# REDESIGN AND EVALUATION OF THE IRRIGATION SYSTEM FOR THE CAL POLY RADIO HILL AVOCADO GROVE

by

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Great Report!

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# ABSTRACT

The existing irrigation system for the avocado grove on the back side of Cal Poly's Radio Tower Hill is not sufficient to support the entire 10 acre grove simultaneously, even though there is plenty of flow and pressure available at the water source. A new design for the system was formed which would improve the distribution uniformity and ease of operation for the irrigators. The full system was analyzed for the installation materials and labor to give a single overall cost estimate.

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# INTRODUCTION

## Background

On the eastern edge of the California Polytechnic State University in San Luis Obispo is a small avocado grove owned and managed by the university. The grove was planted on about 10 acres of the eastern face of Radio Tower Hill. The grove has a total of 1,251 trees but they vary in variety, age, and spacing in the different blocks (Rosecrans, 2013). The main reason for such variance in the different grove blocks is that the new blocks were added into the grove at different times. Therefore, the irrigation system and other logistical factors for the grove were altered to make things work, rather than fully redesigning the system. Because of this, the irrigation system has a somewhat hodge-podge design. Moreover, it is unclear as to the exact design of the system, since there are no up to date maps of the pipelines in that field. The satellite image in Figure 1 shows the grove.

Figure 1. Radio Hill avocado grove (googlemaps.com).

The entire grove is irrigated using 9 gph pressure compensating Netafim micro sprinklers. Several years ago, the micro sprinkler irrigation system used for this grove was poorly managed and offered a terrible distribution uniformity of about 0.75 in 2011. However, recent improvements have greatly increased the proficiency of the system, and a distribution uniformity of 0.85 was recorded in an evaluation conducted in the fall of 2013 (BRAE 236 Report). This distribution uniformity is still a bit low for a micro sprinkler system like this, but is a huge improvement over what it had been. Each micro sprinkler is feed by a ¾ inch nominal size polyethylene hose, which is fed from a buried sub-main or the main line pipe. The polyethylene hose and the micro sprinklers are still relatively new and in good enough condition to be reused in any new design. However, because there is no irrigation system map for the grove there is no clear knowledge of the system pipeline hydraulics.

Although the grove is only about 10 acres, during the summers it must often be operated in two sets because there is insufficient pressure to operate the entire system at once. According to Jonny Rosecrans, the current manager of the grove, if there is 80 psi. pressure at the filtration station at the base of the grove, one can generally expect to have about 20 psi. pressure at the upper end of the grove. Unfortunately, 20 psi. is not enough pressure to reliably operate the pressure compensating micro sprinkler emitters. Thus, irrigators must manually open or close the sub-main or lateral valves to form different irrigation sets within the grove. Each set is run twice per week so if the grove must be split into two sets, the system must be operated four days per week, every week. Such operation increases labor cost and decreases the irrigation flexibility.

Because the grove is on a hillside with significant elevation change, the friction losses through the pipes need to be investigated so that pressure is not being unreasonably lost. A pressure transducer at the filter station communicates with a well pump in Field 25 to theoretically provide sufficient pressure to the system. However, when several other fields are also being irrigated, the pump cannot always keep up with the pressure demands for this grove. The irrigation water for this grove can be supplied by either surface water storage or wells, both of which are on the Cal Poly campus. Yet during drought years, the surface water is often unavailable.

## Project Justification

There is a huge avocado industry in Southern California. However, due to the extensive urbanization of Southern California, many avocado groves are planted on steep hillsides where the land is cheaper. These groves need special irrigation considerations so that the whole grove can be irrigated uniformly, despite significant elevation changes. Especially as water continues to become more expensive and harder to obtain, efficient irrigation systems and strategies are required. Poorly designed or operated systems can waste large quantities of water to deep percolation and runoff. Cal Poly State University has a small hillside grove on Radio Tower Hill, similar to the larger industry groves. The water hydraulics in the buried piping for this grove is unknown and potentially inefficient. Hydraulic inefficiencies can result in unnecessary pressure requirements and poor distribution uniformity across the irrigation system. This senior project will evaluate the current irrigation system for the grove and propose a system redesign that will improve the hydraulic efficiency, distribution uniformity, and irrigation system clarity for the Radio Hill avocado grove.

## Objectives

One objective of this project is to evaluate the water hydraulics in the buried pipelines in the Radio Hill avocado grove. In this evaluation, the grove evapotranspiration rate, pressure losses due to friction and elevation gain, and water control to individual blocks will be analyzed. Once this evaluation has been made, another objective is to create a new design for the underground pipelines that would minimize pressure losses within the system enough so that the whole grove could always be operated in one set. This project does not cover the installation or implementation of this new design. However, it will include cost estimates for installing the system and recommendations for installation and operation.

## LITERATURE REVIEW

### California Avocado Industry

An avocado is a green tropical tree fruit which is high in potassium, healthy fats, protein, and several other key vitamins (Medical News Today 2013). As the American society becomes more concerned about healthy eating, and the Hispanic population increases, demand for avocados is rising. (Ag Marketing Resource Center, 2014). In 2012, the state of California produced about 195,000 tons of harvested avocados, and had nearly 60,000 acres planted (Ag Marketing Resource Center, 2014). With an average price of about $2,500.00 per ton, this represents a $490 million market for California (Ag Marketing Resource Center, 2014). However, high water prices, foreign competition, and strict regulation make avocado farming difficult (Wohlford, 2013). Many avocado groves in Southern California utilize drip or microsprayer irrigation to plant groves on hillsides and rough terrain since most flat land has been urbanized. However, such hillside groves require special consideration when designing the roads, blocks, and irrigation system (Hillebrecht, 2014). Figure 2 shows a hillside avocado grove in Southern California.

Figure 2. Picture of a hillside avocado grove in Southern California (www.thinkavocado.com).

### Avocado Irrigation Requirements

Because avocados are semi-tropical trees, they must be irrigated in California. According to Wohlford, irrigation costs can be as much as 50% of the annual gross income from a grove. Thus, understanding how much water an avocado tree requires or the evapotranspiration rate is key. Evapotranspiration rate is the amount of water removed from the soil by direct evaporation and by transpiration through the plant. Ideally, the irrigation water delivered to each tree should match the evapotranspiration rate. Evapotranspiration rates vary depending upon the crop, the amount of foliage, and the weather (Burt and Styles 2011). Direct measurement of evapotranspiration is difficult especially with tree crops. Therefore, it is found indirectly by adjusting a known evapotranspiration rate in the vicinity with a crop coefficient $K_c$ as shown below.

$$ET_c = K_c * ET_0 \tag{1}$$

$ET_c$ = Crop evapotranspiration
$K_c$ = Crop Coefficient
$ET_0$ = Grass referenced evapotranspiration

To standardize evapotranspiration measurements, all CIMIS stations only measure $ET_0$ and a crop coefficient factor is used to relate that $ET_0$ with the actual evapotranspiration of the crop (the $ET_c$). CIMIS stands for California Irrigation Measurement Information System and it has various stations around California which constantly measure $ET_0$ for that area (CIMIS 2009). From FAO No. 56 by Allen et al., the $K_c$ crop coefficient for avocado trees varies from 0.60 to 0.85 depending upon the time of the year, although Carr predicted the $K_c$ to be as low as 0.4 to 0.6 under certain climate conditions. In general, the K value for avocados tends to increase for the hotter months of the summer and then drops again for the cooler winter months (itrc.org, 2014). This crop coefficient is then multiplied by the $ET_0$ for the area at that time to determine the approximate evapotranspiration rate of an avocado tree in the grove.

Soil type is a factor in determining the amount of water that must be applied, but less important than evapotranspiration rate. Soil infiltration rate, or the speed with which the soil takes in water, has major bearing on the irrigation strategy. If the water application rate is higher than the soil infiltration rate, run-off will occur which wastes the water and can cause erosion issues (Burt and Styles 2011). Water and soil salinity is also a huge factor for avocados as they are salt sensitive (Carr 2013). It is therefore key that enough water is supplied to maintain high soil moisture content and to operate with proper leaching practices.

### Erosion

On a hillside, soil erosion can be an issue of major concern. Especially roads are susceptible to erosion problems as they lack any vegetative cover and are generally sloping. Erosion ought to be one of the main considerations in the design of grove access roads (Brady 2009). It must also be investigated as to where water will drain from the field during a big rain to prevent the formation of massive gullies or soil deposit in undesired locations (Tamás 2011).

### Surface Irrigation

On hillsides, surface irrigation is much more difficult than on a flat uniformly shaped field. However, it is very possible to use surface irrigation as long as the furrows are cut on contours with the hillside to create a uniform slope throughout the furrow (Hillebrecht, 2014). However, the high labor, maintenance, and earthwork requirements make surface irrigation too inefficient when compared with other methods.

## Hand-move or Solid-set Sprinklers

The major changes in elevation on a hillside also make traditional sprinkler systems difficult to operate and manage efficiently. Top sprinklers will always be under-irrigated while the bottom sprinklers will get over-irrigated as a result of the pressure difference between the top and bottom of the grove (Burt and Styles 2011).

## Micro Sprinklers

By far the most common irrigation strategy for avocados today, especially in groves planted on hillsides, is to use single or dual micro sprinklers to irrigate a single tree. There are many different types, styles, and sizes of micro sprinklers. A common spinner type of micro sprinkler is shown in Figure 3 as it waters a young avocado tree.

Figure 3. A micro sprinkler is irrigating a young avocado tree (www.dripirrigation.com).

For agricultural uses, these micro sprinklers are generally rated for flows between 8 and 80 gallons per hour but have considerable variation according to the manufacturer, the emitter size, the application, and many other factors (Netafim 2013). Flow rate is the volume of water an emitter will put out in a given time. For micro sprinklers, this is often referred to in the units of gallons per hour [gph]. For example, a 20 gph emitter will spray 20 gallons of water in one hour. Most micro sprinkler manufacturers will provide a table that gives the specifications for a certain micro sprinkler nozzle under various conditions. For example, Table 1 on the following page shows the performance of some of TORO's micro sprinklers.

