MICRO-IRRIGATION DESIGN FOR AVOCADO ORCHARD IN CALIFORNIA

by

Michael Meyer

Agricultural Systems Management

BioResource and Agricultural Engineering Department

California Polytechnic State University

San Luis Obispo, CA

2014

TITLE : Micro-Irrigation Design for Avocado Orchard in California

AUTHOR : Michael Meyer

DATE SUBMITTED : May 30, 2014

Franklin P. Gaudi Senior Project Advisor	Signature
	Date
Dr. Art MacCarley Department Head	Signature
	Date

ACKNOWLEDGEMENTS

First, I would like to express my appreciation to the grower, Craig Underwood, for providing me with the project parameters, necessary information and great patience as I completed this report.

Second, I would like to thank my advisor, Franklin P. Gaudi, who offered extensive guidance and practical advice throughout the lengthy process of this design and report.

Third, I am particularly grateful for the assistance and product information given by Brian Meyer and Coast Water Solutions out of Oxnard, California.

Fourth, I would like to thank the following groups and companies for their assistance with the collection of my data:

- Mission Produce, Inc.
- Netafim Irrigation, Inc.
- California Avocado Commission
- California Irrigation Management Information System
- Cal Poly Irrigation Training and Research Center

Fifth and most importantly, I would like to express my full gratitude to my parents for believing in me while providing courage and support through my educational career.

ABSTRACT

This project encompasses the design and recommendations for a micro-irrigation system on an avocado orchard owned by Underwood Family Farms in Somis, California. The main objective of this report is to improve the existing irrigation system's efficiency and uniformity with the new design and recommendations. The analysis includes information about good irrigation practices, irrigation system design and all the processes herein. Although there are many opinions on growing, irrigating and maintaining an avocado orchard, all of the methods, procedures and suggestions must be based on accurate data to provide reliable information to the grower. Evaluating the irrigation system and suggesting improvements will require proper steps and full understanding of irrigation systems, avocados, and soil and water requirements. This report will provide essential information for successfully growing avocados in Ventura County, as well as detailed advice for micro-irrigation systems on avocados.

DISCLAIMER STATEMENT

The university makes it clear that the information forwarded herewith is a project resulting from a class assignment and has been graded and accepted only as a fulfillment of a course requirement. Acceptance by the university does not imply technical accuracy or reliability. Any use of the information in this report is made by the user(s) at his/her own risk, which may include catastrophic failure of the device or infringement of patent or copyright laws.

Therefore, the recipient and/or user of the information contained in this report agrees to indemnify, defend and save harmless the Sate, its officers, agents, and employees from any and all claims and losses accruing or resulting to any person, firm, or corporation who may be injured or damaged as a result of the use of this report.

TABLE OF CONTENTS

Page

SIGNATURE PAGE ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv
DISCLAIMER STATEMENT v
LIST OF FIGURES viii
LIST OF TABLES ix
INTRODUCTION 1
  Background 1
  Justification 1
  Objectives 2
LITERATURE REVIEW 3
  Avocado Varieties 3
    Hass 3
    Fuerte 3
    Reed 3
  Irrigation 3
    Common Irrigation Systems for Avocados 4
    Micro-Sprinklers 5
    Types of Micro-Sprinklers 6
  Soil 8
    Soil Requirements 8
    Soil Salinity 9
    Salinity's Effects on Avocado Trees 9
    Salinity Management 9
    Water's Effects on Soil Salinity 9
  Managing Avocado Trees 10
    Managing Avocado Fruit Drop 10
    Fertilizers 10
  Irrigation System Management 11
    Irrigating Avocado Trees 11
    When to Irrigate 11
    Determining How Much Water to Use 11
    Managing Irrigation 12
    Benefits of Irrigation 12
PROCEDURES AND METHODS 14
  Existing Conditions 14
    Field Constraints 14
    Canopy Cover 14
    Water Source and Fertigation 15
    Filtration 16
    System Inspection 16
    Pipelines 17
    Risers 18

Pressure Regulators 18
Lateral Hoses and Emission Devices 18
Energy and Water Use 20
Irrigation System Design 20
Flow Rate Requirements 20
Wetted Area 21
Micro-Sprinkler Selection 21
Flow Rate by Tree Spacing 22
Summary of Selected Equipment 23
AutoCAD Design 23
Design Process 24
Lateral Hose Locations 25
Critical Path 25
Pipe Characteristics 26
Hose Lengths 26
RESULTS 27
Peak Evapotranspiration 27
Required System Flow Rate 27
Irrigation Schedule 27
Selected Micro-Sprinklers 27
Total System Flow Rate 27
Required Inlet Pressure 27
Size and Length of Hose 28
Cost Analysis 28
DISCUSSION 30
Existing Equipment and Constraints 30
Design Considerations and Limitations 30
RECOMMENDATIONS 32
Management 32
Equipment 32
REFERENCES 34
APPENDICES 37
Appendix A: Senior Project Contract 38
Appendix B: Example Design Calculations 41
Appendix C: Pump Information 43
Appendix D: Canopy Cover 46
Appendix E: Manifold Flows and Critical Path Data 50
Appendix F: Irrigation System Design Drawings 55

LIST OF FIGURES

Page

1. Netafim Micro-Sprinkler in Orchard…………………………………………….…..2
2. Example of micro-sprinkler.……………………………………………….…...5
3. Micro-Sprinkler spray patterns.………………………………………….…..6
4. Example of Netafim (SR, SRD) micro-sprinkler.………………………………...7
5. Example of Netafim (LR, LRD) micro-sprinkler.……………………………….…..7
6. Example of Netafim jet micro-sprinkler…………………………………….…8
7. Berkeley centrifugal booster pump……………………………………………16
8. Hydrokleen tubescreen filter…………………………………………………..16
9. Pressure reading downstream of filter…………………………………….....17
10. Example of a 2 GPH drip emitter……………………………………………..19
11. Example of micro-sprinkler in orchard………………………………………..19
12. Aerial view of Underwood avocado orchard………………………………….23
13. Figure eight clamping hose end……………………………………………….24

LIST OF TABLES

Page

1. Net GPH per tree and net total GPM ……………………………………………20
2. Gross GPH per tree required and total GPM required…………………………...21
3. Minimum sprinkler diameter required…………………………………………...21
4. Netafim supernet sprinkler characteristics………………………………………22
5. Total GPM applied and flow/area………………………………………………..22
6. Sprinkler characteristics for each spacing………………………………………..23
7. Pipe characteristics………………………………………………………………26
8. Hose lengths for different spacings………………………………………………26
9. Bill of materials…………………………………………………………………..29

INTRODUCTION

Background

The farming industry in California has been growing at unpredictable measures, which is essential in supporting the ever-increasing population. Many agricultural companies are centralized in California because of its' compatible weather for certain crops that gives farmers the opportunity to achieve an efficient yield and productivity. Farming companies strive to find the most efficient ways to grow their crop in order to generate the most profit and produce the highest yield. All farms try to save as much water as possible, have the best irrigation efficiency and generate the most income as possible. The goal is to provide recommendations and design a micro-irrigation system for avocados that will achieve all of these feats.

The avocado, more formally represented as "Persea Americana", is one of the most delicious and nutritious fruits native to Mexico and Central America. As avocado consumption continues to expand throughout the United States as well as internationally, growers are looking for new ways to increase yields and decrease costs. According to Mission Produce, "California has over 61,000 acres of avocados, which account for about 95% of the U.S. crop" (Shopping the World, 2013). California grown avocados are preferred because of their high quality, year-round growth as a result of coastal microclimates, excellent soil characteristics, and proper maintenance. "Santa Barbara, San Luis Obispo and Ventura Counties have combined to produce over 275 million pounds of avocados per year" (Mission Avocados, 2013). There are about 6,000 avocado growers from San Luis Obispo to the Mexican border producing a combination of over 300 million pounds a year. Despite these high production rates, California alone cannot provide the market with a consistent supply of quality fruit year-round. Fortunately, crop seasons are different in certain areas of the world, so there is adequate overlap of availability throughout the year.

Justification

One of the most important contemporary issues today is how to increase production while decreasing water use and costs. In order for agriculture to continue to feed the world, growers must learn to make existing water supplies stretch as far as possible. More and more growers are switching to micro-irrigation for their tree and row crops because of the potential to increase efficiencies and save water. Micro-irrigation can save water and fertilizer by applying less water exactly where it is needed. In order to maximize yield and profits, growers must perform excellent irrigation practices as well as consistent maintenance of their micro-irrigation system. Some of these practices include proper irrigation design, spacing, sprinkler type, scheduling, fertigation and chemigation. Micro-irrigation with micro-sprinklers is a very common method for irrigating tree crops in California and will be explained in depth throughout this report. Figure 1 on the following page is an image of a Netafim Micro-Sprinkler in an avocado orchard.


Figure 1: Netafim Micro-Sprinkler in Orchard.

Objectives

The objective of this project was to design and recommend an irrigation system that would enable the grower to improve the distribution uniformity in the orchard with given constraints. The grower did not want to spend the time and money to change any of the underground piping system currently in use, nor did he want to change the filter, pump and irrigation method. The factors that could be changed to improve the uniformity include the hoses, micro-sprinklers, pressure regulators, location of hose cuts and the irrigation schedule. It is important to apply enough water to satisfy the needs of the soil, trees and evapotranspiration rates during the hottest time of the year. These project parameters and requirements will be discussed throughout the rest of the report.

LITERATURE REVIEW

Avocado Varieties

Although there are almost 500 different varieties of avocados in the world, only 7 are commercially grown in California (Avocado Varieties, 2014). Among these seven most common varieties are Bacon, Fuerte, Gwen, Hass, Pinkerton, Reed and Zutano. Growers today are constantly trying to find the ideal variety with the most uniform size and appearance, longest shelf life, greatest tolerance to weather changes and widest availability year-round. The avocado that has best fit these characteristics is the Hass, and it accounts for 95% of the total crop in California. The ideal growing conditions along the California coast provide good soil with proper drainage, abundant sunshine and cool ocean breezes that allow avocados to flourish in these regions. The three most common varieties are Hass, Fuerte and Reed, and their descriptions are below.

Hass. Hass avocados are the most commonly grown throughout the world with an excellent shelf life and year-round availability in California. Some of their characteristics include a small to medium sized seed, easy peeling when ripe, skin darkens as it ripens, and great taste. These oval-shaped, average to large sized fruit generally weigh anywhere from 5 to 12 ounces. The most common tree spacing for Hass is 20’ x 15’ with an average of 135 trees per acre. The Hass season typically runs from January to October with the best eating quality during the latter months (Avocado Varieties, 2013).

Fuerte. Fuerte avocados are the established favorite because of their high quality and excellent flavor. The Fuerte is native to Mexico and is one of the only varieties capable of surviving freezing temperatures. Some of their characteristics include smooth green skin, medium sized seed, easy peeling and great taste. These pear-shaped avocados typically weigh anywhere from 5 to 14 ounces but are not commonly marketed in California retail stores. The most common tree spacing for Fuerte is 20’ x 20’ with an average of 100 trees per acre. The Fuerte season typically runs from late fall through spring and the skin stays green throughout the season (Avocado Varieties, 2013).

Reed. Reed avocados are large, round fruit known for their softball shape and excellent taste during their prime. Some of their characteristics include round, medium sized seed, easy peeling and good taste. This summertime variety can often serve as a meal replacement because of its ability to grow anywhere from 8 to 18 ounces. Unfortunately, they are rarely available and exclusively available in Southern California. The most common tree spacing for Reed is 15’ x 15’ with an average of 150 trees per acre. The Reed season is a little shorter running from summer to late fall and the skin darkens as it ripens throughout the season (Avocado Varieties, 2013).

Irrigation

The implementation of new and improved irrigation systems has enabled farmers worldwide to save water, decrease costs and increase crop production. The purpose of irrigation is to supply dry land with water by means of ditches, pipes or streams.

Irrigation systems are used to assist in the growing of agricultural crops, maintenance of landscapes, and leaching of soils in dry areas and during periods of inadequate rainfall. Some of the most important required components in an irrigation system include a water source, a drainage system and correctly sized piping, hose, pumps, valves, fittings and filters. The common water sources include canals, reservoirs and groundwater wells. The invention of irrigation controllers allowed farmers to control pumps, valves and scheduling from any hand-held device or computer. The implementation of a backflow device prevents dirty water from flowing back to the source through the mainline. Using correctly sized commercial grade materials can eliminate or reduce the need to replace and repair parts.

The goal with every type of irrigation system is to have high distribution uniformity and application efficiency. When these goals are met, the plants will receive the same amount of water, fertilizer and chemicals that are needed for plant growth. A high uniformity indicates that water is evenly applied throughout the system, while a low uniformity could be either too much or too little water in different areas of the orchard. The application efficiency is a percentage of the ratio of the average depth of water infiltrated to the average depth of water applied. "The water requirement for a crop is directly related to the water lost through evapotranspiration (ET). Evapotranspiration for a crop depends on solar radiation, humidity, temperature, wind and stage of growth" (Burt, 2013). Knowing the ET and the soil infiltration rates can help growers increase the uniformity and efficiency of the system. Evapotranspiration refers to the amount of water used by the crop plus the amount of water evaporated from the surface of the soil.

In California, the supply of water is very limited and that is why costs are high and farmers are desperate for sustainable innovations. Irrigation costs will continue to rise because of the competition for water, products and labor required to operate and monitor micro-irrigation systems. When not using their own wells, growers are often allotted a certain amount of water pressure and volume, which forces them to divide their ranch into blocks and irrigate them on a schedule, one set at a time. Timing and scheduling is very important because each set will replace the soil moisture that has been used by the crop or has evaporated from the soil. According to (Olsen, 2013), "one irrigation set is the largest area that can be irrigated with the available water pressure and volume". There are many factors for growers to consider when determining the size of a block and the duration of a set. The type of irrigation system influences the scheduling and sizes of blocks. Typical irrigation methods that allow for larger sets and various pressures and flows include drip irrigation and micro-sprinklers.

Common Irrigation Systems for Avocados. Micro-irrigation systems have the capability of distributing water where it is needed at low pressures and low flows. The two common micro-irrigation systems used on avocados in California are drip and micro-sprinklers. Drip is not as common with avocados but sets can be much larger because of the slower application rate (Smith, 2014). Micro-sprinklers are excellent for avocado trees because their low application rate and 10' to 15' wetting diameter on the surface of the soil.

Drip irrigation is an excellent method for saving water as it allows water to slowly drip out of the emitters either onto the soil surface or directly in the root zone. Individual hoses called laterals run down the rows with low-pressure emitters near the bases of each tree applying anywhere from ½ to 2 gallons of water per hour. To accommodate for larger trees, growers sometimes run two hoses down the row, one on each side of the tree. According to Koch, "as the tree grows, additional emitters will be added to the surface hose until 6-8 emitters feed water to each tree" (2013). Although fertilizers and chemicals can be injected right into the drip system, it is necessary to have a reliable filtration system that filters out all the particles that could potentially clog the drip emitters.

