AN ASSESSMENT OF THE GREATEST IMPACTS ON DISTRIBUTION UNIFORMITY FOR DRIP AND MICRO IRRIGATION

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ABSTRACT

An Assessment of the Greatest Impacts on Distribution Uniformity for Drip and Micro Irrigation

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Using the Cal Poly Irrigation Training and Research Centers (ITRC) drip/micro evaluation program, global, or system, DU_{lq} is computed by combining the component DU_{lq} values of: pressure variation, uneven spacing between emitters, unequal drainage and “other” causes. “Other” causes include plugging, wear and manufacturing coefficient. The program also computes what percentage of the non-uniformity is due to each component. Burt (2004) showed that over 95% of the non-uniformity is due to “Other” causes and pressure differences. This thesis looks at what specifically in those components is driving the non-uniformity by analyzing various equipment and field practices and their impact on the distribution uniformity. A regression analysis is used to analyze trends in distribution uniformity in an open environment. The results indicate that more information, specifically water quality, is needed to better analyze which components influence the distribution uniformity of a system.

Keywords: Distribution Uniformity, Irrigation, Drip, and Micro

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Chapter 1: Introduction

Background of the Study

California plays a vital role in the United States, and the world, as a grower of food and agricultural products. Water is the most debated natural resource in California and is one of the most expensive and essential inputs to agricultural production. Since California entered the 2012 drought, focus on irrigation efficiency has escalated each year (Faunt et al., 2015). An essential element to maintain high and uniform crop yields and crop quality at a low cost is to have the right application of water, with an even distribution.

Drip irrigation is commonly recommended as a ‘water-saving’ irrigation method based on assertions that it is more efficient than other irrigation methods (Luquet et al., 2005). “High efficiency does not necessarily imply good irrigation management and in some cases, it is associated with unsatisfactory irrigation” (Burt et al., 1997). This scenario has the potential to happen when the amount of water applied is not enough to meet the crops demands, but there is no water runoff or losses making the system efficient, while irrigating unsatisfactorily (Industry, 2017). Having good timing, low water losses and high distribution uniformity (DU), the measure of how evenly water is applied to an irrigated area, such as a field (Burt, 1997), maximizes the percentage of beneficial use of both land and water.

This thesis will focus on one of the many essential factors for on-farm irrigation efficiency, which is the distribution uniformity of applied irrigation water. With low DU, the field is irrigated non-uniformly and certain areas receive considerably more or less water than others do. In the areas that receive less water, the crop requirements may not

be satisfied causing decreases in the crop yield. On the other hand, in areas that receive additional water, the crop requirements have the potential of being exceeded resulting in deep percolation which leads to water and nutrient losses.

Using the Cal Poly Irrigation Training and Research Centers (ITRC) drip/micro evaluation program, global, or system, DU_{lq} is computed by combining the component DU_{lq} values of: pressure variation, uneven spacing between emitters, unequal drainage and “other” causes. “Other” causes include plugging, wear and manufacturing coefficient. The program also computes what percentage of the non-uniformity is due to each component. Burt (2004) showed that over 95% of the non-uniformity is due to “Other” causes and pressure differences. This thesis looks at what specifically in those components is driving the non-uniformity by analyzing various equipment and field practices and their impact on DU.

Statement of Purpose

The primary purpose of this thesis is to explore which irrigation components have the greatest impact on distribution uniformity (DU). With certainty, various problems are known to reduce DU. For example, sediment in a drip system can cause plugging, decreasing the uniformity of applied water. While filtration is a key component to minimize sediment and improve the DU, little research has been conducted to determine which filtration method is most effective at keeping the DU high. This thesis does this by analyzing specific DU evaluation data from 1,135 fields between the years of 1995-2016.

Significance

Barricarte (1999) and Burt (2004) have examined what causes the variability in the distribution uniformity of drip or micro fields, pressure differences and "other" causes make up 95% of irrigation systems non-uniformity. However, few studies have analyzed which specific equipment or practices in the field have the greatest impact on DU. This project uses existing field evaluation data to discover trends about specific equipment or practices. Growers would directly benefit from this knowledge when making irrigation decisions.

Research Hypotheses

It was hypothesized that:

1. Pressure regulation will have a positive impact on DU.
2. Systems using a sand media tank for filtration will have a positive impact on DU.
3. The system DU will be positively related to the number of emitters per plant.

4. The DU of a system will increase with more frequently injected acid and/ or chlorine.
5. The DU of a system will increase with more frequently flushed hose or tape.

Delimitations (researcher imposed)

This study was delimited to the following parameter:

1. Drip or micro observations obtained by the ITRC mobile field lab, with a recorded date, were considered in the analysis.

Assumptions

This study was based on the following assumptions:

1. ITRC employees accurately followed all procedures with detail while collecting samples to determine field DU values.
2. The data collected was accurately recorded into the evaluation program.
3. The selected samples in the field were representative of the distribution uniformity in the field.
4. Each evaluation team received the same training.

Limitations (externally imposed)

This study was limited by the following factors:

1. All research was conducted in California during the summer months.
2. The data was collected from fields voluntarily submitted to the ITRC for evaluation.
3. In some years, the funding source dictated some participation in the evaluation, limiting the water source and geographic location.

Chapter 2: Review of Literature

Introduction

The main irrigation methods used by growers today include surface irrigation, sprinkler irrigation, and micro irrigation. This research will focus on micro irrigation, which represents several low volume, high frequency irrigation methods described below as drip and micro. Drip and micro irrigation is best suited for tree, vine and row crops and is also suitable for most soils and virtually any topography making it a popular choice as an irrigation method (Burt et al., 2000). Drip and micro irrigation systems consist of a pumping station, filtration system, pipelines and hoses. In most cases, the pumping station adds pressure to water as it travels through the system and eventually out to the emitter and plant. The drip or micro irrigation method is either defined by the crop type or by the hardware used to irrigate.

Drip

Drip irrigation applies the water through small emitters onto the soil surface, close to the plants, at low flow rates with frequent irrigations (usually every 1-3 days) (Brouwer et al., 1988). Drip irrigation systems tend to have smaller hose diameters than micro irrigation because the flow rates of the emitters are much lower compared to micro irrigation (Burt and Styles, 2011).

Tape

Irrigation tape can be installed on the ground, under plastic or subsurface and is commonly made from polyethylene. Thicker walled tapes are commonly used for

permanent subsurface drip irrigation and thinner walled tapes are mainly used for temporary systems such as for high value crops.

Subsurface

Subsurface irrigation is the application of water below the soil surface. Sammis, 1980 claims that the subsurface irrigation method appears to offer the best method of supplying uniform soil moisture in the root zone to the plant throughout the growing season, resulting in the highest yields and high water-use efficiencies for row crops. Although mostly used for row crops, subsurface irrigation on orchards and vineyards poses issues with root intrusion.

Hose

Most hose used for irrigation is manufactured from polyethylene. Irrigation hose can be used in conjunction with emitters, as drip lines or for microsprinklers or microsprayers. The hose can come with emitters pre-installed or emitters can be manually inserted directly into the hose in the field.

Inline Emitters

The general trend is to purchase inline emitters that come pre-installed in the hose, as shown in Figure 1. Individual emitters may be welded to the inside of the polyethylene hose, with a hole provided in the hose for the flow discharge. By having the

emitters pre-installed, the labor required for field installations is reduced. The emitter itself cannot be seen unless the hose is cut apart (Burt and Styles, 2011).

Figure 1: Inline Emitter

Online Emitters

Online emitters are often manufactured separately from the hose and may be installed on the hose either at the factory or in the field, depending upon the emitter configuration and design. There is a “barbed” inlet port that is inserted through a hole in the hose (Burt and Styles, 2011).

Dual Line

In orchards and vineyards, it is common to have one hose per plant row, but if a single line of emitters will not provide sufficient wetted area, a second row of hose can be installed. In California, about half of the almond acreage with drip or micro is dual line drip with six to eight emitters per tree (Burt and Styles, 2011). Figure 2 shows a dual line

drip system for a young pistachio field. When the trees get older, the hose will be spread farther apart.

Figure 2: Dual Line Drip

<u>*Micro*</u>

In the early 1980's, microsprayers and microsprinklers became very popular in the western U.S., and many drip systems were converted to micro at the time. Micro irrigation is often designed and irrigated in sets because of the high application rate, making micro systems often more expensive (Burt and Styles, 2011). Micro irrigation applies water to the soil surface by a small spray or mist resulting in a larger wetted soil area (Burt, 2004).

Microsprinkler vs. Microsprayer

The only difference between a microsprinkler and a microsprayer is that microsprinklers have moving parts, whereas microsprayers have no moving parts. Microsprinklers and microsprayers are typically attached to a stake (pushed into the

ground) that is connected to the lateral hose with a spaghetti hose (Burt and Styles, 2011), as shown below in Figure 3.

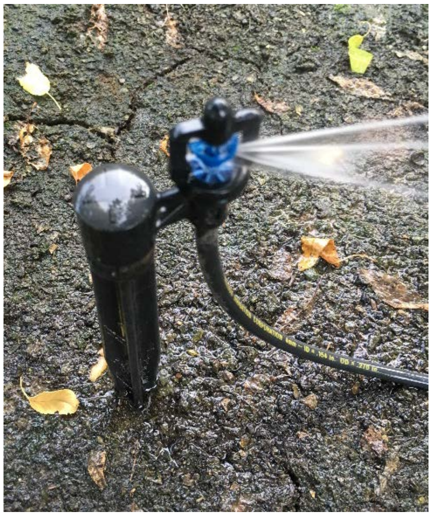

Figure 3: Microsprinkler

Irrigation Efficiency

There are many ways to measure how efficiently a grower is irrigating their crops. Irrigation Efficiency (IE), represented as a percentage, is defined in Equation 1. IE is the water beneficially used compared to the total water applied and accounts for a change in stored within the soil reservoir.

$$IE = \frac{vol.\ irrig.\ water\ beneficially\ used}{vol.\ irrig.\ water\ applied - \Delta\ storage\ of\ irrig.\ water}\ x\ 100\% \qquad [1]$$

Irrigation efficiency values are most often used for a description of annual or seasonal occurrences. Application efficiency is typically used for a rapid estimate of what the irrigation efficiency might be or to determine how well the irrigation system satisfies a perceived need, such as a target soil depletion (Burt, 1997).

It is possible to have a uniform irrigation system (high DU) while irrigating too frequently resulting in excess runoff and excess deep percolation (low IE), both of which are considered non-beneficial uses of water (Burt, 1997). A high IE with minimal under-irrigation can only be obtained if the DU is also high (Burt and Styles, 2011). Barragan et al., 2010 also concluded that uniformity alone is not sufficient to achieve the goal of suitable irrigation, an irrigation schedule is also equally important. Therefore, field evaluations for the DU of an irrigation system are one of the very first steps in improving on farm irrigation efficiency (Burt and Styles, 2011). A common way to demonstrate the concept of irrigation efficiency and distribution uniformity graphically is with a water destination diagram.

Water Destination Diagrams

Water destination diagrams are a visual way to describe the concepts of field irrigation efficiency and DU (Solomon and Kissinger, 2005). The horizontal axis of (Figure 4) (C) represents the irrigated area as (% of area), meaning that at a point along the horizontal axis, up to that percent, the field received at least the amount of water represented on that vertical axis. Along the top of the figure (A), are the catch-cans, previously discussed and rearranged from the highest volume of water collected to the lowest. The slope represents the distribution uniformity - the steeper the slope, the lower the distribution uniformity (Solomon and Kissinger, 2005).

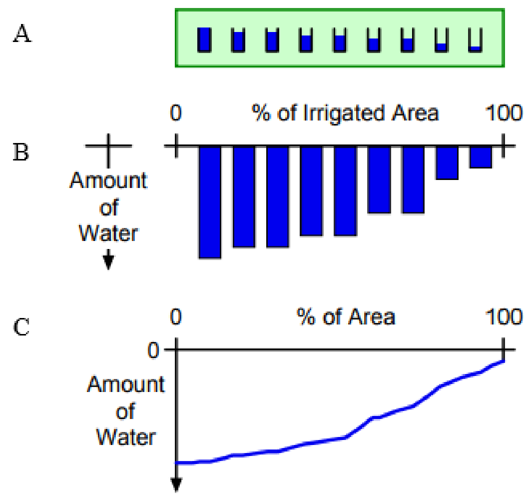

Figure 4: Rearranged catch-cans create the water destination diagram by representing the amount of water applied to the field (A). The diagram can be illustrated as a bar graph (B) or as it is most commonly done, as a water application curve (C) (excerpt from Solomon and Kissinger, 2005).