Table 1. TORO Micro Sprinkler Performance Tables (toro.com).

| Model No. | with Deflector tab Model No. | Nozzle Color | Orifice Dia. Inch (mm) | Pressure | | Flow Rate | | Diameter | | Diameter with Deflector Tab | | Stream Height | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | PSI | Bar | gph | lph | Feet | Meters | Feet | Meters | Feet | Meters |
| SAM610 | SAM610-D | Black | 0.034 (0.86) | 15 | 1.03 | 7.9 | 29.9 | 16.4 | 5.0 | 4.9 | 1.5 | 1.8 | 0.56 |
| | | | | 20 | 1.38 | 9.1 | 34.4 | 17.7 | 5.4 | 5.3 | 1.6 | 2.0 | 0.62 |
| | | | | 25 | 1.72 | 10.2 | 38.6 | 19.0 | 5.7 | 1.7 | 5.8 | 2.1 | 0.65 |
| SAM613 | SAM613-D | White | 0.041 (1.04) | 15 | 1.03 | 11.8 | 44.7 | 20.5 | 6.2 | 6.2 | 1.9 | 1.8 | 0.56 |
| | | | | 20 | 1.38 | 13.7 | 51.9 | 22.4 | 6.8 | 6.7 | 2.0 | 2.0 | 0.62 |
| | | | | 25 | 1.72 | 15.3 | 57.9 | 24.0 | 7.3 | 7.2 | 2.2 | 2.1 | 0.65 |
| SAM614 | SAM614-D | 🟫 | 0.049 (1.24) | 15 | 1.03 | 16.5 | 62.5 | 23.0 | 7.0 | 6.9 | 2.0 | 1.9 | 0.57 |
| | | | | 20 | 1.38 | 19.0 | 71.9 | 25.0 | 7.6 | 7.5 | 2.3 | 2.3 | 0.71 |
| | | | | 25 | 1.72 | 21.2 | 80.3 | 27.5 | 8.4 | 8.3 | 2.5 | 3.0 | 0.90 |
| SAM616 | SAM616-D | Green | 0.055 (1.40) | 15 | 1.03 | 21.5 | 81.4 | 27.0 | 8.2 | 8.1 | 2.5 | 2.0 | 0.60 |
| | | | | 20 | 1.38 | 24.8 | 93.9 | 30.0 | 9.1 | 9.0 | 2.7 | 2.7 | 0.83 |
| | | | | 25 | 1.72 | 27.8 | 105.2 | 31.6 | 9.6 | 9.5 | 2.9 | 3.0 | 0.90 |
| SAM620 | SAM620-D | 🟦 | 0.065 (1.65) | 15 | 1.03 | 29.2 | 110.5 | 30.0 | 9.1 | 9.0 | 2.7 | 2.0 | 0.60 |
| | | | | 20 | 1.38 | 33.7 | 127.6 | 32.2 | 9.8 | 9.7 | 3.0 | 2.6 | 0.80 |
| | | | | 25 | 1.72 | 37.7 | 142.7 | 34.6 | 10.5 | 10.4 | 3.2 | 3.0 | 0.92 |
| SAM622 | - | Gray | 0.071 (1.80) | 15 | 1.03 | 33.8 | 127.9 | 32.0 | 9.8 | - | - | 2.0 | 0.60 |
| | | | | 20 | 1.38 | 39.0 | 147.6 | 34.0 | 10.4 | - | - | 2.5 | 0.77 |
| | | | | 25 | 1.72 | 43.6 | 165.0 | 35.6 | 10.9 | - | - | 3.0 | 0.90 |
| SAM624 | - | Yellow | 0.079 (2.01) | 15 | 1.03 | 41.7 | 157.9 | 32.5 | 9.9 | - | - | 2.1 | 0.65 |
| | | | | 20 | 1.38 | 48.1 | 182.1 | 35.0 | 10.7 | - | - | 2.5 | 0.75 |
| | | | | 25 | 1.72 | 53.8 | 203.7 | 36.8 | 11.2 | - | - | 2.8 | 0.85 |
| SAM628 | - | Red | 0.091 (2.31) | 15 | 1.03 | 56.4 | 213.5 | 32.0 | 9.8 | - | - | 2.4 | 0.74 |
| | | | | 20 | 1.38 | 65.1 | 246.4 | 34.1 | 10.4 | - | - | 3.2 | 0.97 |
| | | | | 25 | 1.72 | 72.8 | 275.6 | 36.8 | 11.2 | - | - | 3.4 | 1.05 |

> Recommended Operating Pressure 20 psi (1.38 Bar)

Certain micro sprayers are designed to be pressure compensating. This means that theoretically, the flow rate through the emitter does not change, even with large changes in the water pressure at the emitter. This is significant for micro sprinkler applications where there could be a reasonable pressure variation between different emitters in the same grove block. Sources of such pressure variation can include elevation changes, friction losses, plugged emitters or hoses, and several others factors. With traditional emitters, the flow rate through these emitters would change with the pressure variance according to Equation 2.

$$Q = K * P^{x} \tag{2}$$

Where:
Q = Emitter Flow Rate
K = Emitter Constant
P = Pressure at the Emitter
x = Pressure Sensitivity

For traditional non-pressure compensating emitters, the pressure sensitivity in Equation 2 is 0.5, meaning that the flow rate will change proportionally to the square root of the pressure. A pressure compensating emitter should have a lower pressure sensitivity value x to minimize the influence of pressure. A perfectly pressure compensating emitter would have an x value of 0, for this would mean that $P^x$ would equal 1. Therefore, the emitter flow rate would always simply be equal to the emitter constant K no matter what the pressure at that emitter would be.

Most pressure compensating micro sprinklers use a rubber diaphragm that partially covers the emitter orifice to conduct the pressure compensation. If the pressure in the emitter increases, then the diaphragm flexes and effectively reduces the orifice size. This smaller orifice essentially changes the emitter's K value so that the flow rate will remain the same even though the pressure is higher. If the pressure then decreases, the rubber diaphragm constricts, effectively enlarging the orifice so that a higher flow rate can be reached at a lower pressure.

A major limitation to pressure compensating emitters is that they require a relatively high operating pressure to provide adequate pressure compensation. At pressures lower than 20 psi, the emitters do not operate correctly and little flow control is provided (Netafim 2013). For this reason, it can be difficult to convert a system from traditional micro sprinklers to pressure compensating emitters. Before such a conversion can be considered, one must ensure that sufficient pressure can be provided to every sprinkler to activate the pressure compensation. Another issue with pressure compensating emitters is that their orifices are quite small. This can increase the chance of an emitter plugging, especially if the water is not properly filtered. Even if the water is filtered well, ants and other insects can crawl into the emitters when they are off and plug them (Hillebrecht, 2013). Ideally every tree's emitter ought to be checked for plugging at the beginning of each irrigation to combat this issue. However, that could require a significant amount of time on larger groves. Also, the rubber diaphragms have a limited life expectancy and may need to be replaced after several years. However, it can be difficult to know whether the sprinklers are performing properly without testing a reasonable number of them. Additionally, these PC micro sprinklers are often significantly more expensive, especially when purchasing large numbers to irrigate an entire grove (Netafim 2013).

### Hoses and Pipelines

In a micro sprayer system, water is generally delivered to the emitters through PVC pipe and polyethylene hose. Nominal size refers to the name used to identify a pipe size, but it does not necessarily refer to its actual dimensions. All pipes of the same type and nominal size will have the same outer dimensions so that fittings are interchangeable. There are two types of PVC pipe which are commonly used in agriculture, namely Iron Pipe Size (IPS) and Plastic Irrigation Pipe (PIP). These two types each have various nominal sizes, such as 6 inch, 8 inch, 12 inch, etc. however the actual dimensions for outer diameter are not the same between these types. If fact, the outer diameter with IPS is about one half inch bigger than the outer diameter for PIP pipe (Burt and Styles 2011). It is therefore very important to be consistent with the type of pipe being used.

Some advantages to using PVC pipe over steel, aluminum, or other materials for the irrigation pipes include materials cost, ease of installation, PVC is inert so corrosion is not an issue, and repairs are generally simpler (Derong 2002).

The lateral lines on which the emitters are located are usually designed and installed with polyethylene tubing (Kang, 1996). The micro sprayers are punched directly into the poly tube lines. These lines are flexible and can be laid directly on the surface of the soil. This greatly reduces the installation cost. However, on the surface rodents, coyotes, and equipment can cause holes in the tubes which must be quickly repaired (Wohlford 2013). The repairs are very simple but if undiagnosed, large amounts of water can be wasted.

Pipeline Hydraulics

Hydraulics here refers to the properties and characteristics of water as it flows through the pipelines of the irrigation system. These properties can be analyzed by using several fluid equations. The first and most basic equation used to describe water hydraulics is the Bernoulli Equation shown below.

$$Elev_1 + P_1 + ( V_1^2 / (2*g) ) = Elev_2 + P_2 + ( V_2^2 / (2*g) ) + H_p - H_f - H_{fm} \tag{3}$$

Where:
$Elev_1$ = Elevation at point 1
$P_1$ = Pressure at point 1
$V_1$ = Water Velocity at point 1
$g$ = gravitational acceleration
$Elev_2$ = Elevation at point 2
$P_2$ = Pressure at point 2
$V_2$ = Water Velocity at point 2
$H_p$ = Pumping energy
$H_f$ = Energy loss due to friction
$H_{fm}$ = Energy loss due to hydraulic minor losses

This equation provides a means by which the hydraulic properties at different points through a system can be related to each other. Using this equation, it is possible to predict the system pressures at any point in the irrigation system, assuming that the elevation, water velocity, pumping energy imparted, and hydraulic energy losses due to friction and minor losses can be determined. The Bernoulli Equation should always be the fundamental basis for every hydraulic system design.

There are several different equations which govern the pressure changes through a pipeline system. For agricultural applications, the Hazen-Williams equation is generally accepted to be the rule for pressure loss due to friction between the pipe and the water (Finnemore 2002).

$$H_f = 10.5 * (Q/C)^{1.852} * L * ID^{-4.87} \tag{4}$$

Where:
$H_f$ = Pressure loss due to friction [ft]
$Q$ = Flow Rate [CFS]
$C$ = Roughness Factor [unit-less]

L = Length of Pipe [ft]
ID = Pipe Inside Diameter [in]

This empirical equation relates flow rate, pipe length, pipe diameter, and friction loss within a pipe. It can therefore be used to determine the proper pipe sizing to achieve the desired pressure at each emitter (Burt and Styles 2011).

### Distribution Uniformity

Evaluating an irrigation system to determine its efficiency begins with examining the distribution uniformity. Distribution uniformity (DU) is a measure of how well water is disbursed across the whole grove by comparing the application rates of each emitter (Burt and Styles 2011). DU low quarter is the average emitter application rate of the fourth of emitters with the lowest application rate divided by the total average emitter application rate. The equation for this is shown below in Equation 5.

$$DU_{lq} = Q_{avg.\ low\ quarter} / Q_{avg.} \tag{5}$$

Where:
$DU_{lq}$ = Distribution Uniformity Low Quarter
$Q_{avg.\ low\ quarter}$ = The average emitter flow rate of 25% of emitters with the lowest flow rate
$Q_{avg.}$ = The average emitter flow rate of all the emitters.

For a micro sprayer system, a good $DU_{lq}$ is between 0.88 and 0.94 in general although this depends largely upon many factors (Burt and Styles 2011).

