Scientific Irrigation Scheduling Baseline Research Study

Portfolio of Work

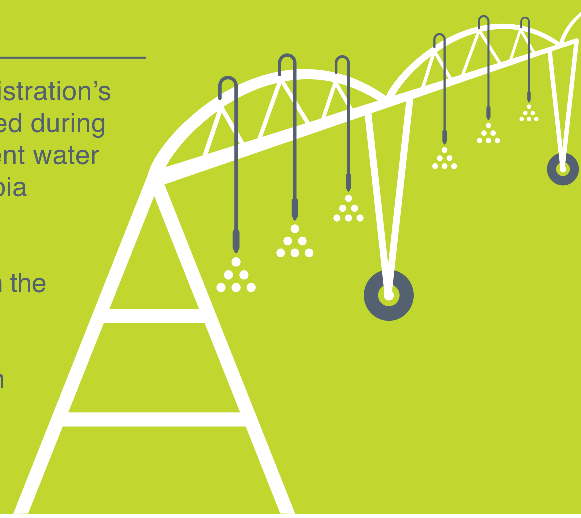
Bonneville
POWER ADMINISTRATION

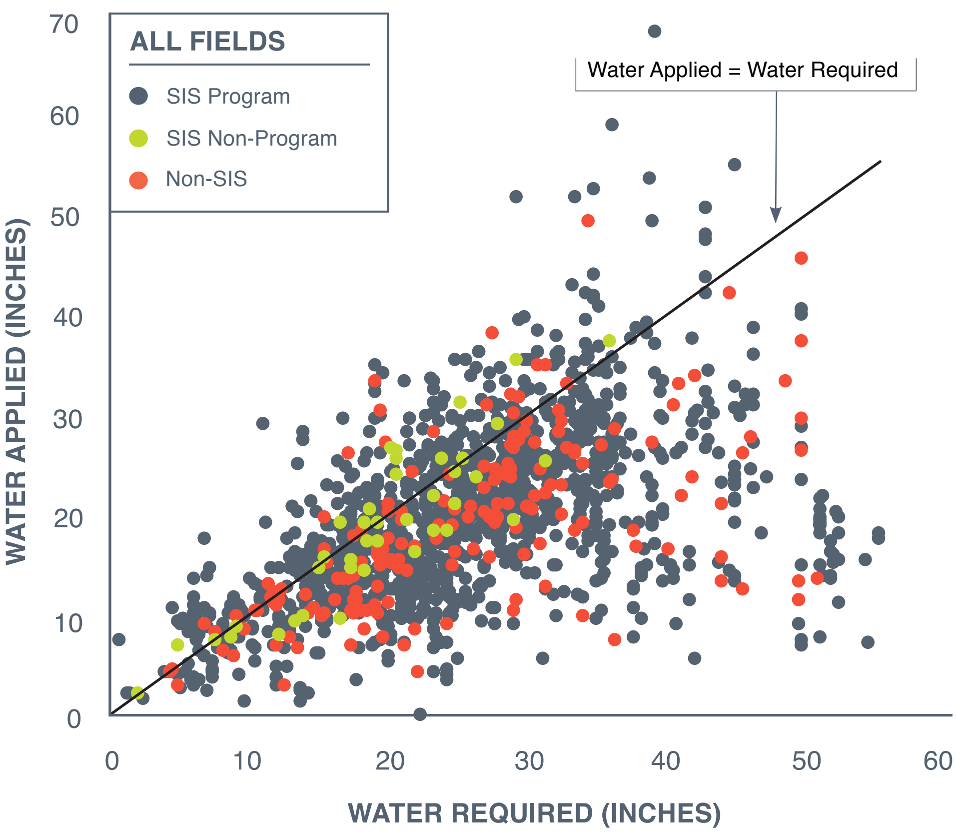
JUNE 2017

EXECUTIVE SUMMARY

This report contains the research team's findings from Bonneville Power Administration's (BPA's) Scientific Irrigation Scheduling (SIS) Baseline Research Study conducted during the 2016 growing season. The purpose of the study was to determine the percent water reduction from BPA's SIS program fields as compared to all fields in the Columbia River Basin.

Based upon review of more than 1,500 fields, the research team determined that in the Columbia River Basin, most fields were irrigated slightly less than what SIS would prescribe as the optimum amount of water. In other words, Columbia River Basin irrigation practices appear to be efficient in the amount of water applied, even when fields did not directly use the information from SIS. As a result, the research team found 0.5% less water applied to SIS program fields than all fields.





What is Scientific Irrigation Scheduling (SIS)?

Scientific irrigation scheduling informs growers when and how much to irrigate their crops by having an irrigation consultant visit their field once a week during the growing season to measure soil moisture, collect water applied data, and indicate the appropriate irrigation amounts.

FIGURE 1 Water applied versus water required for SIS program, SIS non-program, and non-SIS fields during the 2016 growing season

Figure 1 shows the water applied (y-axis) versus the water required (x-axis) for all the fields included in the analysis, with each dot representing a field. The black line represents the hypothetical scenario that the water applied to the field is equal to the water required by the field. As seen below, most of the fields fall below the black line, which means that most of the growers applied less water to their fields than what was required for optimal crop growth. This graphic also provides a visual representation of why the research team determined minimal water savings due to the presence of the SIS program. If there were more water savings, the SIS program fields would have been along the black line and the non-SIS and SIS non-program fields would have been above the black line.

IRRIGATION MARKET OVERVIEW

By collecting data on irrigation strategies, crop characteristics, and the water applied for over 1,500 fields in the Columbia River Basin, the research team identified the following key findings about the irrigation market in the Columbia River Basin:

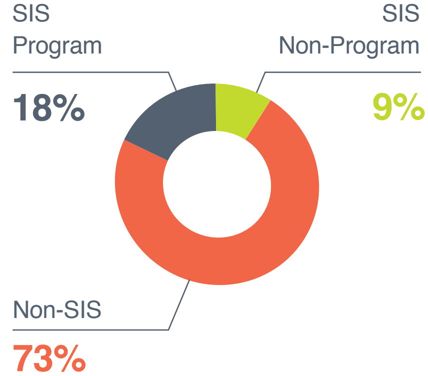
1 Most growers are not receiving SIS services. The research team found that 73% of growers did not receive SIS services during the 2016 growing season.

2 The predominant crops grown in the Columbia River Basin are potatoes and alfalfa. Additionally, alfalfa is one of the region's most water intensive crops; growers apply a median of 25 inches of water to the crops over the course of the growing season.

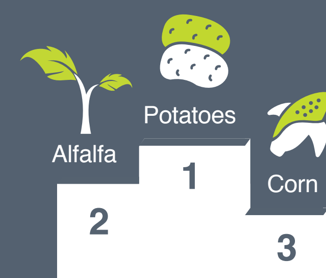
3 Most of the growers in the Columbia River Basin are growing low or medium management crops, such as alfalfa or corn. This trend is true for fields both receiving and not receiving SIS services. The management intensity of the crop is an indication of how much oversight the crop requires from the grower and how sensitive the crop is to the irrigation applied by the grower.

4 A small percentage of growers receive SIS services on their fields each year, but a much larger percentage of growers have received SIS services on their fields at some point in the past. For the 182 non-SIS fields included in the study, 56 of the growers reported they received SIS services on their fields in the past. Although growers may not receive SIS services on their fields every year, they may carry over the irrigation practices they learned while receiving SIS services into future years. In addition, anecdotal evidence suggests growers might use SIS on some fields, using that information to refine their irrigation on their other fields.

SIS Participation in 2016



Frequently Grown Crops



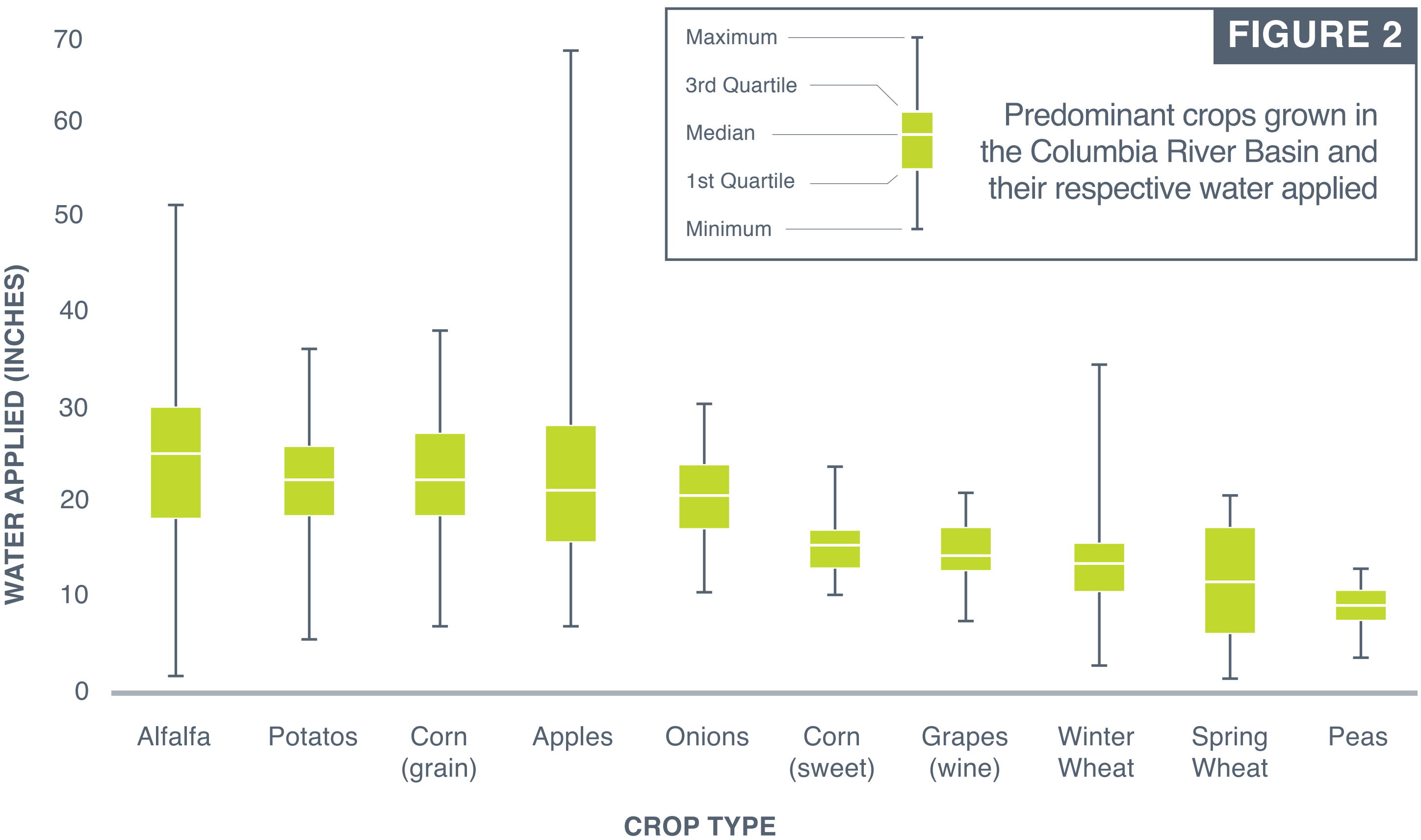
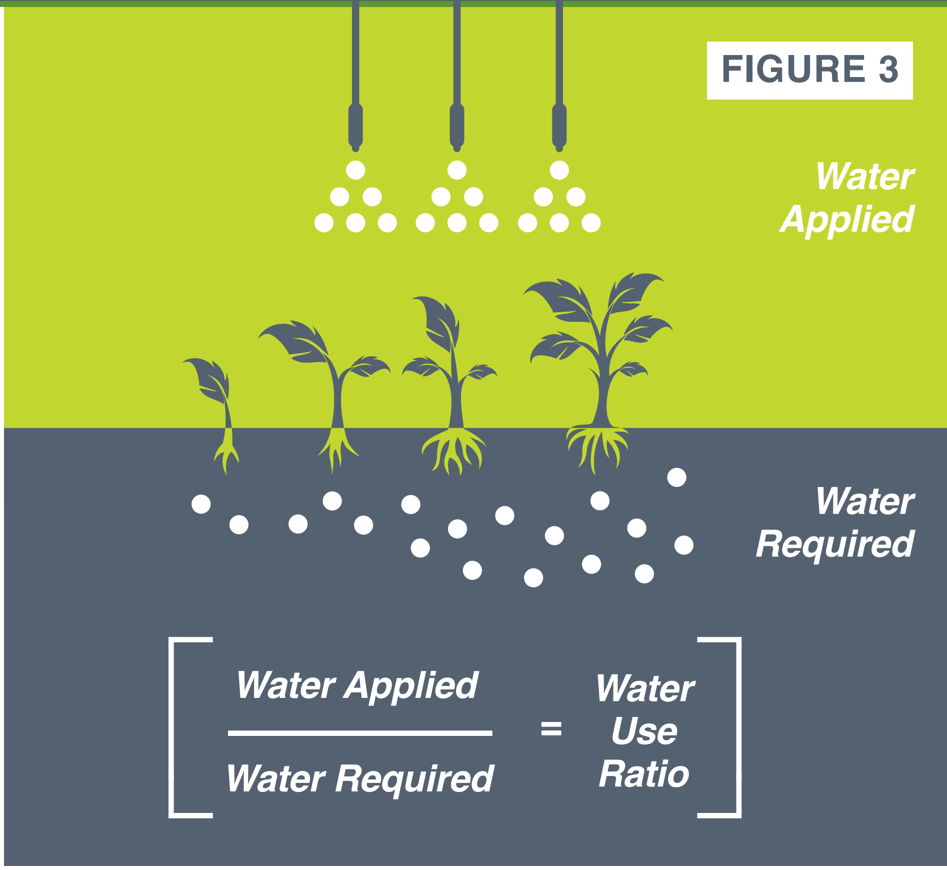


FIGURE 2

Predominant crops grown in the Columbia River Basin and their respective water applied



The primary goal of the SIS Baseline Research Study was to determine the percent water reduction from BPA's SIS program as compared to all fields in the Columbia River Basin. To achieve this goal, the research team collected data for fields across three field study categories. The combination of the three field study categories make up all the fields in the Columbia River Basin, which for the purposes of this report is referred to as the general market. The three field study categories included: fields that received SIS services in 2016 and received an incentive from BPA (SIS program); fields that received SIS services in 2016 and did not receive an incentive from BPA (SIS non-program); and fields that did not receive SIS services in 2016 (non-SIS).

To determine the percent water reduction from the SIS program, the research team calculated three key metrics as illustrated in Figure 3:

Key Metrics

1. Water applied to the fields
2. Water required by the fields for optimal growth
3. Water use ratio, which is the water applied to the fields divided by the water required by the fields

The research team worked with irrigation consultants who measured the water applied to each of the sampled fields and estimated the water required by the fields. The research team calculated the water use ratio for each of the field study categories and the general market using the data for water applied and water required, as supplied by the irrigation consultants. Subsequently, the research team calculated the percent water reduction by taking the water use ratio for the SIS program fields and subtracting it from the water use ratio for the general market fields. The water use ratio for the general market fields was determined by weighting the water use ratios of the field study categories by their relative contribution to the population.

To select fields to include in the study, the research team used a geospatial sampling technique that involved randomly sampling 100,000 points in the Columbia River Basin and narrowing the list to 735 agriculture fields on irrigated land. For SIS program and SIS non-program fields, the research team worked with irrigation consultants who provided the research team the required inputs to determine the water applied and the water required for each field. Since the irrigation consultants were already measuring the water applied to SIS program and SIS non-program fields as part of their regular SIS services, the research team leveraged the irrigation consultants' data instead of installing additional metering equipment. The irrigation consultants do not visit the non-SIS fields as part of their regular SIS services, so the research team worked with key stakeholders to develop a field data collection protocol to collect data regarding the water applied to those fields. The research team hired irrigation consultants to visit the non-SIS fields once a month to download logger data and collect other key data points that were required for the study. The research team ended up collecting data for 1,501 fields across all three field study categories.

FIELDS

1,501

Data used in this study was collected from 1,501 fields

FINDINGS

Based on the review of the percent water reduction from BPA's SIS program, the research team identified several findings that could assist with future agricultural program offerings.

1 **No significant effect on savings was seen from determining the percent water reduction for low or medium management crops separately from high management crops.** Weighting by crop management type resulted in 1% savings, as compared to 0.5% savings when not weighting by crop management type.

2 **Crop management type does not have a significant effect on a grower's decision to receive SIS services on their field.** Of fields receiving SIS services in 2016, 44% were high management crops, while only 36% of fields not receiving SIS services in 2016 were high management crops.

3 **The most common crop types grown in the Columbia River Basin are alfalfa and potatoes.** For growers that grew multiple crops on their fields in 2016, the most common crop pairings were sweet corn with peas and field corn with triticale.

4 **Regardless of whether a BPA incentive is offered for SIS services, approximately the same percentage of growers receive SIS services on their field,** suggesting that the SIS incentive is not a significant driver of uptake in the program. In utility service territories where BPA offers an SIS program, 29% of growers received SIS services in 2016. In contrast, in utility service territories where BPA did not offer an SIS program, 23% of growers received SIS services in 2016.

5 **Nearly 73% of growers in the Columbia River Basin chose not to receive SIS services on their fields in 2016** due to cost, the grower's preference to walk the fields and check moisture levels rather than rely on someone else or an automated system, paperwork, irrigation management being a low priority, and fear of water applied data getting into the wrong hands.

6 **Once the growing season starts, few growers change their mind about wanting to receive SIS services on their fields.** In many cases, once a grower decides to receive SIS services on a field, they continue with SIS until the end of the growing season.

7 **SIS technology is advancing** in the following areas: real-time soil moisture monitoring, growers installing weather stations on their farm to track microclimates, GPS-equipped machinery to better identify crop needs, and data-driven agriculture.

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Acknowledgements

This study benefited from the expertise of agriculture experts across the Pacific Northwest, ranging from irrigation consultants to university officials and everyone in between. We sincerely appreciate the time, effort, and expertise that the individuals listed below provided to this study.

The research team would like to acknowledge a few people who played a vital role in this study. First, the research team would like to acknowledge the guidance and support provided by Carrie Cobb at Bonneville Power Administration (BPA), who was the project manager for this study, and Tom Osborn, who provided technical support. The team would also like to extend a sincere thank you to the irrigation consultants at IRZ Consulting, led by Gina Gray and Gibb Evans, and Professional Ag Services, led by Roger McCary and John Lyle. Without the help of these consultants, this study would not have been possible. The research team would like to thank the field technicians at each of these companies for their time and patience collecting data. Finally, the team would like to thank Troy Peters at Washington State University for providing his agriculture expertise.

The table below summarizes the people who were instrumental to this study's success.

Company	Names
AgriNW	Kyle Barclay
Benton Rural Electric Association	Eric Miller
Big Bend Electric Coop Inc	Dale Anderson
BPA	Carrie Cobb, Tom Osborn, Boyd Wilson, Dick Stroh, Bonnie Watson, Carol Harshman, Jennifer Eskil (retired)
Columbia Basin Electric Coop Inc	Andy Fletcher
Columbia Rural Electric Association Inc	Doug Case
Irrinet	Jaq LeRoux, Jade LeRoux
IRZ Consulting	Gina Gray, Gibb Evans, Lora Mickelsen, Ryan Manning, Amy Scherrer, Kailey Morter, Janet Perez-Ramirez
Northwest Energy Efficiency Alliance	Geoff Wickes
Northwest Power and Conservation Council	Jenn Light
Onset	Matt Rivers
Professional Ag Services	Roger McCary, John Lyle, Sam Kniveton, Chris Friberg, Shawn Beeghly
PUD No 1 of Benton County	Tom Schumacher (retired), Vickie Bergum
PUD No 1 of Franklin County	Vic Hubbard

Company	Names
PUD No 1 of Klickitat County	Anita Clever
Regional Technical Forum	Ryan Firestone, Greg Brown, Josh Rushton
Soiltest Lab	Calvin Payne
Umatilla Electric Coop	Kathy Moore
Washington State University	Troy Peters

Introduction

Bonneville Power Administration (BPA) contracted with Navigant Consulting, Inc. (Navigant) and Cadeo (the research team) to determine the percent water reduction from BPA's scientific irrigation scheduling (SIS) incentive program. The research team collected data for over 1,500 fields in the Columbia River Basin during the 2016 growing season. The fields spanned three different populations—i.e. field study categories—that together make up all fields in the Columbia River Basin. For the purposes of this report, the combination of the three field study categories is referred to as the general market. The three field study categories included: fields that received SIS services in 2016 and received an incentive from BPA (SIS program); fields that received SIS services in 2016 and did not receive an incentive from BPA (SIS non-program); and fields that did not receive SIS services in 2016 (non-SIS). The research team collected water applied data for each of the fields and compared it to the ideal amount of water required by the fields. The team then aggregated the results to determine the percent water reduction for SIS program fields as compared to all fields in the Columbia River Basin. This report summarizes the results of these efforts.

Brief Description of Research Activities

To determine the percent water reduction from BPA's SIS program, the research team took the following key steps. Additional detail on how the team executed the described steps can be found in the Research Portfolio section.

1. **Designed a statistically significant sample.** The research team leveraged statistical assumptions made by similar studies and the team's industry knowledge to design a statistically significant sample of fields to visit during the 2016 growing season.
2. **Used a geospatial approach to select fields to participate in the study.** The research team used the ArcGIS Sampling Design Tool to randomly select 100,000 points in the Columbia River Basin. This preliminary list was narrowed down to a list of 735 fields on irrigated land. The research team used the dataset of 735 fields as the basis for recruiting fields into the study.
3. **Developed a field data collection protocol.** The research team worked with stakeholders to develop a field data collection protocol to collect water applied and water required data for SIS program, SIS non-program, and non-SIS fields.
4. **Collected water applied and water required data for SIS fields.** The research team partnered with irrigation consultants who provided the water applied and water required data for a census of the SIS program fields and a sample of SIS non-program fields. The irrigation consultants collected the required data during the growing season and provided it to the research team at the end of the growing season.
5. **Collected water applied and water required data for non-SIS fields.** The research team worked with irrigation consultants throughout the course of the growing season to measure the water applied to 182 non-SIS fields. The irrigation consultants visited the non-SIS fields monthly and provided the research team with the logger data and other key metrics on the day of the site visit.

6. **Aggregated the field-level results.** The research team aggregated the field-level water applied and water required data to determine a water use ratio—the water applied divided by the water required—for each of the field study categories and the general market. The general market was defined by a weighted average of the water use ratios of the three field study categories based on each field study category's relative contribution to the overall population of irrigated fields in the Columbia River Basin.
7. **Calculated the percent water reduction.** The research team determined the percent water reduction from the SIS program by subtracting the water use ratio of the SIS program fields from the water use ratio of the general market fields.

How to Use this Document

Before reviewing the research findings, it is important to understand the structure of this document as well as the activities completed for the SIS Baseline Research Study. This document consists of two parts: a **Research Summary** and a **Research Portfolio**.

The **Research Summary** distills the findings from the wide-ranging activities the research team completed as part of the SIS research project. In this section, the team highlights the research activities completed as part of this study and the key findings from collecting data for over 1,500 fields in the Columba River Basin during the 2016 growing season.

The second part of this report is the **Research Portfolio**. It contains the 16 deliverables that the research team submitted to BPA between August 2015 and June 2017 following the completion of each research activity. These deliverables detail each activity's methodology and findings. Readers should refer to the Research Portfolio for an in-depth discussion of each activity.

Research Summary

The primary research question the research team answered as part of this study was whether there was a statistically significant percent difference between the water applied to SIS program fields and the water applied to all fields in the Columbia River Basin, which together make up the general market. The research team compiled the final results to determine a percent water reduction of 0.5% due to the presence of the SIS program when compared to all other irrigated fields in the Columbia River Basin. The research team determined that most fields in the Columbia River Basin were irrigated slightly less than what SIS would prescribe as the optimum amount of water. In other words, Columbia River Basin irrigation practices appear to be efficient in the amount of water applied, even when fields did not directly use the information from SIS. In addition to answering the study's central question, the research team identified several other findings that could assist BPA with future agricultural program offerings. A complete summary of this research study's findings is included through the remainder of this section.

Study Background

BPA contracted the research team to identify the percent water reduction from the SIS program during the 2016 growing season due to a mandate from the Regional Technical Forum (RTF). The RTF mandate required BPA to research the percent water reduction resulting from the SIS program or discontinue the program offering. The mandate was issued because it had been a long time since the last review of the program savings assumptions by Quantec in 2005.

There were two key differences in methodology between this study and the previous Quantec study:

1. **The baseline used in the savings calculation:** Quantec calculated the savings by using a control group, whereas this study compared the water consumption of SIS program fields to the general market (SIS program, SIS non-program, and non-SIS fields).[1]
2. **The magnitude of the study:** This study was significantly larger than the Quantec study. The Quantec study included metered data for 38 fields, whereas this study included metered data for 1,501 fields.

Beyond the methodological differences, the findings between the two studies were also significantly different. The Quantec study determined a percent water reduction of 10% when comparing SIS program fields to non-SIS fields, while this study found a percent water reduction of 0.5% when comparing SIS program fields to the general market. The reason for this difference is likely because irrigation practices in the Columbia River Basin have advanced significantly between 2005 and 2016 due to technology advancements and growers more closely monitoring their irrigation practices.

The Importance of SIS

The reason why SIS is important from an efficiency point of view and why BPA has been incentivizing growers to use SIS on their farms is because SIS is meant to ensure that growers are applying the right

[1] The use of a control group as a baseline is no longer consistent with the Regional Technical Forum's Operative Guidelines. https://rtf.nwcouncil.org/subcommittee/guidelines

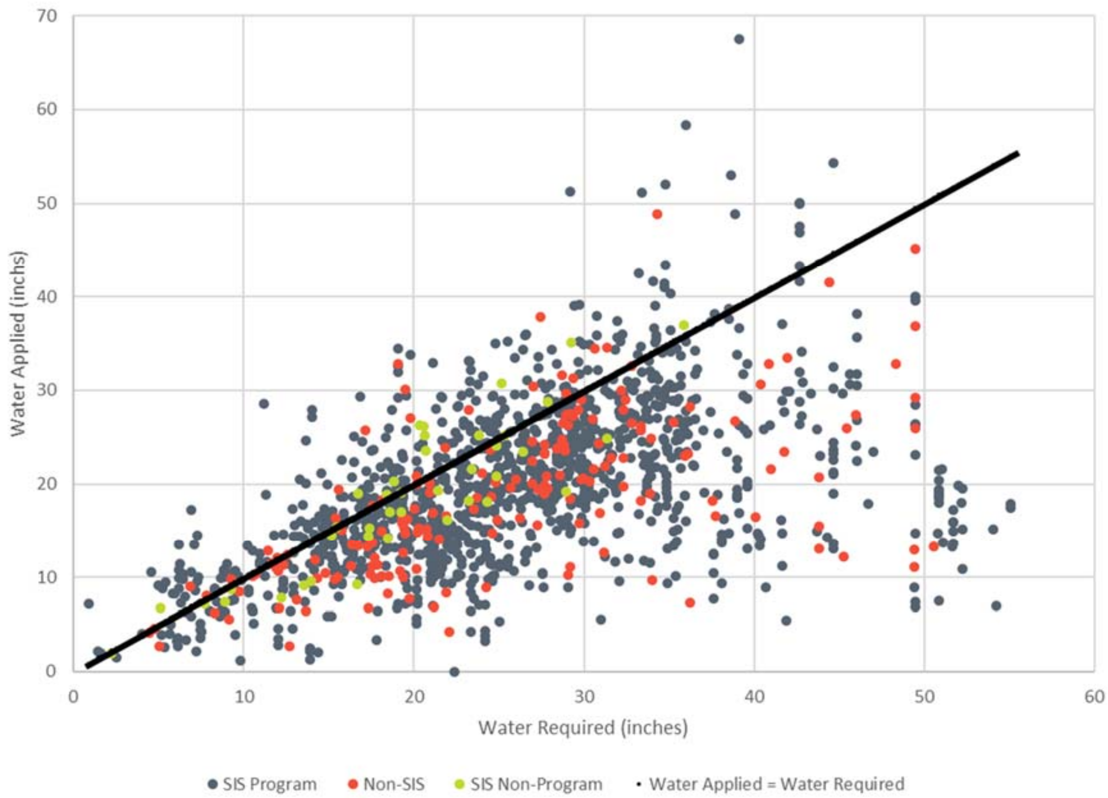
amount of water to a field at the optimal time. This balance is achieved by having an irrigation consultant visit the field on a weekly basis to measure the water applied to the field and the soil moisture content. These metrics feed into the irrigation consultant's irrigation scheduling software, which calculates how many inches of water the grower should apply to their field each week based on how saturated the crop is, any expected rainfall, and the crop's growth stage. SIS is intended to ensure that growers are not overwatering their crops and are instead watering to a crop's exact needs. By more closely monitoring irrigation practices, SIS is intended to reduce the grower's water consumption and increase crop yields. This research study focused on verifying the water savings from SIS; it did not focus on verifying the effect of SIS on crop yield.

Summary of Findings

Upon aggregating the results from all 1,501 fields monitored during the 2016 growing season, the research team found that the percent water reduction between SIS program fields and the general market is 0.5%. This means that the irrigation practices of fields participating in the SIS program are similar to fields not participating in the program. Growers participating in the SIS program may be applying less water at certain times, but over the course of the entire season they are applying similar amounts of water to their fields as growers receiving SIS services but not participating in BPA's SIS program and growers not receiving SIS services. It is a widely held belief that growers participating in the SIS program may experience higher crop yields due to more closely monitoring their irrigation practices, but the research team is unable to corroborate this belief as crop yield data was not collected as part of this study.

Figure 1 provides a visual representation of this study's key finding: SIS program field irrigation practices are similar to all fields in the Columbia River Basin. The graph shows the water applied (y-axis) versus the water required (x-axis) for all fields included in the analysis, with each dot representing one field. The black line represents the hypothetical scenario that the water applied to a field is equal to the water required. As seen below, most fields fall below the black line, which means that most growers applied less water to their fields than what was required for optimal crop growth. If there were more water savings, the SIS program fields would need to be along the black line and the non-SIS and SIS non-program fields would need to be above the black line.

Figure 1: Water Applied vs. Water Required Results for All Fields



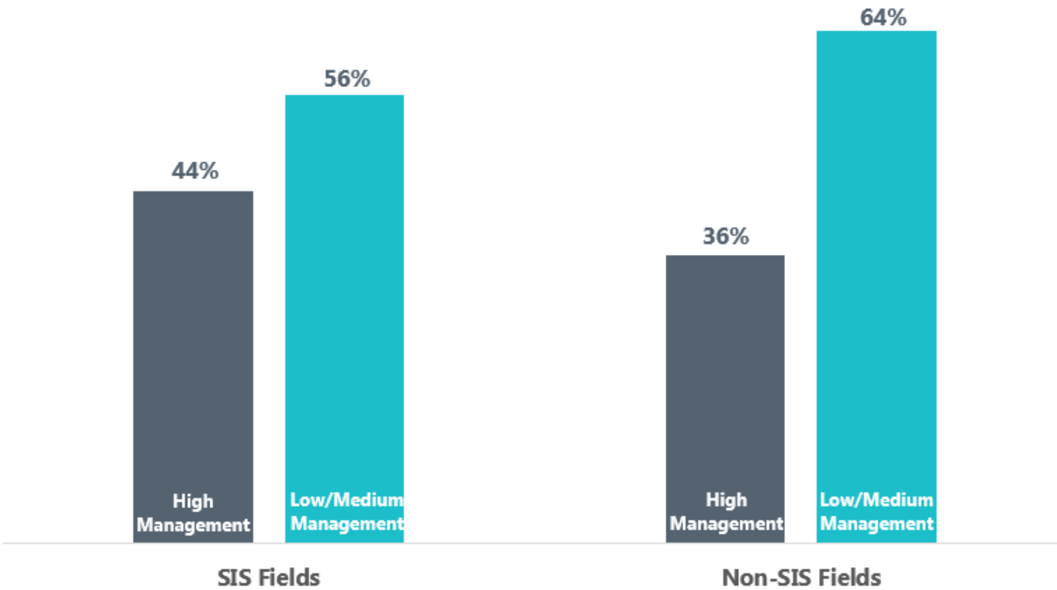
Source: Metered data from the 2016 growing season

In addition to answering the primary research question, the research team identified a few other key findings that could assist BPA with future agriculture program offerings. These findings are discussed below.

1. **Calculating the results by crop management type instead of aggregating all fields together did not result in a significant effect on savings.** A crop's management intensity is an indication of how much oversight it requires from the grower and how sensitive it is to the irrigation applied by the grower. Weighting by crop management type resulted in 1% savings in water usage as a result of the BPA SIS program, as compared to 0.5% savings when not weighting by crop management type.

2. **Crop management type does not have a significant effect on a grower's decision to receive SIS services on their field.** Of fields receiving SIS services in 2016, 44% were high management crops, while only 36% of fields not receiving SIS services in 2016 were high management crops. Figure 2 provides a visual illustration of the trend in crop management type between SIS fields (program and non-program) and non-SIS fields.

Figure 2: Comparison of Crop Management Types Between SIS Fields (Program and Non-Program) and Non-SIS Fields



Source: Interviews with growers

3. **Regardless of whether a BPA incentive is offered for SIS services, approximately the same percentage of growers received SIS services on their field**. In utility service territories where BPA offers an SIS program, 29% of growers received SIS services in 2016. In contrast, in utility service territories where BPA did not offer an SIS program, 23% of growers received SIS services in 2016. This finding suggests that the incentive for receiving SIS services is not a significant driver of uptake in the SIS program.

4. **A majority of growers in the Columbia River Basin did not receive SIS services on their fields in 2016 due to various reasons.** Nearly 73% of growers in the Columbia River Basin chose to not receive SIS services on their fields in 2016 due to one of the following reasons: cost, the grower's preference to walk the fields and check moisture levels rather than rely on someone else or an automated system, paperwork, irrigation management being a low priority, and fear of water applied data getting into the wrong hands.