Micro-Sprinklers. Micro-sprinklers can also be used to efficiently distribute water and fertilizer to the soil surface and base of the trees. Micro-sprinklers can have high application efficiency, allowing farmers to save water and only apply water to the plant's root zone. Similar to drip irrigation, lateral hoses run down each row with micro-sprinklers branching off from an attached spaghetti hose. Although the lateral hoses can be buried in the root zone, it is ideal to keep them on the surface for ease of repair and maintenance. Each sprinkler is generally located equidistant between two trees and is sufficient to supply enough water to one side of both trees. When properly spaced, micro-sprinklers can give a very uniform application of water over the irrigated area. There are many types of sprinklers with different orifice sizes that can be used depending on the pattern, flows, pressures and tree spacing. Growers often start with the smaller sprinklers while the trees are young and then swap them out for larger ones in order to keep the irrigated area on pace with the growth of the root system. An example of a Netafim micro-sprinkler is shown in Figure 1 below, and some of their most common micro-sprinklers are discussed in depth below.

Figure 2: Example of micro-sprinkler.

Micro-sprinklers are classified in low volume irrigation systems that can have high application efficiency, allowing growers to save water by only applying it to the root zone. Applying water at a lower rate than the infiltration rate allows growers to correlate the amount of water infiltrated with the application rate. Every once in a while, growers will irrigate with a much larger set in order to leach salts from the soil. Micro-sprinklers allow growers to irrigate any farmable topography with a small, continuous, steady supply of water. One of the only downsides of micro-sprinklers is that the labor in operation and maintenance does require some skill. These systems require regular maintenance to reduce clogging, including frequent flushing of pipelines and lateral hoses, and addition of chemicals to kill bacteria and other biological growth (Burt, 2013). The filters and sprinklers also need regular maintenance to ensure that they operate as designed.

Types of Micro-Sprinklers. There are a few different types of micro-sprinklers, all of which are most suitable for orchard crops such as lemons, oranges and avocados. Micro-sprinkler systems use small plastic sprinklers or jets that spray water over the soil surface, creating a wetted area 12 feet or more in diameter (Burt, 2013). As opposed to drip, micro-sprinklers have larger passages that help resist clogging. These sprinklers apply water to the soil surface by a small spray or mist at a discharge rate anywhere from 4 to 20 gallons per hour. The simple and replaceable plastic materials are resistant to all agrochemicals and weather. The unique design ensures even water quantities per tree, good distribution uniformity and wetting diameter assuming inlet pressure is within range. There are many different makes and models of micro-sprinklers but almost all of them are available as pressure compensated or non-pressure compensated with a variety of coverage radii and spray patterns. The most common micro-sprinkler spray patterns can be viewed in Figure 2 below.

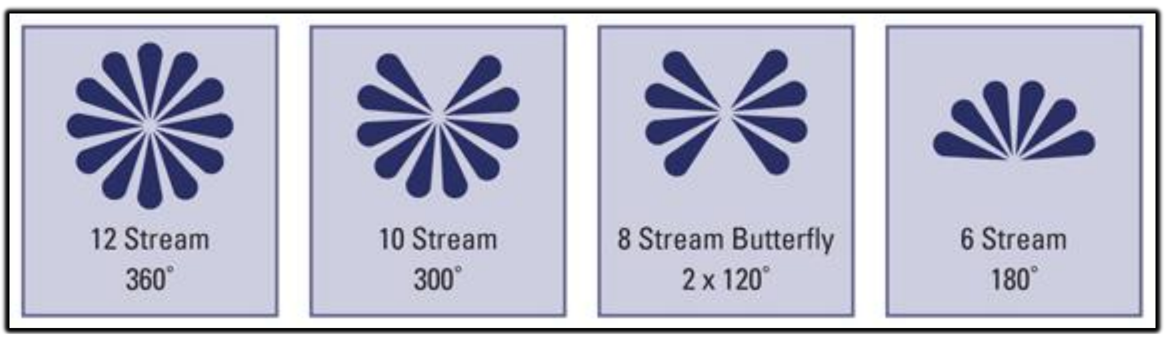


Figure 3. Netafim Micro-Sprinkler spray patterns.

The main ways to differentiate between micro-sprinklers is whether they are short range, long range, pressure compensated or non-pressure compensated. A few of the most common micro-sprinklers exclusively designed for orchards and tree crops are shown below.

Short Radius (SR, SRD). These micro-sprinklers were designed for irrigation of tree plantations and orchards requiring efficient distribution. The SR means that it has a revolving rotor irrigating a medium sized area. The SRD means that it has a stream deflector, which creates a smaller spray area and is used during the initial growing period. Once the root system spreads out, the deflector can be broken off in order to generate a larger wetting area. The micro-emitter comes in 10 sizes emitting flows from 7 to 80 gallons per hour. A short radius micro-sprinkler made by Netafim is shown in Figure 3 below (Micro-Sprinklers, 2014).

Figure 4: Example of Netafim (SR, SRD) micro-sprinkler.

Long Radius (LR, LRD). These micro-sprinklers were designed for irrigation of tree plantations with large root volumes. The LR means revolving rotor irrigating a large area and the LRD means it has the similar stream deflector but for a larger area. The emitter also comes in 10 different sizes emitting flows from 7 to 80 gallons per hour. An example of a long radius micro-sprinkler made by Netafim is shown in Figure 4 below (Micro-Sprinklers, 2014).

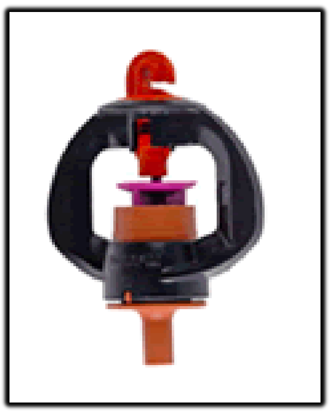


Figure 5: Example of Netafim (LR, LRD) micro-sprinkler.

Jet Micro-Sprinkler. These micro-sprinklers were designed for tree plantations and orchards irrigating with harsh water containing large amounts of sand. It is designed with a special upper bearing that keeps the rotor from spinning. Unlike normal swivels, the static emitter helps prevent wear from sand and other particles in the water. The emitter comes in five sizes emitting flows from 10 to 30 gallons per hour. An example of a jet micro-sprinkler made by Netafim is shown in Figure 5 below (Micro-Sprinklers, 2014).

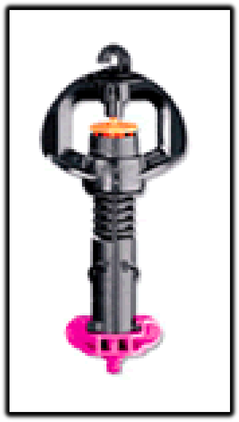


Figure 6: Example of Netafim jet micro-sprinkler.

Pressure Compensated. These micro-sprinklers will deliver a wide regulating range with a high distribution uniformity and large water passage. They are available in all four spray patterns as well as long and short range swivel spray options. The pressure compensation feature will help the sprinkler deliver a precise amount of water regardless of the changes in pressure due to long rows or elevation changes (Micro-Sprinklers, 2014). They are ideal for orchards, vineyards and nursery installations where flow regulation is desired.

Non-Pressure Compensated. These micro-sprinklers offer the maximum diameter of coverage along with a high distribution uniformity. They are cheaper than pressure compensated micro-sprinklers and are ideal for orchards with minimal elevation changes. Non-pressure compensated sprinklers should not be installed in orchards that contain large elevation changes and pressure variations.

Soil

Soil is one of the most, if not the most important factor in any crop's growth and productivity. Avocados can grow in any soil that has low salinity and drains well, but they grow the best in the West coast's sandy loam soil. They will only survive in soils with good drainage and are tolerant of acidic or alkaline soils, but only to a certain point. Once the pH and the fertility of the soil is determined, fertilizers can be added to replenish the soil with needed nutrients such as nitrogen, phosphorous, potassium, iron, zinc and calcium.

Soil Requirements. In order to achieve healthy growth and fruit size, avocado trees must have good soil drainage and sufficient available soil nutrients. Avocado trees thrive in well-aerated and loose soil such as limestone, sandy loam and decomposed granite. If the soil does not drain well, the trees can be planted on raised mounds to increase drainage and control root rot. Proper drainage and consistent irrigation is necessary to leach excess salts and avoid cool and damp winter soils. "Although avocados can tolerate both acidic and alkaline soils, the best pH range is between 5.5 and 6.5" (Rodriquez, 2013). In order to maintain a healthy pH range, provide the shallow root system with as much sunlight as possible while periodically amending the soil with lime and sulfur.

Soil Salinity. Understanding soil salinity is a key concept to successful avocado grove management because high soil salinity negatively affects overall yield. Soil salinity is the amount of salt content in the soil and is caused by processes such as mineral weathering and irrigation. Avocados tend to be sensitive to high soil salinity, which is unfortunate because salts occur in all soil and irrigation water. Soil salinity is measured in decisiemens per meter (dS/m) as the salt concentration in a soil solution with the use of electrical conductivity (EC). For further understanding and depending on the density of the water, 1 dS/m is equal to 640 parts per million (Measuring Units, 2013). A soil salinity with EC < 1.3 dS/m is best for avocado tree productivity (Burt, 2013). Once the soil EC threshold is exceeded, the yield percentage begins to decrease rapidly.

For every unit increase in salinity beyond the threshold, the yield will decrease 21% per dS/m (Burt, 2013). Soil salinity can occur from a variety of causes including evaporation of water leaving salts behind, use of chloride-based fertilizers, application of mulches and manures and water logging. Water logging occurs when excess water seeps down, raises the water table and moves more salt to the surface. When avocado trees utilize water they do not utilize the salt in the water, thus leaving salt behind to accumulate within the soil. This means it is very important to irrigate enough to keep the EC below 1.3 dS/m.

Salinity's Effects on Avocado Trees. High soil salinity makes it more difficult for the tree to absorb moisture. This issue can lead to tip burn, improper photosynthesis and poor root growth. Avocados like fast draining organic soil because too much salt in the soil reduces avocado yield and effects tree size.

Salinity Management. Irrigation, leaching and drainage are critical to salinity management. First, it is important to understand the physical and chemical properties of the soil in order to manage the salinity and water application. The top six inches of the soil are the most important to manage because of the shallow root system. Growers use soil tensiometers to consistently measure the soil moisture and salt content at desired depths. It is best to use low-salinity irrigation water and when necessary, apply gypsum to help lower the salt content, decrease water logging and improve soil structure. Long irrigation cycles every so often will enable salts to be leached effectively. If subject to winter rains, follow up with an irrigation set in order to dilute and leach salts down into the root zone.

Water's Effects on Soil Salinity. While irrigation water can add large amounts of salt to soil, it can also be used to remove salt from the soil through leaching. Leaching is a process occurring after an irrigation set that provides enough water to leach the soil and drain away the excess salt (Burt, 2013). Appropriate leaching amounts depend on irrigation water salinity and target root-zone salinity. It is crucial to know the salt content in the irrigation water. If there is sufficient rainfall, a certain amount of salts will naturally leach from the soil. During dry conditions, the soil dries out faster resulting in salt accumulation in the soil and the need for it to be leached out. Irrigation sets should be slow and deep when leaching salts and avoiding salt burn.

Monitoring soil moisture in avocado groves is very important because growers need to know when and how much to irrigate. Given the increasing costs of water and the need to properly manage irrigation, adjusting the frequency and volume applied is essential. “Avocado trees are heavy users of water, but they have a shallow feeder root system located primarily in the top six inches of soil that are prone to drying out” (New Growers, 2014). The feeder roots also have very few root hairs, thus making them inefficient at absorbing water. Hillside groves with decomposed granite drain well, but they drain rather quickly. Groves with high clay content can suffer from poor drainage that leads to root rot. Growers need to closely monitor the soil moisture levels in order to prevent over- and under-irrigation.

Managing Avocado Trees

Cultural management of avocado groves is necessary throughout the year because avocado trees are tropical rainforest trees that are active year-round. While winter is a good time to assess the most recent avocado production, growers should utilize the autumnal months to prepare avocado groves for winter weather events (Preparing California Avocado Groves for Winter, 2014). Some techniques used for managing avocados include pruning, fertilization and freeze protection. After the winter rains, it is important to flush out accumulated salts and apply pruning techniques and fertilization in order to achieve optimal spring performance. Fruit size can be affected by lack of water, a cold winter, a cool spring and improper management techniques. In areas with more drastic climate changes, proper frost protection measures must be taken in order to protect the trees and prevent a decrease in productivity. The many methods recommended for efficient management of avocado groves will be discussed below.

Managing Avocado Fruit Drop. Unfortunately, avocado fruit drop does happen and can be very frustrating for growers. On the other hand, fruit drop is normal reaction thought to be the trees’ way of getting rid of fruit with defective or weak seeds. Although growers have no direct control over the fruit that drops, there are a few ways to maintain a healthy tree and reduce fruit drop. Two of the most important ways to reduce fruit drop are decreasing stress by excellent irrigation management and picking the mature fruit on time in order to prevent them from competing with the new crop. Low percentages of fruit drop can sometimes be irrelevant considering “avocado trees can produce 100-200 avocados during a bad year and 200-300 avocados during a good year” (Arpaia, 2013). More effective management techniques include over-fertilizing with Nitrogen and cross-pollinating with other varieties.

Fertilizers. Fertilization and having a proper nutritional program is necessary for all crops in order to generate the best possible yields and productivity. Avocados thrive from constant, light applications of nutrients including nitrogen, phosphorous, potassium and zinc. These water-soluble nutrients can be automatically or manually injected into the irrigation system to provide nutrients at any time. Fertilizer injectors allow growers to insert and distribute nutrients and fertilizer throughout the system with very little chance of clogging. As the tree matures, increased nutritional needs are required to maintain the proper pH range and soil nutrient content. Consistent soil pH measurements can help the growers know when to fertilize, as well as what type of fertilizer to use.

Another way to maintain balanced nutrient levels is to collect leaf samples and perform a nutrient analysis. According to Arpaia and Faber, “a young tree needs ½-1 pound of Nitrogen per year, spread out over several applications. As the trees mature, the amount of fertilizer needed will increase accordingly” (Arpaia, 2013). In order to grow healthy avocados, the maximum amount of fertilizer to use for a mature tree should never exceed 1 pound per year per tree. After every fertilization application, growers should follow up with a deep and thorough irrigation set.

Irrigation System Management

Irrigating Avocado Trees. Irrigation is important for avocado trees in California because avocados are native to the humid sub-tropical and tropical regions of central and northern South America where rainfall is abundant. In comparison, California is an arid Mediterranean climate with low rainfall. For best growth and yields, avocado trees need a minimum amount of water each year, approximately 40-50 inches of rain, and moist soils in order to support the number of roots needed for healthy avocado trees (Irrigating Avocado Trees, 2014). The avocado tree does not search for water therefore water needs to be provided to the trees at the right times. In addition, the majority of avocado roots are in the top six inches of soil, typically spreading out to the end of the canopy (Irrigating Avocado Trees, 2014). For these reasons, California avocado growers rely on irrigation systems to support the water needs of their grove and keep the soil from drying out during periods of no rainfall. Optimal irrigation requires uniform water application and helps prevent an economic loss through lower yields. Poor irrigation practices such as prolonged saturated soils, standing water and poor timing can lead to root rot and sacrifice tree health.

