DESIGN OF A DRIP IRRIGATION SYSTEM
FOR 80 ACRES OF ALMONDS IN ARBUCKLE, CALIFORNIA.

by

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First, I would like to thanks my parents for all their support and guidance throughout my college experience and my entire life. I would also like to thank my advisor, Dr. Howes for his patience and guidance during this project.

ABSTRACT

This senior project discusses the detailed steps and calculations involved with the design of a dual line buried drip irrigation system. The system is specifically for an 80 acre orchard of almonds in Arbuckle, California. The new design distribution uniformity of the design in 0.92.

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INTRODUCTION

The commercial production of almonds in the United States has become a large industry. For 2014/2015, almonds grown in the US accounted for 82 percent of the world's supply (Foreign Agricultural Service, 2015). The next largest producer was Australia with 7 percent of the supply (California Almond Board, 2014). California's production makes up practically all of the United States' supply (California Almond Board, 2014). For the 2013/2014 crop year California's almond farms produced nearly 1.8 billion pounds of marketable nuts. The northern Sacramento Valley counties including Colusa, Glenn, Butte, Yolo, Tehama and Sutter make up for 14 percent of California production. The counties of the San Joaquin valley account for the remainder. One of the top counties of the North Valley is Colusa County (California Almond Board, 2014). In the 2013/2014 crop year Colusa county's farmers brought 85.1 million pounds to market. Joseph Marsh is an almond grower located in Colusa County in the small town of Arbuckle. Currently, Mr. Marsh has a field that has been planted to processing tomatoes, adjacent to an existing almond orchard. See Figure 1 for a map of the surrounding area. Mr. Marsh wants to plant this field into almonds during the Winter-Spring months of 2017. The current buried drip irrigation system is not appropriate for almond production. A commonly used method for irrigating almonds is a drip irrigation system. The main advantage of drip irrigation is the precise application of water, as well as the ability to run water in frequent, short sessions, known as sets. This project is the complete design of the pipelines, hoses, manifolds, air vents, and other necessary items for a proper design. The project will follow the procedures outlined in BRAE 414, Irrigation Engineering.

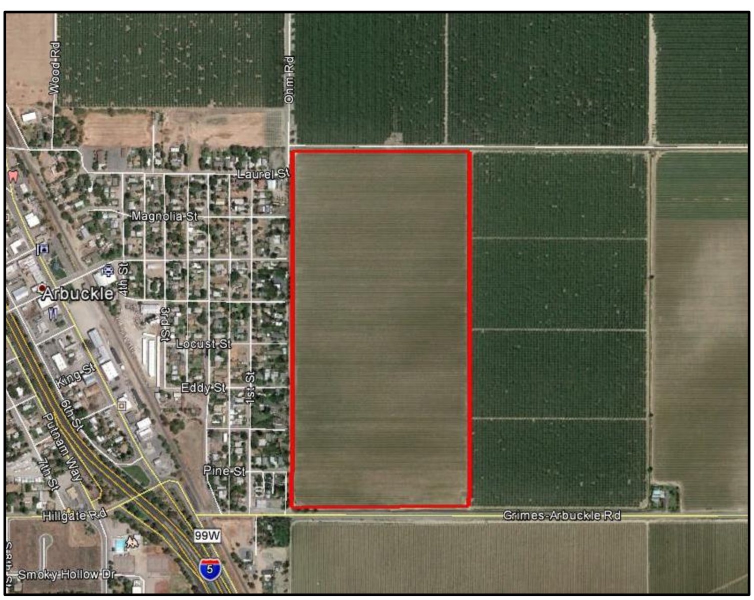

Figure 1. View of Mr. Marsh's field (outlined in red) as of April, 2015

The following objectives for the project are outlined below:

- Pipeline sizing and to-lay lengths of all pipes used in the system.
- A drip irrigation system that is capable of suppling adequate irrigation water to the orchard during times of peak evapotranspiration rates.
- The system will have a final distribution uniformity (DU) of at least 0.92
- Maintain pipeline velocities below five feet per second as to minimize the risks due to water hammer (Burt, C.M. 2014) and to reduce excessive pumping costs.

LITERATURE REVIEW

An irrigation design addresses several key factors. The broadest of these factors include how much water the crop will need, the frequency of irrigation events and finally how the irrigation water will be applied. The following is the research regarding those topics.

Slope and Dimensions of Field

From the length data obtained with Google Earth, the overall dimensions of the field are 2600 ft (North-South direction) by 1280 ft (East-West direction). The elevations of the field were determined with an automatic level and a Philadelphia rod. All elevation readings used the concrete well pad as a benchmark with an assumed elevation of 100’. From the elevation data collected a slope on the East edge of the field can be calculated to be 0.56%. The average East-West slope of the field is 0.48% see Figure 2 below for a map of the field and elevations.

Figure 2. Google Earth view of the field and the surveyed elevations

Soils

One of main driving factors behind an irrigation design is the specific type of soil in the field. The soil type is important because this will influence how often one should irrigate. The measure of how often irrigation is needed is a factor of the soil's available water holding capacity. The soil type can be determined by using data published by the Natural Resources Conservation Service soil survey, Mr. Marsh's field is located in map unit 112. See Figure 3 for the Google Earth view with the NRCS soil survey add-in activated. This unit is 80% comprised of a Westfan Loam soil. The available water holding capacity of this soil is 1.80 inches per foot of soil.

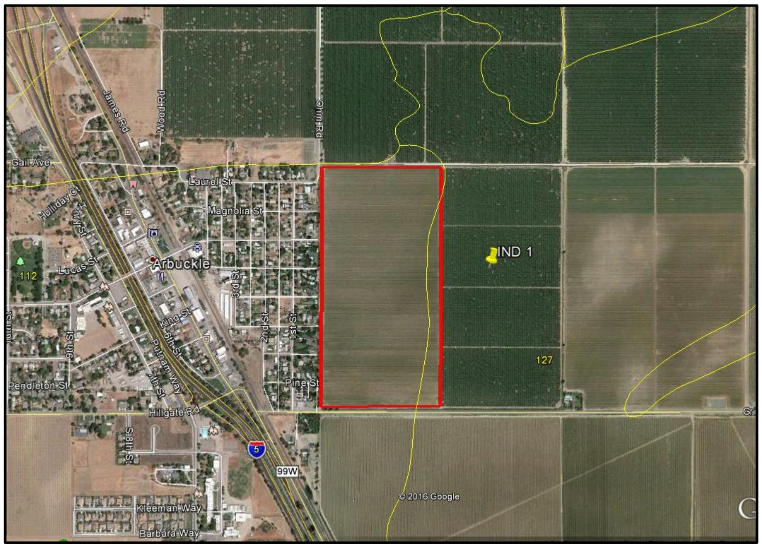

Figure 3. NRCS Soil Survey interface with Google Earth

Evapotranspiration

Evapotranspiration (ET) is a measure or estimate of how much water a plant will use over the course of a specific timeline. This quantity combines how much water is used for cellular respiration in the plant as well as the amount of water that evaporates from the surrounding soil (Burt, 2009). Knowing the ET is very important in irrigation scheduling as meeting this quantity is one of the primary goals of irrigation.

Evapotranspiration rates can be calculated by the following equation.

$$ET_c = ET_o * K_c$$

Where,

ET_c = ET of specific crop
ET_o = ET of reference crop
K_c = Crop Coefficient

The ET_o will vary with the location of the plant or field of interest. California is divided into 18 ET_o zones (ITRC, 2015). To determine what ET zone the field of interest is in, the "reference Evapotranspiration" map by the California Department of Water Resources California Irrigation Management Information System (CIMIS) is used. Based on the map, Arbuckle is located in zone 14. The ET_o for zone 14 can be found on the Irrigation Training and Research Center's website, http://itrc.org/etdata/irrsched.htm. There ET_o for each month is shown. Then the ET_o is multiplied by a crop coefficient to get a corrected estimate of the ET_c. FAO document 66 states K_c for different months, found by different researchers, see Table 1 below.

Table 1. Monthly K_c found by several researchers (FAO 66, 2012)

	Fereres and Puech (1981)	Sanden (2007)	Goldhamer (unpublished)	Girona (2006)
March	0.60	0.59	0.20	0.40
April	0.71	0.78	0.67	0.66
May	0.84	0.92	0.95	0.80
June	0.92	1.01	1.09	0.92
July	0.96	1.08	1.15	0.96
August	0.96	1.08	1.17	1.05
September	0.91	1.02	1.12	0.85
October	0.79	0.89	0.85	0.60
November		0.69		0.40

The month with the highest ET_c is of particular concern to the irrigation system designer, since the system must have the capability to meet the ET_c during this time. Taking the K_c from Goldhamer, and multiplying it by the monthly ET_o during a typical year, during the months of May, June, July and August, yields 7.24, 8.72, 9.61, 8.32 inches per month, respectively.

Hours of Operation

A factor in the calculation of the peak flowrate is the hours of operation. Other orchards owned by Mr. Marsh are irrigated with wells, and those wells are a part of Pacific Gas and Electric Company's (PG&E) time-of-use program. This program for agricultural electrical service gives growers less expensive electrical rates during the "off-peak" times of 6pm and 12pm during weekdays and all day on weekends during the summer months (PG&E, 2015). Since there is a well for the future orchard the system will be sized such that the peak ET can be met while only using "off-peak" electricity.

Buried Drip Irrigation

Drip irrigation using drip hoses and emitter is a common practice in row crop systems. Using buried drip or subsurface drip irrigation (SDI) on orchard crops like almonds is less widespread. Some of the benefits listed by Burt and Styles, 2011, include less evaporation of the applied water from the soil surface, less weed growth, and reduced humidity in the orchard. Some of the disadvantages to SDI versus typical above ground are root intrusion, water still wetting the soil surface due to vertical travel, and discrepancies upon where the hose should be placed in the row, as well as how deep it should be buried.