5. **The most common crop types grown in the Columbia River Basin in 2016 were potatoes and alfalfa.** Of the fields for which the research team collected data during the 2016 growing season, 22% were potato fields and 16% were alfalfa fields. For growers that grew multiple crops on their fields in 2016, the most common crop pairings were sweet corn with peas and field corn with triticale.

6. **Once the growing season starts, few growers change their mind about wanting to receive SIS services on their fields.** In many cases, once a grower decides to receive SIS services on a field, they continue with SIS until the end of the growing season.

7. **SIS technology is advancing in many areas.** The future of SIS includes real-time soil moisture monitoring, growers installing weather stations on their farm to track microclimates, GPS-equipped machinery to better identify crop needs, and data-driven agriculture.

Research Portfolio

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Appendix Documents

Appendix A – Lessons Learned from the Rain Gauge Pilot

To: Carrie Cobb, BPA

From: Emily Merchant, Beth Davis, and Jane Pater Salmon, Navigant

Date: January 26, 2016

Subject: SIS Baseline Research: Lessons Learned from Pilot Study Phase II (FINAL)

This memo outlines the key lessons learned during the second phase of Navigant's scientific irrigation scheduling (SIS) pilot study. The purpose of the study—conducted by Navigant and IRZ Consulting (the research team)—was to test the tipping rain gauge for the SIS baseline research study before the 2016 growing season. The research team conducted the first phase of the pilot study from August 3, 2015 to August 28, 2015 to test the three methods for measuring the actual water applied: manual rain gauge, pressure gauge, and integrated flow meter.

After the conclusion of the initial pilot study and based on comments from stakeholders, Navigant determined that a tipping rain gauge might be more advantageous than a manual rain gauge due to the increased data granularity and the eliminated risk from manually reading a rain gauge. As the rain gauge method will be the dominant method in the 2016 growing season, the research team conducted a second phase of the pilot study in January 2016 to test the tipping rain gauge. The research team tested two tipping rain gauges, one in the Navigant Boulder, CO, office and one in the IRZ Consulting (IRZ) Hermiston, OR, office.

The team organized this memo into three sections: 1) an overview of the pilot study, 2) the lessons learned from the study, and 3) the research team's recommendation. The following summary highlights the key lessons learned in phase two of the pilot study:

- **Calibration**. The research team calibrated both tipping rain gauge setups and found the process to be very cumbersome with little added value.
- **Bird-B-Gone Strip**. Based on recommendations from irrigation consultants, the research team tested a Bird-B-Gone Strip to eliminate the risk of birds or debris obstructing the rain gauge measurements. The research team found the Bird-B-Gone Strip to be difficult to install.
- **Mounting Setup**. The research team tested a variety of vertical mounting options and found that a four-foot-long, one-and-a-half-inch-diameter PVC pipe dug two feet into the ground is the optimal setup.

- **Sensitivity to Wind**. Wind can affect the tipping rain gauge measurements, so installing the rain gauge on a sturdy mounting setup in a location protected from the wind is necessary to avoid erroneous measurements. The manual rain gauge is also sensitive to the wind, but the tipping rain gauge has a higher sensitivity due to the larger surface area of the equipment.
- **Data Outputs**. The tipping rain gauge has a variety of data outputs, including temperature, daily water measurements, and instantaneous water measurements with a timestamp.
- **Data Accuracy**. The research team cross-checked the accuracy of the tipping rain gauge installed in Hermiston, OR, by installing a manual rain gauge next to it and comparing the two measurements. The tipping rain gauge and manual rain gauge measurements were approximately the same over the three-week logging period.
- **Equipment Documentation**. The installation instructions provided by the manufacturer of the tipping rain gauge, Onset, and the manufacturer of the Bird-B-Gone Strip, Texas Instruments, were not very detailed. The research team had to rely on trial and error as well as conversations with the manufacturers to assemble the equipment.
- **Logger Sensitivity to Ultraviolet (UV) Light**. The research team found that if the logger is exposed to UV light for long periods of time, the logger can malfunction. Housing the logger inside of the tipping rain gauge bucket eliminates this problem.

Overview of the Pilot Study

Navigant partnered with IRZ for the second phase of the pilot study. The research team tested two tipping rain gauge setups, one in Navigant's Boulder, CO, office and one in IRZ's Hermiston, OR, office. The purpose of the second phase of the pilot study was to determine whether the tipping rain gauge is a suitable alternative to the manual rain gauge setup. Table 1 summarizes the sites included in the pilot study.

Table 1: Overview of Pilot Sites

Pilot Site	Installation Location	Logging Period	Notes
Pilot 1: Hermiston, OR	Field in Hermiston, OR, irrigated with reuse water	12/28/15–1/20/16	Measured rainfall, snowfall, and reuse water
Pilot 2: Boulder, CO	Backyard of residential home	1/7/16–1/20/16	Measured rainfall and snowfall only

Source: Research team findings from pilot study

The research team encountered the following hurdles during the course of the pilot study:

- The calibration process did not go as smoothly as anticipated. The tipping rain gauge manual said that it would take one hour to empty 473 milliliters of water and, in some instances, it took 20 to 30 minutes to empty the water jug, which made it falsely appear that the tipping rain gauge was not calibrated.

- The Bird-B-Gone Strip was difficult to assemble and did not appear to be made for the RG3 tipping rain gauge, despite confirmation from Texas Instruments that it would work with the RG3 setup. The research team had to cut the strip so that it would fit around the circumference of the collector screen.
- The equipment documentation was not helpful and the research team had to rely on trial and error to get the setup to work.

Lessons Learned

This section discusses the lessons learned throughout the course of the second phase of the pilot study. These lessons will help inform the SIS baseline research study that will take place in the 2016 growing season.

CALIBRATION

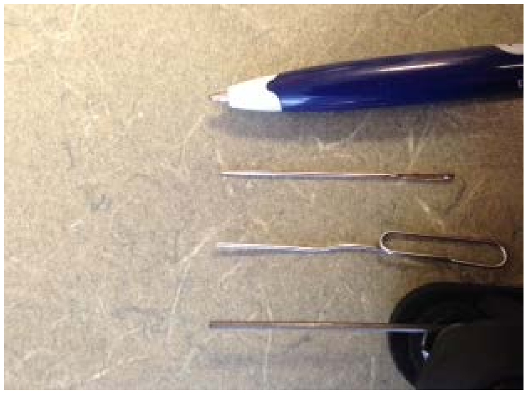
Background

The tipping rain gauge manual provides instructions for calibrating the equipment after installing it in the field because the mechanical equipment can become uncalibrated during shipment. Texas Instruments, who assembles the tipping rain gauge, calibrates every tipping rain gauge before shipment but recommended calibrating the tipping rain gauge upon installation as an added precaution. As a result, the research team tested the calibration process for both tipping rain gauge setups. The calibration process turned out to be far more cumbersome then the manual implied. The calibration involved filling up a water jug with 473 milliliters of water, poking a pin-sized hole in the bottom, and resting the jug on top of the collector screen. The whole process should take one hour and the tipping rain gauge should read 100 tips, where each tip signifies 0.01 inches of water.

Calibration Process

IRZ experienced difficulty in finding an instrument to poke a small enough hole in the jug that resulted in exactly one hour for the jug to empty. Figure 1 below shows the various instruments IRZ used to poke a hole in the bottom of the jug. Each of the setups took between 20 and 30 minutes to empty the jug, which is significantly less than the hour it should have taken based on the installation manual. In the end, the setup that resulted in 100 tips in exactly one hour was a flow regulator hooked up to a CamelBak that trickled water into the tipping rain gauge (see Figure 2). This setup would be far too complex to implement in the field.

Figure 1: Equipment IRZ Used to Puncture the Jug during Calibration



Source: Research team data collection

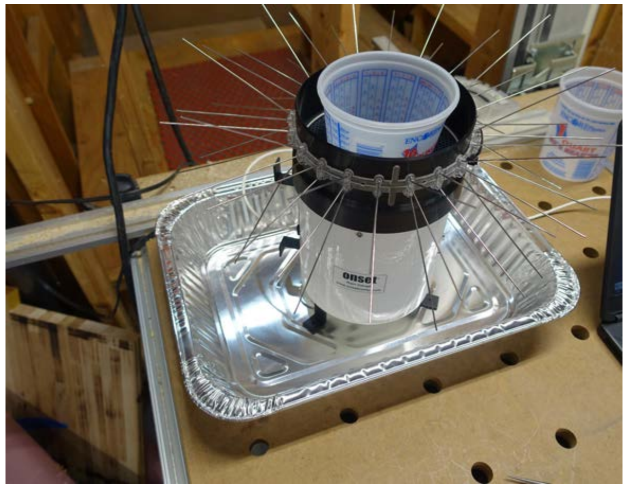
Figure 2: CamelBak with Pressure Regulator that IRZ Used

Source: Research team data collection

Navigant successfully completed the calibration using a 16-ounce plastic container and an awl[1] to poke a small enough hole in the container. The entire process took 99 tips and just over one hour for the 16-ounce container to empty 473 milliliters of water. The process was cumbersome, but the calibration was successful based on the metrics in the tipping rain gauge manual. Figure 3 below shows the calibration setup in Boulder, CO.

[1] An awl is a long pointed spike used to puncture a piece of material.

Figure 3: Calibration Setup in Boulder, CO



Source: Research team data collection

Recommendation

As the manufacturer calibrates the tipping rain gauges before shipment, the research team is comfortable assuming that the rain gauges are still properly calibrated upon arrival. If the tipping rain gauge packaging appears dented or altered during shipment, the irrigation consultant will calibrate the tipping rain gauge upon installation. If the packaging appears to be unaffected upon shipment, calibration will not be required.

BIRD-B-GONE STRIP

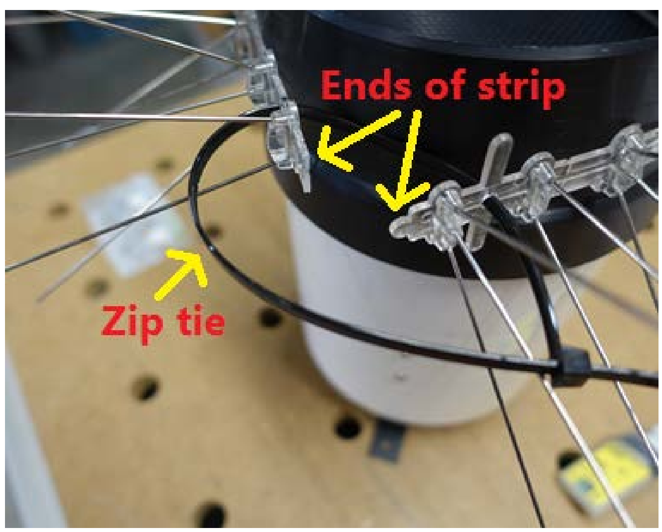
The research team heard from tipping rain gauge manufacturers and irrigation experts that tipping rain gauges can be susceptible to birds and debris clogging the collector screen, which could skew the measurements. The research team determined that a Bird-B-Gone Strip could alleviate this risk by preventing birds and debris from clogging up the collector screen. Texas Instruments, who assembles the RG3 tipping rain gauge, makes a Bird-B-Gone strip designed for the RG3. The research team piloted the strip on both tipping rain gauge setups to test its ease of use and effectiveness. Figure 4 below shows the Bird-B-Gone Strip installed on the tipping rain gauge.

Figure 4: Bird-B-Gone Strip Installed on Tipping Rain Gauge

Source: Research team data collection

The research team found that the Bird-B-Gone Strip is longer than the circumference of the tipping rain gauge and needs to be cut to fit. The research team made a mark on the strip that left a quarter-inch gap between the two ends after it was wrapped around the tipping rain gauge. The research team used tin snips to cut the strip on the mark and then looped a large zip tie through the holes on each end of the strip to make a tight connection between the strip and the rain gauge (see Figure 5).

Figure 5: Bird-B-Gone Strip Assembly



Source: Research team data collection

The Bird-B-Gone Strip comes collapsed in a package and requires significant effort to unravel the metal spikes so that they are pointing upwards. The metal spikes are very sharp, therefore the research team had to use great care when bending the spikes into their intended position. Figure 6 below shows the Bird-B-Gone Strip before assembly (left) and after assembly (right).

Figure 6: Bird-B-Gone Strip Before Assembly (left) and After Assembly (right)

Source: Research team data collection

Recommendation

The Bird-B-Gone Strip required additional modifications to assemble and could be dangerous if not assembled carefully. The Bird-B-Gone strip is too long for the RG3 tipping rain gauge, therefore the research team suggests cutting the strip before installing it on the rain gauge. The research team recommends that the irrigation consultants cut all of the Bird-B-Gone strips at the same time before the study to ensure an efficient installation in the field.

MOUNTING SETUP

The installation manual for the RG3 tipping rain gauge did not have many specific details for vertically mounting the tipping rain gauge, therefore the research team received additional guidance from the manufacturer, Onset. The manufacturer suggested using a one-and-five-eighths-inch steel pole, installed two feet into the ground. The research team explored multiple options and found that a four-foot-long, one-and-a-half-inch-diameter PVC pipe installed two feet into the ground is the optimal mounting setup for the tipping rain gauge. The benefit to using PVC over steel is that it is easier to cut down the PVC pipe to the appropriate size for a specific crop than it is to cut a steel pipe. Not all pipes will need to be four-feet long; the length will depend on how high the rain gauge needs to be to be below the drops of the sprinkler heads. Due to the variability in crop types and sprinkler heights, it is advantageous to have a mounting solution that is easy to adjust the height.

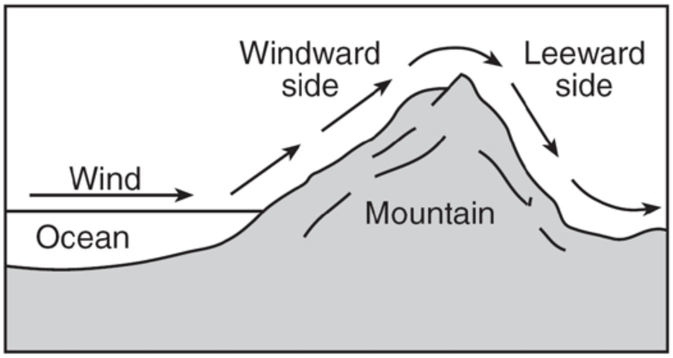
Recommendation

The research team recommends mounting the tipping rain gauge on a four-foot long, one-and-a-half-inch diameter PVC pipe that is installed two feet into the ground. It is important that the rain gauge is below the drop of the sprinkler heads. The height of the PVC pipe may be adjusted so that the rain gauge is below the sprinkler heads.

SENSITIVITY TO WIND

The tipping rain gauge accuracy is sensitive to vibrations; therefore, it is important to minimize the impact of wind on the tipping rain gauge. Onset recommends installing the tipping rain gauge on a sturdy pole that is dug at least two feet into the ground and that the tipping rain gauge is installed on the leeward size of objects or structures to mitigate the effects of high winds (see Figure 7). The manual rain gauge is also sensitive to the wind, but the tipping rain gauge has a higher sensitivity due to the larger surface area of the equipment.

Figure 7: Windward vs. Leeward



Source: http://hdpixa.com/windward+leeward+diagram?image=938556792

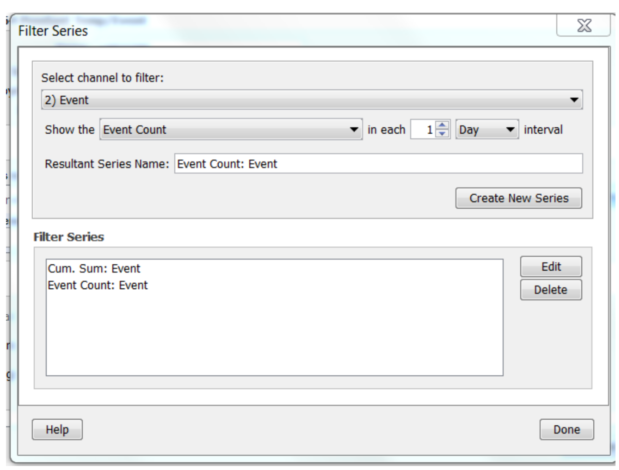
Recommendation

The research team recommends that the irrigation consultants minimize the impact of high winds on the rain gauge by installing the rain gauge on a four-foot-long, one-and-a-half-inch-diameter PVC pipe that is dug at least two feet into the ground. When possible, the rain gauge should be installed on the leeward side of obstructions such as buildings or other tall structures.

DATA OUTPUTS

The tipping rain gauge has the option to log multiple metrics including temperature, daily water measurement, and instantaneous water measurement. The tipping rain gauge records the water measurement as an event, which is when the tipping mechanism receives 0.01 inches of water and tips to the other side like a seesaw. The logger can timestamp every "event" (i.e., every 0.01 inches of water collected) or it can sum up the total events over a time interval, such as a day. Figure 8 shows the screen in the HOBOware software for setting up the tipping rain gauge to count the number of events each day.

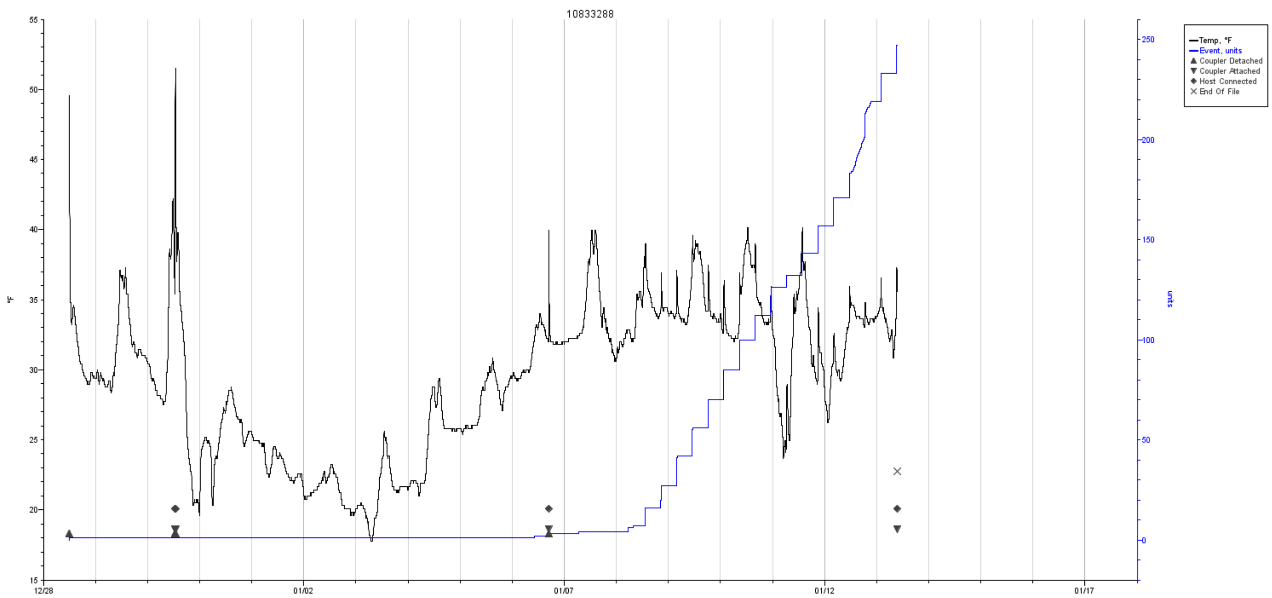
Figure 8: Tipping Rain Gauge Logger Set to Count the Sum of Events Each Day



Source: Research team data collection

The tipping rain gauge also has the option to log the temperature. Figure 9 shows sample output from the HOBOware software with a graph of the temperature (black line) and the event count (blue line).

Figure 9: Graph of the Temperature (black line, left axis) and Event Counts (blue line, right axis) between 12/28/15 and 1/17/16



Source: Research team data collection

Recommendation

The research team recommends logging the timestamp of each tip of the bucket to ensure the highest data granularity. Temperature data is not necessary for the analysis and would take up unnecessary space in the data logger.

DATA ACCURACY

The research team tested the accuracy of the tipping rain gauge installed in a field in Hermiston, OR, by installing a manual rain gauge next to the tipping rain gauge. The research team found that the manual rain gauge measurements and the tipping rain gauge measurements lined up almost exactly.

Recommendation

The research team feels very confident in the accuracy of the tipping rain gauge because the measurements read by the manual rain gauge and the tipping rain gauge over the three weeks of the pilot were almost exactly the same. The benefit of the tipping rain gauge is a higher granularity of data because the manual rain gauge is read once a week, whereas the tipping rain gauge has the capability of timestamping every 0.01 inches of water received by the crop.

EQUIPMENT DOCUMENTATION

The equipment documentation provided by Onset, the manufacturer of the tipping rain gauge, and Texas Instruments, the manufacturer of the Bird-B-Gone Strip, did not provide granular enough detail for the equipment setups. The research team relied on trial and error as well as conversations with the manufacturers to successfully install the equipment.

Recommendation

The research team recommends that the irrigation consultants rely on the step-by-step instructions provided by the research team instead of the installation instructions from the equipment manufacturers.

LOGGER SENSITIVITY TO UV LIGHT

The tipping rain gauge has a built-in data logger that can be stored inside or outside of the rain gauge when it is recording data. The research team in Boulder, CO, left the logger outside of the tipping rain gauge for ease of data exporting, whereas the team in Hermiston, OR, left the logger inside of the tipping rain gauge. The logger in Boulder, CO, malfunctioned due to long-term exposure to UV light, which resulted in an error message when exporting the data (Figure 10). The Hermiston, OR, research team experienced no issues when the logger was housed inside of the tipping rain gauge. The disadvantage to housing the logger inside of the rain gauge bucket is that the irrigation consultant needs to remove the collector screen every time the data is exported and there is risk of erroneous tips if the irrigation consultant accidentally touches the tipping mechanism when accessing the data logger. Housing the logger inside of the tipping rain gauge eliminates the risk of logger malfunction due to UV light exposure.

Figure 10: Error Message When Exporting Data from the Logger Affected by UV Light Exposure

Source: Research team data collection

Recommendation

The research team recommends housing the data logger inside the tipping rain gauge bucket during the logging period. The irrigation consultant should use caution when accessing the data logger to export the data so that there are no erroneous tips. The research team also recommends that the irrigation consultants use a twist tie to tie the wire exiting the data logger so that it does not become tangled around the tipping mechanism.

Overall Recommendation

In summary, the research team recommends using the tipping rain gauge as the primary method for the SIS baseline research study. The benefit of the tipping rain gauge is the higher level of granularity in the data and the elimination of user error when reading the manual rain gauge. The research team has the following recommendations for the tipping rain gauge approach:

- Irrigation consultants should set up the tipping rain gauge to log the timestamp of each event (i.e., each tip), where one event is equal to 0.01 inches of water.
- Irrigation consultants should mount the tipping rain gauge on a four-foot-long, one-and-a-half-inch-diameter PVC pipe that is installed two feet into the ground with the rain gauge below the sprinkler heads.
- Calibration is not required unless the tipping rain gauge packaging was damaged during shipment.
- Irrigation consultants should cut all of the Bird-B-Gone Strips at the same time before the study to ensure an efficient installation in the field.

Appendix B –
Lessons Learned from the Pilot Study

Final

October 27, 2015

Contributors

Developed by Emily Merchant, Beth Davis, and Jane Pater Salmon, Navigant Consulting, Inc.

Developed for Bonneville Power Administration

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Introduction

This memo outlines the key lessons learned during Navigant's scientific irrigation scheduling (SIS) pilot study. The purpose of the study, which was conducted by the Navigant team (the research team), was to test the field data collection protocol for the SIS baseline research study prior to the 2016 growing season. The goal of the SIS baseline study is to develop an accurate and defensible estimate of the water reduction from SIS. The pilot study lasted from August 3, 2015 to August 28, 2015. The research team tested the field data collection protocol on eight fields and will use the data for informational purposes only, and not as data points in the SIS baseline research study next year. The team partnered with IRZ Consulting (IRZ) for this pilot study, with IRZ conducting the field work and Navigant staff coordinating the overall study.

The team organized this memo into two sections: 1) an overview of the pilot study and 2) the lessons learned from the study. Below is a summary of the key lessons learned in the pilot study:

- **Field forms**. The research team made revisions to the field forms throughout the course of the study to improve organization and fluidity.
- **Equipment**. The research team encountered issues with setting up the pressure gauges during the initial site visits that will require minor additions to the field data collection protocol. The primary issues included a defective cord which postponed IRZ from launching the loggers and additional equipment needed for the setup of the pressure gauges.
- **Rain gauges**. Based on discussions with irrigation consultants throughout the study, the research team determined that real-time monitoring rain gauges may be a better solution than manual rain gauges. This topic will require additional deliberation between Navigant and stakeholders.
- **Crops requiring multiple irrigation strategies**. The study showed that some crops, primarily onions, require multiple irrigation strategies during the growing season. This requires multiple strategies to measure the actual water applied.
- **Drought**. The drought in the Pacific Northwest has had a significant impact on multiple pilot sites. Growers were forced to restrict their water use and shut off their irrigation much earlier than expected due to drought.
- **Equipment failures**. One of the pilot sites encountered a pump failure which impacted the amount of water that the grower applied to that field. The research team will work with stakeholders on how to account for equipment failures in the SIS baseline research study in 2016.

Overview of the Pilot Study

Navigant partnered with IRZ for the pilot study, with IRZ conducting the field work and Navigant coordinating the overall study. During the course of the pilot study, IRZ visited eight pilot sites between August 3, 2015 and August 28, 2015 to test the field data collection protocol prior to the 2016 growing season. Each of the sites received four field visits spaced one week apart: one initial visit, two follow-up visits, and one retrieval visit. IRZ installed the equipment during the initial visit and took three measurements of the water applied—one at each follow-up visit and one at the retrieval visit. The team had to replace one of the pilot sites at the start of the pilot due to the grower shutting off the water early due to drought. The research team worked with IRZ to identify pilot sites with varying irrigation system setups so that the team could test all of the approaches laid out in the protocol. Table 1 summarizes the sites that were included in the pilot study.

Table 1: Overview of pilot sites

Pilot Site	Irrigation Type	Crop Type	Approach for Water Use	Notes
Pilot 1	Center Pivot	Corn	Pressure Gauge	Lost one week of data due to pressure gauge equipment failure delays
Pilot 2	Center Pivot	Potato	Flow Meter	
Pilot 3	Drip System	Onion	Flow Meter	
Pilot 4	Wheel Line	Alfalfa	Rain Gauge	Did not apply much water during pilot due to a) pump failure and b) irrigation system intervals (two week interval between irrigation schedules)
Pilot 5	Center Pivot	Potato	Rain Gauge	Stopped watering right before pilot, replaced with Pilot 9
Pilot 6	Center Pivot	Alfalfa	Pressure Gauge	
Pilot 7	Drip System	Poplar	Rain Gauge	Lost one week of data due to pressure gauge equipment failure delays
Pilot 8	Center Pivot	Alfalfa	Rain Gauge	Grower cut back water use due to drought, rain gauge read 0 inches
Pilot 9	Center Pivot	Carrot	Rain Gauge	Replaced Pilot 5

Source: Navigant findings from pilot study

The team encountered the following hurdles during the course of the pilot study:

- A pressure gauge cord malfunction at pilot sites 1 and 7 prevented IRZ from launching the loggers for an entire week. This resulted in getting one less week of pressure gauge data for these sites.
- The drought primarily impacted pilot sites 5 and 8. Growers typically harvest their crops at the end of September or the beginning of October, but due to the drought and the water restrictions, the growers shut off their water earlier than normal and had to harvest their crops earlier than expected.
- There was a pump failure at pilot site 4, which impacted the data gathered by the rain gauge. The gauge only collected water application data for one of the three weeks of the study.

Lessons Learned

This section discusses the lessons learned throughout the course of the pilot study. These lessons will help inform the SIS baseline research study that will take place in the 2016 growing season. The research team was able to identify solutions for a few of the lessons learned during the course of the study; however, there are a few hurdles that will required additional deliberation with project stakeholders.

Field Forms

The research team remained in constant contact with IRZ concerning the effectiveness of the field forms, and made the following adjustments:

Location. The original forms contained two location questions: the field location and the current location. The field location required manual data entry by IRZ, while the current location was automatically populated using global positioning system (GPS) coordinates. The team decided to remove the field location question, eliminating the manual data entry, and pre-populate the field location information in the initial site visit form. The remaining forms (the follow-up visit form and the retrieval visit form) will use the current location field populated by the GPS.

Flow of the questions. Original forms had the arrival time and departure time in sequential order. IRZ requested moving the departure time to the end of the forms, after the quality control (QC) checklist, for ease of use.

Ultrasonic flow measurement form. Initially the ultrasonic flow measurement form did not have the name of the field tech, date, arrival time, and departure time, as the research team assumed IRZ would gather the measurements on one of the follow-up visits. Actual procedures had different teams taking the measurements on various days, so the team added the field tech name, date, arrival time, and departure time to the ultrasonic flow measurement form.

Add a description to the growing dates. Growers indicated that the names of the five key growing dates in AgWeatherNet were not meaningful, and required additional explanation during the closing interview. Navigant reworded the questions and added an information bubble to each of the questions to provide a description of the key dates. The research team also learned that the key growing dates for crops with multiyear growing periods, such as poplar trees, require the questions be worded in a slightly different way. The key dates in AgWeatherNet are for that growing season only, not for the entire growing period of a crop like poplar trees which can grow for up to 12 years before harvesting. The research team spoke with Troy Peters from Washington State University to get clarification about how the key growing dates apply to these crops and the team incorporated the information into the iPad data collection field forms.

Additional data requirements for harvested forages. During the pilot study, discussions with Troy Peters at Washington State University revealed that AgWeatherNet requires additional information to calculate the water requirement for harvested forages like alfalfa, grass hay, and mint, than other crop types. AgWeatherNet requires the dates of the cuttings, the number of days on average it takes for the crop to emerge from the ground after a cutting, and the number of days on average it takes for the crop to return to full growth after a cutting. Inputting the cutting dates and updating the default assumptions for the two growing periods creates a better fitting field model and more accurate water requirement estimates. The team added these questions to the iPad data collection field forms for harvested forage crop types.

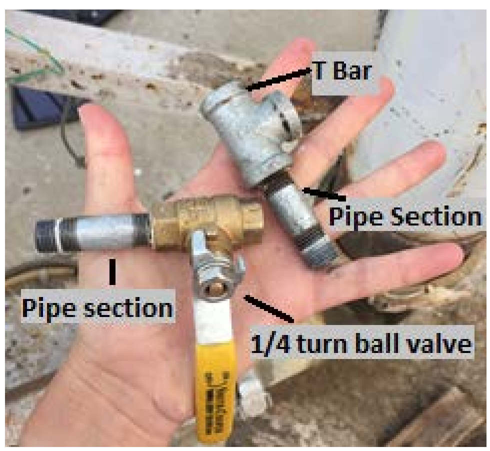
Equipment

IRZ discovered that installing the pressure gauge setups required additional equipment than originally planned. The team conducting the SIS baseline research study will install pressure gauge setups primarily on drip systems and micro-sprinklers. These systems typically have a one-quarter inch diameter port with a built in analog pressure gauge.

In order to test the installation of the pressure gauge setup onto these systems, IRZ needed to unscrew the pre-existing pressure gauge, install fittings (shown in Figure 1), reinstall the pre-existing pressure gauge, and install the pressure gauge setup. The team will incorporate the following equipment in the field data collection protocol: an assortment of pipe fittings, (including a one-quarter turn ball valve, pipe sections, and a T fitting), pipe dope to tighten the seal of the pressure gauge, and a wrench to take off the pre-existing equipment install the new equipment.

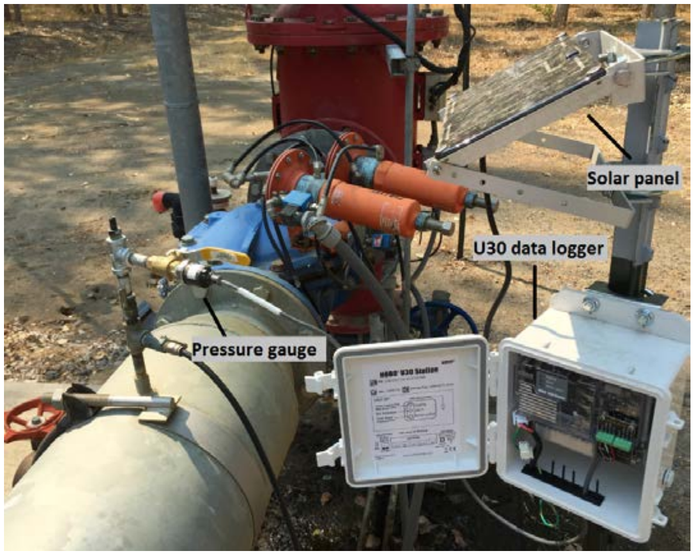
When initially installing the pressure gauge setups, IRZ had difficulty getting the HOBOware software to communicate with the U30 data logger, which caused a week delay in the installation. The issue ended up being a malfunctioning mini-USB cord, which IRZ replaced. The research team will make sure to account for equipment malfunction by ordering five percent more equipment than needed for the pressure gauge setups in case cords, loggers, pressure gauges, or solar panels malfunction. See Figure 2 for a picture of the installed pressure gauge setup.

Figure 1: Fittings required for the pressure gauge setup



Source: Navigant

Figure 2: Pressure gauge setup before takedown



Source: Navigant

Rain Gauges

The current field data collection protocol requires the use of manual rain gauges as the primary method for measuring the actual water use. Discussions with IRZ and an outside irrigation consulting company revealed that real-time monitoring tipping rain gauges may be a more viable option than the manual rain gauges. The real-time monitoring rain gauge is typically connected to a solar panel, which powers the data logger (either cellular or satellite) that sends the data in real time to a computer program. The real-time monitoring rain gauge setup has the benefit of the irrigation consultant only having to go on-site once a month versus weekly for the manual rain gauge. The real-time monitoring gauge also provides significantly more data points than the manual rain gauge, because it sends the rain gauge measurements in real time versus the manual rain gauge that provides one weekly measurement. The monthly checks on the real-time monitoring rain gauge ensure it has not been knocked over, tampered with, or clogged. Additional benefits of the real-time monitoring rain gauge include: reduced errors from manual data entry and reduced coordination of site visits.