When to Irrigate. Knowing when to irrigate is one of the most important factors in maintaining high irrigation efficiency. Deciding when to irrigate can be done using weather-based methods, soil-based schedules, or a fixed frequency every so many days. One of the hardest things to avoid can be over- and under-irrigation. Avocado trees can only handle so much stress before the roots begin to dry out and begin to decrease productivity. Depending on weather, soil and water availability, the most common irrigation schedule for avocados will include two or three, 6-8 hour sets per week (Underwood, 2014).

Properly placed tensiometers can be used for direct soil measurement to determine when to irrigate and to prevent over- or under-irrigation. The tensiometer displays the amount of tension the plant is using to pull water from the soil. Using soil tension measurements to determine groundwater availability can help a grower anticipate a plant’s water needs and avoid plant stress before it occurs. Depending on the soil type, irrigation for avocados should generally start when the 12-inch tensiometer reads 25 to 30 centibars, earlier if the soil is very sandy and later if the soil has high clay content.

Determining How Much Water to Use. The design of the irrigation system and the determination of the amount of water to use depends on the crop and is a job for the professional. To reduce costs and increase productivity, growers aim for at least 80% efficiency with high distribution uniformity. In general, the depth of irrigation should match the location of the avocado roots. Water and nutrients pushed deeper than the rooting depth are considered waste and should be avoided.

Different soils need different amounts of water as sandy soils hold less water and have less lateral movement of water than clay based soils. When dealing with clay based soils, it is important to maintain a consistent schedule because if irrigation is stopped for too long, the soil will harden and runoff will increase. Different sized trees also need different amounts of water. Enough water for a large tree with a good layer of mulch can be less than that for a small growing tree. In order to calculate the amount of water and the best irrigation schedule for a grove, the CIMIS system can be used to calculate the daily water use. The California Irrigation Management Information System (CIMIS) uses a collection of data from over 100 weather stations in California to help growers and managers with water applications, budgets and schedules. The weather data is automatically transmitted to one central location where it is processed and used to determine evapotranspiration rates in all the different locations (Land and Water Use, 2014).

Managing Irrigation. Managing the cost of irrigation is one of the most important methods in becoming a successful California avocado grower. Irrigation can be the greatest cost of production for an avocado grower and that is why we are constantly searching for ways to increase efficiency and distribution uniformity. Unfortunately, the exact amount of water differs for each grove due to differences in soil types, microclimate, elevation changes and tree type, size and health. As a general rule, "growers should budget for 3.5 acre-feet of water per acre per year with sprinklers because Hass avocados typically transpire 40-60 gallons of water per day during the warmer seasons" (Koch, 2013). To ensure your irrigation is not wasting water, consider the following avocado cultural management practices as outlined by the California Avocado Commission (Manage Water Costs by Assessing Your Irrigation System, 2013). These include:

- Capping off sprinklers to diseased and damaged trees
- Stump canopied trees
- Thin crowded groves
- Apply mulch and remove weeds
- Keep skirts low on trees
- Always maintain system for leaks
- Don't irrigate too much on slopes because there will be runoff and potential washing away of soil

Benefits of Irrigation. Although it is obvious that all crops need irrigation, it is beneficial to take a closer look at how and why irrigation is so important. In California, poor avocado yields are often related to poor irrigation practices and soil salinity issues. Water plays an important role in crop production and photosynthesis. Photosynthesis helps create amino acids, proteins, vitamins, hormones and enzymes that support tree growth and fruit production, as well as oils and sugars in the fruit. Water serves as an excellent source in delivering salts and minerals to the roots and leaves. On the other hand, water used for leaching helps rid the root zone of salts that can lead to tip burn and leaf drop, which can reduce fruit production. Water also helps cool the leaves of the tree to prevent overheating and potential shutdown of photosynthesis.

PROCEDURES AND METHODS

The design components placed on this project came about through discussion with the grower, Craig Underwood. There were certain aspects to the project that he wanted changed and others that he wanted to keep the same. Unlike most irrigation system designs, this design is more of an improvement than a design starting from scratch. On that same note, there were certain aspects in the design that were unknown by the grower and left to be decided from a best guess by the designer. The trees are already planted and the system components are already in place. The well, pump, filter, mainline and manifolds are to remain unchanged.

Existing Conditions

The grower is looking for ways to improve his irrigation strategies, yield and distribution uniformity without changing any of the above components. According to his recent evaluation, the trees are being under-irrigated and the distribution uniformity is underperforming and costing him money. To achieve a higher distribution uniformity, a system must be designed to have minimal pressure variation and uniform flow rates from the sprinkler heads. To establish the most accurate design procedure, careful inspection and evaluation of the current irrigation system was required. The first step in the design process is understanding the field constraints, what is available and what problems are already occurring.

Field Constraints. The 10.6 avocado orchard is located in Somis, California, on a gravelly sandy loam soil with a pH of about 7.5 (Underwood, 2014). The elevation differences throughout the field are minimal and result in a slope that varies between 0 and 1%. There are 37 rows of trees with varying amounts of trees per row from 43 to 67. In order to help increase yield, cross-pollinating Fuerte avocado trees were planted in 10% of the orchard. The tree rows run north and south in order to allow maximum sunlight at all times.

Certain sections of trees were planted at different times and thus resulting in three different tree spacings. With a bird's-eye view counting from East to West, the first 18 rows were planted in 2005, on a 10 ft. by 14 ft. spacing and make up about 2.8 acres of the field. Rows 19 through 24 were planted in 1999, on an 18 ft. by 23 ft. spacing and make up about 2.4 acres of the field. Rows 25 through 37 were planted in 2001, on an 18 ft. by 23 ft. spacing. In 2009, interplants were added to part of that section. As can be seen in the irrigation system design, the interplants in rows 25 through 37 end at the 26th tree from the top and result in a 1.9 acre section with a 9 ft. by 23 ft. tree spacing. The remaining section below is on an 18 ft. by 23 ft. spacing and makes up about 3.5 acres. This variant tree spacing is the root of all difficulties for the system design as it causes uneven canopy cover as well as inconsistent ET rates and water requirements throughout the field. A map of the field can be viewed in Appendix F.

Canopy Cover. It is important to know the canopy cover in any orchard because of its effects on ET and the resulting water requirements. As the canopy cover increases so does the ET rates. Canopy cover is expressed in a percentage and refers to the amount of ground coverage that the trees, branches and leaves provide. The ET rate increases as canopy increases because the highest percent of ET occurs in the leaves as they are continually breathing and transpiring water. The overall canopy cover for the entire orchard was determined to be 76%. The canopy cover for the section on a 10 ft. by 14 ft. spacing is 90%. The canopy cover for the section on an 18 ft. by 23 ft. spacing including rows 19 through 24 is 83%. The canopy cover for the section with interplants in rows 25 through 37 is 72% and the canopy cover for the section below the interplants on an 18 ft. by 23 ft. spacing is 79%.

These results were determined from the i-Tree Canopy website and can be seen in the Appendix D. Since the canopy cover percentages in each of the different sections are greater than 60%, the orchard can be considered mature. For a mature orchard where the same or similar percent canopy cover exists throughout, each section needs to receive the same amount of water per acre regardless of the tree spacing. The hours per week or the nozzle size on the sprinklers need to be adjusted for each of the different spacings. Since the grower is irrigating the entire orchard as one block, the only option is to adjust the nozzle sizes on the sprinklers.

The goal is get the highest and most uniform canopy cover percentage as possible throughout the orchard, and the best way of reaching this goal is by irrigating the same amount of water per acre regardless of the spacing. Unfortunately, the only way to really know how much water the trees are using is to install a weather station and soil moisture sensors in each of the different sections. These will help tell how much water the trees are actually using during the different times of the year.

Water Source and Fertigation. Water is available from a concrete standpipe near the top right corner of the field. The water runs from the well on the property and is stored in a 10 ft. concrete standpipe before entering the system. The well water contains 50-100 PPM nitrate and 150 PPM chloride. In order to balance out these high rates and allow for more efficient nutrient uptake by the trees, the grower annually injects 90 lbs. of potassium and 90 lbs. nitrogen. He also annually applies 500 lbs. of sulfur that is hand spread throughout the orchard to help lower the soil and water pH. These fertilizer applications are typically divided out into 3 to 4 events per year. Once an irrigation set is activated, the water is pressurized by a booster pump and enters the pipeline system. When operating at its highest efficiency, the 25 HP Peerless End Suction booster pump is capable of pumping about 500 GPM at about 95 PSI. Pumps are necessary for all micro-irrigation systems in order to maintain consistent pressures and flows throughout the field. Figure 6 below is a picture of the pump that is currently in use for this orchard.

Figure 7. Berkeley centrifugal booster pump.

Filtration. After the well water exits the pump it is passed through a stainless steel Hydrokleen Tubescreen filter. Regardless of the source, water needs filtration in order to reduce emitter plugging and bacterial growth. Failure to use the proper type of filter will generally result in eventual system failure. Although sand-media tanks are typically recommended for micro-irrigation systems, the grower is confident in the cleanliness of his well water and decided to keep using the Tubescreen filter that is already in place. This filter has a backflush cap that is manually activated when the pressure difference across the filter exceeds 7 PSI. Figure 7 below is a picture of the filter that is currently in use for this orchard.

Figure 8. Hydrokleen tubescreen filter.

System Inspection. Since this design did not include installation of a new pump, filter and pipeline system, pressure readings throughout the field were required. In order to make sure there was adequate pressure in the system, several pressure readings were taken while the system was running. The downstream pressure exiting the filter after a recent backflush was about 77 PSI and can be viewed in Figure 8 below.

Figure 9. Pressure reading downstream of filter.

The pressure entering Manifold 1 after Valve 1 was 54 PSI and the pressure at the 28th riser in Manifold 1 was 42 PSI. The pressure entering Manifold 2 after Valve 2 was 55 PSI and the pressure at the 10th riser in Manifold 2 was 59 PSI. The pressure entering Manifold 3 after Valve 3 was 59 PSI and the pressure at the 6th riser in Manifold 3 was also 59 PSI. These pressure readings solidify the fact that there is more than enough pressure throughout the system. A map of these pressure readings can be viewed in Appendix F.

<u>Pipelines.</u> Once the water passes through the filter it is ready to enter the pipeline system, where it can be distributed from a main pipeline system to laterals in the orchard. The mainline and manifolds consist of Class 125 PVC in three different sizes including 1-1/2 inch, 2-1/2 inch and 4 inch. According to the grower, record of the exact location of reduction in the pipelines is unknown, but since there is adequate pressure in the last riser of each manifold, it can be concluded that the pressure loss due to friction in the pipeline is not a critical problem.

On the other hand, it is known that the entire mainline from the exit of the filter to the valve at the beginning of each manifold is 4 inch. Next, each manifold is known to include the three above said pipe sizes but the exact point of reduction is unknown. It is also known that the majority of irrigation systems installed are done so by abiding by the 5 ft/sec. rule. This means that the pipe is sized so that the velocity through each section will not exceed 5 ft/sec. and thus, result in minimal pressure loss due to friction.

The entire pipeline system consisting of Class 125 PVC pipe is underground in place and will not be altered. There is a valve at the beginning of each of the three manifolds that remains wide open at all times, unless manually closed in case of an emergency. Although the orchard could be split up into three different blocks, it is currently and will remain irrigated as 1 block.

Risers. The next source of difficulty for the design is the variant locations of risers, brass hose bibs and pressure regulators at each riser. A riser is usually a flexible PVC pipe that allows the water to rise from the underground pipeline to serve the aboveground laterals. A brass hose bib is a valve that is used to regulate flow in most household hoses and should not be used in any agricultural applications.

Manifold 1 serves 37 rows, it only contains 28 risers. Rows 1 through 18 each have a riser with a 20 PSI regulator at the top. From row 19 to 37 there is a riser every other row that has either a 25 PSI regulator or no regulator at all. Manifold 2 has 10 risers that alternate rows from 19 to 37. Manifold 3 has 6 risers that serve rows 25 through 37. The exact locations of the risers can be seen on the irrigation system design in Appendix F.

Pressure Regulators. A pressure regulator is a device that limits the amount of pressure entering a lateral regardless of the inlet pressure, as long as the inlet pressure is above the pre-set pressure on the regulator. They are necessary because flow rates will change as pressure changes. Each riser has either a 20, 25, or 30 PSI regulator, but several have no regulator at all. Therefore, this design focused on standardizing the pressure regulator for each riser.

Lateral Hoses and Emission Devices. Once the water rises up and passes through the hose bib and pressure regulators, it enters the ½ inch polyethylene hoses that run up and down every row. These ½ inch hoses are undersized relative to the total water flow in the system and as a result, there are large pressure losses due to friction in the hoses. In order to prevent these losses and increase efficiency, the size of these hoses will need to be increased. Water flows through the lateral hoses and out of the emission devices, where it infiltrates the soil to replenish soil moisture.

The grower is currently using 4 different emitter devices that are randomly located throughout the orchard. These devices include 1 and 2 GPH drip emitters at the base of about 60% of the trees in the orchard, as well as 7 or 9 GPH micro-sprinklers in between the trees in every row. The drip emitters are small plastic pieces that are inserted directly into the lateral hose. The drip emitters are adding unnecessary flow to the laterals, which causes an increase in friction loss. A picture of this connection can be seen in Figure 9 below.

Figure 10. Example of a 2 GPH drip emitter.

The micro-sprinklers are connected to the lateral hose via a small spaghetti hose that is typically 1 to 3 feet long. They are also attached to a plastic stake that allows for the sprinkler to be elevated 6 to 12 inches and the hose or sprinkler to be moved around without disturbing the spray pattern. The micro-sprinkler can be seen in Figure 10 below. Since there is no pattern or uniformity relating the location of the emitters to the different tree spacings, this is a major cause of poor distribution uniformity that needs to be improved.

Figure 11. Example of micro-sprinkler in orchard.

Energy and Water Use. The grower is currently on a time-of-use program with Southern California Edison. This means that Edison will provide them a discounted rate when they use power during off-peak hours. In order to take full advantage of this opportunity, the grower does not irrigate between the hours of noon and 6 p.m. to keep costs low. He still has to make sure he has an irrigation window that is long enough to apply the trees with what they need. Under-irrigation can result in a reduction of crop production and increase in soil salinization. He is currently irrigating the entire orchard in 1 set, two times a week for 6 hours. During warmer periods with no rainfall, he will increase the application time to 8-10 hours, and once every two weeks he will irrigate for 15 to 20 hours for leaching. There are no soil tensiometers in the field telling him when to irrigate. Instead, he sticks to his own schedule that he has learned from experience over the years. Unfortunately, his system is so inefficient that he is applying an excess of water to some trees and not enough to others.

Irrigation System Design

The irrigation system design begins with determining the water requirements for the trees in each of the different sections. In order to determine the net water requirement per tree and for the entire orchard, the spacing, ET rate and irrigation window need to be known. The net water requirement refers to only the water that the tree is using. According to the ITRC website, the peak ET rate for Avocados in Zone 4 in Ventura County is 4.97 inches in the month of August, which equates to .16 inches per day. The irrigation window of 9 hours per day, 4 days a week for a total of 36 hours per week was determined to provide the most efficient flow rate out of the pump and into the system.

Flow Rate Requirements. The spacing, irrigation window, flow rate per tree and flow rate per spacing can be viewed in Table 1 below. The calculations for Table 1 can be viewed in Appendix B.

