May 2014

Exploring Efficient Irrigation Methods for the Pueblo of Santa Ana

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Repository Citation

Gonzalez, D., Paulson, E. K., Khayami, M. L., & Hedlund, R. H. (2014). *Exploring Efficient Irrigation Methods for the Pueblo of Santa Ana*. Retrieved from https://digitalcommons.wpi.edu/iqp-all/1477

Exploring Efficient Irrigation Methods
For the Pueblo of Santa Ana

An Interactive Qualifying Proposal submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of the Bachelor of Science.

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Acknowledgments

We would like to thank the following people for their support throughout our project:

The Pueblo of Santa Ana Water Resources Division for sponsoring our project.

Joseph McGinn of the Pueblo of Santa Ana Water Resources Division for his knowledge and being our liaison to the Pueblo.

Governor George Montoya and Aaron Montoya of the Santa Ana Pueblo for allowing us to use their field for our study.

Jean Foster and Brian Sweet of the Natural Resources Conservation Service for providing equipment and assisting us with our efficiency study.

Professors Lauren Mathews and Fabio Carrera for advising our project.

The City of Santa Fe and Fort Marcy Hotel for providing such excellent hospitality during our stay.

Abstract

The goal of this project was to assist the Pueblo of Santa Ana Water Division's efforts to increase irrigation efficiency by proposing an irrigation plan for the newly acquired Northern Field. To create this plan, we designed multiple layouts for the field to try to optimize the area of the field, water efficiency, as well as monetary cost to implement an irrigation system on the Northern Field. To accomplish this, we conducted an efficiency study using the two methods of flood irrigation found in the Pueblo, and compared the two methods to theoretical data on drip and sprinkler irrigation. We provided a breakdown of the monetary costs for each irrigation layouts we designed for the Northern Field, and also designed a new platform for communication between the farmers and the Mayordomo to help scheduling and to eliminate wasteful irrigation practices. Finally, we used our analysis to provide recommendations that would best fit the Pueblo's cultural values and practical needs.

Executive Summary

Being situated in Sandoval County, New Mexico, which is an arid region of the country, the Pueblo of Santa Ana must irrigate to sustain agriculture throughout their growing season, which runs from April 1st to October 31st. Traditionally, the Pueblo uses farm gate flood irrigation, a method in which water is transported through ditches, laterals and sub-laterals until it reaches the field. At this point, the farmer can open gates to allow water to flow onto and flood his field. This system is managed by an official known as the Mayordomo, who is responsible for controlling the flow of water throughout the Pueblo lands and aiding the farmers in the scheduling of their irrigation. However, traditional methods, while less costly than other systems of irrigation, are inherently more wasteful of precious water than more efficient systems such as sprinkler or drip irrigation. Recently, however, the Pueblo has been making great strides toward increasing irrigation efficiency. For example, they have lined some of the traditionally earthen ditches with concrete, replaced wooden check gates with steel, leveled the fields, and implemented a newer method of flood irrigation using bubblers instead of farm-gates. One other source of lost water comes from user error: in addition to water loss through evaporation and transpiration, sometimes a farmer will leave a gate open for too long, and cause an overflow from the field.[1]

Due to the recent settlement of a long-time border dispute, the Pueblo of Santa Ana obtained nearly 160 acres of land, known as the Northern Field, which they intend to allocate for farming. In efforts to conserve water, the Pueblo of Santa Ana is researching more efficient irrigation methods to use; however, there is a conflict between more efficient irrigation technologies and the traditional agricultural practices of the Pueblo. While farmers who are members of the older generations prefer traditional methods of agriculture and irrigation, members of the younger generation are pushing for more efficient methods of irrigation.[2] With these fields, the Santa Ana Water Division wants to implement an irrigation method that provides the greatest water efficiency possible while still being acceptable within the Pueblo. The goal of this project was to assist the Pueblo of Santa Ana Water Division's efforts to increase irrigation efficiency by proposing an irrigation plan for the newly acquired Northern Field. In order to achieve this, we implemented four objectives:

1. Evaluating the geography northern field and designing alternative layouts for flood, drip, and sprinkler irrigation systems.
2. Analyzing the relative efficiency of flood and alternative irrigation systems for the Northern Field.
3. Estimating the monetary costs to install and maintain each irrigation system designed for the Northern Field.

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[1] Gall et al., 2013

[2] McGinn, personal communication 2014

4. Designing a smartphone application to enhance coordination for irrigation throughout the Pueblo.

To do this, we observed the geography and conditions of the Northern Field as well as Field 29, which we used as an experimental field and which is maintained by Governor George Montoya and his son Mr. Aaron Montoya. Our observations were coordinated and assisted by the supervision of Mr. Glenn Tenorio, a former Mayordomo and Tribal Council Member, and Mr. Joseph McGinn, our liaison, of the Pueblo Water Resources Division. Together, we conducted the beginnings of an efficiency study on Field 29 for the Pueblo Natural Resources Division. Eventually, they will utilize the data collected to improve irrigation and irrigation scheduling on the Pueblo. We used the knowledge gained from this study to create plans for the layout of the Northern Field that would be both cost and water efficient, using irrigation optimization software and various efficiency calculations. Then, we compared these results to the costs for and efficiencies of alternative systems. This allowed us to determine which system and layout we would recommend to the Tribal Council and the Pueblo at the end of our study. At the request of our liaison, we also designed and began to develop an application for a smartphone that would help to enhance communication between the farmers and the Mayordomo that would help organize irrigation timing and scheduling and prevent wasteful accidents when gates are left open for too long.

Ultimately, we designed multiple layouts, and, for each of them, we determined necessary equipment and estimated implementation costs and water efficiencies. Drip irrigation methods were ruled out as an option due to the high maintenance requirements, costs of implementing the automated system (which would require electricity and a pumping system and reserve tank), and difficulties presented by the thick clay soils. With the same reasons as drip irrigation, as well as the large manual labor requirements associated with moving the sprinkler system, we determined sprinkler irrigation would not be plausible. In addition, we thought it unlikely that either of these systems would be accepted by the older generations.

In the end, we found that flooding could be made to be almost as efficient as the estimates we developed for drip and sprinkler systems. We found the average application efficiency for both drip and sprinkler irrigation was calculated to be 90% while the new fields we created with either farm gate or bubbler flood irrigation was calculated to be around 94% efficient. Therefore, we recommend two different layouts using bubbler flood irrigation. One of the layouts is a 200’x500’ field which offers 35 fields and costs $380,550 and only takes 2-4 hours to irrigate, while the other layout is 250’x500’ and takes 4-6 hours to irrigate. This entire layout has 31 fields and costs $369,624 to implement on the Northern Field. Both of the layouts have an application efficiency of 94%. We also recommend using the tensiometers, so that the farmers have a better idea of when they actually need to irrigate so they can irrigate efficiently. And lastly we also recommend using the cell phone and computer application to better coordinate the irrigation schedule between the Mayordomo and farmers in the Pueblo of Santa Ana.

We also recommend the implementation of measures that the Pueblo has already begun, such as replacing farm gates and sub-laterals with bubblers and underground piping, exchanging wooden gates that easily become distorted with age and water damage with steel, laser leveling fields in order to more evenly apply water to the fields, shortening flood fields in order to reduce water lost to evaporation and more evenly distribute water in the clay-type soil of the Pueblo.

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1 Introduction

Irrigation uses 60 percent of the world's freshwater.[3] Every year, the United States alone uses 144 million acre-feet for irrigation, accounting for 67 percent of the U.S.'s freshwater withdrawals.[4] In the West, the United States has been experiencing a drought for the past three years and therefore has had to cut down on water use.[5] Most of the western states have been experiencing low rainfall, as well as moderate to severe drought conditions. Due to these conditions, in 2005, New Mexico used 78% of its water withdrawals for 875,415 acres of irrigated land.[6] With such a large reliance on water for irrigation, water conservation is essential.

The average annual rainfall in New Mexico is around 10 inches a year, about one third of the average amount of rainfall the entire U.S acquires.[7] This arid environment makes it difficult to rely solely on rainwater for agriculture. Therefore, farmers use irrigation systems that take up surface water from nearby reservoirs and rivers like the Rio Grande, as well as ground water from wells, to irrigate their crops. New Mexico uses around 3 million acre-feet of both surface and ground water withdrawals for irrigation every year, around .76% of the total water withdrawal's in the U.S. This water is distributed according to water rights enforced by the state engineer to regulate the use of water in order to determine how much water is being used.

The three most common irrigation methods in the U.S. are flood, sprinkler, and drip irrigation. Flood irrigation, is the least expensive to implement, can be more wasteful than either sprinkler or drip irrigation, because a larger proportion of the water is lost through surface evaporation and transpiration within the soil. For this reason, farmers in New Mexico are switching from flood irrigation to drip irrigation. In an interview for Western Farm Press, a New Mexico farmer, Don Hartman, describes his experience with drip irrigation, "I probably wouldn't be farming now if I hadn't converted to drip…Drip irrigation saves so much. If you can afford the initial investment, it's a no-brainer."[8]

The Pueblo of Santa Ana has traditionally used flood irrigation to water its fields throughout the irrigation season, between April 1st and October 31st. The Pueblo elects one of its members as the *Mayordomo* to develop the irrigation schedule and to coordinate and oversee the farmers irrigating their fields. The systems the Mayordomo manages are all variants of flood irrigation, which requires the manual opening of gates, for a predetermined amount of time, to allow water to flow onto the fields from

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[3] United States Geological Survey, 2000
[4] Kenny et al., 2009
[5] Nagourney and Lovett, 2014
[6] United States Geological Survey, 2014
[7] NOAA National Climatic Data Center, 2014
[8] Blake, 2010

ditches that transport the water from the river. In addition to evaporation and transpiration, water can be lost when a farmer leaves a gate open for too long, and causes an overflow from the field.[9] In efforts to conserve water, the Pueblo of Santa Ana is researching more efficient irrigation methods to use; however, there is a conflict between more efficient irrigation technologies and the traditional agricultural practices of the Pueblo. While members of the older farming generation prefer traditional methods of agriculture and irrigation, members of the younger generation are pushing for more efficient methods of watering their fields.[10] The Pueblo has recently obtained new agricultural fields from a settlement with the neighboring Pueblo of San Felipe. These new fields (which we refer to as the Northern Field) provide an opportunity for the Santa Ana Water Division to explore irrigation methods that could provide the greatest water efficiency possible while still being acceptable within the Pueblo.

Over the last few years, the Pueblo of Santa Ana has been making great strides toward increasing irrigation efficiency, while still upholding the traditional methods of flood irrigation. Many of the fields that are currently in use have been laser-leveled to give a more even dispersion of water to the fields and reduce runoff. New steel gates have been built to replace older wooden ones that were used previously, thus reducing the water that would leak through the wood, and preventing the gradual deterioration of the wooden gates that would lead to further water loss. Similarly, earthen ditches have been lined with concrete in order to prevent water loss to the earth. Efforts have also been made to use modern communication methods to connect the farmers to the Mayordomo to better coordinate the irrigation process.[11] Despite all of the recent improvements, traditional flood irrigation is still an inefficient system. While flood irrigation is a low-cost method that is easy to maintain, a large portion of the water used is lost to the environment, either through evaporation or by seeping into the ground outside of planted areas, or into the ground below the root zone.

The goal of this project was to assist the Pueblo of Santa Ana Water Division's efforts to increase irrigation efficiency by proposing an irrigation plan for the new Northern Field. We accomplished this by evaluating the geography of the Northern Field and creating a plan for irrigation for each type of system (flood, drip and sprinkler systems), conducting an irrigation efficiency study of the three systems, and providing an assessment of the monetary costs for the installation and maintenance of each system. . We also designed an application to enhance coordination between the farmers and the Mayordomo in the Pueblo of Santa Ana.

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[9] Gall et al., 2013
[10] McGinn personal communication, 2014
[11] Gall et al., 2013

2 Background

In New Mexico, drought is an ever-present reality, and water conservancy is not only stressed, but also mandated by the state government. [12] In this chapter we will discuss agriculture in New Mexico, water rights and water usage in the arid Southwest, and the current system of irrigation maintained in the Pueblo of Santa Ana. Then we review different systems of irrigation and highlight the advantages and disadvantages of each. Finally, we cover important concepts central to agricultural irrigation and water management that include water potential, evapotranspiration and soil conditions.

2.1 Agriculture in New Mexico

Agriculture has been practiced in the southwestern United States since 2100 B.C.[13] It encompasses not only the farming of crops, but also the raising of livestock. Native Americans, Spanish explorers, and Anglo pioneers all contributed to the development of agriculture in New Mexico.[14] The Spanish influenced the people of New Mexico by bringing domesticated animals such as sheep, cattle, and hogs to the region.

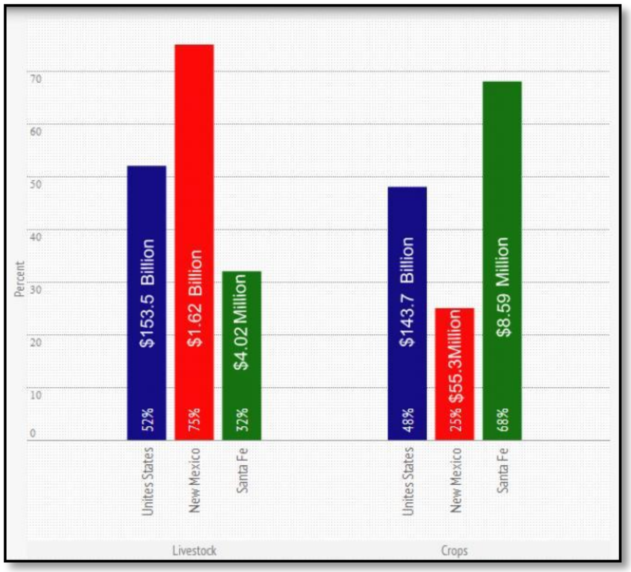

Figure 1: Relative and absolute annual revenue from livestock and crops for the United States, New Mexico, and the Santa Fe County area

In 2007, New Mexico had a market value of 2.175 billion dollars in agricultural products. Figure 1 shows the percentages of revenue gained from the sale of agricultural products, and compares the United States, New Mexico and Santa Fe's revenue percentages.[15] The raising of livestock is prevalent among the farmers of New Mexico, proven by the fact that in 2012 three of the top agricultural products were cattle, dairy products and hay, which is used as feed for cattle.[16]

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[12] The State of New Mexico, 1978
[13] Tamaya NSN, 2010
[14] New Mexico Agriculture, 2013
[15] Vilsack & Clark, 2009
[16] Farm Flavor, 2014.

2.1.1 Agriculture Within the Pueblo of Santa Ana

In the Pueblo of Santa Ana, agriculture is important to the people of Santa Ana as it was their original occupation and is part of their cultural and religious beliefs.[17] The farmers of the Pueblo focus on the cultivation of two drought-tolerant crops, blue corn and alfalfa. Blue corn is used for the religious and cultural ceremonies, as well as an export for the Pueblo, under the brand name *Tamaya Blue*.[18] Although blue corn is important to the people of Santa Ana, their main crop is alfalfa [19], a low maintenance crop that suits the people of Santa Ana, who generally do not farm full time.[20] Alfalfa hay makes up approximately 95% of the Pueblo's agricultural production[21]. Alfalfa is mainly used as a food source for cattle and is easy to sell since the main agricultural product of New Mexico is livestock.

Traditionally, land is allotted to farmers in one of two ways: either a plot of land is assigned to a farmer by the Tribal Council and is passed down the family line, or the farmer leases the land. In general, in the Pueblo, farmers use the traditional method of irrigation by flooding their fields from ditches that are filled using gates from laterals connected to canals diverted from the Rio Grande. Before this irrigation can begin, the Pueblo celebrates a day of spiritual importance in which pueblo members ceremonially clean the ditches and prepare the waterways for irrigation. On this day, any male of the Pueblo between the ages of 18 and 65 must participate in the cleaning of the ditches unless otherwise excused, and non-Pueblo members are not allowed to take part in this significant event.[22] The ditches are traditionally cleaned by burning the overgrown brush and then manually removing remaining debris, which used to take multiple days. Today, with modern technology this process has been shortened to just a few hours.[23]

Today Santa Ana farmers are farming part-time not only to create extra income, but also to keep in touch with their culture, religion, and heritage.[24] According to our liaison, Mr. Joseph McGinn, the Pueblo has been edging a fine line between celebrating traditional practices and embracing modern conveniences.[25] While many older farmers prefer to maintain traditional methods of flood irrigation, which allows them to see the water running from the ditches to the fields, the younger generation is becoming increasingly concerned with the conservation of water. This is leading to tribal discussions on the possible implementation of newer, more efficient systems.[26]

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[17] Indian Pueblo Cultural Center, 2007
[18] The Pueblo of Santa Ana, n.d.
[19] Pueblo of Santa Ana – SantaFedia, 2013
[20] McGinn personal communication, 2014
[21] Gall et al., 2013
[22] McGinn personal communication, 2014
[23] Tenorio personal communication, 2014
[24] Indian Pueblo Cultural Center, 2007
[25] McGinn personal communication, 2014
[26] A. Montoya personal communication, 2014

2.2 Water Use

A total of 144 million acre-feet of water was used in the United States in 2005 for household use as well as livestock, irrigation, mining, power, and industrial purposes. Around 37% of the total water in the United States in 2005 is used for irrigation.[27]

New Mexico used a total of 3.95 million acre-feet of water in 2005, using 77% of the total water for irrigation.[28] The source of water for irrigation is from both ground water and surface water. As Figure 2 shows, the ground water and surface water uptake were fairly even, using around 1.7 million acre-feet of surface water and 1.3 million acre-feet of ground water.[29] Ground water is found below the earth's surface. Moving slowly through the permeable rock system ground water is eventually stored in aquifers. Farmers drill wells and use ground water when the surface water is not easily accessible to their farm.

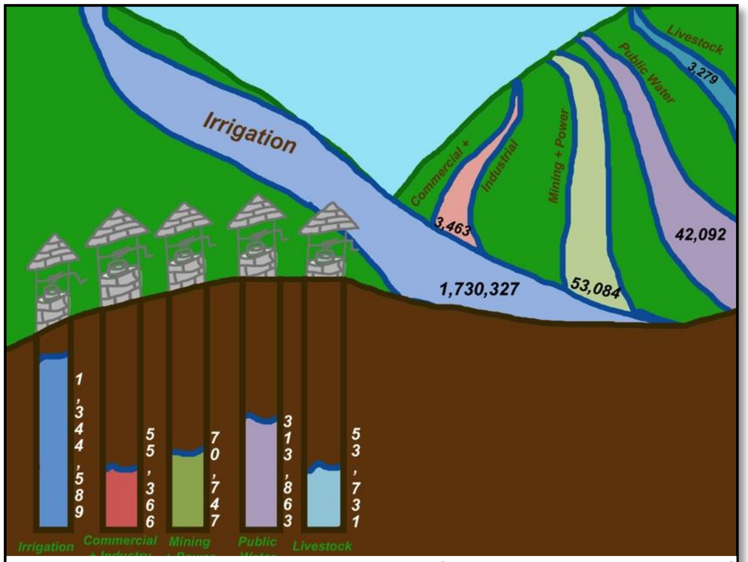

Figure 2: New Mexico's water use in acre-feet per year. The top part of the picture shows the use of surface water, while the bottom left shows the use of ground water sources.

Surface water is any water on the surface of the planet, including rivers, streams, lakes, wetlands, and even the ocean. Surface water can be utilized by using diversions and dams along rivers.

Stretching over 1,900 miles, from southern Colorado to the Gulf of Mexico, the Rio Grande is the main source of surface water in New Mexico since the 1500's[30]. However, due to the almost 8% increase in population along the river since 2005[31], there has been more of a demand on the river's water, causing dry riverbeds as it nears the Gulf of Mexico. Although the Pueblo of Santa Ana is not affected at the moment, the amount of water used in the pueblo does affect the other irrigation systems south of the pueblo.

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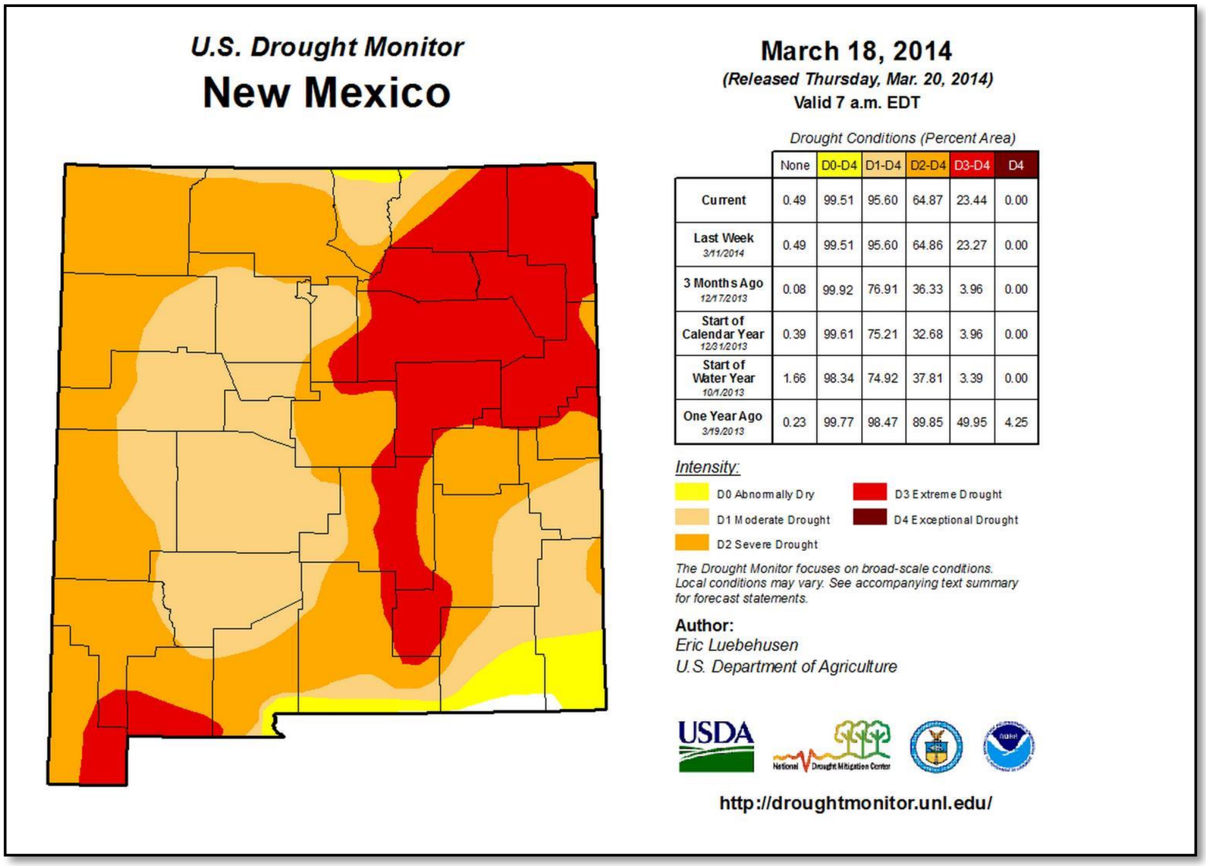
[27] Kenny et al., 2009

[28] Ibid

[29] Longworth et al., 2008

[30] The Pueblo of Santa Ana, n.d

[31] Longworth et al., 2008



U.S. Drought Monitor

New Mexico

March 18, 2014

(Released Thursday, Mar. 20, 2014)

Valid 7 a.m. EDT

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	0.49	99.51	95.60	64.87	23.44	0.00
Last Week 3/11/2014	0.49	99.51	95.60	64.86	23.27	0.00
3 Months Ago 12/17/2013	0.08	99.92	76.91	36.33	3.96	0.00
Start of Calendar Year 12/31/2013	0.39	99.61	75.21	32.68	3.96	0.00
Start of Water Year 10/1/2013	1.66	98.34	74.92	37.81	3.39	0.00
One Year Ago 3/19/2013	0.23	99.77	98.47	89.85	49.95	4.25

Intensity:

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Eric Luebehusen
U.S. Department of Agriculture

http://droughtmonitor.unl.edu/

Figure 3: USDA U.S. Drought Monitor data for New Mexico, as of March 18, 2014. The left panel shows the intensity of the drought throughout New Mexico with dark reddish brown being the most intense and yellow being the least intense. The panel on the right shows the percent area under drought conditions over the past year.