The cost between real-time monitoring rain gauges and manual rain gauges are approximately the same if the field is located near the irrigation consultant's office. The further away the office is from the field increases the cost of visiting the manual rain gauges more often. The research team is still working with irrigation consultants and other stakeholders to determine which rain gauge method to use: real-time monitoring, manual, or a combination of approaches depending on the location of the fields.

Crops with Multiple Irrigation Strategies

During the study, the research team learned that some crop types, primarily onions, require multiple irrigation system strategies throughout the course of the growing season. For example, Pilot 3 shown in Figure 3 is an onion field where the grower uses a center pivot to irrigate the field until the onions mature, then switches to a drip system. This particular site had an integrated flow meter installed on the system; therefore, only one method would have been required to quantify the actual water applied during the growing season, because the flow meter tracks the usage of the drip system and the center pivot. If Pilot 3 didn't have an integrated flow meter, the team would have used a rain gauge for the center pivot, and a pressure gauge setup for the drip system. The team will incorporate these considerations into the recruitment calls, as well as, the field data collection protocol.

Figure 3: Pilot 3 with a drip system (black tube on ground) seen behind the onion

Source: Navigant

Drought

The 2015 drought significantly affected growers in the West, including the pilot sites. All growers interviewed said that the hot weather and lack of rain impacted their irrigation strategies. Growers in the Northwest typically harvest crops in late September or early October. This year's drought forced many growers to cut off water to their crops in late August and early September. When IRZ installed the rain gauge for Pilot 5, the grower shut off their water at the same time, so the team replaced the site with Pilot 9, a carrot field. In addition, the grower for Pilot 8 cut back their water use because of the drought and the rain gauge read zero inches of water applied during August.

Figure 4 shows a picture of the rain gauge at Pilot 8 with the dried up alfalfa in the background because the grower cut back their water.

The drought may be a reoccurring issue in the 2016 growing season when the full SIS baseline research study takes place. The research team will work with stakeholders on an approach for taking into account the drought prior to the start of the full SIS baseline research study.

Figure 4: Pilot 8 with a rain gauge reading of zero inches during the pilot

Source: Navigant

Equipment Failures

During the pilot study, the research team experienced two unanticipated equipment failures impacting Pilot 1, Pilot 4, and Pilot 7. The mini USB cord required to launch the U30 data loggers malfunctioned and required replacement. This resulted in a one-week delay in pressure data for Pilot 1 and Pilot 7. The team will be sure to test all cords going out in the field and include extra cords for field staff to avoid this issue in the future.

The team also experienced a pump failure at Pilot 4, which was unrelated to the pilot study. The pump providing water to that site failed, resulting in less water applied to the field than the grower expected. The rain gauge that IRZ installed, read water applied for only one of the three weeks of the pilot study period. Closing interview questions regarding unanticipated events impacting the grower's irrigation will collect data for these types of situations.

Prior to the SIS baseline research study in the 2016 growing season, the team will brainstorm the typical equipment failures that may be encountered throughout the study and how they may be accounted for in the analysis.

Appendix C – Lessons Learned from the 2015 Program Data Analysis

To: Carrie Cobb, Bonneville Power Administration (BPA)

From: Jeff McMillan, Emily Merchant, Ryan Tanner, Beth Davis, and Jane Pater Salmon, Navigant Consulting, Inc.

Date: March 15, 2016

Subject: Memo on 2015 Program Data Results and Lessons Learned

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This memo outlines the key lessons learned and preliminary results of Navigant Consulting, Inc.'s (Navigant's) data analysis on the scientific irrigation scheduling (SIS) program data for program year (PY) 2015. The purpose of analyzing the 2015 program data was to identify if it was sufficient for calculating water use ratios (WURs) for all SIS program fields in the 2016 SIS Baseline Study. If the 2015 data provides the necessary criteria, the Navigant team (the research team) would not need to conduct primary data collection activities in 2016 for SIS program fields.

The research team created the analytical framework required for calculating WURs for SIS program fields and coordinated with five SIS irrigation consulting firms to compile 2015 program data: IRZ Consulting (IRZ), Professional Ag Services (Pro-Ag), Irrinet, AgriNorthwest, and Soiltest. These five irrigation consultants plan to perform SIS services in PY2016 and will provide data to inform the research team's analytical framework for that program year. Therefore, it is important that the program data contain all of the necessary variables needed for a comprehensive analysis.

The research team used a data sample from each irrigation consultant and looked for variations in methodologies and differences in variables across the datasets. The team focused on how the consultants calculated WURs—the amount of water that reached the crop during the growing season divided by the amount of water the crop required—and whether any engineering bias existed based on crop type or other variables. Reviewing the 2015 data allowed the research team to create a thorough list of data requirements to ensure consistency in data collection for the 2016 SIS baseline study.

Following a summary of key findings, the research team organized this memo into three sections:

- Overview of the data collection and analytical framework
- Lessons learned from this analysis
- Results of the analysis

Summary of Key Findings

The following summary highlights the key issues and lessons learned as identified in the analysis. The research team sorted the findings in order of their impact on the accuracy of the results.

- **Limitations of the IS2.0 database:** BPA's IS2.0 database records all BPA energy efficiency projects at a high level, but due to limited project details in the database, the research team will rely on SIS consultant data to conduct the SIS analysis.
    - **Solution:** The research team will crosscheck the data from the irrigation consultants with utility records in the 2016 growing season to ensure the team has received a census of the program data.
- **SIS calculators:** The irrigation consultants tend to aggregate fields with identical properties into a single calculator run. The research team must receive data from the irrigation consultants at the field level instead of aggregated data for multiple fields.
    - **Solution:** The research team will request field-level data from the irrigation consultants for the 2016 growing season. The team has developed a standardized data collection spreadsheet in which irrigation consultants can submit their data.
- **Interpretation of key growing cycle dates:** The research team found that there could be potential differences in the way each irrigation consultant interprets the key growing dates.
    - **Solution:** The research team will communicate with the irrigation consultants to ensure that they understand the growing dates needed and that they record them consistently.
- **Calculation of actual water applied:** The irrigation consultants use different methods of calculating actual water applied and must be made aware of the difference between water leaving the irrigation system and water hitting the crops.
    - **Solution:** The research team will have a deep understanding of the different actual water applied methodologies used by the irrigation consultants and minimize of effect of consultant bias.
- **Standardizing terms in the data:** Consultants report many essential variables (such as crop type, soil type, and weather station) in the data using different names.
    - **Solution:** The research team will consistently categorize terms in the data so that equivalent variables are treated appropriately.
- **Required updates to AgWeatherNet:** The AgWeatherNet development team must complete several updates in order for the research team to calculate the water requirement for all program fields.
    - **Solution:** The research team will collaborate with AgWeatherNet developers to implement the necessary updates.

- **Limitations of the PY2015 results:** The research team conducted the 2015 program data analysis as closely as possible to how they will conduct the analysis for 2016, but the data lacks key dates for some fields, which makes the results for these fields less informative.
    - **Solution:** The 2015 program data analysis served a necessary function to inform the 2016 analysis, but the 2015 WURs produced by fields lacking growing dates should not be considered a realistic expectation for 2016 results.

Overview of Data Collection and Analytical Framework

The research team collected data from five irrigation consultants—IRZ, Pro-Ag, Irrinet, AgriNorthwest, and Soiltest—that performed SIS services in PY2015. The primary purpose of this data was to understand whether irrigation consultants currently collect the data required to calculate WURs for all fields for the 2016 SIS baseline study. The research team would not need to collect additional primary data if that were the case. The team first requested a small sample of fields from each consultant to check for consistencies in data variables and format and to help inform the analytical framework required for the analysis. The team then requested a census of all fields serviced in 2015 to complete the data analysis.

The program data came through in batches, requiring the research team to collaborate with the irrigation consultants to clarify calculation methods and ensure consistent interpretation of the data. The research team verified such variables as growing cycle dates, water application calculations, and field grouping assumptions used in SIS calculator runs.

The team attempted to use the IS2.0 database to verify quantities of SIS program acreage reported by each consultant and to determine the total acreage treated by the program in 2015. Unfortunately, the IS2.0 database did not include or report all of the variables required for the analytical framework. For example, the database lacked specific dates for SIS services— there was often a multi-year delay between the time the irrigation consultant completed the SIS field service and when that field appeared in the database. These discrepancies in the IS2.0 database caused the research team to rely more heavily on the 2015 field census data provided by the irrigation consultants. In total, the irrigation consultants provided data from 1,317 fields.

The research team sampled roughly 20 fields to include in the analysis from each of the irrigation consultant's datasets[1]. The field analysis included a total of 84 fields. The main obstacle found in the data sample was the lack of irrigation season start and stop dates, which are required for calculating accurate WURs. Therefore, the research team split the analysis into two parts:

1. Fields with accurate start/stop dates
2. Fields without accurate start/stop dates

The team noted that those with accurate dates would yield a more realistic WUR. The research team then reached out to the irrigation consultants to confirm that they accurately record growing season start/stop dates for PY2016. This will ensure reliable WURs for all fields included in the analysis.

[1] In cases where an irrigation consultant provided less than 20 fields, all available fields were included in the analysis.

Table 1 presents a summary of the results from the research team's analysis of a sample of fields from the 2015 SIS program data.

Table 1: Summary of Analysis Results

Accurate Growing Dates	Number of Fields	Acreage-Weighted WUR
Yes	37	1.07
No	47	0.64

Source: Navigant analysis

Lessons Learned

This section discusses the lessons learned from the 2015 SIS program data collection and analysis. These lessons will inform any process changes the research team makes prior to analyzing the 2016 SIS program data.

Limitations of the IS2.0 Database

The research team intended to use the IS2.0 database to crosscheck the data received by the irrigation consultants and ensure that the team had received a complete census of the data. Review of the data showed that the SIS-treated acreage in the IS2.0 database matched the irrigation consultant data for some fields but not others.

A BPA contact informed the research team that there is often a significant delay from the time a consultant completes an SIS project and when they submit it into the database. This delay between project completion and submittal to BPA is the primary issue and makes it impossible for the research team to separate out the IS2.0 data into specific program years. The database does track the submittal date but not the year the consultant provided SIS services for the field. This one factor limits the research team's ability to use the IS2.0 database as a crosscheck for the number of SIS program fields completed in a given program year.

This submittal delay can sometimes span multiple years and is primarily due to limitations in the utility's energy efficiency program budget. Lack of available incentive money can delay when a utility submits a project to BPA, so data from the same program year may appear in different fiscal years in the IS2.0 database.

As a result, the research team was not able to verify independently the number of fields each irrigation consultant submitted for PY2015 using only the IS2.0 database.

The BPA contact suggested reaching out to the utilities to crosscheck the totals from the irrigation consultants with the totals maintained by the utilities. The research team will use this approach when analyzing the 2016 program data.

Conclusion

The research team informed each of the irrigation consultants that they should submit a census of the SIS program fields completed in 2015. Although the team was not able to verify that the consultants did send all of their data, the research team plans to crosscheck quantities with the utilities for PY2016.

SIS Calculators

The irrigation consultants often combine or roll up multiple fields when performing SIS calculator runs. This can occur for fields with identical crop types, soil types, weather stations, growing dates, and so on. The research team intended to analyze each field individually to ensure accurate water requirement calculations and explicitly requested irrigation consultants provide data at the field level. This will prevent any potential misrepresentation of the data in the SIS calculators.

Conclusion

The research team created a data import template for the consultants to enter data into rather than use the consultant-provided SIS calculators. This ensures the data is at the field level and in a consistent format. The irrigation consultants are now familiar with this data collection template and will be more prepared to process it this way for the 2016 study.

Interpretation of Key Growing Cycle Dates

Growing cycle dates are important for calculating accurate WURs for each field. It is imperative that each consultant records these dates consistently because small differences in dates have significant impacts on the final results. There are five key growing dates:

1. Emergence date
2. Date the crop reaches 10% canopy cover
3. Date the crop reaches 70% canopy cover
4. Crop maturation date
5. End of growing season date

The research team realized that there could be differences in how the irrigation consultants interpret these dates, especially the date when the crop emerges. The research team was particularly concerned about this date since irrigation consultants often use it interchangeably with the planting date. The research team found the following variations in the irrigation consultants' interpretations of the emergence date: when the crop is planted, when the crop emerges, and when the water is turned on.

Conclusion

The research team expressed concern about the interpretation of the dates with the consultants, and there was a consensus that watering begins when the crop emerges from the ground. The team has edited the data import forms to be as explicit as possible in defining the key growing season dates so that all the consultants interpret them consistently.

Calculation of Actual Water Applied

Irrigation consultants normally track the amount of water applied to program fields using rain gauges. However, depending on the type of irrigation system used, the consultant could also simply take the farmers at their word for run-time hours and hourly output of the equipment. There is a possibility for self-reported bias from either the farmer or the equipment manufacturer, which would affect the final savings estimates. There is also a concern that the irrigation consultants may adjust the value of water applied depending on irrigation system efficiency or report the amount of water running through the irrigation system rather than the amount hitting the crops.

Conclusion

The research team communicated with each of the consultants to understand any possible differences in the way they calculate the water applied to a program field. The team made it clear that the irrigation consultants should only enter the amount of water actually hitting the crops into the data collection spreadsheet. Discussions with the irrigation consultants revealed that they all perform similar calculations for rain gauges, but the potential bias for collection methods besides rain gauges remains somewhat of a concern. Fortunately, this bias primarily affects drip or micro-sprinkler irrigation systems, which appear in less than 10% of all fields. This bias also affects both program and general market fields, so the research team will still be able to calculate the savings attributable to the SIS program because the bias should cancel out between the two populations.

Standardizing Terms in the Data

The irrigation consultants often use different terms for describing things such as crop names, soil type names, and abbreviations of weather station names. For example, it is not always obvious whether ryegrass, pasture, and grass are indeed the same crop. Since the research team conducts analysis programmatically, it is important to categorize group names correctly and consistently.

Conclusion

The research team built the analytical framework to notice the common and obvious name groupings and standardize their treatment. The team will confirm any vague or ambiguous names with the irrigation consultants or with secondary sources, such as AgWeatherNet experts.

Required Updates to AgWeatherNet

The research team encountered several obstacles using AgWeatherNet for the 2015 program data analysis. A select number of crop types do not appear in AgWeatherNet, and the AgWeatherNet website does not allow users to enter growing dates that span multiple calendar years. In addition, the AgWeatherNet user interface is not designed to calculate efficiently the water requirement for a large number of fields at once.

Conclusion

The research team is currently in communication with the developers of AgWeatherNet and is confident that resolutions to these obstacles will improve the analysis for PY2016. To fix these issues, the AgWeatherNet team is working to add additional crops to their system that are in the SIS program but not currently available for analysis. They are addressing the issue of restricting dates to a single calendar year, as well as implementing a way to bypass the normal website user interface to allow the research team to automate data downloads.

Limitations of PY2015 Results

The research team approached the analysis of the 2015 data as if it was a full program analysis, but there were significant gaps in the data, which prevented an accurate WUR calculation for all program fields.

- **Missing data:** The data provided by the irrigation consultants was missing key variables for many of the SIS program fields, including the beginning and end dates of the growing season. These dates are necessary for understanding exactly when the farmer applied water to the fields, so it is impossible for the research team to determine whether the actual water applied met the water requirement.
- **Time-intensive data effort:** The research team was unable to calculate a water requirement for all 1,317 fields because AgWeatherNet requires users to enter each field individually, which is a time-intensive process. The research team selected a sample of fields from each consultant for analysis in AgWeatherNet. The team then separated fields most likely to produce an accurate WUR from those that would not. It is worth noting that approximately half of the calculated WURs are below expectation because the dates in the growing season were not available.
- **Potential bias across irrigation consultants:** There may also be bias in the WURs from each irrigation consultant due to variations in water requirement calculations. This bias will not affect the ability to calculate program savings in PY2016 because the research team will standardize the water requirement calculation methods for both program and general market fields. This bias may still influence program savings, however, if a particular consultant calculates the water requirement in such a way that advises farmers to use significantly more or less water than other consultants would.

Conclusion

The research team analyzed 84 fields, 37 of which contained actual key growing cycle dates. The research team did not receive actual key growing cycle dates from all of the irrigation consultants; therefore, the research team will ensure that all of the irrigation consultants track this information in 2016. In addition, the WURs varied across irrigation consultants, which could be due to how each company calculates the water requirement for each of the fields. This bias will not affect the ability to calculate program savings in PY2016 because the research team will standardize the water requirement calculation methods for both program and general market fields.

Data Analysis Results

This section provides a brief description of the methods used to calculate the field-level WUR as well as the analysis results for all analyzed fields and the subset of fields with accurate growing season dates.

Analysis Method

The research team compiled data on crop types, soil types, and weather stations from each of the irrigation consultants. The consultants were unable to provide growing season dates for most fields, so the research team generated typical growing season dates through AgWeatherNet for each field based on crop type, soil type, year, and weather station. The team found that these typical growing season dates are not accurate enough to produce realistic WURs, but the fields with these dates were included in the analysis to simulate the process of analyzing a larger sample of sites.

The first step in the analysis was to enter each field into the AgWeatherNet system using the field ID, crop type, soil type, year, weather station, and growing dates, if they were available. AgWeatherNet then generated a table of daily data for the entire growing season. The research team then fed the data into Equation 1 to calculate the water requirement for each field.

Equation 1: Water Requirement

$$\text{Water Requirement} = \sum_{\text{Season}} \left[\text{Reference ET}_{\text{Daily}} * \text{Crop Coefficient}_{\text{Daily}} - \text{Effective Rainfall}_{\text{Daily}}\right]$$

Where:

- $\text{Effective Rainfall}_{\text{Daily}} = \text{Space Left in Root Zone}_{\text{Daily}}$ ***if*** $\text{Precipitation}_{\text{Daily}} > \text{Space Left in Root Zone}_{\text{Daily}}$
- $\text{Effective Rainfall}_{\text{Daily}} = \text{Precipitation}_{\text{Daily}}$ ***if*** $\text{Precipitation}_{\text{Daily}} < \text{Space Left in Root Zone}_{\text{Daily}}$
- $\text{Space Left in Root Zone}_{\text{Daily}} = \frac{\text{Field Capacity}_{\text{Daily}} - \text{Water Storage at MAD}_{\text{Daily}}}{2}$

The research team used the R coding language to calculate Equation 1 and to estimate the seasonal water requirement for each field based on data generated in AgWeatherNet. The team then compared the actual water applied data to the water requirement data using the field ID. The irrigation consultants supply the actual water applied metric. The research team then used the water applied and the water requirement values to calculate the field-level WUR in Equation 2.

Equation 2: Field-Level Water Use Ratio

$$\text{Water Use Ratio}_{\text{Field}} = \frac{\text{Water Applied}}{\text{Water Requirement}}$$

In order to determine how accurate the default growing dates were, the research team split the fields into distinct groups based on their date type. This resulted in the following two groups:

- Fields with actual growing dates
- Fields with default growing dates

The research team calculated the group-level, acreage-weighted WURs using Equation 3.

Equation 3: Group-Level Water Use Ratio

$$\text{Water Use Ratio}_{\text{Group}} = \sum_{\text{Fields}} \left[\text{Water Use Ratio}_{\text{Field}} * \frac{\text{Acreage}}{\sum_{\text{Fields}}[\text{Acreage}]}\right]$$

Analysis Results

Using the methods described, the research team obtained the results shown in Table 2.

Table 2: Summary of Analysis Results

Actual Growing Dates	Number of Fields	Acreage-Weighted WUR
Yes	37	1.07
No	47	0.64

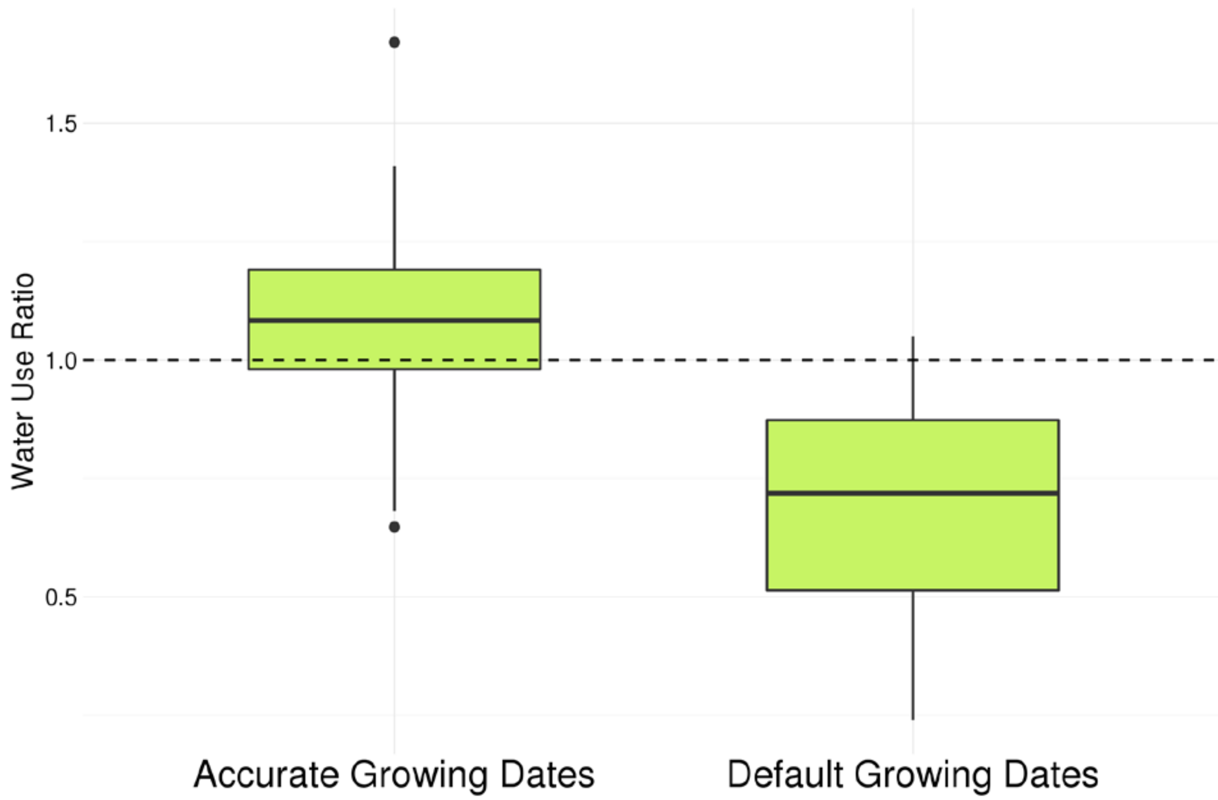
Source: Navigant analysis

Based on Table 2, it is clear that the default dates do not produce a realistic WUR. The fields with default dates yielded WURs much lower than what the research team expects with accurate dates. The weighted average WUR for fields with accurate dates was 1.07, which is in line with realistic expectations, although on the higher end of the expected range.

Upon comparing the length of the growing season with actual dates to the length of the growing season with the default dates, the research team found that the growing season tended to be significantly shorter for the actual dates. This could be a result of the drought that the research team observed during the pilot analysis in 2015. The growers might have expected water restrictions and compensated by accelerating the growing season and harvesting earlier than they would have otherwise. This could explain the small WURs for fields with default dates because farmers likely applied the water over a lesser number of days than expected by AgWeatherNet; therefore, the water requirement appeared much larger than it would have with accurate dates. This demonstrates the importance of receiving accurate growing season dates for the 2016 analysis.

Figure 1 compares the distribution in WURs for fields with accurate growing cycle dates and fields using default growing cycle dates from AgWeatherNet. As one can see in the figure below, knowing the actual key growing cycle dates of the crops has a significant impact on the WUR, which is why it is important for the research team to avoid using default assumptions in AgWeatherNet for the key growing cycle dates.

Figure 1: Comparing WURs for Fields with Accurate Key Growing Cycle Dates and Fields with Default Key Growing Cycle Dates from AgWeatherNet



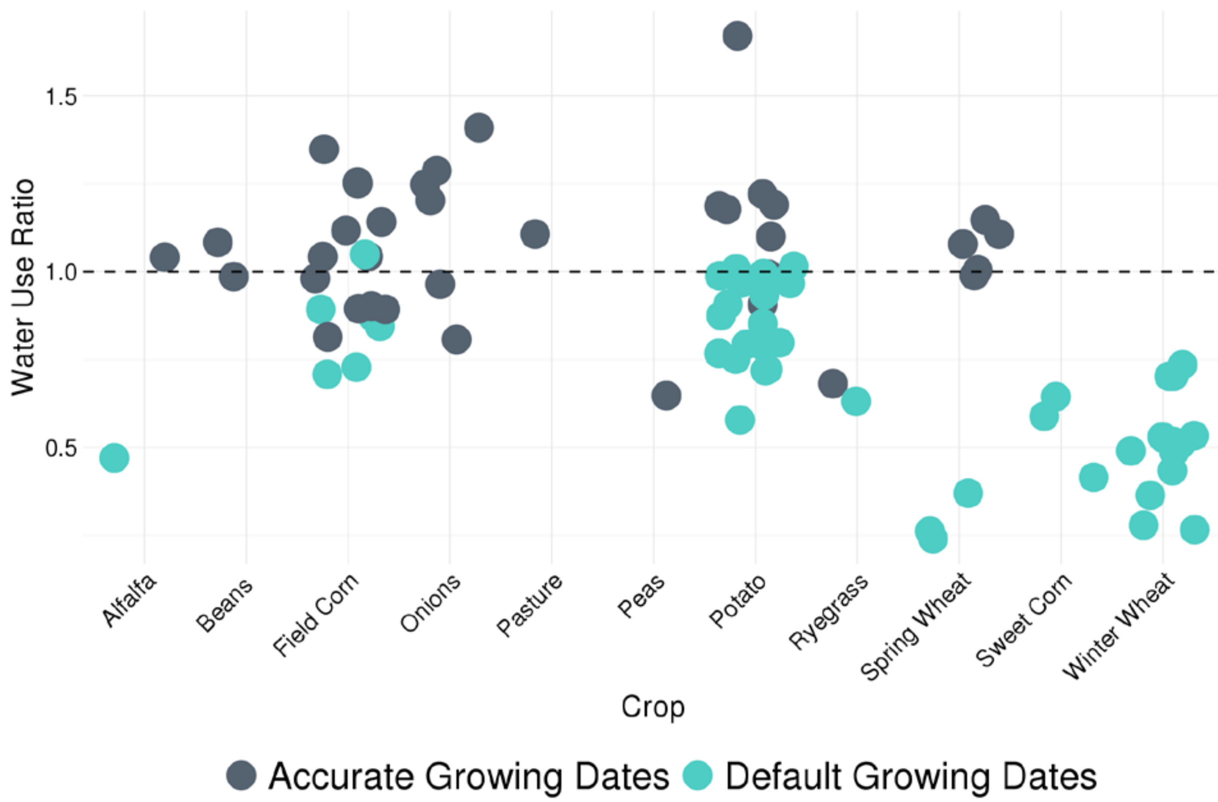
Source: Navigant analysis of SIS Program Data

Note: The dotted line indicates the point where water applied is equal to water required. Disjointed points indicate outliers.

The research team looked at specific crops to see if there were any biases across crop type. The crop type influences which irrigation system type is used, and the irrigation system type often determines which method is used to measure the water applied. Comparing WURs across different crops is a way to investigate possible biases of non-rain-gauge data collection methods or other crop-specific factors.

Figure 2 below compares the WURs by crop type for fields with accurate key growing cycle dates (dark blue dots) and fields with default key growing cycle dates from AgWeatherNet (light blue dots).

Figure 2: Comparing WURs by Crops with Accurate Key Growing Cycle Dates (Dark Blue Dots) and Fields with Default Key Growing Cycle Dates in AgWeatherNet (Light Blue Dots)



Source: Navigant analysis of SIS Program Data

Spring and winter wheat appear significantly lower than other crops, but it appears that a main driver is that wheat crops heavily represented the fields with default dates. Peas and ryegrass produced WURs that were smaller than expected. There is only one sample point for peas and ryegrass in the current set of data; therefore, the sample is too small to draw conclusions. The research team will monitor the possible bias between crops in PY2016.

Appendix D – Sample Design, Approach, and Selection

To:	Carrie Cobb, Bonneville Power Administration (BPA)
From:	Emily Merchant and Beth Davis, Navigant; Elizabeth Daykin, Cadeo Group
Date:	May 18, 2017
Subject:	SIS Baseline Research Study: Sample Design, Approach, and Selection

This memorandum summarizes the sample design and sampling approach for the Scientific Irrigation Scheduling (SIS) Baseline Research Study. It includes a discussion of the process and assumptions that went into the sample design, the final distribution of the sample and the population, and the sample selection process used to determine the fields for data collection.

The primary goal of the research study is to determine the percent water reduction between the general market fields and the SIS program fields. To calculate this reduction, Navigant and Cadeo (the research team) took the difference between the water use ratio of the general market fields and the water use ratio of the SIS program fields. The general market is made up of three field study categories: fields receiving SIS services and an incentive (SIS program fields), fields receiving SIS services but not receiving an incentive (SIS non-program fields), and fields not receiving SIS services (non-SIS fields). The water use ratio is equal to the water applied to the field divided by the optimal amount of water required by the field as determined by an irrigation scheduling software.

To determine the water use ratio of the general market, the research team designed a sampling approach to target 250 total fields for data collection across the three field study categories. The team chose this sample size to target results that would allow it to discern a 10% difference between the water use ratio of the SIS program fields and the general market at the 90% confidence level (two-tailed), assuming a coefficient of variation (CV) of 0.80 and a representative sample. To calculate the water use ratio of the SIS program fields, the research team needed to sample 44 SIS program fields. However, due to data availability, the team achieved a near census, i.e. approximately 100 percent, of the fields that participated in the 2016 SIS program (i.e., 1,286 fields).

Ultimately, data was collected from a total of 1,508 fields, with the sample target achieved for all field categories except non-SIS fields, where data was collected from 182 fields as compared to the target of 183 fields due to recruitment limitations and removing fields from the study due to equipment malfunction. The research team weighted the results from the 1,508 fields included in the analysis based on the estimated percentage of the market comprised by each field study category. The target and achieved sample counts, along with the estimated population percentage for each field study category, are shown in Table 1 and described in further detail below.

Table 1: General Market Sample Goal and Actual Sample Size

Field Study Category	Estimated Population Percentage	Estimated Sample Size to Meet Sample Design	Actual Sample Size
SIS Program Fields	17.9%	44	1,286
SIS Non-Program Fields	9.3%	23	40
Non-SIS Fields	72.9%	183	182
Total	**100.0%**	**250**	**1,508**

Source: Research team analysis

Sample Design

There are several important characteristics to consider when developing any sample design. The design for the SIS Baseline Research Study consists of three primary considerations:

- Metric of greatest interest to the study
- Necessary statistical rigor of the results
- Analysis weightings

The research team discusses these components of the sample design in the sections below.

Water Use Ratio

During the development of the sampling methodology and in the data analysis phase later in the study, the research team collected and presented data in terms of a water use ratio. The water use ratio is the most important metric in this study because it allows the research team to compare fields to each other because the water use ratio is a unitless metric that removes field size from the equation. The team calculates this ratio as the actual water used on the field for irrigation divided by the optimal amount of water required by the crop. In this way, the water use ratio provides a normalized metric of the relative efficiency of how the grower is irrigating their field. A field using the optimal amount of water will have a water use ratio of 1.00; a field using more than the optimal amount of water will have a water use ratio greater than 1.00; and a field using less than the optimal amount of water will have a water use ratio less than 1.00.

After considering several metrics, the research team decided to use the water use ratio as the primary study metric to promote consistency and clarity in the statistics reported throughout the SIS Baseline Research Study. Using a ratio allowed the research team to:

- Maintain the fidelity of collected primary data by tracking water use values that both exceed or fall short of optimal usage amounts
- Create a normalized metric that can be compared easily across fields and groups, regardless of field sizes
- Promote ease of study findings communication by using a metric that is common and well understood in the energy efficiency community

- Generate greater predictability in the study outcomes by creating more stability in the ratio of the standard deviation of the data to the mean of the data (CV)—similar to the application of a realization rate

This last point is worth discussing in greater detail, as both the CV and relative precision are frequently used calculations that include the estimated average in the denominator of a fraction. Thus, the way in which the research team compiled the estimate can have a great impact on the value of the CV and relative precision, even when the raw data is the same. Whether deviation from optimal water use is presented in percent form or ratio form, the same information is being conveyed. The uncertainty, as measured by the standard deviation, is the same in either scenario. However, presenting the primary study metric as a water use ratio makes the statistical variability, CV, and precision far less dependent on the actual outcome of the study. Additionally, the water use ratio metric is much easier to apply to findings outside of the SIS Baseline Research Study, which benefits the changing energy efficiency needs of the region.

Statistical Rigor

As stated above, the research team determined that the most statistically appropriate representation of the deviation from optimal water usage is a ratio of actual water use to optimal water use. With the primary metric of interest determined, the team was then able to develop the key components of the sample design based on the desired statistical rigor of the results. These components are summarized below.