Table 1. Net GPH per tree and net total GPM.

Spacing	A (sq. ft)	# of SPK	Hours/day	GPM	GPH/Tree	Total GPM
10x14	140	841	5.14	0.045	2.714	38.0
9x23	207	338	5.14	0.067	4.012	22.6
18x23	414	654	5.14	0.134	8.025	87.5
					Total =	148 GPM

The total net flow rate required by the trees before including leaching requirement, spray losses and desired distribution uniformity is 148 GPM. Once the net flow rate is determined, the gross flow rate per tree and for the entire orchard can be calculated. Gross refers to the total amount of water applied after accounting for spray losses, desired distribution uniformity and the leaching requirement. Spray losses from the micro-sprinklers are assumed to be 5% and the desired distribution uniformity is .85 to account for potential system deterioration.

The leaching requirement is the extra percentage of water that is needed to keep the soil below the threshold soil salinity (ECe) for the crop. Avocados are very sensitive to salty soils and have an ECe of 1.3 dS/m (Burt, 2012). For every unit increase in soil salinity, avocado yields will decrease 21%. It is very crucial to irrigate enough to leach the salts from the soil and keep the ECe below 1.3 so that the trees can absorb the correct amount of nutrients and moisture. The salinity of the irrigation water (ECw) used at the Underwood orchard is 1.51 ds/m. The ECe and the ECw are used to determine the leaching requirement for the orchard. The leaching requirement for the orchard is .3 and is used in the equation to determine how much irrigation water should be applied to the field. The leaching requirement calculations are shown in Appendix B for Table 2. The total irrigation water required for the orchard is 262 GPM. More detailed calculations for the data in Table 2 below are shown in Appendix B.

Table 2. Gross GPH per tree required and total GPM required.

Spacing	A (sq. ft)	# of SPK	Hours/day	GPH/Tree	GPM/Tree	Total GPM
10x14	140	841	5.14	4.80	0.080	67.3
9x23	207	338	5.14	7.10	0.118	40.0
18x23	414	654	5.14	14.20	0.237	154.7
					Total =	262 GPM

Total Flow = 67.3GPM + 40GPM + 154.7GPM = 262 GPM.

Wetted Area. The next step in the design process is to calculate a minimum required sprinkler diameter. It is important to note that the entire field is irrigated as 1 block and that there is 1 micro-sprinkler per tree. It is also important to note that the gravelly sandy loam soil in the orchard will have an additional lateral movement of water of 0.5 feet, which will at 1 ft. to the total diameter (ITRC, 2008). Larger sprinkler diameters are recommended for avocados because they make better use of the available soil nutrients and moisture while supplying a wider root system. The minimum required sprinkler diameter is calculated using a wetted area of 60% of the total tree spacing area. The minimum required sprinkler diameters can be viewed in Table 3 below and the calculations can be viewed in Appendix B.

Table 3. Minimum sprinkler diameter required.

Spacing	A (sq. ft)	60% of A	Req'd Dia.	Min Rqd Dia
10x14	140	84	10.3	9.3
9x23	207	124.2	12.6	11.6
18x23	414	248.4	17.8	16.8

Micro-sprinkler Selection. Once the required flow rate and minimum required sprinkler diameters are determined, it is time to select a sprinkler that adequately meets the constraints. Recall that since the previously discussed ET rates are similar throughout the orchard regardless of the spacing, the chosen sprinklers will need to apply the same or near the same flow per acre.

The first step is to choose a sprinkler manufacturer, which was easy because the grower requested to replace the old sprinklers with new Netafim micro-sprinklers. Table 4 below shows Netafim's Supernet pressure compensated sprinkler characteristics and the chosen sprinklers that could best match the requirements. Pressure compensated means that the sprinkler will maintain the same flow rate as long as the inlet pressure is within the recommended pressure range. The recommended pressure range for the sprinklers below is anywhere from 25 to 50 PSI, which covers the pressures available at every riser throughout the Underwood orchard. The highlighted sprinklers below best match the required sprinkler flow rates in Table 2 and the required diameter in Table 3. The 5.3 GPH sprinkler will be installed in the section on a 10 ft. by 14 ft. spacing. The 7.4 GPH sprinkler will be installed in the section on a 9 ft. by 23 ft. spacing. Lastly, the 15.3 GPH sprinkler will be installed in the section on an 18 ft. by 23 ft. spacing.

Table 4. Netafim supernet sprinkler characteristics.

Netafim Swivel Performance			Long		Short	
Nozzle in.	#, Color	GPH	Swivel Co	Wet D	Swivel Co	Wet D
0.035	20, purple	5.3	Purple	14.8	Blue	8.2
0.045	28 l green	7.4	Purple	19.7	Blue	11.5
0.045	30 brown	8.2	Purple	19.7	Blue	11.5
0.047	35 sky blue	9.2	Purple	19.7	Blue	11.5
0.05	40 Blue	10.6	Purple	19.7	Blue	11.5
0.056	50 green	13.2	Black	23	Blue	14.8
0.061	58 gray	15.3	Black	23	Blue	14.8
0.068	70 black	18.5	Black	23	Blue	16.4
0.069	90 orange	23.8	Black	23	Blue	16.4

Flow Rate by Tree Spacing. After choosing the sprinklers that will be used for the new irrigation system design, the flow per area and the total flow applied can be calculated. The total flow applied to each section is calculated by multiplying the number of sprinklers by the flow rate per sprinkler. Once the flow rates for each of the sections on a different spacing are calculated, they can be added up to find the total flow rate during an irrigation set. This flow rate was calculated to be 283 GPM and can be viewed in Table 5 below. The reason why the number of trees does not match the number of sprinklers is because in every micro-irrigation design, an extra emitter is added to the outside of every row. Since there are 37 rows of trees, there are 37 more sprinklers than trees. The calculations for Table 5 can be viewed in Appendix B.

Table 5. Total GPM applied and flow/area.

A (sq. ft)	# of SPK	# of Trees	SPK GPH	SPK GPM	Total GPM	Total Area	Flow/Area
140	841	823	5.30	0.088	74.3	115220	0.00064
207	338	332	7.40	0.123	41.7	68724	0.00061
414	654	641	15.30	0.255	166.8	265374	0.00063
Total =	1833	1796		Total GPM =	283		

Summary of Selected Equipment. Table 6 below is a summary of the chosen sprinkler characteristics. It clearly shows which sprinkler will be installed in each spacing and what the required pressure is for each. Under the "swivel" column, "LR" stands for long range and "SR" stands for short range. These headings refer to the distance of the sprinkler diameter.

Table 6: Sprinkler characteristics for each spacing.

Spacing	# of Sets	Req'd GPH	GPH/spk	Swivel	Required P	Min Rqd Dia	Spk. Dia.
10x14	1	4.80	5.30	#20 LR	25-30	9.3	14.8
9x23	1	7.10	7.40	#28 SR	25-30	11.6	11.5
18x23	1	14.20	15.30	#58 LR	30	16.8	23

AutoCAD Design

Once the number of trees, number of sprinklers, flow rate per sprinkler and total system flow rate are determined, the actual design can begin. All of the design parameters discussed below can be viewed on the AutoCAD design of the irrigation system at the end of this report. All necessary measurements and elevations for the design were previously taken at the Underwood orchard or found using Google Earth. Fortunately for this orchard, certain things that were previously discussed are already in place and will remain unchanged. These include the pump, filter, mainline, manifolds, valves, risers and trees. An aerial view of the orchard was used to help ensure the AutoCAD design was similar. Figure 10 below shows the aerial view taken from Google Earth.

Figure 12. Aerial view of Underwood avocado orchard.

Design Process. The first step was to draw the trees on the on the correct spacing for each section in order to ensure the field dimensions were to scale. Once all 1,796 trees were drawn and in place, the other finite objects including the pump, filter, mainline, manifold, valves and risers could be drawn in their respectful locations. Next, the sections of different spacings and location of the interplants were labeled. The interplants in rows 25 through 37 end after the 26th tree from the top. Once these locations were clearly defined, the lateral hoses and sprinklers were drawn in. Each sprinkler of a different flow rate was drawn in a different color for ease of differentiation between them. The layout of the different designated sprinkler areas is very important in order to avoid confusion of the specific areas where the flow rates are different. Next, optimum locations of lateral hose cuts were determined by calculating the flows through the three different manifolds and minimizing hose length as often as possible.

Microsoft Excel was used to make several spreadsheets and perform trial and error calculations until the flow rate in each manifold had the lowest possible friction loss. These calculations can be viewed in Appendix E. At every hose cut in the field, the hose is closed off by bending and securing it with a plastic figure eight. Figure 11 below is a close up of a figure eight clamping and cutting off flow at the end of a hose.

Figure 13. Figure eight clamping hose end.

Since rows 1 through 18 each have their own riser off of Manifold 1, the hoses were cut at both ends of each row. For rows 19 through 24 on Manifold 1, the hoses were cut at the uphill end and after the ninth tree downhill from the riser. For rows 25 through 37 on Manifold 1, the hoses were cut at the uphill end and after the 12th tree downhill from the riser. For rows 19 through 24 on Manifold 2, the uphill hose ends were cut at the same location as the downhill hose ends on Manifold 1, and the downhill hoses were cut at the end of each row. For rows 25 through 30 on Manifold 2, the uphill hose ends were cut at the same location as the downhill hose ends on Manifold 1, and the downhill hose ends were cut after the 7th downhill tree.

For rows 31 through 37, the uphill hose ends were cut at the same place as rows 25 through 30 and the downhill hose ends were cut after the 11th downhill tree. For rows 25 through 30 on Manifold 3, the uphill hose ends were cut at the same location as the downhill cuts on Manifold 2 and the downhill hoses were cut at the end of each row. For rows 31 through 37 on Manifold 3, the uphill hose ends were cut at the same location as the downhill cuts on Manifold 2 and the downhill hoses were cut at the end of each row. It is important to note that the above manifold serves the sprinkler at every downhill hose cut line. For further understanding refer to the irrigation design in Appendix F.

Lateral Hose Locations. Determining the location of the lateral hose cuts was a key step that made it possible to count the number of trees uphill and downhill from the each manifold. The number of trees uphill and downhill of the first riser on Manifold 1 and the end risers on each manifold in row 37 were counted and labeled. This also allowed for the number of sprinklers on each lateral to be counted as well as the total flow rates in each lateral and manifold. Since the risers throughout the orchard serve various amounts of laterals, it is important to note how many each riser serves. In Manifold 1, risers 1 through 18 and riser 28 serve one lateral and risers 19 through 27 serve two laterals. In Manifold 2, each riser serves two laterals except for riser 10, which serves only one lateral. In Manifold 3, riser 1 and 3 serve three laterals, riser 2, 4 and 5 serve two laterals and riser 6 serves one lateral.

The total flows in each lateral and each manifold were calculated in the spreadsheet that can be viewed in Appendix E. The sprinkler flow rates were multiplied by the number of sprinklers in each lateral to determine each individual lateral flow rate. Then each of those flow rates were added together to determine the total manifold flow rate. The total flow rate for Manifold 1 was 174.63 GPM. The total flow rate for Manifold 2 was 82.88 GPM. The total flow rate for Manifold 3 was 25.245 GPM. The sum of the three manifold flow rates was 282.75 GPM, which was the same flow calculated in the early steps of the design. It is important to know the flow rate going into each manifold in order to calculate the friction loss through the hoses and the critical path.

Critical Path. The critical path is the furthest path a water molecule travels in the system that has either the highest flow rate or the highest required inlet pressure. The critical path for the Underwood orchard was determined to be riser 21 on Manifold 1 and was calculated using the spreadsheet in Appendix E. The inputs needed to calculate the friction loss and required inlet pressure for the critical path include hose inside diameter, section flow rates, section lengths, C value and velocity. The C value is the roughness coefficient of the material and is 150 for Class 125 PVC and 140 for polyethylene hose. The Hazen-Williams equation used to calculate friction loss can be viewed in Appendix E.

The calculated inlet pressure requirement for the critical path was 33.01 PSI. This means that as long as there is at least 33.01 PSI available at riser 21 on Manifold 1, then there will be sufficient pressure at every riser in the system. In order to provide certainty of the inlet pressure at every riser, all of the old pressure regulators will be removed and replaced with 35 PSI regulators. Since the inlet pressure requirement for the critical lateral is 33.01 PSI, all other risers will have enough pressure to satisfy every sprinkler in the orchard.

One more critical path calculation was made for the manifolds to confirm there was enough pressure at the head of each manifold. Since the flow in Manifold 1 was determined to be undoubtedly the greatest, it was assumed to have the most critical path. The same Excel spreadsheet was used to calculate the friction loss and required inlet pressure at the head of the manifold. The calculated inlet pressure for Manifold 1 was 55.93 PSI, slightly larger than the pressure reading of 54 PSI that was previously mentioned. This is a very minor difference and will result with insignificant effects because these calculations were based off a desired average pressure of 55 PSI, which is much higher than what actually is needed. The overestimate of desired average pressure was made with regard to the fact that the friction loss calculations are affected by the pipe inside diameter. As previously stated, it is unknown where the exact location of reduction in the manifold pipe size occurs, so it is better to overestimate then underestimate. These calculations can be viewed on the spreadsheet in Appendix E.

Pipe Characteristics. Table 7 below shows the characteristics for the Class 125 PVC and the polyethylene (PE) hose used in the design. It includes the nominal size, inside diameter and C value for each. The inside diameters and C values are used in the Hazen-Williams equations to calculate friction loss in a section of pipe.

Table 7. Pipe characteristics.

	Class 125 PVC			PE Hose
Size	1 1/2"	2 1/2"	4"	3/4"
Inside Dia.	1.784	2.699	4.224	0.805
C Value	150	150	150	140

Hose Lengths. The next step is to calculate the total hose length necessary for the new irrigation design and installation. Table 8 below shows the hose lengths for the three different spacings. To find the total area of each section, the spacing area was multiplied by the number of sprinklers in that area. The hose length was determined by multiplying the number of sprinklers by the sprinkler spacing down the rows. Once the hose lengths for the three different sections were calculated, they were added together to find the subtotal hose length. The total hose length still required the extra sections of hose connecting the areas where two laterals are served by one riser, as well as an additional 2.5% of hose for snaking and flushing the hose ends. The total hose length was calculated to be 24,441.13 feet and the calculations can be viewed in Appendix B.

Table 8. Hose lengths for different spacings.

Spacing	A (sq.ft.)	# of Spk	Hose Length
10x14	140	841	8410
9x23	207	338	3042
18x23	414	654	11772

RESULTS

Peak Evapotranspiration

The peak ET rate is necessary for any irrigation system design. The peak ET rate for avocados during the month of August is .16 inches per day.

Required System Flow Rate

In order to satisfy the desired distribution uniformity, leaching requirement and ET rates of the trees in each of the sections with different spacings, the new required system flow rate was calculated. The total irrigation water required for the orchard is 262.03 GPM and the calculations for this can be viewed in Appendix B.

Irrigation Schedule

The irrigation schedule was calculated to ensure that the trees will be receiving enough water during the hottest month of the year. It is based off of the system flow rate, tree spacing and peak ET rates. During the month of August, the irrigation schedule should consist of four 9-hour sets per week for a total of 36 hours per week. As the days get cooler and ET rates decrease, the hours of operation will be cut back in order to save water and money.