Drip Emitters

The owner specified that the system be designed as a dual-line buried drip system. The owner also requested that the final design utilize pressure-compensated (PC) emitters. A non pressure compensating emitter will flow more water through the orifice as the pressure of the water increases. A pressure-compensating emitter has an internal diaphragm to regulate the flow to a predetermined amount as long as the water pressure stays within the manufacturer's stated range. Due to the fact that this will be a buried drip system, drip injection equipment will be used to bury the hose a specified depth below the orchard floor. To ease the injection process, drip emitter selection will be limited to inline style emitters. When ordering drip hose, the hose diameter must be specified. In order to maintain compatibility with Mr. Marsh's current inventory of hose repair parts, special interest will be given to those hoses available in the same outside diameter as the hoses in Mr. Marsh's other orchards.

Bowsmith is a manufacturer of many different components for drip and microspray irrigation systems. Their inline pressure compensating emitters can be ordered in one of three different nominal flowrates, 0.42, 0.53, and 1.00 GPH. The product literature also states that the recommended operating pressure, that is, where the pressure compensating feature is most effective, is between 10-45 PSI. (Bowsmith, 2015). As reported by the Irrigation Training and Research Center, 10 PSI is a typical minimum water pressure for the pressure compensating mechanism to function properly (ITRC, 2013).

Netafim has two different versions of an inline pressure compensating drip emitter. One line called the "UniRam" has a special anti-siphon feature built into each emitter (Netafim, 2012). This is particularly appealing since in the final installation of the system, the hose will be buried. When the irrigation water is shut off, the draining water in the lines can create a relative vacuum and dirt-laden water can enter the hose and potentially cause plugging. Netafim's other PC emitter offering is described by the company as an economical pressure compensating solution. This emitter, called the DripNetPC comes in many different flow rates, 0.16, 0.26, 0.32, 0.42, 0.53, 0.61, 0.92, 1.00 GPH.

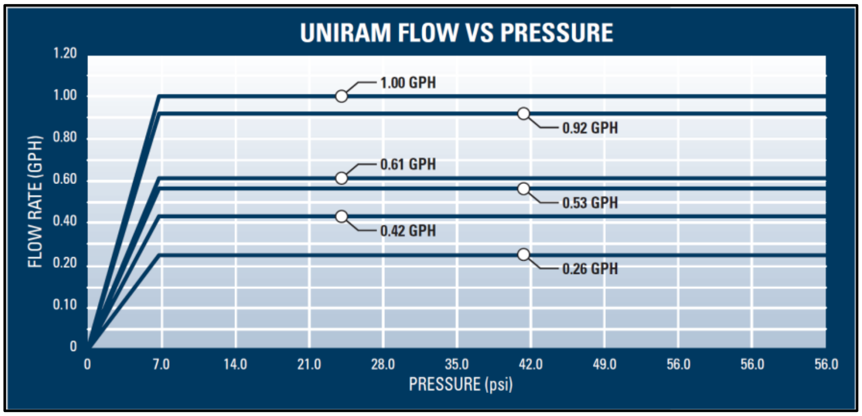

Figure 4. Flow rate versus pressure for UniRam emitter (Netafim, 2012)

Rainbird is another manufacturer of PC emitters. Rainbird's A5 PC emitter comes in flow rates of 0.31, 0.42, 0.53, 0.61, 1.06 GPH. One of the stated features of the A5 PC emitter is that is has a "dual-flushing" feature where debris that has become trapped in the emitter, is flushed out when the water is both turned on and turned off (Rainbird, 2012).

Table 2. Emitter Selection Table

	Variety of Available Sizes	Variety of Nominal Flowrates	Flow Compensating Pressure Range (PSI)	Variety of Emitter Spacings Available
Bowsmith	*	*	***	**
Netafim UniRam	**	**	***	***
Netafim DripNetPC	***	***	***	**
Rainbird A5	**	**	***	***

* = Poor
** = Good
*** = Best

Distribution Uniformity

Distribution uniformity (DU) is a measure of how equally the irrigation water applied is distributed across the field (Burt, 2009). In an irrigation design, the DU will affect mainline sizing downstream of any pressure regulation point (Burt, 2015). Some potential DUs that can obtained with a good irrigation design can be found in Table 3, below.

Table 3. Potential DUlq for moderately well designed irrigation systems. (Burt, 2009)

Irrigation Method	Potential DU_{lq}
Permanent Undertree Sprinkler	.94
Linear Move	.92
Center Pivot	.90
Orchard Drip	.92
Row Crop Drip	.90
Sloping Furrow	.89
Level Furrow	.87
Border Strip	.85
Hand Move Sprinkler (with alternate sets)	.85
Hand Move Sprinkler (without alternate sets)	.75

Pipeline Sizing

As mentioned in the previous section the design DU will dictate the pipeline sizes downstream of a pressure regulator. Specifically, from the design DU, the allowable pressure drop between two points on the pipeline can be calculated. With a lower DU, a larger pressure drop is acceptable. For the pipeline upstream of the pressure regulator an economics-centered strategy will be used. This economics-based strategy uses a maximum water velocity in the pipeline, to balance pumping costs with the cost of larger diameter pipelines.

In sizing the pipelines to be used in the irrigation system, it is required to know the pressures at the start of the pipeline as well as at the end. One of the primary equations is Bernoulli's equation.

$$\left(\frac{V_{u/s}^2}{64.4}\right) + Elev_{u/s} + P_{u/s} = \left(\frac{V_{d/s}^2}{64.4}\right) + Elev_{d/s} + P_{d/s} + H_f - H_p$$

Where,

> $V_{d/s}$,$V_{u/s}$= the velocity of the water leaving and entering the pipeline, respectively, feet per second
> $Elev_{d/s}$, $Elev_{u/s}$= the elevation of the downstream and upstream end of the pipeline, respectively, feet
> $P_{d/s}$, $Pu_{/s}$= the pressure of the water leaving and entering the pipeline, respectively, feet
> H_f=the pressure loss due to friction between the start and end of the pipeline, feet
> H_p=the pressure added by a pump, feet

The friction that occurs between the ends of the pipe can be calculated with several specialized equations. The equation most commonly used for calculating friction in pipelines in sizes found in typical irrigation systems is the Hazen Williams equation.

Given flows, pipeline material, length and inside diameter, one can calculate the friction in units of feet.

Hazen-Williams Equation is as follows:

$$Hf = 10.5 * \left(\frac{GPM}{C}\right)^{1.852} * L * ID^{-4.87}$$

Where,

Hf = pipeline friction, feet
GPM = pipeline flow rate, Gallons per Minute
L = pipeline length, feet
ID = inside diameter of the pipe, inches
C = a friction factor based on material of pipeline and the diameter

Minor Losses

Any time water passes through a fitting or valve, some pressure of the water is lost due to friction. This friction is a function of the velocity of the water as well as the type of fitting. An entire irrigation system will contain many fittings such as tees, elbow, etc. The additive effect of the friction in each fitting can have a significant impact on the system pressure required. The value of pressure lost in units of feet of water can be calculated using the equation below.

$$Hf_{minor} = K\frac{V^2}{64.4}$$

Where,

Hf_{minor}= Friction, feet
K= resistance coefficient
V=velocity of the water in the pipeline, feet

Air Vents

An irrigation system must be equipped with air vents to allow air to both leave the pipeline during startup, as well as enter the pipe during shut-down. There are two different types of air vents, a continuous acting and an air/vacuum relief valve. A continuous air vent is one that allows for entrained air to escape the pipeline (Burt, 2015). An air release/vacuum relief valve, or a dual acting air vent, is used to release the air that is pushed out of a pipeline when the water is started. A dual acting air vent will also allow for air to enter the pipeline when the water is shut off, thus preventing a vacuum from forming. This vacuum is caused by the negative pressure in the pipeline relative to atmospheric pressure. In some instances a sufficient vacuum can cause a pipeline to collapse. There are several critical locations where air vents need to be installed. Some of the locations where this project will specify the installation of both continuous and dual acting air vents are every quarter mile of pipeline, at all high points in the system, and at any point where the pipe starts to slope downhill. In the same paper by Dr. Charles Burt, there are guidelines where only a dual acting air vent is needed. These include upstream of a pump check valve, on the downturn of a backflush manifold and at the end of all mainlines. (Burt, 1999).

Filtration

With any irrigation system is important to determine the amount of filtration needed for proper operation of the system. Generally, for drip irrigation filtration down to 1/10th the emitter diameter is adequate. For typical drip emitter orifice sizes, this equates to 0.001-0.007 inches (0.003 – 0.018 cm) (Burt and Styles, 2011). See Table 4 for a filter media selection table. Currently at Joseph Marsh's field, there is a sand media filtration system in use for the neighboring 80 acres of almonds irrigated with drip. This exiting system will be utilized for the new orchard. The size of the system will remain the same and will still be sufficient since only one orchard or another will be irrigated at one time.

Table 4. Sand media sizes and filtration capacities. (Burt and Styles, 2011)

Media Number	Media Type	Mean Effective Media Size	Mean Filtration Capability (@ 15-25 GPM/ft^2	
12	Round Monterey sand	1.3 mm	0.16 – 0.21mm	90 – 70 mesh
16	Round Monterey sand	0.65	0.12 – 0.1	125 – 100
8	Crushed granite	1.5	0.11 – 0.15	140 – 100
12	Crushed silica	1.2	0.11	140 – 130
20	Round Monterey sand	0.50	0.11	140 – 130
11	Crushed granite	0.78	0.08 – 0.11	200 – 140
16	Crushed silica	0.70	0.08 – 0.10	200 – 150
20	Crushed silica	0.47	0.06 – 0.08	250 – 200

Another design consideration of the filtration system is the ratio of media area to the flow through the filter. From Burt and Styles, 2011, the typical flow through a filter should be 20 GPM/ft^2. See Table 5 for a summary of media tank quantity and diameter and total filtration area.