(Figure 5) illustrates the potential benefit from updating a fields system to increase the DU of a field. The slope of the red and blue lines represents DU and the systems non-uniformity over the field. A steep slope, like the red line in the top left corner of (Figure 5), is evidence of a poor DU. In the same figure, the area under the green target line to the red line shows the amount of over irrigation due to poor uniformity. The top right photo of (Figure 5) shows that with increased distribution uniformity, there are significant water savings, as illustrated in the bottom left photo (Solomon and Kissinger, 2005).

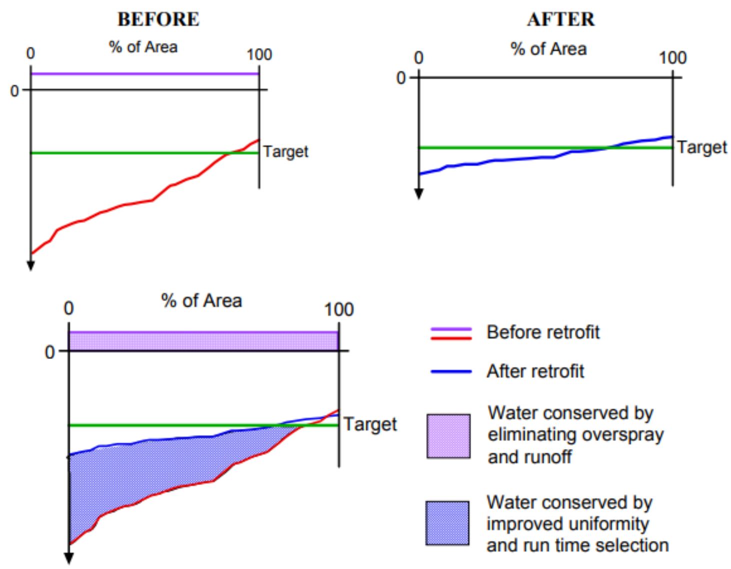

Figure 5: Water destination diagrams for before and after a retrofit. The third graph shows the water conserved by the improvements to either DU or surface losses (excerpt from Solomon and Kissinger, 2005).

Distribution Uniformity

Distribution uniformity (DU) is the measure of how evenly water is applied to an irrigated area, such as a field (Burt, 1997). DU is a mathematical expression intended to quantify the water application variation and assist with irrigation scheduling. DU has become the accepted term to define irrigation uniformity; however, it is not an efficiency term (Burt and Styles, 2011).

The most direct way to observe and numerically evaluate DU is through an irrigation assessment. The key conceptual steps for an irrigation assessment are: 1) place catch-cans or buckets under each emitter, 2) run the irrigation system as intended for the same amount of time for each emitter, 3) analyze and interpret the results by measuring and 4) comparing the volume of water in each catch-can or bucket (Solomon and

Kissinger, 2005). The difference in volume between all the buckets is general evidence of non-uniformity.

Cal Poly ITRC Data

The Cal Poly Irrigation Training and Research Center, developed standardized irrigation system evaluation procedures for all irrigation methods, funded by the California State Water Resources Control Board, referred to as the ITRC rapid evaluation procedure (Burt, 2004). The specifics about data collection and computation of DU component values using the ITRC rapid evaluation procedure can be found in the published paper by Burt, 2004.

Cal Poly student teams, made possible by funding sources like the U.S. Bureau of Reclamation's Mid- Pacific Region or the California Department of Water Resources, collected data for this study. The two-person teams attend regular Cal Poly irrigation classes and attend a five-day irrigation evaluation short course taught by the ITRC every spring. The students receive a high level of technical support and detailed review of their work (Burt, 2004). The forms filled out by the students during a field assessment are included in Appendix A.

Components of Global DU

The measurements of four components are taken to determine a DU value for the system: DU due to changes in pressure, DU other, DU unequal spacing, DU unequal drainage. A combination of all four components of DU provides an estimate of DU

global. Global DU is also referred to as System DU or Field DU and is defined in Equation 2.

$$System\ DU = DU_{\Delta Pressure} * DU_{Other} * DU_{Unequal\ Spacing} * DU_{Unequal\ Drainage}$$

[2]

"Other" causes included everything other than DU due to changes in pressure, DU unequal spacing and DU unequal drainage, which includes things like plugging, wear, chemicals, back siphonage and manufacturing variation. Pressure differences and "other" causes make up a high majority of the explanation for non-uniformity. DU values are expressed as a decimal between 0 and 1.0 and the average drip or micro irrigation systems DU Global values are around 0.85 (Burt, 2004).

DU Changes in Pressure

Differences in pressure at each emitter will cause flow rate variations due to the relationship between pressure and flow as shown in (Equation 2), for non-pressure compensating emitters. Pressure compensating emitters deliver a precise amount of water regardless of changes in pressure due to a flexible diaphragm inside the emitter that regulates the flow.

$$Flow = Crop\ Coefficient\ x\ Pressure^{Discharge\ Exponent}$$

[3]

There is a detailed procedure on where to take pressure measurements in the field and how many measurements need to be taken. The pressure measurement locations used during the irrigation assessment includes: pressures along individual hoses, pressures

between individual hoses along a single manifold, and pressures at the head of each manifold.

The pressure measurement locations are designed to be able to compare and differentiate between pressures along individual hoses, individual hoses along a single manifold and at the head of each manifold. Pressure measurements are taken at the locations where the highest and lowest pressures are expected to be found, to determine the highest-pressure differences on the field. By isolating out where the pressure differences are occurring, an effective option to minimize pressure differences can be selected and implemented to increase DU (Barricarte, 1999). The specific standard for each of the pressure locations and the number of readings required are found in Burt (2004).

DU Other

DU Other accounts for any factor that would cause a variation in flow rate among emitters, assuming the emitters are operating at the same pressure. The most common factors include plugging, wear, and manufacturing variation.

To compute DU Other, emitter flow rates are taken from three locations in the field while the emitters are operating at the same pressure. When operating at the same pressures, the flow rates variation within a sample are due to manufacturing variation, nozzle or emitter path wear (particle caused abrasions) and nozzles or emitters plugging, but not due to pressure differences. The first location of flow measurement in the field is the middle of a hose that is hydraulically close to the water source. The second set of flow tests is taken at the middle of a hose, in the middle of a manifold, that is near the

middle of the field. Lastly, a set of flow reading is taken at the end of a hose that is at the end of the most distant manifold (Burt, 2004). The purpose of the various reading locations is to account for flow rates at the 'cleanest', 'average' and 'dirtiest' areas in the field. By doing so, the data collected is more representative of what is going on throughout the field without having to test each emitter. To calculate DU other, using the flow rate information collected, (Equation 3) is used:

$$DU_{Low\ Quarter\ Other} = 1 - \frac{1}{\sqrt{n}}\left(1 - average\ \frac{q_{minlq}}{q_{avg}}\right)$$

[4]

Where "n" is the number of emitters per plant to compensate for an 'averaging effect' that happens when multiple emitters are combined for one plant.

<u>Number of Emitters per Plant</u>

The number of emitters per plant are included in the equation to account for the averaging effect on manufacturing variation if several emitters are used per tree. Burt and Styles, 2011 note that while manufacturing variation and material aging should be distributed evenly across the field, wear and plugging are often not distributed evenly across the field. A portion of the wear and plugging effects are "evened out" with multiple emitters per plant. Figure 2 shows an orchard with 12 emitters per plant.

<u>Manufacturing Variation</u>

The coefficient of variation (cv) is a statistical measure for emitter manufacturing variation (Wu et. al, 1988). The cv is defined as the ratio of standard deviation to the mean flow rate from a suitable sample of emitters tested at a normal operating pressure.

With higher coefficients of manufacturing variation, the emitters flow rates difference increases (Burt and Styles, 2011). It is believed that the cy will likely be better with newer systems as opposed to older systems. Differences in flow occur because it is impossible to manufacture two emitters exactly alike (Solomon, 1979).

DU Uneven Spacing

DU uneven spacing is an effect of having a different number of emitters in the field such as having two or more different plant spacings, but with the same number of emitters per plant. To calculate the DU due to uneven spacing, the following information is collected in the field: the area of the field with each tree or emitter spacing, plant spacing in each area, emitter spacing in each area, the average emitter flow rate in each area, and the hours of emitter operation per week in each area. With this information, the lowest weekly depth applied, the application depth in the area that receives the least amount of water, the average weighted depth applied, and the average depth applied to the whole field for the week, can be calculated to get the DU uneven spacing value. Most systems have an uneven spacing DU of 1.0 with only one emitter and plant spacing in the field, making it a minor DU component on most fields (Burt, 2004).

DU Unequal Drainage

After turning a drip system off, some emitters may continue to drain for a significant length of time after most of the emitters have stopped discharging water. This is particularly important on sloping ground for systems that have short irrigation sets. Large diameter tapes also largely affect DU unequal drainage. Like DU uneven spacing,

DU unequal drainage usually has minimal impact on the field DU (Barricarte, 1999). The data consists of an observation of the length of time some emitters continue to drain after most of the emitters have stopped, compared to the average set duration. If unequal drainage is affecting the field DU, a solution could be to use longer set durations (Burt, 2004).

Options for Improving DU

<u>Pressure Regulation</u>

There are many different locations to regulate pressure in the field including at the head of each manifold, at the head of each hose, at the emitter via pressure compensating emitters or a combination of those options. Pressure regulation for micro irrigation can be achieved not only by choosing the right pipe size when designing, but also by using pressure regulators, adjustable valves and emitters that compensate their flows with the pressure changes (Burt and Styles, 2011).

Ella et al. 2009, looked at some of the effects on Merriam and Keller's DU between no pressure regulation and pressure regulated by low cost adjustable valve pressure regulators at the head of each manifold. As theoretically expected, the DU was higher for the system using pressure regulation, versus a system that utilized no pressure regulation.

A pressure regulator is a valve designed to regulate pressure downstream of its location in an irrigation system by automatically adjusting the open area as the pressures vary upstream. All pressure regulators are designed to accurately reduce system pressure, making it important to always design for the pressure to be higher upstream of the

regulator for the desired lower pressure downstream (Burks, 2000). There are two types of pressure regulators, which are adjustable pressure regulators or non-adjustable pressure regulators.

Adjustable Pressure Regulation

A couple common placements for adjustable pressure regulators is at the head of each 'block' or at the entrance to the irrigation system (before the filters). The purpose of being at the head of each block, is so that each block will begin with the same pressure. The purpose of an adjustable pressure regulator upstream of the filters is to ensure that the filters are not exposed to high pressures, especially for media filters (Burt and Styles, 2011).

Non- Adjustable Pressure Regulation

It is important to note that a non-adjustable pressure regulator may not provide the stamped discharge pressure. The actual discharge pressure depends on the flow rate, manufacturing variation and the regulator inlet pressure (Burt and Styles, 2011).

Flushing Hoses

Plugging is the most significant factor in decreasing the distribution uniformity of the emitter discharge on the field (Wu et al., 1998). One way to combat plugging is by flushing the hoses. Flushing hoses consists of opening the cap found at the end of the hose or tape, as shown in Figure 6, while the system is on. By allowing the water to run out the end of each hose until it runs clear, cleans the hose of any debris or dirt that may be trapped inside.

Figure 6: The end of a hose where flushing occurs.

Depending on water quality, some growers will need to flush the hoses to reduce plugging. If the water quality is good, flushing may not be only needed once a year. Theoretically, flushing drip laterals weekly would result in less plugging in the emitters than laterals that are flushed monthly, annually, or not at all. However, this is dependent on water quality.

Puig-Bargues et al., 2010 studied the effect of flushing frequency on emitter clogging in micro irrigation with effluents. It was found that more frequent flushing did result in greater DU and the authors suggested flushing laterals periodically before emitters plug up completely. Ravina et al., 1997 found no differences in emitter clogging when testing flushing the drip laterals daily or every two weeks. Both studies used treated wastewater effluent.