Selected Micro-Sprinklers

Each micro-sprinkler was selected based off of the tree spacing and required flow rates in each section of the field. The chosen sprinklers are pressure compensated with a rating of 25 to 50 PSI. In the section on a 10 ft. x 14 ft. spacing, there will be 841 micro-sprinklers with a flow rate of 5.3 GPH. In the section on a 9 ft. x 23 ft. spacing, there will be 338 micro-sprinklers with a flow rate of 7.4 GPH. In the section on an 18 ft. x 23 ft. spacing, there will be 414 micro-sprinklers with a flow rate of 15.3 GPH. Regardless of the spacing, each micro-sprinkler will apply the correct amount of water per acre and will result with an improvement to yield and distribution uniformity.

Total System Flow Rate

The total system flow rate was calculated using the number of sprinklers and each of the sprinkler flow rates. The total system flow rate during peak ET will be 282.75 GPM. This flow rate will remain the same throughout the year, but hours of operation will decrease as ET rates decrease.

Required Inlet Pressure

The critical path method was used to determine the required inlet pressure at the critical manifold and lateral hose. The required inlet pressure for the critical manifold is 55.93 PSI and the required inlet pressure for the critical lateral hose is 33.01 PSI.

Size and Length of Hose

The size of the hose allows the designer to determine whether or not the required flows will be able to reach every emitter with enough available pressure. The ¾ inch hose will be used because it has minimal pressure loss due to friction with the required lateral flow rates. The total required hose length is 24,441.13 feet and was calculated in order to provide enough hose for snaking, flushing hose ends and meeting the length requirements of each micro-sprinkler spacing.

Cost Analysis

An estimate of the costs for the irrigation system improvements was acquired from Coast Water Solutions in Oxnard, California. Table 9 below displays the item number, description, quantity, unit cost and total cost for all of the materials necessary for the irrigation system.

The quantity of hose was determined from the hose length calculations. The quantities for the fittings and sprinklers were rounded up in order to allow the grower to have extra just in case of wear and failure. Since there are 44 risers in the orchard, the grower will receive 50 of each of the necessary fittings. Since there are 71 total laterals and each lateral has two hose ends, the grower will receive 175 figure eight hose ends. He will also receive over 30 extra of each micro-sprinkler. Lastly, 1 pint of glue and 1 pint of primer will be necessary to glue all of the slip fittings together.

The only other costs to the grower will include the labor for installing the new pressure regulated riser assemblies, removal and replacement of irrigation hoses and installation of the new pressure compensating sprinklers. The subtotal for the bill of materials is $7, 135.00. Since the sales tax for agricultural irrigation equipment is 2%, the subtotal will have to be multiplied by 1.02 in order to get the total cost. The total cost to the grower for all of the necessary materials to improve his irrigation system as desired is $7,277.70. All of this data and calculations for this data can be viewed on the next page.

Table 9: Bill of materials.

Item #	Item Description	Qty	Unit Cost	Total
DH3/4	Toro Blue Stripe 3/4" x 1000', .805 x .925	25	106.0	2650
	54 PSI			
M66P	3/4" Male Thread x 3/4" IPS Socket & 1"	50	0.68	34
	Spigot, MHA-34			
GBV75	3/4" Global Ball Valve, MHT x FHT	50	1.40	70
9CST	3/4" Compression Swivel Tee W/Screen,	50	3.12	156
	9 CST			
9AP8	3/4" Figure 8 Hose End	175	0.24	42
9CC	3/4" Compression Coupling for Drip Hose	50	1.09	54.5
PRL-35	3/4" Senninger 35PSI Regulator, FHTxMHT	50	5.25	262.5
31722	Netafim Supernet PC SPK 5.3GPH Purple	875	2.00	1750
	Noz W LR Purple Swivel, D-14.8'			
31725	Netafim Supernet PC SPK 7.4GPH Light	375	2.00	750
	Green Noz W SR Blue Swivel, D-11.5'			
31721	Netafim Supernet PC SPK 15.3GPH Gray	675	2.00	1350
	Noz W LR Black Swivel, D-23'			
5E531	Weld-On Cement, PVC Glue - 1 Pint	1	9.00	9
6KWU5	Weld-On PVC P70 Purple Primer - 1 Pint	1	7.00	7

Subtotal	$ 7,135.00
Sales Tax 2%	$ 142.70
Total	$ 7,277.70

DISCUSSION

Existing Equipment and Constraints

Designing an irrigation system requires certain techniques and knowledge of crops, soils, topography, water supply, boundary constraints, climate and social and economic considerations. When designing an irrigation system, it is important to ensure that all constraints, requirements and calculations are accurately reported. Along with the grower's requests, the distribution uniformity evaluation performed on the Underwood orchard provided reassurance that the current irrigation system needed improvement. In fact, the evaluation missed a few key factors that would have made the evaluation more accurate and result in a lower distribution uniformity. The factors that the evaluation did not mention were the varied tree spacing, the risers serving 2 and 3 rows, the randomly located 1 and 2 GPH drip emitters and the varied pressure regulators. All of which are crucial in performing an irrigation design to improve the distribution uniformity. Several visits to the orchard enabled the designer to acquire all of the necessary knowledge to design and improve the irrigation system in place.

Multiple emitter flow rates were installed randomly throughout the orchard. The most likely reason for this is that as sprinklers began to wear, they were accidentally replaced with another sprinkler of the wrong size. Two different sized sprinklers and two different sized drip emitters were found. The 1 and 2 GPH drip emitters could have been used when the trees were younger, but now they are serving no beneficial purpose. Having multiple emitter flow rates randomly spaced in the field can drastically hurt the distribution uniformity.

Most irrigation systems designed today typically have one riser for every lateral. Unfortunately, the Underwood orchard has a very random layout of risers in the field. It seems as if some of the risers were installed sometime after the initial irrigation system was installed. Risers throughout the orchard serve up to three laterals. This could have a negative effect on the distribution uniformity and was not mentioned in the distribution uniformity report. The flows through every riser must be known in order to calculate pressure requirements and total flow rates.

Every micro-irrigation system requires pressure regulation whether it has regulators at the manifold or at the risers. The Underwood orchard has three different sized pressure regulators also randomly spaced in the orchard. The different pressure regulators at the risers include 20 PSI, 25 PSI and 30 PSI, while some risers have no pressure regulation at all. This is another negative effect on distribution uniformity because the available pressure in the laterals vary. Also, the non-pressure compensating sprinklers that are used in the orchard are adversely effected by varying pressures.

Design Considerations and Limitations

Quite possibly the most important characteristic of the Underwood orchard is the fact that three different tree spacings are irrigated all as one block. Since the sprinkler flow rates are random, the grower has very little chance of confirming that he is applying enough water per acre. This is a common way of non-uniformly applying water because an excess of water is applied to some trees and not enough to others. The current sprinklers need to be replaced with sprinklers with the necessary flow rates for each spacing because for a mature orchard, the number of gallons needed per day per acre is the same regardless of tree spacing.

Using the three chosen sprinklers, the emitter flow rates can be matched with the tree spacings and the correct amount of water per acre will be applied. Another option could be to use the same sprinkler flow rate on the same spacing throughout the orchard, but every so often a sprinkler would inevitably be placed adjacent to a tree and consequently cause more problems with distribution uniformity. If the grower had a way of changing the system so that it could be run on three separate blocks, then the same sprinkler flow rates could be used and the hours of operation per block would be the only variable.

Other problems with the irrigation system include undersized lateral hoses and large pressure variations throughout the system. In all irrigation systems, it is very important to match the flow rates with the correct pipe inside diameter. The ½ inch hose currently in place is too small for the flows they are withstanding and therefore, the friction loss through the laterals is higher than it should be. As a result, there are large pressure differences from the inlet to the end of each lateral, causing poor overlap, uneven distribution, large droplet size and sprinkler rotation problems. Adequate pressures will ensure that each sprinkler is applying the correct flow rate, which will result in an improvement to the yield and distribution uniformity.

Once all of the design constraints and current irrigation system problems were considered, the actual design requirements and improvements were clearly defined. The previously discussed design calculations and drawings were performed in order to confirm that the new hose, sprinklers and flow rates would suffice the available flow and pipeline system. Given the improved irrigation design and the total flow of 282.75 GPM during the month of August, the avocado trees at the Underwood orchard will no doubt be receiving enough water to meet the plant ET rates. The distribution uniformity will increase and the overall yield will improve. The desires of the grower will be met and the trees will flourish.

RECOMMENDATIONS

Making improvements in irrigation systems and irrigation water management not only saves water, but can save nutrients, chemicals, time and money. For best quality and yield bring the irrigation system up to par while managing the system to provide the correct amount of water at the optimum timing. The main issue for the Underwood orchard is how to improve the distribution uniformity and still utilize the existing pump, filter, mainline, manifolds and risers.

Management

For better irrigation system management, growers should update their systems with available technologies for scheduling irrigations according to plant needs, as well as controlling volumes and frequencies of applications. Installing soil moisture tensiometers in each section of different spacing will enable the grower to monitor how much water is being taken up by the tree and thus, when and how much to irrigate. An irrigation controller can help the grower save time and manpower by automatically controlling the irrigation system and distributing water and nutrients to the orchard. The automated irrigation and fertilization system will collaborate with the soil moisture sensors to provide an efficient means irrigation scheduling.

The grower is currently applying 90 pounds of nitrogen throughout the orchard every year, which equates to about .01 pounds per tree. Increasing the amount of nitrogen application will help increase yield and overall tree health and growth. Each tree should annually receive .5 to 1 pound of nitrogen spread out over 3 to 4 applications. After fertilizer cycles are completed, the grower should follow up with a deep thorough irrigation set to flush out the lines and help the nitrogen infiltrate the soil.

Although the grower is not experiencing drastic problems with clogging, frequent measures should be taken to monitor the water quality. If the water quality gets worse, the grower should consider replacing the Tubescreen filter with sand media tanks, the highest recommended filters for all micro-irrigation systems.

During the hottest time of the year, each irrigation set should be 9 hours per day for 4 days a week. During the rest of the year, the irrigation sets should be cut back and adjusted to match ET rates.

Equipment

The ½ inch polyethylene hose that is currently in use is undersized relative to the total flow of the system and as a result, large pressure drops are occurring down every lateral. Replacing the ½ inch hose with ¾ inch hose will deliver more volume of water with less friction loss, as well as eliminate all of the 1 and 2 GPH drip emitters that are serving no purpose other than negatively affecting the distribution uniformity. Also, running the shortest laterals as possible is recommended to help decrease friction loss and total flows in each lateral.

In order for the grower to know exactly how much pressure is at the head of each lateral, 35 PSI pressure regulators should be installed. Since the ¾ inch polyethylene hose is rated at 54 PSI, it is very important that there are not excess pressures in the hose. Also, the recommended Netafim SuperNet pressure compensated micro-sprinklers are rated for 25 to 50 PSI, so the grower can be sure there will be sufficient pressure and flow to each sprinkler. These sprinklers are optimum for a wide range of applications and have a unique nozzle that gives them one of the highest distribution uniformities on the market.

The brass hose bibs that are used as valves at the top of ever riser should never be used in any agricultural irrigation system. Over the years, the handles become brittle, rusted shut and leaking problems occur. Replacing the hose bibs with plastic ball valves are a cheap fix that will have less friction loss and provide ease of replacement when they begin to wear.

REFERENCES

Arpaia, Mary L., and Ben Faber. "Answers to Questions." *Answers to Questions*. UCANR, n.d. Web. 15 Oct. 2013. <http://ucavo.ucr.edu/General/Answers.html>.

"Assess Avocado Grove Irrigation Methods." *California Avocado Commission*. The California Avocado Commission, 2014. Web. 20 Apr. 2014. <http://www.californiaavocadogrowers.com/cultural-management-library/assess-avocado-grove-irrigation-methods>.

"Avocado Varieties." *California Avocado*. California Avocado Commission, n.d. Web. 17 June 2014. <http://www.californiaavocado.com/avocado-varieties/>.

"Avocado Varieties - Types of Avocados." *California Avocados Direct*. N.p., 2013. Web. 16 Oct. 2013. <http://www.californiaavocadosdirect.com/8/avocado-varieties-types-of-avocados.aspx>.

Burt, C.M. 2013. Irrigation Water Management BRAE 340. ITRC, Cal Poly State University, San Luis Obispo

Burt, C.M. 2013. Agricultural Irrigation Systems BRAE 440. ITRC, Cal Poly State University, San Luis Obispo.

Faber, Ben. "Irrigation Book 2 - Chapter 1." *Avocado Production in California: Cultural Care*. By Gary Bender. San Diego: Regents of the U of California, 2014. 1-26. Print. <http://ucanr.org/sites/alternativefruits/files/121292.pdf>.

"Irrigating Avocado Trees." *California Avocado Commission*. The California Avocado Commission, 2014. Web. 20 Apr. 2014. <http://www.californiaavocadogrowers.com/cultural-management-library/irrigating-avocado-trees>.

ITRC. 2008. Principles of Irrigation. Cal Poly Irrigation Training and Research Center, San Luis Obispo, CA.

"i-Tree Canopyv6.0". *i-Tree Canopy*. U.S. Forest Service, n. d. Web. 2 May 2014. <http://www.itreetools.org/canopy/index.php>.

Koch, Frank. "Orchard Layout." *Avocado Grower's Handbook (Chapter 2)*. The Hofshi Foundation, 1983. Web. 13 Oct. 2013. <http://www.avocadosource.com/books/koch_1983/koch_2b.htm> .

"Land and Water Use." Department of Water Resources, 2014. Web. 10 June 2014. <http://www.cd.water.ca.gov/land_wateruse/cimis.cfm>.

"Manage Water Costs by Assessing Your Irrigation System." *California Avocado Commission*. The California Avocado Commission, 2014. Web. 20 Apr. 2014. <http://www.californiaavocadogrowers.com/cultural-management-library/manage-water-costs-assessing-your-irrigation-system>.

"Measuring Units." *Environment and Heritage*. NSW, 11 Oct. 2013. Web. 21 May 2014. <http://www.environment.nsw.gov.au/salinity/basics/units.htm>.

Meyer, B. 2014. Personal Communication. Brian Meyer, CEO, Coast Water Solutions, Oxnard, CA.

"Micro Sprinklers - Netafim." *Sprinklers and Micro-Sprinklers for Agriculture*. Netafim, n.d. Web. 15 Apr. 2014. <http://www.netafim.com/product-category/agriculture-micro-sprinklers-emitters>.

"Mission Avocados -- Growers." *Regional Crop Reports*. Mission Produce, Inc., 2013. Web. 13 Oct. 2013. <http://www.missionpro.com/regionalcropreport.html>.

"Netafim Drip/Micro Irrigation Solutions – Agriculture Division". *Netafim USA*. Netafim Irrigation, Inc., 2014. Web. 28 April 2014. <http://www.netafimusa.com/agriculture/products/supernet>.

"New Growers." *California Avocado Commission*. The California Avocado Commission, 2014. Web. 20 Apr. 2014. <http://www.californiaavocadogrowers.com/growing/new-growers>.