For the past year, the United States Department of Agriculture (USDA) has been monitoring the current surface water drought conditions in the United States. They have predicted that more regions in the western United States will develop drought conditions, even leading into the wild fire season. Figure 3[32] indicates that the drought will likely be more intense than previous years. In times of drought, it is important to make sure the amount of water is regulated to each farmer to water the fields.

In New Mexico, water usage is regulated by the Office of the State Engineer (OSE) by applying water rights over the Rio Grande, established in 1907. Water rights are the legal rights to use water for a specific purpose. The oldest water rights belong to those who inhabited the area first and include the use of *acequias*, or earthen ditches, that divert surface water for distribution to the native Pueblos. . These water rights ensure that the Pueblos have the first priority. The New Mexico state engineer is then responsible for regulating all of the surface water and making sure the Pueblos receive water for their irrigation systems, as well ensuring that water is running through the Rio Grande and into Texas. [33]

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[32] USDA, 2014
[33] Regulation of Water Versus Hydrolic Reality in New Mexico, 2003

Within the Pueblo, water use is viewed differently. The Pueblo is considered to be a sovereign nation, and has its own rules and regulations. While farmers who wish to irrigate must still file for a water right, they also need to follow the rules for irrigation within the Pueblo. Once a water right is issued, the Mayordomo is notified and farmers can ask to irrigate their farm whenever it is needed.

2.3 Water Management at the Pueblo of Santa Ana

The Pueblo's Tribal Government created the Pueblo of Santa Ana Department of Natural Resources (DNR) in 1996 in order to develop and promote better natural resource management practices.[34] The DNR consists of five divisions, one of them being the Santa Ana Pueblo Water Resources Division (WRD).[35] The goal of the WRD is to help the government and the people preserve their land and deals with any water issues such as protection of all wells on the Pueblo, community outreach to Pueblo members regarding water resources and irrigation and flood control.[36] The WRD works with a larger organization called the Natural Resources Conservation Service (NRCS). The mission of the NRCS is to work with farmers, local and state governments, and federal agencies to help maintain healthy and working landscapes by providing information and financial assistance.[37] Together the NRCS and the WRD have been working to increase irrigation efficiency on the Pueblo.

A set of agreements in the 1920s between the Bureau of Indian Affairs and Middle Rio Grande Conservancy District (MRGCD), which maintains and monitors the water in the Rio Grande, were established to assign which parts of the irrigation system each organization would operate. The MRGCD has broken down the operations by two categories: Major facilities (List A) and minor ones (List B). List A facilities are major water systems directly controlled by the MRGCD, which include the Albuquerque Main Canal, the head of the Indian Ditch, and several other primary ditches and drains. List B facilities are locally operated by smaller communities, including pueblos. The Pueblo of Santa Ana controls List B facilities such as the remaining segment of the Indian Ditch and all other elements of the irrigation structure within the Pueblo that are not controlled by the MRGCD.[38] This separation allows for the Santa Ana Water Resource Division to control the water needed by the farmers during the irrigation season once it enters the Pueblo's section of the Indian Ditch. The WRD works with the tribally elected *Mayordomo* to operate the irrigation structure, which include the ditches, valves, and floodgates.

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[34] The Pueblo of Santa Ana Department of Natural Resources, n.d.

[35] Gall et al., 2013

[36] USDA Natural Resources Conservation Service, n.d.

[37] History of NRCS, 2014

[38] Gall et al., 2013

Figure 4 shows the irrigation layout of the Pueblo of Santa Ana that the *Mayordomo* has to manage.

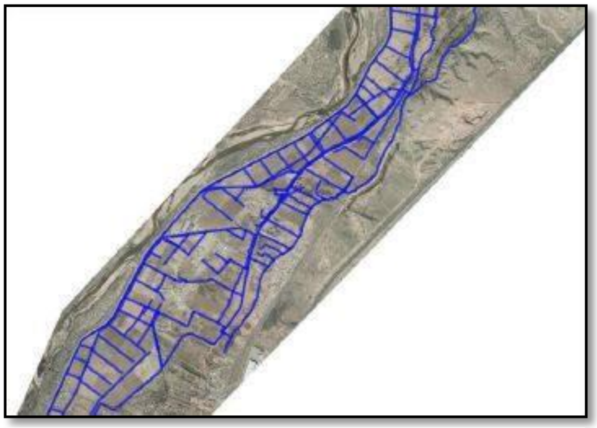

Figure 4 - The irrigation layout the Mayordomo manages in the Pueblo of Santa Ana. The blue lines indicate where the water flows within the Pueblo.

2.4 Irrigation Methods

There are many irrigation systems in use around the world, but they generally fall into one of three categories: flood irrigation, drip irrigation, and sprinkler irrigation, which vary in implementation cost and efficiency. In this section, we review drip irrigation, sprinkler irrigation and flood irrigation. In order to recommend the most efficient irrigation method, we researched different irrigation methods based on water efficiency, monetary cost for both installation and maintenances, and other advantages, and disadvantages of the each individual system.[39] In New Mexico, a slight majority of farms (51% by acre) utilize flood irrigation, while 47 % by acre use sprinkler irrigation, and only 2% by acre use drip irrigation[40].

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[39] Gall et al., 2013

[40] Ibid

2.4.1 Drip Irrigation

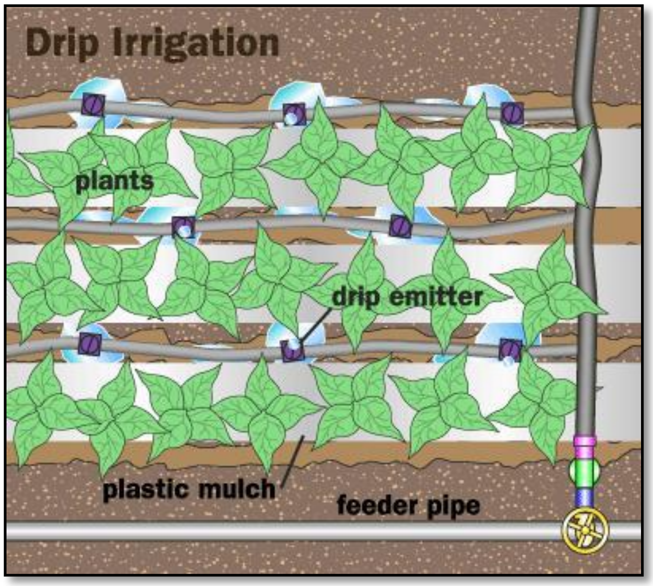

Figure 5: A diagrammatic representation of a drip irrigation system, showing layout of the water delivery system and drip emitters which release water to the crops.

Drip irrigation is one of the most efficient methods of irrigation in most cases. It allows water to be applied directly to the roots of the crop, causing minimal evaporation to occur.[41] In a study at the University of North Dakota State University it was concluded that the main disadvantage of drip irrigation is its cost, as it can be up to about $2,470 hect-acre.[42] The larger the fields, the more water hoses and emitters the infrastructure needs, making the cost increase as the field increases in size. One disadvantage with drip irrigation is that the hoses need to be moved every year because the field needs to be prepared for the next irrigation season, for example leveling or plowing the field. If the hoses are not removed then the filed preparations can damage the hoses and entire system. Figure 5[43] shows the drip irrigation method.

The supplies needed to install drip irrigation include components necessary to deliver water to the fields which include the pump, tank, mainlines, sub-mainlines (supply mainlines), drip lines, valves and emitters. The other supplies needed for drip irrigation include parts needed for filtration and maintenance of the system that includes the filter, flush valves and flush manifolds, as shown in Figure 5[44] and Figure 6[45]. Figure 7[46] shows the layout of a typical drip irrigation system.

Figure 6: Drip irrigation system components

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[41] Gall et. al., 2013
[42] Ibid
[43] Enisco, 2004
[44] Ibid
[45] Ibid
[46] Ibid

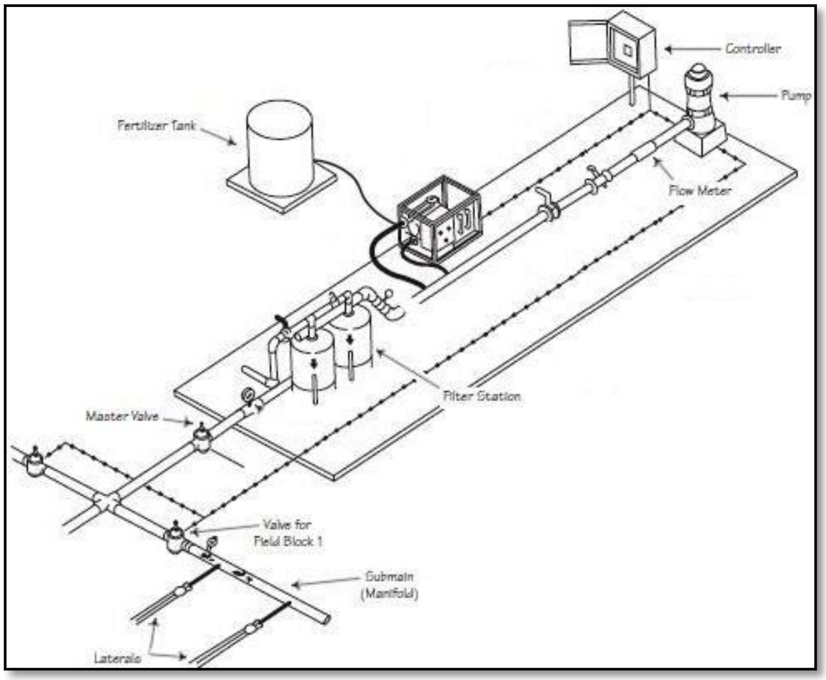

Figure 7: Drip irrigation layout showing the where the pump, filtration, and tank are located.

Before installation of the drip system the fields must be laser-leveled. Since the source of the water is coming from a subsurface ditch, a pump and a filtration system are needed. A pump is needed in order to take water from the ditch and onto the storage tank, thus onto the rest of the drip irrigation system. A filtration system is needed because the water entering this system would contain debris and cause clogging in the pipes if it was not filtered.

A pump is placed near the water source so it can pump water out of the ditch into a mainline that will go through a filtration system and then to a tank that feeds a mainline and the supply manifolds that supply the drip lines as seen in Figure 8[47].

The pump and filtration must be powered by electricity to pump the water from the ditch to the tank, where water is stored. The tank must be large enough to create enough gravitational pressure, when opened, ensure the water can flow onto the field through the mainline and drip lines.

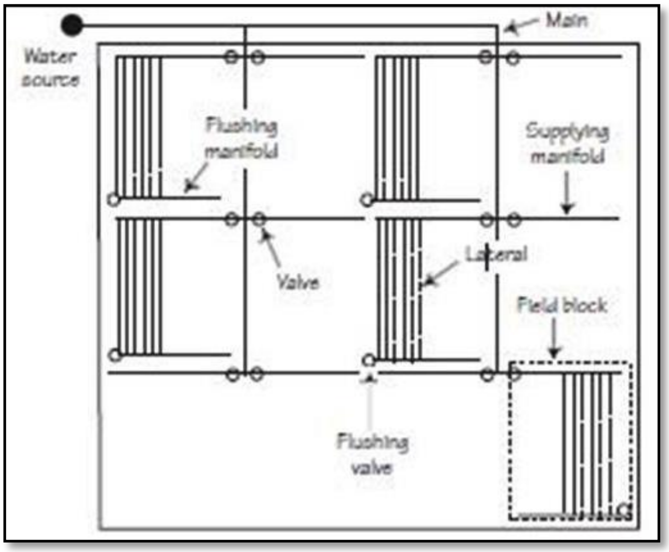

Figure 8: Drip irrigation system layout showing the drip lines on the field.

Figure 7 also shows where each valve is typically located. The values are important because they control the water for each field. A main valve running from the filtration system tank to the main line is installed to ensure that the water supply can be stopped if there is a malfunction in the drip irrigation system.

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[47] Enisco, 2004

Once the mainline, supply manifolds, and the sub-lines, that direct water from the mainline to the fields, are installed, a drip line injector and shank are used to install the drip lines (Figure 9 and Figure 10). The shank creates a ditch and the drip injector lays down the drip line, which may then be buried. This ensures the sun's ultraviolet light does not damage the plastic hoses. It also increases the water efficiency of the system.[48] If ditch lines are not to be buried, then a drip injector is simply used to lay down the drip lines and mulch can be used so that the hoses are covered from the sun's rays [49] A farmer may choose not to bury the drip lines in order to facilitate an easier removal process, but the trade-off is the loss of some of the efficiency of a direct application of water underground. Additionally, burying the drip lines lowers the chances of weeds growing in the winter. On the other hand, unburied drip lines results in warmer soil due to greater solar energy close to the plant roots, and some crops benefit from the extra heat the sun provides by not burying the drip lines thus producing more crops, provided that enough water enters the root zone. Alfalfa and corn prefer to have the drip lines buried because their root zone is deeper than other crops.[50] The drip lines vary in spacing depending on the crop being grown. For alfalfa, it would be 12 inches apart. The emitters are connected to the drip lines and placement of the emitters also depends on how wide the crop grows as shown in Figure 5[51]. This ensures that the emitters drip the water to the root zone of the crop. When the desired drip line length is obtained the next step is to install the flush manifolds. The flush manifolds are used when the system needs to be cleared of debris. They connect to the drip lines and are located along one side of the field also shown in Figure 8. The flush manifolds

Figure 9: A shank making drip lines

Figure 10: Drip line injector

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[48] Enisco, 2004
[49] Iowa State University, 2009
[50] Colorodo State University, 2009
[51] Enisco, 2004

contain flush valves that can easily be opened and closed to allow the flushing of any sediment built up in the drip lines. Figure 11[52] shows how the flush valves work when they are opened and closed.[53]
Drip irrigation can also be set up with a control computer system that waters the crops when it is needed. This control system can be powered by solar power in the place of traditional electric lines, which is convenient for isolated areas. The system uses moisture sensors that are dug into the depth of the crop's root zone to measure the moisture content of the soil and are placed in each field. When the moisture level reaches some lower threshold, set by the user, the moisture sensor sends a message to the control system that then opens the irrigation system. The control system stores all the data in a computer program that then opens the desired valves to the field that needs water.[54] The layout of the control system can also be seen in Figure 8[55]. Drip irrigation is the most efficient because water is delivered directly to the plants' roots and minimal evaporation takes place.[56] With the addition of an automated control system, drip irrigation can be even more efficient because the sensors make sure that the crops get water when the crops actually need it instead of when the farmer thinks that the crops need it.[57]

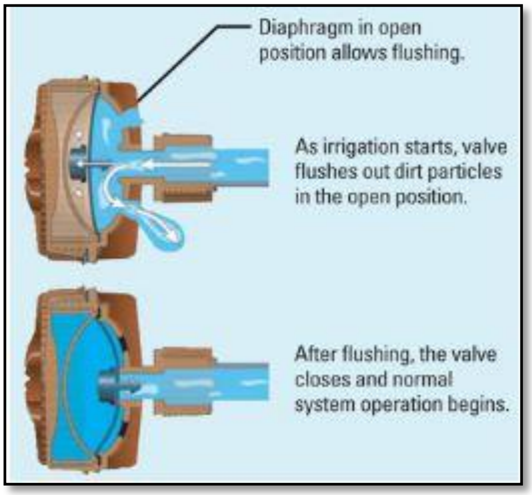

Figure 11: Operation of flush valves

2.4.2 Lateral Sprinkler Irrigation

Sprinkler irrigation can come in many options depending on the configuration of the fields. Because the Pueblo of Santa Ana uses rectangular fields, we focused our investigation on lateral

Figure 12: Lateral-sprinkler irrigation system

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[52] Ibid
[53] Enciso, 2004
[54] Satyendra Tripathi, 2011
[55] Netafim Drip/ Micro Irrigation Solutions, n.d.
[56] Ibid
[57] Satyendra Tripathi, 2011

sprinkler systems, which move in a straight line. A lateral sprinkler irrigation system is a continuous, self-moving, straight lateral that is ideal for irrigating a rectangular field. The lateral sprinkler infrastructure is made up of a pipe supported by trusses, cables, and towers mounted on to wheels that help it move up and down the field (Figure 12[58]).

The lateral moves in a timed start-up operation, with the speed of the infrastructure controlled at a single tower that powers the self-guided motion of the system. All other towers are in start-stop mode, allowing the system to function with a single motor in an end tower in most cases. This would allow the other towers to follow along with the primary tower to maintain alignment of the structure. Thus, as long as the field is perfectly level, a lateral system moves in a perfectly straight line along the field. Water can be supplied to the lateral sprinkler irrigation either through a canal or through a supply hose. The hose may be connected to a main line and dragged, or may be manually connected and disconnected from hydrants as the lateral system moves down the field as shown in Figure 12[59]. The water then goes through the lateral pipe and down to sprinkler heads where it then waters the crops. The sprinkler heads can range in size from 5-12.5 centimeters in diameter.[60]

The size of the sprinkler heads determines how much water can be delivered over a specific period of time at a specific water pressure. On the Pueblo, water would be obtained from an open ditch, and thus a filtration system would be needed in order to make sure sediment does not build up in the water pipes. If wider sprinkler heads are used instead with a closed source of water without many loose particulates, like a well, then no filtration system is needed. This would allow the small amount of sediment present in the water to escape through the nozzle heads.[61]

Aside from the fact that it wastes less water than flooding, one advantage of lateral sprinkler irrigation is that the entire field gets evenly irrigated; however, the disadvantage to this system is the high initial cost and the high annual operating costs. The annual operating costs include gas or electricity needed for the infrastructure to operate and also labor costs, because once the structure moves from one end of the field to the other, it must then be moved to the start position of the next field to be irrigated.[62] Overall the sprinkler lateral irrigation system is more efficient than the flood irrigation system that the Pueblo of Santa Ana is using, because it evenly applies water to the crops, ensuring that the appropriate amount of water needed is obtained by the crop. The sprinkler system can also be controlled by a control system that waters the crops through a computer or smartphone. Sprinkler irrigation, however, is not quite as efficient as drip irrigation because more water is lost through evaporation.

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[58] University of North Dakota, 2000
[59] Scherer, 2010
[60] Brouwer, 1988
[61] Foster, 2014
[62] Belcher, 2012

2.4.3 Flood Irrigation

Flood irrigation is the application of water by gravity flow to the entire field, and this is the method of irrigation that the Pueblo of Santa Ana currently uses. In this type of system, the water is either fed into furrows or basins from the ditches that go along the sides of the field and hold the water for irrigation.[63]

Furrows are long, narrow, shallow trenches made in the ground by plows that run between crop rows (Figure 13[64]). Water enters the field through the furrows, which are constructed with the slope of the field. The water infiltrates from the ditch and flows into furrows moving laterally with the slope of the field and downward towards the roots of the crops. Water enters the furrows through either open ditches or pipelines[65].

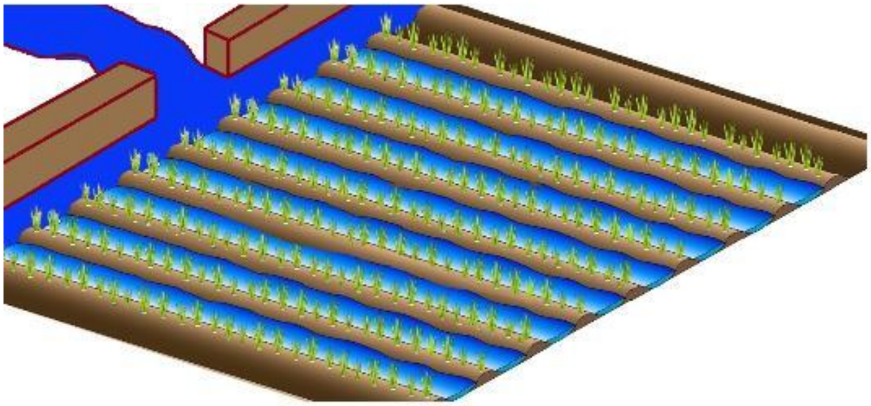

Figure 13: Furrow flood irrigation. The brown parallels show the crop rows and the blue parallels show water filled furrows.

Basins are square, irregular or rectangular configurations. Figure 14[66] demonstrates basin flood irrigation. The fields are leveled in all directions, and are encompassed by a short, earthen wall, berm, to prevent runoff, and provide an undirected flow of water onto the field[67].

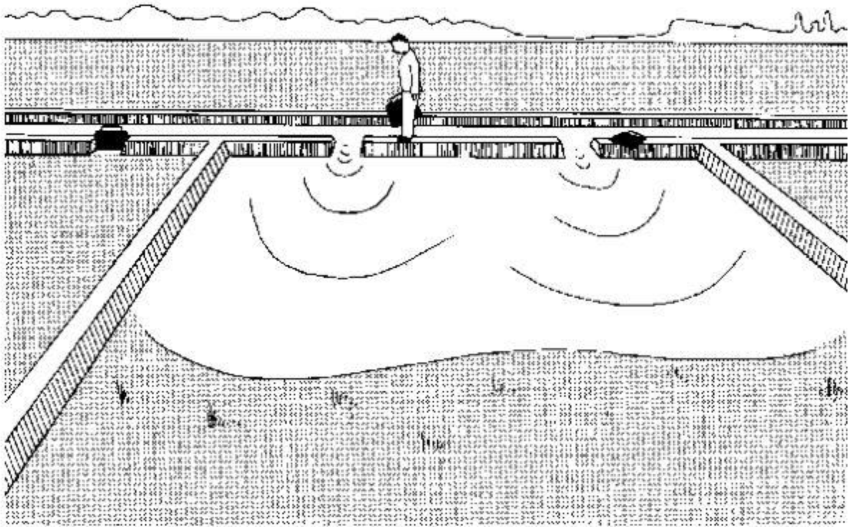

Figure 14: Basin-Flood irrigation

Whether a farmer opts for basin or furrow irrigation depends upon the crop he or she plans to

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[63] Irrigation water management: training manual, 1988
[64] Merriam-Webster Online Dictionary, 2014
[65] Scherer, 2010
[66] Brouwer et al, 1985
[67] Ibid

grow. For example, if alfalfa is being grown, then a basin flood method is used; however, if blue corn is being grown, then furrows may be the preferred field format. Alfalfa is a deep-root crop that needs moisture deep within its soil profile; since basin flood irrigation causes water to sit at the surface and then drain slowly into the soil, this ensures deep penetration of the water[68]. In comparison, furrow flood irrigation is used more often for row crops. Furrow irrigation provides water to the roots but keeps the shoot of the plant dry. For example, if full flood irrigation were used for blue corn, the base of the plant would be in standing water, damaging the plant.[69]

Another method for flood irrigation is utilizing bubblers, also called bubblers, shown in Figure 15 instead of basins or furrows. Water enters through the field gates and into an underground pipe, and then the bubblers bring the water to the soil surface.[70] The bubblers only flood a small portion of the field; therefore multiple bubblers have to be added for every field.[71] Bubblers are more efficient than using check gates because less water is lost due to evapotranspiration.[72]

Figure 15: Bubbler valve used in Santa Ana

Flood irrigation is the simplest and cheapest irrigation method because it requires minimal infrastructure (gates), but it is not the most efficient in water use.[73] Last year the Santa Ana Water Division made their flood irrigation more efficient by leveling many of the fields, replacing wooden gates with steel, and lining several ditches with concrete. Leveling the fields reduces the slope of the field and allows for an even distribution of water. This decreases the water's velocity as it goes across the field ensuring that more water is absorbed in the designated crop areas as opposed to becoming runoff. Concrete ditches increase the velocity of the water flow and reduce the amount of water absorbed by the earthen ditches. The concrete will prevent water from escaping through the walls of the ditch in to the earth and prevent sediment from flowing along with it as much as with the earthen ditches. This allows the concrete ditches to charge more quickly and reduces water waste. The depth of the concrete ditches change from 1 foot to 2 feet to create different pressures for the water to flow onto the field. The 1-foot depth is used for the sublaterals to create a smaller pressure, versus the 2 feet depth that creates a greater

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[68] Irmak et. al. 2007
[69] Iowa State University, 2009
[70] IrrigationRepair.com, 2010
[71] The University of Arizona, 1999
[72] Foster personal communication, 2014
[73] Gall et al., 2013

pressure to fill the sublaterals.