Filtration

Water Quality

Water quality is the primary factor in determining the filter needed for an irrigation system. There are two main water sources for drip or micro irrigation; surface water and groundwater. Surface water with significant organic content like algae and bacteria requires the use of a sand media filter or disk filtration with backup screen filters. Conversely, for well water containing inorganic sand and/or scale, screen filters in combination with sand separators would work well (McFadden, 2007). Knowing what solids need to be filtered out, plays a role in picking which filtration system is best suited for that situation to best avoid plugging of the hoses or emitters.

There are two main types of filtration in agricultural systems, pre-filtration and filtration. The main purpose of pre-filtration is to remove large particles of debris such as aquatic plants, bottles, fish and strings of algae (Burt and Styles, 2011). Because of the high need for pre-filtration, in some cases, multiple filters may be present for the same irrigation system.

There are many types of filtration systems used in drip or micro irrigation, the following were used in this analysis:

Disc Filters

Disc filters are a stack of circular disks, with each disk having a cross-hath pattern of grooves based on the level of filtration needed. As water goes through the disks, the grooves allow water to pass, while retaining any contaminants.

Figure 7: Disc Filters.

Sand Media Filters

Sand media tanks have traditionally been the most popular filter for dirty water situations. When there is a ‘high’ dirt load of organic and/or inorganic material, sand media tanks work excellently. The sand is sized to provide the required degree of filtration. Sand media tanks are set to backflush one at a time based on elapsed time or pressure differentials set across the tanks (Burt and Styles, 2011).

Figure 8: Sand Media Tanks.

Overflow Screens

Burt and Styles, 2011 state that gravity overflow screens are great for pre-filtration of sand media tanks when there is very dirty water because they can handle large loads of sand and organic debris without the need for constant back flushing. Water falls onto a tight, fine mesh screen where the contaminants are washed to the edge of the screen, and the clean water collects in a lower chamber. The clean water in the lower chamber is picked up by a booster pump and delivered to the drip system (Burt and Styles, 2011).

Tubular Screens

Tubular screens are primarily used as backups to the primary filtration device or in very clean water situations with no organic material. They provide low-capacity, emergency filtration (Burt and Styles, 2011).

Figure 9: Tubular Screen.

Chemigation

Drip or micro irrigation has a reputation for water efficiency, but many growers adopt a drip or micro system for effective delivery of chemicals and fertilizers (McFadden, 2007). Drip or micro irrigation is almost always associated with the

application of nutrients, these systems also allow for better nutrient management (Benouniche et al., 2014).

Burt and Styles, 2011 identify five types of plugging in a drip system that require chemical injection into the water: slimy bacteria which can grow on the interior walls of the hose and emitters, iron and manganese oxides, iron and manganese sulfides, calcium and magnesium carbonate precipitation and root intrusion into buried emitters.

Physical, biological or chemical contaminants can cause the plugging of emitters. Inorganic materials like sand, silt, clay or plastics cause physical clogging. Organic materials such as animal residues and snails and microbiological debris, algae etc., can be combined with physical materials. Chemical problems are a result of dissolved solids when they interact with each other to form precipitates. Biological clogging is due to algae, iron slimes and Sulphur slimes. The causes of plugging are different from location to location (Capra and Scicolone, 1998). Not all growers have to deal with biological contaminants, therefore do not need to inject chlorine or acid. This study will focus only on the injection of chlorine and acid.

Chlorine Injection

Chlorine injection is a common treatment to kill slimy bacteria and algae, which are too small to be removed with filtration. The main reason to have the injection location upstream of the filter is so the filters will remove any dirt introduced to the system by dirty hose connections, sludge from the bottom of the chemical tanks or dirt/chemical participates that might inadvertently form during injection.

Acid Injection

Acid injection is also used to treat slimy bacteria, as well as enhance the effectiveness of chlorine. To avoid corrosion damage to the filter, strong acids may be injected directly into the PVC mainline downstream of the filters, although it is very dangerous to inject anything downstream of the filters because it may clog the emitters and have a negative effect on the systems distribution uniformity. (Burt and Styles, 2011).

Chapter 3: Methods and Procedures

Overview

A total of 1,135 evaluations of drip or micro systems were conducted with over 100 assessed variables including many pressure and flow readings throughout the field, by student teams through 2016. Some of the variables are direct readings from the field and some are answered by the grower or observed during the assessment. There was an average of 56 drip or micro evaluations completed a year. The ITRC also completes field assessments for under tree sprinkler systems as well as linear move sprinklers, border strip, furrow, hand move and solid set sprinkler systems.

Data Organization

Before analyzing the data, many steps were taken to improve the raw data for an accurate analysis. Location of the observation was added to the analysis based on the name of the mobile lab. The emitter path type was reviewed and corrected based on the manufacturer and model information. For example, Bowsmith FanJets emitter path type was corrected from 'Rotating microsprinkler' to 'Non-rotating microsprayer.' Microsprinklers have moving parts whereas microsprayers have no moving parts.

Modifications to the Program

If multiple filter types were reported in one system, the option, 'Multiple Filter Types' was added to that observation. In 2010, the option of 'Frequency of chlorine, acid, etc. injection' was expanded to 'Frequency of chlorine or polymer injection' and 'Frequency of acid injection.' For this study, 'Frequency of chlorine, acid, etc. injection'

was combined with ‘Frequency of chlorine or polymer injection’ and ‘Frequency of acid injection.’

The option of ‘Location of injector with respect to filter’ was also expanded in 2010 to: ‘Location of fertilizer injector with respect to filter,’ ‘Location of pesticide injector with respect to filter,’ ‘Location of acid injector with respect to filter’ and ‘Location of gypsum injector with respect to filter.’ For this study, ‘Location of injector with respect to filter’ was combined with ‘Location of fertilizer injector with respect to filter,’ ‘Location of pesticide injector with respect to filter,’ ‘Location of acid injector with respect to filter’ and ‘Location of gypsum injector with respect to filter.’

Collected Data Omitted from Analysis

System type, such as subsurface drip or above ground drip with hose, hose spacing (feet), crop type and soil type were all left out of the analysis because they were not reported on until 2015. Manufacturer, model and nominal flow were all omitted from the analysis because of the scarcity and reliability of the recorded responses. The model name is often difficult to obtain if the grower does not know what it is, since there are various models commercially available.

The responses to ‘Is there a water penetration problem?’, ‘Is there undulating (rolling; up-and-down) topography?’ and ‘Percentage of applied water that runs off the field’ were all omitted from this research because the responses to those questions are subjective and often-times answered by the grower. The responses to these questions are only used to generate recommendations for the grower, not to calculate or determine the distribution uniformity.

Pressure Loss through Hardware

Total filter loss, total pump control valve loss and loss from the throttled manual valves were omitted from the analysis because they are represented in the pump discharge pressure and pressure downstream of the filters and control valves. While the lower pressure can have an impact on DU, that is a design or management problem, which is not something being tested. The program does provide recommendations to improve the DU, but there is no way to know if they make the recommended changes, therefore it cannot be included in the analysis.

The field pressure measurements section of the program was omitted from the first model because it simply demonstrates pressure variation in the field, which may not impact DU. While pressure variation is the field component of the DU for drip, it is impossible to tell what causes the variation. It could be caused by the hydraulics, poor design, plugged hose screen washers or elevation change by running an analysis of just the field pressure values. The second and third models included analysis if there is a partially throttled manual valve and if there is an automatic pressure control valve.

Water Source

The type of water source was omitted from the first model because it was not reported during the following years: 1995, 1997, 2000-2002 (approximately one-third of the data). However, after looking at the results from the first model, it was determined that water quality, assumed through water source, has an influence on DU that would be interesting to look at. For the second model, all water sources were included. After

looking at the results from the second model, it was still clear that water quality had an impact. The third model only includes observations that used surface water, which is assumed to have the worse water quality.

Emitter Flow Measurement

The ‘Emitter Flow Measurement’ section was omitted from the analysis because there are many reasons why the flows may vary from emitters: pressure variation, emitter plugging, insects, wear, chemicals, etc. This unknown variation is DU Other which accounts for any variation in the field that isn’t related to pressure, uneven spacing or unequal drainage. By analyzing only flow readings, the cause of the variation cannot be determined.

Emitter Spacing

The ‘Emitter Spacing’ section was left out of the analysis because this information is represented with 'Emitter Spacing Combination' and ‘Emitters per Plant.’

Contaminants and Plugging/ Leak and Valving

The ‘Contaminants and Plugging/ Leaks’ and ‘Valving’ sections were left out of the analysis because of the subjectivity level associated with the responses and because the responses are used to generate recommendations for the grower, not to calculate or determine the distribution uniformity of a system. It is unknown whether the growers implemented the recommendation, so it cannot be tested.

Unequal Drainage

The 'Unequal Drainage' section was left out of the analysis. While it does have a slight impact on the distribution uniformity; it is based on given information, rather than measured information, so the reliability of the data is low. Also, many observations did not report responses for unequal drainage.

Emitter Spacing Combination

The 'Emitter Spacing Combination' was included in the first model but omitted from the second and third model. It was omitted because there weren't enough responses for more than one emitter spacing combination.

Statistical Analysis

Preparation for Statistical Analysis

Observations need to have a response for each variable to be included in the model. If a response was missing from the selected variables, then the observation was omitted. Most of the data is categorical data, meaning dummy variables are needed to conduct a statistical analysis. Dummy variables are when a categorical term is given a binary 0 or 1. For example, location has two responses, either Sacramento Valley or San Joaquin Valley. If the observation took place in the Sacramento Valley, a 1 would appear in the Sacramento Valley column and a 0 in the San Joaquin Valley column. If an observation had less than 24 responses after the categorical variables were broken down into dummy variables, the data was omitted.

When categorical data is used in a regression analysis, one or the responses for the observation is omitted from the data as a 'base case.' The variable will be represented in the analysis by the other dummy variables for that observation all being equal to zero.

Regression

A regression analysis is used in statistics for evaluating the relationship of one or more independent variables to a single, continuous variable. A regression analysis is most often used to represent 'the real world' or when the independent variables cannot be controlled (Kleinbaum et al., 2013). A multiple regression analysis was used to predict the behavior of the various independent variables and test if there is a statistically significant relationship between these variables and the response variable of global distribution uniformity. While variables may be related in a controlled environment, the identification of important variables in an open environment can help determine the significant factors that influence a systems distribution uniformity out in the field. The program Minitab was used to calculate the regression analysis.

Three Models

Three models were analyzed for this research. In all three models, the year observations were taken by the ITRC student teams have been included in the regression analysis to account for a portion of the variability associated with the different student teams collecting and recording the data. It will not, however, be used for interpretation or analysis. The characteristics of each model should be kept in mind while interpreting the results and considering further research.

Model 1

The following components were omitted from the regression model as the 'Base Case': Year of Observation- 1997, Sacramento Valley, Rotating Microsprinkler, Emitter Spacing Combination of Two or More, No Automatic Flush on the Primary Filter, Overflow Screen, Frequency of Hose Flushing- Never, No Pressure Regulation, No Injection System and No Chlorine and/or Acid Injection.

A summary of the data used for Model 1 is shown in Table 1. The number of observations for this analysis is 607. If the variable is continuous, the mean and standard deviation are reported in Table 1. If the variable is categorical, the frequency of that variable is reported in Table 1. For example, pressure compensating emitters have a frequency of 0.321 meaning that 32% of the responses used pressure compensating emitters in Model 1. Table 1 provides a summary of the descriptive statistics for the data used in Model 1.