Olsen, Craig. "What Is Irrigation?" *What Is Irrigation?* N.p., n.d. Web. 13 Oct. 2013. <http://www.olsensprinkler.com/What_is_Irrigation.html>.

"Preparing California Avocado Groves for Winter." *California Avocado Commission*. The California Avocado Commission, 2014. Web. 20 Apr. 2014. <http://www.californiaavocadogrowers.com/cultural-management-library/preparing-california-avocado-groves-winter>.

Rodriguez, Amy. "Cross-Pollination of an Avocado." *Home Guides*. Demand Media, n.d. Web. 16 Oct. 2013. <http://homeguides.sfgate.com/cross-pollination-avocado-43038.html>.

Rodriguez, Amy. "What Kind of Soil Is Good for Avocado Trees?" *Home Guides*. Demand Media, n.d. Web. 12 Oct. 2013. <http://homeguides.sfgate.com/kind-soil-good-avocado-trees-39791.html>.

Rose, Leslie. "Home Guides." *The Best Fertilizers for Avocado Trees*. Demand Media, n.d. Web. 12 Oct. 2013. <http://homeguides.sfgate.com/fertilizers-avocado-trees-55019.html>.

"Shopping the World for Avocados." *Mission Avocados*. Mission Produce, Inc., 2013. Web. 14 Oct. 2013. <http://www.missionpro.com/avocadosourcing.html>.

Smith, Bryan. "Drip vs. Micro Sprinklers." *Trickle-L Forum*. N.p., n.d. Web. 15 April 2014. <http://www.trickle-l.com/new/archives/dvms.html>.

"Tubescreen". *Hydrokleen*. Web. 7 May 2014. <http://www.hydrokleensystems.com/tubescreen.html>.

Underwood, C. 2014. Personal communication. Craig Underwood, CEO, Chief Engineer, Underwood Family Farms, Somis, CA.

APPENDICES

APPENDIX A

Senior Project Contract

California Polytechnic State University BioResource and Agricultural Engineering Department **BRAE Senior Project Contract**	May 30, 2014 Meyer, Michael ASM
Project Title: Micro-Irrigation Design for Avocado Orchard in California	
Background Information: Farmers are always trying to find the most efficient ways to grow their crop in order to make the most profit and produce the highest yield. The goal is to design an irrigation system for an avocado orchard that satisfies the given constraints. The intention is to determine a plot of land, type of irrigation system, plant and soil requirements and an irrigation schedule. I will be communicating with certain companies that specialize in avocados and sprinkler irrigation. All farms try to save the most water as possible, have the best irrigation efficiency and generate the most income as possible. The goal is to come up with an irrigation design that will achieve all of these feats.	
Statement of Work: The first phase of this project would be to research everything about avocados, as well as the best irrigation management techniques for it. The second phase will be to get in touch with as many different companies that can be used as resources and references for the project. The third phase will be to work with the grower and discuss his desires and goals for the design. The fourth phase should include the design steps, calculations and drawings. The focus will be on meeting the project requirements, improving distribution uniformity, and providing recommendations for the most efficient irrigation design.	
How Project Meets Requirements for the BRAE Major	
Major Design Experience – The ASM senior project must incorporate a major design experience to meet specific needs. The design process typically includes the following fundamental elements.	
Establishment of objectives and criteria	**–** The ASM senior project includes a problem solving experience that incorporates the application of technology and the organizational skills of business and management, the quantitative, analytical problem solving.
Synthesis and analysis	The project involves the application of irrigation design, soil analysis, economic feasibility and crop management.
Construction, testing and evaluation	The project involves design/management skills in the areas of irrigation system evaluation, design and cost analysis.
Incorporation of applicable engineering standards	Quantitative problem solving will include design calculations and the cost analysis of the project.
Capstone Design Experience - The ASM senior project must be based on the knowledge and skills acquired in earlier coursework (Major, Support and/or GE courses).	
Incorporates knowledge/skills from earlier coursework	**BRAE** 133 Engineering Graphics, 151 AutoCAD, 340 Irrigation Water Management, 418/419 Ag Systems Management, 440 On-Farm Irrigation Systems, 438 Micro-Irrigation Systems, SS 121 Introduction to Soil Science, AGB 212 Ag Economics, AGB 310 Ag Credit and Finance
ASM Approach – Agricultural Systems Management involves the development of solutions to technological, business or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas are common features of this type of problem solving.	
	The project applies specialized knowledge in irrigation system design and

Systems Approach	management.
Interdisciplinary Features	The project involves the integration of multiple design aspects that requires knowledge in soil, water, irrigation and plant management.
Sustainability	Design a system that can save the most water and produce the least amount of waste. Achieve the best possible irrigation efficiency and distribution uniformity.

Health and Safety	Growing, picking, injecting acids and fertilizers.
Project Parameters	The project must be cost effective. The design must meet the goals of the grower and the needs of the crop. The design must work effectively. The farmer must be able to apply the design.

List of Tasks and Time Estimate

TASK	Hours
Research in library (irrigation systems, crop requirements)	40
Their positives and negatives	15
Their feasibility	25
Talking to the middle men	10
Talking to both companies	10
Visiting the business	15
Working drawing of design	20
Business Plans	20
Crop Information	20
Calculations	10
Final evaluation	5
Preparation of written report	20
TOTAL	**210**

Financial Responsibility

Preliminary estimate of project costs: $______________________

Finances approved by (signature of Project Sponsor): ______________________

Final Report Due: | **Number of Copies**:

Approval Signatures | **Date**

Student: ______________________ ________

Project Supervisor: ______________________ ________

Department Head: ______________________ ________

APPENDIX B

Example Design Calculations

Table 1
Area = 10’ x 14’ = 140 sq. ft.
Hours/day = 36 / 7 = 5.14 hrs.
Net GPM/tree = (.16 in/day x 140 sq. ft.) / (96.3 x 5.14 hrs.) = .045 GPM
Net GPH/tree = .045 GPM x 60 minutes = 2.714 GPH/tree
Total GPM/spacing = 2.714 GPH x 841 sprinklers = 38.038 GPM
Net Flow = 38.038 GPM + 22.604 GPM + 87.472 GPM = 148.11 GPM

Table 2
ECe = 1.3 dSm
ECw = 1510 umhos/cm x .001 dSm = 1.51 dSm
LR = 1.51 dSm / ((5 x 1.3 dSm) – 1.51 dSm) = .30
Gross GPH/tree = 2.714 GPH / ((1-5%) x .85 x (1-.30)) = 4.8 GPH
Gross GPM/tree = 4.8 GPH / 60 minutes = .080 GPM
Total GPM/spacing = .080 GPM x 841 sprinklers = 67.29 GPM
Gross Flow = 262.03 GPM

Table 3
60% of Area = 140 sq. ft. x .60 = 84 sq. ft.
Area = (3.14 x D^2) / 4
Required Diameter = √(4 x 84 sq. ft. / 3.14) = 10.3 ft.
Additional Lateral Movement = .5 ft. x 2 sides = 1.0 ft.
Minimum Required Diameter = 10.3 ft. – 1 ft. = 9.3 ft.

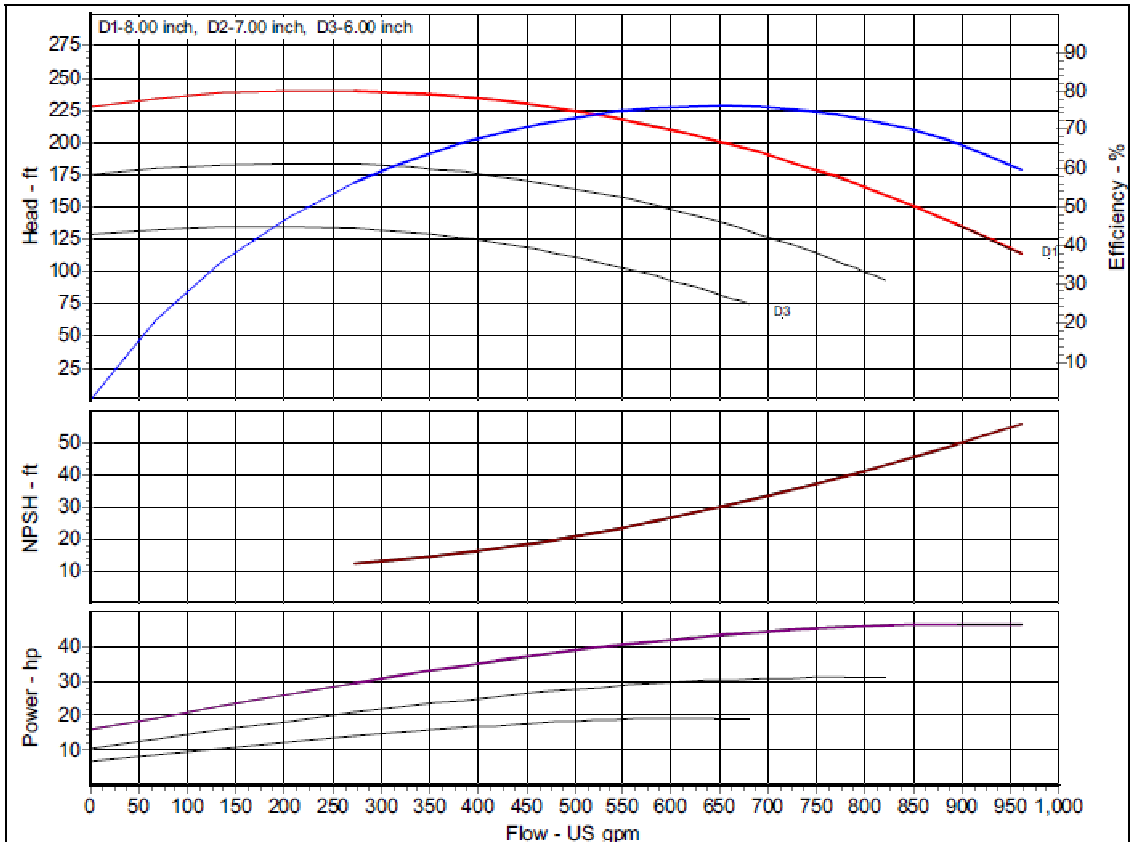
Table 5
Total # of Sprinklers = 841 + 338 + 654 = 1833
Sprinkler GPM = 5.3 GPH / 60 minutes = .088 GPM
Total Flow per Spacing = .088 GPM x 841 sprinklers = 74.288 GPM
Total Flow = 74.288 GPM + 41.687 GPM + 166.77 GPM = 282.745 GPM
Total Area = 140 sq. ft. x 823 trees = 115,220 sq. ft.
Flow/Area = 74.288 GPM / 115,220 sq. ft. = .00064

Table 8
Hose Length = 841 sprinklers x 10 ft. = 8410 ft.
Lateral Connections = 27 sections x 23’ per section = 621 ft.
Total Hose Length = ((8410 ft. + 3042 ft. + 11,772 ft.) + 621 ft.) x 1.025 = 24,441.13 ft.

APPENDIX C

Pump Information

Pump Model:	Peerless - C F1 F2 830A M & P	Nom. Speed:	3500 RPM, 60 Hz Electric	Duty Flow :	US gpm
Type:	C - Close-Coupled or F Frame Mounted End Suction	Impeller Dia.:	inch	Duty Head :	ft
				Efficiency :	%
		Temperature:	68 °F	Power Required :	hp
		Viscosity:	1.007 cSt	NPSH Required :	ft
Curve No.:	3115066/Rev 3-13	Sp. Gravity:	1.000	Peak Power:	hp
Impeller No.	SeePtslist	Fluid:	Water	Closed Valve Pressure	ft
Item :					
Your Ref.:		Tolerance :	Hyd Inst-Peerless Std		

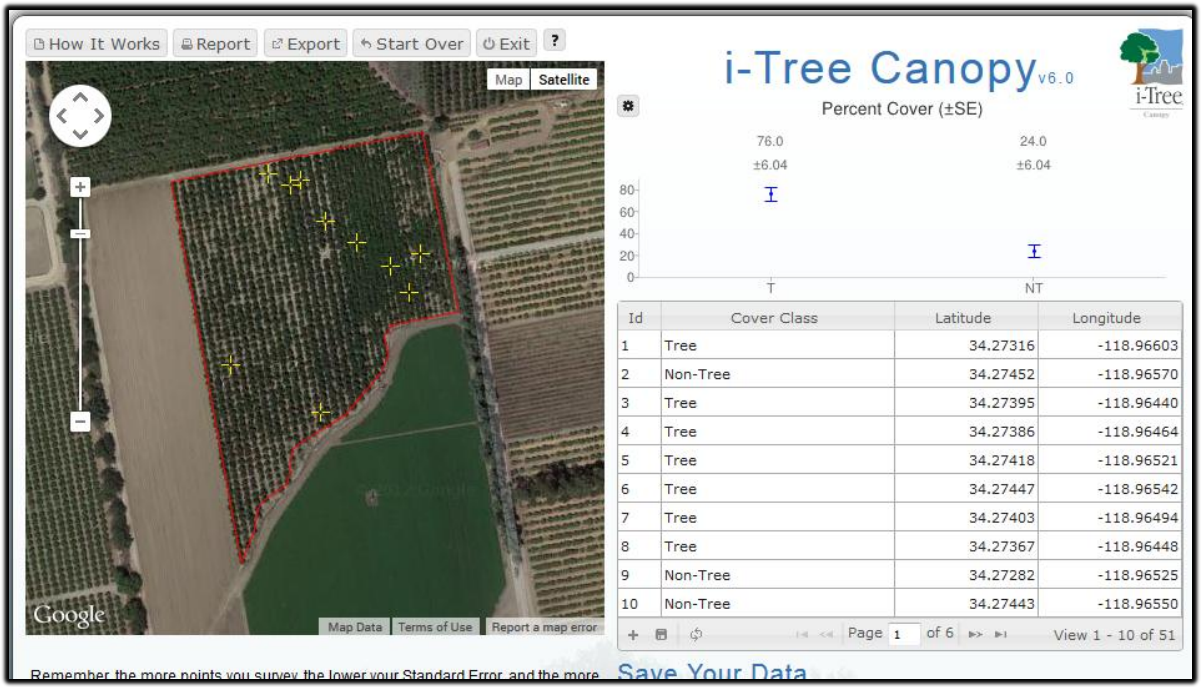


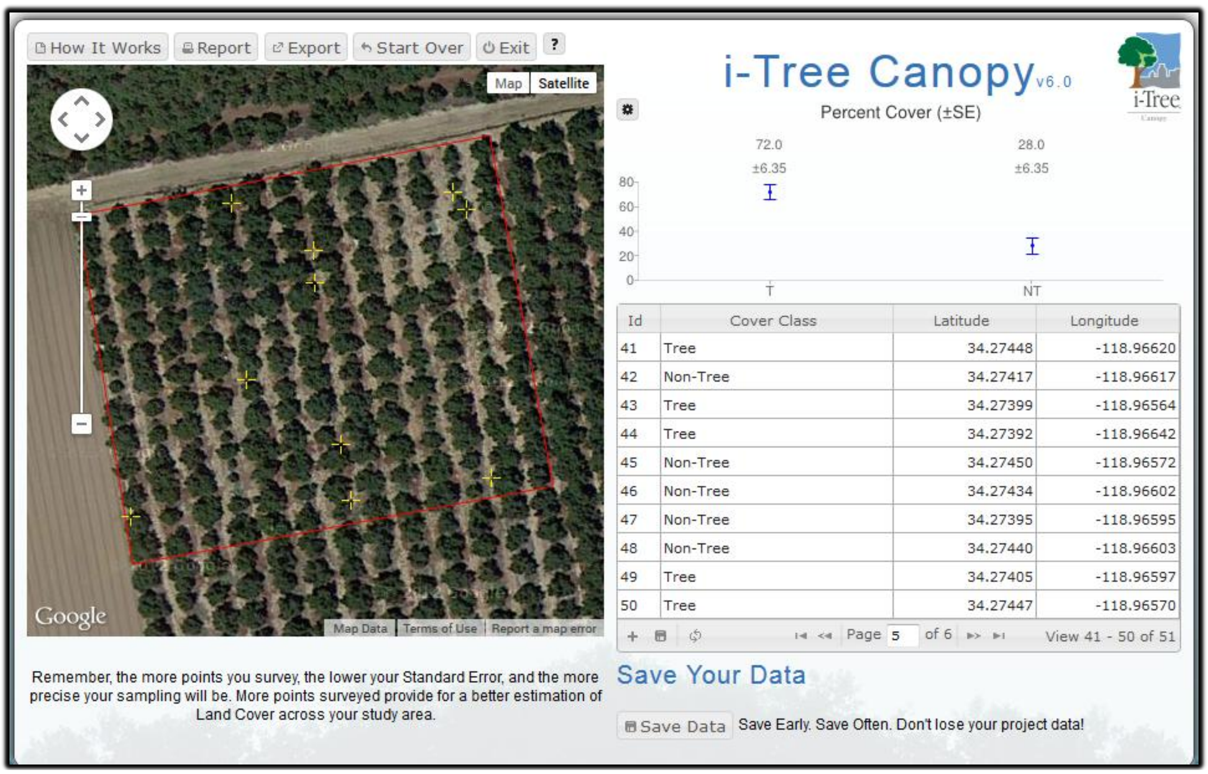
Comments:
Perf. curve represents typical perf, vel. head is incld. Perf. curves tests are performed in accordance with H.I.Stds.