The distribution uniformity largely determines the system needs because the system must be designed so that every tree receives at least the amount of water required. This will result in a large portion of the grove being over-irrigated. However, a smaller DU will reduce the amount of over-irrigation required by limiting the variation in emitter application rate (Burt and Styles 2011).

## METHODS AND PROCEDURES

### Distribution Uniformity Requirements

The target distribution uniformity for this irrigation system is 0.95. This means that the average emitter flow rate for the worst 25% of the emitters cannot be less than 95% of the overall average emitter flow rate for the entire grove. For this design, the overall distribution uniformity is simply due to variation in emitter flows. Although the micro sprinklers do not wet their entire pattern uniformly, it is assumed that all the water that leaves the emitter is applied to a single tree. Unlike with larger sprinklers, micro sprinklers are not meant to wet the entire field but rather to apply the water only to a small area where the tree can easily use it. Thus, catch-can DU can be neglected.

### Evapotranspiration Rate Analysis

Determining the evapotranspiration rate of the grove is the first step in designing or evaluating an irrigation system. The entire purpose of an irrigation system is to ensure that sufficient water is supplied to each tree to match the evapotranspiration rate for each tree. Because the evapotranspiration rate changes throughout the year, the system must be designed to support the trees when experiencing the highest ET, which in California generally occurs during the month of July. For the other months, either the irrigation duration or frequency can be adjusted to match the ET.

In order to determine the maximum ET for the Radio Hill avocado grove, historical data from several sources was examined. On the Cal Poly campus, there is a CIMIS station which monitors local $ET_0$ rates. CIMIS stands for California Irrigation Management Information System and is composed of over 150 different weather stations throughout the state. These weather stations use a combination of different types of sensors to measure, record, and publish the $ET_0$ of the reference crop grass. That published $ET_0$ can then be used by farmers and other growers to predict the irrigation requirements for their crop. On the CIMIS website, local daily $ET_0$ data spanning many years can be acquired. Table 2 shows the $ET_0$ from the Cal Poly CIMIS station for the month of July spanning from 2004 to 2013.

Table 2. Total ET for July in Various Years (CIMIS.com).

| Year | $ET_0$ | Year | $ET_0$ |
|---|---|---|---|
| 2004 | 5.33 in | 2009 | 6.26 in |
| 2005 | 6.08 in | 2010 | 5.58 in |
| 2006 | 5.94 in | 2011 | 6.44 in |
| 2007 | 6.35 in | 2012 | 6.38 in |
| 2006 | 6.05 in | 2013 | 6.34 in |

From the data in Table 2, it was determined that the average $ET_0$ data for the month of July over the last 10 years is 6.075 inches. However, the average $ET_0$ is not the best measure for designing an irrigation system. The design should consider the maximum reasonable ET for all its parameters in order to guarantee that sufficient water could be applied if the maximum ET was ever met. Therefore, 6.50 inches per July was used as the $ET_0$ basis for the redesign.

In order to apply this $ET_0$ to avocados, it must be multiplied by the proper $K_c$ value. According to FAO No. 56 by Allen et al., the $K_c$ for avocados ranges from 0.6 to 0.85 through the year peaking during the hotter summer months. Therefore, for this design 0.8 was used as the $K_c$. This resulted in an $ET_c$ of 5.2 inches per July. This is very similar to the $ET_c$ of 5.39 inches that the ITRC estimated for avocado trees on California's Central Coast during a dry year (itrc.org, 2014).

Ensuring System Can Meet $ET_c$ Demands

With the $ET_c$ now determined, the 9 GPH micro sprinklers must now be examined to ensure that they can provide sufficient water to meet the maximum $ET_c$. To do this, the $ET_c$ must first be converted from a depth of water into a flow rate, and then compared to the micro sprinkler flow rate. The calculations for this are shown below.

To convert the $ET_c$ for July into an average daily $ET_c$:

$ET_c$ daily = $ET_c$ July / 31 days in July

$ET_c$ daily = 5.2 in / 31 days = 0.168 in/day

Area = 25 ft * 10 ft = 250 $ft^2$ (from the average tree spacing)

To convert a depth to a flow rate:

GPM = (Inches * Area) / (96.3 * Hours)

GPM = (0.168 in/day * 250 $ft^2$) / (96.3 * 24 hours/day)

GPH = GPM * 60 minutes / hour = 1.09 GPH

The distribution uniformity must then be considered as a portion of the field will be over-irrigated so that other points will not be under irrigated. The value 0.87 was used as the DU rather than the design DU of 0.95 so the system could be overdesigned in case of system ware or disrepair.

GPH Net = (1.09 GPH / 0.87 DU ) = 1.25 GPH

This is significantly smaller than the 9 GPH flow rate of the emitters. Therefore, the emitters have sufficient capacity. Next the length of the irrigations should be determined, assuming the use of the 9 GPH emitters and that there are 2 irrigations every week.

(1.25 GPH * 24 hrs/day * 7 days/wk) / (9 GPH emitters * 2 irrigations/wk) = 11.6 hrs/irrigation

Therefore, the maximum irrigation duration that must be used if irrigating two times per week in July is 11.6 hours.

Field Survey

With the help of Mr. Keith Crowe, one of the professors in the BRAE Department, GPS units were checked out in order to conduct a GPS survey of the field. The GPS offered the quickest and simplest means for conducting a survey of the avocado field because of the relatively large area that needed to be covered. Since the information needed from the survey required accuracy of a few feet, the GPS units would have provided plenty of accuracy and precision. From this survey, the plan was to create a topographical map of the field in order to analyze elevation change and distances. However, upon arrival to the field the GPS unit was unable to receive a useful signal from the base station on campus. Therefore the survey could not be conducted.

Mr. Tom Mastin was then contacted for advice on obtaining the needed data. He recommended that the Cal Poly Facilities Plan website be used where one could download a topographical map of the entire campus. This map has contour lines every two feet. The Radio Hill section of this topographical map was overlaid on a googlemaps satellite image of the field as shown in Figure 4. A larger and more detailed version of this map is found in Appendix C.

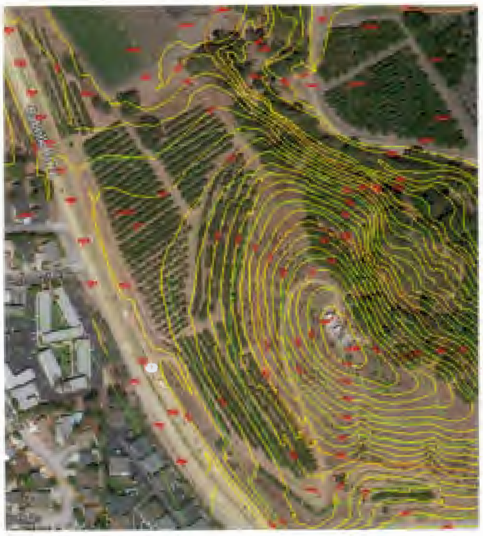

Figure 4. General Topographical Map of the Field.

## Design Procedures

Determine Irrigation Blocks. Although the ultimate goal of this project was to design an irrigation system for this grove so that it would not require multiple sets, the system should still be subdivided into blocks. By designing separate blocks in the system, a certain part of the grove could be hydraulically isolated in case of a break in the pipe. Additionally, this offered a more efficient distribution of the water and gave more control over the system. Ideally, the valves for these blocks would be open the far majority of the time since the entire grove would be irrigated together. In this situation, one could simply open the valve on the mainline at the filter station to irrigate the grove. The grove was divided into six separate blocks as shown in Figure 5.

Figure 5. Map of Block Divisions in the Field.

The road locations and tree planting arrangement were the driving factors for determining these blocks. Each block would be fed by a single manifold or sub-main line which connects to the main line via a Tee. The individual hose risers for each row are then fed by that manifold line. Because the blocks vary so much in size and shape, each manifold needed to be individually designed.

Manifold Design. When designing the manifold, the biggest concern was the pressure loss through that manifold. Pressure loss is dependent primarily upon elevation gain and friction loss. The sum of the elevation gain and the friction loss for a certain segment of pipe equals the total pressure loss across that segment.

To determine the elevation gain, the topographical map shown in Appendix C was examined. This allowed estimates of the elevation change between rows along the laterals to a 1 foot precision to be made. The elevation change between every row is shown in the Manifold Tables of Appendix B.

In order to determine the hydraulic friction loss, it was required that the manifold be divided into segments because the flow rate through the manifold would not be constant across its whole length. As water would be delivered to each hose riser, the flow rate down the rest of the manifold would decrease accordingly. The Manifold Tables shown in Appendix B were thus created to determine the friction loss due to each segment between rows. With this and the change in elevation, the maximum pressure loss through the manifold for each block could be determined. Once the manifolds were designed, maps and diagrams of each were drawn using the AutoCAD and SolidWorks programs. These are shown in Appendix C.

Main Line Design. The mainline supplies water to all of the various manifolds. It required a similar calculation to that of the manifolds for its flow also varies along the length of the line. As manifolds branch off, there would be less flow through the pipe, thus reducing the friction. The main line was designed to follow the current drive road through the middle of the field. This would provide for easy access for both installation and repairs. For the initial design the Mainline Table, shown in Appendix B, was created in order to analyze the expected pressure loss through this mainline. AutoCAD and SolidWorks were then used to create drawings of the main line. These drawings are shown in Figure 6 and in the Results Section.

Figure 6. Map showing Location and Design of Main Line.

Critical Path Analysis. In order to properly size the pipes for the main line and each of the manifolds, the critical path must be determined. The critical path is the course through which water flows to get to the "most difficult" point in the system. This point can be identified by looking at the pressures at each point in the system. The point with the lowest pressure is the end of the critical path. All pipe sizing should be referenced from the critical path to ensure that there is sufficient pressure at that point. If there is sufficient pressure for the point at the end of the critical path, then there will be at least that much pressure everywhere else in the system.

For this design, the critical path runs up the main line to Manifold 4, then to the end riser, and down the southern hose from that riser. This was determined by first finding the pressures at each row riser for every manifold using the Hazen-Williams Equation, the Bernoulli Equation, and determining the minor losses. The tables for these calculations are shown in Appendix B. After the riser with the lowest pressure was discovered, the hose leading to the emitter was analyzed. The riser through which the critical path runs feeds hoses in either direction. Therefore, each hose had to be analyzed for pressure loss to determine the final critical path. This analysis is recorded in Appendix B. Interestingly, the critical path ends before the end of the hose. This is because the dropping elevation actually added pressure to the line after the critical path.