2.5 Water Rights and Irrigation in the Santa Ana Pueblo

Figure 16: A check gate

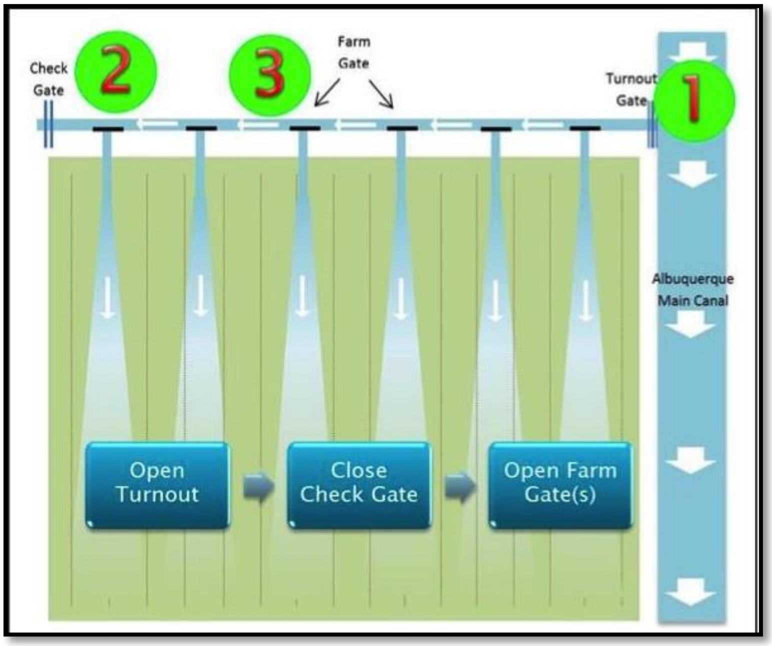

Figure 17: Pueblo of Santa Ana flood irrigation operation

In the Pueblo of Santa Ana, flood irrigation is used, and is managed by an official called the Mayordomo. The Mayordomo oversees a ditch crew that helps maintain and operate the flood irrigation system within the Pueblo of Santa Ana. Once a farmer needs water, the farmer contacts the Mayordomo and tells the ditch crew to deliver water to the particular farm. The Pueblo of Santa Ana's main water sources are the Albuquerque Main Canal, which is operated by the Middle Rio Grande Conservancy District (MRGCD), and the Indian Ditch, which is operated by the Pueblo. Delivery of the water to the desired fields consists of opening the floodgates (called the "turnout") from the major canals to the corresponding ditches and sub-ditches. The turnouts are movable gates that move water from one waterway to another and can be adjusted up and down. This allows for water to flow into the corresponding fields that need to be irrigated. Then the ditch crew closes the check gate as shown in Figure 16[74]. The check gate creates a barrier that keeps water from going further into other waterways. This allows for water pressure to build up within the closed region, which is critical for the final step. The last step is to open the farm gates, which are similar

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[74] Gall et al., 2013

to the turnouts; these gates are on the ditches and separate the fields from the water. Once all these steps are completed water is able to enter into the fields as shown in Figure 17. To ensure that the water delivery happens correctly, the ditch crew routinely monitors the Pueblo's irrigation structure.[75] Another improvement implemented in the Pueblo of Santa Ana flood irrigation is the use of bubbler systems[76] on some of the fields, which reduces water waste within the Pueblo. With the help of the Mayordomo and ditch crew, the Pueblo of Santa Ana Water Resource Division can help the Pueblo of Santa Ana conserve water for their next irrigation season by continually improving the current system and by investigating alternative systems.

2.5.1 Water Regulation

The United States Department of the Interior Bureau of Reclamation oversees the regulation of water using a real-time application that displays all of the different gauges for each city, town or pueblo. Figure 16[77] is an example of the gauge map the department uses to oversee the Cochiti Division. These gauges are all monitored online by the state engineer and can be checked to make sure everyone is irrigating using the appropriate amounts of water.[78] Starting from the El Vado Reservoir, the Middle Rio Grande region flows to the Cochiti Reservoir then into the Angostura Diversion to the Pueblo of Santa Ana, shown in Figure 18.

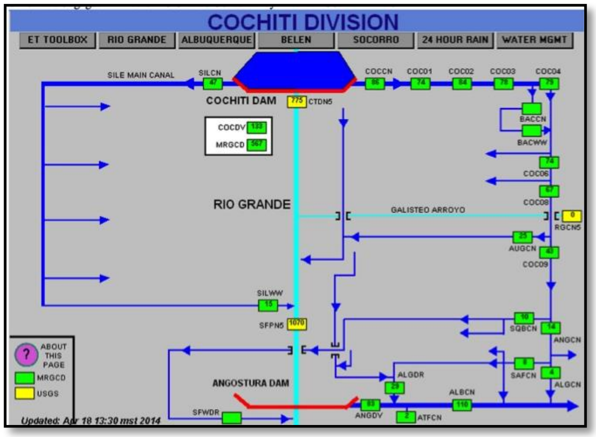

Figure 18: Cochiti Division gauge map showing the locations of the gauges along the Rio Grande from the Cochiti Dam to the Angostura Dam. The green boxes show MRGCD gauges and the yellow boxes show USGS gauges.

Zooming in, shown in Figure 19 the Angostura Diversion (1) splits into the Riverside Drain (3) and the Albuquerque Main Canal (4). The Indian Ditch (5) and the Albuquerque Main Canal are what the Pueblo mainly uses.[79] The Indian Ditch, maintained by the Pueblos the ditch, originates from the Cochiti Reservoir, providing water to the Cochiti, Santo Domingo, and San Felipe Pueblos. There are gauges, installed by the United States Department of Agriculture (USDA) (double check), located at the Algodones Riverside Drain, and Albuquerque Main Canal that monitor the water flow during the irrigation season. The Bosque Lateral is the longest lateral carrying around 12 cubic-feet per second (cfs)

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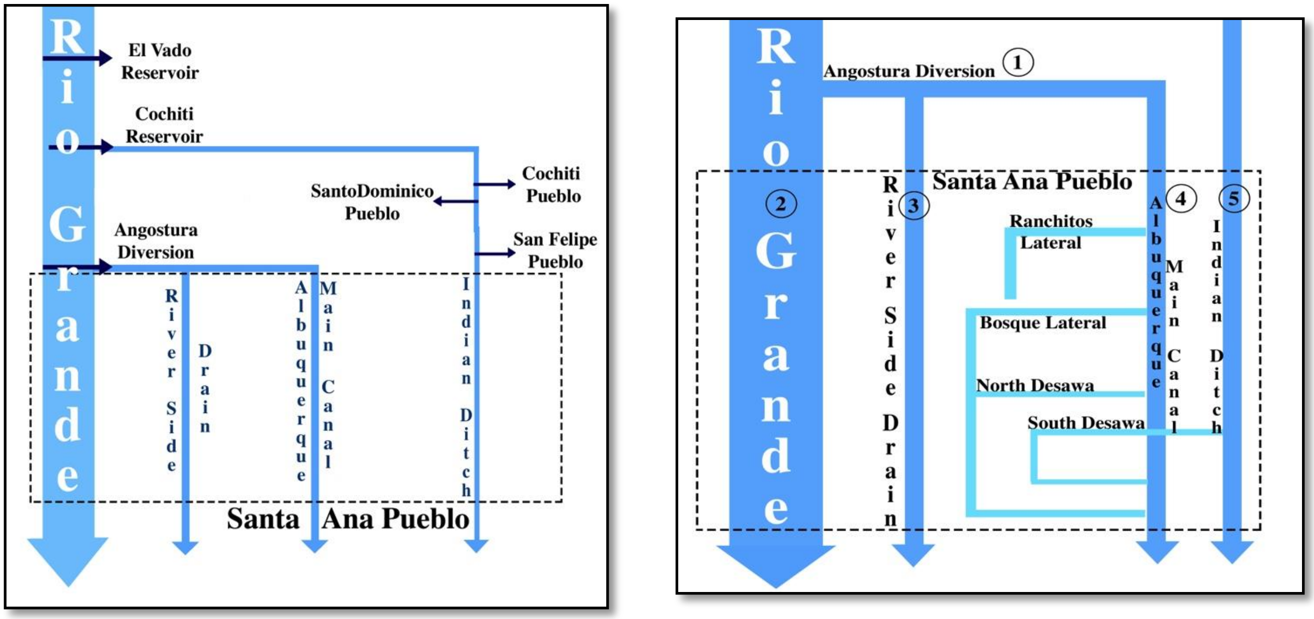
[75] Gall et al., 2013
[76] Ibid
[77] River Systems Software :Bureau of Reclamation : U.S. Department of the Interior, n.d
[78] McGinn personal communication, 2014
[79] Ibid

while the Ranchitos Lateral, North Deswa, and South Desawa carry around 6 cfs. These gauges are all monitored online and can be checked to make sure everyone is irrigating using the appropriate amounts of water.[80]



Panel A

Panel B

Figure 19: A representation of water ways that serve many Pueblos. Panel A shows waterways that run from the Rio Grande to the Pueblos. Panel B shows details of the smaller water divisions that serve the Pueblo of Santa Ana.

2.6 Pueblo of Santa Ana The Northern Field

The Pueblo of Santa Ana has recently obtained new agricultural fields called the *Northern Field* from a settlement after a land dispute with the bordering Pueblo of San Felipe. This field is located at the northern edge of the Pueblo of Santa Ana bordering the Pueblo of San Felipe as shown in Figure 20[81]. These fields have not been used for agricultural purposes for over 40 years. The new fields are not leveled but do have access to canals for flood irrigation through a previously used lateral that edges the field. The Northern

Figure 20: The Northern Field outlined in white

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[80] Gall et al., 2013

[81] McGinn personal communication, 2014

Field also has an old earthen ditch that goes across the field. The Pueblo of Santa Ana Water Resources Division wants to use this new Northern Field to explore alternative irrigation systems to possibly implement in the new irrigation fields.[82]

2.7 Water Requirements

The Pueblo of Santa Ana mainly grows two types of crops, alfalfa and blue corn. It is important understand what the water requirements are of the crops to know how much water should be added because improper water application could lead to a lower crop yield.

2.7.1 Alfalfa Water Requirements

Alfalfa has a longer growing season than most crops and therefore uses more water annually than most crops grown on farms.[83] It also has the ability to survive long periods between irrigations, because it is able to absorb 70% [84]of the soil water, making it a drought-resistant crop, as normally most plants can only absorb 50% of the soil water. [85] This plant is a deep-rooted perennial and the roots can reach 8 to 12 feet in the soil, allowing alfalfa to obtain water that has percolated down deeper in the soil.[86] In the Pueblo of Santa Ana alfalfa is not replanted every year, but has to be replanted when the ground is laser leveled as laser leveling moves around the soil.

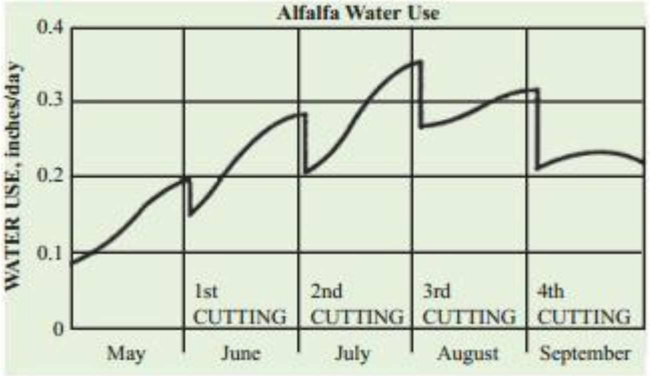

Figure 21: Growing Season for alfalfa during the months of May through September showing the amount of water that should be added at each time and also when the alfalfa can be harvested

Even though alfalfa can absorb water through the whole root length, the majority of water, 75 to 90 percent of soil moisture, is obtained from the upper four feet of soil called the root zone.[87] The amount of water that should be added depends on the soil's water capacity and the amount of rainfall but there is very little rain in the Pueblo of Santa Ana so the water requirements mostly depend on the soil type and

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[82] McGinn personal communication, 2014
[83] Irmak et al., 2007
[84] Alam and Rogers, 2009
[85] Bauder, 2005
[86] Irmak et al., 2007
[87] Ibid

crop.[88] Alfalfa normally needs 0.35 inch per day in mid alfalfa season or about 1 inch of water every three days.[89] Figure 21[90] shows the growing season of alfalfa, how much water should be added to the alfalfa throughout the growing season and also when alfalfa can be harvested. On the Pueblo of Santa Ana alfalfa is grown in conjunction with a small amount of oats mixed in with oats being the cover crop. This is done because planting oats along with the alfalfa can interrupt the growth of weeds without using herbicides.[91] Also, the oats grows above the alfalfa providing shade for the alfalfa so that the alfalfa can grow higher.[92] The oats grow above the alfalfa helping protect the alfalfa from wildlife such as birds since the birds will feed on the oats instead.[93]

2.7.2 Corn water requirements

Blue corn, also known as Hopi maize, is a variety of flint corn or Indian corn and has a blue pigmentation in the seeds; otherwise it is similar to varieties of yellow corn. Corn can require up to a third of an inch per day of water, shown in Figure 23 at the peak of its growing season when the plant has reached full height and has developed a tassel, shown in Figure 22[94], which produces the pollen for the corn, located at the top of the corn. Corn roots normally grow down to a depth of four feet or more with a width of 12 to 18 inches from the stalk.[95] The corn absorbs water with varying efficiencies depending on root depth, as can be seen in Figure 24. Also,

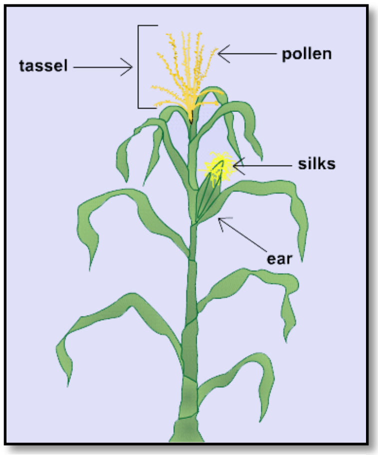

Figure 22: Parts of a corn

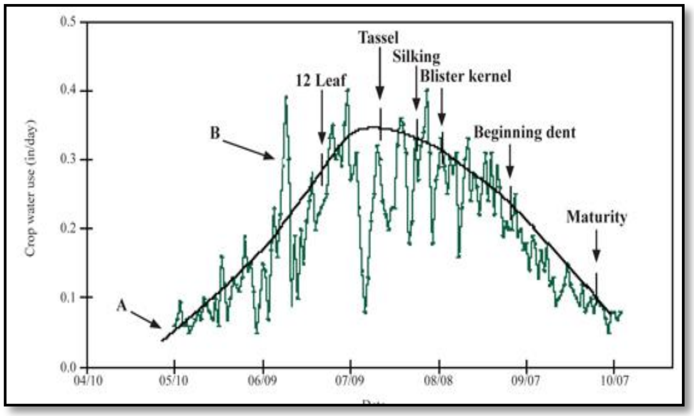

Figure 23: Water usage for corn over the annual growing season, showing different stages in corn development.

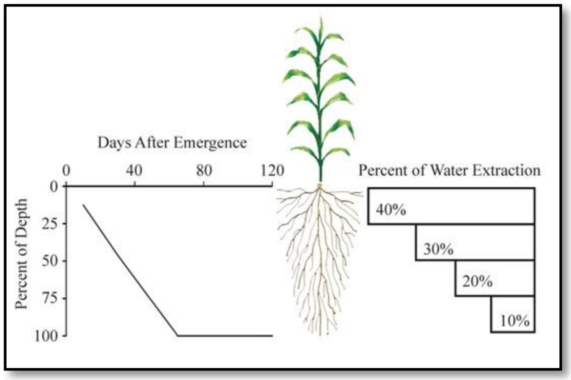

Figure 24: Percent of water absorbed by corn at each root depth along with the percent of depth for corn roots as the days after emergence increase.

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[90] Irmak et al., 2007
[91] Canevari, 2014
[92] McGinn personal communication, 2014
[93] Ibid
[94] Plant and Soil Sciences eLibrary, 2014
[95] Cropview, 2012

in Figure 24 the percent of corn root depth can be seen as the days of emergence increase. Emergence in corn is when the corn can first be seen sprouting out of the ground.

2.8 The Effects of Water Potential, Evapotranspiration and Soil Conditions on Irrigation

Water potential, evapotranspiration and soil conditions all play important roles in agriculture, irrigation and irrigation scheduling. Many irrigation schedules are based on soil moisture and soil water potential or evapotranspiration data. Water potential is used to help determine irrigation efficiency, and can be useful to supplement evapotranspiration-based scheduling.[96] Evapotranspiration is used to schedule irrigation as well as estimate water requirements in different regions and climates for crops, but can be limited based on the margin of error present in approximated water needs for crops. Soil conditions dictate the types of crops that can be grown in a region as well as how often one must irrigate.[97] In this section, we review some of the factors that go into planning irrigation and the equations used to implement them.

2.8.1 Water Potential

Water potential is the driving force behind water movement through soil, into plants, and back into the atmosphere. Depending on the time of year, this data can help the Mayordomo in scheduling irrigation periods, because soil moisture data and evapotranspiration data can be limited.[98]

$$\psi = \psi_o + \psi_m + \psi_g$$

ψ = water potential

ψ_o = osmotic potential

ψ_m = matric potential

ψ_g = gravitational potential

Figure 25: Equation for water potential

Water potential is the potential energy of water per unit volume in relation to pure water under reference conditions, which is water at equilibrium. Water potential is measured in kilopascals, and soil water potential can be measured with a device called a tensiometer. The tensiometer is an instrument that measures water content of the surrounding earth by means of a vacuum gauge, with low readings indicating high water saturation of the soil. The mechanics of the tensiometer can be found in Appendix A.

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[96] Lampinen et al., n.d.

[97] Environmental Protection Agency, 2003

[98] Lampinen et al., n.d.

This quantifies water's tendency to move from area to area due to forces such as osmosis, gravity, pressure and matric effects.[99] Soil water potential tells the user how much moisture the crops can absorb from the soil. If the soil tension is high then the plants will have a more difficult time extracting the water and if the soil tension is low then the plants will have an easier time extracting the water from the soil.[100] This relates directly to how much water the plants can absorb over time with each irrigation.[101]Water moves from areas of high water potential to areas of low water potential. While a tensiometer will measure water potential directly, it can also be calculated using the formula that gives the breakdown of factors that affect water potential, shown in Figure 25.[102] Osmotic, or solute, potential is simply the portion of the total water potential that is due to the presence of solutes in the soil. Pure water will move by diffusion across a soluble membrane from areas that have a higher concentration of water to areas that have a lower concentration of water, but the addition of solutes such as salts or organic compounds will attract water molecules and reduce the overall energy of water.

Matric potential varies with soil conditions, with strongly negative values found in dry soils.[103] Gravitational potential is the difference in elevation between the water found in the soil and the reference pool of water, typically the groundwater.[104]

2.8.2 Evapotranspiration

Evapotranspiration is the combination of two processes: evaporation and transpiration, as depicted in Figure 26.[105] Evaporation occurs when water is vaporized from the abiotic environment (like the soil surface) and enters the atmosphere. Transpiration occurs when liquid water within plants vaporizes and enters the atmosphere. Both processes are dependent upon many factors, including air temperature, humidity, and wind. Soil water content and crop characteristics also greatly influence transpiration, because the amount of water in the soil directly

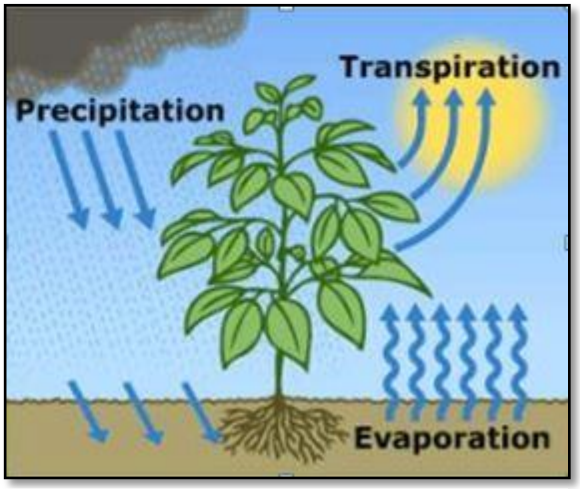

Figure 26: Evapotranspiration

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[99] Hopmans and Rolston, 2000
[100] Migliaccio et al., 2002
[101] Smajstria and Harrison, 1998
[102] Ibid.
[103] Juma, 2001
[104] Ibid
[105] United States Department of the Interior, 2014

relates to the amount of water a plant can absorb. Having low crop characteristics such as the amount of light reflected off of the surface of the crop (known as the *albedo*), plant height, the aerodynamic properties of plant parts, and leaf properties also influence the evapotranspiration calculations greatly. This is because these factors help to determine how easily water is transpired from the plant.[106] The amount of water present in the soil versus the amount of water present in the plant can alter the ratio of evapotranspiration. For example, after it rains, there will be a higher value for evapotranspiration that would be attributed to the excess water in the soil.