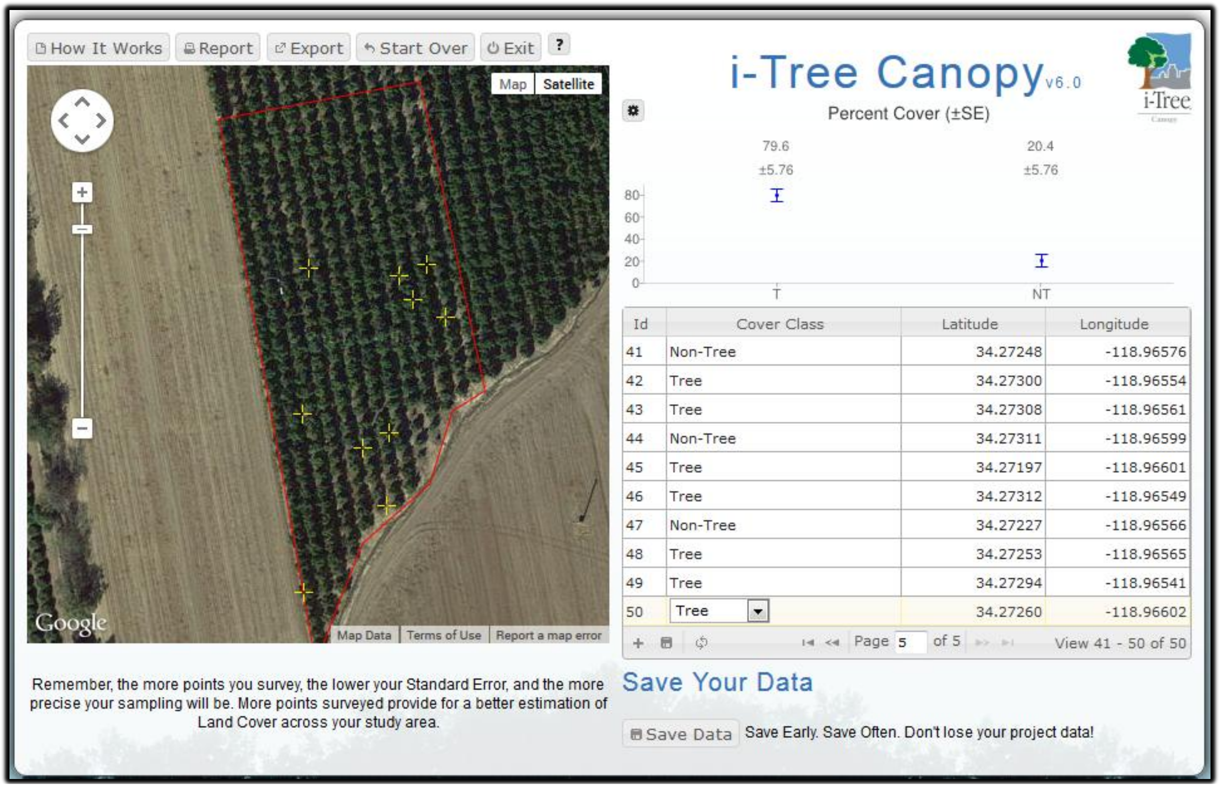
Image of Filter, Pump and Concrete Standpipe
at Underwood Orchard

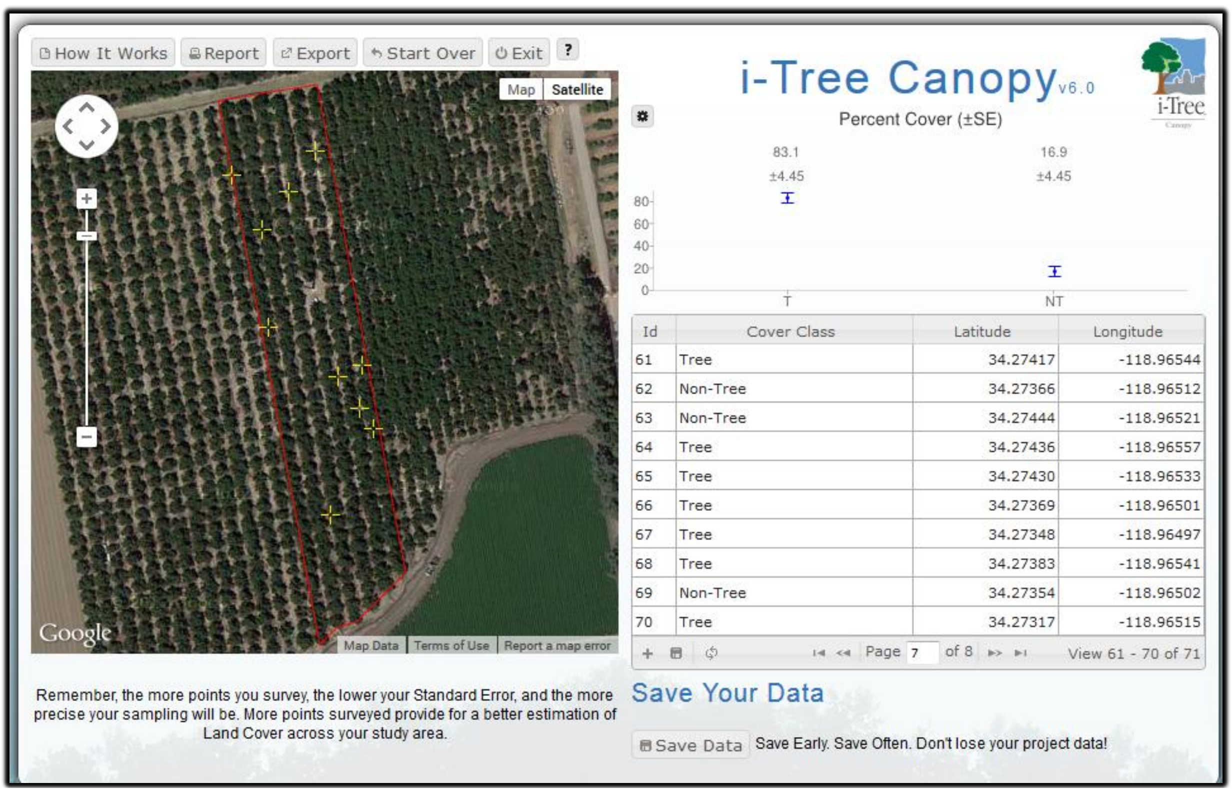
APPENDIX D

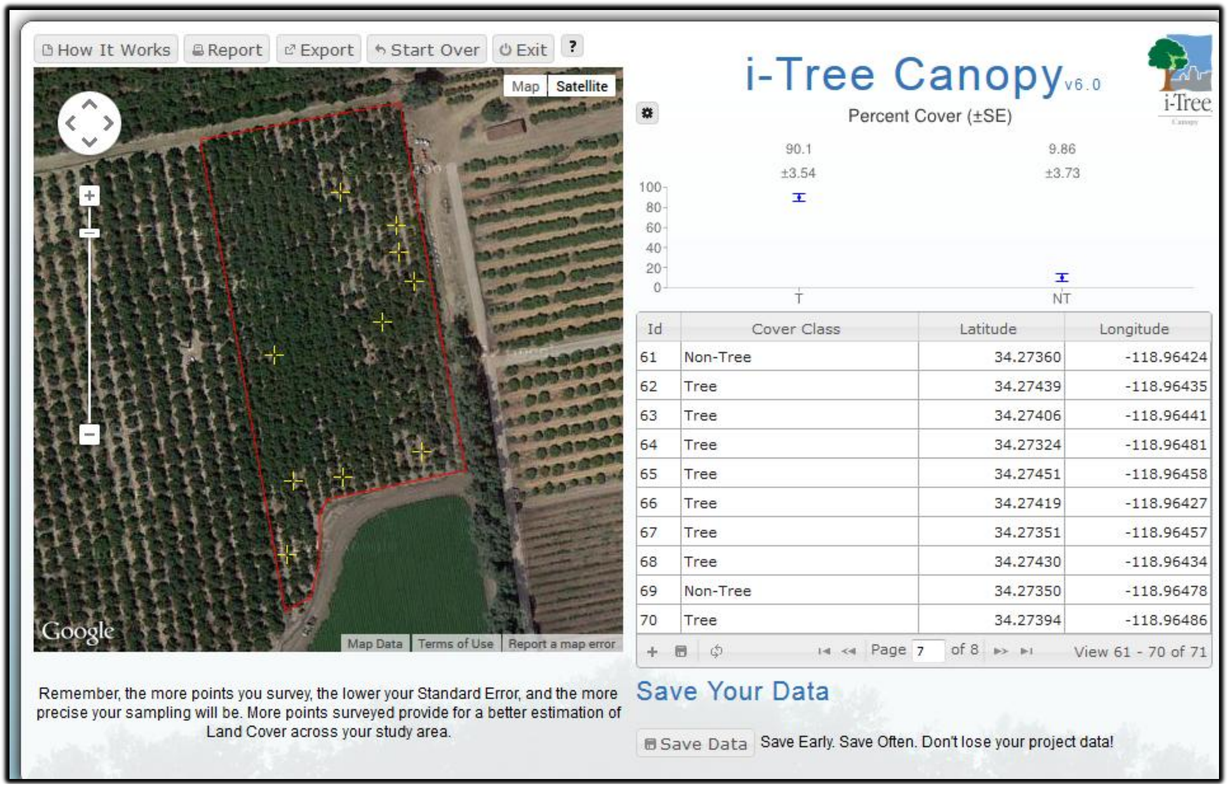
Canopy Cover


How It Works
Report
Export
Start Over
Exit
?
Map
Satellite
Google
Map Data
Terms of Use
Report a map error
i-Tree Canopy v6.0
Percent Cover (±SE)
76.0
±6.04
24.0
±6.04
80
60
40
20
0
T
NT
Id | Cover Class | Latitude | Longitude
1 | Tree | 34.27316 | -118.96603
2 | Non-Tree | 34.27452 | -118.96570
3 | Tree | 34.27395 | -118.96440
4 | Tree | 34.27386 | -118.96464
5 | Tree | 34.27418 | -118.96521
6 | Tree | 34.27447 | -118.96542
7 | Tree | 34.27403 | -118.96494
8 | Tree | 34.27367 | -118.96448
9 | Non-Tree | 34.27282 | -118.96525
10 | Non-Tree | 34.27443 | -118.96550
Page 1 of 6
View 1 - 10 of 51
Save Your Data


How It Works
Report
Export
Start Over
Exit
?
Map
Satellite
Google
Map Data
Terms of Use
Report a map error
i-Tree Canopy v6.0
Percent Cover (±SE)
72.0
±6.35
28.0
±6.35
80
60
40
20
0
T
NT
Id | Cover Class | Latitude | Longitude
41 | Tree | 34.27448 | -118.96620
42 | Non-Tree | 34.27417 | -118.96617
43 | Tree | 34.27399 | -118.96564
44 | Tree | 34.27392 | -118.96642
45 | Non-Tree | 34.27450 | -118.96572
46 | Non-Tree | 34.27434 | -118.96602
47 | Non-Tree | 34.27395 | -118.96595
48 | Non-Tree | 34.27440 | -118.96603
49 | Tree | 34.27405 | -118.96597
50 | Tree | 34.27447 | -118.96570
Page 5 of 6
View 41 - 50 of 51
Remember, the more points you survey, the lower your Standard Error, and the more precise your sampling will be. More points surveyed provide for a better estimation of Land Cover across your study area.
Save Your Data
Save Data
Save Early. Save Often. Don't lose your project data!


How It Works
Report
Export
Start Over
Exit
?
Map
Satellite
Google
Map Data
Terms of Use
Report a map error
i-Tree Canopy v6.0
i-Tree
Percent Cover (±SE)
79.6
±5.76
20.4
±5.76
80
60
40
20
0
T
NT
Id | Cover Class | Latitude | Longitude
41 | Non-Tree | 34.27248 | -118.96576
42 | Tree | 34.27300 | -118.96554
43 | Tree | 34.27308 | -118.96561
44 | Non-Tree | 34.27311 | -118.96599
45 | Tree | 34.27197 | -118.96601
46 | Tree | 34.27312 | -118.96549
47 | Non-Tree | 34.27227 | -118.96566
48 | Tree | 34.27253 | -118.96565
49 | Tree | 34.27294 | -118.96541
50 | Tree | 34.27260 | -118.96602
Page 5 of 5
View 41 - 50 of 50
Remember, the more points you survey, the lower your Standard Error, and the more precise your sampling will be. More points surveyed provide for a better estimation of Land Cover across your study area.
Save Your Data
Save Data
Save Early. Save Often. Don't lose your project data!