- **Level of confidence:** To ensure the study findings are robust and valuable to regional decision makers, the research team chose a target level of **90% confidence** for the sample design, which is the standard statistical confidence in energy efficiency evaluations. The team utilized a **two-sided confidence interval** when presenting the results of the study. The rationale for this choice is that the primary research question is whether there is a difference in the water use ratio for SIS program fields as compared to the market baseline, without necessarily assuming the direction of any difference.
- **Desired level of precision:** For this study, the targeted level of precision for the sample is answering the question, *"How small of a difference in water use ratios between SIS program fields and the market baseline do we want to be able to discern with confidence?"* The research team refers to this difference between the two water use ratios as the delta, the measure of which is synonymous with the measure of absolute precision. The team determined that measuring the delta, or precision, in absolute terms would provide greater stability to the statistical design and analysis of the SIS Baseline Research Study and would also provide results that are more applicable to regional irrigation planning and forecasting of energy and water savings. Since the goal of the study is to determine whether there is a difference in water use ratios, the aim should be for the precision to be as low as possible given the analysis techniques and available budget. In consultation with BPA and other stakeholders, **the research team determined that the sample would be designed to detect a difference of at least 0.10 (or 10% absolute precision)**.
- **Assumed CV:** In general, there is relatively little information available to set expectations regarding the amount of variability that one can expect in the water use ratio sample. A previous study performed by Quantec in 2005 found CVs ranging between 1.00 and 1.09 depending on

how the population is viewed.[1] However, the research team had some concerns about the randomness of the selected sample in the Quantec study, so the CV may not be directly applicable to the SIS Baseline Research Study. Anecdotal evidence suggests that irrigation practices have generally improved over the last decade, which may have a downward impact on the variability of the data. Based on professional judgment, the research team utilized a **CV of 0.80** in the sample design.

With the primary sampling characteristics determined, the research team was then able to calculate the number of fields needed in the sample to achieve the desired targets. The formula for the sample size requirement, as a function of standard deviation and sample mean, is as follows:

Equation 1: Sample Size Requirement

$$n \geq \left(\frac{t * \sigma}{\Delta}\right)^2$$

Where:

n =	the sample size required
t =	the t-score based on a normal distribution corresponding to 90% confidence, depending on the degrees of freedom (~1.645)
σ =	the population standard deviation (based on the assumed CV and an educated guess of the market baseline water usage ratio of 1.20)
Δ =	the desired precision level or delta of 0.10

Note that the research team has already accounted for the sample size normalization in squaring the right-hand side of the equation. The team utilized this equation to calculate that it needed a total sample size of 223 to achieve the desired statistical results, assuming the sample was representative of the distribution of the population across the field study categories of interest and that the other assumptions discussed previously were met. However, the research team decided to increase the target sample size by an additional 12%, to 250 total fields, to account for the possibilities of faulty data or a somewhat non-representative sample. The final target sample sizes for each field category are shown in Table 2.

[1] A Study of Irrigation Scheduling Practices in the Northwest, Part II: Measurement of Water and Electricity Impacts (Quantec), 2005.

Table 2: Target Sample Size

Field Study Category	Target Sample Size
SIS Program Fields	44
SIS Non-Program Fields	23
Non-SIS Fields	183
Total	**250**

Source: Research team analysis

The sample sizes shown in Table 2 were weighted based on the population percentage of the three field study categories of interest to the SIS Baseline Research Study: SIS program fields, SIS non-program fields, and non-SIS fields. Fields in the first two categories utilize SIS irrigation practices. SIS program fields do so through participation in the BPA SIS program, whereas SIS non-program fields utilize SIS techniques even though they are not involved in the program. In contrast, non-SIS fields are not known to utilize any SIS techniques in their irrigation practices. The next section describes the derivation of the estimated population percentages that lead to the distribution of the study sample.

Analysis Weighting

The research team aggregated the results from the three field study categories to determine the water usage of the general market. However, the data gathered by the research team is not representative of the population of fields in the market, by design. This is primarily because the team selected a sample of SIS non-program fields and non-SIS fields for data collection, but due to the availability of data from regional irrigation consultants, data from a census of all SIS program fields was analyzed instead of a sample. Including data from all SIS program fields in the analysis significantly increased the confidence and precision of the water use ratio of SIS program fields and the market baseline. However, it also required that the research team weight the results to ensure the calculated market baseline water use ratio was representative of the actual regional population.

Since the population frame for the irrigated fields in the region is unknown, the research team needed to estimate the proportion of the population that falls into each of the three categories of interest: SIS program, SIS non-program, and non-SIS. As a proxy, the team utilized a random geospatial sampling technique (described in greater detail in the General Market Sampling Approach section). Ultimately, this sampling technique led to 700 unique fields[2] on which the research team collected basic characteristics regarding the fields' irrigation techniques and crop type. Since these fields were selected randomly without any known bias associated with irrigation techniques, the category proportions demonstrated by these 700 fields are assumed to be representative of the population at large. The number of fields in each

[2] In total, the research team selected 735 fields using this random geospatial technique; however, 35 fields were eliminated from this weighting exercise due to field duplication or growers deciding to not irrigate their field in 2016. Additionally, the team was unable to collect information on 99 of the 700 fields regarding their irrigation practices. For the purposes of weighting, the research team placed these fields into the non-SIS category because they were confident that more than 50% of these fields were likely to be non-SIS. The regional irrigation consultants (IRZ and ProAg) stated that if these fields were utilizing SIS techniques, they would likely be aware. Given that, including these 99 fields as non-SIS fields in the weighting would introduce less bias than if these fields were excluded entirely from the weighting due to a lack of information.

category is shown in Table 3, which demonstrates the assumption that 27.2% of the population utilizes SIS, with 17.9% of the population doing so within an SIS program.

Table 3: Assumed Population Percentages in Each Study Category

Field Study Category	Number of Fields in Category	Estimated Population Percentage
SIS Program Fields	125	17.9%
SIS Non-Program Fields	65	9.3%
Non-SIS Fields	510	72.9%
Total	**700**	**100.0%**

Source: Research team analysis

The research team used the percentages in Table 3 to weight the water use ratio results from each of the three field study categories to aggregate them together to form a general market water use ratio.

Sampling Approach and Selection

The research team used a geospatial sampling technique to select the sample for the study. This section details the general market sample, the general market sampling approach, and the SIS program sample.

General Market Sample

The purpose of the general market sample is to provide a comparison of the water applied for the general market to the water applied of the SIS program fields so the research team can determine the percent water reduction from the presence of the SIS program. The general market is intended to be representative of the population, and it encompasses all three field study categories (SIS program, SIS non-program, and non-SIS). The main goals of the general market sample frame were that it was random, large enough to meet the sample design, and representative of the population. Table 4 shows the general market sample size goal and the actual sample size. The results from the actual sample size was weighted to reflect the portion of the total sample that each field study category represents.

Table 4: General Market Sample Goal and Actual Sample Size

Field Study Category	Estimated Sample Size to Meet Sample Design	Actual Sample Size
SIS Program Fields	44	1,286
SIS Non-Program Fields	23	40
Non-SIS Fields	183	182
Total	**250**	**1,508**

Source: Research team analysis

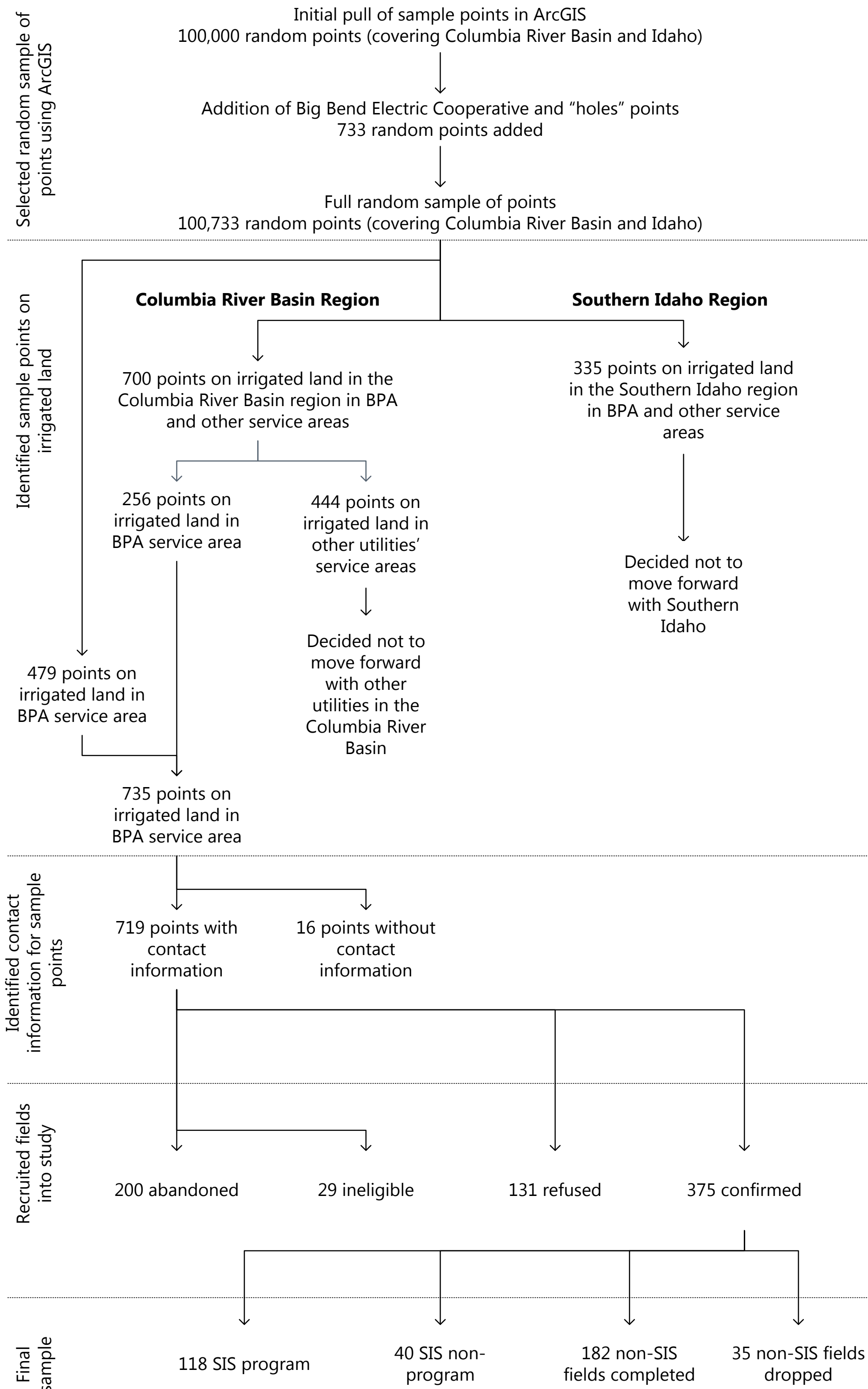
Figure 1 shows the sample selection process used for the general market sample, starting with selecting random points on irrigated land and ending with the final sample achieved. As shown below, the research team sampled 10,733 random points in the Columbia River Basin and Idaho using an ArcGIS sampling tool. From those points, the team worked with irrigation consultants to determine the points on irrigated land, which resulted in 735 points in the Columbia River Basin. Southern Idaho decided to opt out of the study at this point in the process; therefore, the research team did not move forward with identifying contact information for the 335 points on irrigated land in Southern Idaho. The research team moved forward with the recruitment phase with 735 fields, all of which were in the Columbia River Basin.

The next step was to have the irrigation consultants contact the fields on irrigated land to see which growers were interested in participating in the study. The irrigation consultants identified contact information for 719 of the 735 points on irrigated land and then began the recruitment process. The 735 identified fields fell into the following categories:

- **Abandoned:** Fields that the irrigation consultants were unable to get ahold of to participate in the study, either because the research team did not have contact information or the research team made contact but did not get ahold of the contact
- **Ineligible:** Fields that were not on irrigated land or do not use a pressurized irrigation system
- **Refused:** Fields that refused to participate in the study
- **Confirmed:** Fields that were interested in participating in the study

Out of the 375 fields that agreed to participate in the study, the research team ended up with data for 182 non-SIS fields, 40 SIS non-program fields, and a near census of the SIS program fields. The research team recruited 118 SIS program fields to participate in the study, but ended up getting the data directly from the irrigation consultants, which allowed the team to obtain a near census of the 1,200-plus fields that participated in the 2016 SIS program. The research team also worked directly with the irrigation consultants to obtain the data for the sampled SIS non-program fields. The non-SIS fields were the only sample group where the team worked with the irrigation consultants on a real-time basis to obtain the data. Of the 217 non-SIS fields confirmed to participate in the study, the research team collected data for 182 of the fields. The team removed 35 non-SIS fields from the study due to equipment malfunction, growers tampering with the equipment, and stolen equipment.

Figure 1: Process for Achieving the General Market Sample



Source: Research team analysis

General Market Sampling Approach

The research team used a geospatial sampling approach to select the general market sample for the study. As part of this sampling effort, the team took the following steps:

1. Tested a proposed sampling approach
2. Defined the final study boundaries
3. Identified sample points on irrigated land
4. Developed participation scenarios for each region
5. Chose a participation scenario
6. Identified contact information for irrigated fields in the Columbia River Basin study region

The *SIS Baseline Research: Field Selection and Recruitment Plan* also discusses the plan for the sampling approach and much of the text below overlaps with the recruitment document. The text below provides additional detail regarding the research team's final approach.[3]

A field randomly selected to participate in the study via the random sampling process outlined below is known as a general market field and includes SIS program, SIS non-program, and non-SIS fields. The research team worked with irrigation consultants to install equipment in the non-SIS fields only. The team aimed for a near census of the SIS program fields and intended to collect data for as many SIS non-program fields as possible. At the beginning of the 2016 growing season the research team sent the irrigation consultants a spreadsheet with the data points that the team would request from the consultants at the end of the growing season for the SIS program and SIS non-program fields. The analysis was weighted appropriately to account for sampling the non-SIS fields and over-sampling the SIS program and SIS non-program fields. The following sections describe the research team's sampling approach steps in detail.

Step 1: Conducted a Pilot to Test Proposed Sampling Approach (December 2014–January 2015)

The research team conducted a sampling approach pilot with BPA and IRZ Consulting (an irrigation consultant) to assess the proposed sampling approach's feasibility. The research team conducted the pilot with two BPA utilities: Umatilla Electric Cooperative and Franklin PUD. Specifically, the team assessed the ability to select and identify 50 fields on irrigated agriculture land and then assessed the feasibility to gather contact information for those fields.

As part of the pilot, the research team selected sample points using ArcGIS. The team generated random sample points within a defined layer on a map using the ArcGIS *Sampling Design Tool.*[4] The ArcGIS *Sampling Design Tool* provided latitude and longitude coordinates of selected sites with the associated utility (based on utility area shapefiles from Ventyx).

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[3] FINAL - SIS Baseline Field Selection and Recruitment Plan (Navigant), 2015. https://conduitnw.org/Pages/File.aspx?rid=2919

[4] The research team used the area-based sampling approach where random points are generated within a polygon. Details are located here: http://www.arcgis.com/home/item.html?id=ecbe1fc44f35465f9dea42ef9b63e785 (accessed December 7, 2016).

The research team created two layers for two study regions: Columbia River Basin and Southern Idaho. The Columbia River Basin layer included the 13 utilities listed below (including nine BPA utilities) for the geographies of interest, which included Washington and Oregon. The Southern Idaho layer included the seven utilities listed below (including five BPA utilities) for the geography of interest in Idaho. The BPA utilities either currently offer or may offer their customers an incentive for implementing SIS. At this point in the study, the research team included all utilities that would potentially participate in the study, realizing that some utilities might not participate or some portions of utility areas would be excluded in the final study boundaries.

Columbia River Basin Layer

- BPA Columbia River Basin utilities:[5]
    - Benton County PUD No. 1
    - Columbia Basin Electric Cooperative, Inc.
    - Columbia Rural Electric Association
    - Umatilla Electric Cooperative
    - Wasco Electric Cooperative
    - Milton Freewater
    - Klickitat PUD
    - Franklin PUD
    - Benton Rural Electric Association
- Other utilities:[6]
    - PacifiCorp
    - Idaho Power
    - Avista
    - Grant County PUD

Southern Idaho Layer

- BPA Idaho utilities:[7]
    - Fall River Rural Electric
    - Raft River Electric Coop
    - United Electric Cooperative
    - Riverside Electric Coop
    - South Side Electric
- Other utilities:[8]
    - PacifiCorp

[5] Oregon Trail Electric Cooperative was eligible to participate but was not interested in offering incentives; thus, it is not included in the study. Big Bend Electric Cooperative was added at a later time; see text under Step 2.
[6] The study was only completed in BPA Columbia River Basin utility regions; thus, these utilities were not included in the final sample.
[7] The study was not completed in the Southern Idaho region; thus, these utilities were not included in the final sample.
[8] The study was only completed in BPA Columbia River Basin utility regions; thus, these utilities were not included in the final sample.

- o Idaho Power

The randomly generated sample points were located on various types of land, (e.g., roads, rivers, buildings, agricultural land, and forest service land). As not all sampled points in either the pilot study or the overall study would qualify to participate in the study,[9] the research team started with many initial sample points (100,000 points) to ensure irrigation consultants had enough fields to recruit into the study.

After discussing the pilot results with BPA and other key stakeholders, the research team deemed the pilot successful and decided to move forward with the approach for the full study. The team captured lessons learned and refined the selection and recruitment plan based on the pilot's outcomes.

Step 2: Defined the Final Study Boundaries (April 2015–May 2015)

After the success of the pilot, the research team moved forward with the large-scale sampling, starting with defining the final study boundaries. At this point in the study, the team prepared for the study to take place in both Idaho and the Columbia River Basin (Washington and Oregon). The research team met with BPA staff to draw the study boundaries for both regions. These boundaries were within the larger layers discussed in Step 1, except for the addition of Big Bend Electric Cooperative and two small regions (referred to as holes), which the team describes in more detail below. The research team received confirmation to proceed with the study boundaries from BPA on May 7, 2015.[10]

Columbia River Basin Study Boundary. The Columbia River Basin study boundary included the northeastern portion of Oregon and the southeastern portion of Washington. The boundary, shown in Figure 2, attempted to include only visible irrigated land area within the territories of the BPA Columbia River Basin utilities listed below. It also included some portions of the non-BPA (i.e., "other") utilities listed below that fall within the boundary. The boundary excluded two regions with no visible irrigated land (one cut out near the text "PacifiCorp" and another cutout near the text "Umatilla Electric Coop"). The boundary also included two additional holes that were added back in to the boundary during this step. The details of the holes are discussed in the text below.

BPA Columbia River Basin Utilities

- Benton County PUD No. 1
- Columbia Basin Electric Cooperative, Inc.
- Columbia Rural Electric Association
- Umatilla Electric Cooperative
- Wasco Electric Cooperative
- Milton Freewater
- Klickitat PUD
- Franklin PUD
- Benton Rural Electric Association
- Big Bend Electric Cooperative[11]

[9] Reasons include not on irrigated agriculture land, no contact information available, and non-response.
[10] Email from Kevin Geraghty (BPA) to Beth Davis (Navigant) on May 7, 2015.
[11] See note on the addition of Big Bend Electric Cooperative in the text in this section.

Other Utilities

- PacifiCorp
- Avista
- Grant County PUD

Figure 2: Columbia River Basin Study Boundary (Blue Outline)

Notes: The imagery comes from Esri, DigitalGlobe, GeoEye, i-cubed, U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS), AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. The research team drew the blue outline based on a call with Tom Osborn, Dick Stroh, and Kevin Geraghty.
Source: Utility polygon created by the research team using a Ventyx utility shape file.

Southern Idaho Study Boundary. The Southern Idaho study boundary included irrigated land in Southern Idaho between the western border with Oregon and the eastern border with Wyoming to provide a representative sample of irrigated land in Southern Idaho. The boundary, shown in Figure 3, sought to include only visually identifiable irrigated land area within the territories of the BPA Idaho utilities listed below. It also includes portions of the non-BPA utilities listed below that fall within the boundary.

The boundary excluded consistently (year-over-year) water-short regions.[12] It also excluded utilities that

[12] Though the research team took this approach for the Southern Idaho Study Boundary, the study did not move forward in Idaho; thus, this approach is not relevant to the overarching study.

do not serve agricultural customers.

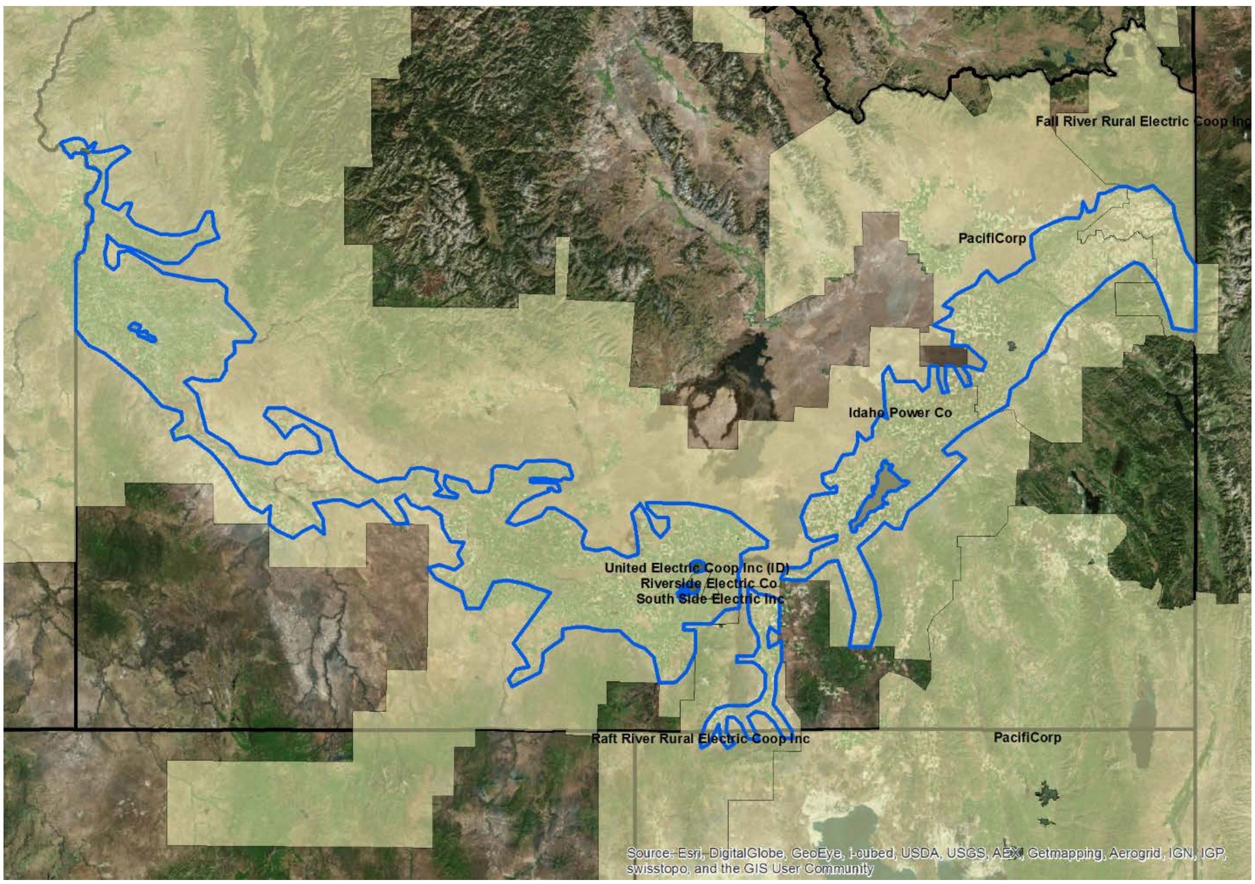
BPA Idaho Utilities

- Fall River Electric Coop
- Raft River Electric Coop
- United Electric Coop
- Riverside Electric Coop
- South Side Electric

Other Utilities

- PacifiCorp
- Idaho Power

Figure 3: Southern Idaho Study Boundary (Blue Outline)



Notes: The imagery comes from Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. The research team drew the blue outline based on a call with Tom Osborn, Dick Stroh, and Kevin Geraghty.
Source: Utility polygon created by the research team using a Ventyx utility shape file.

Addition of Big Bend Electric Cooperative and holes. BPA requested the research team add the Big Bend Electric Cooperative to the study after the team conducted the sampling approach pilot. There were also a few holes within the research boundaries initially excluded because they did not appear in any utility territory per the Ventyx maps. BPA requested the research team include these holes in the boundary. Therefore, the research team added Big Bend Electric Cooperative and eliminated the holes to produce the full sample frame. Due to overlap with other utility areas, most of Big Bend Electric Cooperative's region was included in the pilot; therefore, the team only needed to add Big Bend Electric Cooperative's southern area into the sample. To maintain the integrity of the original set of 100,000 sample points, the research team pulled additional sample points for the excluded area of Big Bend Electric Cooperative and the holes. The team then assigned a random number to those points within the same ranges as the first sample but with additional digits (e.g., 10.185844, 105.290394). The new sample was then inserted into the original sample based on the random number (e.g., 10.185844 would go in between sample point 10 and 11 of the original sample). The following steps were taken to change the boundaries and update the sample points:

1. **Filled in gap areas in Columbia River Basin region.** To do this, the research team first established the average sample density per square mile of the original sample. The team then clipped a new Big Bend partial polygon and a new holes polygon to fill in the gaps.
2. **Populated sample points for gap areas in the Columbia River Basin.** The research team calculated the area of the new Big Bend partial polygon and the new holes polygon and then generated new random points for the areas. The team then joined the new random points to the Ventyx data to pull in all associated utility data to the points. Note: the holes points have no utility data because they do not appear in any utility territory per the Ventyx data.
3. **Created a final merged sample dataset.** The research team clipped the 100,000 Columbia River sample points to the new polygons of interest, then joined the clipped points to the Ventyx data to pull in all associated utility data for the points.
4. **Conducted a quality control check.** The research team verified five latitude and longitude values in Google Earth to ensure that points in known locations (such as the middle of a river) appeared in the locations the team expected them to be.
5. **Generated an Excel file of the data.** The completed file of sample points contained the following datasets:
    - All previously pulled sample points clipped to those points that fell within the Columbia River study boundary
    - 697 new sample points within a previously excluded polygon in Big Bend Electric territory
    - 36 new sample points within a previously excluded polygon with no assigned utility, titled holes
6. **Merged the new samples from Big Bend and the holes into the larger Columbia River Basin sample set.** The research team generated random numbers between 0.0000 and 99,999.0000 using 10189 as the seed number to assign each data point a random number as its new unique ID. The team then merged the new data points with the larger file and sorted by unique ID. This ensured that the new points were incorporated into the full sample in a random order.

Step 3: Identified Sample Points on Irrigated Land (May 2015–June 2015)

The research team worked with irrigation consultants[13] to identify which sample points fell on irrigated land, which is a study requirement. The irrigation consultants reviewed each point to determine whether each field was on or off irrigated agriculture land. The goal was to identify 700 points on irrigated land in the Columbia River Basin and 335 points on irrigated land in Southern Idaho based on assumed success rates for identifying contact information, recruiting fields into the study, and an estimated buffer for the sample.[14]

The research team used Google Earth to perform quality control checks on 10% of the field assignments to ensure that the irrigation consultants had consistently designated points as on and off irrigated agriculture land. The team then sent the sample to BPA, which BPA approved on June 25, 2015.[15]

Step 4: Developed Participation Scenarios for the Columbia River Basin Boundary and the Southern Idaho Boundary (June 2015)

Using the sample from the previous step, the research team developed participation scenarios for each region. The team developed these scenarios so other utilities would have an estimate for the study cost if they wanted to include their regions. One important caveat to the participation scenario results relates to the uncertainty in the scenario tables caused by estimating utility assignments using Ventyx maps of utility service areas, which could contain errors.

- **Columbia River Basin Participation Scenarios.** There were eight possible utility participation scenarios for utilities in the Columbia River Basin. Each scenario represented a different combination of study participants: BPA, Grant County PUD, PacifiCorp, and Avista. Table 5 presents the approximate distribution of sample points across participating utilities for each possible combination of participants. Using Scenario 1 in Table 5 as an example, the 12% share for Avista reflects the fact that if Avista participated, the number of potential sample points in its territory would represent 12% of the goal of 700 sample points.

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[13] IRZ Consulting and Franklin Conservation District, both irrigation consultants, assisted with this step.

[14] Assumptions included an estimate that the research team would be able to identify contact information for 85%-90% of irrigated land points and that 66% of contacts would decline to participate. At this time, the non-SIS sample size was estimated at 200 points for the Columbia River Basin and 100 points for Southern Idaho.

[15] Approval via email from Kevin Geraghty (BPA) to Nicole Reed Fry and Beth Davis (Navigant) with Carrie Cobb (BPA) and Jane Pater Salmon (Navigant) on copy.

Table 5: Columbia River Basin Participation Scenarios

Scenario	BPA	Avista	PacifiCorp	Grant County PUD
Scenario 1	36%	12%	19%	33%
Scenario 2	76%	24%	DNP	DNP
Scenario 3	66%	DNP	34%	DNP
Scenario 4	52%	DNP	DNP	48%
Scenario 5	55%	17%	28%	DNP
Scenario 6	45%	14%	DNP	41%
Scenario 7	41%	DNP	21%	38%
Scenario 8	100%	DNP	DNP	DNP

Note: DNP = Does not participate
Source: Research team analysis

- **Southern Idaho Participation Scenarios.** There were four possible utility participation scenarios for utilities in the Southern Idaho region. Each scenario represented a different combination of study participants: BPA, Idaho Power, and PacifiCorp. Table 6 illustrates the approximate distribution of sample points across participating utilities for each possible combination of participants in Southern Idaho.

Table 6: Southern Idaho Participation Scenarios

Scenario	BPA	Idaho Power	PacifiCorp
Scenario 1	7%	78%	16%
Scenario 2	100%	DNP	DNP
Scenario 3	8%	92%	DNP
Scenario 4	30%	DNP	70%

Note: DNP = Does not participate
Source: Research team analysis

Step 5: Chose a Participation Scenario Based on Responses from Utilities (July 2015–November 2015)

The research team and BPA held a call with the utilities in July 2015 to discuss the scenarios. After discussions with BPA and the research team, no utilities other than the BPA utilities participated in the study. Therefore, the research team chose Scenario 8 for the Columbia River Basin Participation (Table 5). Due to the low amount of irrigated agriculture in the Southern Idaho region that fell in BPA's territory, BPA decided to not complete the study in Southern Idaho; thus, the research team did not use any of the scenarios for Southern Idaho.

As only BPA utilities participated in the Columbia River Basin, the research team had to complete Step 3 (identify sample points on irrigated land) again to identify additional points that fell only in the BPA utility regions to have a large enough sample from which to identify contact information and recruit fields into the study. The team ultimately identified 735 points on irrigated land, in the Columbia River Basin boundary, and assigned to a BPA utility. This was 35 more points than the goal due to one irrigation consultant identifying more points than originally assigned. However, this allowed for a larger buffer for contact identification and recruitment.

Step 6: Identified Contact Information for Irrigated Fields in the Columbia River Basin (July 2015–November 2015)

Once the research team chose the scenario and identified points on irrigated land, the irrigation consultants[16] identified the owner/main contact for the sampled fields. The team provided the latitude, longitude, and assigned utility of each irrigated agriculture location to the consultants who then identified farm name and contact information, if available.

The research team asked the irrigation consultants to obtain the following information for each field:

- Farm name
- Main contact name
- Main contact phone number
- Owner name
- Owner phone number
- Owner email
- Main contact email

Of the 735 sample points on irrigated land in the Columbia River Basin boundary and assigned to a BPA utility, the consultants identified contact information for 719 points.

The research team then provided latitude, longitude, and the farm name to utilities for sample points in their respective service territory. Utilities had the option to utilize their internal processes to confirm the points were within their utility service territory. If the utility was unable to identify some of the points as customers in their territory, the team assigned these contacts to an irrigation consultant to ask the grower for their utility during the recruitment call. The utility was also confirmed during the field work.

The research team then assigned the points to irrigation consultants to recruit growers for the study. The irrigation consultants completed the initial recruitment and final confirmation with the growers.[17] The recruitment information is provided in the *SIS Baseline Research: Field Selection and Recruitment Plan memo.*[18]

SIS Program Sample

Since the goal of the study is to determine the percent water reduction between the SIS program fields and the general market fields, the research team needed to select a sample of fields that participated in the 2016 SIS program. To achieve the required confidence and precision targets for the SIS program sample, the team needed to sample 44 SIS program fields. However, due to the availability of data from the irrigation consultants, the research achieved a near census of the 2016 SIS program fields. At the end of the 2016 growing season the team sent a data request to the five irrigation consultants that

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[16] Irrigation consultants who assisted with this step included IRZ Consulting, Professional Ag Services, Inc., Irrinet, and Principle Ag.

[17] Irrigation consultants who completed this step included IRZ Consulting, Professional Ag Services, Inc., Irrinet, and Principle Ag.

[18] FINAL - SIS Baseline Field Selection and Recruitment Plan (Navigant), 2015. https://conduitnw.org/Pages/File.aspx?rid=2919

participated in the 2016 SIS program. The research team received data for 1,286 fields from four of the irrigation consultants that participated in the 2016 SIS program, including data from the irrigation consultants with the largest number of fields participating in the SIS program. Therefore, the research team estimates it received data for about 98% of the 2016 SIS program fields.

Appendix E –
Field Selection and Recruitment Plan

Contributors

Developed by Nicole DelSasso, Rachel Baron, Beth Davis, and Jane Pater Salmon, Navigant

Developed for the Bonneville Power Administration

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Table of Contents

Introduction

This memo outlines the strategy to select and recruit growers in the Pacific Northwest to participate in the scientific irrigation scheduling (SIS) baseline research. The approach builds on previous steps in this planning process, which included defining the SIS-eligible population and developing a sample strategy. Stakeholders may review this memo in conjunction with the Field Data Collection Protocol memo for a more comprehensive view of the study logistics.

The goal of the SIS baseline study is to develop accurate and defensible estimates of water reduction resulting from SIS and the corresponding reduction in energy use. SIS helps growers determine how much water to apply to crops based on factors such as crop type, evapotranspiration (ET), and precipitation. The Navigant research team will develop water reduction estimates by measuring the water use and water requirements of a representative sample of irrigated lands (including farms using SIS), and comparing those to the water use and water requirements of farms receiving an incentive for participating in a SIS program. The research team has updated the plan upon completion of the stakeholder feedback period in June 2015.

The first part of this memo will reference the 2014 Field Selection Pilot conducted by Navigant in collaboration with BPA and IRZ Consulting, an irrigation consultant. The pilot influenced the development of the Field Selection and Recruitment process outlined herein. The second part of this memo discusses roles of partners in the study and outlines a detailed five-step recruitment approach.

