00	$56.00
13		10	each	2" couplers	$1.55	$15.50
14		15	bags	2" clamps	$6.50	$97.50
15		1	can	liquid teflon	$14.00	$14.00
16						$0.00
17		14	bags	flexnet plugs	$12.50	$175.00
18						$0.00
19						$0.00
20		28	each	4" female adapters	$5.50	$154.00
21		14	each	4" camlock B	$18.50	$259.00
22		14	each	4" camlock F	$15.00	$210.00
23		14	each	4" camlock C	$22.00	$308.00
24		14	each	4" camlock E	$14.00	$196.00
25		1	assembly	4" hook and latch x camlock adapter	$65.00	$65.00
26						$0.00
27						$0.00
28						$0.00
29						$0.00
30						$0.00
31						$0.00
32						$0.00
33						$0.00
34						$0.00
35						$0.00
36						$0.00

Notes:

	Total	$10,417.00

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