$ET_c = ET_o \times K_c$

ET_c = Evapotranspiration

ET_o = Crop evapotranspiration under standard conditions

K_c = crop coefficient

Figure 27: Formula for evapotranspiration

While it is difficult to measure evaporation and transpiration separately, together they are used to approximate water usage throughout a crop cycle. It is commonly known that when seeds are first being planted, almost 100% of the evapotranspiration is derived from pure evaporation, because the seeds would not be able to take in much water or have a large surface area from that which water could be lost. When crop coverage increases and the ground becomes more shaded, a majority of the evapotranspiration is a result of transpiration from the plants.[107] Evapotranspiration is calculated using the formula shown in Figure 27 crop evapotranspiration under standard conditions is determined using meteorological data that includes solar radiation, air temperature, air humidity and wind speed. The crop coefficient, which varies depending on the type of crop, is determined using different factors that include the crop type, climate, soil evaporation, and the stage of growth the crop is in.[108] For example, a fully-grown acre of corn is estimated to transpire approximately 11,400 – 15,100 liters of water each day.[109]

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[106] Allen et al., 1998

[107] Ibid

[108] Ibid

[109] United States Department of the Interior, 2014

2.8.3 Soil Conditions

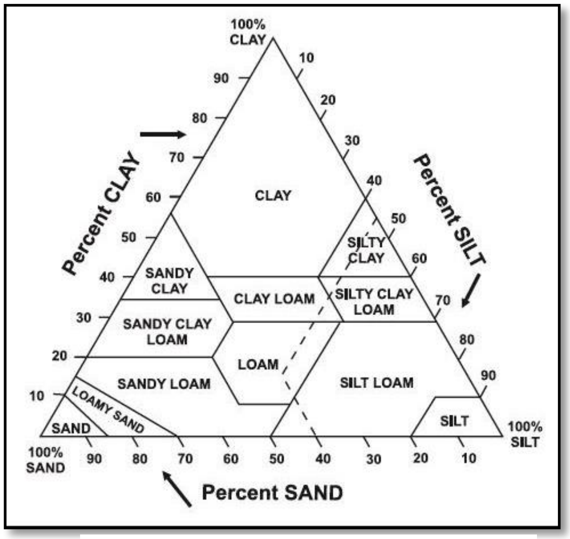

Figure 28: Soil type triangle

Soil conditions such as pH, soil type, and soil water potential are important to the success of crops. Most plant life requires a very specific balance of pH to ensure optimal growth, typically ranging from 4.5 to 7.5. If the environment is too acidic (low pH), plants will atrophy or die starting with the roots. The acidity inhibits root growth and absorption of nutrients through plant cell walls.[110] If the soil is too alkaline (high pH), some nutrients will not dissolve easily, preventing the plant from taking them in as well.[111] Soil type is primarily made up of two different factors. Soil texture is the proportion of the various sizes of soil particles that include sand, silt and clay. Soil structure is the natural arrangement and organization of the particles into units of aggregation. Soil type is identified using these characteristics, as shown in Figure 28.[112] This determines whether soil is loam, sand or clay. Water is stored in different spaces in the soil, but is most easily available to plants when it is stored in pores between soil particles. Soil texture and structure have a large effect on the size, shape, and number of pores present in the soil. In general, clay soils retain water better, and have a low permeability, while sandy soils are very permeable.[113]

2.8.4 Effects of Water Potential for Irrigation and Irrigation Scheduling

Water potential, evapotranspiration and soil conditions all play important roles in agriculture, irrigation and irrigation scheduling. Many irrigation schedules are based on soil moisture and soil water potential or evapotranspiration data. Water potential is used to help determine irrigation efficiency, and can be useful to supplement evapotranspiration-based scheduling. Using a tensiometer on a field, one can determine the water potential of the soil by giving a measurement of the water pressure inside of the device. The tensiometer is placed within the root zone of the crop planted onto the field at two different levels to give readings for a high root zone as well as the deeper soil on the field. This is because sometimes the topsoil might look dry, but the deeper soil is actually still moist. The farmer might be unaware that the deeper soil within the roots is still getting water, therefore watering the crops too much

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[110] Chipotle Powder, 2009
[111] Understanding pH, 2007
[112] Loganathan, 1987
[113] Ibid

and favoring the growth of weeds.[114] Using tensiometers, the farmer can irrigate effectively, as well as reduce the amount of unwanted weeds sprouting on their farm.

Evapotranspiration is used to schedule irrigation as well as estimate water requirements in different regions and climates for crops, but can be limited based on the margin of error present in approximated water needs for crops. Soil conditions dictate the types of crops that can be grown in a region and the types of irrigation that can be used as well as how often one must irrigate.[115] By knowing these important factors, one can optimize irrigation.

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[114] Foster personal communication, 2014
[115] McGinn personal communication, 2014

3 Methodology

The goal of this project was to assist the Pueblo of Santa Ana Water Division's efforts to increase irrigation efficiency by proposing an irrigation plan for the new Northern Field. Our plan was based on an irrigation efficiency study of flood, drip and sprinkler irrigation, and provided a breakdown of the monetary costs for the irrigation layouts designed for the Northern Field. We also designed a new platform for communication between the farmers and the Mayordomo.

The objectives of our project are as follows:

1. Evaluating the geography of the Northern Field and designing alternative layouts for flood, drip, and sprinkler irrigation systems.
2. Analyzing the relative efficiency of flood and alternative irrigation systems for the Northern Field.
3. Estimating the monetary costs to install and maintain each irrigation system designed for the Northern Field.
4. Designing a smartphone application to enhance coordination for irrigation throughout the Pueblo.

This project took place in the newly acquired Northern Field, obtained by the Pueblo of Santa Ana, in Sandoval County New Mexico, as shown in Figure 29, This began during the early part of their irrigation season, which lasts from April 1st to October 31st, and the efficiency study will be continued by the Water Division throughout the remainder of the season.

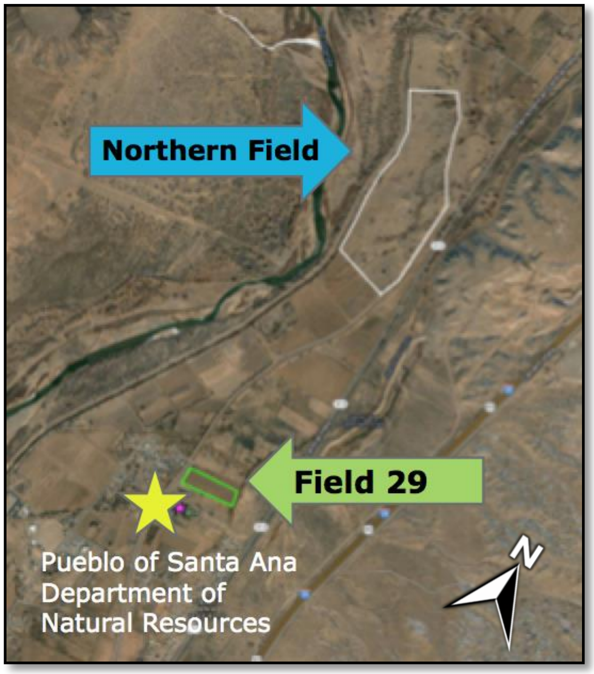


Figure 29: The location of the Northern Field, Field 29 (the experimental field) as well as the Pueblo of Santa Ana Department of Natural Resources

3.1 Designing a Layout for Flood, Drip and Sprinkler Irrigation Systems

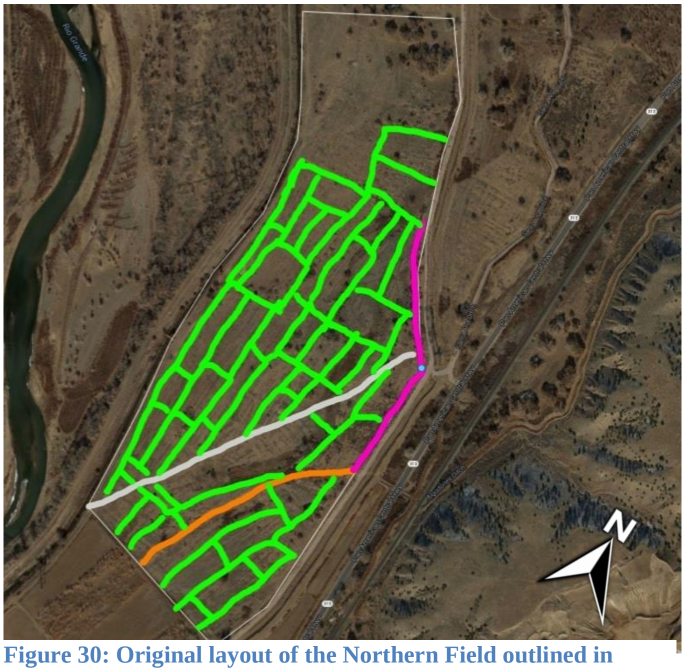


Figure 30: Original layout of the Northern Field outlined in green. The grey indicates the road which was made to drive across the fields, the pink is the old lateral they made to transport water. The orange is the location of an old earthen ditch. The blue dot indicates where the old distribution box is located.

In order to create a layout for an irrigation system for the Northern Field, we first began to look at the Northern Field using GIS and Google Earth. We determined the location in relation to the rest of the Pueblo and found the orientation of the field. We were then given an informal tour of the field during which we located significant landmarks and previous structures that we could use for planning the different system layouts. Using an enlargement of a Google map of the Northern Field, shown in Figure 30, we began to locate and label structures and landmarks. With this map and the located structures, we began to construct a visual representation of the previous layout used approximately 40 years ago.

We found that the previous layout, shown in Figure 30, would not be ideal for efficiency. That field layout means that it would be difficult to get water to the eastern-most side of the field. In addition, the field sizes are not uniform, making it difficult to implement any irrigation system dependent on field size. We began to plan different layouts while attempting to preserve previous structures, like the main lateral and the distribution box, which we thought could still be used. We decided to create multiple layouts for each system to compare monetary cost and efficiency of irrigation, but each includes a wildlife-grazing area for the animals moving through the area. This area was intended to maintain the habitats of local wildlife while preventing them from encroaching on the farmers' fields.

To gain a basic understanding of irrigation systems on the Pueblo, we investigated different fields in the Pueblo that use both flood gates as well as bubblers. The team then went out and measured Field 29, maintained by Governor Montoya and his son Aaron, which was used to conduct an efficiency study using tensiometers. After getting the dimensions of Field 29, as well as locating and mapping the bubblers, we were able to compare them to the general dimensions of other fields the Pueblo of Santa Ana uses for flood irrigation. Since Field 29 only uses bubblers, we obtained information on the distances between each check gate and farm gate for a typical flood irrigation field without bubblers from our liaison Mr. McGinn. This gave us an approximation for the dimensions of each field for the layout of the flood irrigation system for the Northern Field. We then created two field designs for flood irrigation on the Northern Field that best utilized the land.

North-South Field Layout

East-West Field Layout

Figure 31: Two different layouts of the fields. The orange indicates the sublaterals along the field, the pink indicates the main laterals running north to south. The blue dot indicates the distribution box, the green line indicates the underground piping, and the pink dots indicate the bubblers placed on the field.

The first layout, shown in Figure 31, is what we have called the North-South Field Layout. This orientation is based on the original field layout shown in Figure 29, but creates more uniform fields so that they could theoretically be used for all three types of irrigation. The water flows from the north to the south, from the sublateral to the end of each individual field.

The second layout, called East-West Field Layout, was created for comparison to determine if it would be more efficient or less costly to implement than the North-South layout. This was done similarly to the North-South layout, but instead of using the natural slope, we divided the Northern Field down the middle using a main lateral and therefore the irrigation is from the east to west.

For both of the layouts, East-West and North-South, we utilized the previous lateral that edges the Northern Field, while moving the distribution box further up toward the border of the wildlife preservation area. Using the GIS layers we mapped the different pieces of necessary equipment on the fields, creating multiple layouts for both farm gate flood irrigation and bubblers.

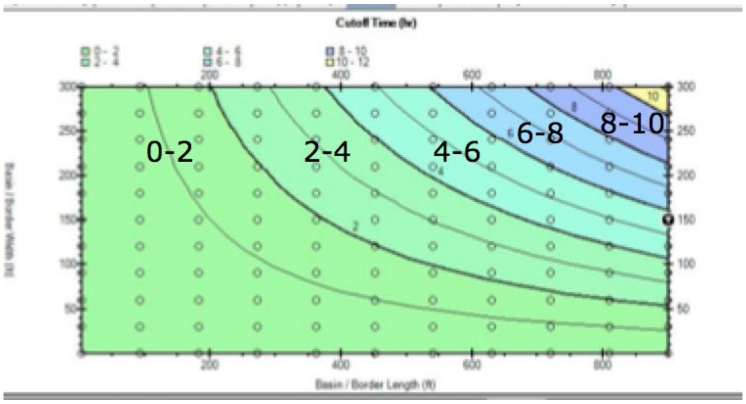


Figure 32: Data created from WinSRFR by using a constant flow rate as well as the maximum dimensions recommended by Joseph McGinn.

To create efficient fields, we took WinSRFR and designed a field for the Northern Field. WinSRFR is a free program provided by the NRCS that is used for evaluating flood irrigation. This program allowed us to establish a physical design using maximum and minimum dimensions, as well as apply the soil type from the Northern Field to determine the amount of time a farmer would need to irrigate based on field length and width. In the program, we set the flow rate in the program to 4.5 cubic feet per second, one of the lower flow rates the farmer can use to water their field, estimated by Mr. McGinn, as well as the depth within the soil to around 6 inches. We also inputted the type of soil the Northern Field will have to create an accurate simulation in WinSRFR. Once we ran the program, WinSRFR was able to give us the amount time the farmer needs to irrigate for different lengths of fields on the field shown in Figure 32. Once we found around 6 fields from the WinSRFR data, we created 6 different field layouts using GIS. The dimensions of the 6 fields were determined by using the maximum dimensions Mr. Joseph McGinn provided us, from observations of the larger and smaller fields on the Pueblo of Santa Ana and there we were able to narrow down the ideal dimensions for efficient irrigation. Mr. Joseph McGinn also suggested that a shorter irrigation time would be more efficient, therefore we decided to keep the irrigation time between 2-6 hours.

3.2 Determining the Efficiency of Each Irrigation System

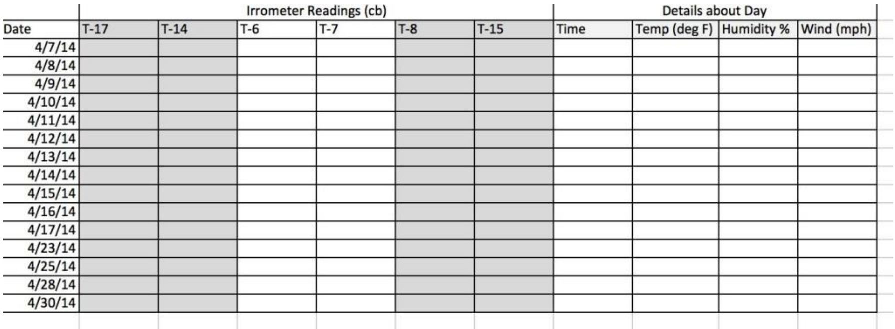
The team conducted a hypothetical efficiency study on three different systems of irrigation in order to determine the most effective system to present to the Pueblo of Santa Ana Tribal Council. A preliminary study on the current flooding system used in the Pueblo was conducted using tensiometers on Field 29 that were checked regularly throughout the duration of the project. The tensiometer study was a separate project for the Natural Resources Division that is intended to help irrigation scheduling and will be continued throughout the irrigation season. For the Northern Field, farm gate flood irrigation and bubbler flood irrigation were studied using the knowledge gained from the tensiometer study and using WinSRFR. Drip and lateral sprinkler irrigation were studied hypothetically using data provided by the NRCS.

3.2.1 Flood Irrigation Efficiency Study

In order to assess the efficiency of the Pueblo of Santa Ana's flood irrigation system, we conducted a study using one field planted with alfalfa. Under the guidance of our liaison, Mr. McGinn, and Mr. Glenn Tenorio, former Mayordomo and a member of the Pueblo, the team installed 6 tensiometers (model number 2725ARL jet fill tensiometers, from the Soil Moisture Equipment Corp).[116], on the field to be monitored during the irrigation season. The tensiometers were made in 2011 and were provided by Mrs. Jean Foster of the NRCS for the purposes of this study.

Starting before the reseeding of the field, which was required because the field had recently been laser-leveled, we took the length and width measurements of the field using 100 ft. measuring tape. The entire field was divided into four approximately equal sections, each section constituting 25% of the field's area. Before the tensiometers could be placed, we dug holes for them using an auger and filled the bottom of the holes with a slurry of water and soil from the field at a 2:1 ratio. The slurry ensured that the tensiometers stayed in place while we filled the holes back up. We placed two tensiometers, one at a depth of 6 inches and the other at a depth of 12 inches at the 25, 50, and 75% markers (Figure 33). The nested placement of the tensiometers, one higher and one lower in the ground, allowed for a better understanding of the water conditions within the soil between the instruments, as each instrument measured soil moisture at only one level. The tensiometers were filled with water and primed by pumping the top approximately sixty times to remove all air bubbles from the stem. The purpose of the tensiometers was to monitor the water conditions within that section and depth of the field, and determine when the field should be irrigated.

Figure 33: Field 29 with tensiometers installed. The yellow dots are the tensiometers that were placed 6 inches into the ground, while the blue dots are the tensiometers installed 12 inches deep. The green dots are bubblers.



	Irrometer Readings (cb)						Details about Day			
Date	T-17	T-14	T-6	T-7	T-8	T-15	Time	Temp (deg F)	Humidity %	Wind (mph)
4/7/14										
4/8/14										
4/9/14										
4/10/14										
4/11/14										
4/12/14										
4/13/14										
4/14/14										
4/15/14										
4/16/14										
4/17/14										
4/23/14										
4/25/14										
4/28/14										
4/30/14										

Table 1: Tensiometer reading and weather data form

During the first

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[116] See Appendix A

irrigation on April 10th, the team recorded the amount of time the water took to reach the field markers at 25, 50 and 75 percent, and for full field coverage, which was used for the calculation of the depth of the water applied in order to find the percent efficiency of bubbler flood irrigation. Each day during the first week of irrigation, we returned to take daily measurements, and returned to take weekly measurements thereafter. This data was recorded throughout the month of April on a data sheet that included the date, tensiometer, time, temperature, humidity and wind (Table 1). Better insight into water usage in the field will require data collection throughout the irrigation season, so we left our procedures with The Water Division so they can continue the study. The tensiometer data will be used along with the weather and temperature by the Natural Resources Division in order to get a more accurate idea of how much water is used by the crops and how much water should be applied to the fields throughout the irrigation season in order to optimize their irrigation scheduling.

3.2.2 Efficiency Study for the Northern Field

In order to approximate the efficiency of the different plans we created, and to select the optimal plan to recommend, we modeled flood irrigation using WinSRFR. Assuming that a majority of the fields will be planted with alfalfa, we planned to have the fields irrigated with water to 6 inches, once every three weeks, which is ideal for alfalfa. Beginning using the Physical Design application, we selected the soil type found on Field 29 and input the maximum and minimum desirable dimensions of the fields in order to get an idea of how long the different field layouts should be irrigated for. Using this information we ran simulations (using the Simulation tab) for each field size using the times given by the Physical Design tab, The infiltration was checked in order to make sure that the required depth was reached, and a cutoff of 5.5 inches at the beginning of the field was found to be an acceptable value in order to water the roots properly without unnecessarily wasting large amounts of water. For each field, the efficiency of the application of water was recorded. This gave us the application efficiency of bubbler flood irrigation. Then, in order to approximate the application efficiency of farm gate flood irrigation from the point that the water enters the sub-lateral, we calculated how much water evaporated during the irrigation

The amount of evaporated water can be expressed as:

$g_h = \theta A(x_s - x)$

where

g_h = amount of evaporated water per hour (kg/h)

$\theta = (25 + 19v)$ = evaporation coefficient (kg/m^2h)

v = velocity of air above the water surface (m/s)

A = water surface area (m^2)

x_2 = humidity ratio in saturated air at the same temperature as the water surface (kg/kg)

x = humidity ratio in the air (kg/kg)

Equation 1: Calculation of evaporation from the surface of water

period to find how much was used based on the design. For each design, the flow rate was held constant at 4.5 cubic feet per second. This allowed us to find exactly how much water was applied to the field. Then, we calculated how much water that was exposed to the open air within the sub-laterals was lost from the time that the sub-laterals were fully charged using Equation 1**[117]**.

This was done by taking regional weather data for New Mexico that includes average temperature, average wind speed, and average humidity and incorporating it into an equation that uses the complete surface area of the water in the sub-laterals in order to find how much water would evaporate from the point that the sub-laterals were fully charged and irrigation began. The average temperature for New Mexico was 53.1 degrees Fahrenheit. The average humidity was 76.63%. The average wind speed was 17.82 miles per hour.[118] The value x_s, the humidity ratio in saturated air was found using a table containing temperature, saturation pressure, and maximum humidity ratio from the same source.[119] These values allowed us to find the amount of water that evaporated from the surface of the sub-laterals before it could be applied to the field. The efficiency of farm gate flood irrigation was then found by dividing the total amount of water that was applied to the field per hour (4.5 cfs) by the total amount taken from the system both by the application and by evaporation and multiplying the percentage efficiency given by the base efficiency given for the same layout with bubblers.

The values for drip and sprinkler irrigation were taken from attainable and average application efficiency values provided by the NRCS.

3.3 Determining the Cost of Each Plan

Using the model layouts, the cost of each system of irrigation was calculated. The costs for flood irrigation were taken from recent construction invoices within the Pueblo from a company called Sichler Construction. These invoices were for a project that involved renovations for several fields that implemented bubblers as well as concrete lining the earthen ditches and thus include line item prices for much of the work that would be involved in installing the flood systems we designed. The data for lateral sprinkler and drip irrigation was obtained from the NRCS, taken from recent installations of similar systems in nearby regions within New Mexico. Total numbers of each type of hardware or equipment were tallied using the GIS layers, and then were multiplied by the cost of the equipment to give a total cost for installment. Life span of the hardware and equipment was taken into account to determine any maintenance costs for up to 10 years after installation. Because laser leveling would be done for each

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[117] Engineering Toolbox, 2014
[118] USA.com, 2014
[119] Engineering Toolbox, 2014

system, regardless of what system is implemented, we did not take it into account for the cost comparison.

3.3.1 Drip Irrigation Costs

The cost analysis for drip irrigation in the Northern Field was derived from a technical journal from the University of Nevada.[120] In the technical journal one of its objectives is to see the cost of installing drip irrigation for alfalfa. The journal breaks down the cost for each hardware and equipment needed for the drip irrigation system in an arid area like New Mexico. This technical journal is accurate for our breakdown cost of drip irrigation on the Northern Field because it is a technical journal with a research experiment done on a field with a similar environment as the Northern Field. We used the layouts we designed and then calculated the area of each field. Within each configuration, all fields had the same dimensions, so we simply made a cost estimate for one field and multiplied it by the number of fields; to obtain the number of acres the field needed to be covered by drip irrigation. This was done to each of the six North-South layouts. The main pump, tank, and electrical works were a set price, but the other components were priced per acre area. The drip lines laid on the field for delivering water to the fields, the PVC piping in order to get water on to the fields and PVC fittings to connect all the PVC piping, the filtration system needed to prevent sediment build-up in the piping, the valves, controller system, and SDI system (computer automated system) to direct the flow of water onto the field, sub-pumps needed to pump water onto the correct field, and installation cost of the entire drip system were all components that were priced per acre. We then multiplied the price of each component by the acres we obtained and added them all up to the set price of the tank, pump, and maintenance to obtain the total cost. A further breakdown cost can be seen in Table 2.