2014 Field Selection Pilot

The research team conducted a pilot to assess the feasibility of the field selection and recruitment plan. The research team conducted the pilot with IRZ Consulting and two BPA utilities: Umatilla Electric Cooperative and Franklin PUD. The pilot tested the ability to select and identify 50 fields on irrigated agriculture land and gather contact information for those fields. The team captured lessons learned and refined the selection and recruitment plan based on the outcomes of the pilot.

Value of Study to Utilities and Growers

The ability to solicit and maintain active engagement from utilities and their grower customers will determine the success of this study. This section outlines the value proposition to each of them.

***Value to Utilities*:** The study provides an opportunity for utilities to strengthen customer relationships and generate positive exposure with growers. Utilities have the opportunity to enhance the dialogue with their customers by providing them with information about this study and using the results to inform future SIS program opportunities for their customers.

Value to Growers: At the end of the study period, participating growers that do not have SIS services will be provided with the data collected at their field during the study.[1] The report will inform growers about how much water they applied to their field during the season compared to how much water the field required. This information will let growers know if there is an opportunity to save water and energy by switching to SIS.

Roles of Partners

The success of the field selection and recruitment plan relies on the cooperation and participation of utilities, irrigation consultants, growers, BPA, and the research team. For example, all partners will need to engage in an initial webinar and training session at the beginning of the study so that all partners are informed of the coordination among teams. Transparent communication with the research team regarding progress and any obstacles encountered throughout recruitment will ensure success. This section presents the roles that each of those groups will need to play to achieve project success.

Role of Utilities: Utilities will play an important role in the success of this study. Utilities will be asked to verify that the selected points are within their territory, and they will be given the option to support recruitment by notifying growers of the study.

Role of Irrigation Consultants: Irrigation consultants will be subcontractors to the research team and will assist with field identification, recruitment, scheduling, and collecting data via site visits throughout the 2016 growing season. In particular, the irrigation consultants will use GIS or other mapping applications to determine which random sample points are located on irrigated agriculture land. The consultants will then identify the field name and contact information for as many sampled fields as possible. Irrigation consultants will also recruit growers into the study and schedule all site visits.

Role of Growers: Growers who are sampled, eligible, and agree to participate in the study will provide irrigation consultants access to the sample field throughout the 2016 growing season, on a regular basis (weekly to monthly, dependent upon water measurement method). In cases where growers already practice SIS on the field, the research team will ask the grower for access to their SIS data and the grower will give permission to the irrigation consultant to provide that data to the research team.

Role of BPA: BPA will approve the field selection and recruitment plan, and serve as the main conduit between the research team and the utilities. BPA will work with the research team to ensure that the selection and recruitment process is robust and maximizes value to key partners.

Role of the Navigant Research Team: The research team will facilitate regular communication with the project team and partners, and will ensure all parties have the information and resources needed to successfully fulfill their respective roles in the study. In addition, the research team will generate the initial random sample selection and will work with irrigation consultants to identify contacts for the points on irrigated agriculture land. The research team will then provide utilities with the coordinates and associated farm name (when available) to verify the coordinates fall within the utility's territory.

[1] Providing this report at the end of the study rather than during the growing season is important to determining an accurate baseline. Providing the report during the season may result in growers changing their watering practices during the study, obscuring the true baseline.

Additionally, the research team will provide utilities with materials to support their individualized outreach efforts. The research team will also attend and lead an initial webinar with utilities to introduce the study and enlist support in notifying growers, lead a recruitment training, and host other meetings that relate to field selection and recruitment.

Field Selection and Recruitment

This section outlines the steps involved in selecting and recruiting growers to participate in the SIS baseline study. The team will use a five-step approach:

- ***Step 1: Select sample points.*** The research team will use the ArcGIS *Sampling Design Tool*[2] to select randomized latitude and longitude points within a defined layer on a map.
- ***Step 2: Identify sample points on irrigated land.*** The research team will work with irrigation consultants to identify which sample points fall on irrigated land.
- ***Step 3: Identify the grower.*** The research team will enlist irrigation consultants to identify growers' contact information and utility for each randomly selected location.
- ***Step 4: Review sample points and notify growers of study.*** The research team will provide the utilities with the latitude and longitude coordinates and farm name (if available) for each irrigated land point to confirm that each grower is a customer of the assigned utility. During the notification phase, utilities will notify growers of the study utilizing the communication materials provided to utilities by the research team.
- ***Step 5: Enroll growers in study.*** Irrigation consultants will enroll growers in the study, first by recruiting growers to participate, and second by scheduling field site visits.

An overview of the field selection and recruitment plan steps, and the partners involved in each step is depicted in Figure 1.

[2] Sampling Design Tool (ArcGIS 10.0). http://www.arcgis.com/home/item.html?id=ecbe1fc44f35465f9dea42ef9b63e785

Figure 1. Partners involved in each step of the Field Selection and Recruitment Plan

RECRUITMENT PROCESS (Steps 4–5)

PLAN STEPS	STEP 1: Select sample points	STEP 2: Identify sample points on irrigated land	STEP 3: Identify the grower	STEP 4: Review sample points and notify growers of study	STEP 5: Enroll growers in study
PARTNERS					
Utilities				X	
Irrigation Consultants		X	X		X
Growers					X
BPA					
Navigant	X	X	X		

Source: Navigant 2015

Field Selection

The fields selected to participate will be placed in one of two populations: SIS program fields or general market fields. The process of classifying these distinct sample populations will be further discussed in detail in Step 5: Enroll Growers in Study.

1. ***SIS program fields.*** An SIS program field is defined as a field that will be participating in a utility sponsored SIS program during the 2016 growing season. Rather than collecting data by directly visiting growers that are currently participating in a utility sponsored SIS program, the team intends on receiving data via irrigation consultants and from the utilities or BPA. The BPA SIS calculator may not contain all the necessary data points. Other data will need to be either requested from irrigation consultants directly or requested through the utilities as part of the 2016 program requirements. This approach will provide the necessary data for a census of SIS program participants.

2. ***General market fields (baseline).*** A general market field is defined as a field that is randomly selected to participate in the study via a random sampling process outlined below. These fields may consist of SIS participants receiving a utility incentive, SIS participants not receiving a utility incentive, and fields that are not receiving SIS services.

Step 1: Select sample points

The team will follow a random spatial sampling approach to select fields into the study. The benefit to this approach is that each latitude/longitude point has an equal chance of selection. Since larger fields cover more land area, those fields have a better chance of selection. The random sampling approach will provide a representative sample of farms throughout the Pacific Northwest.

The research team will start by generating random sample points within a defined layer on a map using the ArcGIS *Sampling Design Tool*. The team will create two layers for the two different study regions: Columbia Basin and southern Idaho. The Columbia Basin layer will include ten BPA and four other utilities listed below for the geographies of interest, which include Washington and Oregon. The southern Idaho layer will include five BPA and two other utilities listed below for the geography of interest in Idaho. The BPA utilities either currently offer or may offer their customers an incentive for implementing SIS.

For this draft, the team has included all utilities that may participate in the study, realizing that some utilities may decide not to participate. The utilities outlined below are included in this draft of the sample frame. Once the sample points are drawn, Navigant will provide BPA with the percentage of the total sampled population that falls within each non-BPA utility. The research team will then work with the utilities to confirm their participation.

Details of the study boundaries are outlined in Appendix B and include maps of the defined areas.

Columbia Basin Layer

- BPA Columbia Basin Utilities:
    - Benton County PUD No. 1
    - Columbia Basin Electric Cooperative, Inc.
    - Columbia Rural Electric Association
    - Umatilla Electric Cooperative
    - Wasco Electric Cooperative
    - Milton Freewater
    - Klickitat PUD
    - Franklin PUD
    - Benton Rural Electric Association
    - Big Bend Electric Cooperative
- Other Utilities:
    - PacifiCorp
    - Idaho Power
    - Avista
    - Grant County PUD

Southern Idaho Layer

- BPA Idaho Utilities:
    - Fall River Electric Coop
    - Raft River Electric Coop
    - United Electric Coop

- Riverside Electric Coop
- South Side Electric

- Other Utilities:
  - PacifiCorp
  - Idaho Power

The team has attempted to draw the layers to only cover irrigated land; however, the random points will likely be located on various types of land (e.g., roads, rivers, buildings, agricultural land, and forest service land). Since the team will exclude points from the study that are not on irrigated land, the research team will start with a large number of initial sample points (100,000 points). This will ensure that utilities have a sufficient number of fields to recruit into the study after the research team selects and identifies the fields. Of the large initial sample, the research team estimates that roughly 250 points in the Columbia Basin will be study participants. Other details will affect the final number, including the number of sample points receiving SIS services, whether other utilities opt to participate in the study, and the final size of the Idaho study region.

The ArcGIS *Sampling Design Tool* will provide latitude and longitude coordinates of randomly selected sites along with the associated utility based on the utility area shapefiles from Ventyx. Appendix A contains a visual to illustrate the ArcGIS Sampling Design Tool.

BPA requested that Big Bend Electric Cooperative be added to the study after the research team conducted the pilot of this approach. Therefore, the team added Big Bend Electric Cooperative to the Columbia Basin layer to produce the full sample. Due to overlap with other utility areas, a majority of Big Bend Electric Cooperative's region was included in the pilot; therefore, the research team only needed to add the southern area of Big Bend Electric Cooperative into the sample. To maintain the original sample's integrity, the research team pulled additional sample points for the excluded area of Big Bend Electric Cooperative. The team then assigned a random number to those points within the same ranges as the first sample, but with additional digits (e.g., 10.185844, 105.290394). The new sample was then be inserted into the original sample based on the random number (e.g., 10.185844 would go in between sample point 10 and 11 of the original sample).

Step 1 Pilot Result: The research team was able to pull 100,000 random sample points in ArcGIS from the layer of all utilities.

Recommendation: Based on these results, the research team recommends using this selection approach for the full study.

Step 2: Identify sample points on irrigated land

Appendix A contains an example output from the ArcGIS Sampling Design Tool. The research team has added columns to the ArcGIS output spreadsheet to be completed by the irrigation consultants. The additional columns indicate the coordinates that fall on irrigated agricultural land. At the top of the spreadsheet, the number of irrigated points is identified (Irrigated Ag Points: XX). The goal is also shown (Goal: XXX). The irrigation consultant identifies points on irrigated land sorted by the random sample, from top to bottom of the list, until the Irrigated Ag Points number equals the Goal. The research team will exclude points on non-agriculture land from the sample. The research team will use Google Earth to perform quality control checks on 10% of the field assignments to ensure that the irrigation consultants have correctly designated points as on or off irrigated agriculture land. The team will then use the USDA cropscape maps for any points that are difficult to determine in Google Earth.

Step 2 Pilot Result: IRZ was able to identify whether points were on or off irrigated land using this method.

The research team extracted the 2,013 random sample points from two pilot utilities, Umatilla and Franklin, out of the initial sample of 100,000 points. The research team provided these points to IRZ and instructed the consultant to stop after the consultant identified 50 points on irrigated agriculture land. The irrigation consultant reviewed 331 random points in order to identify 50 points on irrigated land (15% hit rate).

The research team performed quality control checks on 10% of the field assignments (33 points) and determined that 32 out of 33 points were identified correctly (97% success). When the research team and IRZ reviewed the results the team learned that the one missed point was identified using an older GIS layer. IRZ then incorporated the new layer and was then able to identify the last point. The QC process revealed that using an updated GIS layer provides more accurate results and IRZ will use this new GIS layer going forward.

Recommendation: Based on these results, the research team recommends using this approach for the full study.

Step 3: Identify the grower

Once the research team receives and confirms the list of irrigated field sample points, the irrigation consultants will identify the owner/main contact for the field. The research team will provide the latitude, longitude, and assigned utility of each irrigated agriculture location to irrigation consultants who will then identify farm name and contact information, if available. The research team estimates that the irrigation consultants will be able to identify approximately 85% of the sites selected.

The team will ask the irrigation consultants to complete the following information for each field:

- Farm name*
- Main contact name*
- Main contact phone number*
- Main contact email
- Owner name
- Owner phone number
- Owner email

The items with a * are key fields to be collected during the grower identification phase. All information will be necessary if the grower agrees to participate in the study and will be collected upon enrollment.

Step 3 Pilot Result: IRZ successfully identified main contact names and main contact phone numbers for nearly all of the 50 sample points.

To test the third step, the research team provided IRZ with latitude and longitude coordinates for 50 random points in Umatilla and Franklin PUD territories (28 and 22 points, respectively). IRZ was able to provide phone numbers for all 50 fields (100% success rate) and a main contact person for 47 fields (94% success).

Recommendation: Based on these results, the research team recommends using irrigation consultants to identify contact information for the random sample points in the other utility territories for the full study. While the irrigation consultant's information proved very successful for the pilot, the research team cannot confirm the accuracy of the information provided by the consultant. There is no way to verify the contact information until the utilities or irrigation consultants call the growers during the recruitment phase of the project.

The research team will adhere to specific data handling protocols regarding the handling of all grower information. The following protocols are the recommended security architecture for personally identifiable information (PII) and other sensitive information, and will be followed during this study:

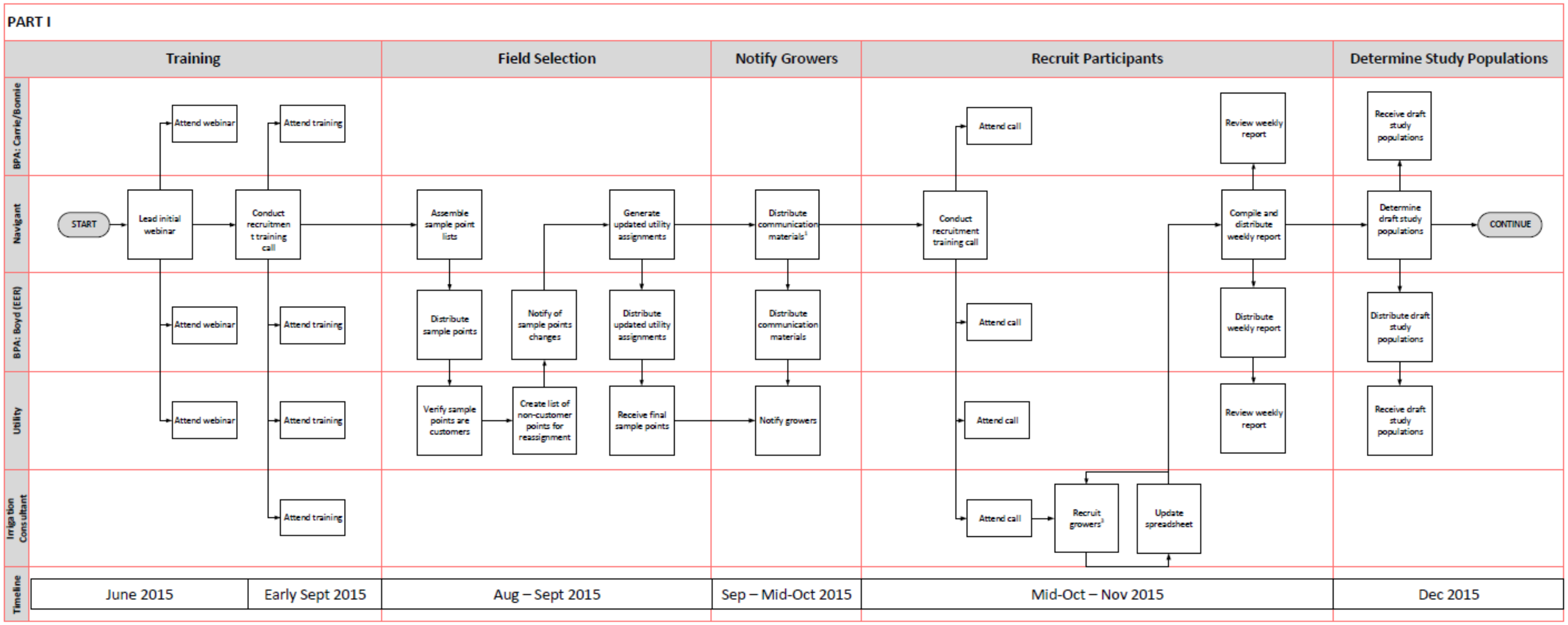
> ***Navigant's NavCloud server.*** The research team will use Navigant's Data Center hosted environment to share any grower information within Navigant. This secure cloud tool has increased security and user-specific access to keep non-project personnel from being able to access files and data. The research team will use restricted shared folders on office servers for project-related information instead of e-mail. If e-mail has to be used to transfer a file, the research team will encrypt all client-sensitive attachments using an encrypted WinZip, or other Navigant-approved archive software. The archive password has to be transferred using a phone call or a separate email.
>
> ***Secure FTP Transfer.*** The research team will use secure FTP file transfer to exchange any PII information outside of Navigant.

Recruitment

The research team has allotted time in the process for utilities to notify growers about the study and encourage them to participate. While utilities play an important role in notifying growers of the study, each grower will interact with an irrigation consultant who will request and confirm the grower's participation, enroll growers in the study and coordinate the site visits.

The research team has developed a two-part process flow diagram that details the steps involved in the recruitment process. These are outlined in Figure 2 and Figure 3 below. Part I of the process flow diagram depicts the process for utilities to notify growers of the study and irrigation consultants to enroll participants. Part II of the process flow diagram depicts the process for irrigation consultants to schedule and visit sites.

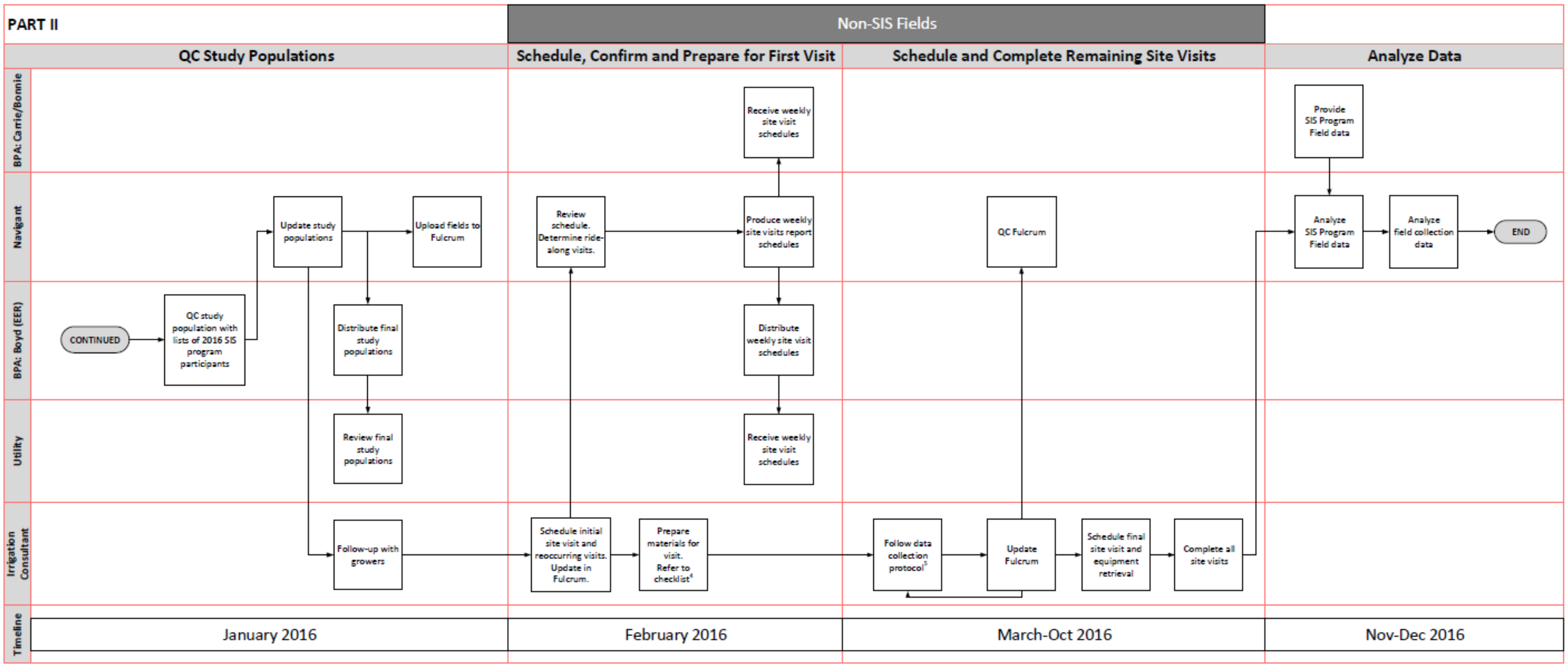
Figure 2: Process for Utilities to Notify Growers of Study and Irrigation Consultants to Enroll Participants[3]



1. **Communication Materials:** Packet of materials used by utilities in conducting outreach to growers. Packet contains an email template, flyer, FAQs and a process flow diagram.
2. **Recruitment Materials:** Information irrigation consultant needs to recruit growers to participate. Materials include a call script, FAQs, recruitment tracker, and flyer.
3. **Recruit Growers:** Process for irrigation consultants to call or email growers to request their study participation.
4. **Fulcrum:** Online tool used for participant management, accessed via a secure site.
5. **Initial Site Visit Checklist:** One-page document outlining everything the irrigation consultant will need to prepare for the first visit.
6. **Data Collection Protocol:** Document detailing how to collect data at each site visit.

[3] Boyd Wilson will be the primary point of contact between the research team and the utilities. All communications will flow through Boyd. While not depicted here, Tom Osborne and Dick Stroh will also be involved in all communications where appropriate.

Figure 3: Process for Irrigation Consultants Schedule and Visit Sites



1. **Communication Materials:** Packet of materials used by utilities in conducting outreach to growers. Packet contains an email template, flyer, FAQs and a process flow diagram.
2. **Recruitment Materials:** Information irrigation consultant needs to recruit growers to participate. Materials include a call script, FAQs, recruitment tracker, and flyer.
3. **Recruit Growers:** Process for irrigation consultants to call or email growers to request their study participation.
4. **Fulcrum:** Online tool used for participant management, accessed via a secure site.
5. **Initial Site Visit Checklist:** One-page document outlining everything the irrigation consultant will need to prepare for the first visit.
6. **Data Collection Protocol:** Document detailing how to collect data at each site visit.

Step 4: Review coordinates and notify growers of study

Prior to utilities notifying growers of the study, the research team will provide utilities with a list of sample GPS coordinates, associated farm name (where known) and utility. Utilities will be asked to review the sample and identify growers that are not their customers. The list will be modified by Navigant and a final list of growers will be distributed to the utilities. If the utility is unable to identify customers with the provided information, irrigation consultants will call the field contact and confirm their utility.

Utilities will have a month and a half from September – mid October to notify growers of the study through their preferred means of communication. The research team has designed communications materials to assist utilities with this outreach to the grower. For example, the research team has designed an informational flyer, FAQs, and an email template that the utilities can provide to growers to validate the study and provide further information. When the research team provides utilities with the communication materials, the team will also identify the irrigation consultant has been assigned to that utility. See Appendix D for communication templates.

Step 4 Pilot Result: Franklin was able to confirm whether or not each point was located in Franklin's utility territory. However, nine of the 22 points were not located in Franklin's territory. Umatilla confirmed that some points assigned to their utility were not located in Umatilla's service territory, though their systems and the data format were not compatible.

The research team sent the irrigation consultant's spreadsheet to Umatilla and Franklin PUD for them to provide additional contact information. Franklin identified the basic field type (e.g., pivot, orchard, vineyard, or wheel line) for all 22 points assigned to them. In addition, Franklin provided information on the parcel number and confirmed whether the identified fields were located in their utility territories. However, Franklin could only confirm that 13 of the 22 points were located within their service area. The utility representative provided customer account numbers for those 13 points.

The low success rate identifying the utility may be due to the small size of Franklin's territory. When the sample points are located on smaller utility territories, there is a higher probability that those points are located on or near a territory border, as opposed to points located in larger utility territories with a higher area to perimeter ratio. Therefore, the research team expects a higher success rate identifying the associated utility territory for the full study that includes larger utilities.

Lessons Learned: The utility shapefiles from Ventyx do not appear to be the best source of utility service area boundaries. Shapefiles from BPA or the utilities could improve the research team's identification of the utility for each field; however, it does not seem feasible to get shapefiles from these sources.

Recommendation: The research team recommends continuing to use the Ventyx shapefiles for the utility boundary estimation, based on discussions with BPA. These are likely the best approximation of utility service area. The study will rely on confirmation from utilities that the location is a within their service area and the assigned utility is the most appropriate utility to make contact. If the utility is unable to identify some of the growers as customers in their territory, the research team will assign these contacts to an irrigation consultant who will contact the grower and ask for their utility.

Step 5: Enroll growers in study

In Step 5, irrigation consultants will enroll growers in the study, first by recruiting growers to participate, and second by scheduling field site visits. There is a step in between this process where the study populations are determined based on the initial call with growers and the list of 2016 utility SIS program participants. The research team will provide irrigation consultants with talking points and will utilize a secure spreadsheet as a repository for tracking the participation of coordinates from the initial call.

Recruit growers to participate: Irrigation consultants will call an assigned list of growers and recruit them to participate in the SIS Baseline Study. Target participation rates are around 250 sites out of 700 for BPA utilities in the Columbia Basin only.

Determine study population: During this step of the process irrigation consultants will classify a participant as an SIS field, non-SIS field, or SIS field participating in a utility program. The research team will review the classifications along with the 2016 SIS utility program participants to determine a final study population. There will be some attrition from growers that have changed their mind about participating in the study, between the initial recruitment call and the call to schedule site visits.

Confirm participation and schedule site visits: The contractor will confirm grower's willingness to participate in the study, and will schedule the first site visit and all subsequent site visits throughout the growing season, except for the final site visit.

Irrigation consultants will collect the same data for general market fields as the utilities collect at the SIS program fields, thus allowing for an apples-to-apples comparison of data between fields. If the team selects a general market field that receives SIS services through their utility, the team will use the SIS data from the utilities, rather than completing site visits for that field. If the field receives a utility incentive for their SIS services, the field will be placed in both the general market field and the SIS program field population for analysis. In some cases, the selected field will receive SIS services without participating in a utility SIS program. The research team will work to obtain the data that these growers already receive. This will likely involve working with their irrigation consultant.

As the enrollment process reaches completion, the research team will provide a list of all utility customers participating in the study to the utility. Utilities will receive a first draft of participants at the end of November and a revised list in January after the study population QC process.

Step 5 Pilot Result: The pilot did not include the recruitment step.

Appendix A. Key Partner Contact Information

BPA

Contact Name: Carrie Cobb
Email: CLCobb@bpa.gov
Phone Number: 503.230.4985
Location: Portland, OR

Contact Name: Boyd Wilson
Email: BWilson@bpa.gov
Phone Number: 509-792-0881
Location: Pasco, WA

Navigant Research Team

Contact Name: Beth Davis
Contact Position: Lead Project Manager, Field Protocol and Data Collection
Phone Number: 303.728.2476
Email: Beth.Davis@navigant.com

Contact Name: Nicole DelSasso
Contact Position: Deputy Project Manager, Field Selection and Recruitment
Phone Number: 360.828.4024
Email: Nicole.Delsasso@navigant.com

Irrigation Consultants

Company Name:

Contact Name:
Contact Position:
Phone Number:
Location:

Company Name:

Contact Name:
Contact Position:
Phone Number:
Location:

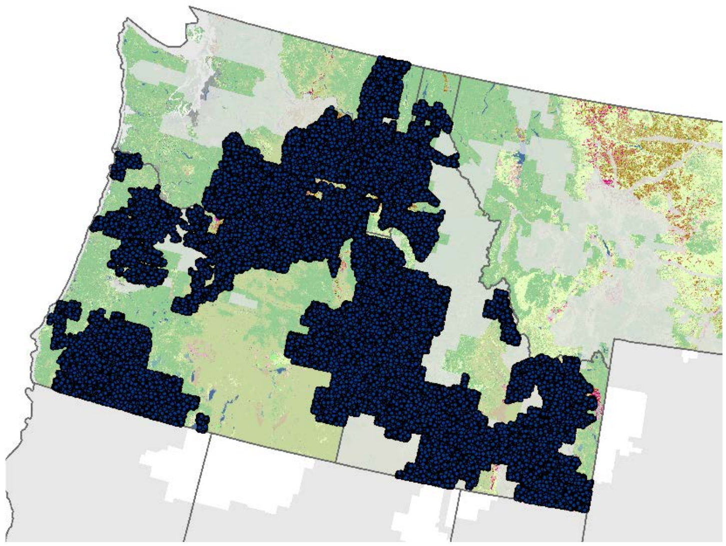
Company Name:

Contact Name:
Contact Position:
Phone Number:
Location:

Appendix B. Sampling Selection Using ArcGIS

Figure 4 depicts the random sample geographic output using the ArcGIS tool. The sample points look like a black blob due to the high number of sample points selected.

Figure 4. Sample Design Tool: Geographic Output



Source: Navigant 2015

Figure 5 illustrates the coordinates output from the Sampling Design Tool. The research team provides these coordinates to irrigation consultants for them to identify the coordinates that fall on irrigated agricultural land.

Figure 5. Sample Design Tool for ArcGIS: Example Output

	A	B	C	D	E
1	Id,N,6,0	PS_XCoor	PS_YCoor	Latitude,N,19,11	Longitude,N,19,11
2	0	-984553	2616692	45.94457262	-108.7191915
3	1	-987760	2617850	45.95104302	-108.7621314
4	2	-1796736	2772784	45.94425339	-119.3772921
5	3	-1825497	2809770	46.20357139	-119.8544558
6	4	-1368507	2563504	44.92566121	-113.4582084
7	5	-1949501	2858123	46.33744033	-121.5665026
8	6	-2217197	2570331	43.18672186	-123.8119568
9	7	-1217303	2973569	48.81457918	-112.4655965
10	8	-1931088	2903047	46.77239963	-121.4907315
11	9	-1875422	2420814	42.70849688	-119.261946
12	10	-1424770	2917859	47.96728952	-115.0529132
13	11	-1791236	2848047	46.61443272	-119.5463565
14	12	-1863417	2643689	44.67149929	-119.797337
15	13	-1785037	2683064	45.1861296	-118.9545631
16	14	-2198205	2683940	44.21061173	-123.9951068
17	15	-2030524	2318260	41.47390672	-120.7776572

Source: Navigant 2015

Appendix C. Study Boundaries

Columbia River Basin (Figure 6)

The Columbia Basin study boundary includes the northeastern portion of Oregon and the southeastern portion of Washington. The boundary attempts to include only visible irrigated land area within the "BPA Columbia Basin Utilities" listed below. It also includes some portions of the "Other Utilities" listed below that fall within the boundary.

The boundary excludes two small regions that are not covered by any utility in the Ventyx maps (the two cutouts near the text "PUD No 1 of Benton County") as well as two regions with no visible irrigated land (one cut out near the text "PacifiCorp" and another cutout near the text "Umatilla Electric Coop").

- BPA Columbia Basin Utilities:
    - Benton County PUD No. 1
    - Columbia Basin Electric Cooperative, Inc.
    - Columbia Rural Electric Association
    - Umatilla Electric Cooperative
    - Wasco Electric Cooperative
    - Milton Freewater
    - Klickitat PUD
    - Franklin PUD
    - Benton Rural Electric Association
    - Big Bend Electric Cooperative
- Other Utilities:
    - PacifiCorp
    - Idaho Power
    - Avista
    - Grant County PUD

Figure 6. Columbia Basin Study Boundary (Blue Outline)

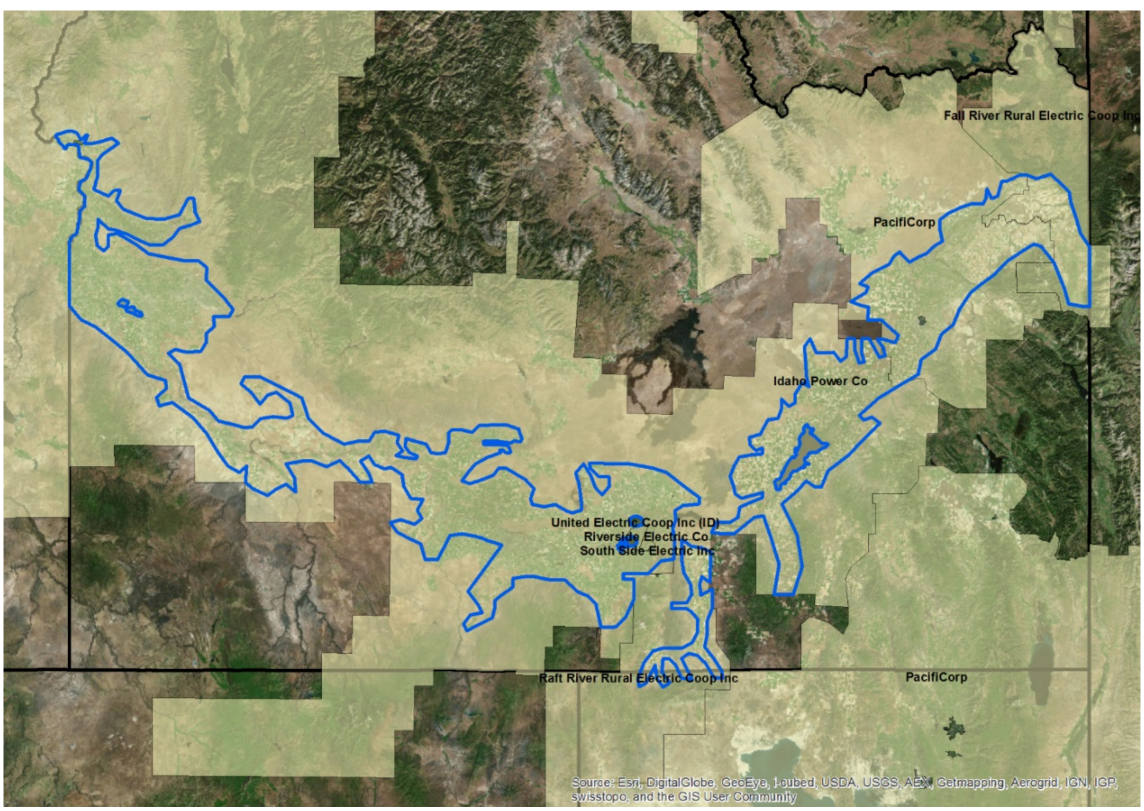
Southern Idaho (Figure 7)

The southern Idaho study boundary includes irrigated land in southern Idaho from the western border with Oregon to the eastern border with Wyoming, to provide a representative sample of irrigated land in southern Idaho. The boundary attempts to only include visually identifiable irrigated land area within the "BPA Idaho Utilities" listed below. It also includes portions of the "Other Utilities" listed below that fall within the boundary.