Table 5. Filter Media Area Based on Tank Quantity and Diameter (Burt and Styles, 2011)

Tank configuration	Total Filtration Area, ft^2
2-18" tanks	3.5
2 -24" tanks	6.2
2-30" tanks	9.8
2-36" tanks	14.2
2-48" tanks	25.0
3-48" tanks	37.5

4-48” tanks	50.0
5-48” tanks	62.5

PROCEDURES AND METHODS

Irrigation Design Procedures

The following are the steps involved with the design and calculations of the irrigation system.

Field Information Supplied by Owner

An irrigation system must be designed to accommodate the specific features of the site. Some of the main parameters that influence a design are the crop to be irrigated, location, overall dimensions of the field, the slope, water source, and the available hours of operation. Some of this information was provided by the owner and is summarized in the list below.

The information supplied by the owner of the field includes:

- Crop: Almonds
- Water Source: Existing well and Irrigation district turnout
- Rows orientated North-South
- Tree Spacing: 22' between rows, 18' down the row
- Dual-line buried drip system utilizing pressure-compensating emitters
- Emitter selection from Netafim UniRam PC product line.
- Utilization of time-of-use program and off-peak electrical rates, 18 hours per day Monday through Friday, and 24 hours per day on weekends.
- A Treflan™ injection procedure will be conducted three times per year to prevent root intrusion into the hoses.
- The owner's desired hose burial depth is 10 in. as was done in Mr. Marsh's other buried drip orchards.

Other information can be gathered from outside sources. These include, but are not limited to, soil type, field dimensions and ET_c. The slope of the field was surveyed using an automatic level and Philadelphia rod. The dimensions of the field and soil type were determined using Google Earth with the NRCS SoilWeb add-in.

- Slope in North-South direction, 0.56%
- Slope in East-West direction, 0.48%
- Width of field, along East-West direction, 1280 ft
- Length of field, along North-South direction 2600 ft
- Soil type, Westfan Clay Loam (Available Water Holding Capacity 1.80 inches/foot)

Calculation of Peak ET

The system was designed to meet the peak monthly evapotranspiration rate while operating during off-peak hours. The peak ET for almonds in zone 14 was calculated by multiplying the reference monthly ET by the crop coefficient for the corresponding month. Using the aforementioned reference ET from the Irrigation Training and Research Center, and the crop coefficient as found by David Goldhamer, the peak monthly ET for almonds in Zone 14 was calculated to be 9.61 inches/month.

New System Design Distribution Uniformity (DU)

A designer has the option to choose a DU that he or she will design the irrigation system to have after installation is complete. As shown in Table 3 in the literature review section, a potential DU for orchard drip is 0.92. This was the design DU used in following calculations for the system.

Number of Trees

The first step in determining how many trees will be planted is to determine the number of rows there will be in the orchard. First, the width of the field is divided by the row spacing. Then this number is either rounded up or down to the nearest whole number. To decide how the number of rows should be rounded, the spacing between the edge rows and the road around the field is calculated. Then, after the exact number of rows is resolved, the number of trees in each row can be calculated in much the same way, except using the length of the field and the down-the-row tree spacing. The same rounding guidelines were used in this step as in determining the number of rows.

Net and Gross Flow per Tree

The peak monthly ET was used to calculate the net application rate required by each tree. This monthly rate was divided by the number of weeks in that month to yield a weekly application rate. Then the weekly rate was converted to a flowrate in gallons per minute (GPM) per tree by the following formula.

$$GPM\ per\ tree = \frac{\frac{inches}{week} * tree\ spacing}{hours\ of\ operation\ in\ one\ week * 96.3}$$

Drip emitters have a nominal flow rate usually specified in gallons per hour (GPH). The GPM/tree calculated in the above steps was multiplied by 60 min/hour to determine the flowrate per tree in units of GPH.

The GPH/tree is a net rate required by the trees. This rate does not account for any losses or inefficiencies in application. To calculate the actual rate that must be supplied by the system the net GPH/tree was divided by an assumed future DU of the system. A typical future DU is assumed to be 0.85. This is lower than the design DU to ensure that the system will be adequate in meeting peak ET, even after the system has aged and performance has deteriorated.

Emitters per Tree

To determine the number of emitters per tree a target wetted area must be chosen, a common wetted area for tree crops with drip irrigation is 60%. The wetted area is portion of the soil around the tree that is wetted by the emitters. The desired wetted area is multiplied by the area allotted to each tree, or in other words, the tree spacing. With drip emitters, after the water starts to infiltrate the soil surface there is horizontal travel as the water travels down into the soil profile. According to Burt and Styles, 2011 the horizontal movement for drip irrigation can range between 3.0-4.5 feet in a loam soil. Additionally, there is extra distance gained by the fact that there will be two hoses per tree. These hoses will be buried about four feet from each tree, giving eight feet of additional distance in the area calculation. See Figure 5 for the plot of the wetted area of each emitter, and the dimensions of a rectangular area wetted by all the emitters. The area of the wetted area rectangle is compared to the target wetted area. If the supplied area is larger than the target, then that number of emitters will be sufficient.

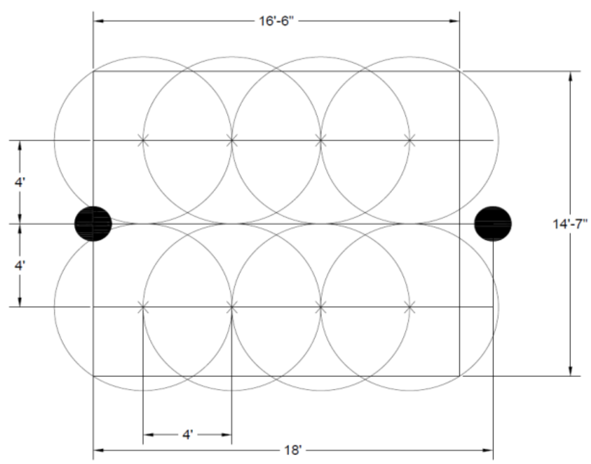

Figure 5. Plotted wetted area with 48 in. emitter spacing

Emitter Flow Rate/ Number of Sets

Since the owner specified the implementation of pressure compensating emitters in the system the design calculations will use flow rates of pressure compensating emitters. The flow delivered by each emitter is kept very close to constant, as long as the hose inlet pressure is kept above a certain pressure. For the hose specified by the owner, Netafim UniRam, the minimum emitter pressure is 7 PSI. To adjust the amount of water applied to the field, the designer of the system will simply adjust the recommended hours of operation in a given time period. As previously mentioned, it is desired that the hours of operation do not exceed those available while using off-peak electricity. The specific flow rate available from each emitter was used in the calculation of the hours of operation. If only off-peak electrical rates were not sufficient, then the next larger emitter flow rate was selected and the hours of operation were calculated again. The number of sets, or how many portions of the field are operated at one time also changed the hours of operation. A number of sets was selected that allowed the maximum hours of operation to be less than or equal to those with time-of-use. The number of sets can also affect the agronomic practices of the grower, such as the time that must pass before irrigations can resume after the harvest process is complete. With multiple sets, smaller blocks can be completely harvested and receive irrigation while the other blocks have not been harvested yet or are being harvested.

Rows per Manifold

The manifolds of the system were determined to run East-West. This means that the number of rows served by the manifold is the width of the field divided by the row spacing. Each manifold will serve every row, albeit a portion of the total length of each row. See Figure 6 for the steps taken to determine the number of rows per manifold.

6) Manifold Sizing			
Number of laterals served by manifold	58.18182	<--Width/22'	
	58	<--Rounded	
Trees per lateral	36.111111		
	36	<--Rounded	

Figure 6. Calculation of the number of rows served by each manifold.

Number of Manifolds

Due to the way the orchard was divided into several sets, the length of the hoses fed by the manifolds was calculated by dividing the orchard length (orientated along the rows) by the number of sets and divided by the desired number of manifolds. This yielded the total length of one hose. The length of hose in one direction from the manifold varies as a function of the hydraulics of the water flowing though the hose. The method that was used to determine the exact distance will be explained in the following section. Then using the posted pressure drop charts supplied by the hose manufacturer, a reasonable pressure loss is determined and the corresponding number of manifolds is selected. The more manifolds are in a field, the shorter the hoses will be and the pressure loss across the hoses will decrease, but the cost of the system will increase. The configuration of the future orchard also was a factor in determining the number of manifolds necessary for a system. Mr. Marsh wishes to have two drive rows that are placed at the quarter points along North-South dimension of the field. Thus dividing the orchard into four independent blocks. This request, and location of the mainline, require the system to have two manifolds per set, yielding four manifolds total.