Table 1: Model 1-Variable Definitions and Descriptive Statistics

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Global System DU LQ	Distribution Uniformity for the irrigation system- Response Variable	0.856	0.105
Year of Observation- 1997	Binary = 1 if the observation took place in 1997	0.046	
Year of Observation- 1999	Binary = 1 if the observation took place in 1999	0.096	
Year of Observation- 2000	Binary = 1 if the observation took place in 2000	0.096	
Year of Observation- 2001	Binary = 1 if the observation took place in 2001	0.054	
Year of Observation- 2002	Binary = 1 if the observation took place in 2002	0.058	
Year of Observation- 2003	Binary = 1 if the observation took place in 2003	0.063	
Year of Observation- 2010	Binary = 1 if the observation took place in 2010	0.058	
Year of Observation- 2011	Binary = 1 if the observation took place in 2011	0.102	
Year of Observation- 2013	Binary = 1 if the observation took place in 2013	0.035	
Year of Observation- 2014	Binary = 1 if the observation took place in 2014	0.114	
Year of Observation- 2015	Binary = 1 if the observation took place in 2015	0.109	
Year of Observation- 2016	Binary = 1 if the observation took place in 2016	0.171	
San Joaquin Valley	Binary = 1 if the observation took place in the San Joaquin Valley	0.867	
Sacramento Valley	Binary = 1 if the observation took place in the Sacramento Valley	0.133	
Age of system (years)	Age of the irrigation system, in years	6.463	5.321
Rotating Microsprinkler	Binary = 1 if the emitter path type was a rotating microspinkler	0.082	
Tortuous Path	Binary = 1 if the emitter path type was tortuous path	0.196	
Non- Rotating Microsprayer	Binary = 1 if the emitter path type was a non-rotating microsprayer	0.400	
Emitters per Plant	Number of emitters per plant	3.584	3.678
Emitter Spacing Combination-1	Binary = 1 if only one emitter spacing combination was used	0.946	
Emitter Spacing Combination-2+	Binary = 1 if two or more emitter spacing combinations were used	0.054	

Continued

Table 1

Continued

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Pressure Compensating	Binary = 1 if the emitter path type was pressure compensating	0.321	
Automatic Flush on the Primary Filter	Binary = 1 if the system has an automatic flush on the primary filter	0.816	
No Automatic Flush on the Primary Filter	Binary = 1 if the system does not have an automatic flush on the primary filter	0.185	
Sand Media Filter	Binary = 1 if the filtration system is a sand media filter	0.662	
Disc Filter	Binary = 1 if the filtration system is a disc filter	0.071	
Tubular Screen	Binary = 1 if the filtration system is a tubular screen	0.096	
Overflow Screen	Binary = 1 if the filtration system is an overflow screen	0.064	
Multiple Filter Types	Binary = 1 if the filtration system is multiple filter types	0.107	
Frequency of hose flushing-Weekly or More	Binary = 1 if the grower flushes their hoses weekly or more	0.104	
Frequency of hose flushing-Annually	Binary = 1 if the grower flushes their hoses annually	0.450	
Frequency of hose flushing-Monthly	Binary = 1 if the grower flushes their hoses monthly	0.389	
Frequency of hose flushing-Never	Binary = 1 if the grower never flushes their hoses	0.058	
Pressure downstream of filters	Observed pressure downstream of the filters, in psi	37.204	13.192
Pump discharge pressure	Observed pump discharge pressure, in psi	42.634	13.656
Pressure Regulation Location-Emitter	Binary = 1 if the location of pressure regulation is at the emitter	0.193	
Pressure Regulation Location-Head of Each Hose	Binary = 1 if the location of pressure regulation is at the head of each hose	0.079	

Continued

Table 1

Continued

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Pressure Regulation Location-Multiple	Binary = 1 if the pressure is regulated at multiple locations	0.130	
Pressure Regulation Location-Head of Each Manifold	Binary = 1 if the location of pressure regulation is at the head of each manifold	0.244	
No Pressure Regulation	Binary = 1 if pressure is not regulated	0.354	
Location of Injector with Respect to Filter- Downstream	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is downstream of the filter	0.526	
Location of Injector with Respect to Filter- Upstream	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is upstream of the filter	0.412	
No Injection system	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is upstream of the filter	0.063	
Frequency of Chlorine and/or Acid Injection- Annually	Binary = 1 if the frequency of chlorine and/or acid is injected annually	0.188	
Frequency of Chlorine and/or Acid Injection- Monthly	Binary = 1 if the frequency of chlorine and/or acid is injected monthly	0.049	
Frequency of Chlorine and/or Acid Injection- Weekly or More	Binary = 1 if the frequency of chlorine and/or acid is injected weekly or more	0.437	
No Chlorine and/or Acid Injection	Binary = 1 if chlorine and/or acid is not injected	0.326	

Model 2

After looking at the results from the first model, it was determined that water quality, assumed through water source, has an influence on DU that should be further explored. Originally, the type of water source was omitted from the first model because it was not reported during the following years: 1995, 1997, 2000-2002 (approximately one-third of the data). After reviewing preliminary results, it became evident that the water source could have an impact on the distribution uniformity. I decided to include all water sources in the second model to explore if they did in fact have an impact on the distribution uniformity. All water sources were included in the second model.

The following components were omitted from the regression model as the 'Base Case': Year of Observation- 1999, Sacramento Valley, Well Water, Non-Rotating Microsprayer, No Automatic Flush on the Primary Filter, Tubular Screen, Frequency of Hose Flushing- Annually, Location of Injector- Downstream, No Chlorine and/or Acid Injection, No Automatic Pressure Regulator- Head of Each Hose, No Automatic Pressure Regulator- Head of Each Manifold, No Automatic Pressure Control Valves and No Partially Throttled Manual Valve.

A summary of the data used for Model 2 is shown in Table 2. The number of observations for this analysis is 392. If the variable is continuous, the mean and standard deviation are reported in Table 2. If the variable is categorical, the frequency of that variable is reported in Table 2. For example, Water Source- Surface has a frequency of 0.569 meaning that 57% of the responses use surface water in Model 2.

Table 2: Model 2- Variable Definitions and Descriptive Statistics

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Global System DU LQ	Distribution Uniformity for the irrigation system- Response Variable	0.863	0.110
Age of system (years)	Age of the irrigation system, in years	6.722	5.312
Emitters per Plant	Number of emitters per plant	3.791	3.588
Pump discharge pressure	Observed pump discharge pressure, in psi	44.142	12.252
Pressure downstream of filters	Observed pressure downstream of the filters, in psi	38.464	11.687
Year of Observation- 1999	Binary = 1 if the observation took place in 1999	0.117	
Year of Observation- 2000	Binary = 1 if the observation took place in 2000	0.061	
Year of Observation- 2003	Binary = 1 if the observation took place in 2003	0.071	
Year of Observation- 2010	Binary = 1 if the observation took place in 2010	0.066	
Year of Observation- 2011	Binary = 1 if the observation took place in 2011	0.128	
Year of Observation- 2014	Binary = 1 if the observation took place in 2014	0.163	
Year of Observation- 2015	Binary = 1 if the observation took place in 2015	0.166	
Year of Observation- 2016	Binary = 1 if the observation took place in 2016	0.227	
San Joaquin Valley	Binary = 1 if the observation took place in the San Joaquin Valley	0.878	
Sacramento Valley	Binary = 1 if the observation took place in the Sacramento Valley	0.122	
Rotating Microsprinkler	Binary = 1 if the emitter path type was a rotating microspinkler	0.056	
Tortuous Path	Binary = 1 if the emitter path type was tortuous path	0.194	

Continued

Table 2

Continued

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Non- Rotating Microsprayer	Binary = 1 if the emitter path type was a non-rotating microsprayer	0.370	
Pressure Compensating	Binary = 1 if the emitter path type was pressure compensating	0.380	
Automatic Flush on the Primary Filter	Binary = 1 if the system has an automatic flush on the primary filter	0.883	
No Automatic Flush on the Primary Filter	Binary = 1 if the system does not have an automatic flush on the primary filter	0.117	
Sand Media Filter	Binary = 1 if the filtration system is a sand media filter	0.793	
Disc Filter	Binary = 1 if the filtration system is a disc filter	0.069	
Tubular Screen	Binary = 1 if the filtration system is a tubular screen	0.069	
Multiple Filter Types	Binary = 1 if the filtration system is multiple filter types	0.069	
Location of Injector with Respect to Filter- Downstream	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is downstream of the filter	0.564	
Location of Injector with Respect to Filter- Upstream	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is upstream of the filter	0.436	
Frequency of hose flushing- Monthly	Binary = 1 if the grower flushes their hoses monthly	0.426	
Frequency of hose flushing- Weekly or More	Binary = 1 if the grower flushes their hoses weekly or more	0.128	
Frequency of hose flushing- Annually	Binary = 1 if the grower flushes their hoses annually	0.446	
Frequency of Chlorine and/or Acid Injection- Annually	Binary = 1 if the frequency of chlorine and/or acid is injected annually	0.212	
Frequency of Chlorine and/or Acid Injection- Weekly or More	Binary = 1 if the frequency of chlorine and/or acid is injected weekly or more	0.541	

Continued

Table 2

Continued

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
No Chlorine and/or Acid Injection	Binary = 1 if chlorine and/or acid is not injected	0.248	
Throttled Manual Valve- Yes	Binary = 1 if there is a throttled manual valve	0.125	
Throttled Manual Valve- No	Binary = 1 if there is no throttled manual valve	0.875	
Automatic Pressure Regulator at the Head of Each Manifold- Yes	Binary = 1 if there is an automatic pressure regulator at the head of each manifold	0.444	
Automatic Pressure Regulator at the Head of Each Manifold- No	Binary = 1 if there is no automatic pressure regulator at the head of each manifold	0.556	
Automatic Pressure Regulator at the Head of Each Hose- Yes	Binary = 1 if there is an automatic pressure regulator at the head of each hose	0.087	
Automatic Pressure Regulator at the Head of Each Hose- No	Binary = 1 if there is no automatic pressure regulator at the head of each hose	0.913	
Water Source- Surface	Binary = 1 if the water source is surface	0.569	
Water Source- Well	Binary = 1 if the water source is well	0.153	
Water Source- Both	Binary = 1 if the water source is a combination of both surface and well	0.278	

Model 3

After looking at the results from the second model, it was still clear that water quality could have an impact on the distribution uniformity. In order to further explore the impact of water quality on the distribution uniformity, the third model only includes observations that used surface water, which is assumed to have the worst water quality. By observing only one type of recorded water quality, the impact on the distribution uniformity may be exposed. Filtration was left out of this analysis because the sample size for non-sand media filters that was too low.

The following components were omitted from the regression model as the 'Base Case': Year of Observation- 1999, Sacramento Valley, Tortuous Path, Frequency of Hose Flushing- Annually, Injection Downstream, No Chlorine and/or Acid Injection, No Automatic Pressure Regulator- Head of Each Manifold, No Automatic Pressure Control Valves and Partially Throttled Manual Valve.

A summary of the data used for Model 3 is shown in Table 3. The number of observations for this analysis is 189. If the variable is continuous, the mean and standard deviation are reported in Table 3. If the variable is categorical, the frequency of that variable is reported in Table 3. For example, non-rotating microsprayers have a frequency of 0.302 meaning that 30% of the responses used non-rotating microsprayers in Model 3.

Table 3: Model 3- Variable Definitions and Descriptive Statistics

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Global System DU LQ	Distribution Uniformity for the irrigation system- Response Variable	0.879	0.107
Age of system (years)	Age of the irrigation system, in years	6.298	4.987
Emitters per Plant	Number of emitters per plant	4.234	3.879
Pump discharge pressure	Observed pump discharge pressure, in psi	44.183	11.834
Pressure downstream of filters	Observed pressure downstream of the filters, in psi	39.085	11.506
Year of Observation- 1999	Binary = 1 if the observation took place in 1999	0.153	
Year of Observation- 2003	Binary = 1 if the observation took place in 2003	0.138	
Year of Observation- 2011	Binary = 1 if the observation took place in 2011	0.153	
Year of Observation- 2014	Binary = 1 if the observation took place in 2014	0.243	
Year of Observation- 2016	Binary = 1 if the observation took place in 2016	0.312	
San Joaquin Valley	Binary = 1 if the observation took place in the San Joaquin Valley	0.852	
Sacramento Valley	Binary = 1 if the observation took place in the Sacramento Valley	0.148	
Tortuous Path	Binary = 1 if the emitter path type was tortuous path	0.222	
Non- Rotating Microsprayer	Binary = 1 if the emitter path type was a non-rotating microsprayer	0.302	
Pressure Compensating	Binary = 1 if the emitter path type was pressure compensating	0.476	
Automatic Pressure Control Valve- 1	Binary = 1 if there is 1 automatic pressure control valve	0.862	
Automatic Pressure Control Valve- None	Binary = 1 if there is no automatic pressure control valve	0.138	

Continued

Table 3

Continued

Variable	*Definition*	*Mean/ frequency*	*Standard deviation*
Location of Injector with Respect to Filter- Downstream	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is downstream of the filter	0.550	
Location of Injector with Respect to Filter- Upstream	Binary = 1 if the location of the fertilizer, pesticide, acid or gypsum injector is upstream of the filter	0.450	
No Chlorine and/or Acid Injection	Binary = 1 if no chlorine and/or acid is injected	0.233	
Frequency of Chlorine and/or Acid Injection- Annually	Binary = 1 if the frequency of chlorine and/or acid is injected annually	0.164	
Frequency of Chlorine and/or Acid Injection- Weekly or More	Binary = 1 if the frequency of chlorine and/or acid is injected weekly or more	0.603	
Frequency of hose flushing- Monthly	Binary = 1 if the grower flushes their hoses monthly	0.524	
Frequency of hose flushing- Weekly or More	Binary = 1 if the grower flushes their hoses weekly or more	0.169	
Frequency of hose flushing- Annually	Binary = 1 if the grower flushes their hoses annually	0.307	
Throttled Manual Valve- Yes	Binary = 1 if there is a throttled manual valve	0.122	
Throttled Manual Valve- No	Binary = 1 if there is no throttled manual valve	0.878	
Automatic Pressure Regulator at the Head of Each Manifold- Yes	Binary = 1 if there is an automatic pressure regulator at the head of each manifold	0.540	
Automatic Pressure Regulator at the Head of Each Manifold- No	Binary = 1 if there is no automatic pressure regulator at the head of each manifold	0.460	

Correlation

A correlation is used to measure the linear dependence between two continuous variables. It shows how strongly pairs of variables are related ranging from -1.0 to 1.0 and if the relationship is positive or negative.