The boundary excludes consistently (year over year) water-short regions. It also excludes utilities that do not serve agricultural customers.

- BPA Idaho Utilities:
  - Fall River Electric Coop
  - Raft River Electric Coop
  - United Electric Coop
  - Riverside Electric Coop
  - South Side Electric
- Other Utilities:
  - PacifiCorp
  - Idaho Power

Figure 7. Southern Idaho Study Boundary (Blue Outline)



Appendix D. Utility Grower Notification Materials

Figure 8. Email template

Dear [NAME],

[UTILITY NAME] is partnering with Bonneville Power Administration to conduct an important research study to determine how much irrigated water Northwest growers can save through Scientific Irrigation Scheduling. This study will assess the direct impacts of Scientific Irrigation Scheduling services on energy use and will inform the energy efficiency programs we are able to offer our customers.

As an irrigator, you may be invited to participate in this study. Study participants will be randomly selected using generated GPS coordinates and will represent a sample of both growers who practice Scientific Irrigation Scheduling and those who do not, to allow for comparisons between the two groups.

For growers who do not currently practice Scientific Irrigation Scheduling, study participation includes:

- A brief phone interview
- The installation of a water measurement device on the selected field to measure water applied and soil moisture for the duration of the 2016 growing season.
- Regular site visits by a local irrigation consultant to the field throughout the growing season (4 to 16 times). The number of visits will depend upon the water measurement device selected for use on the field.
- A water use report provided at the end of the growing season showing optimal water use compared to the measured application.

For growers who currently practice Scientific Irrigation Scheduling, participation just includes sharing your Scientific Irrigation Scheduling data with the research team.

A [UTILITY NAME]-qualified irrigation consultant may reach out to you about this study in the coming weeks. We hope you consider participating. If you have any questions about this study or about Scientific Irrigation Scheduling, please call (XXX) XXX-XXXX or email, name@company.com.

Thank you for your consideration.

Sincerely,

[UTILITY CONTACT]

Figure 9. Flyer (front)

SCIENTIFIC IRRIGATION SCHEDULING STUDY

OVERVIEW:

The Bonneville Power Administration (BPA), in partnership with your local utility, is conducting an important research study to determine how much irrigated water Northwest growers can save through Scientific Irrigation Scheduling. The study will take place during the 2016 growing season.

Fields for this study have been randomly selected using generated GPS coordinates and represent both growers who do and do not practice Scientific Irrigation Scheduling. If your field is selected to participate in this study, you will be contacted by your local utility.

STUDY PARTICIPATION INCLUDES:

- An initial phone interview to confirm participation
- Scheduled site visits by an irrigation consultant during the 2016 growing season to measure water application (non-SIS fields only)
- A water use report provided at the end of the growing season showing optimal water use compared to the measured application (non-SIS fields only)

CONTACT YOUR LOCAL UTILITY WITH QUESTIONS.

Flyer (back)

CONTACT YOUR LOCAL UTILITY WITH QUESTIONS.

Scientific Irrigation Scheduling helps growers know exactly when to irrigate crops and how much water to apply through a system that monitors weather and soil moisture data. Past annual water and energy savings from Scientific Irrigation Scheduling have been estimated at 10 percent. The goal of this study is to review current practices and update savings estimates.

Benefits to growers:

At the end of the study period, fields without SIS will be provided with a report showing the measured water application on the study field. The report may provide optimal watering guidance for future years.

No cost to growers:

Growers will not be responsible for any costs associated with participating in this study. Any equipment used on site will be provided by BPA or its affiliates.

Selection process:

All fields were chosen using randomly generated GPS coordinates. Growers were not chosen for any reason relating to crops, growing practices, energy use, or water use.

Information security:

During the course of this study, all personal information, water use, energy use, and growing practice information will be protected on a secured website. All research data will be presented in aggregate, and no reports published internally or externally will contain any personally identifiable information.

Primary contact:

The primary contact throughout the study will be a local irrigation consultant. The irrigation consultant will schedule the site visits and meet with growers in person during the 2016 growing season. For more information on the SIS research study, please contact your local utility.

LOGO HERE

Utility name
phone number
email

Figure 10. FAQs

Q: What is the purpose of the Scientific Irrigation Scheduling study?

This study is being conducted to determine energy savings associated with Scientific Irrigation Scheduling. In order for utilities to continue to be able to offer incentives for participating in the Scientific Irrigation Scheduling program, we need data to prove Scientific Irrigation Scheduling practices save energy. Studies like this one allow Northwest utilities to continue to provide energy-saving programs.

Q: Who is sponsoring this study?

A: This study is sponsored by Bonneville Power Administration in partnership with your local utility. Bonneville Power Administration conducts studies like this every few years to evaluate energy efficiency program opportunities. Past studies are available on the Bonneville Power Administration website located at http://www.bpa.gov/EE/Sectors/agriculture/Pages/SIS.aspx.

Q. Is there a cost to participate?

A: No. Participants will not be responsible for any costs associated with participating in this study. Any equipment used on site will be provided by Bonneville Power Administration or participating study partners.

Q: How do participants sign up?

A: Fields are randomly selected using generated GPS coordinates. If your field is randomly selected to participate in the study, a utility-approved irrigation consultant will contact you this fall/winter (Mid-Oct – January). Irrigation consultants will determine your eligibility and enroll participants in the study over the phone.

Q: How are participants selected for this study?

A: All fields were selected using randomly generated GPS coordinates. Fields were not chosen for any reason relating to crops, growing practices, energy use, or water use.

Q: How will my information be kept secure?

A: During the course of this study, all personal information, water use, energy use, and growing practice information will be protected on a secured website. All research data will be presented in aggregate, and no reports published internally or externally will contain any personally identifiable information.

Q: Who is the primary contact for this study?

A: The primary contact throughout the study period will be a local irrigation consultant. Irrigation consultants will contact participants by phone first and then will schedule in-person site visits over the 2016 growing season.

Q: Does this study provide advice on optimal water usage?

A: The purpose of this study is to establish how much water is saved by Scientific Irrigation Scheduling practices. For the 2016 growing season, the study will collect data on current water usage. After the growing season, when the study is complete, an irrigation consultant can answer additional questions about specific water techniques appropriate to your field.

Q: What are the benefits of participating?

A: Participants will be assisting in a very important study that will help to identify energy reduction strategies. At the end of the study period, growers who do not currently practice Scientific Irrigation Scheduling will be provided with a water usage report from the selected field. This report may provide watering guidance for future growing seasons.

Q: Will the study measure water usage on entire farms or just one field?

A: For the purpose of this study, data will only be collected on the water usage of the field that was randomly selected by GPA coordinates. The irrigation consultant will describe the exact field location.

Q: Can I volunteer to participate if I was not selected for the study?

A: Unfortunately, no. Since this is a randomized study, only growers whose fields were randomly selected using GPS coordinates will be invited to participate.

Q: What if the selected field is not being cultivated or irrigated?

A: To be eligible for this study, fields must be irrigated, and the crop must be managed to maximize output.

Appendix F – Recruitment Communication Materials – E-mail Template

Dear [NAME],

[UTILITY NAME] is partnering with Bonneville Power Administration to conduct an important research study to determine how much irrigated water Northwest growers can save through Scientific Irrigation Scheduling. This study will assess the direct impacts of Scientific Irrigation Scheduling services on energy use and will inform the energy efficiency programs we are able to offer our customers.

As an irrigator, you may be invited to participate in this study. Study participants will be randomly selected using generated GPS coordinates and will represent a sample of both growers who practice Scientific Irrigation Scheduling and those who do not, to allow for comparisons between the two groups.

For growers who do not currently practice Scientific Irrigation Scheduling, study participation includes:

- A brief phone interview
- The installation of a water measurement device on the selected field to measure water applied and soil moisture for the duration of the 2016 growing season.
- Regular site visits by a local irrigation consultant to the field throughout the growing season (4 to 16 times). The number of visits will depend upon the water measurement device selected for use on the field.

A water use report provided at the end of the growing season showing optimal water use compared to the measured application.

For growers who currently practice Scientific Irrigation Scheduling, participation just includes sharing your Scientific Irrigation Scheduling data with the research team.

A [UTILITY NAME]-qualified irrigation consultant may reach out to you about this study in the coming weeks. We hope you consider participating. If you have any questions about this study or about Scientific Irrigation Scheduling, please call (XXX) XXX-XXXX or email, name@company.com.

Thank you for your consideration.

Sincerely,

[UTILITY CONTACT]

Appendix G –
Field Data Collection Protocol

Final Version: June 16, 2017

Contributors

Developed by Emily Merchant, Rudy Kahsar, Beth Davis, and Jane Pater Salmon, Navigant Consulting, Inc.

Developed for Bonneville Power Administration

Please refer questions to:
Carrie Cobb, clcobb@bpa.gov, 503.230.4985

Table of Contents

Introduction

This memo outlines the proposed strategy to collect and analyze field data as part of the upcoming scientific irrigation scheduling (SIS) baseline research in the Northwest. The approach builds on previous steps in this planning process, which included defining the SIS-eligible population and developing a sampling strategy. Stakeholders may review this memo in conjunction with the Field Selection and Recruitment Plan memo for a more comprehensive view of the study logistics.

The goal of the SIS baseline study is to develop accurate and defensible estimates of the percent water reduction resulting from the SIS program. In order to obtain this goal, Navigant has worked with the following stakeholders to develop the methods in this protocol: Bonneville Power Administration (BPA), the Regional Technical Forum (RTF), and irrigation consultants. Navigant will develop water reduction estimates by measuring the water use and water requirements of a representative sample of irrigated lands (including farms using SIS), and comparing those to the water use and water requirements of farms receiving an incentive by participating in a SIS program. SIS helps growers determine how much water they need to apply to their crops based on factors such as crop type, evapotranspiration (ET), and precipitation.

Navigant has organized the memo as follows:

- Study Overview
- Field Staff Training
- Pre-Visit Protocol
- Site Visits
- Data Collection Methods
- Data Collection Forms
- Post-Visit Protocol
- Quality Control
- Safety
- Appendix A: References
- Appendix B: Contact Information
- Appendix C: Equipment to Measure Actual Water Use
- Appendix D: Examples of Data Collection Forms

Study Overview

The overall objective of the study is to calculate the percent water reduction resulting from BPA's SIS program. The study will examine water use practices in two populations: SIS program fields and general market fields. The SIS program fields are SIS participants receiving a utility incentive. The general market fields (i.e., the baseline) consists of three field study categories that together make up all of the fields in the Columbia River Basin. The three field study categories include fields that received SIS services in 2016 and received an incentive from BPA (SIS program); fields that received SIS services in 2016 and did not receive an incentive from BPA (SIS non-program); and fields that did not receive SIS services in 2016 (non-SIS).

Navigant will draw a statistically significant sample of fields from the SIS program fields and the general market fields. Irrigation consultants will collect data from the sampled fields to determine the water applied and water required for each sampled field. Navigant will use the field level data to calculate water use ratios for each of the field study categories and the general market. The water use ratio is equal to sum of the water applied to all of the fields in a given category divided by the sum of the water required for all of the fields in a given category. Navigant will calculate the general market water use ratio as a weighted average of the water use ratios for each of the field study categories based on their relative contribution to the population. Finally, Navigant will calculate the percent water reduction due to the SIS program by subtracting the water use ratio for the SIS program fields from the water use ratio for the general market fields.

The Data Collection Methods section contains additional information about the following metrics:

- The **actual water use** is the amount of water that reaches the field by the irrigation system only, excluding the water lost during application and the water gained from rainfall.
- The **water requirement** is equal to the optimal amount of water required by the crop and it takes into account weather, evapotranspiration, and crop coefficients.
- The **water use ratio** is a fraction, and Navigant will calculate it by taking the actual water use divided by the water requirement.
- The **SIS water reduction** is the average water use ratio of the SIS program fields subtracted from the average water use ratio of the general market (baseline) fields.

Navigant plans to use the same methods to obtain the data for both the general market fields and the SIS program fields to maintain consistency between the two populations, which is a critical component of this research. Navigant developed the protocol for both the water requirement and the actual water use based on the approaches that the irrigation consultants currently use. The purpose of aligning the methodologies in the protocol with the irrigation consultant practices is to ensure proper implementation of the protocol for all fields selected in the study. This includes fields receiving SIS services and fields not receiving SIS services. The method for the actual water use will depend on the irrigation system type; see Table 1 for additional information.

Navigant intends to leverage the data that the irrigation consultants currently collect for SIS program and SIS non-program fields. The team assumes that the irrigation consultants are generally following the guidelines outlined in this protocol for the actual water use. This will eliminate the need for a separate site visit to SIS fields to achieve the desired data collection thresholds for this study. However, the irrigation consultants will need to ask a few additional questions to meet the needs of this study, such as the key dates in the crop's growing cycle.

The irrigation consultants will not share the water use information with the non-SIS participants during the growing to avoid skewing the general population baseline. The purpose of this study is to compare SIS program fields to the general population to determine the percent savings as a result of SIS programs. The general market fields represent what the market is doing in general, both with and without the impact of SIS. Navigant acknowledges that the growers for the non-SIS participant fields may adjust their irrigation strategy simply because they are being monitored, but it is impossible to quantify this impact.

Field Staff Training

Navigant will subcontract with irrigation consultants to complete the field work. Navigant field staff will support the field work by providing quality control processes to ensure consistency in data collection. Prior to going on-site, all field staff (Navigant field staff supporting quality control and irrigation consultants) will attend a training on the field data collection protocol and other field data collection documents. Navigant will offer the training over two, in-person sessions and cover the following information:

Overview of the SIS baseline research study

This portion of the training will include the overview of the study, main objectives, expectations for quality control, and an overview of the approaches.

Pre and post site visit protocols

This section will discuss the expectations of the irrigation consultants prior to going to the field and upon return from the field. The protocols include downloading the relevant forms onto the tablet prior to the site visit, reviewing the field forms after the site visit to ensure no data is missing, and syncing the tablet on the evening of the site visit.

Data collection methods

During this module of the training, Navigant will discuss the method for calculating the two primary data points for this study: the water requirement and the actual water use. Navigant will discuss the source and frequency of the required inputs for each of the groups within this study: SIS fields receiving a utility incentive, SIS fields not receiving a utility incentive, and fields that have not received SIS services from a SIS consultant. Lastly, Navigant will discuss which approach to use for determining the actual water use based on the irrigation system type. The required inputs, as well as the source and frequency of the inputs, depends on the type of irrigation system; therefore, Navigant will break this out into detail.

Ensuring consistency in data collection methods

This study will only include a sample of the fields that make up the entire population of fields in the Northwest; therefore, in order to extrapolate the results to the entire population it will be important for the irrigation consultants to collect the data consistently across the fields. Navigant will discuss the expectation for applying the field data collection protocol to SIS program fields and the general market fields.

Field forms

The data for this study will be collected using an iPad data collection software. In this section Navigant will go over the various field forms that the irrigation consultant will use for the initial site visit, the follow-up site visits, and the retrieval visit.

Data entry and reporting

On-time data entry and reporting is vital for this study in order to ensure that no data is lost, therefore Navigant will deal with data issues in real-time. This section will discuss the expectations of the irrigation consultants regarding data entry and reporting after the site visits are complete.

Equipment

The type of equipment used on-site will depend on the irrigation system and the method for determining the actual water use. This section will discuss the various types of equipment that the irrigation consultants will use depending on the irrigation system, as well as best practices for installing the equipment.

Ride-along site visits

At the beginning of the study, Navigant will conduct ride-along visits with the irrigation consultants. This section will discuss the structure and the purpose of these ride-along visits.

Quality control of forms and data entry

Quality data is essential to this study because Navigant will only be sampling a subset of the fields in the Northwest and the data collected on-site will be extrapolated to fields that were not visited. This section will discuss the quality control procedures that Navigant has established to ensure that the irrigation consultants collect quality data in a consistent way.

Safety

Safety is the main priority in data collection; therefore, this section will discuss safety while on-site. This discussion on safety will not be a formal safety training. Navigant expects the irrigation consultants to have their own safety protocols in place.

Pre-Visit Protocol

The purpose of this section is to outline the steps that the irrigation consultant will take the day before the initial site visit.[1]

1. **Field Forms**. Download the field forms onto the tablet on the evening prior to the site visit. The following field forms will be included for each site: Initial Site Visit Form, Follow-Up Visit Form, and Retrieval Visit Form. Navigant will use an iPad data collection software for this study.
2. **Equipment**. Prepare the tablet, field tools, safety equipment, and extra batteries for the field equipment. See the Data Collection Methods section for the required field equipment to determine the actual use, which is dependent on the irrigation system type.

[1] Recruiting the grower and scheduling the site visit will occur prior to the pre-visit protocol. The "BPA SIS Baseline Field Selection and Recruitment Plan" discusses these steps in more detail.

Site Visits

This section provides an overview of the different types of site visits that will occur throughout the duration of the field study, as well as a detailed description of the data collection methods the team will use while in the field. The irrigation consultants will visit each field once at the beginning and end of the growing season, as well as a few times during the growing season at a frequency dictated by the method selected for the actual water use. See Table 1 for additional detail on the frequency of site visits based on the method selected for actual water use.

Initial Site Visit

The purpose of the initial site visit is to interview the grower and install the field equipment to measure the actual water use. While on-site, the irrigation consultant will:

- Conduct a brief grower interview to document and confirm farm characteristics, irrigation strategy, crop type, etc. It is important to confirm these items prior to installing equipment in the field because the crop type and irrigation strategy will impact the approach for measuring the actual water use. For example, the irrigation consultant will use a tipping rain gauge for all irrigation systems, except for drip systems and micro-sprinklers where alternative methods will be required.
- Install appropriate field equipment to determine the actual water use based on the type of irrigation system installed. See Table 1 for more information.
- Take a photo in the Solocator app of the equipment serial number and the field ID written on a piece of paper. The Solocator app stamps latitude and longitude coordinates on the photo, which allows Navigant to verify that the equipment was installed in the correct field. The Solocator photo will be uploaded to the SharePlus app, which is a secure app where the irrigation consultants will store all personal identifiable information (e.g., field location, field name, farm name, site contact information).

Follow-Up Site Visits

The irrigation consultants will conduct follow-up visits based on the frequency dictated in Table 1, which is dependent on the method selected for actual water use. The irrigation consultant will record the required data points at the frequency specified in Table 1, on a tablet using the iPad data collection software. In addition, the irrigation consultant will scan the serial number of the equipment that was photographed with the Solocator app on the initial visit, which will allow Navigant to verify that the irrigation consultant entered data for the correct field.

On the evening prior to the follow-up visit, the irrigation consultant will download their sites onto their tablet in preparation for the next day. On the evening after the site visit, the irrigation consultant will upload the data they collected on their tablet to the iPad data collection software website by syncing their tablet upon getting cell service. The purpose of uploading the data on the same day that it is collected is to ensure that Navigant can conduct a quality control check the next morning. The irrigation consultants will be going to many sites per day, so it is important that the consultants submit the field forms in a timely fashion. Daily submittal of field forms will ensure that Navigant can identify and address any issues with the data early in the process. Refer to the Section "Navigant's Quality Control Efforts" for additional information.

Retrieval Visit

During the retrieval visit the irrigation consultant will do the following:

1. Take final measurements from the installed equipment
2. Remove the installed equipment
3. Conduct a brief exit interview with the grower

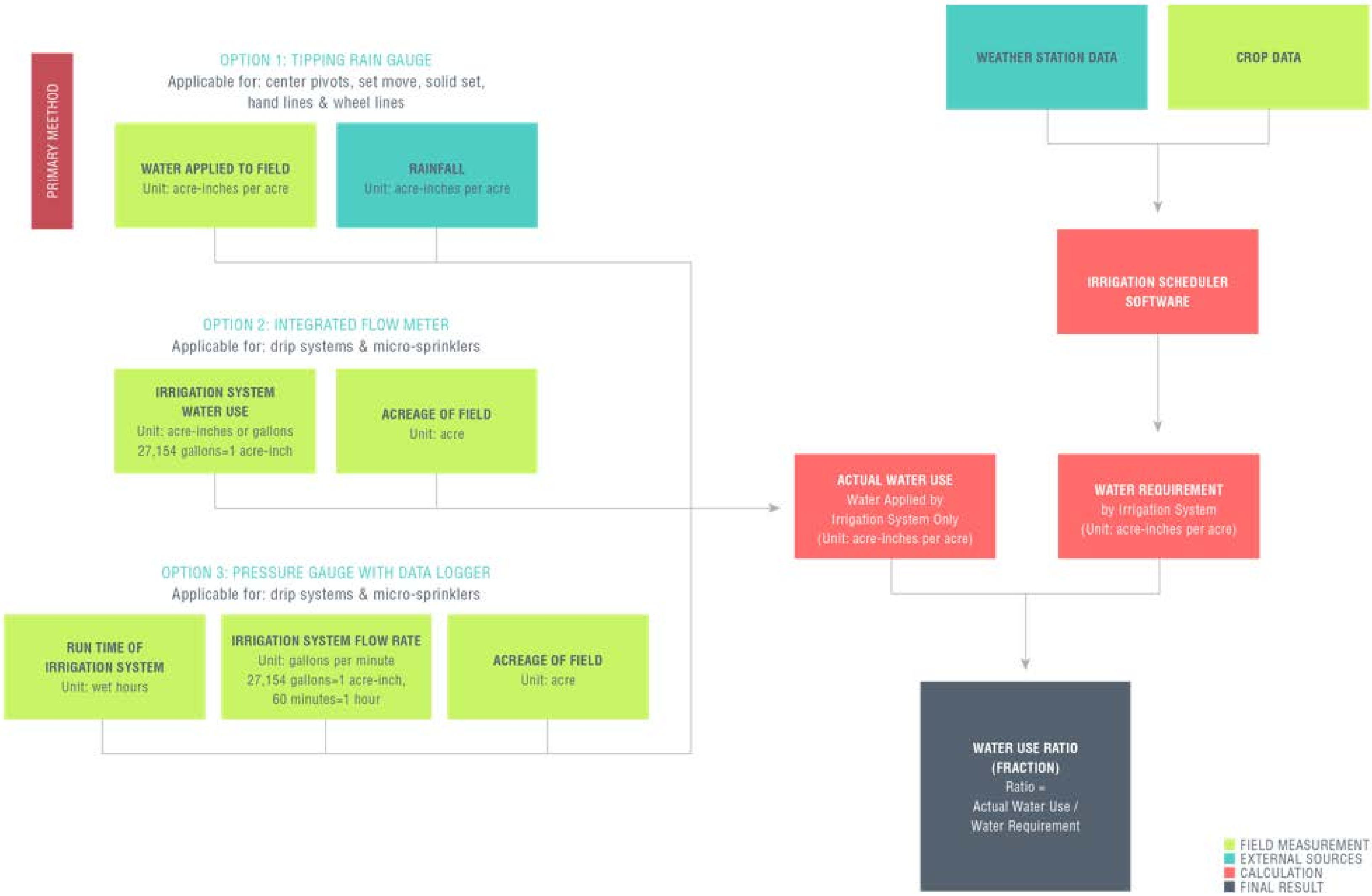
The purpose of the exit interview is to cover any outstanding questions that the irrigation consultant has not asked the grower during the follow-up visits. These will include asking the grower about:

- Key growing cycle dates required for input into AgWeatherNet, including the emergence date, the date canopy cover exceeded 10% of field, the date canopy cover exceeded 70% of field, crop initial maturation date, and the end of growing season date. If it is a forage crop, the following information is required for AgWeatherNet: when the cutting dates occurred, average number of days between a cutting and when regrowth begins, and average number of days between when regrowth begins and the crop reaches full coverage.
- Any out-of-the-ordinary events that happened during the growing season that may have impacted the amount of water they used on their field.
- Any follow-up questions that come out of Navigant's quality control efforts.

Data Collection Methods

This section provides a summary of the data points that the irrigation consultants will collect on-site so that Navigant can calculate the water use ratio. Figure 1 highlights the data that the team will collect as part of the field data collection study. The green boxes are data points that the irrigation consultant will collect through field measurement, the blue boxes are data points that Navigant will collect through external sources, the pink boxes are calculations that Navigant will complete using the data collected on-site and through external sources, and the grey box is the final result.

Figure 1: Data collection flow diagram



Source: Navigant

Actual Water Use

The actual water use, expressed in acre-inches per acre, is one of the components used to calculate the water use ratio. The actual water use is the water applied to the field by the irrigation system only. Due to the different types of irrigation system setups the irrigation consultants encounter in the field, there are three possible methods that may be used. The order of preference starts with Option 1 (the tipping rain gauge), which is relevant for all irrigation systems except for drip systems and micro-sprinklers. If the system is a drip system or a micro-sprinkler and the system has an integrated flow meter, then the irrigation consultant will use Option 2. If the system does not have an integrated flow meter, then the irrigation consultant will use Option 3, which involves installing a pressure gauge with an integrated data logger.

The actual water is the amount of water applied to the field through the irrigation system, excluding the water lost due to application losses and the water gained from rainfall. The SIS calculator takes into account the water lost during the application as a result of the irrigation system inefficiencies and weather impacts (e.g., wind, evaporation).

Navigant will include growers using beneficial irrigation in both the SIS program fields group and the general market group. Beneficial irrigation primarily impacts tree fruits. Examples of beneficial irrigation include leaching fraction for salinity, frost protection, and evaporative cooling. Under water rights laws, the growers are not allowed to over-water their crops, therefore Navigant will not make an exception for growers using beneficial irrigation.

Overview of Methods

Table 1 below breaks out the three methods by each of the three population groups: SIS participants receiving a utility incentive, SIS participants not receiving a utility incentive, and growers that have not received SIS services through a SIS consultant. Navigant summarizes the required inputs, as well as, their source and frequency, in the table below.

Table 1: Methods for Actual Water Use

Input	No SIS Services through an SIS Consultant	
	Source	**Frequency**
Option 1: Tipping Rain Gauge (Primary Method)		
Water applied to field (acre inches per acre)	Site visit	Records water applied in 0.01 inch increments, data is downloaded monthly
Precipitation (acre inches per acre)	AgWeatherNet	Daily, summed over metering period
Option 2: Integrated Flow Meter		
Irrigation system water use (total acre inches or gallons)	Site visit, integrated flow meter	Cumulative measurement of water applied, reading taken four times during the growing season
Acreage of field (acre)	Irrigation consultant	Once, first site visit
Option 3: Pressure Gauge with Integrated Data Logger		
Total run time of irrigation system (hours)	Site visit, pressure gauge reading	Records pressure readings in 1 minute increments, data is downloaded monthly
Flow rate (gallons per minute)	Site visit, ultrasonic flow meter	Once during growing season
Acreage of field (acre)	Irrigation consultant	Once, first site visit

Input	SIS Participants, Received a Utility Incentive		SIS Participants, No Incentive	
	Source	**Frequency**	**Source**	**Frequency**
Actual water applied (inches of water hitting crop)	Irrigation consultant	Once, from irrigation consultant	Irrigation consultant	Once, from irrigation consultant

Source: Navigant

Option 1: Tipping Rain Gauge

<u>Method Overview</u>

The primary method for determining the actual water use is the [tipping rain gauge](), which measures the amount of water applied to the field after the application losses from the irrigation system and the weather (e.g., wind, evaporation). The output from the tipping rain gauge method is net water applied, which is the format required for this study.

<u>Equipment Installation</u>

The irrigation consultants will install one tipping rain gauge per field. The placement of the tipping rain gauge will depend on the irrigation system and the irrigation practices. It is important that the tipping rain gauge is installed as consistently as possible, which is clearly documented in the field forms. For example, the irrigation consultants should install the tipping rain gauge between the second and third tower in from the outer end of center pivots, in a manner that does not jeopardize the gauge, or allow it to be knocked over by the irrigation system itself. The irrigation consultant will install a Bird-B-Gone metal wire around the circumference of the tipping rain gauge to prevent birds from clogging up the equipment.

Calibration of the tipping rain gauge upon installation will only be required if the box that the equipment arrived in appears to have been damaged or shaken up during shipping. All of the tipping rain gauges are calibrated by the manufacturer upon shipping but there is a possibility that it could become uncalibrated during shipping. Calibration requires filling up a jug with 473 milliliters of water, poking a pin-sized hole in the bottom, placing the jug on top of the funnel of the rain gauge, and allowing the jug to empty. Successful field calibration should result in one hundred tips plus or minus two. If the calibration takes less than an hour then the hole in the jug is too small and the test needs to be repeated.

The irrigation consultant will visit the site on a monthly basis to download the data from the tipping rain gauge and to clean out the tipping rain gauge bucket. During the site visit, the irrigation consultant will download the data from the tipping rain gauge using a USB base station, as well as check to make sure that the tipping rain gauge is still set to "logging." In addition, the irrigation consultant will clean the tipping rain gauge by 1) removing the metal screen by removing the spring clip from inside the rain gauge, and 2) cleaning the filter screen, funnel, and tipping bucket with mild soap and water with a cotton swab.[2]

Actual Water Use Calculation

Navigant will sum up the tipping rain gauge measurements over the metering period to determine the total water applied to the field. Navigant will then sum up the daily rainfall values from AgWeatherNet over the metering period to determine the total amount of rainfall hitting the crop. The actual water use is determined by subtracting the total rainfall during the metering period (acre-inches per acre) from the water applied to the field as measured by the tipping rain gauge during the metering period (acre-inches per acre).

The only exception to this calculation is for fields that have cutting dates during the growing season. Rainfall will be zeroed out for four days before and seven days after the cutting dates because the metering equipment is removed from the field during this time due to farming equipment actively working in the field. Navigant decided to exclude 12 days around the cutting date due to conversations with the irrigation consultants about the average amount of time that the metering equipment is removed from the field during a cutting. This calculation primarily affects alfalfa, grass hay, peppermint, and radish seed fields.

Option 2: Integrated Flow Meter

Method Overview

If the irrigation system is a drip system or a micro-sprinkler and the system has an integrated flow meter, then the irrigation consultant will use this method. This method leverages the pre-existing integrated flow meter to measure the actual water use. The flow meter keeps an ongoing record of the total acre-inches or gallons of water applied to the field by the irrigation system throughout the entire growing season. This method does not require the installation of additional equipment.

[2] http://www.onsetcomp.com/files/manual_pdfs/10241-F%20MAN-RG3%20and%20RG3-M-web.pdf

Equipment Installation

This method does not require the irrigation consultant to install any additional equipment on-site. The irrigation consultant will read the total water applied (read in acre-inches or gallons) from the integrated flow meter. In order to ensure crucial data is not lost, the irrigation consultant will read the flow meter once at the beginning of the season, twice during the growing season, and once at the end of the growing season.

Actual Water Use Calculation

The total water applied during the growing season will be determined by taking the difference between the reading at the beginning and the end of the season. In order to convert to acre-inches per acre, Navigant will divide the total water applied by the acreage of the field. This results in gross water applied and this study requires net water applied. Therefore, Navigant will multiply the gross water applied by the application efficiencies in the Resource Technical Forum's (RTF) calculator to convert to net water applied.[3]

Option 3: Pressure Gauge with Integrated Data Logger

Method Overview

If the irrigation system is a drip system or a micro-sprinkler and the system does not have an integrated flow meter, then the irrigation consultant will use Option 3. This method involves installing a pressure gauge with an integrated data logger. The irrigation consultant will use a pressure gauge as an indicator of when the irrigation system is on or off. This assumes that the pressure of the irrigation system remains relatively constant. The flow rate will be determined through a one-time measurement of the irrigation system using an ultrasonic flow meter. The actual water use will be determined by summing up the total time that the irrigation system was on during the growing season, as read by the pressure gauge, and multiplying by the flow rate of the irrigation system.

Equipment Installation

Irrigation systems typically have a pressure gauge installed, but they do not have the capability to connect to a data logger to measure pressure. As a result, this method will involve installing equipment that does not already exist on-site. The irrigation consultant will install a pressure gauge into a ¼ inch port at a point in the irrigation system where the gauge only reads pressure when the irrigation system is on, which is typically after the shutoff valves located after the pump. The irrigation consultant will then attach the pressure gauge to a U30 data logger powered by a solar panel to keep it charged throughout the growing season. The irrigation consultant will download the data on a monthly basis to ensure no data is lost. Navigant summarizes the additional hardware required to install this setup in Appendix C, Option 3.

The irrigation consultant will determine the flow rate through a one-time measurement of the irrigation system using an ultrasonic flow meter. The ultrasonic flow measurement requires at least 10 pipe diameters of straight, unobstructed pipe from the point of measurement. It does not matter when the irrigation consultant takes the measurement during the growing season, just that the

[3] Application efficiencies will be leveraged from Version 2.1 of the RTF's Protocol Calculator, which can be found here: http://rtf.nwcouncil.org/measures/measure.asp?id=184

irrigation system is fully functional and that there is laminar flow going through the pipe where the irrigation consultant takes the measurement.

If the irrigation consultant cannot find a long enough piece of straight pipe or if the flow rate is turbulent then the irrigation consultant can calculate the flow rate by using Washington State University's (WSU) Sprinkler Application Rate Calculator or WSU's Drip Line Rate Calculator.[4] The following inputs are required to calculate the flow rate (i.e. the application rate) for sprinklers: nozzle diameter, pressure, line spacing, and sprinkler efficiency. The follow inputs are required to calculate the flow rate (i.e. the application rate) for drip systems: emitter flow, emitter spacing along the line, and distance between drip lines.