Hose Hydraulics

There is a computer program available that can use several inputs to closely estimate the hydraulics of each hose as well as determine an approximate length of the hose on both the uphill and downhill sides of the manifold. This program, called PLACEM5, is available from the Irrigation Training Research Center. The inputs PLACEM5 uses are desired flow rates, nominal flow rates, emitters per tree, emitter spacing, additional length for thermal expansion, total length of each lateral, emitter coefficient of variance (CV) water temperature and slope of field. Another input to PLACEM5 is the emitter exponent. For pressure compensating emitters, the emitter exponent is theoretically zero. The program cannot use zero as an input for the calculations, so a near-zero exponent of 0.0001 was used. As mentioned earlier, the program will calculate a distance of the hose on the uphill and downhill sides of the manifold. This distance given by the program is approximate since the program does not account for the actual installation of the manifold being buried between trees. Another output of the program inlet pressure. The smallest hose that will produce a reasonable inlet pressure, will be the least expensive to purchase. See Figure 7 for a screen captured image of the outputs summary page of PLACEM5.

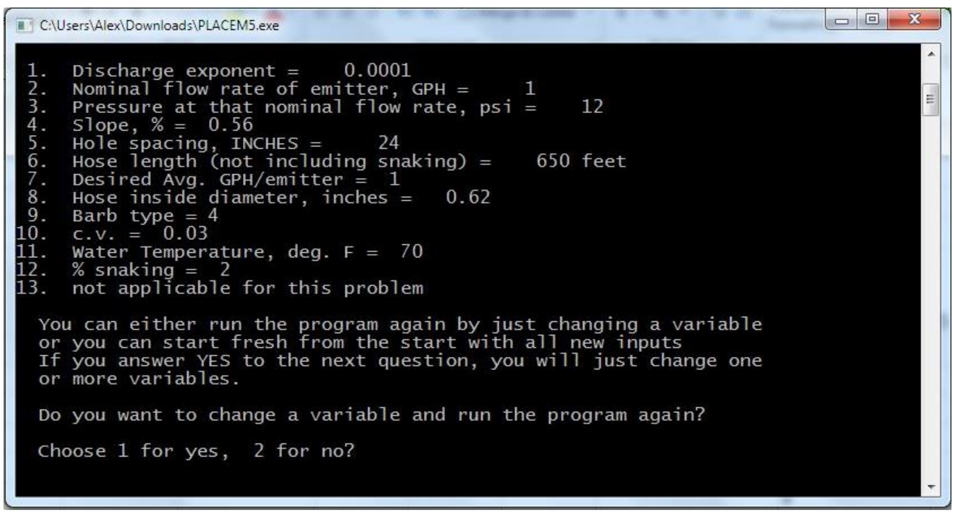

Figure 7. Image of the inputs to PLACEM5

Manifold Sizing/Manifold Inlet Pressure

Since pressure compensating emitters are used in this system the emitters themselves can be considered the pressure regulating point. If the designer ensures the minimum inlet pressure to each hose is maintained, theoretically the DU of the system will not be reduced. This means that the manifolds can be sized according to economics. To size a pipeline economically, a break-even point between the annual pumping costs and the initial pipeline cost is found. This balance point is assumed to be where the velocity of the flow in the pipe is 5 ft/sec. Lower velocities would reduce the pressure loss due to friction, and therefore reduce the pumping costs, but will increase the initial cost of installing the system due to the larger pipe diameters. Smallest diameter pipe is a 4 in. nominal. This was chosen due to the guideline that the smallest pipe diameter along a manifold should not be less than about half of the largest pipeline. This guideline helps to ensure acceptable flushing velocities.

A “Bernoulli Table” was used to calculate the velocity of the water in between each riser along the manifold, as well as the pressure at each point along the manifold. If the velocity started to near 5 ft/sec, then a larger pipe size was specified for that section or sections of pipe. The flows used in the table were determined by PLACEM5. Since each manifold outlet serves two hoses, the flow given by PLACEM5 was multiplied by two. This flow became the “Point Q” column in the table. See Figure 8 for a captured screen image containing all the outputs of the program. Note the velocity in the far-right column never exceeds 5 ft/sec, as these were the points where the pipe sizes were increased. To determine the inlet pressure, the minimum pressure of all the points was set to the minimum pressure given by PLACEM5. This was done by using the Goal Seek function in Excel. The pressure at “Point 1” was adjusted until the minimum pressure equaled 14.9 PSI. See Figure 9 for a shortened version of the table used to size the manifolds and to determine the inlet pressure to the manifolds.

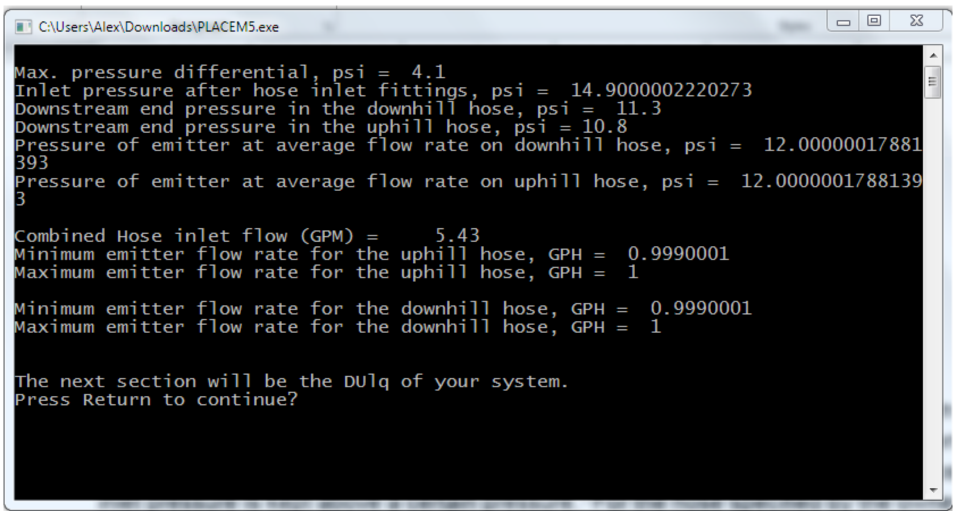

Figure 8 Image of the output window of PLACEM5

Manifold Sizing										
Outlet	Point PSI	Point Q [GPM]	u/s Seg. Q [GPM]	Pipe ID	Segment Length [feet]	Segment Hf [feet]	Segment Hf [PSI]	Δ Elev.	Δ PSI	Velocity [ft/sec]
			0							
1	15.16	10.86	10.86	4.224	22	0.00	0.00	-0.1056	-0.04502	0.25
2	15.12	10.86	21.72	4.224	22	0.01	0.00	-0.1056	-0.04321	0.50
3	15.07	10.86	32.58	4.224	22	0.01	0.01	-0.1056	-0.04041	0.75
4	15.03	10.86	43.44	4.224	22	0.02	0.01	-0.1056	-0.03668	0.99
5	15.00	10.86	54.30	4.224	22	0.03	0.01	-0.1056	-0.03205	1.24
6	14.97	10.86	65.16	4.224	22	0.04	0.02	-0.1056	-0.02657	1.49
7	14.94	10.86	76.02	4.224	22	0.06	0.03	-0.1056	-0.02024	1.74
8	14.92	10.86	86.88	4.224	22	0.08	0.03	-0.1056	-0.01309	1.99
50	16.02	10.86	543.00	8.095	22	0.09	0.04	-0.1056	-0.00482	3.39
51	16.01	10.86	553.86	8.095	22	0.10	0.04	-0.1056	-0.00329	3.45
52	16.01	10.86	564.72	8.095	22	0.10	0.04	-0.1056	-0.00173	3.52
53	16.01	10.86	575.58	8.095	22	0.11	0.05	-0.1056	-0.00015	3.59
54	16.01	10.86	586.44	8.095	22	0.11	0.05	-0.1056	0.00145	3.66
55	16.01	10.86	597.30	8.095	22	0.11	0.05	-0.1056	0.00308	3.72
56	16.01	10.86	608.16	8.095	22	0.12	0.05	-0.1056	0.004736	3.79
57	16.01	10.86	619.02	8.095	22	0.12	0.05	-0.1056	0.006417	3.86
58	16.02	10.86	629.88	8.095	22	0.12	0.05	-0.1056	0.008124	3.93
Inlet	16.03		629.88	8.095	30	0.17	0.07	-0.144	0.011078	3.93
Pavg	15.55	PSI								
Pmin	14.90	PSI	<--Goal Seek to set inlet pressure such that the Pmin is the inlet pressure given by hydraulics program							

Figure 9. Shortened "Bernoulli's Table" used to size the manifolds.

Mainline Sizing

The mainline is the pipe that supplies the manifolds and connects the manifolds to the water source. Like the manifolds, the mainline also lies upstream of the pressure

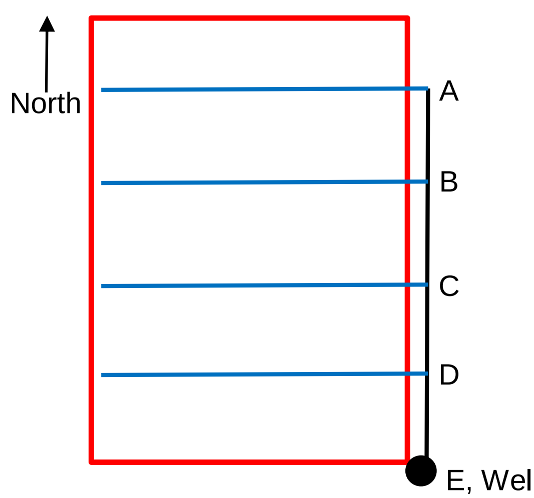

Figure 10. Schematic showing approximate locations of mainline and manifolds (Not to Scale)

regulating point, meaning that the diameter can be based on economic constraints rather than DU. See Figure 10 for a schematic of the layout of the mainline and manifolds. The mainline was also sized such that the velocity of the water did not exceed 5 ft/sec.