Once the critical path was determined, the mainline pipe sizes were adjusted for maximum efficiency and economics. Smaller pipe is cheaper than larger pipe, so pipes ought to be downsized as much as possible without exceeding the pressure loss limit determined by the end of the critical path. Friction loss through the pipe is the main factor determining the minimum pipe size for a given segment. As the flow rate through the line decreases due to various blocks, the pipe size can also be decreased. Thus the main line was sized in order to provide sufficient pressure to properly operate the pressure compensating emitter at the end of the critical path since it would have the least pressure in the entire system. For all the pipe sizing, it was assumed that the pressure after the filters is at least 80psi. This is a safe assumption as the Cal Poly irrigation system pressure is maintained by a well pump that will automatically turn on if the pressure drops too low.

After the main line was sized, the critical path for each block was determined. Each extended from the intersection with the main line to the place hydraulically farthest from that intersection. Each block was then resized to the minimum pipe size required to provide adequate pressure to the end of that block's critical path. The tables for these calculations are shown in Appendix B.

Estimate Pressure Loss through the Filter Station. One key consideration for this design is the effect of the filtration system. Especially with pressure compensating emitters, clean water is extremely important. If water is dirty, the emitters could become plugged easily since they use small orifices. Therefore, filtration is a definite requirement for this system. Filter capacity is extremely important, especially for backflow situations. When the pressure difference between the upstream and downstream points of the filters exceed a set limit, the filters will undergo a back flush cycle. During this cycle, one filter must provide the flow for the entire system along with the back flush flow. If the filters are too small, during this cycle the flow and pressure will drop for the whole system.

Because the water feeding this system could be either from a well or from surface water, the filtration system must be able to clean the dirtier surface water. Generally for a micro sprinkler system, the water must be filtered to allow particles no bigger than 1/7th the orifice size (Burt, 2013). Since the orifice diameter is about 0.05 inches, this means that particles bigger than 0.007 inches must be removed. Therefore, the 80 mesh filtration offered by #8 Crushed Granite is adequate. Next the media tanks were sized for flow rate. The maximum flow rate through the tanks would be about 190 GPM if the entire grove were operated at once. According to the Drip and Micro Irrigation Design and Management book by Burt and Styles, at least three 30 inch tanks should be used to supply that flow rate. Therefore, the current tanks ought to be replaced.

Air Vent Placement. The sizing and placement of air valves is a very important aspect of designing an irrigation system. Air vents are used to let air escape out of the pipes when the system is started, and to allow air back into the system when it is shut off. Air vents should be installed at the ends of all the main and manifold lines to release air pushed to the end of the pipe when the water is turned on. They should also be at every high point in the system, because air will naturally tend to rise to the local high spot. If the air is not allowed to escape from the pipeline, then it will remain in the high spot and effectively reduce the cross sectional area of the pipe at that point. Finally, air vents should be located before and after every irrigation valve. The vent before the valve will release air pushed against the valve when it is closed but the rest of the system is running. The vent after the valve will reduce the effects of water hammer on the system if the valve is closed too quickly. Water hammer occurs when a valve is quickly closed and the water in the pipeline is at a relatively fast velocity. The velocity head of the water will continue to carry it down the pipe, thus creating a vacuum behind it. Once the velocity head dissipates, the water rushes back to fill the vacuum it left and will slam into the valve. This can send pressure waves through the whole system which have the potential to severely damage the pipes. However, if an air vent is located directly after the valve, it will allow air to fill the vacuum left by the water, minimizing the effects of water hammer.

### Parts List & Cost Analysis

Once the entire system was designed, a detailed parts list was created. The list is divided into sections for the main line and each block. Then the lists were combined into a single comprehensive list of all the parts and equipment that would be required to install the new design. Each item from the parts list was then priced out so that the capital cost for the system could be determined. Finally the estimated labor and equipment costs for installing the system were estimated. This was added to the system capital cost to represent the estimated total cost for the new system design.

# RESULTS

## Final System Design

The final system design is shown in Figure 7. For points in the system that require special installation, SolidWorks drawings are provided to aid with installation. These along with a more detailed design map are shown in Appendix C. The red line shows the mainline for the system. The blue line represents the manifold piping and the green lines stand for the individual ¾" polyethylene hose on which the micro sprinklers are attached.

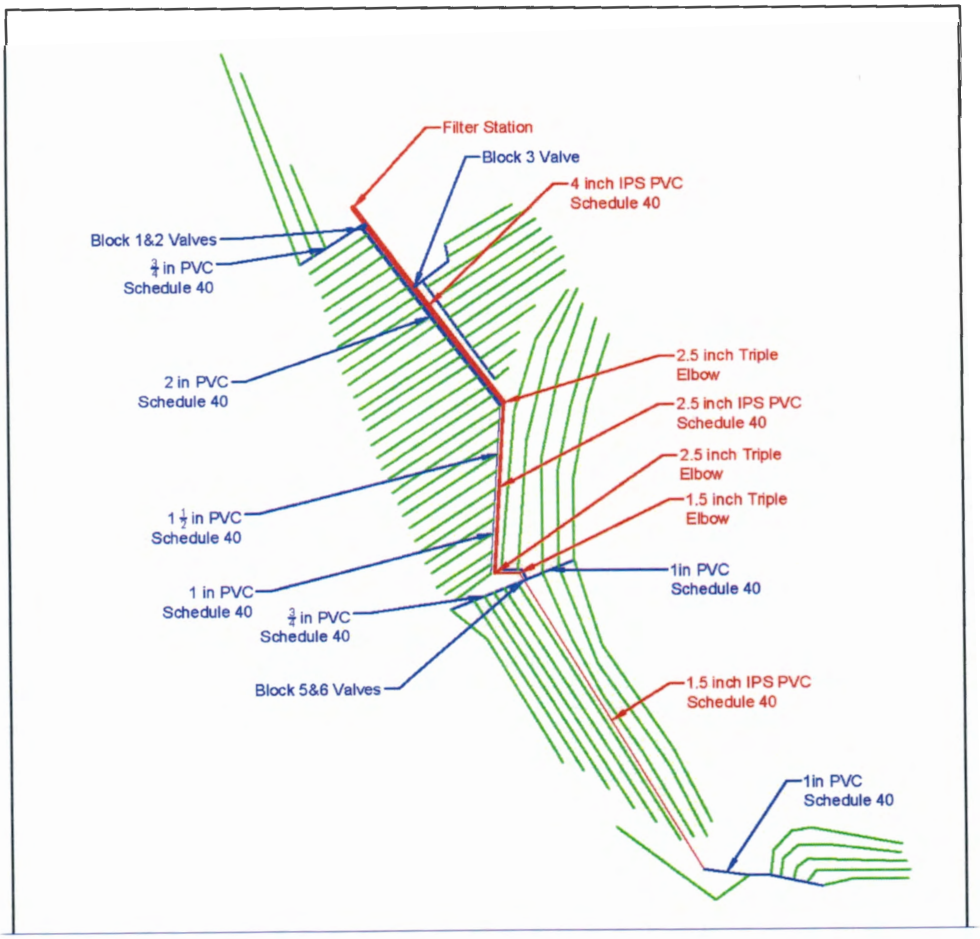

Figure 7. Design Drawing for the New System.

Along with the AutoCAD drawings of the field design, detail drawings were created using SolidWorks to better demonstrate how the system would be built. Figure 8 on the next page shows an example of such a detail drawing.

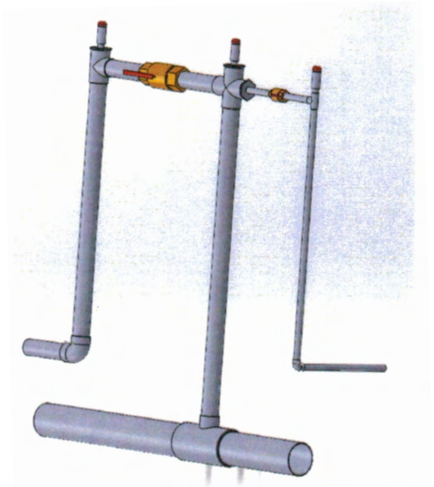

Figure 8. Design detail for the main valves for Blocks 1 & 2.

Final Distribution Uniformity

The final design's distribution uniformity was about 0.97. This was determined by examining the various pressures at the hose heads and linearly interpolating to determine the flow rate that the emitters would offer at that pressure. Because pressure compensating emitters were used, the pressure did not drastically change the emitter flow. The overall average emitter flow rate was then compared with the low quarter average, yielding a DU of about 0.99 between the hoses. The DU was then adjusted by the DU between emitters along the same hose, which was estimated at 0.97. This was determined by evaluating pressure differences along the hose, and accounting for manufacturer variability among emitters. Multiplying the hose DU of 0.99 by the emitter DU of 0.97, a final DU of 0.96 can be determined. This exceeded the design parameter of a DU no less than 0.95. The calculation spread sheets for this analysis are in Appendix B.

Parts List & Cost

Table 3 on the following page shows a list of all the different parts that would be required for installing this design. It also lists the prices for the different parts. These prices were added together to show the total estimated material cost. The list is ordered according to pipe and fitting sizes. The new sand media tank station should cost about $3,000.

The total trenching required was also determined and priced out. It was estimated that about 2,500 feet of trenching must be done in order to install all of the buried pipe necessary for the new system. The Mainline pipe and the Manifold 2 pipe would both be laid in the same trench in order to minimize the trenching required. If allowed to use a trencher from Cal Poly's Farm Shop, and assuming a trencher speed of about 200 feet per hour, the total trenching would take about 12.5 hours. If it costs about $25 per hour in labor and fuel, total trenching would be about $300. Assume burying the pipe will be about $300 as well. Installation labor could be $1,000.

Therefore, the total cost for installing the system is about $12,000.