Actual Water Use Calculation

The actual water use will be determined by multiplying the irrigation system run time by the flow rate in acre-inches of water. Navigant will determine the run time by analyzing the pressure gauge readings and using engineering judgement to determine when then irrigation system is on and summing up the total on time over the growing season. The actual water use is in acre-inches; therefore, Navigant will divide the actual water use by the total acreage of the field to determine the acre-inches per acre. This method results in gross water applied; therefore, Navigant will multiply the water by the application efficiencies in the RTF calculator to determine the net water applied in acre-inches per acre, which is the format required for this study.

Crop-Specific Methods

Orchards

Orchards often have multiple different irrigation system types in order to properly irrigate the crops. Typical orchards may have any combination of the following irrigation systems: drip systems, under-tree sprinklers, and over-tree sprinklers for evaporative cooling. Drip systems and under-tree sprinklers are the primary irrigation system types in orchards and over-tree sprinklers are only turned on during extremely warm temperatures to prevent the crop from sunburn. When there are multiple irrigation systems types in an orchard the irrigation consultant will identify the point in the system before the other irrigation systems break off. The irrigation consultant will ask the grower about the pressure ranges of each of the systems, as well as when each system typically operates. In a majority of cases only one irrigation system runs at a time therefore if the irrigation consultant is able to collect the pressure ranges and conditions of operation for each system type then Navigant will be able to tell from the data when each system is running.

Navigant will determine the amount of water applied by each irrigation system during the growing season by having an irrigation consultant take an ultrasonic flow measurement on each individual irrigation system type. It will be important for the irrigation consultant to isolate each system type before taking the ultrasonic flow measurement. Navigant will multiply the ultrasonic flow measurement by the run time of the irrigation system to determine the total amount of water applied by each irrigation system.

[4] The link to the calculators is also located in Appendix A.

One manifold often serves multiple irrigation blocks in an orchard, therefore it will be important for the irrigation consultants to isolate the irrigation block that was sampled. The irrigation consultant will need to consult with the grower about where the pressure gauge setup should be installed to ensure that the equipment is only measuring the water applied for the irrigation block that Navigant sampled.

Some orchards will utilize only under-tree solid set sprinklers to irrigate the crop. This is most often seen in apple orchards. The irrigation consultants would typically install a tipping rain gauge for solid set irrigation systems but if the system is installed in an orchard they would use the pressure gauge method. The reason for this is because it is impossible to install a tipping rain gauge in an orchard in a location that is representative of the entire field. The water leaving the solid set sprinkler is often hitting the crop canopy; therefore, it is difficult to install a tipping rain gauge in a place that would intercept the water before it reaches the crop. As a result, the irrigation consultant will utilize the pressure gauge method for orchards with solid set sprinklers.

Forage Crops

Growers are constantly operating farming equipment in forage crop fields due to the multiple cuttings that occur during a given growing season. As a result, there is a higher probability of the tipping rain gauge being knocked over by farming equipment in forage crop fields than fields that are harvested once a growing season. The irrigation consultant is expected to remain in constant contact with the grower so that if the equipment needs to be removed prior to a cutting in order to avoid damage to the equipment, then the irrigation consultant knows exactly when they need to go out in the field. The expectation is that once the farming equipment is removed from the field then the irrigation consultant returns to the field immediately to reinstall the tipping rain gauge to ensure that all water applied to the crop is captured by the tipping rain gauge.

Corn

Due to the height of corn, there is a high likelihood that the tipping rain gauge collector screen could be clogged with crop debris or get knocked over when the corn is topped before harvest. In order to avoid any damage to the equipment, the irrigation consultants are expected to notify the grower that they will clear out a 5 foot by 5 foot square around the tipping rain gauge to protect it from being affected by the crop debris. The reason why this is important is because if crop debris clogs up the collector screen then the data logger could read lower measurements of water applied to the crop than what the crop is actually receiving. In order to protect the tipping rain gauge when the crop gets topped before harvest, the irrigation consultant is expected to stay in constant contact with the grower so that the irrigation consultant can remove and reinstall the tipping rain gauge before and after the topping occurs.

Water Requirement

Navigant will use the water requirement, expressed in acre-inches per acre, as the second component to calculate the water use ratio. The water requirement calculation uses a combination of Washington State University's (WSU's) AgWeatherNet irrigation scheduling software and irrigation consultants' irrigation scheduling software.

The AgWeatherNet Process

Navigant will use the reference evapotranspiration and daily precipitation outputs from AgWeatherNet to calculate the water requirement. AgWeatherNet requires the growing cycle dates, crop type, soil type, year of growing season, weather station, and weather network to determine daily parameters for each field. Table 2 summarizes the required inputs to AgWeatherNet as well as the outputs from AgWeatherNet that Navigant will use for the water requirement calculation.

Table 2: Inputs and Outputs from AgWeatherNet

AgWeatherNet Parameters		Source of Data: Non-SIS Fields	Source of Data: SIS Fields (Program and Non-Program)
Inputs	Field ID	Navigant	Navigant
	Year	2016	2016
	Weather Network	AgriMet or AgWeatherNet	AgriMet or AgWeatherNet
	Crop Type	Irrigation Consultant Initial Site Visit	Irrigation Consultant Program Data
	Location (Lat/Long)		
	Weather Station		
	Soil Type[5]		
	Date of Emergence	Irrigation Consultant Retrieval Site Visit	
	Date Canopy Cover Exceeds 10% of Field		
	Date Canopy Cover Exceeds 70% of Field		
	Date of Initial Maturation		
	Date of End of Growing Season		
	Cutting Dates (Forage Crops Only)		
Outputs	Reference Evapotranspirtation	AgWeatherNet	AgWeatherNet
	Precipitation		

Source: Navigant

Irrigation consultants will work with Navigant to collect all of the required inputs to AgWeatherNet while onsite. To determine the weather station for each field, Navigant will use a combination of the closest weather station to the field based on the latitude and longitude coordinates of the field and the irrigation consultants' knowledge about microclimates near the field.

The irrigation consultants will use the daily reference evapotranspiration values from the AgWeatherNet output as a key input to their irrigation algorithm to determine the water requirement for each field. Navigant will also use the daily precipitation output from AgWeatherNet to calculate the water required by the crop from the irrigation system only, as the water requirement calculated by the irrigation consultants is the total water required by the crop from both the irrigation system and precipitation.

[5] The soil type is a required input to AgWeatherNet, but it does not affect the reference evapotranspiration or precipitation outputs. Navigant will use the same soil type for all fields for simplicity purposes.

Irrigation Consultants' Irrigation Algorithm

The irrigation consultants will use the daily reference evapotranspiration values from AgWeatherNet and apply their crop coefficients to determine the crop-specific evapotranspiration for each field. The crop-specific evapotranspiration is equal to the amount of water required by the crop for optimal growth, which can come from irrigation or precipitation. The irrigation consultants will sum up the daily evapotranspiration values between the equipment install date and the equipment removal date to determine the seasonal evapotranspiration for each field. The only exception to this calculation is for fields that have cutting dates during the growing season. The irrigation consultants will zero out the evapotranspiration four days before and seven days after the cutting dates because the metering equipment is removed from the field during this time due to farming equipment actively working in the field. The irrigation consultants will zero out the evapotranspiration values while the equipment is removed from the field because the water applied data will not include measurements during that time; therefore, it does not make sense to include the water required by the crop for those days. Navigant decided to exclude 12 days around the cutting date due to conversations with the irrigation consultants about the average amount of time that the metering equipment is removed from the field during a cutting. This calculation primarily affects alfalfa, grass hay, peppermint, and radish seed fields.

Upon calculating the season crop evapotranspiration values for each field in the study, the irrigation consultants will provide Navigant with a spreadsheet that includes the values for each field in the study, as well as any notes about the calculation.

Water Requirement Calculation

After receiving the crop evapotranspiration information between the equipment install date and the equipment removal date from the irrigation consultants, Navigant will subtract the precipitation during the same time period to calculate the water required by the crop from the irrigation system only. Similar to the evapotranspiration calculation, Navigant will zero out the precipitation from four days before to seven days after cuttings to account for the metering equipment being removed from the field. Equation 1 summarizes the equation Navigant will use to calculate the water requirement for each field in the study.

Equation 1: Water Requirement

$$\text{Water Requirement} = \sum_{\text{Install date}}^{\text{Removal date}} [\text{Reference ET}_{\text{Daily}} * \text{Crop Coefficient}_{\text{Daily}}] - \sum_{\text{Install date}}^{\text{Removal date}} [\text{Precipitation}_{\text{Daily}}]$$

$$= \sum_{\text{Install date}}^{\text{Removal date}} [\text{Crop ET}_{\text{Daily}}] - \sum_{\text{Install date}}^{\text{Removal date}} [\text{Precipitation}_{\text{Daily}}]$$

Where:

Reference ET_{Daily} = The reference evapotranspiration.

Crop ET_{Daily} = The crop-specific evapotranspiration.

$\text{Crop Coefficient}_{\text{Daily}}$ = The coefficient that makes the reference evapotranspiration crop-specific.

$\text{Precipitation}_{\text{Daily}}$ = The precipitation measured by the nearest weather station.

Water Use Ratio

The water use ratio is the key metric that Navigant will use to calculate the percent water reduction from the SIS program and it is equal to the water applied (acre-inches per acre) divided by the water requirement (acre-inches per acre). Navigant will calculate the water use ratio for each of the field study categories and then calculate the water use ratio of the general market, which is a weighted average of the field study categories based on their relative contribution to the population. Equation 2 summarizes the equation Navigant will use to calculate the water use ratio for each field study category.

Equation 2: Water Use Ratio of Field Study Categories

$$\text{Water Use Ratio}_{\text{Field Study Category, i}} = \frac{\sum_{\text{All fields}}[\text{Water Applied}]}{\sum_{\text{All fields}}[\text{Water Requirement}]}$$

Navigant will calculate the general market water use ratio by weighting the field study category water use ratios by their relative portion in the general market. The weight of the field study categories will be determined by calculating the percentage of fields in each field study category in the sample frame of 735 fields that Navigant started recruitment with.

Equation 3 demonstrates how Navigant will calculate the general market water use ratio.

Equation 3: General Market Water Use Ratio

$$\begin{aligned}\text{WUR}_{\text{General Market}} &= \text{WUR}_{\text{SIS Program}} * \text{Weight}_{\text{SIS Program}} + \text{WUR}_{\text{SIS Non-Program}} * \text{Weight}_{\text{SIS Non-Program}} \\ &+ \text{WUR}_{\text{Non-SIS}} * \text{Weight}_{\text{Non-SIS}}\end{aligned}$$

Where:

WUR_i = The water use ratio, which is the water applied divided by the water requirement.

Weight_i = The fraction of the general market that field study category i represents.

Percent Water Reduction from the SIS Program

Navigant will calculate the percent water reduction from the SIS program to determine the amount of irrigation water that is reduced due to the presence of the SIS program. Equation 4 shows that the SIS program percent water reduction is the difference between the general market water use ratio and the SIS program water use ratio.

Equation 4: SIS Water Reduction

$$\text{SIS Water Reduction} = \text{Water Use Ratio}_{\text{General Market}} - \text{Water Use Ratio}_{\text{SIS Program}}$$

Data Collection Forms

Navigant will use tablets to develop the field forms, which Navigant will develop using an iPad data collection software. The field technicians will utilize the following three apps for data collection: Fulcrum, Solocator, and SharePlus. Each field will have the following three distinct data collection forms: Initial Site Visit Form, Follow-Up Visit Form, and Retrieval Visit Form. Fulcrum will be used to store all non-personal identifiable information collected on-site, such as crop status and equipment serial numbers. Solocator is a GPS photo app that will be used to verify that the irrigation consultants install the equipment at the correct field. SharePlus will be used to store all personal identifiable information, such as latitude and longitude coordinates, site contact information, etc.

There will be a quality control (QC) checklist within each of the forms on Fulcrum that summarizes the data that needs to be collected on-site. Navigant will populate the checklist depending on the site visit type and the data collection priorities for the site visit. Navigant will automatically generate a Field ID for each field to keep track of all the data collected at each site. Each form in Fulcrum also records the name of the field crew, the time on-site, and the crew's general notes about the visit.

All personal identifiable information will be stored in SharePlus. The following information will be pre-populated in SharePlus prior to the irrigation consultants going on-site: field ID, field name, farm name, site contact name, site contact number, assigned company, expected crop type, expected method for water applied, expected utility, expected field location, link to google maps, and link to Fulcrum. During the initial visit the irrigation consultant will take a photo with the Solocator app of the equipment serial number and a piece of paper with the field ID. Solocator stamps the latitude and longitude coordinates on the photo with the location of where the photo was taken, which Navigant will cross-check against the location of the sampled field. Navigant will use this as a quality control check to verify that the irrigation consultant installed the equipment in the correct field. Upon taking the photo the irrigation consultant will upload the photo to the corresponding field ID in SharePlus.

Initial Site Visit Form

The irrigation consultants will use the Initial Site Visit Form to collect basic data about the site: electric utility, crop type, description of crop rotation, water source, field acreage, irrigation system type (center pivot, set move, solid set, hand line, wheel line, drip, and micro-sprinkler), description of irrigation strategy, presence of a variable frequency drive, use of beneficial irrigation, and past and present use of SIS. Navigant will provide the irrigation consultant with the latitude and longitude coordinates of the sampled field to ensure that they install the equipment in the correct field.

Upon completing the grower interview, the irrigation consultant will install the equipment, scan the serial numbers of all the installed equipment, and describe the location of the installed equipment. In addition, the irrigation consultant will let the grower know that at the end of the growing season they will ask the grower about the key dates in the crop's growing cycle. If the irrigation consultant is unable to answer all of the grower interview questions at the time of the site visit the expectation is that the irrigation consultant follows up with the grower the day of the visit to get the remaining questions answered.

Upon installing the equipment, the irrigation consultant has two additional tasks before leaving the site. The first task is to take a photo with the Solocator app of the equipment serial number and a piece of paper with the field ID. The photo will show the latitude and longitude coordinates of the location where the photo was taken. Upon taking the photo the irrigation consultant will upload the photo the corresponding field ID record in SharePlus. Finally, the irrigation consultant will review the QC checklist, which is at the bottom of the Initial Site Visit Form in Fulcrum. The QC checklist provides a high level overview of the action items that the irrigation consultant is responsible for taking care of prior to leaving the field.

Follow-Up Visit Form

The Follow-Up Visit Form will keep track of the measurements taken on-site based on the required data points and frequency dictated by the method selected for actual water use (see Table 1). There will be a separate form for every visit to the field. The form will include the date, field tech name and company, actual water use reading, and a brief description of the crop status and the irrigation strategy. While on-site, the irrigation consultant will scan the serial number of the installed equipment using the Fulcrum app, which Navigant uses to verify that the scanned serial number matches the serial number taken at the initial visit using the Solocator app. The purpose of this check is to verify that the irrigation consultant is entering data for the correct field.

Included within the Follow-Up Visit Form will be a QC checklist, which provides a high level overview of the action items that the irrigation consultant is responsible for taking care of prior to leaving the field.

Retrieval Visit Form

The Retrieval Visit Form (i.e., the "exit interview") will be the same across all of the fields and it will consist of any outstanding questions that the irrigation consultant did not address during the follow-up site visits. During the retrieval visit, the irrigation consultant will also ask the grower about any events that occurred during the growing season that altered their typical irrigation strategy or any equipment failures in the season that would have an impact on the amount of water they used on their field. The retrieval visit form will also include questions about the dates for the five key points in the crop's growing cycle, which include: emergence date, canopy cover exceeds 10% of field, canopy cover exceeds 70% of field, crop initial maturation, and end of growing season. For forage crops, the irrigation consultant will also collect when the cutting dates occurred, the average number of days between a cutting and when regrowth begins, and the average number of days between when regrowth begins and the crop reaches full coverage. Examples of forage crops include alfalfa, mint, and grass hay.

If there are any outstanding questions that are specific to the field then there will be a "Supplementary Retrieval Visit Form" that the irrigation consultants will be required to fill out on-site. When the irrigation consultants sync their tablet the evening prior to the site visit, the "Supplementary Retrieval Visit Form" will be pushed to their tablet if they need to fill it out. If the supplementary form does not appear then they only have to fill out the Retrieval Visit Form.

Included within the Retrieval Visit Form will be a QC checklist, which provides a high level overview of the action items that the irrigation consultant is responsible for taking care of prior to leaving the field.

Post-Visit Protocol

Upon the conclusion of the site visit, the irrigation consultant will take the following steps:

1. Review the field forms prior to leaving the site to ensure that all of the data points have been collected
2. Flag any items that will need follow-up after the site and identify a plan of action for getting them resolved
3. Sync the tablet to the data collection software website on the night of the site visit when cell service is available

Quality Control

This section summarizes the quality control (QC) efforts that both the irrigation consultants and Navigant will take throughout the course of the study. Table 3 includes a summary of the risks, as well as the mitigation strategies, that Navigant will deploy throughout the growing season to ensure quality control.

Table 3: Data Quality Risks & Mitigation Strategies

Risk	Mitigation
Reliability and accuracy in results	• Navigant will ride along with an irrigation consultant from each company for the first couple of visits, and debrief with all of the irrigation consultants to discuss observations. The ride-alongs will be for non-SIS fields only. • Navigant will have weekly check-in meetings with all of the irrigation consultants conducting field monitoring for the study to discuss any issues with the study and any questions regarding the protocol. • The field forms will have built in QC that only allow data entry of certain number ranges. There will also be QC checklists as part of every field form. • Navigant will QC the submitted field forms in the iPad data collection software on the morning after the site visit. • Navigant will analyze the SIS data from the 2015 program year to identify any issues with the data prior to the 2016 program year. • Navigant will use a tipping rain gauge as the primary method for measuring the actual water use. The tipping rain gauge timestamps when every 0.01 inches of water is applied to the field, which increases the accuracy of the data collection because it gives a full picture of the irrigation events.
Consistency in results across irrigation consultants	• Navigant will ride along to the first one to two visits for one irrigation consultant at every irrigation consulting company and then debrief with all of the irrigation consultants to discuss observations. The ride-alongs will be for non-SIS fields only. • Navigant will analyze the SIS data from the 2015 program year to identify any issues with the data prior to the 2016 program year. • Navigant will use a tipping rain gauge as the primary method for measuring the actual water use. The tipping rain gauge automatically timestamps when every 0.01 inches of water is applied to the field,

Risk	Mitigation
	which reduces the error from manual data collection and ensures consistency in the results.
Loss of data	• The irrigation consultants will bring blank paper copies of the field forms in case the tablets malfunction on-site. • For the tipping rain gauge method, the irrigation consultant will visit the field 1x/month to ensure the tipping rain gauge does not clog or get knocked over, for the integrated flow meter method the irrigation consultant will visit the fields 4x/growing season to ensure no data is lost, and for the pressure gauge, the irrigation consultant will visit the field 1x/month to download the data and ensure no data is lost.
Less QC on SIS fields than on non-SIS fields	• Navigant designed the SIS field data collection protocol to mirror what the irrigation consultants are already doing for SIS fields. If Navigant identifies a QC issues for a non-SIS fields, then the issue and resolution will likely carry over to the SIS fields as well. • Navigant is analyzing SIS data from the 2015 program year, which will allow Navigant to identify issues with the SIS data early on so that the issues can be resolved by the 2016 program year.

Source: Navigant

While On-Site

Before leaving the site, each irrigation consultant will do the following:

1. Verify that they properly installed the equipment required to measure the actual water use (see Table 1).
2. Go through the QC checklist and make sure that all of the data has been collected.
    a. Read through the general information table, data collection form, and QC checklist
    b. Note which data points were not collected on-site, as well as the steps that the irrigation consultant will take to obtain the missing data point
3. Confirm that the following critical data points have been collected:
    a. Crop status
    b. Equipment status
    c. Actual water use measurement (dependent on method used for actual water use)
4. Obtain site contact information in the event that we have follow-up questions before the next visit.
5. Ensure that the customer is aware that someone will be coming back throughout the duration of the growing season to document the amount of water they used on their field.

Post-Visit

The irrigation consultant will take the following actions in the evening following the site visit to the field:

1. Review the forms to ensure that they filled out all of the required fields. If the irrigation consultant was unable to collect a data point on-site then they will make a note as to why they could not collect the data, when they plan to collect the data, and how they plan to collect the data.
2. Make sure the following key data points were collected on-site:
    a. Site visit date
    b. Field tech name and company
    c. Crop type
    d. Irrigation system type
    e. Actual water use measurement (dependent on method used for actual water use)
    f. Pictures of the field, equipment installed to measure actual water use, and irrigation system (initial site visit only)

Navigant's Quality Control Efforts

Navigant's quality control efforts will come in three forms: reviewing the data submitted in the field forms on the morning after the site visit, conducting ride-alongs with the irrigation consultants, and holding a weekly check-in meeting with the irrigation consultants. Navigant summarizes each of the formats of quality control below.

Post-Visit Quality Control

Navigant will log into the data collection software website on the morning after the site visit to review the forms submitted for the sites from the previous day. Navigant will review the following information for each of the sites:

1. Confirm that there is no missing information
2. Review the entered data to ensure that it is reasonable and does not need to be re-checked
3. Confirm that that the irrigation consultant visited the correct field based on the GPS coordinates of the sampled field

If Navigant identifies any aspects of the field forms that the irrigation consultant needs to address, Navigant will follow-up with the irrigation consultant through either a call or e-mail. The irrigation consultant should respond back to Navigant within 24 hours of Navigant identifying the issue.

Ride-Along Visits

Navigant will conduct ride-alongs with one consultant at each irrigation consulting company for their first one to two site visits. The expectation is that the irrigation consultant who received a ride-long will relay the information back to the other irrigation consultants conducting field monitoring for the study. Navigant will also hold a debrief meeting with all of the irrigation consultants in the irrigation consulting company to discuss any notable observations during the ride-along.

Check-in Meetings with Irrigation Consultants

Navigant will check in with the irrigation consultants on a weekly basis, at a minimum. During the course of the study this frequency may be higher as issues arise. The irrigation consultants will reach out to Navigant via e-mail or phone if issues or questions come up while they are on-site.

Safety

Navigant has an Injury and Illness Prevention Program (IIPP), which serves as a guide to assist managers and supervisors to promote the health and safety of their employees. The IIPP complies with the Cal/OSHA requirement to provide a safe and healthful workplace for all employees (California Labor Code 6401.7). It establishes methods for identifying and correcting workplace hazards, providing employee safety training, communicating safety information, and ensuring compliance with safety programs. This IIPP is subject to change to reflect any changes in regulations, personnel, or procedures.

Appendix A. References

BPA SIS Calculator

http://www.bpa.gov/EE/Policy/IManual/Pages/IM-Document-Library.aspx

HOBO Data Logging Rain Gauge RG3 User's Manual

http://www.onsetcomp.com/files/manual_pdfs/10241-F%20MAN-RG3%20and%20RG3-M-web.pdf

RTF Protocol Calculator

http://rtf.nwcouncil.org/measures/measure.asp?id=184

WSU AgWeatherNet

http://weather.wsu.edu/awn.php?page=irrigation-scheduler

WSU's Drip Line Rate Calculator

http://irrigation.wsu.edu/Content/Calculators/Sprinkler/Sprinkler-Application-Rate.php

WSU's Irrigation Map

http://weather.prosser.wsu.edu/awn.php?page=irrigationmap

WSU's Sprinkler Application Rate Calculator

http://irrigation.wsu.edu/Content/Calculators/Sprinkler/Sprinkler-Application-Rate.php

Appendix B. Contact Information[6]

The contact information for each of the key contacts will be provided to the irrigation consultants in a similar format below.

If you encounter any of the issues described below while you are on-site, call the people as specified below. Additional contacts are provided below for your reference. The main point of contact for the field data collection study is ________ at ________ who can be reached at XXX-XXX-XXXX.

- If you encounter a safety related issue on-site, call ________ at ________ who can be reached at XXX-XXX-XXXX.
- If you are unable to find the field and the customer is not answering, call ________ at ________ who can be reached at XXX-XXX-XXXX.
- If the customer refuses to have you visit their field, call ________ at ________ who can be reached at XXX-XXX-XXXX.
- If the field that was originally sampled is not accessible or available to be looked at, call ________ at ________ who can be reached at XXX-XXX-XXXX.
- If you have a technical related question, call ________ at ________ who can be reached at XXX-XXX-XXXX.
- If you have a question related to the field data collection protocol, call ________ at ________ who can be reached at XXX-XXX-XXXX.
- If you are unable to install or read the equipment that measure the actual water use, then call ________ at ________ who can be reached at XXX-XXX-XXXX.

BPA Key Contacts

Contact Name:
Contact Position:
Phone Number:
Location:

Contact Name:
Contact Position:
Phone Number:
Location:

Navigant Consulting Key Contacts

Contact Name:
Contact Position:

[6] This section is still in progress and will be fleshed out in time for the study during the 2016 growing season.

Phone Number:
Location:

Contact Name:
Contact Position:
Phone Number:
Location:

Utility Key Contacts

Utility Name:

Contact Name:
Contact Position:
Phone Number:
Location:

Contact Name:
Contact Position:
Phone Number:
Location:

Utility Name:

Contact Name:
Contact Position:
Phone Number:
Location:

Contact Name:
Contact Position:
Phone Number:
Location:

Irrigation Consultant Key Contacts

Company Name:

Contact Name:
Contact Position:
Phone Number:
Location:

Contact Name:
Contact Position:
Phone Number:
Location:

Appendix C. Equipment to Measure Actual Water Use

Option 1: Tipping Rain Gauge

Tipping Rain Gauge

Manufacturer: Onset HOBO Data Loggers
Model: HOBO Rain Gauge Data Logger (RG3)

Source: http://www.onsetcomp.com/products/data-loggers/rg3

Bird-B-Gone Strip

Manufacturer: Texas Electronics
Model: Bird-B-Gone Strip (BB-525 24" Strip)

Source: http://texaselectronics.com/bird-b-gone-strip.html

USB Base Station

Manufacturer: Onset HOBO Data Loggers
Model: Optic USB Base Station (BASE-U-4)

Source: http://www.onsetcomp.com/products/communications/base-u-4

Option 2: Integrated Flow Meter

The irrigation consultant will not install an integrated flow meter during the site visit; the integrated flow meter will already be installed on the irrigation system. The specifications of the flow meter will vary depending on the irrigation system. The picture below is for illustration purposes.

Source: Navigant on-site data collection

Option 3: Pressure Gauge with Integrated Data Logger

Irrigation systems typically have a pressure gauge installed, but they are not usually capable of connecting to a data logger. As a result, the irrigation consultant will need to install the equipment below.

HOBO U30 Data Logger

Manufacturer: Onset HOBO Data Loggers
Model: U30 USB Weather Station Data Logger - U30-NRC

Source: http://www.onsetcomp.com/products/data-loggers/u30-nrc

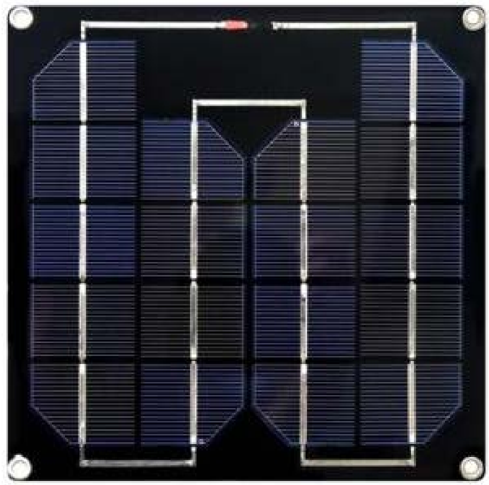
Pressure Gauge

Manufacturer: Onset HOBO Data Loggers
Model: Ashcroft Gauge Pressure Sensor/100-psig Sensor - T-ASH-G2-100

Source: http://www.onsetcomp.com/products/sensors/t-ash-g2-100

Small Solar Panel Kit, 6 Watts

Manufacturer: Onset HOBO Data Loggers
Model: SOLAR-6W Power - SOLAR-6W



Source: http://www.onsetcomp.com/products/power/solar-6w

Additional Tools Required for Each Installation

1 - Steel T post

2 - ¼ inch brass ball valves

2 - ¼ inch galvanized tees

6 - ¼ inch galvanized nipples

1 - Paste thread sealant

1 - Penetrating oil

1 - Pipe wrench

1 - Post driver

2 - Adjustable wrench

1 - End wrench (½ in.) to put the HOBO Logger and Solar Panel on the T post

4- Black Poly Fence Ties (Zip Ties) to put the HOBO Logger and Solar Panel on the T post

1 - Multi-meter (Used to check the battery when we were troubleshooting the Hobo Logger.)

1- Laptop with HOBOware installed

1 – mini USB cable

Appendix D. Examples of Data Collection Forms

Table D-1: Site Information in SharePlus

Site Details	
Field ID	Automatically populated
Field Name	Automatically populated
Farm Name	Automatically populated
Site Contact Name	Automatically populated
Site Contact Number	Automatically populated
Site Address	Automatically populated
Assigned Company	Automatically populated
Expected Crop Type	Automatically populated
Expected Irrigation System Type	Automatically populated
Expected Method for Water Applied	Automatically populated
Expected Utility	Automatically populated
Expected Field Location (Latitude/Longitude)	Automatically populated
Hyperlink to Field in Google Maps	Automatically populated
Hyperlink to Field in Fulcrum	Automatically populated
Solocator Photo	Added by Irrigation Consultant

Initial Visit Form

Table D-2: Initial Visit Data Collection Form

Initial Visit General Information	
Field ID	Automatically populated
Irrigation Consultant at Initial Visit	Drop-down with options
Date of Initial Visit	Timestamp Field
Arrival Time of Initial Visit	Timestamp Field
Initial Visit Notes from Irrigation Consultant	Text field – open ended
Field Details	
Electric Utility Name	Drop-down with options
Crop Type	Drop-down with options
Description of Crop Rotation	Text field – open ended
Water Source	Drop-down with options
Field Acreage	Numerical entry with allowable range
Irrigation System Type	Drop-down with options
Description of Irrigation System Strategy	Text field – open ended
Is there a Variable Frequency Drive on the Pump?	Yes/No
Does the Grower Anticipate using Beneficial Irrigation?	Text field – open ended
Is the Grower Currently Receiving SIS Services on this Field?	Yes/No
Has the Grower Received SIS Services on this Field and any other Fields in the Past? If so, When?	Yes/No with an added question if the answer is "Yes"
Picture of Field	Pictures taken by grower with tablet
Equipment Details	
Approach for Actual Water Use	Drop-down with options
Equipment Installed	Drop-down with options
Equipment Serial Numbers	Text field – open ended

Took Solocator Photo and Uploaded it to SharePlus?	Yes/No
Describe Location of Installed Equipment	Text field – open ended
Flow Meter Reading *(if an integrated flow meter is installed)*	Numerical Field
Flow Meter Reading Units *(if an integrated flow meter is installed)*	Drop-down with options
Pictures of Installed Equipment	Pictures taken by grower with tablet
QC Checklist	Checklist
Departure Time of Initial Visit	Timestamp Field

Initial Visit Checklist

- Confirm that you have correctly located the sampled field
- Identify irrigation system setup
- Install appropriate equipment for the actual water use based on the irrigation system type
- Take Solocator photo of equipment serial number and field ID then uploaded it to SharePlus
- Obtain electric utility name, crop type, crop rotation, water source, field acreage
- Take photos of the installed equipment and of the field
- Complete closing interview with the grower

Follow-Up Visit Form

Table D-3: Follow-Up Visit Data Collection Form

Follow-up Visit General Information	
Field ID	Automatically populated
Irrigation Consultant at Follow-up Visit	Drop-down with options
Follow-up Visit Date	Timestamp Field
Arrival Time of Follow-up Visit	Timestamp Field
Follow-up Visit Measurements	
Status of Installed Equipment	Text field – open ended
Status of Crop at Follow-Up Visit	Text field – open ended
Actual Water Use Method	Drop-down with options
Actual Water Use Measurement *(if method is an integrated flow meter)*	Numerical entry with allowable range
Units of Measurement *(if method is an integrated flow meter)*	Drop-down with options
Notes about Measurement *(if method is an integrated flow meter)*	Text field – open ended
Scan Serial Number of Installed Equipment	Text field – open ended
Downloaded Data and Equipment is still Logging? *(if method is a tipping rain gauge or pressure gauge)*	Yes/No
Picture of Installed Equipment	Pictures taken by grower with tablet
Notes from Irrigation Consultant about Site Visit	Text field – open ended
QC Checklist	Checklist
Departure Time of Follow-up Visit	Timestamp field

Follow-Up Visit Checklist

- Record a measurement of the actual water use (including units)
- Note the status of the equipment measuring the actual water use
- Note the crop status

- Notify the grower (if the grower is present) when we will be returning for the next visit

Table D-4: Ultrasonic Flow Measurement Form

Retrieval Visit General Information	
Field ID	Automatically populated
Irrigation Consultant Doing Ultrasonic Flow Measurement	Drop-down with options
Date of Ultrasonic Flow Measurement	Timestamp Field
Start Time of Ultrasonic Flow Measurement Visit	Timestamp Field
Scan Serial Number of Installed Equipment	Text field – open ended
Measurements	
What Type of Irrigation System is it?	Drop-down with options
Able to Find a Straight Enough Piece of Pipe with Laminar Flow?	Drop-down with options
Measure the Following: *(If unable to find a straight piece of pipe and it is a sprinkler or micro-sprinkler*) • Nozzle Diameter • Nozzle Pressure • Head Spacing • Line Spacing • Sprinkler Efficiency	Numerical entry with allowable range
Measure the Following: *(If unable to find a straight piece of pipe and it is a drip system)* • Emitter Flow Rate • Emitter Spacing Along the Line • Distance Between Drip Lines	Numerical entry with allowable range
Location of Measurement *(If able to find a straight enough piece of pipe)*	Text field – open ended
Flow Measurement Reading *(If able to find a straight enough piece of pipe)*	Numerical entry with allowable range
Flow Measurement Units *(If able to find a straight enough piece of pipe)*	Drop-down with options
Notes about Flow Measurement	Text field – open ended
End Time of Ultrasonic Flow Measurement Visit	Timestamp Field

Retrieval Visit Form

Table D-5: Retrieval Visit Data Collection Form

Retrieval Visit General Information	
Field ID	Automatically populated
Irrigation Consultant at Retrieval Visit	Drop-down with options
Retrieval Visit Date	Timestamp Field
Arrival Time of Retrieval Visit	Timestamp Field
Retrieval Visit Notes from Irrigation Consultant	Text field – open ended
Measurements	
Actual Water Use Method	Drop-down with options
Scan Serial Number of Installed Equipment	Text field – open ended
Status of Installed Equipment	Text field – open ended
Status of Crop	Text field – open ended
Actual Water Use Measurement *(if method is an integrated flow meter)*	Numerical entry with allowable range
Units of Measurement *(if method is an integrated flow meter)*	Drop-down with options
Notes about Measurement *(if method is an integrated flow meter)*	Text field – open ended
Downloaded Data & Equipment is still Logging? *(if method is a tipping rain gauge or pressure gauge)*	Yes/No
Pictures of Installed Equipment	Pictures taken by grower with tablet
Notes about Measurement	Text field – open ended
Notes about Equipment Removal	Text field – open ended
Questions for Grower	
Abnormal Events during the Growing Season Affecting their Irrigation Strategy	Text field – open ended
Did they use Beneficial Irrigation during the Growing Season? *(frost protection, evaporative cooling, etc.)*	Text field – open ended

Any other Notable Information about the Growing Season	Text field – open ended
Date of Crop Emergence	Date field
Date that Crop Cover Exceeded 10% of Field	Date field
Date that Crop Cover Exceeded 70% of Field	Date field
Date of Initial Crop Maturation	Date field
Date of End of Growing Season	Date field
Cutting Dates *(If it is a forage crop, for example: alfalfa, mint, grass hay)*	Date field
Average number of days it takes before regrowth begins after cutting a forage (e.g., 10 days) *(If it is a forage crop, for example: alfalfa, mint, grass hay)*	Numerical entry with allowable range
Average number of days between when the crop begins to regrow and it reaches full coverage after a cutting (e.g., 20 days) *(If it is a forage crop, for example: alfalfa, mint, grass hay)*	Numerical entry with allowable range
QC Checklist	Checklist
Departure Time of Retrieval Visit	Timestamp Field

Retrieval Visit Checklist

- Record a final measurement of the actual water use (including units)
- Take a photo of the installed equipment
- Remove the installed equipment
- Ask the grower about any abnormal events affecting their irrigation strategy during the growing season
- Ask the grower if they used beneficial irrigation during the growing season (frost protection, evaporate cooling, etc.)
- Ask the grower when the five key points in the crop's growing cycle occurred: emergence date, canopy cover exceeds 10% of field, canopy cover exceeds 70% of field, crop initial maturation, and end of growing season. If it is a forage crop ask about: when the cutting dates occurred, average number of days between a cutting and when regrowth begins, and average number of days between when regrowth begins and the crop reaches full coverage.