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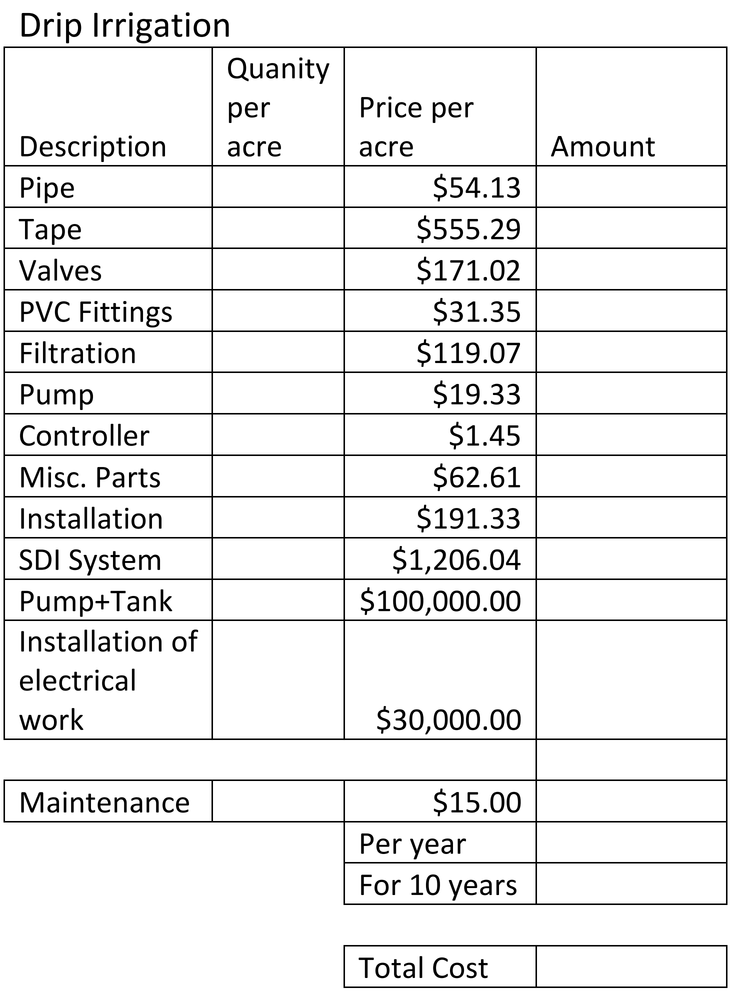
[120] Breazeale, Davison, Myer, Neufeld, 2000



Drip Irrigation

Description	Quanity per acre	Price per acre	Amount
Pipe		$54.13	
Tape		$555.29	
Valves		$171.02	
PVC Fittings		$31.35	
Filtration		$119.07	
Pump		$19.33	
Controller		$1.45	
Misc. Parts		$62.61	
Installation		$191.33	
SDI System		$1,206.04	
Pump+Tank		$100,000.00	
Installation of electrical work		$30,000.00	
Maintenance		$15.00	
		Per year	
		For 10 years	
		Total Cost	

Table 2: A cost breakdown to implement a drip irrigation system.

The sprinkler lateral cost analysis was determined by using the NRCS database. The price of the sprinkler lateral was priced per linear feet. Each field has the same widths so the widths were all added up from east to west to determine the total linear feet. The amounts of linear feet were multiplied by $80 to get the price of the sprinkler irrigation method. The pump, tank, and electrical were all set prices and were added to the cost of the sprinkler system to obtain the total cost. A breakdown of the cost to implement a sprinkler system is shown in Table 3.

Sprinkler Irrigation

Description	Length	Price per linear ft	Amount
Sprinkler System		$80	
Pump and Tank		$100,000	
Installiation of electrical work		$300,000	
		Total Cost	

Table 3: The cost breakdown to implement a sprinkler irrigation system

3.3.2 Flood Irrigation Costs

The breakdown of the calculations for total cost for the four layouts of the flood irrigation system can be found in Table 4.

Description	Quantity	Price	Amount
Mobilization and Demobilization		$2,300.00	
Concrete Ditch Lining: Depth 2 ft.(per ft.)		$30.00	
Concrete Ditch Lining: Depth 1 ft.(per ft.)		$21.00	
12" Slide Gates		$300.00	
Check Gates		$550.00	
Compacted Fill (per ft.)		$5.00	
12-15" PVC 80 psi (per ft.)		$17.00	
15" Bubbler		$450.00	
High flow turnout		$1,900.00	
Total Cost			

Table 4: The breakdown of costs for installation for both farm-gate as well as bubbler flood irrigation.

Mobilization, or building the flood irrigation system, and demobilization, breaking down the land to prepare for the installation of flood irrigation, refer to set costs for the labor and construction of the flood system. In order to bring water into a drip system for the Northern Field we noted that one high flow turnout was going to be needed after we surveyed the Northern Field. A high flow turnout would be needed because the field has a higher elevation than the Albuquerque Main Canal that feeds into the main lateral, therefore creating enough pressure to provide for irrigation along the field. We multiplied the number of turnouts (one) by the price to determine the total cost for turnouts. In order to determine the cost of the concrete ditches, we measured the 1' and 2' depth concrete ditches separately using GIS. The depths vary because the main lateral (2') needs a higher pressure than the sublaterals (1'). As the price per foot is different for these two ditch sizes, we separately determined total costs by multiplying the total length by the price per foot for the 1' and 2' depth concrete ditches. Using GIS we first looked at the length of the 1' depth concrete ditch (the sub-lateral) to determine the number of 12" slide gates (farm gates) needed for each layout. At every 60' of the sub-lateral a farm gate was needed for flood irrigation to build up enough pressure to irrigate.[121] We then counted how many farm gates were needed per layout and multiplied it by the cost of the farm gate to end up with the total cost for the farm gates. The same procedure was carried out for the check gates but, instead of using the 1' ditches, we took the length of the 2' deep concrete ditches, laterals, and at every 300' placed a check gate on GIS for each of the layouts. The compacted fill is the soil around the concrete that supports the concrete ditches, that price was determined by adding the lengths of the 1' and 2' concrete ditches together per foot and then multiplying by the price. The 12-15" PVC 80 PSI total cost was determined by measuring the width of the wildlife area filed on one side to determine how much PVC piping was going to be needed and then multiplying the width per foot and finally multiplying it by the price. Using the width of the wildlife field we then measured every 75'on GIS to place a 15" bubbler. We then counted the bubblers needed and multiplied it by the cost to get the total cost of the bubblers. Finally, we added all the costs together to get the total cost for each layout.

3.4 Modeling an application to increase irrigation coordination between the Mayordomo and the farmers

We began by talking with Mr. Joseph McGinn as well as Mr. Glen Tenorio to identify the causes for water wasted while farmers irrigate within the Pueblo of Santa Ana. One of the problems is that the farmers sometimes to forget to close their farm gates once they start to irrigate their field, wasting a lot of water and flooding the roads along the fields. Some farmers also irrigate too often which cause grass to grow on their field rather than alfalfa. Another issue that they talked about was that some farmers north of others would irrigate, and another farmer who would like to irrigate would be told he could, however, the

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[121] McGinn personal communication, 2014

ditch would run out of water before it would reach the last farmer, therefore, not allowing the farmer to not irrigate the day they would like to. To reduce the water wasted within the Pueblo of Santa Ana, we designed an application with two view screens that will facilitate communication between the Mayordomo and the farmers. We used a program called Xcode to model the application for iPhones, as well as Photoshop to design the program. We also looked into a way for farmers to approximate the length of time they need to wait before irrigating again. This application will remind farmers to close their floodgates and improve when they irrigate as well as the duration of irrigation.

4 Results and Analysis

In this section, we discuss the results and analysis of our four objectives. First, we discuss the evaluation of the Northern Field the Pueblo of Santa Ana has obtained and the layouts we created for each irrigation method. Next, we present our analysis of water efficiency for the three types of irrigation systems by setting up an experiment for flood irrigation as well as theoretically analyzing drip and sprinkler irrigation efficiency. Then we present our analysis of the costs for the three different irrigation systems and determined the costs to implement each system on the Northern Field. Finally, in order to maximize efficiency for the Pueblo's current system, we discuss the model application we designed to facilitate coordination between the Mayordomo and the farmers.

4.1 Evaluation of the Northern Field and Creation of Field Layout

After we looked at the original layout of the Northern Field, we decided to create two separate layouts shown in Figure 34. The first layout we created, shown below, is what we have called the North-South Field Layout. This orientation is based on the original field layout shown in Figure 29, but creates more uniform fields so that they could theoretically be used for all three types of irrigation. The water flows from the north to the south, from the sublateral to the end of each individual field.

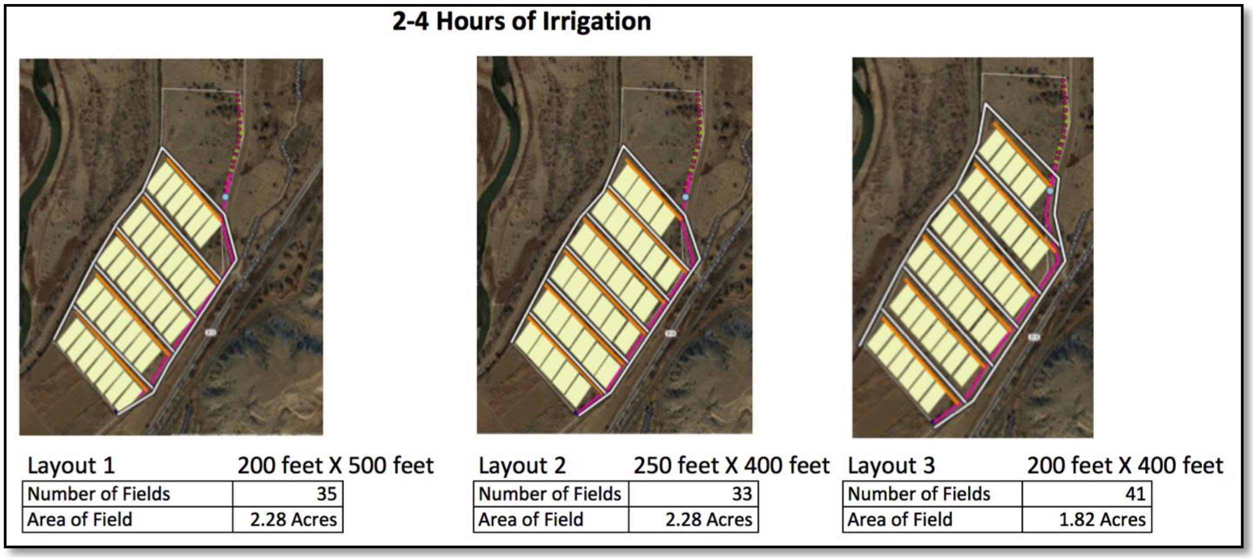
North-South Field Layout

East-West Field Layout

Figure 34: Two different layouts of the fields. The orange indicates the sublaterals along the field the pink indicates the main laterals running north to south. The blue dot indicates the distribution box, the green line indicates the underground piping, and the pink dots indicate the bubblers placed on the field.

The second layout, called East-West Field Layout, was created for comparison to determine if it would be more efficient or less costly to implement than the North-South layout. This was done similarly to the North-South layout, but instead of using the natural slope, we divided the Northern Field down the middle using a main lateral and therefore the irrigation is from the east to west.

Once we analyzed the North-South and East-West orientations shown in Figure 34, we decided that the North-South orientation best utilized the area of the entire Northern Field than the East-West orientation. This decision was determined because the orientation of the field mimicked the original layout as well as it allowed for more uniform fields to be created within the Northern Field. This also allowed us to utilize the natural slope of the land. We also realized that for a farmer who has a field on the southern-most side of the Northern Field to irrigate for the East-West orientation, the Mayordomo would have to charge up the entire two main laterals to run one irrigation system therefore wasting water due to evaporation. We used WinSRFR to identify the six layouts we created that fell within the limits of a maximum field size of 300' by 900', as well as 2-6 hours for the field to be completely irrigated. Once we got these numbers, we used GIS to implement as many fields as we can fit for each These parameters were given to us by Mr. McGinn based on current fields within the Pueblo as well as water efficiency, the bigger the field, the more time it takes to water the field, therefore more water is wasted. The following fields shown in Figure 35 can be completely irrigated in 2-4 hours and Figure 36 can be completely irrigated in 4-6 hours depending on the flow rate of the laterals near the fields. These six fields can be used with flood, drip or sprinkler irrigation methods.



Layout 1 200 feet X 500 feet

Number of Fields	35
Area of Field	2.28 Acres

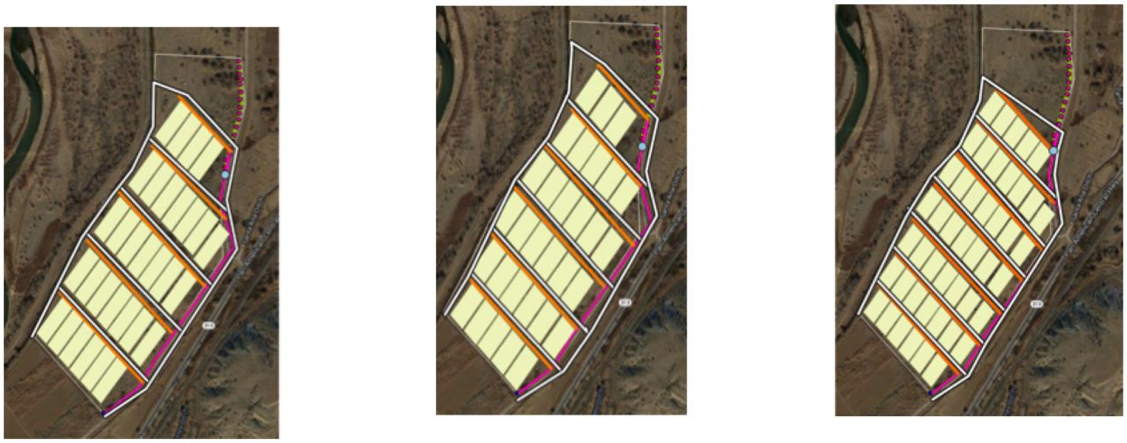
Layout 2 250 feet X 400 feet

Number of Fields	33
Area of Field	2.28 Acres

Layout 3 200 feet X 400 feet

Number of Fields	41
Area of Field	1.82 Acres

Figure 35: Three fields designed for the Northern Field for 2-4 hours. The time for irrigation is dependent on the flow rate onto the field; therefore the there is a 2 hour time range for these layouts.



Layout 4 200 feet X 600 feet

Number of Fields	30
Area of Field	2.75 Acres

Layout 5 250 feet X 500 feet

Number of Fields	31
Area of Field	2.87 Acres

Layout 6 300 feet X 400 feet

Number of Fields	46
Area of Field	2.75 Acres

Figure 36: Three fields designed for the Northern Field for 4-6 hours. The time for irrigation is dependent on the flow rate onto the field; therefore the there is a 2-hour time range for these layouts.

4.2 Irrigation Efficiency Study

We used field and theoretical experiments to evaluate and compare the water efficiency of the three systems. We monitored a field that utilized bubbler flood irrigation in the Pueblo planted with alfalfa and used tensiometers to monitor the soil moisture within the soil. For drip and sprinkler irrigation, we used provided values to estimate application efficiency and then modeled flood irrigation using WinSRFR 3.1 software to estimate the application efficiency.

4.2.1 Flood Irrigation Efficiency

After installing the tensiometers, the field’s bubblers were opened and Mr. Aaron Montoya started the irrigation. It took a total of 9 hours for the entire field to be completely covered with water and thus fully irrigated. After two days passed, we returned every day for a full week to check the readings.

Figure 37 shows the data we collected from the time we put the tensiometers into the ground until May 2, 2014. When the irrigation started, the tensiometer readings declined to around 10 centibars for each tensiometer, showing that there was ample water in the soil. Over the course of a few days, the readings started to increase slowly as the water started to get taken up by the roots of the plants as well as to evaporate from the ground. When the tensiometers read approximately twenty centibars, they decided to irrigate again even though the readings showed that there was a sufficient amount of water still present in the clay in order to put more water into the lower root zone. The data collected showed how long the water is retained in the soil and will be able to indicate when the field needs to be watered during the irrigation season.

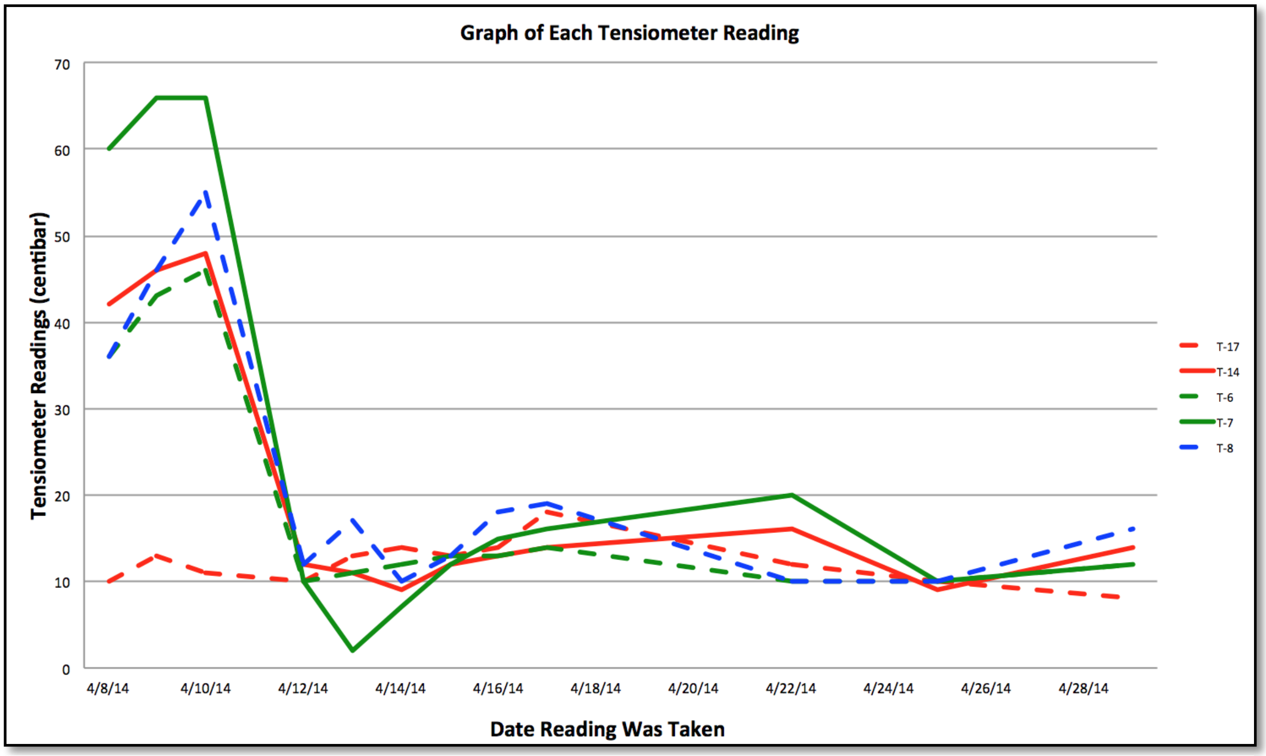


Figure 37: A graph of the tensiometer readings. The dotted lines indicate the tensiometers that are placed at a depth of 12 inches and the solid lines indicate the tensiometers that are placed at a depth of 6 inches.

4.2.2 Efficiency on the Northern Field

Using WinSRFR, the team calculated the efficiency of bubbler flood irrigation. Then, using Equation 1, the amount of water evaporated from the surface of the water in the sub-laterals was calculated. The results were calculated for each layout, assuming field size, soil properties, flow rate and crop remains constant for bubbler flood irrigation. Then, calculations for farm gate flood irrigation were completed for the comparison. The percent of water that was applied to the fields as well as the amount of water that was used in total considering only evaporation from the sub-laterals, and the efficiency percentage was applied to the values for bubbler flood irrigation to find the theoretical application efficiency for farm gate flood irrigation. The results are as follows in Table 5.

Layout	Bubbler Efficiency	Farm Gate Efficiency
Layout 1	94%	93.9%
Layout 2	94%	93.9%
Layout 3	97%	96.9%
Layout 4	92%	91.9%
Layout 5	95%	94.9%
Layout 6	92%	91.9%

Table 5: Results of each layout's efficiency for bubbler and farm gate irrigation

In general, bubbler layouts were more efficient than farm gate layouts by approximately 0.1%. However, these results only cover the time from which irrigation begins after the sub-laterals are fully charged. The time it takes to charge the sub-lateral and the amount of time it is allowed to sit while full are also sources of evaporation loss that are not taken into account with these calculations. A few other important factors that are large sources of loss not accounted for within the calculations are transportation through the ditches and main laterals, especially when they are not concrete lined. Seepage from an earthen ditch can cause anywhere from 20-50% loss of water that would be otherwise used.[122]

For lateral sprinkler irrigation with spray heads that have a hose feed, possible values range from 75-95 percent efficiency. The average efficiency for sprinkler systems of that type is 90 percent. For subsurface drip irrigation systems, the efficiency can range from 75-95 percent and the average is also 90 percent.

4.3 Cost Analysis

Using recent construction data, a journal from the University of Nevada, and data provided by the NRCS, we approximated how much installation would cost for each of the three systems. Then, looking at the life span of different parts found in the systems, we approximated maintenance costs over ten years. However electricity and labor cost were not included because these factors constantly change depending on each irrigation season of the Pueblo. Electricity and labor cost should be taken into account because these expenses add up per year especially for drip and sprinkler irrigation. During our efficient analysis we concluded that the North-South layout were the most efficient layouts, so our cost analysis focuses on

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[122] Hill, 2000

the six different layouts of the Northern Field. Table 6 gives a cost breakdown of each type of irrigation for each layout labeled in Appendix E.

Type of Irrigation	Layout 1	Layout 2	Layout 3	Layout 4	Layout 5	Layout 6
Flood-Farm Gate	$455,197.00	$455,853.00	$563,973.83	$495,282.00	$439,867.17	$509,433.00
Flood-Bubbler	$380,550.00	$381,020.00	$458,405.50	$409,332.50	$369,624.50	$455,115.50
Drip	$341,686.28	$335,826.17	$322,889.99	$341,686.28	$357,881.72	$335,826.17
Sprinkler	$440,000.00	$432,000.00	$432,000.00	$448,000.00	$440,000	$432,000.00

Table 6: A cost breakdown for each type of irrigation for each layout labeled in Appendix E.

4.3.1 Drip Irrigation Costs

The cost for the six North-South layouts is shown in Table 6. A cost breakdown of each of the six North-South layouts is shown in Appendix B. Speaking with Jean Foster the maintenance for drip irrigation is going to be the constant flushing of the drip lines to clean up all the built up of sediments in the piping.

4.3.2 Sprinkler lateral Irrigation Cost

The total cost of sprinkler lateral irrigation for the six different North-South layouts is shown in Table 6. A cost breakdown of each layout is shown in Appendix C. Maintenance was not included as a cost for this system because a filtration system and wide nozzle head would be used in the sprinkler system to ensure that no sediment builds up in the piping. However the amount of electricity and labor needed make up for more than the maintenance that the system does not acquire.