How It Works
Report
Export
Start Over
Exit
?
Map
Satellite
Google
Map Data
Terms of Use
Report a map error
i-Tree Canopy v6.0
i-Tree
Percent Cover (±SE)
83.1
±4.45
16.9
±4.45
80
60
40
20
0
T
NT
Id | Cover Class | Latitude | Longitude
61 | Tree | 34.27417 | -118.96544
62 | Non-Tree | 34.27366 | -118.96512
63 | Non-Tree | 34.27444 | -118.96521
64 | Tree | 34.27436 | -118.96557
65 | Tree | 34.27430 | -118.96533
66 | Tree | 34.27369 | -118.96501
67 | Tree | 34.27348 | -118.96497
68 | Tree | 34.27383 | -118.96541
69 | Non-Tree | 34.27354 | -118.96502
70 | Tree | 34.27317 | -118.96515
Page 7 of 8
View 61 - 70 of 71
Remember, the more points you survey, the lower your Standard Error, and the more precise your sampling will be. More points surveyed provide for a better estimation of Land Cover across your study area.
Save Your Data
Save Data
Save Early. Save Often. Don't lose your project data!


How It Works
Report
Export
Start Over
Exit
?
Map
Satellite
i-Tree Canopy v6.0
i-Tree
Percent Cover (±SE)
90.1
±3.54
9.86
±3.73
100
80
60
40
20
0
T
NT
Id | Cover Class | Latitude | Longitude
61 | Non-Tree | 34.27360 | -118.96424
62 | Tree | 34.27439 | -118.96435
63 | Tree | 34.27406 | -118.96441
64 | Tree | 34.27324 | -118.96481
65 | Tree | 34.27451 | -118.96458
66 | Tree | 34.27419 | -118.96427
67 | Tree | 34.27351 | -118.96457
68 | Tree | 34.27430 | -118.96434
69 | Non-Tree | 34.27350 | -118.96478
70 | Tree | 34.27394 | -118.96486
Page 7 of 8
View 61 - 70 of 71
Google
Map Data
Terms of Use
Report a map error
Remember, the more points you survey, the lower your Standard Error, and the more precise your sampling will be. More points surveyed provide for a better estimation of Land Cover across your study area.
Save Your Data
Save Data
Save Early. Save Often. Don't lose your project data!

APPENDIX E

Manifold Flows and Critical Path Data

Manifold 1

Riser	Sprinklers	GPH	GPM	GPM	Sprayers	GPH	GPM	Total GPM
1	44	5.3	0.09	-	-	-	-	3.89
2	44	5.3	0.09	-	-	-	-	3.89
3	44	5.3	0.09	-	-	-	-	3.89
4	44	5.3	0.09	-	-	-	-	3.89
5	44	5.3	0.09	-	-	-	-	3.89
6	44	5.3	0.09	-	-	-	-	3.89
7	44	5.3	0.09	-	-	-	-	3.89
8	44	5.3	0.09	-	-	-	-	3.89
9	44	5.3	0.09	-	-	-	-	3.89
10	44	5.3	0.09	-	-	-	-	3.89
11	44	5.3	0.09	-	-	-	-	3.89
12	44	5.3	0.09	-	-	-	-	3.89
13	44	5.3	0.09	-	-	-	-	3.89
14	46	5.3	0.09	-	-	-	-	4.06
15	52	5.3	0.09	-	-	-	-	4.59
16	56	5.3	0.09	-	-	-	-	4.95
17	57	5.3	0.09	-	-	-	-	5.04
18	58	5.3	0.09	-	-	-	-	5.12
19	42	15.3	0.26	-	-	-	-	10.71
20	42	15.3	0.26	-	-	-	-	10.71
21	42	15.3	0.26	-	-	-	-	10.71
22	52	7.4	0.12	6.41	16	15.3	0.255	10.49
23	52	7.4	0.12	6.41	16	15.3	0.255	10.49
24	52	7.4	0.12	6.41	16	15.3	0.255	10.49
25	52	7.4	0.12	6.41	16	15.3	0.255	10.49
26	52	7.4	0.12	6.41	16	15.3	0.255	10.49
27	52	7.4	0.12	6.41	16	15.3	0.255	10.49
28	26	7.4	0.12	3.21	8	15.3	0.255	5.25

Total GPM in Manifold 1 =	174.63

GPM = 5.3 GPH / 60 minutes = .09 GPM
Total Lateral GPM = 44 sprinklers x .09 GPM = 3.89 GPM
Total Manifold GPM = sum of all 28 lateral flows = 174.63

Manifold 2

Riser	Sprayers	GPH	GPM	Total GPM
1	31	15.3	0.255	7.91
2	35	15.3	0.255	8.93
3	36	15.3	0.255	9.18
4	30	15.3	0.255	7.65
5	30	15.3	0.255	7.65
6	30	15.3	0.255	7.65
7	38	15.3	0.255	9.69
8	38	15.3	0.255	9.69
9	38	15.3	0.255	9.69
10	19	15.3	0.255	4.85

Total GPM in Manifold 2 =	82.88

Manifold 3

Riser	Sprayers	GPH	GPM	Total GPM
1	10	15.3	0.255	2.550
2	13	15.3	0.255	3.315
3	21	15.3	0.255	5.355
4	16	15.3	0.255	4.080
5	24	15.3	0.255	6.120
6	15	15.3	0.255	3.825

Total GPM in Manifold 3 =	25.245

Total System GPM = 174.63 GPM + 82.88 GPM + 25.245 GPM = **282.75 GPM**

	CRITICAL PATH - Manifold 1, Riser 21							
	Pipe Size	Inside	Sch./		Sec.		Fric.	Sec.
Sec	Nominal	Diameter	Class	Flow	Length	Velocity	Loss	Fric. Loss
	(in)	(in)		(gpm)	(ft)	(ft/s)	(psi/100ft)	
1	3/4	0.805	Hose	0.255	18	0.16	0.03	0.00 psi
2	3/4	0.805	Hose	0.51	18	0.32	0.09	0.02 psi
3	3/4	0.805	Hose	0.765	18	0.48	0.19	0.04 psi
4	3/4	0.805	Hose	1.02	18	0.64	0.33	0.06 psi
5	3/4	0.805	Hose	1.275	18	0.80	0.50	0.09 psi
6	3/4	0.805	Hose	1.53	18	0.96	0.70	0.13 psi
7	3/4	0.805	Hose	1.785	18	1.12	0.94	0.17 psi
8	3/4	0.805	Hose	2.04	18	1.28	1.20	0.22 psi
9	3/4	0.805	Hose	2.295	18	1.44	1.49	0.27 psi
10	3/4	0.805	Hose	2.55	18	1.61	1.81	0.33 psi
11	3/4	0.805	Hose	2.805	9	1.77	2.16	0.19 psi
	Desired Average Pressure			25 psi	psi	Pipe Friction Loss		1.51 psi
	Elevation Difference			2	ft	Minor Losses (10%)		0.15 psi
	If spr is uphill from lateral inlet, enter a pos. #					*(+uphill,-downhill)*		0.87 psi
	If spr is downhill from lateral inlet, enter a neg. #					**Total Friction Loss**		**2.52 psi**
Inlet Pres. = Ave. Pres. + k(Total Friction Loss))								
+ 0.5(± Ele. diff/2.31 ft/psi)			*k = 0.75 for laterals using a single pipe size*				k =	0.75
			k = 0.67 for laterals using 2 or more pipe sizes					
					Required Inlet Pressure			**27.33 psi**
	SUBMAIN - Riser and 23' Section of Hose							
	Pipe Size	Inside	Sch./		Sec.		Fric.	Sec.
	Nominal	Diameter	Class	Flow	Length	Velocity	Loss	Fric. Loss
Sec	(in)	(in)		(gpm)	(ft)	(ft/s)	(psi/100ft)	
1	3/4	0.805	hose	5.355	23	3.37	6.30	1.45 psi
2	3/4	0.805	hose	10.71	12	6.74	22.75	2.73 psi
						Total Friction Loss		**4.18 psi**
	CONTROL VALVES							
Zone	Name					Flow		Fric. Loss
1	PGV-ASV 1"			*Critical Path*		6.7 gpm		**1.50 psi**
							Total =	33.01

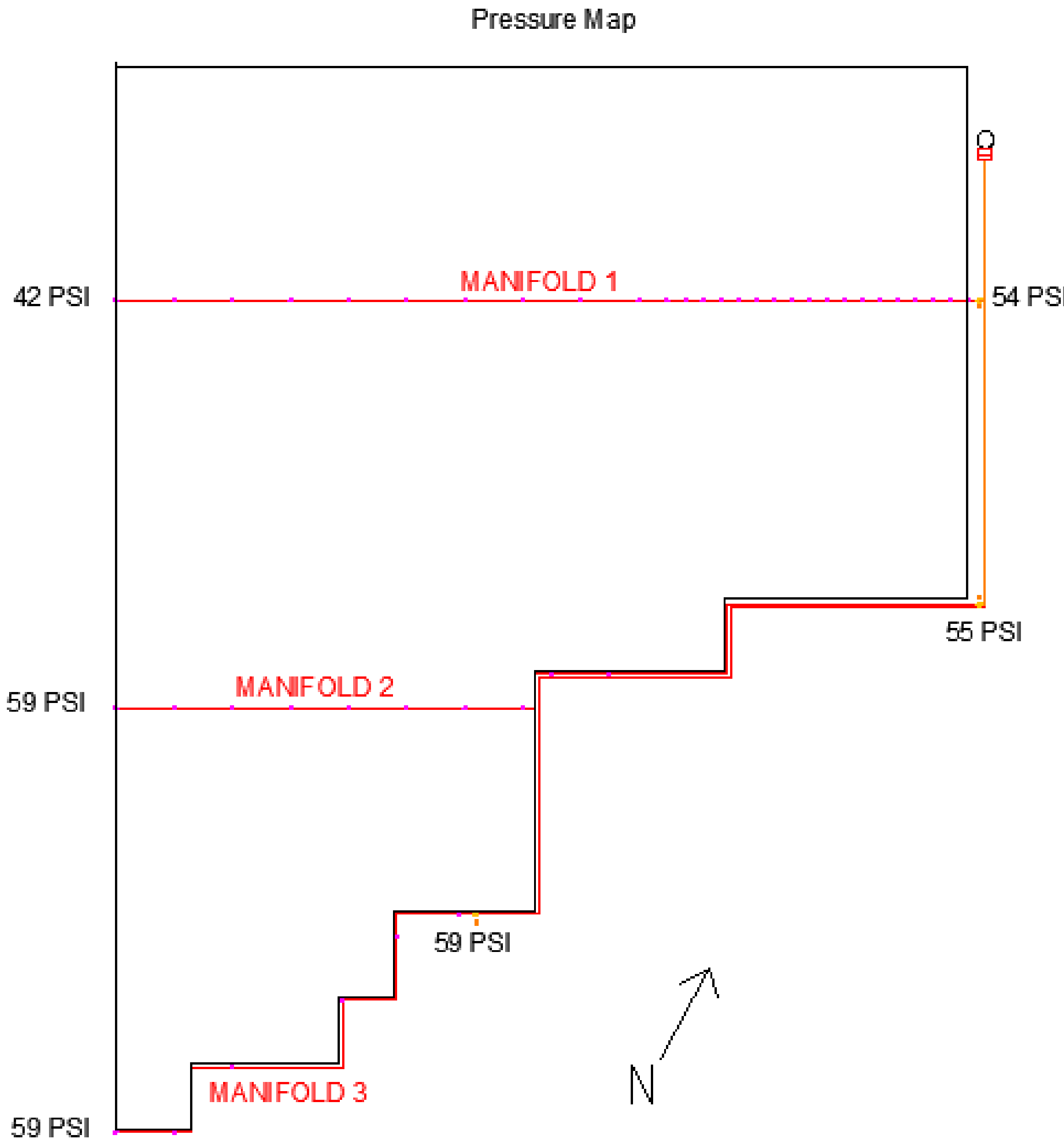
Friction Loss in Hose: Hf = 10.5 x (GPM/C)^1.852 x L x ID^-4.87

	CRITICAL PATH - Manifold 1							
	Pipe Size	Inside	Sch./		Sec.		Fric.	Sec.
Sec	Nominal	Diameter	Class	Flow	Length	Velocity	Loss	Fric. Loss
	(in)	(in)		(gpm)	(ft)	(ft/s)	(psi/100ft)	
1	1 1/2	1.784	c125	5.25	23	0.67	0.13	0.03 psi
2	1 1/2	1.784	c125	15.74	46	2.02	0.96	0.44 psi
3	1 1/2	1.784	c125	26.23	46	3.36	2.48	1.14 psi
4	2 1/2	2.699	c125	36.72	46	2.06	0.62	0.28 psi
5	2 1/2	2.699	c125	47.21	46	2.64	0.98	0.45 psi
6	2 1/2	2.699	c125	57.7	46	3.23	1.42	0.65 psi
7	2 1/2	2.699	c125	68.19	46	3.82	1.94	0.89 psi
8	2 1/2	2.699	c125	78.9	46	4.42	2.54	1.17 psi
9	2 1/2	2.699	c125	89.61	46	5.02	3.21	1.48 psi
10	4	4.224	c125	100.32	46	2.29	0.45	0.21 psi
11	4	4.224	c125	105.44	14	2.41	0.49	0.07 psi
12	4	4.224	c125	110.48	14	2.53	0.53	0.07 psi
13	4	4.224	c125	115.43	14	2.64	0.58	0.08 psi
14	4	4.224	c125	120.02	14	2.74	0.62	0.09 psi
15	4	4.224	c125	124.08	14	2.84	0.66	0.09 psi
16	4	4.224	c125	127.97	14	2.93	0.70	0.10 psi
17	4	4.224	c125	131.86	14	3.02	0.74	0.10 psi
18	4	4.224	c125	135.75	14	3.10	0.78	0.11 psi
19	4	4.224	c125	139.64	14	3.19	0.82	0.12 psi
20	4	4.224	c125	143.53	14	3.28	0.87	0.12 psi
21	4	4.224	c125	147.42	14	3.37	0.91	0.13 psi
22	4	4.224	c125	151.31	14	3.46	0.96	0.13 psi
23	4	4.224	c125	155.2	14	3.55	1.00	0.14 psi
24	4	4.224	c125	159.09	14	3.64	1.05	0.15 psi
25	4	4.224	c125	162.98	14	3.73	1.10	0.15 psi
26	4	4.224	c125	166.87	14	3.82	1.15	0.16 psi
27	4	4.224	c125	170.76	14	3.90	1.20	0.17 psi
28	4	4.224	c125	174.65	14	3.99	1.25	0.17 psi
	Desired Average Pressure			55 psi	psi	Pipe Friction Loss		5.06 psi
	Elevation Difference			-6	ft	Minor Losses (10%)		0.51 psi
	If spr is uphill from lateral inlet, enter a pos. #					*(+uphill,-downhill)*		-2.60 psi
	If spr is downhill from lateral inlet, enter a neg. #					**Total Friction Loss**		**2.97 psi**
Inlet Pres. = Ave. Pres. + k(Total Friction Loss))								
+ 0.5(± Ele. diff/2.31 ft/psi)			*k = 0.75 for laterals using a single pipe size*				k =	0.75
			k = 0.67 for laterals using 2 or more pipe sizes					
							Required Inlet Pressure	**55.93 psi**

Friction Loss in Hose: Hf = 10.5 x (GPM/C)^1.852 x L x ID^-4.87

APPENDIX F

Irrigation System Design Drawings



Pressure Map
42 PSI
MANIFOLD 1
54 PSI
55 PSI
59 PSI
MANIFOLD 2
59 PSI
MANIFOLD 3
59 PSI
N