Critical Path

The critical path is the pipelines that lead to the point of the system that requires the greatest pumping pressure. For this design, the critical path was first assumed to be at the east end of the northernmost manifold. A table was developed to calculate the pressure losses and diameters using that initial assumption. See Figure 11 for a table where the pressures are determined at the beginning and of each segment of pipe leading to point "A".

7) Mainline Sizing assuming point A is critical point		Point PSI	Point Q [GPM]	Pipe ID	Segment Length [feet]	Segment Hf [feet]	Segment Hf [PSI]	Δ Elev. [ft]	Δ PSI	Velocity [ft/sec]
	Point A	16.03	629.88	8.095	650	3.67	1.59	-3.64	0.014909	3.93
	U/S pt B	16.04	1259.76	11.966	650	1.98	0.86	-3.64	-0.71972	3.59
	U/S pt C	15.32	1259.76	11.966	650	1.98	0.86	-3.64	-0.71972	3.59
	U/S pt D	14.60	1259.76	11.966	305.5	0.93	0.40	-1.7108	-0.33827	3.59
	Point E, Well	14.27	1259.76	11.966	-	-	-	-	-	3.59

Figure 11. Mainline sizing table assuming Point A is part of the critical path.

It was found that point "B" was the actual critical point of the system. In Figure 12 it can be seen that Point E, Well has a higher pressure, and thus can deliver the minimum 16.03 PSI required at the inlet to the manifolds. The other manifolds will have an inlet pressure greater than 16.03 PSI, but the extra pressure will not affect flow in those manifolds, since the pressure compensating emitters will reduce the pressure at each emitter such that the flow will still be the desired 1.0 GPH.

8) Checking for Other Critical Points		Point PSI	Point Q [GPM]	Pipe ID	Segment Length [feet]	Segment Hf [feet]	Segment Hf [PSI]	Δ Elev. [ft]	Δ PSI	Velocity [ft/sec]
	Point A	17.45	629.88	8.095	650	3.67	1.59	-3.64	0.014909	3.93
	U/S pt B	17.47	1259.76	11.966	650	1.98	0.86	-3.64	-0.71972	3.59
	U/S pt C	16.75	1259.76	11.966	650	1.98	0.86	-3.64	-0.71972	3.59
	U/S pt D	16.03	1259.76	11.966	305.5	0.93	0.40	-1.7108	-0.33827	3.59
	Point E, Well	15.69	1259.76	11.966	-	-	-	-	-	3.59

Figure 12. Mainline sizing table with correct critical path.

Filtration Requirements

Currently at the field, there is a sand media filtration system in place for the existing 80 acres of almonds. This system will also be used for the new orchard. To check the adequacy of the system, a new system's specification were determined so that a recommendation can be made to the owner of the field regarding the existing system.

The first step in determining the details of the filtration system was determining the necessary level of filtration. As stated by Styles and Burt, 2011, a typical requirement is 1/10th the orifice diameter for drip irrigation. According to the Netafim product literature for the UniRam product line, a filtration of 80 mesh is recommended for all flow rate emitters except for those with a flow rate of 0.26GPH where 120 mesh filtration is recommended. To be sure there is adequate filtration for the system, further calculations will use 120 mesh filtration capacity. Table 4 in the literature review section summarizes the various media types and their respective mesh equivalents. Using a filter flow per area value of about 15 GPM/sq. ft. it was calculated that seven 48 in. sand media tanks filled with number 20 Round Monterey sand be used.

Air Vents/Vacuum Release Vents

Important devices that must be installed on drip irrigation systems are air vents, vacuum release vents and continuous air vents. Air vents and vacuum release vents are often combined into a single unit know as a dual acting air vent. The design specified dual acting air vents at the ends of all mainlines. The design also called for continuous air vents to be installed at any high point of the pipeline. A dual acting air vent and a continuous air vent are to be installed upstream of each manifold valve. Since the manifold valves are spaced closer than a quarter mile, the maximum allowable distance between vents is not exceeded. Sizing of the air vents depends on the air flow necessary based on the nominal diameter of the pipe. See Table 6 for a table summarizing the required air flow for each type of pipeline protection category. For the 12 in. nominal pipe used for the first segment of mainline, a 3 in. AV-150 from Waterman Industries will be sufficient. For the 8 in. segment of mainline a 3 in. Netafim Guardian air vent will be installed. Since it is impossible to have too much air flow, the 3 in Netafim guardian will be the air vent of choice throughout the rest of the system. For continuous air vent requirements, two 2 in. combination air vents also made by Netafim will be installed in tandem on the downstream side of each manifold valve. A combination valve will be used at these location because of the air release and vacuum release capabilities of these vents, back siphonage of debris into the hoses can be reduced. . At the start of the mainline two 2 in Pro Air vents from Netafim will be used.

Table 6. Air Vent Types and Necessary Air Flow Capabilities (Jain, 2014)

Pipe Nominal Diameter	Necessary Air Release Flow [CFM]	Necessary Vacuum Release Flow [CFM]	Continuous Air Relief Flow [CFM]
8 inch	220	110	24
12 inch	480	240	11

Flushouts

Flushouts are another important part of a proper drip irrigation system. These flushouts will allow debris that has accumulated in the manifolds to be cleaned periodically. The flushouts were designed to be located at the ends of all the manifolds. Each flushout valve is the same diameter as the section of manifold it is connected to. This is to ensure that high enough flows can be achieved in order to effectively clean out the manifolds.

RESULTS

The results of the project were a thorough technical drawing for installing the system, see Figure 13, including the to-lay lengths of PVC pipe. The orchard will be irrigated in two sets. That is the north half or the south half will be operated at one time. Each set duration will be the maximum hours available under the time-of-use program, which is 66 hours per week. The design uses Netafim UniRam 1.0 GPH pressure compensated emitters. The gross application rate achieved by the system is 0.039 in/hr. The specified emitter spacing is 24 inches. A hose with an inside diameter is 0.620 inches is to be used throughout the system. There will be two hoses per row, the hoses being buried at four feet from the tree. The hoses will run for 344.5 feet north from the risers, and 304.5 feet to south. During operation the pump will be set to a pumping pressure of 32.5 PSI.

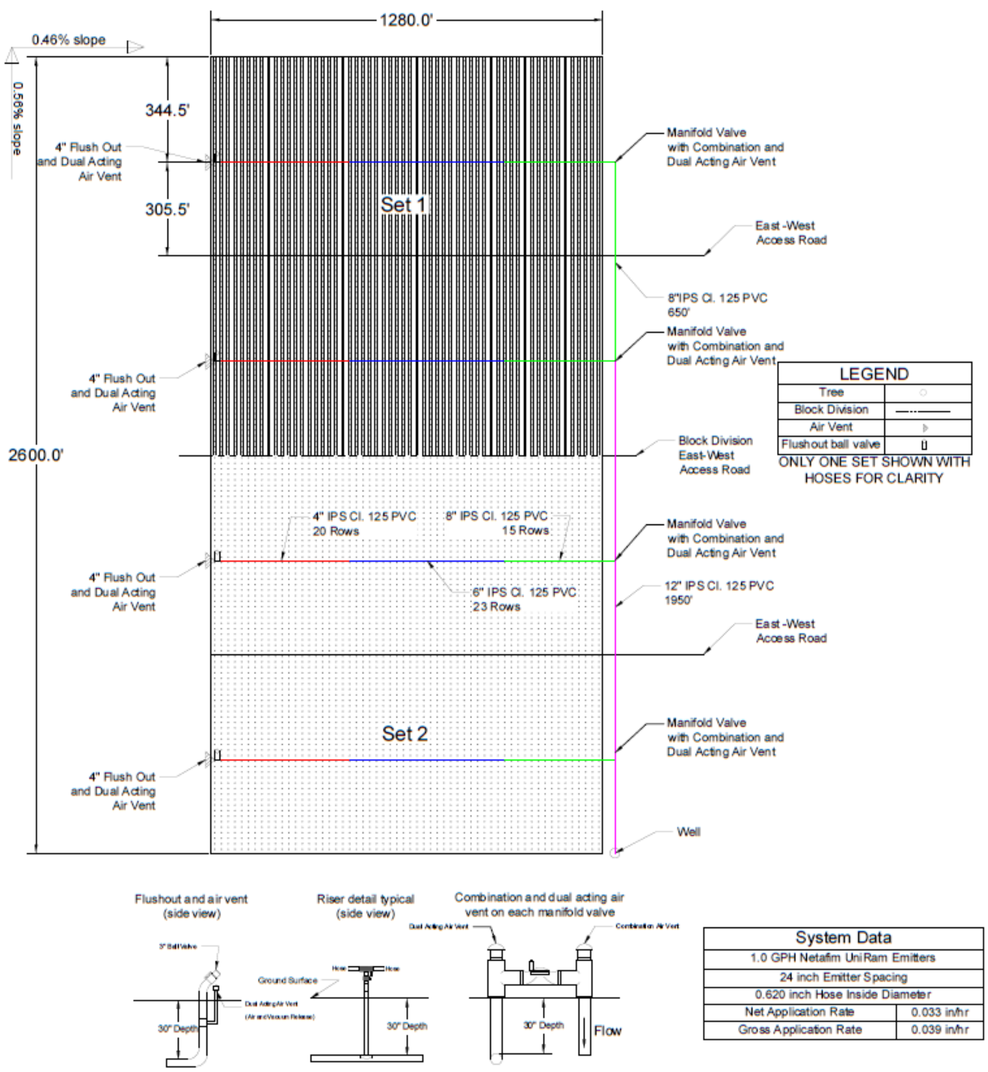

Figure 13. Plot of the orchard and the irrigation system

DISCUSSION

Some of the main difficulties in the design regarded the fact that with pressure compensating emitters, the flow rate is close to constant despite changes in pressure. While this can be extremely advantageous in some situations, it can be a challenge in others. In this design, the hours of operation had to be adjusted to achieve one of the available flow rates. If the design were to utilize non-pressure compensating emitters, the pressure can be adjusted along with the hours of operation to give the designer many options in terms of useable emitter flows.