Given an approximated cost of a sprinkler irrigation system by each linear foot of the lateral sprinkler irrigation system, our team found the total amount of money that the implementation of the lateral sprinkler system would cost. The implementation of the lateral move sprinklers would require a layout where the fields would be the same width the whole way down the field so that the whole field could be watered.[123]

4.3.3 Flood Irrigation Costs

The cost for farm gate and bubbler flood irrigation can be seen in Table 6. A further breakdown cost for farm gate and bubbler flood irrigation is shown in Appendix D. Speaking to last years Mayordomo, Glen Tenorio, flood irrigation does not have any maintenance except for the cleaning of the ditches. However this is taken care of by a traditional practice by the male tribe members 18 years old and

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[123] Hill, 2000

older, in which before the irrigation season start the members take a day to clean all the ditches in the Pueblo.

4.4 Application

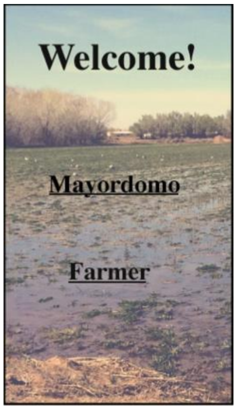

Figure 38: Welcome screen of the application

After speaking with Mr. McGinn and Mr. Tenorio, we decided to design an iPhone application as well as a computer application with two view screens, one to be used by the farmers and one to be used by the Mayordomo. We decided to design a multi-tab application for the farmer and the Mayordomo to use to accommodate the multiple problems that arouse when we talked to Mr. McGinn and Mr. Tenorio. A breakdown of the application can be seen in Figure 40.

The farmer's start screen (A) is designed to have multiple tabs. These tabs include a timer, tensiometer data, messenger, and news feed tab. We made the timer a button that farmer presses when they open their gate in order to initiate a timer. The timer counts down the time the farmer has to irrigate, then set off an alarm when the irrigation period is complete. This reminds the farmer that it is time to close the gate. Once the farmer closes their gate, they can push the button again to alert the Mayordomo.

Each time the button is pressed, the Mayordomo is notified of who opened or closed their floodgate by having the farmer's name light up (G,H) on the Mayordomo's screen, as well as turn green in the Mayordomo's main screen. This allows the Mayordomo to keep track of who is irrigating. The Mayordomo also has a view of the farmer's timer (I) as well so that the Mayordomo knows how long the farmer has to irrigate. The Mayordomo also controls how long the farmer needs to irrigate, which will allow the Mayordomo to organize the schedule then be able to predict who can irrigate when. This application for the Mayordomo also has a counter that tells the farmer how many times they have irrigated this year.

The tensiometer tab (D, J) is based on data collected by tensiometers planted on a field with similar soil types around the pueblo. This allows the farmer to check the tensiometer readings and help them approximate when they need to irrigate. The messenger application (E, L) can help the farmers and the Mayordomo communicate and allow the farmer to ask the Mayordomo if they can irrigate on a certain day as well as allow the farmers to communicate among themselves. The last tab is the news feed tab (M, F) which allows the Mayordomo to post important news information without having to message each farmer individually.

This application has been designed, however it is not programmed yet. The following screenshots seen below in Figure 41 that shows the images we designed using Photoshop.

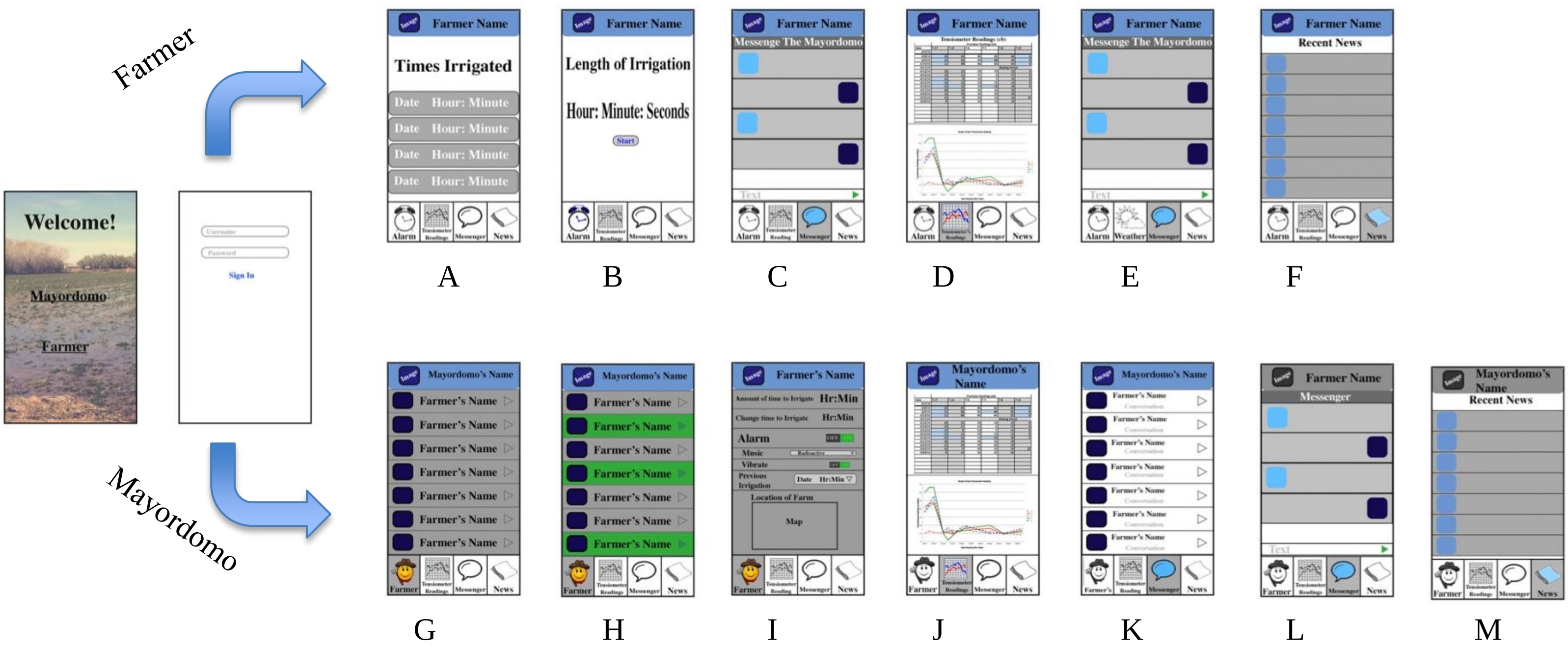

Figure 39: Application breakdown of what it would look like. Each letter is explained in the paragraphs above. In the parenthesis, the first letter is the farmer's application; the second letter refers to the Mayordomo's application.

5 Conclusions and Recommendations

Our project focused on analyzing alternative irrigation methods as well as a layout proposal for the Northern Field. This analysis led us to the conclusion that for the Pueblo of Santa Ana, alterative irrigation methods would reduce water waste, the traditional flood irrigation methods can be upheld with careful irrigation scheduling.

To accompany our analyses, we have multiple recommendations for the Santa Ana Pueblo Water Division. We believe that these recommendations will go together with the other results of our project and will help the efficiency of irrigation in the Pueblo of Santa Ana.

Our first recommendation would be that, independent of the field configuration the Pueblo chooses, they should use bubbler flood irrigation on the Northern Field. Bubbler flood irrigation stays close to the traditional values of being able to see the water flow onto the fields that the tribal members of the Pueblo are used to. Bubbler flood irrigation also has a better efficiency than using the farm gate flood irrigation as the bubbler system utilizes underground piping to minimize the water lost through evaporation in the laterals and sub-laterals.

Figure 40: 250'x500' fields using 4-6 hours of irrigation.

Our second recommendation is that the Pueblo of Santa Ana should utilize the North-South layout of the Northern field seen in Figure 40. This layout is the bubbler flood irrigation layout and cost $369,624.50. It has 31 fields with dimensions of 250 ft. by 500 ft., is 95% efficient, and takes 4-6 hours to irrigate. This layout costs slightly more than some of the other layouts but will provide the Pueblo with more fields allowing more of the Pueblo members to get a field. If a cheaper layout is desired than we recommend using the North-South layout of the Northern Field as seen in Figure 41. This layout also uses bubbler flood irrigation and cost $381,020.00. It has 33 fields with the dimensions of 250ft. by 500ft., is 92% efficient and takes 2-4 hours to irrigate. This layout will provide the cheapest implementation cost for the Pueblo and will provide with a shorter irrigation time for the farmers.

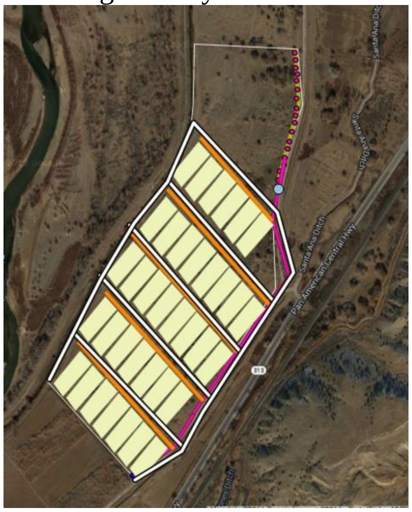

Figure 41: 200'x500' North-South Field

Our third recommendation is that tensiometers should be placed on each field in the Pueblo and that the Santa Ana Pueblo Water Division should work with the farmers to teach them how to install and use them. Putting the tensiometers on each field will allow the farmer to know when the correct time to irrigate will occur, instead of the farmer guessing when the next irrigation time is. When the farmer irrigates at the correct time water is used more efficiently and thus the crop will not be drowned in water, causing a lower crop yield.

Our fourth and last recommendation is that the Mayordomo and the farmers use the application we modeled to create a more organized irrigation schedule for the irrigation season. This will ensure that the farmers do not forget to close their bubblers or farm gates when irrigating, thus wasting less water in the Pueblo. These recommendations will help the Pueblo of Santa Ana optimize their irrigation system in the future and help conserve water especially in times of drought.

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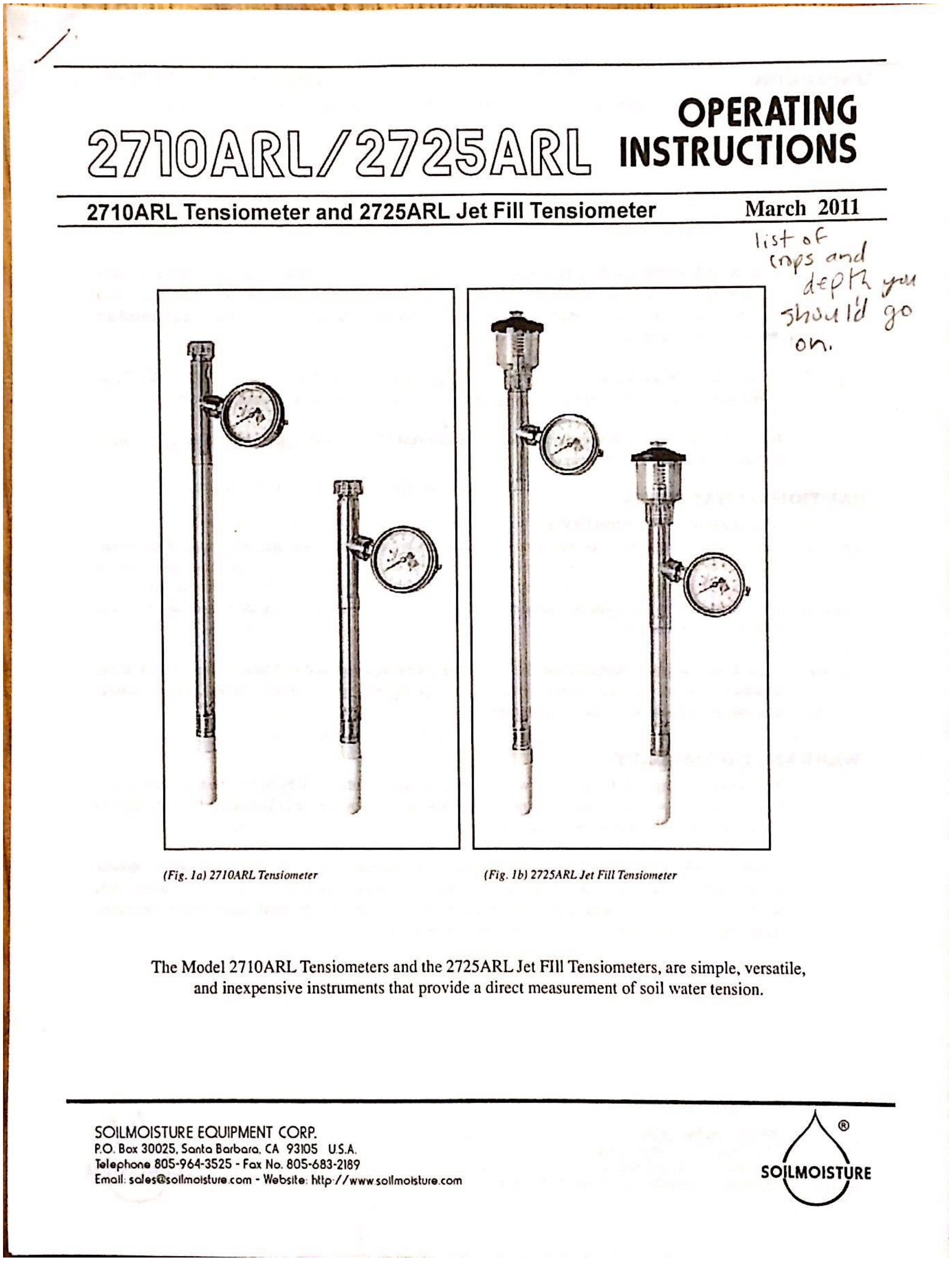
Appendix A: Tensiometer Use and Mechanics[124]



2710ARL/2725ARL OPERATING INSTRUCTIONS

2710ARL Tensiometer and 2725ARL Jet Fill Tensiometer March 2011

list of crops and depth you should go on.

(Fig. 1a) 2710ARL Tensiometer

(Fig. 1b) 2725ARL Jet Fill Tensiometer

The Model 2710ARL Tensiometers and the 2725ARL Jet FIll Tensiometers, are simple, versatile, and inexpensive instruments that provide a direct measurement of soil water tension.

SOILMOISTURE EQUIPMENT CORP.
P.O. Box 30025, Santa Barbara, CA 93105 U.S.A.
Telephone 805-964-3525 - Fax No. 805-683-2189
Email: sales@soilmoisture.com - Website: http://www.soilmoisture.com

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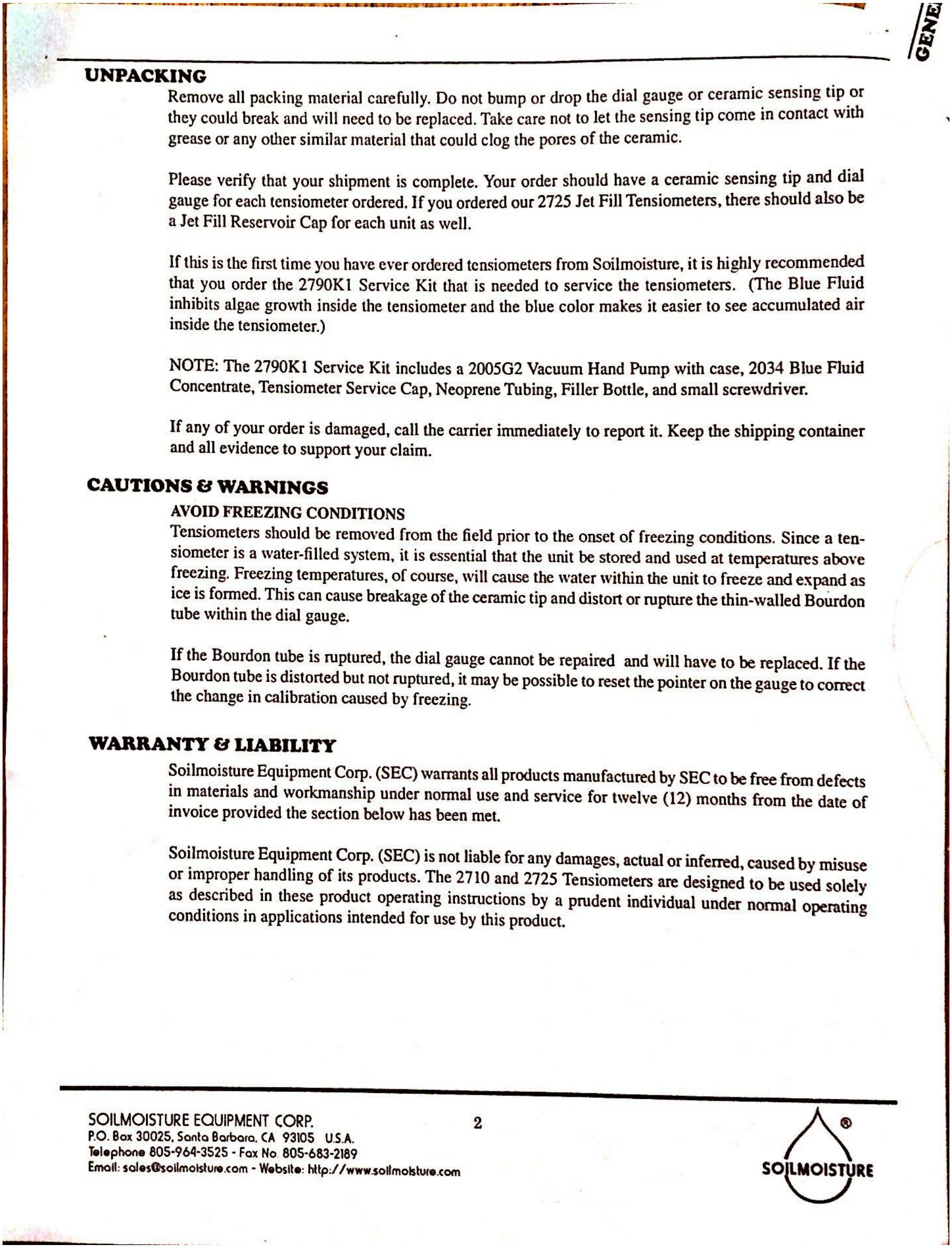
[124] SoilMoisture Equipment Corp, 2011



UNPACKING

Remove all packing material carefully. Do not bump or drop the dial gauge or ceramic sensing tip or they could break and will need to be replaced. Take care not to let the sensing tip come in contact with grease or any other similar material that could clog the pores of the ceramic.

Please verify that your shipment is complete. Your order should have a ceramic sensing tip and dial gauge for each tensiometer ordered. If you ordered our 2725 Jet Fill Tensiometers, there should also be a Jet Fill Reservoir Cap for each unit as well.

If this is the first time you have ever ordered tensiometers from Soilmoisture, it is highly recommended that you order the 2790K1 Service Kit that is needed to service the tensiometers. (The Blue Fluid inhibits algae growth inside the tensiometer and the blue color makes it easier to see accumulated air inside the tensiometer.)

NOTE: The 2790K1 Service Kit includes a 2005G2 Vacuum Hand Pump with case, 2034 Blue Fluid Concentrate, Tensiometer Service Cap, Neoprene Tubing, Filler Bottle, and small screwdriver.

If any of your order is damaged, call the carrier immediately to report it. Keep the shipping container and all evidence to support your claim.

CAUTIONS & WARNINGS

AVOID FREEZING CONDITIONS

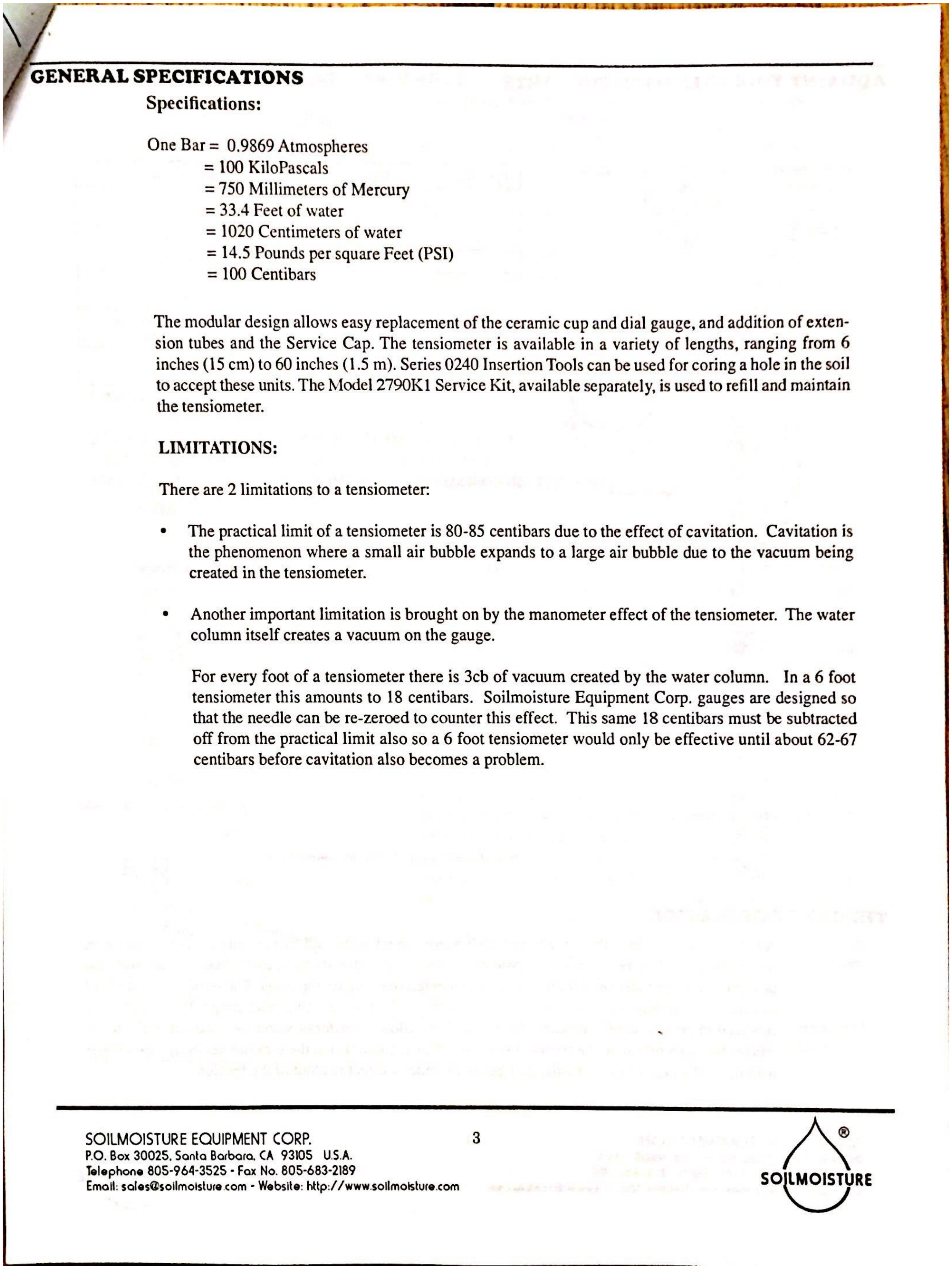
Tensiometers should be removed from the field prior to the onset of freezing conditions. Since a tensiometer is a water-filled system, it is essential that the unit be stored and used at temperatures above freezing. Freezing temperatures, of course, will cause the water within the unit to freeze and expand as ice is formed. This can cause breakage of the ceramic tip and distort or rupture the thin-walled Bourdon tube within the dial gauge.