Table 3. Overall Parts List for Design

| Overall Parts List | | | |
|---|---|---|---|
| Part | Number of Units | Unit Price | Total Part Cost |
| 4" Pipe/Fittings | | | |
| 4" Brass Ball Valve | 1 | $387.75 | $387.75 |
| 4" Propeller Flow Meter | 1 | $1,559.00 | $1,559.00 |
| 4" 45 deg Elbow | 2 | $9.00 | $18.00 |
| 4" 90 deg Elbow | 2 | $6.91 | $13.82 |
| 4" Tee | 1 | $10.26 | $10.26 |
| 4" x 2" Bushing | 1 | $4.15 | $4.15 |
| 4" x 4" x 3/4" Tee | 1 | $12.92 | $12.92 |
| 4" x 2.5" Bushing | 1 | $4.16 | $4.16 |
| 4" Schedule 40 IPS PVC Pipe [ft] | 650 | $3.40 | $2,210.00 |
| 2.5" Pipe/Fittings | | | |
| 2.5" 90 deg Elbow | 4 | $3.23 | $12.92 |
| 2.5" x 2.5" x 3/4" Tee | 2 | $5.15 | $10.30 |
| 2.5" x 2.5" x 1.5" Tee | 1 | $5.15 | $5.15 |
| 2.5" x 1.5" Bushing | 1 | $1.27 | $1.27 |
| 2.5" Schedule 40 IPS PVC Pipe [ft] | 300 | $1.74 | $522.00 |
| 2" Pipe/Fittings | | | |
| 2" x 3/4" Bushing | 2 | $1.59 | $3.18 |
| 2" Cross (X) | 1 | $3.10 | $3.10 |
| 2" x 6" Nipple | 1 | $10.07 | $10.07 |
| 2" Brass Ball Valve | 1 | $78.01 | $78.01 |
| 2" Tee | 1 | $1.31 | $1.31 |
| 2" 90 deg Elbow | 1 | $1.07 | $1.07 |
| 2" x 2" x 3/4" Tee | 17 | $4.19 | $71.23 |
| 2" x 1.5" Bushing | 1 | $1.59 | $1.59 |
| 2" Schedule 40 IPS PVC Pipe [ft] | 425 | $1.08 | $459.00 |
| 1.5" Pipe/Fittings | | | |
| 1.5" 90 deg Elbow | 3 | $0.68 | $2.04 |
| 1.5" Tee | 5 | $0.90 | $4.50 |
| 1.5" x 1.5" x 3/4" Tee | 7 | $2.79 | $19.53 |
| 1.5" x 1" Bushing | 2 | $0.95 | $1.90 |
| 1.5" x 3/4" Bushing | 2 | $0.95 | $1.90 |
| 1.5" Cross (X) | 1 | $1.40 | $1.40 |
| 1.5" x 6" Nipple | 1 | $3.08 | $3.08 |
| 1.5" Brass Ball Valve | 1 | $50.40 | $50.40 |
| 1.5" Schedule 40 IPS PVC Pipe [ft] | 865 | $0.79 | $683.35 |
| 1" Pipe/Fittings | | | |
| 1" x 1" x 3/4" Tee | 12 | $1.09 | $13.08 |
| 1" 90 deg Elbow | 8 | $0.36 | $2.88 |
| 1" x 3/4" Bushing | 2 | $0.69 | $1.38 |
| 1" x 6" Nipple | 2 | $2.07 | $4.14 |
| 1" Brass Ball Valve | 2 | $26.44 | $52.88 |
| 1" Tee | 3 | $0.48 | $1.44 |
| 1" Schedule 40 IPS PVC Pipe [ft] | 575 | $0.49 | $281.75 |
| 3/4" Pipe/Fittings | | | |
| 3/4" Brass Ball Valve | 2 | $16.27 | $32.54 |
| 3/4" x 8" Nipple | 30 | $0.60 | $18.00 |
| 3/4" Tee | 20 | $0.26 | $5.20 |
| 3/4" Air Vent | 19 | $6.90 | $131.10 |
| 3/4" 50psi Pressure Regulater | 18 | $15.45 | $278.10 |
| 3/4" 90 deg Elbow | 64 | $0.20 | $12.80 |
| 3/4" Plastic Ball Valve | 57 | $1.39 | $79.23 |
| N1 Nipple (3/4" hose x pipe thrd) | 57 | $1.22 | $69.54 |
| 3/4" Schedule 40 IPS PVC pipe [ft] | 680 | $0.35 | $238.00 |
| Total Material Costs | | | $7,390.42 |

# DISCUSSION

This design was based off the assumption that there is consistently at least 80 psi pressure at the filter station from the Cal Poly Irrigation Line connection. It also assumes that sufficient flow can always be provided from this source to run the entire grove at once. These assumptions are based on the fact that the filters are fed by a four inch line from the Cal Poly irrigation system. Since a four inch pipe can easily deliver far more than this grove should require, this is a reasonable assumption. Additionally, the well pump controlled by a pressure transducer should always ensure that a pressure of at least 80 psi is maintained.

Pressure compensating emitters were definitely required for the trees in Block 2 since there is significant elevation change along the tree rows. However, most of the other blocks had the trees planted along the contour of the hill. Therefore, it may have been possible to use non-pressure compensating emitters for these. Instead pressure regulators could have been used at the head of each hose. Yet, since the hoses and emitters could be recycled from the existing system, there is no advantage in buying new non-pressure compensating emitters. Thus, the entire system was designed for pressure compensating emitters.

# RECOMMENDATIONS

## Implementation

If this system is to be installed, it is recommended that the installation take place during the winter season. During the winter, the ET for avocados drops significantly and precipitation provides extra water for them. Ideally, there would be no irrigation requirements from the grove during the entire installation process since the system would have to be off-line. Installation should not take more than a few weeks, so if done after a rain event, there should be no need for irrigation over that time. When installing the system, workers should begin at the bottom of the field with the main line and work their way up. The main line and the manifold line for Block 2 could be placed in the same ditch up the field to save on trenching cost. Diagrams of the system and drawings of the more complex parts of the system are found in Appendix C.

## Maintenance

Once the system is installed, very little maintenance should be required for the buried pipelines. The PVC will not corrode nor will it become brittle if it is buried. It is recommended that markers or flags be posted next to the various block valves to prevent people from hitting or tripping over them. Additionally, basic PVC fittings should be stored in case something breaks.

The flush outs at the ends of the main line and each manifold should be opened regularly to clear any debris or silt that may have settled out in the pipe. Additionally, each hose end should also regularly be opened to flush out anything from the hoses.

In order to maintain the high distribution uniformity that the system was designed for, the sprinklers should be checked for plugging at the beginning of each run. This may take more time but will ensure that each tree always receives the water it requires. Additionally, micro sprinklers should be tested at random to ensure that they are emitting 9 gph. This can be done with a simple stop watch and bucket. If the sprinkler is not performing properly, it should be replaced and discarded. It is recommended that several new micro sprinklers are kept on hand as replacements. This will ensure that the proper micro sprinklers are used to replace broken ones.

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# APPENDIX A

## HOW PROJECT MEETS REQUIREMENTS FOR THE BRAE MAJOR

# HOW PROJECT MEETS REQUIREMENTS FOR BRAE MAJOR

Major Design Experience

The BRAE senior project must incorporate a major design experience. Design is the process of devising a system, component, or process to meet specific needs. The design process typically includes fundamental elements listed. Below, it is explained how this project addresses each of these design elements.

Establishment of Objectives and Criteria. The project objectives and criteria are established in order to meet the irrigation needs of a specific grove of avocado trees on the Cal Poly Campus. This requires special consideration as the grove is on a relatively steep hillside.

Synthesis and Analysis. This project incorporates fluid hydraulics calculations, energy conversions, and economic analysis for the system.

Construction, Testing, and Evaluation. This project is strictly a design project with no construction or testing aspects.

Incorporation of Applicable Engineering Standards. The project adhered to various ASABE design standards for a micro sprinkler system, along with standard pipe sizing and air vent placement procedures.

Capstone Design Experience

This project utilized different skills and lessons from the following courses:

| | |
|---|---|
| • BRAE 151 | AutoCAD |
| • BRAE 152 | SolidWorks |
| • BRAE 236 | Introduction to Irrigation |
| • BRAE 312 | Water Hydraulics |
| • BRAE 331 | Irrigation Theory |
| • BRAE 414 | Irrigation Design |
| • SS 121 | Introduction to Soils |
| • ENGL 149 | Technical Writing |

Design Parameters and Constraints

Physical. The size of the field (about 10 acres), along with the location of drive roads and the arrangement of the trees was one major limitation on the design. Additionally, the pressure at the filter station is a constraint since that is dependent upon the Cal Poly system, rather than the Radio Hill irrigation system. The sprinklers and the hoses were also pre-determined since they would be reused from the current system. Hillside slopes and topography were also strict parameters.

Economic. There were no strict economic constraints for this project. However, the pipes were sized to be the smallest possible while maintaining the required minimum pressure loss for distribution uniformity, since smaller pipes are cheaper.

Environmental. By improving the distribution uniformity, the irrigation efficiency can be made higher. This will save more water and could reduce groundwater pumping. This would help to maintain the groundwater aquifer which would have environmental benefits.

Sustainability. This irrigation system is designed to operate for a long life with minimum wear. Sprinklers and hoses will need to be replaced periodically but the buried PVC will not corrode or wear.

Manufacturability. This does not apply it is a specific situation and required a special design.

Health and Safety. At the flush out locations, signs should be posted indicating that the water should not be used to drink.

Ethical. There were no ethical concerns for this project.

Social. There were no social issues related to this project.

Political. This project has the potential to conserve water. Water conservation is often a major political concern in California, especially during drought years.

Aesthetic. All the pipes will be buried except for the manifold valves and the hose headings. This will create a uniform and organized look to the grove.

Distribution Uniformity. The distribution uniformity should be at least 0.95.

# APPENDIX B

# DESIGN CALCULATIONS

# Distribution Uniformity

## DU Parameters:

The target Distibution Uniformity for this design is:
DU = 0.93

Emitter Q = 0.15
Sprinkler CV = 0.025
Micro Sprinkler Analysis:

Using 9 GPH micro sprinklers
From the TORO Micro Sprinkler PC Catalog, the specifications below were found:

| Model | Nozzle Color | Pressure | Flow Rate | Diameter |
|---|---|---|---|---|
| MS7PC9 | Black | 20 | 9.0 | 15.7 |
| | | 30 | 9.8 | 19.7 |
| | | 40 | 9.2 | 19 |
| | | 50 | 9.5 | 18.4 |
| | | 60 | 9.8 | 19.7 |

As can be seen from the data above, even though the sprinklers are pressure compensating, they still deliver slightly different flow rates under differing pressures.

Therefore, the K value for the sprinklers must be determined.
Because the micro sprinklers are pressure compensating, the x value in the equation must also be determined.
Q = K*P^x

Because the sprinklers are pressure compensating, the P^x value would theoretically be reduced to zero.
Therefore, the K value should be equal to the flow rate the sprinkler is rated for.

Thus, for these spinklers,
K = 9

With K known, you can rewrite the formula to solve for x:
(Q/K) = P^x
ln(Q/K) = ln(P^x)
ln(Q/K) = x * ln(P)
x = ( ln(Q/K) ) / ( ln(P) )

Now solve for x at each of the pressure points from the table above.

| Pressure | Flow Rate | Diameter | Assumed K | x |
|---|---|---|---|---|
| 20 | 9 | 15.7 | 9.0 | 0.000 |
| 30 | 9.8 | 19.7 | 9.0 | 0.025 |
| 40 | 9.2 | 19 | 9.0 | 0.006 |
| 50 | 9.5 | 18.4 | 9.0 | 0.014 |
| 60 | 9.8 | 19.7 | 9.0 | 0.021 |

Because there is a significant amount of variation in the x values at different pressures, using an average x for calculating individual emitter flow rates would be inaccurate. Rather, I will linearly interpolate between the table values to better assess the emitter flow rates for the different emitter pressures.