Another difficulty encountered with this project was in determining the actual critical path of the system. The initial assumed critical point was incorrect. The end of the actual critical path was found to be the start of the second northernmost manifold. Due to the interaction of elevation changes and pipeline friction, the actual critical path cannot be determined by inspection. The actual critical path and critical point must be found with an iterative approach.

Another notable aspect of the irrigation design is that this design was made specifically for Joe Marsh's new orchard. This design cannot be applied to another field, even the field is seemingly identical. The additive effects of soil type, slope, dimensions and operational constraints of Mr. Marsh's field make this design only useable for his field.

RECOMMENDATIONS

One recommendation is to conduct an economic analysis to determine time to balance increased pumping costs with the savings due to fewer manifolds in the orchard. With pressure compensating emitters, the pressure lost due to friction along the hose will not affect flow from the emitter, so long as it is above the minimum compensation pressure. This means longer hoses could possibly be used and thus, reduce the number of manifolds in the field. With fewer manifolds, the initial cost of the system will decrease, but the annual pumping costs to operate the system will increase. An economic analysis could determine how many years of system operation at higher pressures, would be required to justify the additional cost to install the system with more manifolds.

The system and the calculations are all based on meeting the evapotranspiration during the peak month of July. The ET during July was higher than during the other months. The hours of operation were calculated based on this value. For the other months where the trees may require irrigation, such as May, June, August and September, the requisite hours of operation will be less than those in July. Using the calculated net application rate of 0.033 in. per hour, the hours of operation on a weekly basis during those months can be calculated. The hours of operation is the monthly ET converted to a weekly ET, then that rate is divided by 0.033 in. per hour to yield hours of operation. For May, June, August, and September the calculated weekly hours of operation are 49.7, 59.9, 57.5, and 44.8 hours per week, respectively.

As mentioned earlier, the system's require hours of operation are proportional to the ET for a given time period. The reference ET, ET_o, used in the preceding sections, is an approximate value. A recommendation to arrive at results that more closely model the actual evapotranspiration of the crop, would be to adjust the reference ET based on weather conditions.

Another recommendation is to determine the actual break even velocity used in sizing the mainline and manifolds. This project used an assumed break even velocity of 5 ft/sec. It would be productive to determine the actual break-even velocity given the actual electrical rates and annual hours of operation of the system.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

Major Design Experience

The general steps involved in the design include the determination of evapotranspiration requirement of almonds. Then an available emitter flow rate and spacing was selected, based on the maximum hours of operation. The necessary diameters of the pipelines of the manifolds and mainline of the system were determined. Finally, the filtration requirements of the system were determined.

Establishment of Objectives and Criteria

The objective of the project was to provide a design for the installation of the system as well as operational recommendations, such as hours of operation. See “Design Parameters and Constraints” section below for additional objectives and criteria.

Synthesis and Analysis

The project incorporated friction calculations of water flowing in a pipeline, the analysis of soil types and evapotranspiration requirements of almonds in Arbuckle, California.

Construction, Testing and Evaluation

The design was completed, and the objectives outlined at the beginning of the literature review sections were achieved. A complete drawing was developed for the system.

Incorporation of Applicable Engineering Standards

The system utilized guidelines and methodologies as taught in BRAE 414, Irrigation Engineering.

Capstone Project Experience

This project is the culmination of skills and concepts learned in the following classes, SS 121, BRAE 151 AutoCAD, 236 Principles of Irrigation, 239 Engineering Surveying, 312 Hydraulics, 331 Irrigation Theory ,414 Irrigation Engineering.

Design Parameters and Constrains

The system addresses the parameters and constraints listed below.

Physical

The system incorporated buried pipelines and hose, along with above ground valves to control individual hose. The system was designed to not interfere with agronomic practices of the owner.

Economic

The system was designed to meet peak evapotranspiration while using "off-peak" electrical rates. The system also utilizes a break-even point between pumping costs and initial pipeline cost.

Environmental

With drip irrigation, as this system is, runoff and deep percolation can be reduced, thus reducing the impact on surface and ground water quality.

Sustainability

The system was designed for an excellent, yet realistic distribution uniformity, which will allow for the potential to not waste water during irrigation events.

Manufacturability

The project minimized pipeline classification changes and considered the ease of installing the system. The system specified common pipe sizes and the use of "off-the-shelf" parts.

Health and Safety

Pipe protection was designed into the system to minimize the risk of water hammer and therefore pipes bursting.

Ethical

In the interest of ethical concerns, this design did not compromise any aspects of safety in favor of economics.

Social

The system was designed with efficiency in mind, thereby a quality crop can be produced while wasting as little applied water as possible.

Political

The design was designed to work with the on-site well. In anticipation of future legal requirements as well as to inform the owner, an accurate flow meter will be included in the installation in the system.

Aesthetic

The design specified above ground risers, in the final system, all the risers will be the same height as to maintain a uniform appearance through the orchard.

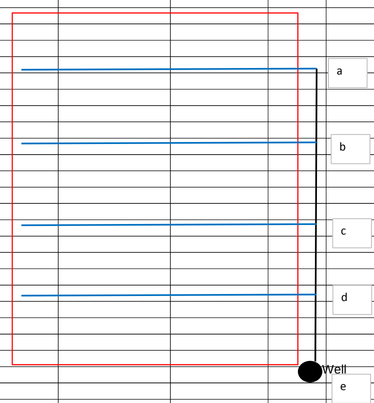
APPENDIX B

IRRIGATION DESIGN CALCULATIONS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Alex Marsh													
2	Senior Project													
3	Spring 2016													
4														
5	Givens													
6		Crop	Almonds											
7		Orchard Dimensions												
8		Length	2600	ft										
9		Width	1280	ft										
10		Acres	76.4											
11		Tree Spacing												
12		Row Spacing	22	ft										
13		Down-the-row Spacing	18	ft										
14		Slope												
15		North-South	-0.56%	Falls to North										
16		East-West	-0.48%	Negative means falls to East										
17		Soil Type	Westfan Loam											
18		Soil AWHC	1.8	in/ft soil										
19		Rootzone Depth												
20		Peak Monthly ET_o	8.36	in/month										
21		Peak K_c	1.15											
22		Peak Monthly ET_c	9.61	in/month										
23		Days in Peak Month (July)	31											
24		New System DU	0.92											
25		Hours of operation with TOU												
26		Weekdays	18	hrs/day										
27		Weekends	24	hrs/day										
28		Netafim UniRam PC Emitters												
29														
30	Design													
31		1) Determine Peak Weekly ET												
32		Peak ET	9.61	in/month	<--From ITRC website for Drip irrigation during normal year for Zone 14									
33		Number of days in peak month	31	days										
34		Days per week	7											
35		$Peak\ Weekly\ ET = \frac{Peak\ Monthly\ ET}{(\frac{days}{month} / \frac{7\ days}{week})}$												
36														
37														
38		Peak weekly ET	2.17	in/week										
39														
40		2) Gross Application Rate												
41		Peak Weekly Et	2.17	in/week										
42		Maximum Hours of Operation Using only off peak hours	138	hrs										
43		Hours Available to this orchard	66	hrs	<-- Total hrs - 3*24 hr irrigations of existing orchard									
44		$GPM\ per\ tree = \frac{\frac{inches}{week} * tree\ spacing}{hours\ of\ operation\ in\ one\ week * 96.3}$												
45														
46														
47		Net GPM/Tree	0.14	GPM/Tree										
48		Net GPH/Tree	8.112	GPH/Tree	<-- using 66 hrs/week									
49														
50		Assumed Future DU after system degradation	0.85	<--Lower DU than "new system design" to allow for adequate irrigation in the future										
51		Assumed Spray Loss	0%											
52		$GrossGPM\ per\ tree = \frac{Net\ GPM/Tree}{DU * (1 - Spray\ loss)}$												
53														
54		Gross GPM/tree	0.16	GPM/Tree										
55		Gross GPH/tree	9.544	GPH/Tree										
56														
57		3) Emitters per Tree and Wetted Area												
58		Target wetted area	60%											
59		Area of one tree	396	ft^1										
60		Targeted wetted area	237.6	ft^2										
61														
62		Horizontal movement of water in given soil type	4	ft										
63		Area wetted by one emitter	50.26548246											
64														
65		Available Emitter Spacings	18,24,30,36,42,48,60		inches									
66														
67			Emitters/tree											
68		Emitter Spacing	One hose	Two hoses										
69		18	12.0	24.0										
70		24	9.0	18.0										
71		30	7.2	14.4										
72		36	6.0	12.0										
73		42	5.1	10.3										
74		48	4.5	9.0										
75		60	3.6	7.2										
76														
77		Overlaying the wetted patterns in AutoCAD												
78		198"*175" Area and 8' Between hoses	34650	in^2										
79			240.63	ft^2										
80		Achieved wetted area using 8 emitters per tree, total	60.76	%										
81														
82														
83		Total number of emitters per tree	9	<-- Change this to change flowrate in cell D3										
84														
85		4) Number Of Sets												
86		The number of sets was selected that yielded a reasonably close flow to those available in the UniRam product line												
87		Hours of operation	66	<-- Less than or equal to 66 hours, which is the maximum available to the new orchard										
88														
89		Available Emitter Flow [GPH]												
90		0.26, 0.42, 0.53, 0.92, 1.0												
91					0.42	0.53	0.61	0.92	1.00					
92			Number of sets	GPH/Emitter										
93			1	1.060					x					
94			2	2.121										
95			3	3.181										
96			4	4.242										
97			5	5.302										
98			6	6.362										
99														
100			55 hrs of operation and 36in spacing		0.42	0.53	0.61	0.92	1.00					
101			Number of sets	GPH/Emitter										
102			1	0.954					x					
103			2	1.909										
104			3	2.863										
105			4	3.817										
106			5	4.772										