If the Bourdon tube is ruptured, the dial gauge cannot be repaired and will have to be replaced. If the Bourdon tube is distorted but not ruptured, it may be possible to reset the pointer on the gauge to correct the change in calibration caused by freezing.

WARRANTY & LIABILITY

Soilmoisture Equipment Corp. (SEC) warrants all products manufactured by SEC to be free from defects in materials and workmanship under normal use and service for twelve (12) months from the date of invoice provided the section below has been met.

Soilmoisture Equipment Corp. (SEC) is not liable for any damages, actual or inferred, caused by misuse or improper handling of its products. The 2710 and 2725 Tensiometers are designed to be used solely as described in these product operating instructions by a prudent individual under normal operating conditions in applications intended for use by this product.



GENERAL SPECIFICATIONS

Specifications:

One Bar = 0.9869 Atmospheres
= 100 KiloPascals
= 750 Millimeters of Mercury
= 33.4 Feet of water
= 1020 Centimeters of water
= 14.5 Pounds per square Feet (PSI)
= 100 Centibars

The modular design allows easy replacement of the ceramic cup and dial gauge, and addition of extension tubes and the Service Cap. The tensiometer is available in a variety of lengths, ranging from 6 inches (15 cm) to 60 inches (1.5 m). Series 0240 Insertion Tools can be used for coring a hole in the soil to accept these units. The Model 2790K1 Service Kit, available separately, is used to refill and maintain the tensiometer.

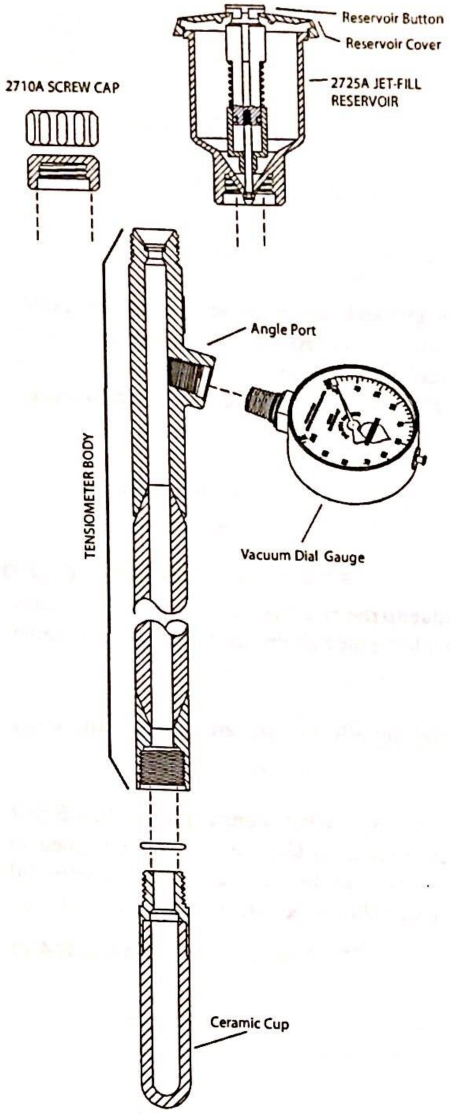
LIMITATIONS:

There are 2 limitations to a tensiometer:

- The practical limit of a tensiometer is 80-85 centibars due to the effect of cavitation. Cavitation is the phenomenon where a small air bubble expands to a large air bubble due to the vacuum being created in the tensiometer.
- Another important limitation is brought on by the manometer effect of the tensiometer. The water column itself creates a vacuum on the gauge.

  For every foot of a tensiometer there is 3cb of vacuum created by the water column. In a 6 foot tensiometer this amounts to 18 centibars. Soilmoisture Equipment Corp. gauges are designed so that the needle can be re-zeroed to counter this effect. This same 18 centibars must be subtracted off from the practical limit also so a 6 foot tensiometer would only be effective until about 62-67 centibars before cavitation also becomes a problem.

AQUAINT YOURSELF WITH THE PARTS



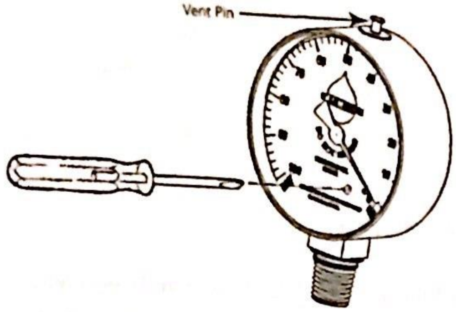
Quantity	Part #	Description
1	2060FG3	VACUUM DIAL GAUGE, RECALIBRATOR-STYLE
1	M802X111PKG05	PACK OF 5 O-RING CUP SEALS
1	Z2630A-100	TENSIOMETER CERAMIC CUP
1	Z2630A-200L##	TENSIOMETER BODY (L## SPECIFY LENGTH*)
NOTE: THE TENSIOMETER BODY IS AVAILABLE IN A VARIETY OF LENGTHS, RANGING FROM 6 INCHES (15 CM) TO 60 INCHES (1.5 M).		
1	Z2079	SCREW CAP (FOR 2710 TENSIOMETERS
1	2075	JET FILL RESERVOIR CAP COMPLETE

* THE TENSIOMETER BODY (FOR EITHER 2710 OR 2725 STYLE) IS AVAILABLE IN A VARIETY OF LENGTHS, RANGING FROM 6 INCHES (15 CM) TO 60 INCHES (1.5M).

(Fig. 2) 2710ARL and 2725ARL Tensiometer Parts

THEORY OF OPERATION

A tensiometer measures the force with which water is held in the soil by the soil particles. This force, referred to as soil suction, tension, or potential, indicates how tightly the water is bound in the soil, and how much energy must be exerted by plant roots to remove and use the water. The basic components of a tensiometer include a porous ceramic cup, a plastic body tube, and a vacuum gauge. The ceramic cup is placed in good hydraulic contact with the soil and allows transfer of water into and out of the tensiometer body according to the tension in the soil. The vacuum inside the tensiometer body equilibrates with the soil water tension, and the dial gauge provides a direct readout of the tension.



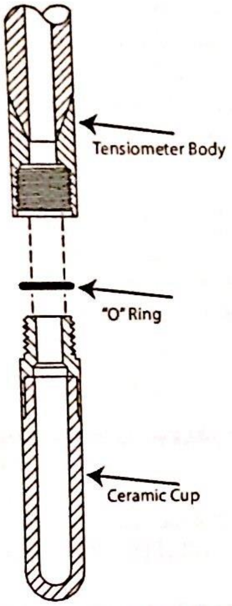
(Fig. 3) Vacuum Gauge Adjustments

ADJUSTING THE POINTER ON THE DIAL GAUGE

The tensiometer dial gauge is hermetically sealed at the factory at sea level. If you live at a higher elevation, the pointer on the dial gauge may read higher than zero when you unpack it. This is due to the lower atmospheric pressure at your elevation.

First, simply press the vent pin located at the top of the gauge to release any collected air.

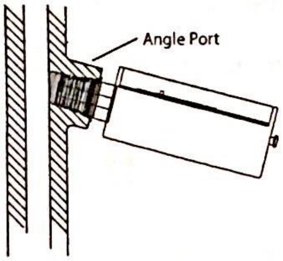
Located on the face of the gauge is an insertion point for a small flathead screwdriver. If the gauge is reading high, turn the screwdriver clockwise an estimated amount to correct the error. If the gauge reads low, turn the screwdriver counterclockwise an estimated amount to correct the error. Repeat the process if necessary until the pointer is on zero.



(Fig. 4) Attaching the Ceramic Tip

ASSEMBLY OF THE UNIT

In order to prevent damaging your order during shipment, both the 2710 and 2725 Tensiometers are packed with the ceramic cup removed. To assemble the unit, invert the tensiometer and insert the O-ring into the threaded end of the body tube, making sure that it is seated properly in the hole. Next, screw the ceramic cup into the body tube until it makes a tight seal on the O-ring *(Fig. 4)*. Do not over tighten. The O-ring makes the vacuum seal, not the threads. Damage to the threads will occur as a result of excessive tightening.

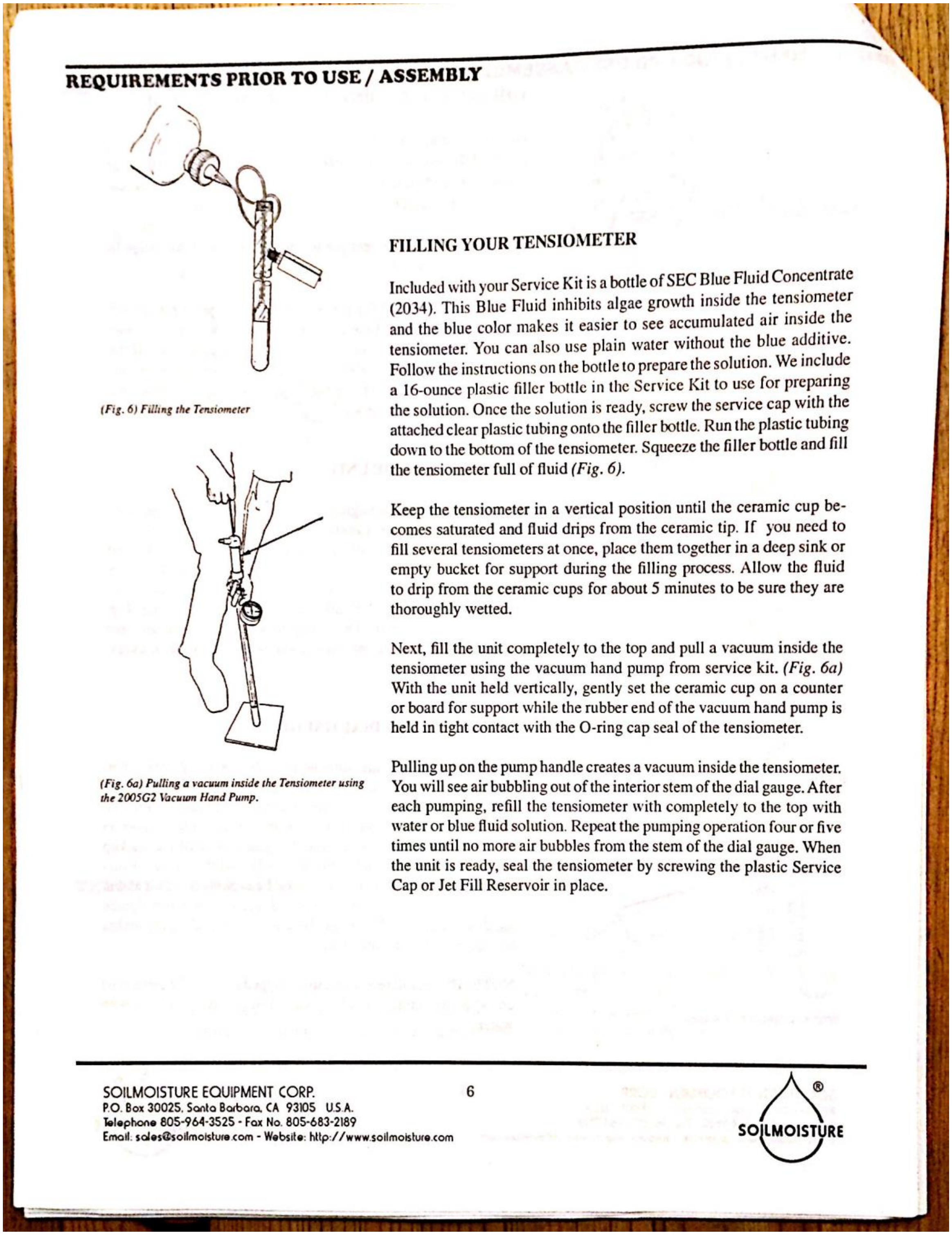


(Fig. 5) Attaching the dial gauge

ATTACHING THE DIAL GAUGE

Grease O-ring with the silicone included in the 2790K1 Kit. Next, screw the dial gauge into the threaded angle port in the side of the body tube (see Fig.4). Be sure that the threads on the dial gauge stem line up properly with the threads of the angle port on the tensiometer body. Screw the dial gauge in until the backup washer on the stem touches the body tube and then unscrew dial gauge slightly until the face of the dial gauge is facing up and in the desired position for easy reading *(Fig. 5)*. Do not over tighten the dial gauge. The O-ring on the stem of the dial gauge makes the vacuum seal, not the threads.

NOTE: The Jet Fill reservoir cap is shipped completely assembled and is easily screwed in place when you are ready to fill it with water.



REQUIREMENTS PRIOR TO USE / ASSEMBLY

(Fig. 6) Filling the Tensiometer

(Fig. 6a) Pulling a vacuum inside the Tensiometer using the 2005G2 Vacuum Hand Pump.

FILLING YOUR TENSIOMETER

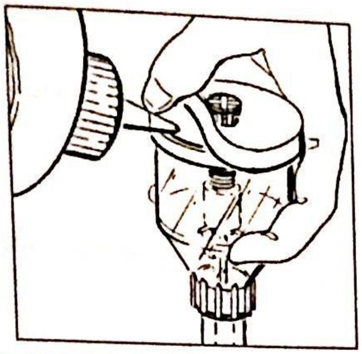
Included with your Service Kit is a bottle of SEC Blue Fluid Concentrate (2034). This Blue Fluid inhibits algae growth inside the tensiometer and the blue color makes it easier to see accumulated air inside the tensiometer. You can also use plain water without the blue additive. Follow the instructions on the bottle to prepare the solution. We include a 16-ounce plastic filler bottle in the Service Kit to use for preparing the solution. Once the solution is ready, screw the service cap with the attached clear plastic tubing onto the filler bottle. Run the plastic tubing down to the bottom of the tensiometer. Squeeze the filler bottle and fill the tensiometer full of fluid *(Fig. 6)*.

Keep the tensiometer in a vertical position until the ceramic cup becomes saturated and fluid drips from the ceramic tip. If you need to fill several tensiometers at once, place them together in a deep sink or empty bucket for support during the filling process. Allow the fluid to drip from the ceramic cups for about 5 minutes to be sure they are thoroughly wetted.

Next, fill the unit completely to the top and pull a vacuum inside the tensiometer using the vacuum hand pump from service kit. *(Fig. 6a)* With the unit held vertically, gently set the ceramic cup on a counter or board for support while the rubber end of the vacuum hand pump is held in tight contact with the O-ring cap seal of the tensiometer.

Pulling up on the pump handle creates a vacuum inside the tensiometer. You will see air bubbling out of the interior stem of the dial gauge. After each pumping, refill the tensiometer with completely to the top with water or blue fluid solution. Repeat the pumping operation four or five times until no more air bubbles from the stem of the dial gauge. When the unit is ready, seal the tensiometer by screwing the plastic Service Cap or Jet Fill Reservoir in place.

REQUIREMENTS PRIOR TO USE / ASSEMBLY



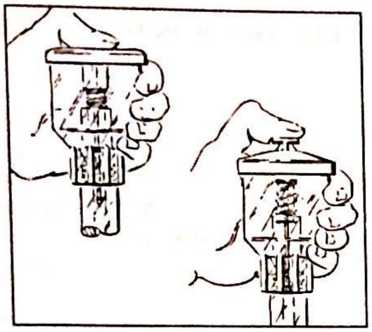
(Fig. 7a) Filling the Jet Fill Tensiometer

FILLING THE 2725 JET FILL TENSIOMETER RESERVOIR

If you have purchased the 2725 Jet Fill Tensiometer, you will also need to fill the Jet Fill Reservoir Cap. To fill the reservoir cap, peel the neoprene reservoir cover back from the top of the reservoir and fill it 3/4 full with SEC Blue Fluid Solution or water *(Fig. 7a)*.

If you don't have a hand vacuum pump handy, you can also remove air from the dial gauge by pumping the reservoir button repeatedly after the tensiometer and reservoir have been filled *(Fig. 7b)*. Push the button down quickly 50 to 60 times over a period of a minute or so, while observing the interior stem of the dial. Continue pumping until no more air bubbles come from the interior gauge stem. To let the air escape more easily from the gauge stem, tip the tensiometer at an angle with the dial gauge pointing down while pumping.

NOTE: If you are not able to install the tensiometer immediately after filling, cover the ceramic cup with a plastic bag to prevent evaporation of water from the ceramic cup.

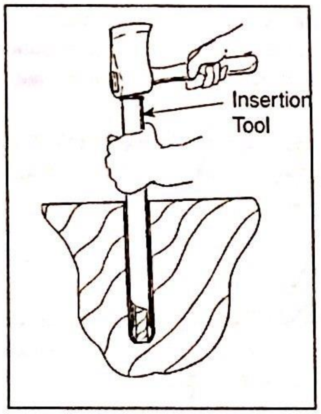


(Fig. 7b) Removing the air from the Tensiometer Body

HOW TO OPERATE UNIT / INSTALLATION

Soilmoisture tensiometers are readily installed in the soil by using conventional soil sampling tools. The body tube and porous sensing tip of the tensiometer are 7/8" (2.2 cm) in diameter. Installation must be made so that the porous ceramic ceramic cups in tight contact with the soil.

The Model 0240L54, 0240L54, 0240L78 Insertion Tools can be used in rock-free soils *(Fig. 8a)*. Standard 1/2" (U.S.) steel pipe can also be used to drive a hole into the soil to accept the tensiometer.



(Fig. 8a) Coring the hole

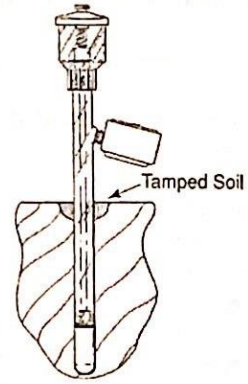
Augers may also be used in rocky soils to core a larger hole. The soil is then sifted and packed around the porous ceramic cup to make good contact before the hole is back filled. The surface soil is tightly tamped around the body tube to seal surface water from entering.In difficult installations, such as in rocky soils or deep installations, a slurry of water and soil can be made up and poured into the bottom of the hole. The ceramic end of the tensiometer is then pushed into the slurry to ensure good contact between the cup and the soil. Large holes cored to

HOW TO OPERATE UNIT / INSTALLATION (cont.)

accept the tensiometer are always backfilled and the soil at the surface tamped tightly around the body tube. *(Fig. 8b)*

After installation, the tensiometer may required several hours before it reads the correction soil suction value. This is due to the disturbance to the soil caused by the installation procedure. The correct reading will be reached more quickly in moist soils than in dry soils.

After this initial installation period, the tensiometer will accurately indicate the soil suction value and will follow closely changes in the soil suction from hour to hour.



(Fig. 8b)

SELECT THE PROPER LENGTH SO THAT THE POROUS CERAMIC CUP WILL BE IN THE ACTIVE ROOT ZONE.

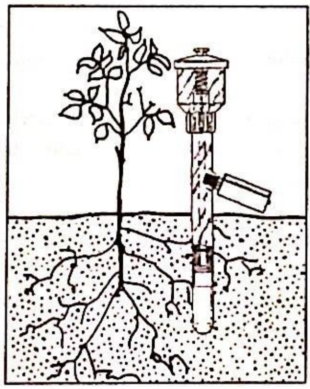
FOR SHALLOW ROOTED PLANTS *(Fig. 9a)*

For plants with shallow root systems of less than 18" in depths, such as certain row crops, a single tensiometer with porous ceramic cup located 3/4 of the way down the root zone can give adequate information. The tensiometer cup can be located near the surface when the plant is young and then lowered as the root system develops.

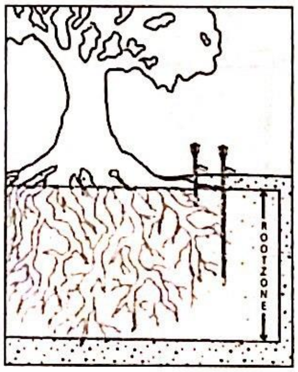
FOR DEEP ROOTED PLANTS *(Fig. 9b)*

For plants and trees with large root systems it is necessary to use two Soilmoisture Tensiometers at each selected station, as shown in *(Fig.09b)* to the right. One shallow unit is placed with tip approximately one-quarter of the way down the root zone. One deep unit is placed with cup approximately three-quarters of the way down into the root zone.

In an orchard with an average root system, the shallow unit would be at 12" to 18" in depth and the deep unit would be at 24" to 36" in depth. By using two Soilmoisture Tensiometers at a station, the grower knows the moisture condition throughout the active root zone. When the shallow unit indicates high soil suction values, irrigation is started. Irrigation is continued until the reading on the deep unit drops – indicating that the irrigation water has penetrated to that depth and the whole active root zone has been re-wetted.



(Fig. 9a)



(Fig. 9b)

TENSIOMETER LOCATION PLACEMENT FOR IRRIGATION CONTROL

Install the Soilmoisture Tensiometer by inserting the body of the Tensiometer into a hole made by a length of standard pipe / rod or by a soil sampling tube. Make sure that the porous cup of the Tensiometer is in good contact with the soil. Lightly tamp the surface soil around the Tensiometer body to make a good seal.

LOCATION OF STATION

"Tensiometer station" is the name given to a tensiometer installation consisting of one or more tensiometers at one place. To monitor moisture conditions in the field, tensiometer stations are located in critical places, required by the irrigation system. Careful selection of a Soilmoisture Tensiometer station is important. The following factors should be kept in mind in selecting a station.

RELATIONSHIP TO PLANTS

- For row crops, locate the Soilmoisture Tensiometer station directly in the row.
- For orchards, locate the station at the drip line of a tree on the tree side of the first furrow, preferably on the south or west side.
- If sprinkler irrigation is used, it is important to locate the Soilmoisture Tensiometers to make sure they are not shielded by a low hanging branch or flooded by runoff.

TYPE OF SOIL

Rates of penetration and storage capacity vary greatly between different soil types. Therefore, the Soilmoisture Tensiometer installation should be made where the soil is most representative of the field to be irrigated. Additional stations should be located where soil type is radically different in order to provide information on proper irrigation timing for those different areas. In large level fields of uniform deep soil that are subject to uniform irrigation practice, a single Tensiometer station may serve as a guide for several acres.

TOPOGRAPHY

On hilly fields place Soilmoisture Tensiometer stations at the high and low areas where drainage conditions may be different. By placing Tensiometer stations in the most productive area of an irrigated plot observations can be made about the moisture conditions in each area. Then changes in irrigation practice can be made so moisture conditions in the unproductive area match those of the productive area.

IRRIGATION LAYOUT

Where furrow or basin irrigation is practiced, place one Tensiometer station near the upper end and one near the lower end of long runs so the head of water and timing can be adjusted to make the distribution as uniform as possible.

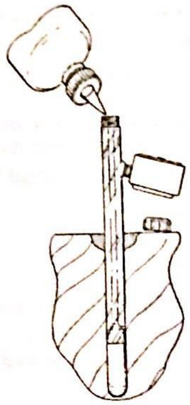
WHEN TO IRRIGATE

In general, if soil suction values are kept below 70 centibars in the active root zone (reading of 70 on Bourdon dial type gauges or 700 on manometer type units) well established plants will not suffer from lack of water. In sandy soils where water storage capacity is small, it is best to start irrigation at lower readings especially if a delay in the irrigation procedure is likely.

If Soilmoisture Tensiometer readings remain at 0-10 centibars for days at a time, this indicates a harmful saturated condition. Steps should be taken to withhold irrigation water and/or improve drainage. It is very useful to plot Soilmoisture Tensiometer readings on a graph during the growing season. In particular, the rate of increase in soil suction that is shown on the graph indicates when irrigation will be required.