In order to maintain a DU.lq of 0.93, the majority of the emitters must have a pressure between 30 psi and 60 psi.

## Final DU Evaluation Between Hoses

Overall Average P = 44.3 psi
Overall Average Q = 9.3 gph

Low Quarter Average P = 38.9 psi
Low Quarter Average Q = 9.27 gph

DU = 0.99

Assumed Emitter DU = 0.97

Final System DU = 0.96

# Manifold Calculations

## Manifold 1:

Hazen-Williams Roughness Factor = 146

| Segment between Row # | Trees in Row | Flow down Row [GPM] | Segment Flow [GPM] | Pipe ID [in] | Segment Length [ft] | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] |
|---|---|---|---|---|---|---|---|---|
| 2-3 | 20 | 3 | 3 | 0.824 | 25 | 0.51 | 0 | 0.51 |
| 1-2 | 18 | 2.7 | 5.7 | 0.824 | 25 | 1.66 | 1 | 2.66 |
| Valve-1 | 10 | 1.5 | 7.2 | 0.824 | 75 | 7.68 | 2 | 9.68 |

Total Pressure Loss = 12.84 ft

| Row # | Pressure Loss [ft] | Pressure at Row Riser [ft] | Pressure at Row Riser [psi] | |
|---|---|---|---|---|
| 3 | 0.51 | 102.66 | 44.4 | |
| 2 | 2.66 | 103.17 | 44.7 | |
| 1 | 9.68 | 105.82 | 45.8 | |
| Pressure at Manifold Valve = | | 115.50 | 50.0 | PR |
| | | Average P | 45.0 | |

## Manifold 2 downhill: if fed from the bottom:

Hazen-Williams Roughness Factor = 146

| Segment between Row # | Trees in Row | Flow down Row [GPM] | Segment Flow [GPM] | Pipe ID [in] | Segment Length [ft] | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] |
|---|---|---|---|---|---|---|---|---|
| 28-29 | 10 | 1.5 | 1.5 | 1.049 | 25 | 0.04 | 1 | 1.04 |
| 27-28 | 12 | 1.8 | 3.3 | 1.049 | 25 | 0.19 | -1 | -0.81 |
| 26-27 | 14 | 2.1 | 5.4 | 1.049 | 25 | 0.46 | 1 | 1.46 |
| 25-26 | 14 | 2.1 | 7.5 | 1.049 | 25 | 0.85 | 0 | 0.85 |
| 24-25 | 15 | 2.25 | 9.75 | 1.049 | 25 | 1.38 | 0 | 1.38 |
| 23-24 | 17 | 2.55 | 12.3 | 1.049 | 25 | 2.13 | 0 | 2.13 |
| 22-23 | 18 | 2.7 | 15 | 1.049 | 25 | 3.07 | 0 | 3.07 |
| 21-22 | 18 | 2.7 | 17.7 | 1.61 | 25 | 0.52 | 1 | 1.52 |
| 20-21 | 20 | 3 | 20.7 | 1.61 | 25 | 0.69 | 2 | 2.69 |
| 19-20 | 22 | 3.3 | 24 | 1.61 | 25 | 0.91 | 1 | 1.91 |
| 18-19 | 24 | 3.6 | 27.6 | 1.61 | 25 | 1.18 | 1 | 2.18 |
| 17-18 | 24 | 3.6 | 31.2 | 1.61 | 25 | 1.48 | 3 | 4.48 |
| 16-17 | 26 | 3.9 | 35.1 | 2.067 | 25 | 0.55 | 3 | 3.55 |
| 15-16 | 28 | 4.2 | 39.3 | 2.067 | 25 | 0.67 | 2 | 2.67 |
| 14-15 | 28 | 4.2 | 43.5 | 2.067 | 25 | 0.81 | 2 | 2.81 |
| 13-14 | 26 | 3.9 | 47.4 | 2.067 | 25 | 0.95 | 3 | 3.95 |
| 12-13 | 24 | 3.6 | 51 | 2.067 | 25 | 1.09 | 3 | 4.09 |
| 11-12 | 22 | 3.3 | 54.3 | 2.067 | 25 | 1.22 | 2 | 3.22 |
| 10-11 | 22 | 3.3 | 57.6 | 2.067 | 25 | 1.37 | 2 | 3.37 |
| 9-10 | 21 | 3.15 | 60.75 | 2.067 | 25 | 1.51 | 2 | 3.51 |
| 8-9 | 21 | 3.15 | 63.9 | 2.067 | 25 | 1.66 | 2 | 3.66 |
| 7-8 | 20 | 3 | 66.9 | 2.067 | 25 | 1.80 | 2 | 3.80 |
| 6-7 | 20 | 3 | 69.9 | 2.067 | 25 | 1.95 | 2 | 3.95 |
| 5-6 | 18 | 2.7 | 72.6 | 2.067 | 25 | 2.10 | 2 | 4.10 |
| 4-5 | 18 | 2.7 | 75.3 | 2.067 | 25 | 2.24 | 2 | 4.24 |
| 3-4 | 17 | 2.55 | 77.85 | 2.067 | 25 | 2.39 | 2 | 4.39 |
| 2-3 | 16 | 2.4 | 80.25 | 2.067 | 25 | 2.52 | 4 | 6.52 |
| 1-2 | 16 | 2.4 | 82.65 | 2.067 | 25 | 2.67 | 2 | 4.67 |
| Valve-1 | 15 | 2.25 | 84.9 | 2.067 | 25 | 2.80 | 2 | 4.80 |

Total Pressure Loss = 89.21 ft

| Row # | Pressure Loss [ft] | Pressure at Row Riser [ft] | Pressure at Row Riser [psi] | |
|---|---|---|---|---|
| 29 | 1.04 | 87.90 | 38.1 | |
| 28 | -0.81 | 88.95 | [illegible] | |
| 27 | 1.46 | 88.13 | [illegible] | |
| 26 | 0.85 | 89.60 | 38.8 | |
| 25 | 1.38 | 90.45 | 39.2 | |
| 24 | 2.13 | 91.83 | 39.8 | |
| 23 | 3.07 | 93.96 | 40.7 | |
| 22 | 1.52 | 97.04 | 42.0 | |
| 21 | 2.69 | 98.55 | 42.7 | |
| 20 | 1.91 | 101.25 | 43.8 | |
| 19 | 2.18 | 103.16 | 44.7 | |
| 18 | 4.48 | 105.34 | 45.6 | |
| 17 | 3.55 | 109.82 | 47.5 | |
| 16 | 2.67 | 113.37 | 49.1 | |
| 15 | 2.81 | 116.04 | 50.2 | |
| 14 | 3.95 | 118.85 | 51.5 | |
| 13 | 4.09 | 122.80 | 53.2 | |
| 12 | 3.22 | 126.89 | 54.9 | |
| 11 | 3.37 | 130.12 | 50.0 | PR |
| 10 | 3.51 | 133.48 | 50.0 | PR |
| 9 | 3.66 | 136.99 | 50.0 | PR |
| 8 | 3.80 | 140.64 | 50.0 | PR |
| 7 | 3.95 | 144.45 | 50.0 | PR |
| 6 | 4.10 | 148.40 | 50.0 | PR |
| 5 | 4.24 | 152.50 | 50.0 | PR |
| 4 | 4.39 | 156.74 | 50.0 | PR |
| 3 | 6.52 | 161.13 | 50.0 | PR |
| 2 | 4.67 | 167.65 | 50.0 | PR |
| 1 | 4.80 | 172.32 | 50.0 | PR |
| Pressure at Manifold Valve = | | 177.12 | 76.7 | |
| | | Average P | 46.5 | |

## Manifold 3: if fed from the bottom:

Hazen-Williams Roughness Factor = 146

| Segment between Row # | Trees in Row | Flow down Row [GPM] | Segment Flow [GPM] | Pipe ID [in] | Segment Length [ft] | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] | |
|---|---|---|---|---|---|---|---|---|---|
| 11-12 | 2 | 0.3 | 0.3 | 0.824 | 25 | 0.01 | 3 | 3.01 | Uphill |
| 10-11 | 3 | 0.45 | 0.75 | 0.824 | 25 | 0.04 | 2 | 2.04 | Uphill |
| 9-10 | 5 | 0.75 | 1.5 | 0.824 | 25 | 0.14 | 2 | 2.14 | Uphill |
| 8-9 | 8 | 1.2 | 2.7 | 0.824 | 25 | 0.42 | 3 | 3.42 | Uphill |
| 7-8 | 14 | 2.1 | 4.8 | 0.824 | 25 | 1.21 | 2 | 3.21 | Uphill |
| 6-7 | 14 | 2.1 | 6.9 | 0.824 | 25 | 2.36 | 2 | 4.36 | Uphill |
| 5-6 | 14 | 2.1 | 9 | 0.824 | 25 | 3.87 | 3 | 6.87 | Uphill |
| 4-5 | 14 | 2.1 | 11.1 | 0.824 | 25 | 5.70 | 2 | 7.70 | Uphill |
| 3-4 | 14 | 2.1 | 13.2 | 0.824 | 25 | 7.86 | 3 | 10.86 | Uphill |
| Valve-3 | 14 | 2.1 | 15.3 | 0.824 | 0 | 0.00 | 0 | 0.00 | Uphill |
| Valve-2 | 8 | 1.2 | 2.1 | 0.824 | 50 | 0.52 | -3 | -2.48 | Downhill |
| 2-1 | 6 | 0.9 | 0.9 | 0.824 | 25 | 0.05 | -4 | -3.95 | Downhill |
| | | | | | | Max Pressure Loss = | | 43.61 | ft |

| Row # | Pressure Loss [ft] | Pressure at Row Riser [ft] | Pressure at Row Riser [psi] | |
|---|---|---|---|---|
| 12 | 3.01 | 118.98 | 51.5 | |
| 11 | 2.04 | 121.98 | 52.8 | |
| 10 | 2.14 | 124.02 | 53.7 | |
| 9 | 3.42 | 126.16 | 54.6 | |
| 8 | 3.21 | 129.58 | 56.1 | |
| 7 | 4.36 | 132.78 | 57.5 | |
| 6 | 6.87 | 137.15 | 50.0 | PR |
| 5 | 7.70 | 144.02 | 50.0 | PR |
| 4 | 10.86 | 151.72 | 50.0 | PR |
| 3 | 0.00 | 162.58 | 50.0 | PR |
| 2 | -2.48 | 165.06 | 50.0 | PR |
| 1 | -3.95 | 169.00 | 50.0 | PR |
| Pressure at Manifold Valve = | | 162.58 | 70.4 | |
| | | Average P | 52.2 | |