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
107			6	5.726										
108														
109			**66 hrs per week and 24in spacing**		0.42	0.53	0.61	0.92	1.00					
110			Number of sets	GPH/Emitter										
111			1	0.530		x								
112			**2**	**1.060**					**x**	<-- Use this one since it's a two set system				
113			3	1.591										
114			4	2.121										
115			5	2.651										
116			6	3.181										
117														
118			66 hrs per week and 48 in spacing		0.42	0.53	0.61	0.92	1.00					
119			Number of sets	GPH/Emitter										
120			1	1.060					x					
121			2	2.121										
122			3	3.181										
123			4	4.242										
124			5	5.302										
125			6	6.362										
126														
127		Orchard Length	2600	ft										
128		Number of sets	2											
129		Length per set	1300	ft										
130														
131			Number of manifolds	Total length of hoses	Appx. length for one hose									
132			1	1300.0	650.0									
133			2	650.0	325.0									
134			3	433.3	216.7									
135			4	325.0	162.5									
136			5	260.0	130.0									
137														
138			Hose ID	Length uphill	length downhill	Dulq	Inlet PSI	Min Pressure along Hose	Min Allowable Manifold DU					
139			0.54	312	338	0.98	17.5	9.8	0.94					
140			0.57	312	338	0.98	16.3	10.3	0.94					
141			0.62	305.5	344.5	0.98	14.9	10.7	0.94	<-- Use this size, since the same as existing orchards				
142			0.69	292.5	357.5	0.98	13.7	12.2	0.94					
143			0.82	260	390	0.98	12.7	11.5	0.94					
144														
145			Min Pressure along hose calculated from inlet pressure - max pressure differential as given by PLACEM5											
146														
147		Actual Manifold Placement	16.97	<--Length downhill/down row tree spacing										
148														
149		Trench manifold between the 16 and 17 tree												
150														
151		Trees uphill from manifold (To the North)	16											
152		Trees downhill from manifold (to the south)	20.11	<-- Length/2 sets/2 manifolds per set/18' down row spacing										
153			20	<--Rounded										
154														
155														
156		5) Allowable pressure change across the manifold												
157														
158		Inlet Pressure	**14.9**	PSI	<--From PLACEM5									
159		Minimum Pressure for compensation	7	PSI										
160		Desired Average Pressure	12	PSI										
161		Max Pressure	17	PSI	$P_{max} = (P_{avg} - P_{min}) + P_{avg}$									
162		Total ΔP	10	PSI	$\Delta P = P_{max} - P_{min}$									
163		ΔP Across Hose	5.8	PSI	$\Delta P_{across\ hose} = Inlet\ P_{min} - P_{avg}$									
164		ΔP Across Manifold	4.2	PSI	$\Delta P_{manifold} = \Delta P_{total} - \Delta P_{hose}$									
165														
166		6) Manifold Sizing												
167		Number of laterals served by manifold	58.18	<--Width/22'										
168			58	<--Rounded										
169		Trees per lateral	36.11											
170			36	<--Rounded										
171		Flow per lateral	10.86	<--GPM (=2* 1 Hose Flow As Given by PLACEM5)										
172														
173							Manifold Sizing							
174			Outlet	Point PSI	Point Q [GPM]	u/s Seg. Q [GPM]	Pipe ID	Segment Length [feet]	Segment Hf [feet]	Segment Hf [PSI]	Δ Elev.	Δ PSI	Velocity [ft/sec]	
175						0								
176			1	15.16	10.86	10.86	4.224	22	0.00	0.00	-0.1056	-0.045021	0.25	
177			2	15.12	10.86	21.72	4.224	22	0.01	0.00	-0.1056	-0.043211	0.50	
178			3	15.07	10.86	32.58	4.224	22	0.01	0.01	-0.1056	-0.04041	0.75	
179			4	15.03	10.86	43.44	4.224	22	0.02	0.01	-0.1056	-0.036678	0.99	
180			5	15.00	10.86	54.30	4.224	22	0.03	0.01	-0.1056	-0.032054	1.24	
181			6	14.97	10.86	65.16	4.224	22	0.04	0.02	-0.1056	-0.026567	1.49	
182			7	14.94	10.86	76.02	4.224	22	0.06	0.03	-0.1056	-0.020241	1.74	
183			8	14.92	10.86	86.88	4.224	22	0.08	0.03	-0.1056	-0.013094	1.99	
184			9	14.91	10.86	97.74	4.224	22	0.09	0.04	-0.1056	-0.005143	2.24	
185			10	14.90	10.86	108.60	4.224	22	0.11	0.05	-0.1056	0.003599	2.49	
186			11	14.90	10.86	119.46	4.224	22	0.14	0.06	-0.1056	0.013119	2.74	
187			12	14.92	10.86	130.32	4.224	22	0.16	0.07	-0.1056	0.023406	2.98	
188			13	14.94	10.86	141.18	4.224	22	0.19	0.08	-0.1056	0.03445	3.23	
189			14	14.97	10.86	152.04	4.224	22	0.21	0.09	-0.1056	0.046244	3.48	
190			15	15.02	10.86	162.90	4.224	22	0.24	0.10	-0.1056	0.058777	3.73	
191			16	15.08	10.86	173.76	4.224	22	0.27	0.12	-0.1056	0.072044	3.98	
192			17	15.15	10.86	184.62	4.224	22	0.30	0.13	-0.1056	0.086036	4.23	
193			18	15.24	10.86	195.48	4.224	22	0.34	0.15	-0.1056	0.100748	4.48	
194			19	15.34	10.86	206.34	4.224	22	0.37	0.16	-0.1056	0.116173	4.72	
195			20	15.45	10.86	217.20	4.224	22	0.41	0.18	-0.1056	0.132305	4.97	
196			21	15.59	10.86	228.06	6.217	22	0.07	0.03	-0.1056	-0.016049	2.41	
197			22	15.57	10.86	238.92	6.217	22	0.07	0.03	-0.1056	-0.01338	2.53	
198			23	15.56	10.86	249.78	6.217	22	0.08	0.04	-0.1056	-0.010605	2.64	
199			24	15.55	10.86	260.64	6.217	22	0.09	0.04	-0.1056	-0.007726	2.75	
200			25	15.54	10.86	271.50	6.217	22	0.09	0.04	-0.1056	-0.004743	2.87	
201			26	15.53	10.86	282.36	6.217	22	0.10	0.04	-0.1056	-0.001656	2.98	
202			27	15.53	10.86	293.22	6.217	22	0.11	0.05	-0.1056	0.001534	3.10	
203			28	15.53	10.86	304.08	6.217	22	0.12	0.05	-0.1056	0.004826	3.21	
204			29	15.54	10.86	314.94	6.217	22	0.12	0.05	-0.1056	0.008219	3.33	
205			30	15.55	10.86	325.80	6.217	22	0.13	0.06	-0.1056	0.011714	3.44	
206			31	15.56	10.86	336.66	6.217	22	0.14	0.06	-0.1056	0.015309	3.56	
207			32	15.57	10.86	347.52	6.217	22	0.15	0.06	-0.1056	0.019005	3.67	
208			33	15.59	10.86	358.38	6.217	22	0.16	0.07	-0.1056	0.022801	3.79	
209			34	15.62	10.86	369.24	6.217	22	0.17	0.07	-0.1056	0.026695	3.90	

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
210			35	15.64	10.86	380.10	6.217	22	0.18	0.08	-0.1056	0.030689	4.02	
211			36	15.67	10.86	390.96	6.217	22	0.19	0.08	-0.1056	0.034781	4.13	
212			37	15.71	10.86	401.82	6.217	22	0.20	0.08	-0.1056	0.038971	4.25	
213			38	15.75	10.86	412.68	6.217	22	0.21	0.09	-0.1056	0.043258	4.36	
214			39	15.79	10.86	423.54	6.217	22	0.22	0.09	-0.1056	0.047643	4.48	
215			40	15.84	10.86	434.40	6.217	22	0.23	0.10	-0.1056	0.052125	4.59	
216			41	15.89	10.86	445.26	6.217	22	0.24	0.10	-0.1056	0.056703	4.71	
217			42	15.95	10.86	456.12	6.217	22	0.25	0.11	-0.1056	0.061377	4.82	
218			43	16.01	10.86	466.98	6.217	22	0.26	0.11	-0.1056	0.066147	4.94	
219			44	16.07	10.86	477.84	8.095	22	0.07	0.03	-0.1056	-0.013437	2.98	
220			45	16.06	10.86	488.70	8.095	22	0.08	0.03	-0.1056	-0.012066	3.05	
221			46	16.05	10.86	499.56	8.095	22	0.08	0.04	-0.1056	-0.010668	3.11	
222			47	16.04	10.86	510.42	8.095	22	0.08	0.04	-0.1056	-0.009244	3.18	
223			48	16.03	10.86	521.28	8.095	22	0.09	0.04	-0.1056	-0.007793	3.25	
224			49	16.02	10.86	532.14	8.095	22	0.09	0.04	-0.1056	-0.006317	3.32	
225			50	16.02	10.86	543.00	8.095	22	0.09	0.04	-0.1056	-0.004815	3.39	
226			51	16.01	10.86	553.86	8.095	22	0.10	0.04	-0.1056	-0.003288	3.45	
227			52	16.01	10.86	564.72	8.095	22	0.10	0.04	-0.1056	-0.001734	3.52	
228			53	16.01	10.86	575.58	8.095	22	0.11	0.05	-0.1056	-0.000155	3.59	
229			54	16.01	10.86	586.44	8.095	22	0.11	0.05	-0.1056	0.00145	3.66	
230			55	16.01	10.86	597.30	8.095	22	0.11	0.05	-0.1056	0.00308	3.72	
231			56	16.01	10.86	608.16	8.095	22	0.12	0.05	-0.1056	0.004736	3.79	
232			57	16.01	10.86	619.02	8.095	22	0.12	0.05	-0.1056	0.006417	3.86	
233			58	16.02	10.86	629.88	8.095	22	0.12	0.05	-0.1056	0.008124	3.93	
234			Inlet	16.03		629.88	8.095	30	0.17	0.07	-0.144	0.011078	3.93	
235														
236			Pavg	15.55	PSI									
237			Pmin	14.90	PSI	<--Goal Seek to set inlet pressure such that the Pmin is the inlet pressure given by hydraulics program								
238														