Chapter 4: Results

Table 4 shows the results of the regression analysis for the three separate models. It is important to note what the base case is, for each model, while reviewing the results. An example interpretation is, in Model 3, using both surface and well water is statistically different than using just well water. If a grower were to switch from using just well water to a combination of both surface and well water, the distribution uniformity of his system will decrease by 0.04, with 95% confidence.

Table 4: Regression Results for Distribution Uniformity

Variable	*Model 1*	*Model 2*	*Model 3*
Year of Observation- 1999	-0.045*		
Year of Observation- 2000	-0.022	0.005	
Year of Observation- 2001	-0.019		
Year of Observation- 2002	-0.020		
Year of Observation- 2003	-0.011	0.011	-0.001
Year of Observation- 2010	-0.036	-0.035	
Year of Observation- 2011	-0.032	0.010	-0.015
Year of Observation- 2013	-0.028		
Year of Observation- 2014	0.024	0.059**	0.012
Year of Observation- 2015	-0.008	0.037	
Year of Observation- 2016	-0.023	0.009	-0.011
Age of system (years)	-0.016	0.002**	-0.001
San Joaquin Valley	-0.021	0.008	-0.028
Tortuous Path	-0.016	-0.028	
Non- Rotating Microsprayer	0.002		0.003
Pressure Compensating	0.181	0.030*	0.031
Rotating Microsprinkler		-0.028	
Emitters per Plant	0.006***	0.006***	0.005*
Emitter Spacing Combination- 1	0.129***		
Automatic Flush on the Primary Filter	0.011	0.016	
Sand Media Filter	0.001	-0.004	
Disc Filter	0.011	-0.001	

Table 4

Continued

Variable	*Model 1*	*Model 2*	*Model 3*
Tubular Screen	-0.023		
Multiple Filter Types	0.017	0.007	
Frequency of hose flushing- Weekly or More	0.039	0.023	0.014
Frequency of hose flushing- Annually	0.024		
Frequency of hose flushing- Monthly	0.042**	0.023	0.031
Pressure downstream of filters	0.000	0.000	0.000
Pump discharge pressure	0.000	0.001	0.002
Pressure Regulation Location- Emitter	-0.158*		
Pressure Regulation Location- Head of Each Hose	0.011	-0.015	
Pressure Regulation Location- Multiple	-0.161*		
Pressure Regulation Location- Head of Each Manifold	-0.003	0.026	-0.019
Location of Injector with Respect to Filter- Downstream	0.005		
Location of Injector with Respect to Filter- Upstream	0.017	0.015	0.006
Frequency of Chlorine and/or Acid Injection- Annually	-0.007	-0.004	0.023
Frequency of Chlorine and/or Acid Injection- Monthly	0.024		
Frequency of Chlorine and/or Acid Injection- Weekly or More	-0.008	0.028	0.025
Water Source- Surface		-0.019	
Water Source- Both		-0.040**	
Automatic Pressure Control Valve		0.017	0.004
Partially Throttled Manual Valve		-0.036**	-0.045*
N-Value	607	392	189
Adjusted R- Squared	.2198	.1526	.1216

Note: Asterisks indicate the estimated coefficient is statistically different from 0 (*** p<0.01, ** p<0.05, * p<0.1)

The adjusted R-squared value is an indication of how close the data is to the fitted regression line. The adjusted R-squared for model 1 is 0.2198, which means that 21.98% of the variance in distribution uniformity can be explained by this regression model in the population. Model 2 has an adjusted R-Squared of 0.1526 and Model 3 is 0.1216. Figure 10 below shows how close the regression model got to fitting the distribution uniformity

value for Model 1. While there is a point that is 0.75 off from the actual DU, there is a relatively even spread of over or under estimating the value.

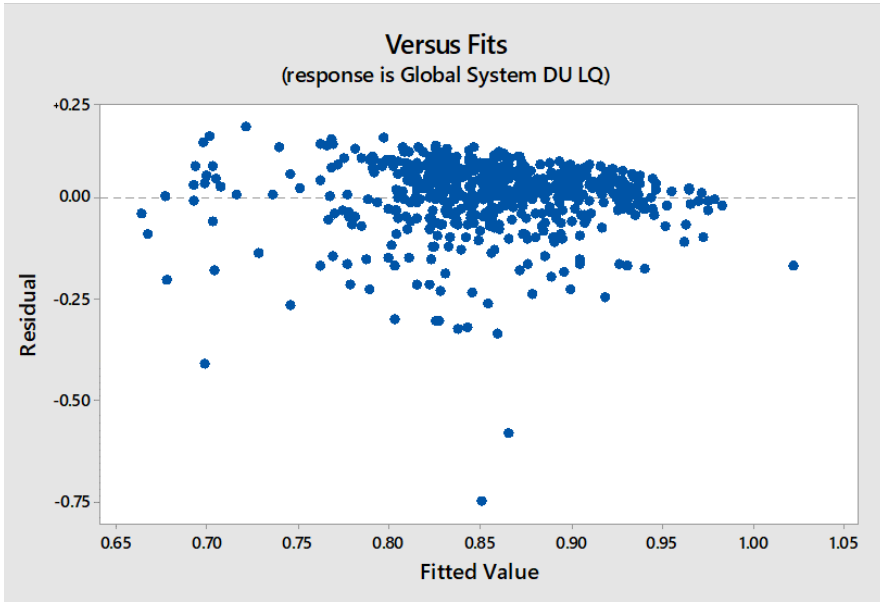

Figure 10: Regression Analysis Residuals vs. Fitted Value for Model 1.

Table 5 shows the results from the Pearson Correlation Matrix of Continuous Variables in Model 1.

Table 5: Model 1- Correlation Matrix of Continuous Variables

	Global System DU	Age of system (years)	Emitters per Plant	Pressure Downstream of Filters
Age of system (years)				
Pearson correlation	-0.092			
P-Value	0.024**			
Emitters per Plant				
Pearson correlation	0.302	0.003		
P-Value	0.000***	0.932		
Pressure Downstream of Filters				
Pearson correlation	0.129	-0.011	0.158	
P-Value	0.001***	0.784	0.000***	
Pump Discharge Pressure				
Pearson correlation	0.120	0.008	0.142	0.912
P-Value	0.003***	0.836	0.000***	0.000***

Note: Asterisks indicate the correlation variable is statistically different from 0 (*** p<0.01, ** p<0.05, * p<0.1)

Hypothesis 1: Pressure regulation will have a positive impact on DU.

Table 6: Pressure regulation regression results, (Excerpt Table 4).

Variable	*Model 1*	*Model 2*	*Model 3*
Pressure Regulation Location- Emitter	-0.158*		
Pressure Regulation Location- Head of Each Hose	0.011	-0.015	
Pressure Regulation Location- Multiple	-0.161*		
Pressure Regulation Location- Head of Each Manifold	-0.003	0.026	-0.019
Automatic Pressure Control Valve		0.017	0.004
Partially Throttled Manual Valve		-0.036**	-0.045*

Note: Asterisks indicate the estimated coefficient is statistically different from 0 (*** $p<0.01$, ** $p<0.05$, * $p<0.1$)

Model 1

According to Table 6, there is no statistical difference in distribution uniformity between a system with no pressure regulation and a system that regulates pressure at each hose or at each manifold. Furthermore, the analysis concludes that the distribution uniformity is significantly different (p- value= .090 respectfully) negatively between systems that do not regulate pressure at any location and those that regulate pressure at the emitter, via pressure compensating emitters, and at multiple locations.

Model 2

According to Table 6, there is no statistical difference in distribution uniformity between a system that regulates pressure at each hose or at each manifold or does not regulate at all. There is also no statistical difference if there is an automatic control valve. However, there is a statistically significant difference between having a partially throttled manual valve or not. According to this model, if a grower doesn't have a partially

throttled manual valve and they decide to install one, the distribution uniformity of their system will decrease by 0.036, with 95% confidence.

Model 3

According to Table 6, there is no statistical difference in distribution uniformity between a system that regulates pressure at each manifold or not or if there is an automatic pressure control valve. Like Model 2, there is statistical significance between if the system has a partially throttled manual valve or not. With 90% confidence, irrigation systems that have a partially throttled manual valve will have a lower DU than those that don't.

Hypothesis 2: Systems using a sand media tank for filtration will have a positive impact on DU.

Table 7: Filtration system regression results, (Excerpt Table 4).

Variable	*Model 1*	*Model 2*	*Model 3*
Sand Media Filter	0.001	-0.004	
Disc Filter	0.011	-0.001	
Tubular Screen	-0.023		
Multiple Filter Types	0.017	0.007	

Note: Asterisks indicate the estimated coefficient is statistically different from 0 (*** p<0.01, ** p<0.05, * p<0.1)

Model 1

There is no difference in distribution uniformity between filtering with an overflow screen and using a sand media filter, disc filter, tubular screen or multiple filter types, as shown in Table 7.

Model 2

There is no difference in distribution uniformity between filtering with a tubular screen and using a sand media filter, disc filter or multiple filter types, as shown in Table 7.

Model 3

Filtration was left out of the analysis because there were not enough responses for other filter types other than sand media tanks, as shown in Table 7.

Hypothesis 3: The system DU will be positively related to the number of emitters per plant.

Table 8: Number of Emitters per plant regression results, (Excerpt Table 4)

Variable	*Model 1*	*Model 2*	*Model 3*
Emitters per Plant	0.006***	0.006***	0.005*

Note: Asterisks indicate the estimated coefficient is statistically different from 0 (*** $p<0.01$, ** $p<0.05$, * $p<0.1$)

Model 1

Table 8 shows that there is a statistically significant relationship between the number of emitters per plant and the distribution uniformity. As shown in Table 9 and Figure 11, there is sufficient evidence that a positive relationship exists between the distribution uniformity and the number of emitters per plant which is consistent with the findings in Table 8.

Table 9: Correlation Between Emitters per Plant and the Global System DU.

	Global System DU
Emitters per Plant	
Pearson correlation	0.302
P-Value	0.000***

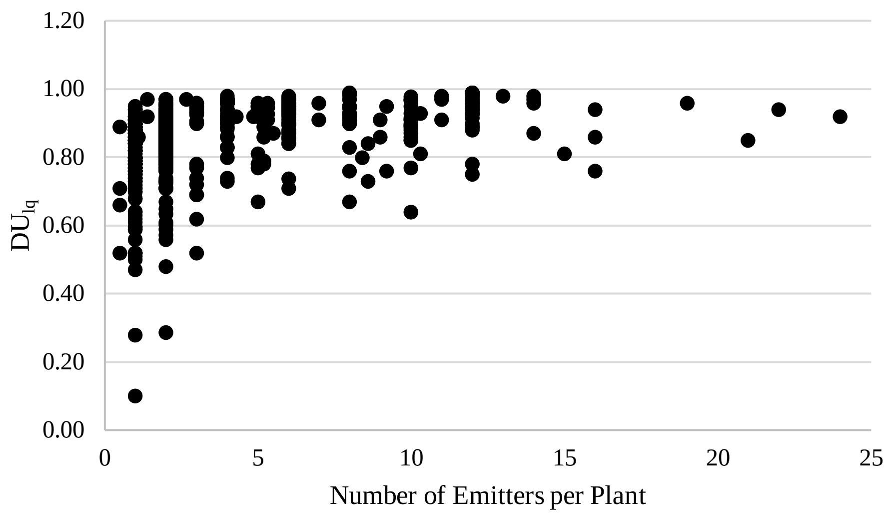

Figure 11: DU_{lq} versus Number of Emitters per Plant for Model 1.