## Manifold 4: if fed from the bottom & middle:

Hazen-Williams Roughness Factor = 146

| Segment between Row # | Trees in Row | Flow down Row [GPM] | Segment Flow [GPM] | Pipe ID [in] | Segment Length [ft] | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] | |
|---|---|---|---|---|---|---|---|---|---|
| 4-5 | 52 | 7.8 | 7.8 | 1.61 | 30 | 0.14 | 6 | 6.14 | Uphill |
| 3-4 | 54 | 8.1 | 15.9 | 1.61 | 30 | 0.51 | 8 | 8.51 | Uphill |
| Valve-3 | 54 | 8.1 | 24 | 1.61 | 15 | 0.55 | 6 | 6.55 | Uphill |
| Valve-2 | 20 | 3 | 7.5 | 0.824 | 15 | 1.66 | -4 | -2.34 | Downhill |
| 2-1 | 30 | 4.5 | 4.5 | 0.824 | 30 | 1.29 | -4 | -2.71 | Downhill |
| | | | | | | Max Pressure Loss= | | 21.19 | ft |

| Row # | Pressure Loss [ft] | Pressure at Row Riser | Pressure at Row Riser [psi] |
|---|---|---|---|
| 5 | 6.14 | 79.77 | 34.5 |
| 4 | 8.51 | 85.90 | [illegible] |
| 3 | 6.55 | 94.41 | 40.9 |
| 2 | -2.34 | 103.30 | 44.7 |
| 1 | -2.71 | 106.02 | 45.9 |
| Pressure at Manifold Valve = | | 100.96 | 43.7 |
| | | Average P | 40.6 |

## Manifold 5: if fed from the top & north:

Hazen-Williams Roughness Factor = 146

| Segment between Row # | Trees in Row | Flow down Row [GPM] | Segment Flow [GPM] | Pipe ID [in] | Segment Length [ft] | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] |
|---|---|---|---|---|---|---|---|---|
| 5-6 | 35 | 5.25 | 5.25 | 1.049 | 25 | 0.44 | -4 | -3.56 |
| 4-5 | 34 | 5.1 | 10.35 | 1.049 | 25 | 1.55 | -3 | -1.45 |
| 3-4 | 32 | 4.8 | 15.15 | 1.049 | 25 | 3.13 | -3 | 0.13 |
| 2-3 | 28 | 4.2 | 19.35 | 1.049 | 25 | 4.93 | -4 | 0.93 |
| 1-2 | 26 | 3.9 | 23.25 | 1.049 | 25 | 6.92 | -3 | 3.92 |
| Valve-1 | 23 | 3.45 | 26.7 | 1.049 | 25 | 8.94 | -5 | 3.94 |
| | | | | | | Total Pressure Loss = | | 3.91 |

| Row # | Pressure Loss [ft] | Pressure at Row Riser [ft] | Pressure at Row Riser [psi] |
|---|---|---|---|
| 6 | -3.56 | 97.05 | 42.0 |
| 5 | -1.45 | 93.49 | 40.[illegible] |
| 4 | 0.13 | 92.04 | 39.[illegible] |
| 3 | 0.93 | 92.17 | [illegible] |
| 2 | 3.92 | 93.09 | [illegible] |
| 1 | 3.94 | 97.02 | 42.0 |
| Pressure at Manifold Valve = | | 100.96 | 43.7 |
| | | Average P | 40.8 |

## Manifold 6

Hazen-Williams Roughness Factor = 146

| Segment between Row # | Trees in Row | Flow down Row [GPM] | Segment Flow [GPM] | Pipe ID [in] | Segment Length [ft] | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] |
|---|---|---|---|---|---|---|---|---|
| 5-6 | 12 | 1.8 | 1.8 | 1.049 | 30 | 0.07 | -4 | -3.93 |
| 4-5 | 15 | 2.25 | 4.05 | 1.049 | 30 | 0.33 | -6 | -5.67 |
| 3-4 | 22 | 3.3 | 7.35 | 1.049 | 30 | 0.98 | -4 | -3.02 |
| 2-3 | 28 | 4.2 | 11.55 | 1.049 | 30 | 2.27 | -4 | -1.73 |
| 1-2 | 32 | 4.8 | 16.35 | 1.049 | 100 | 14.42 | -10 | 4.42 |
| Valve-1 | 20 | 3 | 19.35 | 1.049 | 30 | 5.91 | -4 | 1.91 |
| | | | | | | Total Pressure Loss = | | -8.01 |

| Row # | Pressure Loss [ft] | Pressure at Row Riser [ft] | Pressure at Row Riser [psi] |
|---|---|---|---|
| 6 | -3.93 | 102.99 | 44.6 |
| 5 | -5.67 | 99.06 | 42.9 |
| 4 | -3.02 | 93.38 | 40.4 |
| 3 | -1.73 | 90.37 | 39.[illegible] |
| 2 | 4.42 | 88.64 | [illegible] |
| 1 | 1.91 | 93.07 | 40.3 |
| Pressure at Manifold Valve = | | 94.98 | 41.1 |
| | | Average P | 40.9 |

# Main Line Calculations

## Main Line

| Manifold # | Flow down Manifold [GPM] | Segment Flow [GPM] | U/S Segment Length [ft] | Pipe ID [in] | Hazen-Williams Factor | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] | Pressure at Manifold Valve |
|---|---|---|---|---|---|---|---|---|---|
| 6 | 19.35 | 19.35 | 650 | 2.469 | 146 | 1.98 | 4 | 5.98 | 94.98 |
| 5 | 27 | 46.05 | 0 | 2.469 | 146 | 0.00 | 0 | 0.00 | 100.96 |
| 4 | 31.5 | 77.55 | 300 | 2.469 | 146 | 11.96 | 6 | 17.96 | 100.96 |
| bend | 0 | 77.55 | 450 | 4.026 | 146 | 1.66 | 42 | 43.66 | 118.92 |
| 3 | 17.4 | 94.95 | 100 | 4.026 | 146 | 0.54 | 14 | 14.54 | 162.58 |
| 2 | 84.9 | 179.85 | 0 | 4.026 | 146 | 0.00 | 0 | 0.00 | 177.12 |
| 1 | 7.2 | 187.05 | 100 | 4.026 | 146 | 1.88 | 6 | 7.88 | 177.12 |
| Filters | 0 | 187.05 | 0 | 4.026 | 146 | 0.00 | 0 | 0.00 | 185 |
|  |  | 187.05 | 187 |  |  |  |  |  |  |

For the Pressure at Manifold Valve column, I am assuming 80 psi pressure at the filters.
80 psi * 2.32 ft/psi = 185 ft

# Critical Path Calculations

## Northern Hose Analysis for Block 4 Top Riser

| Section | Segment GPM | Friction Loss [ft] | Elevation Change [ft] | Pressure Loss [ft] | Point Pressure [ft] |  |
|---|---|---|---|---|---|---|
| 30 | 0.15 | 0.002 | -0.75 | -0.748 | 75.2 |  |
| 29 | 0.3 | 0.008 | -0.75 | -0.742 | 74.4 |  |
| 28 | 0.45 | 0.016 | -0.75 | -0.734 | 73.7 |  |
| 27 | 0.6 | 0.027 | -0.75 | -0.723 | 72.9 |  |
| 26 | 0.75 | 0.041 | -0.75 | -0.709 | 72.2 |  |
| 25 | 0.9 | 0.058 | -0.75 | -0.692 | 71.5 |  |
| 24 | 1.05 | 0.077 | -0.75 | -0.673 | 70.8 |  |
| 23 | 1.2 | 0.099 | -0.75 | -0.651 | 70.1 |  |
| 22 | 1.35 | 0.123 | -0.75 | -0.627 | 69.5 |  |
| 21 | 1.5 | 0.149 | -0.75 | -0.601 | 68.9 |  |
| 20 | 1.65 | 0.178 | -0.75 | -0.572 | 68.3 |  |
| 19 | 1.8 | 0.209 | -0.75 | -0.541 | 67.7 |  |
| 18 | 1.95 | 0.243 | -0.75 | -0.507 | 67.2 |  |
| 17 | 2.1 | 0.279 | -0.75 | -0.471 | 66.6 |  |
| 16 | 2.25 | 0.317 | -0.75 | -0.433 | 66.2 |  |
| 15 | 2.4 | 0.357 | -0.75 | -0.393 | 65.7 |  |
| 14 | 2.55 | 0.399 | 0 | 0.399 | 65.3 | end of critical path |
| 13 | 2.7 | 0.444 | 0 | 0.444 | 65.7 |  |
| 12 | 2.85 | 0.490 | 0 | 0.490 | 66.2 |  |
| 11 | 3 | 0.539 | 0 | 0.539 | 66.7 |  |
| 10 | 3.15 | 0.590 | 0 | 0.590 | 67.2 |  |
| 9 | 3.3 | 0.643 | 0 | 0.643 | 67.8 |  |
| 8 | 3.45 | 0.699 | 0.5 | 1.199 | 68.5 |  |
| 7 | 3.6 | 0.756 | 0.5 | 1.256 | 69.7 |  |
| 6 | 3.75 | 0.815 | 0.5 | 1.315 | 70.9 |  |
| 5 | 3.9 | 0.877 | 0.5 | 1.377 | 72.2 |  |
| 4 | 4.05 | 0.940 | 0.5 | 1.440 | 73.6 |  |
| 3 | 4.2 | 1.006 | 0.5 | 1.506 | 75.0 |  |
| 2 | 4.35 | 1.073 | 0.5 | 1.573 | 76.5 |  |
| 1 | 4.5 | 1.143 | 0.5 | 1.643 | 78.1 |  |
| Total Friction Loss through hose = |  | 3.517 |  |  | 79.77 |  |

Southern Hose Analysis for Block 4 Top Riser

| Section | Segment GPM | Friction Loss | Elevation Change | Pressure Loss | Point Pressure |
|---|---|---|---|---|---|
| 25 | 0.15 | 0.002 | -1.5 | -1.498 | 88.7 |
| 24 | 0.3 | 0.008 | -1.5 | -1.492 | 87.2 |
| 23 | 0.45 | 0.016 | -1.5 | -1.484 | 85.7 |
| 22 | 0.6 | 0.027 | -1.5 | -1.473 | 84.2 |
| 21 | 0.75 | 0.041 | -1.5 | -1.459 | 82.8 |
| 20 | 0.9 | 0.058 | -1.5 | -1.442 | 81.3 |
| 19 | 1.05 | 0.077 | -1.5 | -1.423 | 79.9 |
| 18 | 1.2 | 0.099 | -0.75 | -0.651 | 78.4 |
| 17 | 1.35 | 0.123 | -0.75 | -0.627 | 77.8 |
| 16 | 1.5 | 0.149 | -0.75 | -0.601 | 77.2 |
| 15 | 1.65 | 0.178 | -0.75 | -0.572 | 76.6 |
| 14 | 1.8 | 0.209 | -0.75 | -0.541 | 76.0 |
| 13 | 1.95 | 0.243 | -0.75 | -0.507 | 75.4 |
| 12 | 2.1 | 0.279 | -0.75 | -0.471 | 74.9 |
| 11 | 2.25 | 0.317 | -0.75 | -0.433 | 74.5 |
| 10 | 2.4 | 0.357 | 0 | 0.357 | 74.0 |
| 9 | 2.55 | 0.399 | 0 | 0.399 | 74.4 |
| 8 | 2.7 | 0.444 | 0 | 0.444 | 74.8 |
| 7 | 2.85 | 0.490 | 0 | 0.490 | 75.2 |
| 6 | 3 | 0.539 | 0 | 0.539 | 75.7 |
| 5 | 3.15 | 0.590 | 0 | 0.590 | 76.3 |
| 4 | 3.3 | 0.643 | 0 | 0.643 | 76.9 |
| 3 | 3.45 | 0.699 | 0 | 0.699 | 77.5 |
| 2 | 3.6 | 0.756 | 0 | 0.756 | 78.2 |
| 1 | 3.75 | 0.815 | 0 | 0.815 | 79.0 |
| Total Friction Loss through |  | 1.510 |  |  | 79.77 |