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
239														
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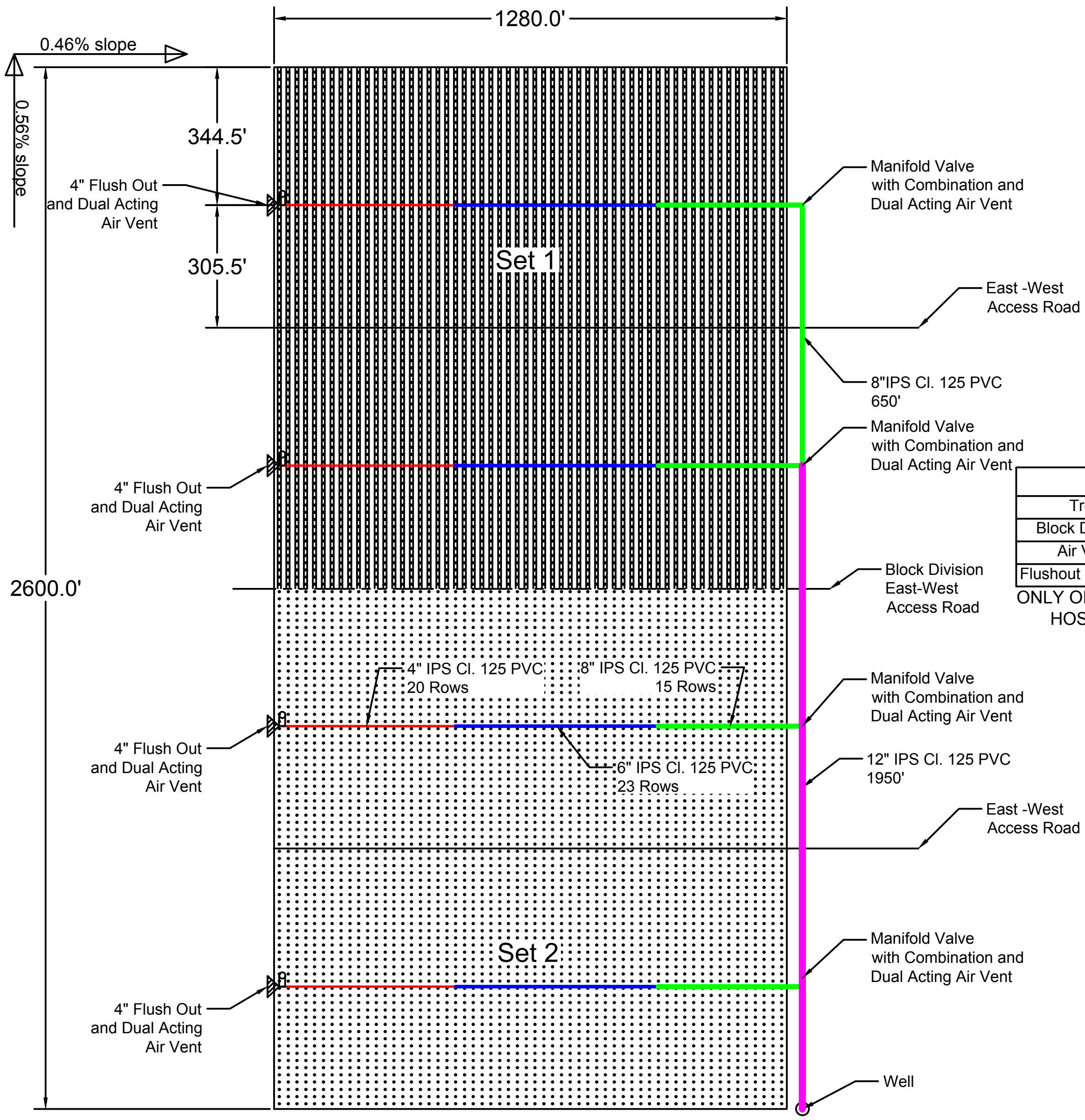
259														
260														
261														
262														
263														
264														
265		7) Mainline Sizing assuming point A is critical point		Point PSI	Point Q [GPM]	Pipe ID	Segment Length [feet]	Segment Hf [feet]	Segment Hf [PSI]	Δ Elev. [ft]	Δ PSI	Velocity [ft/sec]		
266			Point A	16.03	629.88	8.095	650	3.67	1.59	-3.64	0.014909	3.93		
267			U/S pt B	16.04	1259.76	11.966	650	1.98	0.86	-3.64	-0.719723	3.59		
268			U/S pt C	15.32	1259.76	11.966	650	1.98	0.86	-3.64	-0.719723	3.59		
269			U/S pt D	14.60	1259.76	11.966	305.5	0.93	0.40	-1.7108	-0.33827	3.59		
270			Point E, Well	14.27	1259.76	11.966	-	-	-	-	-	3.59		
271														
272		8) Checking for Other Critical Points		Point PSI	Point Q [GPM]	Pipe ID	Segment Length [feet]	Segment Hf [feet]	Segment Hf [PSI]	Δ Elev. [ft]	Δ PSI	Velocity [ft/sec]		
273			Point A	17.45	629.88	8.095	650	3.67	1.59	-3.64	0.014909	3.93		
274			U/S pt B	17.47	1259.76	11.966	650	1.98	0.86	-3.64	-0.719723	3.59		
275			U/S pt C	16.75	1259.76	11.966	650	1.98	0.86	-3.64	-0.719723	3.59		
276			U/S pt D	16.03	1259.76	11.966	305.5	0.93	0.40	-1.7108	-0.33827	3.59		
277			Point E, Well	15.69	1259.76	11.966	-	-	-	-	-	3.59		
278														
279		9) Pumping Pressure Required												
280			Pressure at pt E	15.69	PSI									
281			ΔP When Filters are Dirty	7	PSI									
282			Riser height	2.5	Ft									
283				1.08	PSI									
284				0.36	PSI<--From friciton in riser									
285														
286			Minor Losses	0.347	PSI <--From check valve									
287				0.035	PSI <--From 2 elbows on mainline									
288				5	PSI<-- Assumed loss from connections from well to filter station									
289				0.043	PSI <--From a Butterfly Valve									
290				0.083	PSI <--From manifold valve elbows									
291				3	PSI<-- Assumed pressure drop across manifold valve									
292				0.001	PSI<-- From saddle connection on submain									
293				0.122	PSI<--Minor loss from first riser tee, branch flow, K=1									
294				0.061	PSI<--Minor loss from second tee to connect hose, branch flow, K=1									
295														
296			Pressure Required	**32.48**	PSI									
297														
298		9) Filtration Requirements												
299			Max flow rate	1328.48	GPM									
300			Mfg. rec. filtration	120	mesh									
301			Opening @ 120 Mesh	0.0049	inches									
302				0.12	mm									
303			20 Round Monterey Sand @ 15 GPM/Sq ft		<--Provides slightly better filtration than recommended by the manufacturer, and better filter media									
304					longevity due to round particles									
305														
306			Area needed	88.5653	sq ft <--Max Flow/15GPM/Sq ft									
307			Tanks (theoretical)	7.05	48" Dia tanks									
308														
309			Recommend	**7**	48" Diameter tanks									
310					Even though 7<7.05 The flow per sq ft. is very conservative. Exactly 7 Tanks would be									
311					required if the flow per filter area was 15.1 GPM/sq ft									

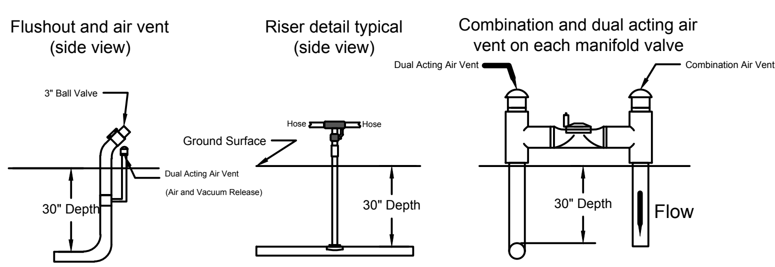
APPENDIX C

DRAWING OF IRRIGATION SYSTEM



LEGEND	
Tree	○
Block Division	—·—·—
Air Vent	▶
Flushout ball valve	

ONLY ONE SET SHOWN WITH HOSES FOR CLARITY



System Data	
1.0 GPH Netafim UniRam Emitters	
24 inch Emitter Spacing	
0.620 inch Hose Inside Diameter	
Net Application Rate	0.033 in/hr
Gross Application Rate	0.039 in/hr