Table 9 shows that there is a statistically significant relationship between the number of emitters per plant and the distribution uniformity. For every increased emitter, the distribution uniformity is expected to increase by 0.006, with 99% confidence, shown in Table 8.

Model 2

The same as Model 1, Table 8 shows that there is a statistically significant relationship between the number of emitters per plant and the distribution uniformity. For every increased emitter, the distribution uniformity is expected to increase by 0.006, with 99% confidence.

Model 3

Table 8 shows that there is a statistically significant relationship between the number of emitters per plant and the distribution uniformity. For every increased emitter, the distribution uniformity is expected to increase by 0.005, with 90% confidence.

Hypothesis 4: The DU of a system will increase with more frequently injected acid and/ or chlorine.

Table 10: Acid and/or chlorine injection regression results, (Excerpt Table 4)

Variable	*Model 1*	*Model 2*	*Model 3*
Frequency of Chlorine and/or Acid Injection- Annually	-0.007	-0.004	0.023
Frequency of Chlorine and/or Acid Injection- Monthly	0.024		
Frequency of Chlorine and/or Acid Injection- Weekly or More	-0.008	0.028	0.025

Note: Asterisks indicate the estimated coefficient is statistically different from 0 (*** p<0.01, ** p<0.05, * p<0.1)

Model 1

As shown in Table 10, there is no statistical difference between not injecting chlorine and/ or acid and injecting it weekly or more, monthly or annually.

Model 2

As shown in Table 10, there is no statistical difference between not injecting chlorine and/ or acid and injecting it weekly or more or annually.

Model 3

As shown in Table 10, there is no statistical difference between not injecting chlorine and/ or acid and injecting it weekly or more or annually.

Hypothesis 5: The DU of a system will increase with more frequently flushed hose or tape.

Table 11: Frequency of hose/tape flushing regression results, (Excerpt Table 4)

Variable	*Model 1*	*Model 2*	*Model 3*
Frequency of hose flushing- Weekly or More	0.039	0.023	0.014
Frequency of hose flushing- Annually	0.024		
Frequency of hose flushing- Monthly	0.042**	0.023	0.031

Note: Asterisks indicate the estimated coefficient is statistically different from 0 (*** p<0.01, ** p<0.05, * p<0.1)

Model 1

Table 11 shows, that there is no difference in the distribution uniformity between never flushing the hoses or tapes and flushing weekly or more or annually. There is a significant difference in distribution uniformity between systems that never flush their hoses or tapes to those that flush monthly. If a grower never flushes their hoses or tapes

and decides to start flushing monthly, the distribution uniformity is expected to increase by 0.042, with 95% confidence.

Model 2

Table 11 shows, that there is no difference in the distribution uniformity between flushing the hoses or tapes annually and flushing monthly, weekly or more.

Model 3

Table 11 shows, that there is no difference in the distribution uniformity between flushing the hoses or tapes annually and flushing monthly, weekly or more.

Chapter 5: Discussion

To review, three models were evaluated for this analysis. Model one had 607 observations and included a pressure compensating emitter path type and no water source. Model 2 had 392 observations and didn't include a pressure compensating emitter path type but did include the water source. Model 3 includes 189 observations that only used surface water, which is assumed to have the worst water quality. Model 3 doesn't include filtration because not enough observations used something other than sand media tanks.

Hypothesis 1: Pressure regulation will have a positive impact on DU.

Model 1

Any form of pressure regulation should have a positive impact on the distribution uniformity because of the relationship pressure has with the flow rate, for non-pressure compensating emitters.

As seen in *Table 6*, if an irrigation system is not regulating pressure at any location and the grower decides to add pressure compensating emitters, the distribution uniformity of the system will decrease by 0.158. Similarly, if an irrigation system is not regulating pressure at any location and the grower decides to install pressure regulation at multiple locations, the distribution uniformity of the system will decrease by 0.0161, which does not make sense.

Theoretically, pressure regulated at multiple locations would result in the highest DU, followed by pressure regulated at the emitter via pressure compensation, at the head of each hose, at the head of the manifold and lastly, no pressure regulation.

Part of the error may be an issue with the sample or because a pressure compensating emitter path type was also included in the model. Pressure compensating emitters are positively statistically significant (p-value= 0.061) compared to rotating microsprinklers. The slope, or the change in elevation, of the field was also not considered.

Model 2

After taking out pressure compensating emitters as a location for pressure regulation, a positive impact between the distribution uniformity and pressure regulated at the head of each hose compared to not regulated at each hose is expected. Pressure regulated at the head of each manifold would have a positive impact of the distribution uniformity, compared to no pressure regulation at the manifold. Having an automatic pressure control valve near the filter and pump would result in a higher distribution uniformity compared to not having one, although it does drive up the energy cost. Lastly, having a partially closed 'throttled' manual valve would have a negative impact on the distribution uniformity. Table 6 also shows, for Models 1 and 2 that having a partially 'throttled' manual valve is statistically significant and has a negative effect on the DU compared to not having a partially throttled manual valve, which makes since as it reduces pressure, like pressure regulators.

Although not statistically significant, it is interesting that both pressure regulation at the head of each manifold and at the head of each hose changed coefficient signs from Model 1 to Model 2. For example, Table 6 shows, although not statistically significant, that compared to no pressure regulation, pressure regulated at the head of each hose

would have a positive impact on the distribution uniformity for Model 1, but for Model 2, would have a negative impact on the distribution uniformity.

Model 3

By using data that came from observations only using surface water, there was not enough observations recorded of systems that regulated pressure at the head of each hose or not to include it in the analysis. What is interesting, however, is the sign of the coefficient changed between Model 2 and Model 3 for pressure being regulated at the head of each manifold.

Further Discussion

It is believed that the second model is most representative of the impact pressure regulation has on the distribution uniformity because multiple water sources were included in that model. It would be interesting to include slope or the change in elevation in future research. As shown in this analysis, a component that influences the relationship between pressure and the distribution uniformity is not being represented in this data set and analysis. Although it is not evident which component is not being represented, it could be slope or a more specific water quality analysis.

Hypothesis 2: Systems using a sand media tank for filtration will have a positive impact on DU.

Model 1

The lack of a relationship between the distribution uniformity and the filtration type may be because there is minimal variety in the data with 66% of the data points utilizing a sand media filter for the filtration of their system. The lack of relationship may also be because water source, and more specifically water quality, which wasn't looked at in the model. The type of filtration needed on a system is dependent upon the quality of the irrigation water. If the grower is using clean well water, for instance, filtration is less of an issue. Filtration only has a major impact when the water quality is poor, such as having a high amount of biological matter.

If the water quality is poor and full of biological matter, a sand media filter should have a higher impact on the distribution uniformity over a screen filter, which is typically used to filter inorganics, like sand, from well water.

Model 2

The second model included water source to try and better capture the relationship between the filtration type and the distribution uniformity. By including the water source, some of the coefficient signs changed, although no filtration type has a statistically significant relationship. Like Model 1, this may be because there is minimal variety in the data with sand media filters accounting for 79% of the data.

Model 3

No filtration was analyzed in the third model because there were not enough responses to filtration types other than sand media filters. In order to combat this in the future, more observations in different water qualities or water sources would be required.

Further Discussion

For future research, it would be interesting to see the impact water quality has on the dataset. For Model 2, water quality was assumed based on water source, but to catch the relationship in the future between the filtration type and distribution uniformity, water quality will need to be included in the analysis. One way to include water quality in the future is to have the student teams compare a water sample to a standardized chart and assign the sample a numerical value.

Hypothesis 3: The system DU will be positively related to the number of emitters per plant.

All Models

The number of emitters per plant and the distribution uniformity are positively correlated and this would be expected due to the 'averaging effect.' The number of emitters per plant and the distribution uniformity have a statistically significant relationship with all the models at very similar coefficients. Typically, most systems with microsprayers or microsprinklers only have one or two nozzles per plant. Similarly,

depending on the crop, only one or two drip emitters per plant may be needed, therefore providing no averaging effect for those crop types.

This data can be used to decide if adding another emitter to your irrigation system, for the sole purpose of increasing your distribution uniformity is worth it, while looking to install a new irrigation system.

According to Model 1 and Table 4, if a grower, looking to install a new irrigation system, was trying to decide between adding another emitter per plant to their system, and changing the emitters to pressure compensating emitters, pressure compensating emitters may be a better option, if the grower is unable to do both options, which would be the best option. Pressure compensating emitters have a statistically significant (p-value = 0.061) positive relationship with distribution uniformity and would be expected to increase DU by 0.181, which is a significant increase. If an irrigation system has a DU of 0.80 and they switched to pressure compensating emitters, the DU of that system is believed to be 0.981.

Hypothesis 4: The DU of a system will increase with more frequently injected acid and/ or chlorine.

Model 1

If the location of the fertilizer, acid, gypsum or chlorine injector is upstream of the filters, the distribution uniformity should be higher because the filters would remove any of the precipitates that might form because of the injection. Chlorine and acid are injected into irrigation systems to keep the hoses and emitters clean, so if chlorine and acid are

injected, the distribution uniformity should be higher. The more frequent the chlorine and/or acid injection occurs, the higher the distribution uniformity should be.

The insignificant impact that injecting chlorine and/ or acid has on the distribution uniformity may be due to the water quality of the samples. It is important to consider why the group is not injecting any acid or chlorine into their system. Simply, it may be because they aren't having any issues with slimy bacteria which can grow on the interior walls of the hose and emitters.

The growers that do have biological contaminant issues, like having organic matter in their water, are injecting the chlorine and acid. If the growers who are actively injecting, were to stop, they may have issues with their systems distribution uniformity.

Frequency of injecting chlorine and/or acid monthly may be statistically significant because of the scarcity of the observations injection monthly. While still meeting the minimum sample size requirement, only 5% of the used observations injected monthly.

Model 2

The second model included water source to try and better capture the relationship between the frequency of chlorine and/or acid injection and the distribution uniformity. Injecting chlorine and/or acid monthly was not included in the analysis because there were not enough observations that injected monthly in this Model. Like Model 1, which did not include water source, there is no statistically significant difference from not injecting acid and/or chlorine to those that inject weekly.

Model 3

Only observations using surface water were analyzed to try and catch the relationship between the distribution uniformity and the frequency of injecting chlorine and/or acid. Even while analyzing data using the same water source, a relationship between the distribution uniformity and the frequency of injecting chlorine and/or acid was unable to be captured. This is likely due to the water quality being assumed based on the water source.

Further Discussion

Water quality was assumed based on water source, but to catch the relationship in the future between the frequency of injecting chlorine and/or acid and the distribution uniformity, water quality will need to be included in the analysis. As previously discussed, one way to include water quality in the future is to have the student teams compare a water sample to a standardized chart and assign the sample a numerical value. By comparing the frequency of injecting chlorine and/or acid on systems using the same quality of water, a relationship to the distribution uniformity may be established.

Hypothesis 5: The DU of a system will increase with more frequently flushed hose or tape.

Model 1

Table 11 states there is no statistical difference, and there will be no impact on the distribution uniformity, between not flushing hoses and flushing weekly or more. In

practice, if a grower were flushing weekly or more and one day decided to never flush, a negative impact on the distribution uniformity is expected.

The higher the frequency of hose flushing, the higher the distribution uniformity should be because there should be a lower chance for emitters and hoses to get plugged up with impurities. Like the frequency of injecting acid and/or chlorine, growers who never flush their hoses or tapes may not need to because they are irrigating with cleaner water than those that flush weekly or more. The insignificant impact between never flushing the hoses or tapes and flushing weekly or more or annually may be since of all the observations, only 6% never flush their hoses. The insignificant impact may also be due to the lack of water quality in the analysis.

Model 2

The second model included water source to try and better capture the relationship between the frequency of hose flushing and the distribution uniformity. Never flushing hoses was not included in the analysis because there were not enough observations that did not flush in this Model. Like Model 1, the results don't align with field observations. According to Table 11, if a grower were to switch from flushing weekly to flushing annually, there would be no difference in distribution uniformity, which does not make sense if the water quality was bad and required flushing to keep the hoses clean.