GENERAL CARE AND MAINTENANCE/MINOR ADJUSTMENTS

SERVICING YOUR TENSIOMETERS IN THE FIELD



(Fig. 10)

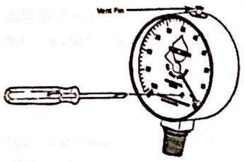
SEC tensiometers are weatherproof and require little servicing other than occasionally refilling the tensiometer with solution using the filler bottle from your Service Kit or by pumping the button on the Jet Fill Reservoir Cap to remove accumulated air within the tensiometer.

If the soil in which the tensiometer has been installed is moist and the soil suction readings are low, very little air will accumulate in the body tube of the tensiometer. If, however, the tensiometer has been installed in relatively dry soil and soil suction values are in the range of 40 to 60 centibars, air will accumulate rather quickly for the first few days after installation. This initial accumulation of air is due to air coming out of solution and detaching itself from the internal walls of the tensiometer when exposed to high vacuum for the first time.

After initial installation, check the tensiometer every day or two and remove accumulated air from the 2725 Jet Fill Tensiometer by pushing the Jet Fill Reservoir Button or refilling the 2710 Style Tensiometer with solution *(Fig. 10)*. The 2710 Tensiometer should be refilled when the water level inside the tensiometer is 1/2-inch to 1-inch or more below the Service Cap.

After the first few air removal servicing operations using the vacuum hand pump in the field, the rate of air accumulation will drop off markedly, and air removal servicing will then be required only on a weekly or longer basis.

ADJUSTING THE POINTER ON THE DIAL GAUGE *(Fig. 11)*

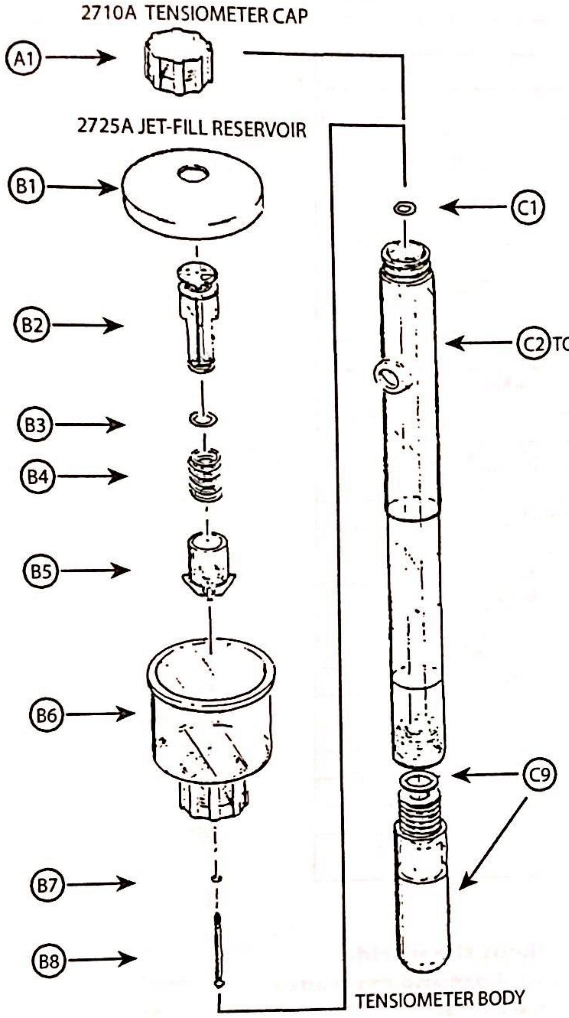


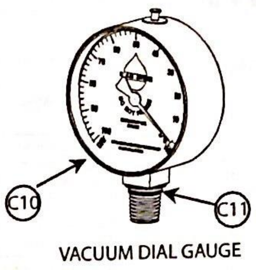
(Fig. 11) Vacuum Gauge Adjustments

First, simply press the vent pin located at the top of the gauge to release any collected air.

Located on the face of the gauge is an insertion point for a small flathead screwdriver. If the gauge is reading high, turn the screwdriver clockwise an estimated amount to correct the error. If the gauge reads low, turn the screwdriver counterclockwise an estimated amount to correct the error. Repeat the process if necessary until the pointer is on zero.

REPLACEMANT PARTS LIST





ITEM #	MODEL #	DESCRIPTION
A1	Z2079	2710A Screw Cap for 2710 Tensiometers
B1	Z2075-001	Reservoir Cover, Jet Fill Reservoir
B2	Z2075-003	Piston for Jet Fill Reservoir
B3	M802X012PKG05	O-Ring Seal, Pack of 5
B4	MSM002-003	Spring, for Jet Fill Reservoir
B5	Z2075-004	Pump Cylinder, for Jet Fill Reservoir
B6	Z2075-002	Reservoir Body, for Jet Fill Reservoir
B7	M802X003PKG05	O-Ring Seal for Gauge, pack of 5
B8	Z2075-100	Piston Stem Assembly, for Jet Fill Reservoir
C1	ZM802X010PKG05	O-Ring Port Seals, Pack of 5
C2	Z2630A-200L06	Tensiometer Body Only, 6 inch length
C3	Z2630A-200L12	Tensiometer Body Only, 12 inch length
C4	Z2630A-200L18	Tensiometer Body Only, 18 inch length
C5	Z2630A-200L24	Tensiometer Body Only, 24 inch length
C6	Z2630A-200L36	Tensiometer Body Only, 36 inch length
C7	Z2630A-200L48	Tensiometer Body Only, 48 inch length
C8	Z2630A-200L60	Tensiometer Body Only, 60 inch length
C9	Z2630-100K1	Tensiometer Screw Top Cup, with O-Ring Seal
C10	2060FG3	Vacuum Dial Gauge, Recalibrator Style
C11	M802X013PKG05	O-ring seal for Gauge, Pack of 5

OTHER USEFUL ITEMS

Part No.	Name
Z2029	Gauge Adjusting Screwdriver
Z2710-001	Service Cap with Nipple
2790K1	Service Kit - Comes with 2005G2 Hand Pump, Charts and Algaecide
2790U1	Tensiometer Filling Fixture
0234LOMBD04	Edelman Auger, 4 cm Diameter, Bayonet Connection
0234SHDLB	Auger Handle, Detachable Grip, Bayonet Connection, 60 cm long
0234NHDLB	Auger T-Handle, Bayonet Connection, 60 cm length
0234HAMR	Dead Blow Hammer
0234SHDLLBXL100	Auger Extension Rod, Bayonet Connection, 100 cm
1907	Sieve Kit
MFJ012PK	¼ Oz. Silicone Grease Kit
2720L06	Tensiometer Extension Tube, 6 inch
2720L12	Tensiometer Extension Tube, 12 inch
2720L18	Tensiometer Extension Tube, 18 inch
2720L24	Tensiometer Extension Tube, 24 inch
2720L36	Tensiometer Extension Tube, 36 inch
2720L48	Tensiometer Extension Tube, 48 inch
2720L60	Tensiometer Extension Tube, 60 inch
Z2710K2	2710 "O" Ring Kit
Z2725K1	2725 "O" Ring Kit
5301-B1	4-20 mA Transducer, Zero to -1 Bar
5301-B.5	4-20 mA Transducer, Zero to -0.5 Bar
5301-B.5	4-20 Ma Transducer
5302	0-100 mV Tranducer
Z2630A-100-B0.5M2	Half Bar Ceramic Screw Top Cup For Tensiometers

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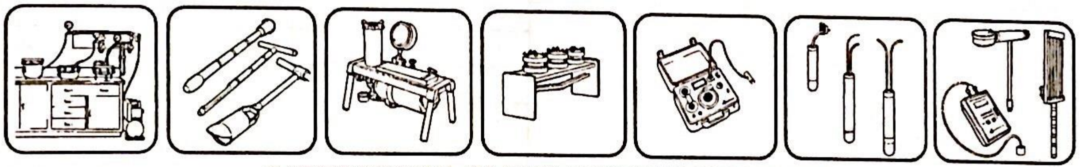
you have convenience of purchase and assurance
of after-sales service.**



Appendix B: Drip Irrigation Cost Breakdown

Drip Irrigation Layout 1

Description	Quantity per acre	Price per acre	Amount
Pipe	82.64	$54.13	$4,473.30
Tape	82.64	$555.29	$45,889.17
Valves	82.64	$171.02	$14,133.09
PVC Fittings	82.64	$31.35	$2,590.76
Filtration	82.64	$119.07	$9,839.94
Sub-Pump	82.64	$19.33	$1,597.43
Controller	82.64	$1.45	$119.83
Misc. Parts	82.64	$62.61	$5,174.09
Installation	82.64	$191.33	$15,811.51
SDI System	82.64	$1,206.04	$99,667.15
Pump+Tank	1	$100,000.00	$100,000.00
Installation of electrical work	1	$30,000.00	$30,000.00
			$329,296.28
Maintenance	82.64	$15.00	$1,239.60
		Per year	$1,239.60
		For 10 years	$12,396.00
		Total Cost	$341,692.28

Drip Irrigation Layout 2

Description	Quantity per acre	Price per acre	Amount
Pipe	80.35	$54.13	$4,349.35
Tape	80.35	$555.29	$44,617.55
Valves	80.35	$171.02	$13,741.46
PVC Fittings	80.35	$31.35	$2,518.97
Filtration	80.35	$119.07	$9,567.27
Sub-Pump	80.35	$19.33	$1,553.17
Controller	80.35	$1.45	$116.51
Misc. Parts	80.35	$62.61	$5,030.71
Installation	80.35	$191.33	$15,373.37
SDI System	80.35	$1,206.04	$96,905.31
Pump+Tank	1	$100,000.00	$100,000.00
Installation of electrical work	1	$30,000.00	$30,000.00
			$323,773.67
Maintenance	80.35	$15.00	$1,205.25
		Per year	$1,205.25
		For 10 years	$12,052.50
		Total Cost	$335,826.17

Drip Irrigation Layout 3

Description	Quantity per acre	Price per acre	Amount
Pipe	75.3	$54.13	$4,075.99
Tape	75.3	$555.29	$41,813.34
Valves	75.3	$171.02	$12,877.81
PVC Fittings	75.3	$31.35	$2,360.66
Filtration	75.3	$119.07	$8,965.97
Sub-Pump	75.3	$19.33	$1,455.55
Controller	75.3	$1.45	$109.19
Misc. Parts	75.3	$62.61	$4,714.53
Installation	75.3	$191.33	$14,407.15
SDI System	75.3	$1,206.04	$90,814.81
Pump+Tank	1	$100,000.00	$100,000.00
Installation of electrical work	1	$30,000.00	$30,000.00
			$311,594.99
Maintenance	75.3	$15.00	$1,129.50
		Per year	$1,129.50
		For 10 years	$11,295.00
		Total Cost	$322,889.99

Drip Irrigation Layout 4

Description	Quantity per acre	Price per acre	Amount
Pipe	82.64	$54.13	$4,473.30
Tape	82.64	$555.29	$45,889.17
Valves	82.64	$171.02	$14,133.09
PVC Fittings	82.64	$31.35	$2,590.76
Filtration	82.64	$119.07	$9,839.94
Sub-Pump	82.64	$19.33	$1,597.43
Controller	82.64	$1.45	$119.83
Misc. Parts	82.64	$62.61	$5,174.09
Installation	82.64	$191.33	$15,811.51
SDI System	82.64	$1,206.04	$99,667.15
Pump+Tank	1	$100,000.00	$100,000.00
Installation of electrical work	1	$30,000.00	$30,000.00
			$329,296.28
Maintenance	82.6	$15.00	$1,239.00
		Per year	$1,239.00
		For 10 years	$12,390.00
		Total Cost	$341,686.28

Drip Irrigation Layout 5

Description	Quantity per acre	Price per acre	Amount
Pipe	88.96	$54.13	$4,815.40
Tape	88.96	$555.29	$49,398.60
Valves	88.96	$171.02	$15,213.94
PVC Fittings	88.96	$31.35	$2,788.90
Filtration	88.96	$119.07	$10,592.47
Sub-Pump	88.96	$19.33	$1,719.60
Controller	88.96	$1.45	$128.99
Misc. Parts	88.96	$62.61	$5,569.79
Installation	88.96	$191.33	$17,020.72
SDI System	88.96	$1,206.04	$107,289.32
Pump+Tank	1	$100,000.00	$100,000.00
Installation of electrical work	1	$30,000.00	$30,000.00
			$344,537.72
Maintenance	88.96	$15.00	$1,334.40
		Per year	$1,334.40
		For 10 years	$13,344.00
		Total Cost	$357,881.72

Drip Irrigation Layout 6

Description	Quantity per acre	Price per acre	Amount
Pipe	80.35	$54.13	$4,349.35
Tape	80.35	$555.29	$44,617.55
Valves	80.35	$171.02	$13,741.46
PVC Fittings	80.35	$31.35	$2,518.97
Filtration	80.35	$119.07	$9,567.27
Sub-Pump	80.35	$19.33	$1,553.17
Controller	80.35	$1.45	$116.51
Misc. Parts	80.35	$62.61	$5,030.71
Installation	80.35	$191.33	$15,373.37
SDI System	80.35	$1,206.04	$96,905.31
Pump+Tank	1	$100,000.00	$100,000.00
Installation of electrical work	1	$30,000.00	$30,000.00
			$323,773.67
Maintenance	80.35	$15.00	$1,205.25
		Per year	$1,205.25
		For 10 years	$12,052.50
		Total Cost	$335,826.17

Appendix C: Sprinkler Irrigation Breakdown

Sprinkler Irrigation Layout 1

Description	Length	Price per linear ft	Amount
Sprinkler System	500	$80	$40,000
Pump and Tank	1	$100,000	$100,000
Installation of electrical work	1	$300,000	$300,000
		Total Cost	$440,000

Sprinkler Irrigation Layout 2

Description	Length	Price per linear ft	Amount
Sprinkler System	400	$80	$32,000
Pump and Tank	1	$100,000	$100,000
Installation of electrical work	1	$300,000	$300,000
		Total Cost	$432,000

Sprinkler Irrigation Layout 3

Description	Length	Price per linear ft	Amount
Sprinkler System	400	$80	$32,000
Pump and Tank	1	$100,000	$100,000
Installation of electrical work	1	$300,000	$300,000
		Total Cost	$432,000

Sprinkler Irrigation Layout 4

Description	Length	Price per linear ft	Amount
Sprinkler System	600	$80	$48,000
Pump and Tank	1	$100,000	$100,000
Installation of electrical work	1	$300,000	$300,000
		Total Cost	$448,000

Sprinkler Irrigation Layout 5

Description	Length	Price per linear ft	Amount
Sprinkler System	500	$80	$40,000
Pump and Tank	1	$100,000	$100,000
Installation of electrical work	1	$300,000	$300,000
		Total Cost	$440,000

Sprinkler Irrigation Layout 6

Description	Length	Price per linear ft	Amount
Sprinkler System	400	$80	$32,000
Pump and Tank	1	$100,000	$100,000
Installation of electrical work	1	$300,000	$300,000
		Total Cost	$432,000

Appendix D: Flood Irrigation Breakdown

Farm Gate Flood Irrigation

Layout 1

2-4hrs:200x500-36 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	8014	$21.00	$168,294.00
12" Slide Gates	134	$300.00	$40,070.00
Check Gates	40	$550.00	$22,242.00
Compacted Fill	12132	$5.00	$60,660.00
12-15" PVC 80 psi	1573	$17.00	$26,741.00
15" Bubblers	21	$450.00	$9,450.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$455,197.00**

Bubbler Flood Irrigation

Layout 1

2-4hrs:200x500-35 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	0	$21.00	$0.00
12" Slide Gates	0	$300.00	$0.00
Check Gates	14	$550.00	$7,700.00
Compacted Fill	12132	$5.00	$60,660.00
12-15" PVC 80 psi	9587	$17.00	$162,979.00
15" Bubblers	48	$450.00	$21,471.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$380,550.00**

Farm Gate Flood Irrigation

Layout 2

2-4hrs:300x500-35 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	8034	$21.00	$168,714.00
12" Slide Gates	134	$300.00	$40,170.00
Check Gates	41	$550.00	$22,278.67
Compacted Fill	12152	$5.00	$60,760.00
12-15" PVC 80 psi	1573	$17.00	$26,741.00
15" Bubblers	21	$450.00	$9,450.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$455,853.67**

Bubbler Flood Irrigation

Layout 2

2-4hrs:300x500-35 Fields

250x 400 ft

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	0	$21.00	$0.00
12" Slide Gates	0	$300.00	$0.00
Check Gates	14	$550.00	$7,700.00
Compacted Fill	12152	$5.00	$60,760.00
12-15" PVC 80 psi	9607	$17.00	$163,319.00
15" Bubblers	48	$450.00	$21,501.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$381,020.00**

Farm Gate Flood Irrigation

Layout 3

2-4hrs:200x400-41 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	11327	$21.00	$237,867.00
12" Slide Gates	189	$300.00	$56,635.00
Check Gates	51	$550.00	$28,315.83
Compacted Fill	15445	$5.00	$77,225.00
12-15" PVC 80 psi	1573	$17.00	$26,741.00
15" Bubblers	21	$450.00	$9,450.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$563,973.83**

Bubbler Flood Irrigation

Layout 3

2-4hrs:200x400-41 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	0	$21.00	$0.00
12" Slide Gates	0	$300.00	$0.00
Check Gates	14	$550.00	$7,700.00
Compacted Fill	15445	$5.00	$77,225.00
12-15" PVC 80 psi	12900	$17.00	$219,300.00
15" Bubblers	59	$450.00	$26,440.50
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$458,405.50**

Farm Gate Flood Irrigation

Layout 4

4-6hrs:250 x500-31 fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	9059	$21.00	$190,239.00
12" Slide Gates	151	$300.00	$45,295.00
Check Gates	47	$550.00	$25,707.00
Compacted Fill	14022	$5.00	$70,110.00
12-15" PVC 80 psi	1573	$17.00	$26,741.00
15" Bubblers	21	$450.00	$9,450.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$495,282.00**

Bubbler Flood Irrigation

Layout 4

4-6hrs:250x500-31 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	0	$21.00	$0.00
12" Slide Gates	0	$300.00	$0.00
Check Gates	14	$550.00	$7,700.00
Compacted Fill	14022	$5.00	$70,110.00
12-15" PVC 80 psi	10632	$17.00	$180,744.00
15" Bubblers	51	$450.00	$23,038.50
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$409,332.50**

Farm Gate Flood Irrigation

Layout 5

4-6hrs:200x600-30 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	7461	$21.00	$156,681.00
12" Slide Gates	124	$300.00	$37,305.00
Check Gates	40	$550.00	$21,987.17
Compacted Fill	11993	$5.00	$59,965.00
12-15" PVC 80 psi	1573	$17.00	$26,741.00
15" Bubblers	21	$450.00	$9,450.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$439,869.17**

Bubbler Flood Irrigation

Layout 5

4-6hrs:200x600-30 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	0	$21.00	$0.00
12" Slide Gates	0	$300.00	$0.00
Check Gates	14	$550.00	$7,700.00
Compacted Fill	11993	$5.00	$59,965.00
12-15" PVC 80 psi	9034	$17.00	$153,578.00
15" Bubblers	46	$450.00	$20,641.50
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$369,624.50**

Farm Gate Flood Irrigation

Layout 6

4-6hrs:300x400-46 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	11187	$21.00	$234,927.00
12" Slide Gates	20	$300.00	$6,000.00
Check Gates	51	$550.00	$28,050.00
Compacted Fill	15305	$5.00	$76,525.00
12-15" PVC 80 psi	1573	$17.00	$26,741.00
15" Bubblers	21	$450.00	$9,450.00
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$509,433.00**

Bubbler Flood Irrigation

Layout 6

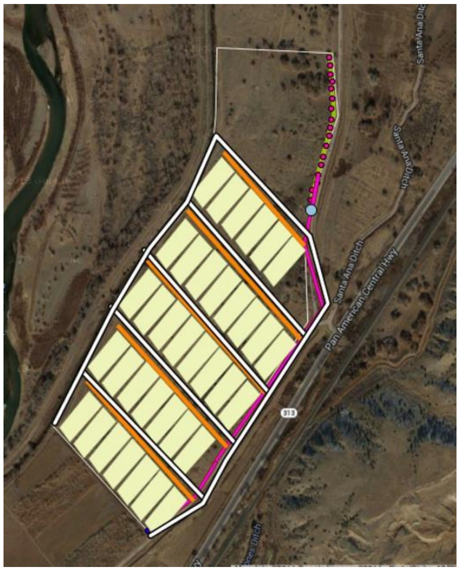
4-6hrs:300x400-46 Fields

Description	Quantity	Price	Amount
Mobilization and Demobilization	1	$2,300.00	$2,300.00
Concrete Ditch Lining: Depth 2 ft(per ft)	4118	$30.00	$123,540.00
Concrete Ditch Lining: Depth 1 ft(per ft)	0	$21.00	$0.00
12" Slide Gates	0	$300.00	$0.00
Check Gates	14	$550.00	$7,700.00
Compacted Fill	15305	$5.00	$76,525.00
12-15" PVC 80 psi	12760	$17.00	$216,920.00
15" Bubblers	58	$450.00	$26,230.50
High flow turnout	1	$1,900.00	$1,900.00
Total Cost			**$455,115.50**

Appendix E: Full Breakdown of Different Field Layout

🟨	Land
🟧	Sublateral
🟪	Main Lateral
▭	Road
🟩	Underground Piping
●	Bubbler's
●	Distribution Box

2-4 Hours of Irrigation



Layout 1	200 feet X 500 feet
Number of Fields	35
Area of Field	2.28 Acres

	Flood-Basin	Flood-Bubbler	Drip	Sprinkler
Cost	$455,197	$380,550.00	$341,686.28	$440,000.00
Efficiency	87.90%	88%	90%	90%

Layout 2	250 feet X 400 feet
Number of Fields	33
Area of Field	2.28 Acres

	Flood-Basin	Flood-Bubbler	Drip	Sprinkler
Cost	$455,853.00	$381,020.00	$335,826.17	$432,000.00
Efficiency	87.90%	92%	90%	90%

Layout 3	200 feet X 400 feet
Number of Fields	41
Area of Field	1.82 Acres

	Flood-Basin	Flood-Bubbler	Drip	Sprinkler
Cost	$563,974	$458,405.50	$322,889.99	$432,000.00
Efficiency	96.90%	97%	90%	90%

4-6 Hours of Irrigation

Layout 4	200 feet X 600 feet
Number of Fields	30
Area of Field	2.75 Acres

	Flood-Basin	Flood-Bubbler	Drip	Sprinkler
Cost	$495,282	$409,332.50	$341,686.28	$448,000.00
Efficiency	91.90%	92%	90%	90%

Layout 5 250 feet X 500 feet

Number of Fields	31
Area of Field	2.87 Acres

	Flood-Basin	Flood-Bubbler	Drip	Sprinkler
Cost	$439,867.17	$369,624.50	$357,881.72	$440,000
Efficiency	95%	95%	90%	90%

Layout 6 300 feet X 400 feet

Number of Fields	46
Area of Field	2.75 Acres

	Flood-Basin	Flood-Bubbler	Drip	Sprinkler
Cost	$509,433	$455,115.50	$335,826.17	$432,000.00
Efficiency	91.90%	92%	90%	90%