## Various Minor Losses:

| Minor Loss | K Value | Flow [GPM] | Pipe ID [in] | Velocity [fps] | Hf.minor [ft] |
|---|---|---|---|---|---|
| Tee w/ 1 line flow | 0.9 | 179.85 | 4.026 | 0.03 | 1.39E-05 |
| Tee w/ 2 line flow | 0.9 | 94.95 | 4.026 | 0.02 | 3.86E-06 |
| Tee w/ 3 line flow | 0.9 | 77.55 | 4.026 | 0.01 | 2.58E-06 |
| 4-2.5 Contraction | 0.3 | 77.55 | 2.469 | 0.04 | 6.07E-06 |
| Elbow mid 2 | 0.9 | 77.55 | 2.469 | 0.04 | 1.82E-05 |
| Elbow mid 2 | 0.9 | 77.55 | 2.469 | 0.04 | 1.82E-05 |
| Elbow top 2 | 0.9 | 77.55 | 2.469 | 0.04 | 1.82E-05 |
| Elbow top 2 | 0.9 | 77.55 | 2.469 | 0.04 | 1.82E-05 |
| Elbow mid 4 | 0.9 | 77.55 | 2.469 | 0.04 | 1.82E-05 |
| Elbow mid 4 | 0.9 | 77.55 | 2.469 | 0.04 | 1.82E-05 |
| Tee w/ 4 & 5 branch flow | 1.3 | 58.2 | 2.469 | 0.03 | 1.48E-05 |
| 2.5-2 Contraction | 0.2 | 58.2 | 2.067 | 0.04 | 4.64E-06 |
| Tee b/tn 4 & 5 branch flow | 1.3 | 26.7 | 2.067 | 0.02 | 6.35E-06 |
| Valve to 4 | 0.2 | 26.7 | 2.067 | 0.02 | 9.77E-07 |
| Elbow down | 0.9 | 26.7 | 2.067 | 0.02 | 4.39E-06 |
| Elbow across road | 0.9 | 26.7 | 2.067 | 0.02 | 4.39E-06 |
| Elbow horizontal | 0.9 | 26.7 | 2.067 | 0.02 | 4.39E-06 |
| Elbow up hill | 0.9 | 26.7 | 2.067 | 0.02 | 4.39E-06 |
| Tee line flow | 0.9 | 24 | 2.067 | 0.02 | 3.55E-06 |
| Tee line flow | 0.9 | 15.9 | 2.067 | 0.01 | 1.56E-06 |
| Tee line flow | 0.9 | 7.8 | 2.067 | 0.005 | 3.75E-07 |
| Elbow | 0.9 | 7.8 | 2.067 | 0.005 | 3.75E-07 |
|  |  |  | Total Minor Losses = |  | 0.0002 |

The minor losses are so small that they are essentially zero or insignificant.

## Pressure Loss Due to Spaghetti Hose

Assume that there is a 4 ft spaghetti hose connecting the sprinkler to the hose.

Assumed Pressure loss = 2 ft

## Minimum Calculated Pressure

Min Pressure = Pressure at end of critical path - minor losses - spaghetti hose losses

Min Pressure [ft] = 63.3 ft

Convert to psi by dividing by 2.31

Min Pressure [psi] = 27.4 psi

## Minimum Required Pressure

Minimum Pressure for the sprinklers to operate properly according to manufacturer

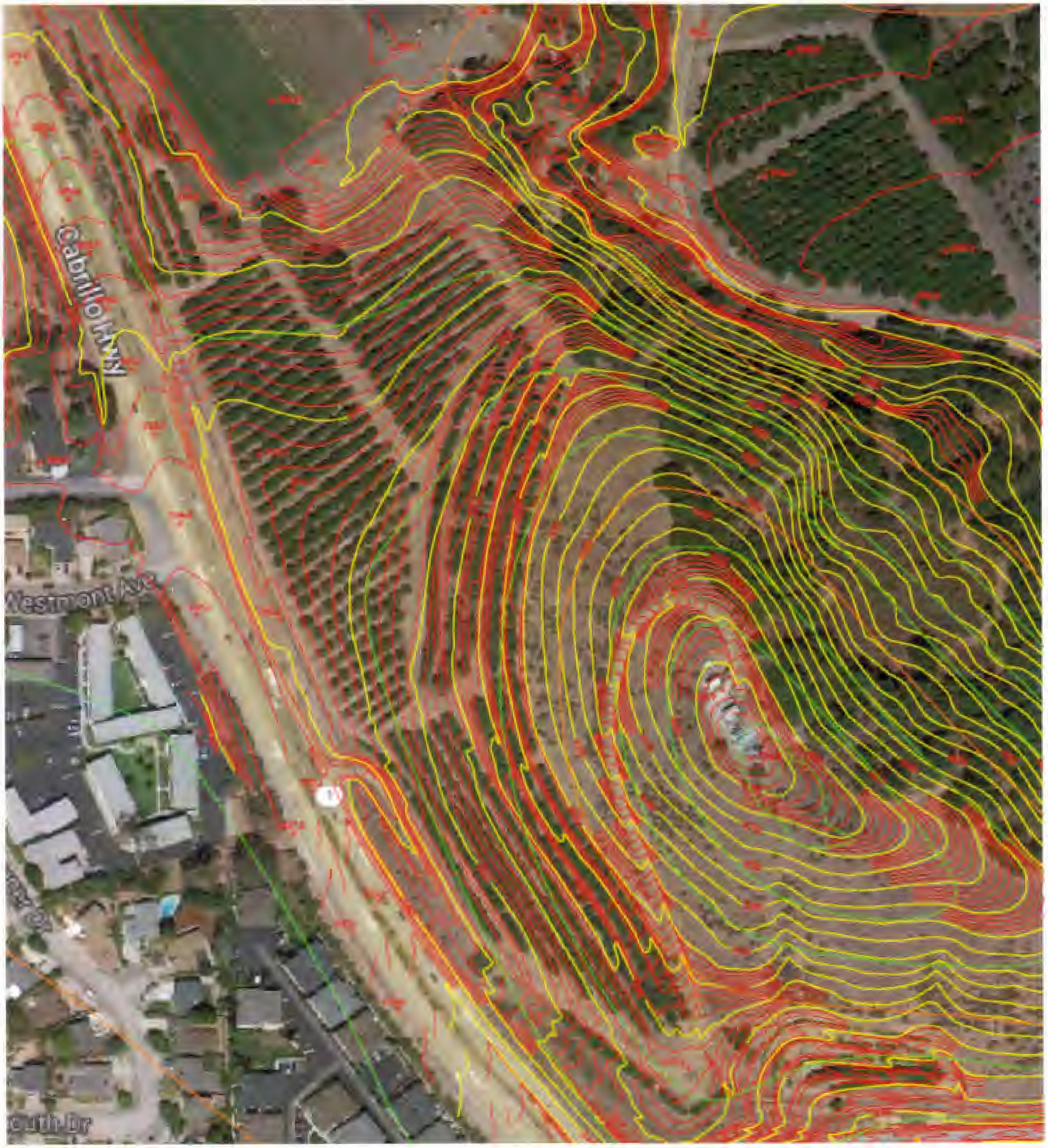
Min Required Pressure = 20 psi

Safety Buffer = 7.4 psi

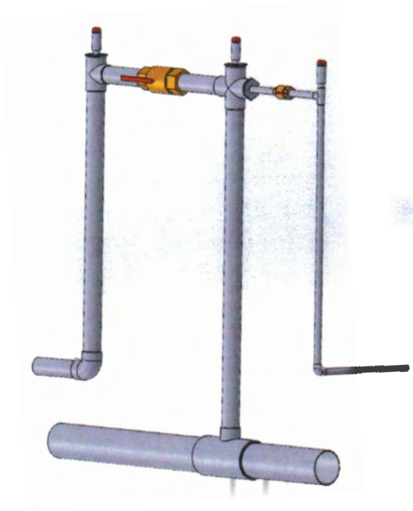
# APPENDIX C

## Field and System Design Maps

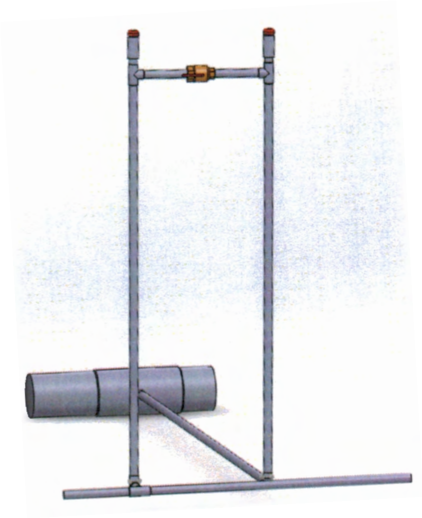
## Topographical Map of the Field



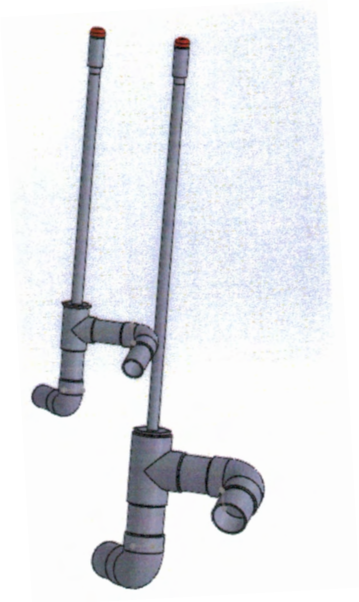
## Block 1&2 Diagram



## Block 3 Valve Diagram



## Triple Elbow Bend



## Overall System Design Drawing