Model 3

Only observations using surface water were analyzed to try and catch the relationship between the distribution uniformity and the frequency of flushing hoses.

Even while analyzing data using the same water source, a relationship between the distribution uniformity and the frequency of flushing hoses was unable to be captured. This may be since water quality is being assumed based on water source.

Further Discussion

Water quality was assumed based on water source, but to catch the relationship in the future between the frequency of flushing hoses and the distribution uniformity, water quality will need to be included in the data collection. As previously discussed, one way to include water quality in the future is to have the student teams compare a water sample to a standardized chart and assign the sample a numerical value. By comparing the frequency of hose flushing on systems using the same quality of water, a relationship to the distribution uniformity may be established.

Chapter 6: Conclusions

A large data collection effort has been going on for a long time and it is not adequate to find what is affecting the distribution uniformity of a system in 'the real world'. It would be beneficial to reiterate to the student teams how important it is for research to record accurate and complete data. Over half of the data for this study was dismissed due to unanswered questions or incorrect data entry.

As discussed previously, water quality may have an impact on determining the specific influencers to distribution uniformity. It would be beneficial to add water quality as part of the DU assessment. By comparing systems with the same water quality, more variation should be explained. Since most of the hypothesis dealt with DU Other, it could be beneficial to see how these variables influence the DU Other variable.

Hypothesis 1: Pressure regulation will have a positive impact on DU.

The results show that there is no difference in distribution uniformity between where pressure is regulated, but having a partially throttled manual valve will have a negative impact on the distribution uniformity. As previously discussed and shown in this analysis, a component that influences the relationship between pressure and the distribution uniformity is not being represented in this data set and analysis. Although it is not evident which component is not being represented, it could be slope or a more specific water quality analysis.

Hypothesis 2: Systems using a sand media tank for filtration will have a positive impact on DU.

The results show that there is no difference in distribution uniformity between any of the tested filtration systems, including sand media. As previously discussed, the lack of relationship may be because of the water source, and more specifically water quality. The type of filtration needed on a system is dependent upon the quality of the irrigation water. If the grower is using clean well water, for instance, filtration is less of an issue. The lack of relationship may also be due to the lack of variability with the filtration types in the dataset.

Hypothesis 3: The system DU will be positively related to the number of emitters per plant.

The results show there is sufficient evidence that a positive relationship exists between the DU and the number of emitters per plant. As previously discussed, the number of emitters per plant and the distribution uniformity are positively correlated which would be expected due to the 'averaging effect.'

Hypothesis 4: The DU of a system will increase with more frequently injected acid and/ or chlorine.

The results show that there is no statistical difference between not injecting chlorine and/or acid and injecting it weekly or more, monthly or annually. As previously discussed, water quality was assumed based on water source, but to catch the relationship in the future between the frequency of injecting chlorine and/or acid and the distribution

uniformity, water quality will need to be included in the analysis. By comparing the frequency of injecting chlorine and/or acid on systems using the same quality of water, a relationship to the distribution uniformity may be established.

<u>Hypothesis 5: The DU of a system will increase with more frequently flushed hose or tape.</u>

The results show that there is no difference in distribution uniformity between systems that never flush their hoses or tapes to those that flush weekly or more or annually. As previously discussed, water quality was assumed based on water source, but to catch the relationship in the future between the frequency of flushing hoses and the distribution uniformity, water quality will need to be included in the data collection. By comparing the frequency of hose flushing on systems using the same quality of water, a relationship to the distribution uniformity may be established.

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APPENDIX A

ITRC Drip/Microirrigation System Evaluation Manual- Field Data Sheets

FIELD IDENTIFICATION

1	Field ID:	
2	System Type:	Please Select From List Above ground drip with hard hose Above ground drip with tape SDI with hard hose SDI with tape Microsprinkler Microsprayer Other
3	Emitter Location:	Please Select From List On-line In-line
4	Hose Spacing (feet)	
5	Crop Type:	
6	Soil Type:	Please Select From List Clay Sand Silt Loam Sandy Clay Silty Clay Sandy Loam Silt Loam Clay Loam Loamy Sand Sandy Clay Loam Silty Clay Loam Unknown
7	County:	

JOB IDENTIFICATION

8	Evaluator:	
9	Date:	

SYSTEM DESCRIPTION

10	Age of system:	______	years
11	Is there a water penetration problem?	Please Select From List: Yes / No	
12	Is there undulating (rolling; up-and-down) topography?	Please Select From List: Yes / No	
13	Percentage of applied water that runs off the field:	______	%
14	Number of models/emitter designs used in the system:		
15	Type of water source:	Please Select From List: Well / Surface / Both	

EMITTER INFORMATION

16	Manufacturer:	______	
17	Model:	______	
18	Nominal flow/emitter (gph or lph):	______	
19	Units of nominal flow rate:	Please Select From List: gph / lph	
20	Emitter path type:	Please Select From List: Long, smooth path / Pressure compensating / Vortex / Tortuous path / Multiple flexible orifice / Rotating microsprinkler / Non-rotating microsprayer / Other	

FILTRATION

21	Automatic flush on the primary filter?	Please Select From List Yes No

Type of filter (select all that apply):

22	Tubular screen?	Please Select From List Yes No
23	Overflow screen?	Please Select From List Yes No
24	Media filter?	Please Select From List Yes No
25	Sand (centrifugal) separator?	Please Select From List Yes No
26	Disc filter?	Please Select From List Yes No
27	"Vacuum cleaned" tubular screen?	Please Select From List Yes No

CHEMICAL INJECTION SYSTEM

28	Location of fertilizer injector with respect to filter:	Please Select From List No fertilizer injection system Downstream Upstream
29	Location of pesticide injector with respect to filter:	Please Select From List No pesticide injection system Downstream Upstream
30	Location of acid injector with respect to filter:	Please Select From List No acid injection system Downstream Upstream
31	Location of gypsum injector with respect to filter:	Please Select From List No gypsum injection system Downstream Upstream
32	Frequency of chlorine or polymer injection:	Please Select From List Never Annually Monthly Weekly or more
	If no acid injection, skip the following question.	
33	Frequency of acid injection:	Please Select From List Never Annually Monthly Weekly or more
	If no injection system, skip the next question.	
34	Do any of the injection systems use a throttling valve on the mainline to create a pressure differential?	Please Select From List Yes No
35	Frequency of hose/tape flushing:	Please Select From List Never Annually Monthly Weekly or more

PUMP STATION MEASUREMENTS

36 Pump discharge pressure: ____________________ psi

37 Pressure downstream of filters and control valves: ____________________ psi

Optional Pressure Values:

38 Total filter loss: ____________________ psi

39 Total pump control valve loss: ____________________ psi

40 Loss from throttled manual valves: ____________________ psi

VALVING

41 Number of automatic pressure control valves near the filter and pump (0 for none): ____________________

42 Is there a partially closed (i.e., "throttled") manual valve near the pump discharge to reduce pressure?

Please Select From List
Yes
No

Check upstream and downstream of filter if filter is downstream of pump discharge.

43 Does the head of each manifold have an automatic pressure regulator?

Please Select From List
Yes
No

44 Does the head of each hose have an automatic pressure regulator?

Please Select From List
Yes
No

45 Is there a flow meter?

Please Select From List
Yes
No

FIELD PRESSURE MEASUREMENTS

Note: Water must be flowing through the hoses when the measurements are made.

Location #**1**: Submain or regulated manifold closest to the pump.

Closest hose to the inlet of the submain (or regulated manifold):

46 Downstream end of "uphill" side pressure: ______________ psi

47 Middle of "uphill" side pressure: ______________ psi

48 Hose inlet pressure: ______________ psi

49 Middle of "downhill" side pressure: ______________ psi

50 Downstream end of "downhill" side pressure: ______________ psi

Most distant hose from the inlet of the submain (or regulated manifold):

51 Downstream end of "uphill" side pressure: ______________ psi

52 Middle of "uphill" side' pressure: ______________ psi

53 Hose inlet pressure: ______________ psi

54 Middle of "downhill" side pressure: ______________ psi

55 Downstream end of "downhill" side pressure: ______________ psi

Location #**2**: Submain or regulated manifold most distant from the pump (or where the pressure is lowest).

Closest hose to the inlet of the submain (or regulated manifold):

56 Downstream end of "uphill" side pressure: ______________ psi

57 Middle of "uphill" side pressure: ______________ psi

58 Hose inlet pressure: ______________ psi

59 Middle of "downhill" side pressure: ______________ psi

60 Downstream end of "downhill" side pressure: ______________ psi

Most distant hose from the inlet of the submain (or regulated manifold):

61 Downstream end of "uphill" side pressure: ______________ psi

62 Middle of "uphill" side' pressure: ______________ psi

63 Hose inlet pressure: ______________ psi

64 Middle of "downhill" side pressure: ______________ psi

65 Downstream end of "downhill" side pressure: ______________ psi

Location #**3**: Submain or regulated manifold at an intermediate distance from the pump.

Closest hose to the inlet of the submain (or regulated manifold):

66 Downstream end of "uphill" side pressure: ______________ psi

67 Middle of "uphill" side pressure: ______________ psi

68 Hose inlet pressure: ______________ psi

69 Middle of "downhill" side pressure: ______________ psi

70 Downstream end of "downhill" side pressure: ______________ psi

Most distant hose from the inlet of the submain (or regulated manifold):

71 Downstream end of "uphill" side pressure: ______________ psi

72 Middle of "uphill" side' pressure: ______________ psi

73 Hose inlet pressure: ______________ psi

74 Middle of "downhill" side pressure: ______________ psi

75 Downstream end of "downhill" side pressure: ______________ psi

Location #**4**: Intermediate submain or regulated manifold close to the pump.

Closest hose to the inlet of the submain (or regulated manifold):

76 Downstream end of "uphill" side pressure: ______________ psi

77 Middle of "uphill" side pressure: ______________ psi

78 Hose inlet pressure: ______________ psi

79 Middle of "downhill" side pressure: ______________ psi

80 Downstream end of "downhill" side pressure: ______________ psi

Most distant hose from the inlet of the submain (or regulated manifold):

81 Downstream end of "uphill" side pressure: ______________ psi

82 Middle of "uphill" side' pressure: ______________ psi

83 Hose inlet pressure: ______________ psi

84 Middle of "downhill" side pressure: ______________ psi

85 Downstream end of "downhill" side pressure: ______________ psi

Location #**5**: Intermediate submain or regulated manifold distant from the pump.

Closest hose to the inlet of the submain (or regulated manifold):

86 Downstream end of "uphill" side pressure: ____________ psi

87 Middle of "uphill" side pressure: ____________ psi

88 Hose inlet pressure: ____________ psi

89 Middle of "downhill" side pressure: ____________ psi

90 Downstream end of "downhill" side pressure: ____________ psi

Most distant hose from the inlet of the submain (or regulated manifold):

91 Downstream end of "uphill" side pressure: ____________ psi

92 Middle of "uphill" side' pressure: ____________ psi

93 Hose inlet pressure: ____________ psi

94 Middle of "downhill" side pressure: ____________ psi

95 Downstream end of "downhill" side pressure: ____________ psi

Location #**6**: Intermediate submain or regulated manifold.

Closest hose to the inlet of the submain (or regulated manifold):

96 Downstream end of "uphill" side pressure: ____________ psi

97 Middle of "uphill" side pressure: ____________ psi

98 Hose inlet pressure: ____________ psi

99 Middle of "downhill" side pressure: ____________ psi

100 Downstream end of "downhill" side pressure: ____________ psi

Most distant hose from the inlet of the submain (or regulated manifold):

101 Downstream end of "uphill" side pressure: ____________ psi

102 Middle of "uphill" side' pressure: ____________ psi

103 Hose inlet pressure: ____________ psi

104 Middle of "downhill" side pressure: ____________ psi

105 Downstream end of "downhill" side pressure: ____________ psi

Pressure **loss** across hose entrance screens at heads of hoses:

106 Hose 1: ____________ psi

107 Hose 2: ____________ psi

108 Hose 3: ____________ psi

109 Hose 4: ____________ psi

110 Hose 5: ____________ psi

EMITTER FLOW MEASUREMENTS

All volume measurements are in MILLILITERS.

111 Number of emitters that supply water to each plant: ____________________

*This is **NOT** the ratio of emitters to plants. One emitter can supply water to multiple plants. If each emitter is spaced evenly between two plants, even though the emitter/plant ratio is 1, the number of emitters that supply water to each plant is 2.*

For all emitter types, flows must be measured at 3 locations (A-C) throughout the field.

Location A - The middle of a hose (midway between the inlet and the downstream end) that is a "clean" area of the field. Typically this is hydraulically close to the pump. Flow measurements must be taken at 16 emitters, all at the same pressure.

Location B - The middle of a hose (midway between the inlet and the downstream end) that is near the middle of the field. Flow measurements must be taken at 16 emitters, all at the same pressure.

Location C - The tail end of a hose that is at the tail end of the field. Flow measurements must be taken at 28 emitters, all at the same pressure.

Location A

There are differences in how many tests of emitter flows are to be measured in Location A. Answer the following questions to determine which tests to perform at Location A.

You must answer ONE of the following questions with a "YES". There can only be <u>one</u> "YES" answer.

112 **<u>Question #1</u>**: Do you know that the discharge exponent of the emitters is about 0.5 (non-pressure compensating microsprayers, non-pressure compensating microsprinklers, clean tortuous path emitters, and most tapes)?

Please Select From List
Yes
No

If you know the emitter exponent is about 0.5, it is more accurate to assume 0.5 than to do in-field calculations.

113 **<u>Question #2</u>**: Is the emitter non-pressure compensating, and the discharge exponent is not known to equal 0.5 ?

Please Select From List
Yes
No

If the emitter exponent is not known to be 0.5 and the emitters are not pressure compensating, you must perform 2 flow tests to determine the emitter exponent.

114 **<u>Question #3</u>**: Does the emitter or microsprayer or microsprinkler have a pressure compensating (PC) feature?

Please Select From List
Yes
No

If the emitter is pressure compensating, you must perform five tests to create a pressure-flow rate curve.

If you answered "YES" to Question 1, perform only Test 1 at Location A.

If you answered "YES" to Question 2, perform only Tests 1 and 2 at Location A.

If you answered "YES" to Question 3, perform Tests 1 through 5 at Location A.

Location A: The middle of a hose (between the inlet and the downstream end) that is a "clean" area of the field.

All 16 emitters must have the same pressure

Select a hose with a relatively high pressure, or adjust the pressure so that it is relatively high.

Location A, Test 1:

Test 1 is required for all emitter types.

16 volume measurements are required. If less than 16 are obtained, either re-perform the test or estimate the missing values.

115	Collection time:	______________	minutes
116	Hose pressure at emitters:	______________	psi
		Collected volume:	
117	#1	______________	mL
118	#2	______________	mL
119	#3	______________	mL
120	#4	______________	mL
121	#5	______________	mL
122	#6	______________	mL
123	#7	______________	mL
124	#8	______________	mL
125	#9	______________	mL
126	#10	______________	mL
127	#11	______________	mL
128	#12	______________	mL
129	#13	______________	mL
130	#14	______________	mL
131	#15	______________	mL
132	#16	______________	mL

Location A, Test 2:

*Test 2 is required for all emitter types, **except** those for which you know the exponent = 0.5.*
Use the same 16 emitters as Test 1. Lower the pressure to about the lowest measured in the field.

133 Collection time: ______________________ minutes

134 Hose pressure at emitters: ______________________ psi

135 Volume of water accumulated from all the emitters: ______________________ mL

Individual emitter water volume values are not needed for Test 2.
Sum the total volume collected from all of the emitters during this test.

136 Number of emitters: ______________________

This value should be 16. But, for example, if one bucket fell over, input 15.

Location A, Test 3:

PC emitters only. Low intermediate pressure. Same emitters as Test 1.

137 Collection time: ______________________ minutes

138 Hose pressure at emitters: ______________________ psi

139 Volume of water accumulated from all the emitters: ______________________ mL

Individual emitter water volume values are not needed for Test 2.
Sum the total volume collected from all of the emitters during this test.

140 Number of emitters: ______________________

This value should be 16. But, for example, if one bucket fell over, input 15.

Location A, Test 4:

PC emitters only. Intermediate pressure. Same emitters as Test 1.

141 Collection time: ______________________ minutes

142 Hose pressure at emitters: ______________________ psi

143 Volume of water accumulated from all the emitters: ______________________ mL

Individual emitter water volume values are not needed for Test 2.
Sum the total volume collected from all of the emitters during this test.

144 Number of emitters: ______________________

This value should be 16. But, for example, if one bucket fell over, input 15.

Location A, Test 5

PC emitters only. High Intermediate pressure. Same emitters as Test 1.

145 Collection time: ______________________ minutes

146 Hose pressure at emitters: ______________________ psi

147 Volume of water accumulated from all the emitters: ______________________ mL

Individual emitter water volume values are not needed for Test 2.
Sum the total volume collected from all of the emitters during this test.

148 Number of emitters: ______________________

This value should be 16. But, for example, if one bucket fell over, input 15.

<u>Location B</u>: The middle of an "average hose" in the field.

Required for all emitter types. All 16 emitters must be at the same pressure.

16 volume measurements are required. If less than 16 are obtained, either re-perform the test or estimate the missing values.

149	Collection time:	______________________	minutes
150	Hose pressure at emitters:	______________________	psi
		<u>Collected volume</u>:	
151	#1	______________________	mL
152	#2	______________________	mL
153	#3	______________________	mL
154	#4	______________________	mL
155	#5	______________________	mL
156	#6	______________________	mL
157	#7	______________________	mL
158	#8	______________________	mL
159	#9	______________________	mL
160	#10	______________________	mL
161	#11	______________________	mL
162	#12	______________________	mL
163	#13	______________________	mL
164	#14	______________________	mL
165	#15	______________________	mL
166	#16	______________________	mL

Location C: At the downstream end of a hose at the most downstream end of the system.

Required for all emitter types. All 28 emitters must be at the same pressure.

28 volume measurements are required.
If less than 28 are obtained, either re-perform the test or estimate the missing values.

167	Collection time:	______________	minutes
168	Hose pressure at emitters:	______________	psi
		Collected volume:	
169	#1	______________	mL
170	#2	______________	mL
171	#3	______________	mL
172	#4	______________	mL
173	#5	______________	mL
174	#6	______________	mL
175	#7	______________	mL
176	#8	______________	mL
177	#9	______________	mL
178	#10	______________	mL
179	#11	______________	mL
180	#12	______________	mL
181	#13	______________	mL
182	#14	______________	mL
183	#15	______________	mL
184	#16	______________	mL
185	#17	______________	mL
186	#18	______________	mL
187	#19	______________	mL
188	#20	______________	mL
189	#21	______________	mL
190	#22	______________	mL
191	#23	______________	mL
192	#24	______________	mL
193	#25	______________	mL
194	#26	______________	mL
195	#27	______________	mL
196	#28	______________	mL

EMITTER SPACING

*If there is only one spacing, only fill out the data for "**AREA NUMBER 1**". If there are two or three spacings, fill out the additional AREAS.*

Note that differing plant spacings, emitter spacings, emitter flow rates, irrigation duration or frequency, plant ages, plant types, canopy cover, or ET rates in different blocks within a field qualify as multiple spacings.

AREA NUMBER: 1

197 Area with this combination: ____________________ acres

198 Area per plant (row spacing x plant spacing): ____________________ ft^2

This is the total area of the field dedicated to an individual tree, NOT the area under the canopy.

199 Number of emitters per plant (emitter/plant ratio): ____________________

Does not need to be a whole number, but must be at least 1. This is the ratio of emitters to plants. If there are two emitters for every one tree, the value would be "2".

200 Do you want to over-ride the computed flow per emitter? Please Select From List

- Yes
- No

The average flow rate per emitter is automatically calculated from your emitter flow measurements. Entering a value below overrides that value.

If you answered "Yes" above, answer the following 2 questions.

201 Over-ride flow rate (gph, lph, or mL/min): ____________________

This value could be computed by performing a flow test or estimated. This is the true emitter flow rate during operation, not the nominal emitter flow rate.

202 Units of over-ride flow rate: Please Select From List

- gph
- lph
- ml/min

203 Wetted soil area per emitter: ____________________ ft^2

204 100% Root zone available water holding capacity: ____________________ inches

Use a reasonable, manageable root zone depth, not the maximum depth a root may reach.

205 Set duration during peak ET: ____________________ hours

206 Irrigation frequency at peak ET: ____________________ days

Measure the days between irrigations from the start of the first irrigation to the start of next.

207 Crop ET during peak ET period: ____________________ inches/day

AREA NUMBER: 2

208 Area with this combination: ____________ acres

209 Area per plant (row spacing x plant spacing): ____________ ft^2

This is the total area of the field dedicated to an individual tree, NOT the area under the canopy.

210 Number of emitters per plant (emitter/plant ratio): ____________

Does not need to be a whole number, but must be at least 1. This is the ratio of emitters to plants. If there are two emitters for every one tree, the value would be "2".

211 Do you want to over-ride the computed flow per emitter? Please Select From List

Yes

No

The average flow rate per emitter is automatically calculated from your emitter flow measurements. Entering a value below overrides that value.

If you answered "Yes" above, answer the following 2 questions.

212 Over-ride flow rate (gph, lph, or mL/min): ____________

This value could be computed by performing a flow test or estimated. This is the true emitter flow rate during operation, not the nominal emitter flow rate.

213 Units of over-ride flow rate: Please Select From List

gph

lph

ml/min

214 Wetted soil area per emitter: ____________ ft^2

215 100% Root zone available water holding capacity: ____________ inches

Use a reasonable, manageable root zone depth, not the maximum depth a root may reach.

216 Set duration during peak ET: ____________ hours

217 Irrigation frequency at peak ET: ____________ days

Measure the days between irrigations from the start of the first irrigation to the start of next.

218 Crop ET during peak ET period: ____________ inches/day

AREA NUMBER: 3

219 Area with this combination: ____________ acres

220 Area per plant (row spacing x plant spacing): ____________ ft^2

This is the total area of the field dedicated to an individual tree, NOT the area under the canopy.

221 Number of emitters per plant (emitter/plant ratio): ____________

Does not need to be a whole number, but must be at least 1. This is the ratio of emitters to plants. If there are two emitters for every one tree, the value would be "2".

222 Do you want to over-ride the computed flow per emitter? Please Select From List

Yes

No

The average flow rate per emitter is automatically calculated from your emitter flow measurements. Entering a value below overrides that value.

If you answered "Yes" above, answer the following 2 questions.

223 Over-ride flow rate (gph, lph, or mL/min): ____________________

This value could be computed by performing a flow test or estimated.
This is the true emitter flow rate during operation, not the nominal emitter flow rate.

224 Units of over-ride flow rate: Please Select From List
- gph
- lph
- ml/min

225 Wetted soil area per emitter : ____________________ ft^2

226 100% Root zone available water holding capacity: ____________________ inches

Use a reasonable, manageable root zone depth, not the maximum depth a root may reach.

227 Set duration during peak ET: ____________________ hours

228 Irrigation frequency at peak ET: ____________________ days

Measure the days between irrigations from the start of the first irrigation to the start of next.

229 Crop ET during peak ET period: ____________________ inches/day

CONTAMINANTS AND PLUGGING/LEAKS

230 Flushing time to get clear water from the end of the lowest, most distant hose: ____________________ seconds

Rate the amount of material caught in the nylon sock when flushing the hoses:

231 Sand: Please Select From List
- None
- Slight
- Medium
- Major

232 Clay: Please Select From List
- None
- Slight
- Medium
- Major

233 Bacteria/algae: Please Select From List
- None
- Slight
- Medium
- Major

Rate the following causes of emitter plugging:

For this question, remove five emitters with apparent low flows.
Take them apart to inspect for the cause of plugging.

234 Sand: Please Select From List
None
Slight
Medium
Major

235 Precipitate (bubbles with acid drop): Please Select From List
None
Slight
Medium
Major

236 Bacteria: Please Select From List
None
Slight
Medium
Major

237 Clay/silt: Please Select From List
None
Slight
Medium
Major

238 Insects: Please Select From List
None
Slight
Medium
Major

239 Plastic parts: Please Select From List
None
Slight
Medium
Major

240 Rate the visible signs of abnormal emitter flow due to cracked hoses, barb leaks, etc.: Please Select From List
None
Slight
Medium
Major

UNEQUAL DRAINAGE

241 Time some emitters run after most emitters stop: ______________ minutes

242 Percentage of emitters that do this: ______________ %