Table D-6: Supplementary Retrieval Visit Form

Supplementary Questions	
Field ID	Automatically populated
Field-Specific Question 1:	Text field – open ended
Answer to Field-Specific Question 1:	Text field – open ended
Field-Specific Question 2:	Text field – open ended
Answer to Field-Specific Question 2:	Text field – open ended
Field-Specific Question 3:	Text field – open ended
Answer to Field-Specific Question 3:	Text field – open ended
Field-Specific Question 4:	Text field – open ended
Answer to Field-Specific Question 4:	Text field – open ended
Field-Specific Question 5:	Text field – open ended
Answer to Field-Specific Question 5:	Text field – open ended

Appendix H – Field Work Issues and Solutions

To: Carrie Cobb

From: Emily Merchant and Beth Davis (Navigant)

Date: December 12, 2016

Subject: SIS study field work issues and solutions at completion of field work

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This memo outlines the field work issues and solutions encountered through the BPA scientific irrigation scheduling (SIS) baseline research study through the end of field work, which finished in November of 2016. The first section of the memo includes the field work issues and solutions discussed in the memo submitted on June 13, 2016. The second section of the memo discusses the field work issues and solutions that occurred between June and the completion of field work in November of 2016. Issues that were discussed in the June memo that occurred again since June are not discussed in the second section of the memo.

Issues from the Start of the Study to June 2016

- **Issue**: Orchards and vineyards can have multiple irrigation systems, including any combination of drip systems, under tree sprinklers, and over tree sprinklers. It is difficult to capture the total water applied to the entire field using one pressure gauge setup when there are multiple irrigation systems.
    - ***Solution***: When orchards and vineyards have multiple irrigation system types on the same field they typically operate one system at time, which allows us to use one pressure gauge per field as long as we can tell from the data when each system is operating. We identified the location in the water pipe before all of the irrigation systems break off so we could monitor the water applied by all of the systems. In order to determine the water applied by each irrigation system, we plan to ask the grower the pressure ranges of each system type and then determine from the data when each system is operating. We will then take ultrasonic flow measurements of each system to determine the flow rate of each system. Next, we will multiple the flow rate of the system by the runtime of the system to determine the water applied by each system. For instances where we cannot find a spot in the water pipe that supplies water to both irrigation systems then we will install two pressure gauge setups.
    - ***Follow-up Note***: Based on our conversations with the irrigation consultants we thought this would work for all of the fields with multiple irrigation systems. After we checked on

these fields a month later we found that this solution did not work for all fields. The bullet below discusses our solution for those fields.

- **Issue**: The solution we came up with for monitoring multiple irrigation systems in orchards and vineyards did not work for all of the sites.
    - o **Background Information**: Upon visiting some of the orchard and vineyard sites, we found that some of the fields had multiple irrigation system types. The field techs configured a setup that allowed us to use one pressure gauge setup at each site, despite there being multiple irrigation system types. Upon visiting the field one month later, the field techs found the set up did not work for all the fields with multiple irrigation systems. We used a check valve for one of the fields with multiple irrigation systems so we could use one pressure gauge. When the field tech went back one month later they found the data to be unusable. The grower does not track their irrigation use so we had to drop the field.
    - o ***Solution***: Moving forward, we will use one pressure sensor per irrigation system for all fields with multiple irrigation system types. We will not use one sensor for multiple irrigation systems.
    - o ***Follow-up Note***: As mentioned in the bullet above, we encountered an issue with orchard and vineyard fields that had multiple irrigation systems. Our initial solution turned out to not work for all fields so we came up with this alternate method for those fields.
- **Issue**: Corn debris and leaves can impact the measurements due to the height of the crop.
    - o ***Additional Background***: The height of the corn will eventually exceed the height of the tipping rain gauge, which can affect the accuracy of the tipping rain gauge if the collector screen is clogged. It is important that the tipping rain gauge collector screen stays clear of obstructions so the tipping mechanism can accurately capture the water applied to the field.
    - o ***Solution***: The irrigation consultants cleared out a five foot by five-foot area around the tipping rain gauge to prevent the corn from obstructing the tipping rain gauge measurements.
- **Issue**: At the beginning of the study we experienced issues with the tipping rain gauge base stations, which connect the data logger to the computer so the field techs can launch the loggers and extract data from the loggers.
    - o ***Additional Background***: We identified a design flaw in the base station at the beginning of the study, which was due to a recent update to the equipment.
    - o ***Solution***: We installed manual rain gauges until the issue was fixed, which took five days. Onset updated the part and overnighted them to the irrigation consultants so we could launch the tipping rain gauges. We will add the measurement from the manual rain gauge to the tipping rain gauge reading at the end of the study.
- **Issue**: The data logger cable in the tipping rain gauges is too long and can easily get tangled in the tipping mechanism.
    - o ***Additional Background***: We used a black sticky mechanism and a zip tie to secure the cord against the side of the bucket so the cord would be out of the way of the tipping mechanism. Due to the temperature swings and humidity the black sticky lost contact with the side of the tipping bucket and fell on the tipping mechanism, obstructing the measurements. As a result, the tipping bucket read no water for the entire month. We had to throw out that field.
    - o ***Solution***: We came up with a new cable management strategy and mandated that the irrigation consultants implement it for all of the tipping rain gauge sites. We added a

section in the field form that requires the irrigation consultants to take a picture of the internals of the tipping bucket before leaving the site so we can review it the next day to check for any cable issues. The photo allows the QC'ers to catch any cable management issues within a day of the site visit so the field techs can go back immediately if there are any issues.

- **Issue**: Within the period of a week, two tipping rain gauges got knocked over and destroyed by a spray truck in the same field.
    - o ***Additional Background***: We installed a tipping rain gauge in a field and a spray truck knocked it over and destroyed the tipping rain gauge. The grower notified ProAg immediately so we were able to install a new tipping rain gauge without losing any data. Within a week the same spray truck knocked over the new tipping rain gauge so we had to go back and install a third tipping rain gauge.
    - o ***Solution***: We were able to keep the field in the sample because we found out within days of the issue. The field techs installed a new tipping rain gauge and interviewed the grower about the water applied between when the tipping buckets got knocked over and when they installed a new tipping bucket. The grower is finished spraying for the growing season so we do not anticipate encountering this issue again. ProAg called the grower and reiterated the importance of our equipment and asked them to contact the sprayer to tell them to be more careful.
- **Issue**: We found that tipping rain gauges do not accurately capture water from solid set systems in orchards and vineyards.
    - o ***Additional Background***: Our field data collection protocol says we would install a tipping rain gauge in fields with solid set systems but we found this method does not work in orchards and vineyards because there is not a way to get a tipping bucket installed between the water leaving the sprinkler and the water hitting the canopy.
    - o ***Solution***: We installed a pressure gauge setup in all orchards and vineyards with solid set systems.
- **Issue**: The tipping rain gauges utilize a base station which connect the data logger to a computer. The base station is highly sensitive to light and if it is a bright day outside then the logger will not communicate with the computer.
    - o ***Solution***: The field techs put a sock over the base station or cover it with a binder to avoid interaction from the sun.
- **Issue**: We could only use 16 of the 31 U30 data loggers we borrowed from BPA because not all of the loggers had the VIA board that we need to hook up the pressure transducer.
    - o ***Solution***: We mailed back the 16 U30s we couldn't use and had David Smith update the loan agreement. We ordered additional U30s from Onset that have the VIA board we need.
- **Issue**: Of the 15 BPA loggers with VIA boards, we found that at least 50% of them produced unusable data. Some of the loggers read 0 psi for an entire month, others fluctuated between 0 & 5 psi, and others stayed at 100 psi (on 24/7) all month.
    - o ***Solution***: We followed up with the growers to see if they keep track of the run time of the system and then we replaced the malfunctioning U30 with a new U30. At the end of the growing season we will add the run hours from the beginning of the season to our pressure sensor measurements to get the total run time of the system.
- **Issue**: When the field tech went to go read out a tipping rain gauge site they found the top of the rain gauge to be 10 feet away from the tipping rain gauge bucket.
    - o ***Additional Background***: The field tech believes that the grower tampered with the tipping rain gauge because there is no way that the wind could have taken off the top of

the tipping rain gauge. The grower seemed skeptical when the field tech was initially installing the equipment.
    - ***Solution***: We had to throw out the field from the sample due to the lost data.
- **Issue**: One of the field techs forgot to remove the rubber band from inside the tipping bucket so the tipping rain gauge did not read any measurements for the entire month. The rubber band holds the tipping mechanism in place.
    - ***Solution***: The field tech returned to the field and removed the rubber band. The grower only irrigated once during the time that that the rubber band was installed and they were able to download the water applied information from their irrigation system. As a result, we were able to keep the field in our sample. In order to prevent this from happening again we added a section in the field form that requires the field tech to take a photo of the internals of the tipping rain gauge bucket so the QC'er can check if the rubber band is still installed within a day of the site visit.
- **Issue**: One of the tipping rain gauges was placed under a broken sprinkler so it did not read any water for the entire month.
    - ***Solution***: We moved the tipping rain gauge to a better spot, and we requested the water applied information from the grower for the month we missed so we could keep the field in our sample.
- **Issue**: The irrigation consultant installed the equipment in the wrong field. The field where they installed the equipment was not the same as the field that we sampled.
    - ***Solution***: The sampled field is receiving SIS so we had to drop that field from the non-SIS population.
- ***Issue***: The irrigation consultant installed the equipment in another wrong field. The field where they installed the equipment was not the same as the field that we sampled.
    - ***Solution***: We were able to catch the issue in time due to our QC process and have the irrigation consultant install the equipment in the correct field.
- **Issue**: Cows knocked over and destroyed two tipping rain gauges.
    - ***Solution***: We replaced the tipping rain gauges with pressure gauge setups, which are out of the way of the cows. The grower did not irrigate the fields yet so we were able to keep the fields in our sample.
- **Issue**: One of the loggers stopped logging because it was full of data. We did not capture one weeks' worth of the logging period.
    - ***Solution***: We were able to install a new tipping rain gauge and keep the field in the study because the grower did not irrigate during the week that we missed. We called Onset to ensure this would not be an issue for any other sites. Onset said the reason why the logger filled up is because the field tech mistakenly logged temperature in one minute increments, which quickly used up the memory. We reiterated to the field techs the importance of only logging irrigation or rain events and not logging temperature. In addition, we added a QC check to open up the logger files to check if the logger is logging temperature. If the QC'er finds the logger is logging temperature the field tech is required to go back to the field immediately to relaunch the logger so it is only logging irrigation or rain events.
- **Issue**: When downloading the data from one of the tipping rain gauges the field tech got an error saying "bad header error."
    - ***Solution***: We were able to do a force offload and retrieve the data. We replaced the tipping rain gauge with a new tipping rain gauge.
- **Issue**: Onset said the tipping rain gauge battery should last the duration of the growing season; however, we found that the batteries went down by 25% in the first month of data collection. We

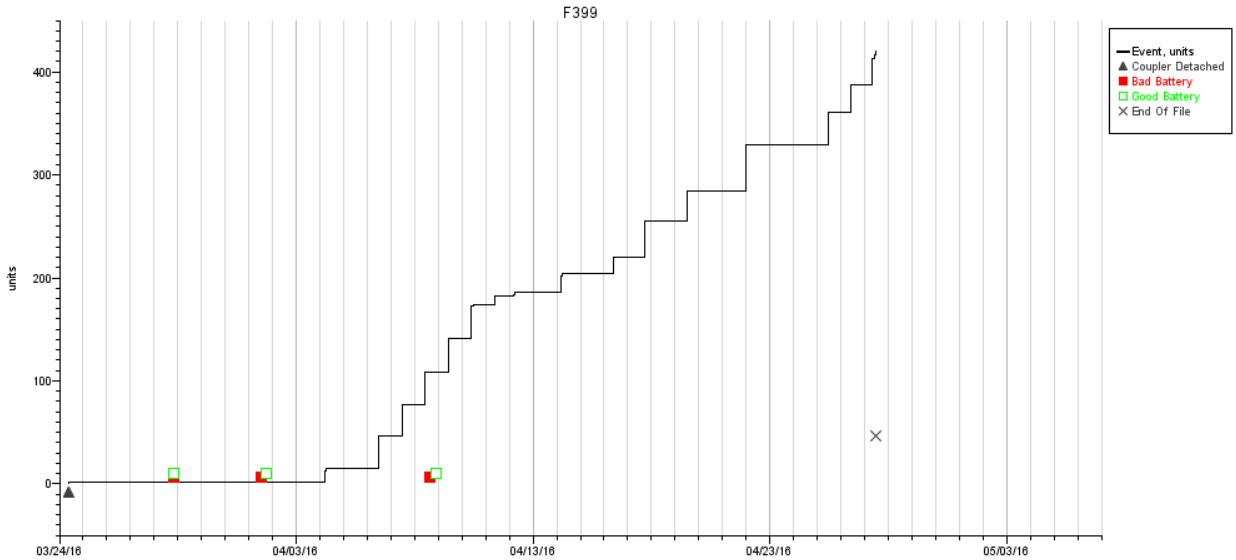
will be deploying the equipment for up to seven months; therefore, it is highly likely that the batteries will not last for the entire growing season.

  - ***Solution***: We ordered extra three volt batteries and sent them to the field techs, along with detailed instructions on how to change them. We also added a section in the field forms that asks the field techs to input the battery percentage and reminds them to change the battery if it less than 40%. The QC'er checks the battery level the next day and if the field tech did not change out the battery when the battery is less than 40% then the field tech is required to go back to the field immediately.

Issues from June 2016 through November 2016

- **Issue**: The tipping rain gauges got clogged with corn debris on a few occasions, despite the field tech's best efforts to remove tall crops within a five-foot radius of the equipment. Corn fields can grow over six feet tall, which exceeds the maximum height of the tipping rain gauge. The field tech tried to stomp down an area around the equipment in corn fields but debris would often still get in the rain gauge due to high winds.
  - ***Solution***: The field tech was able to unplug the rain gauge and the tipping mechanism recorded the water that was still being held in the collector screen. We knew no data was lost due to the design of the collector screen and its ability to hold water until the end of the funnel is open. Since we are confident no data was lost we were able to keep these fields in the sample.
- **Issue**: The field techs encountered an error with two tipping rain gauges saying that the battery had been reset when they tried to read out the data logger. We called Onset and they said this error can occur due one of the following reasons: replacing the battery, if the battery gets too cold, lightning, or if condensation shorted the electronics. The data is stored on the logger until the power is reset but no additional data is recorded after the power is reset. We lost a few weeks' worth of data in both situations.
  - ***Solution***: We sent the loggers to Onset for diagnostic testing and they were not able to recreate the issue. They said it could have been because of a nearby lightning strike. The field tech did not replace the battery so that was not the issue. Onset sent us back replacement loggers and we installed them in the tipping rain gauges. We had to drop one of the fields due to data loss and we were able to keep one field due to the timing of when we found the error.
- **Issue**: When reading out the logger data from the tipping rain gauges we saw bad battery signals on the graph (see Figure 1). This occurred on three pieces of equipment, two we had to drop because the logger eventually stopped recording, and one we were able to save because it didn't stop recording data before the field was harvested.
  - ***Solution***: We sent the loggers back to Onset for diagnostic testing. They were not able to recreate the issue; therefore, they were unable to provide clarity on the issue. They sent us back replacement loggers.

Figure 1: Example of bad battery signals in the tipping rain gauges

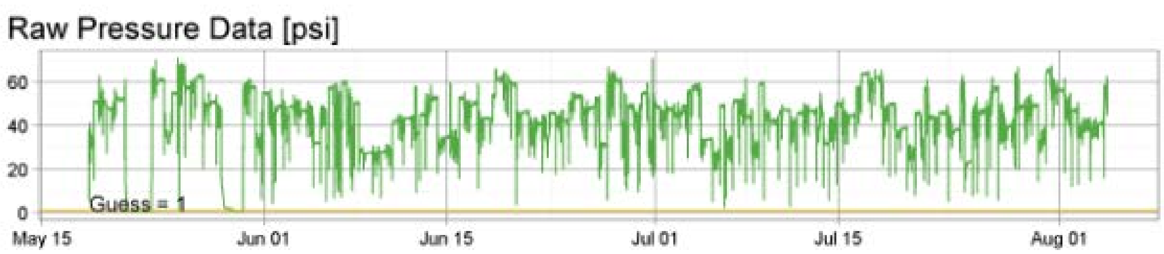


Source: Navigant data collection

- **Issue**: A tipping rain gauge never recorded any events, despite there being irrigation and rainfall events.
    - ***Solution***: We had to drop the field because the grower did not track their water applied through an hour meter or other methods. We spoke to Onset about the issue and they were not able to provide any clarity on the issue.
- **Issue**: The tipping rain gauge was recording irrigation and rainfall events for the first month and then it stopped recording data after the first follow-up visit.
    - ***Solution***: We were able to leverage data recorded by the grower for the days we missed and then we replaced the tipping rain gauge. We spoke to Onset about the issue and they were not able to provide any clarity on the issue.
- **Issue**: Our equipment went missing during cuttings or harvests because multiple teams were moving through the fields, and it is hard to track down who took the equipment. The reason why the equipment can go missing during harvest is because farming equipment comes through the field, which can result in things in the field getting knock over or grabbed up by the farming equipment if it has not been removed prior to harvest.
    - ***Solution***: For some of the tipping rain gauges we were able to track the equipment down, for others they were never found. We were able to keep the fields in the sample when we were able to track down the equipment because we were able to download the data off of the logger and contact the grower for the closing interview. We were able to keep some of the lost tipping rain gauges in our sample due to getting water applied data from the growers. We dropped five fields due to lost equipment because we were unable to get the missed water applied data from the grower.
- **Issue**: We were unable to take the ultrasonic flow measurements for two of the pressure gauge fields due to the grower not getting back to us to schedule the site visit prior to them shutting off the water for the growing season.
    - ***Solution***: We were still able to keep the two fields in the sample by using parameters such as the nozzle diameter, head spacing, and sprinkler efficiency to calculate the flow rate of the irrigation system.

- **Issue**: A grower did not contact the field tech prior to doing an alfalfa cutting and they removed the equipment then put it back it in. The grower did not level the equipment correctly and therefore the tipping rain gauge read erroneous measurements for a few weeks.
    - ***Solution***: The field tech leveled the equipment during the follow-up visit and was able to get hour meter data from the grower for the few weeks with erroneous measurements. As a result, we were able to keep the field in our sample. The field tech spoke to the grower and reiterated that the grower should call us in advance of a cutting so we can remove our equipment in time.
- **Issue**: The tipping rain gauge was launched in July and when the field tech went back a month later it didn't record any data even though there were rainfall and irrigation events. The field tech checked the status of the equipment in HOBOware to see if the logger was picking up any tips when they manually moved the black tipping mechanism back and forth, which it did not.
    - ***Solution***: Onset recommended that the field tech do a manual offset of the data to see if the logger recorded and data, which it did not. We ended up dropping the field because the grower did not have any hour meter data or a record of their water applied.
- **Issue**: An apple field had two irrigation systems, under tree sprinklers and over tree sprinklers. Due to the way the system was set up, it was impossible to monitor each system separately. The pressure data was so noisy that it wasn't possible to determine when each system was on due to the high variability in pressure ranges that each system operates at (see Figure 2). It is common for apple fields to have multiple irrigation situations but the field techs can usually find a way to either monitor each system separately or the pressure ranges are different enough that they can tell them apart if they are monitoring them with the same piece of equipment. This situation was unique in that we couldn't use either of these methods.

Figure 2: Pressure variability in an apple field



Source: Navigant data collection

- ***Solution***: The field tech took an ultrasonic flow measurement on each of the irrigation systems. Since we were unable to distinguish between the two systems in the data we took an average of the two ultrasonic flow measurements and applied it to the run time recorded over the growing season. The pressure ranges of the two systems were very similar and the grower runs each system about half of the time. As a result, we are confident in averaging the flow rates, particularly since we spoke to multiple irrigation experts about our methodology.

- **Issue**: There are often multiple companies going in and out of a field at any given time applying pesticides, harvesting, etc. Due to the time sensitivity of some of the issues that come up on a farm, the grower isn't always able to contact us to remove the equipment in time. Some crops have to be harvested at night time, which makes it difficult for the person driving the swathing equipment to avoid our equipment. On multiple occasions our equipment got damaged by getting knocked over by farming equipment, making it unusable.

  - ***Solution***: We were able to keep these fields in our sample because the grower alerted us in time to install new pieces of equipment before we missed any water applied to the crop. The equipment was no longer usable but we were still able to download the logger data off of it. Every time our equipment got damaged we called the grower to reiterate the importance of this study and to call us in advance of any farming equipment going into the field so we could remove our equipment in time.

- **Issue**: Birds often like to perch up on equipment in the field, which is we why we installed Bird-B-Gone strips on the tipping rain gauges. We found signs of birds resting on our equipment even despite our efforts to prevent them from doing so.
  - ***Solution***: We cleaned out the equipment during the follow-up visits and made adjustments to the Bird-B-Gone strip to prevent any more birds from perching on our equipment. There was not a concern of data loss because the funnel was clean enough for the water to still pass through and the bird deposits did not go down the funnel, it just affected the collector screen.

Appendix I – Data Collection Approach Used for SIS Program and SIS Non-Program Fields

To: Carrie Cobb, Bonneville Power Administration (BPA)

From: Emily Merchant, Navigant Consulting, Inc.

Date: December 15, 2016

Subject: Data Collection Approach for SIS Program and SIS Non-Program Fields

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This memo discusses the data collection approach that Navigant Consulting, Inc. (Navigant) implemented during Bonneville Power Administration's (BPA's) Scientific Irrigation Scheduling (SIS) study to collect SIS program and SIS non-program data from irrigation consultants.

This memo contains the following two sections:

- **SIS Program Data:** This section discusses the approach that Navigant used to collect data for the SIS program fields, which are fields that received SIS services and received an incentive through BPA's SIS program.
- **SIS Non-Program Data:** This section discusses the approach that Navigant used to collect data for the SIS non-program fields, which are fields that received SIS services but did not receive an incentive through BPA's SIS program.

SIS Program Data

In order to characterize the general market for the SIS study, Navigant aimed to collect data from a census of the fields that participated in BPA's 2016 SIS program. Data quality is one of the highest priorities of this study, which is why Navigant conducted a pilot with the 2015 SIS program data in December 2015 to work through any data quality issues prior to the 2016 SIS program year. Navigant submitted a data request to Professional Ag Services (ProAg), IRZ Consulting (IRZ), and Irrinet in December 2015 for the fields that participated in BPA's 2015 SIS program in the Columbia River Basin. This request included a spreadsheet that was nearly identical to the one Navigant used for the 2016 SIS program year.[1] Navigant had a variety of back and forth with the irrigation consultants about the request in January 2016 and reiterated that the consultants would need to provide data again in November 2016 for the 2016 SIS program year.

See below for a timeline of events to acquire the 2015 and 2016 SIS program datasets.

- **December 2015:** Navigant requested the 2015 SIS program data from IRZ, ProAg, and Irrinet to test the data request protocol prior to the 2016 SIS program year.
- **March 2016:** Navigant completed a memo of results and lessons learned from the 2015 SIS program data test.[2]
- **April 2016:** Tom Osborn at BPA emailed the irrigation consultants who planned to participate in BPA's 2016 SIS program about the program data request due in November 2016.
- **November 2016:** Navigant received the 2016 SIS program data from IRZ and ProAg. Tom Osborn contacted the other irrigation consultants that participated in BPA's 2016 SIS program that had not yet sent Navigant data; these consultants included Irrinet, SoilTest, and AgriNorthwest (AgriNW).
- **December 2016:** SoilTest and AgriNW sent Tom Osborn their 2016 SIS program data. Irrinet did not submit their 2016 SIS program data; therefore, Navigant was unable to include their fields in the analysis. Navigant reviewed the program data from IRZ, ProAg, SoilTest, and AgriNW, and communicated with the irrigation consultants about assumptions and missing data until the 2016 SIS program dataset was complete.

The data request spreadsheet included all of the data points that Navigant needed from the irrigation consultants to calculate the seasonal water requirement and water applied for each field. Navigant included a data dictionary in this spreadsheet to ensure that the irrigation consultants had a consistent interpretation of the spreadsheet. The list below includes the data points and definitions that Navigant included in the SIS program data request spreadsheet.

- **Field ID:** Unique identifier for the field.
- **Latitude:** Latitude of field location.
- **Longitude:** Longitude of field location.
- **Weather Station:** Weather station closest to the field in terms of location and topography.
- **Crop Type:** Crop type receiving SIS services on the field.
- **Soil Type:** Dominant soil type on the field.
- **Field Acreage:** Total acreage of the field being irrigated.
- **Irrigation System Type:** Method for applying irrigated water. If there are multiple systems, please specify.

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[1] The only difference between the 2015 data request spreadsheet and the 2016 data request spreadsheet is that in 2015 Navigant asked the irrigation consultants for two additional data points related to forage crops (e.g., alfalfa and mint). Navigant decided to drop these two data points from the 2016 data request and rely on defaults in AgWeatherNet due to the minimal variability in those data points.

[2] Memo on 2015 Program Data Results and Lessons Learned (Navigant), 2016.

- **Method for Water Applied:** If this is "other," note what it is (e.g., rain gauge, flow meter, hour meter).
- **Water Applied Method Notes:** State any assumptions used to adjust numbers recorded by the rain gauge, flow meter, hour meter, etc. (e.g., application efficiency adjustments).
- **Water Applied (inches):** This should be the water hitting the crop, not the water going through the pipes.
- **Emergence Date:** Date that the crop emerges and/or the plant starts using water.
- **10% Canopy Cover Date:** Date that the crop water use starts increasing and crop coverage exceeds 10% of the field area or shades 10% of the ground area. Leaves start changing colors, crop starts growing larger in earnest.
- **70% Canopy Cover Date:** Date the crop canopy exceeds 70%-80% of the field area or shades 70%-80% of the ground area. Crop is nearly full grown and/or the rows close (from above you can only see 20%-30% of soil).
- **Maturation Date:** Date the crop begins to dry up and water use begins to decrease. Senescence starts, crop begins changing colors (less vibrant green, starting to see brown).
- **End of Growing Season:** Date the water use stops, which typically coincides with the harvest or first frost.
- **Cutting Dates:** Dates that cuttings occurred, which is applicable to forage crops only (e.g., alfalfa and mint).

SIS Non-Program Data

Another key component of the general market population are the fields that received SIS services but did not receive an incentive from BPA, which are referred to as SIS non-program fields. Navigant did not conduct a census approach for this group of fields, but instead used statistics to determine how many 2016 SIS non-program fields Navigant would need to sample to match the relative contribution of this group to the general market population, which is 7%. Based on these conditions, Navigant needed to sample 19 SIS non-program fields assuming no fields dropped out of the sample or 22 fields assuming 15% of fields dropped out of the sample.

Of the 735 fields that Navigant had contact information for at the start of the study, 42 were identified as SIS non-program fields by the irrigation consultants. Even though Navigant only needed 22 fields to satisfy a 15% contingency, Navigant included all 42 SIS non-program fields in the sample to account for the likelihood of growers switching field study categories (i.e., starting out the growing season in the SIS program and switching to non-SIS partway through the study) or the grower refusing to sign the waiver that released their data to Navigant.

Prior to the start of the 2016 growing season, Navigant notified IRZ and ProAg about the data they would need to submit at the end of the growing season for the 42 SIS non-program fields, as well as the expectation that the consultants obtain a signed waiver from each grower to release the data to Navigant. The data request spreadsheet Navigant sent to IRZ and ProAg had two tabs: one for the 2016 SIS program fields and one for the 2016 SIS non-program fields. The data points requested in both tabs were identical. The SIS Program Data section provides the names and definitions of the data points.

At the conclusion of the growing season in November of 2016 both IRZ and ProAg sent the data for the SIS non-program fields, along with the completed waivers from those growers. Two fields dropped out of the original group of 42 fields because the grower switched from SIS non-program to non-SIS partway through the growing season, but this did not compromise the results because Navigant only needed 19 SIS non-program fields to meet the confidence and precision targets for that stratum.

Appendix J – Quality Control Methods and Data Quality Problems Remedied

To: Carrie Cobb, Bonneville Power Administration (BPA)

From: Emily Merchant and Beth Davis, Navigant Consulting, Inc.

Date: December 15, 2016

Subject: Quality Control Methods and Data Quality Issues in the SIS Study

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This memo discusses the quality control (QC) methods that Navigant Consulting, Inc. (Navigant) implemented during the Bonneville Power Administration (BPA) Scientific Irrigation Scheduling (SIS) study. Irrigation consultants conducted over 1,200 site visits for non-SIS fields in the sample, which resulted in a significant amount of data being shared between Navigant and the irrigation consultants. Thus, Navigant developed rigorous QC procedures to ensure that the irrigation consultants gathered high quality data on-site. In addition to the non-SIS field data, Navigant also received SIS program and SIS non-program data from the irrigation consultants, which included over 1,300 fields. SIS program and SIS non-program data is a significant portion of the general market population, which is why Navigant conducted a thorough data QC prior to incorporating it into its analysis.

This memo is broken out into four sections:

- **Proposed vs. Implemented QC Methods:** This section discusses the QC methods Navigant outlined in the BPA SIS Field Data Collection Protocol memo prior to the start of field work as compared to the final methods Navigant used.[1]
- **Field Data QC:** This section discusses the QC methods Navigant used to review the field data collected by the irrigation consultants.
- **QC Automation:** This section discusses the data automation Navigant developed to streamline some of the QC processes.
- **SIS Program, SIS Non-Program, and Non-SIS Data QC:** This section discusses the QC methods Navigant used to review the SIS program and SIS non-program data, which included data from over 1,300 fields. This section also discusses the review Navigant conducted of the non-SIS data as well as the next-day QC of the field data.

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[1] FINAL - AG SIS Baseline Field Data Collection Protocol (Navigant), 2016. https://conduitnw.org/Pages/File.aspx?rid=3389

Proposed vs. Implemented QC Methods

Prior to beginning field work, Navigant developed a Field Data Collection Protocol that outlined the data collection procedures used in this study. One of the sections in the Field Data Collection Protocol, Quality Control, discussed the QC procedures that field techs would follow during and after a site visit. Table 1 shows the QC procedures included in the protocol, as well as a description of what Navigant implemented during the study. Below the table are additional QC procedures that Navigant implemented during the study that the field data collection protocol did not discuss.

Table 1: Proposed vs. Implemented QC Strategies

Proposed QC Strategy	Implemented QC Strategy
Navigant will ride along with an irrigation consultant from each company for the first couple of visits and debrief with all of the irrigation consultants to discuss observations. The ride-alongs will be for non-SIS fields only.	Navigant conducted ride-along visits with IRZ Consulting (IRZ) and Professional Ag Services (ProAg) in February 2016.
Navigant will have monthly check-in meetings with all of the irrigation consultants conducting field monitoring for the study to discuss any issues with the study and any questions regarding the protocol.	Navigant had a weekly check-in meeting with IRZ and a less structured check-in schedule with ProAg, which evened out to a biweekly check-in with ProAg.
The field forms will have built-in QC that only allows data entry of certain number ranges. There will also be QC checklists as part of every field form.	Navigant built in data validation into the field forms. Navigant also had a QC checklist section in all of the field forms as a reminder for the field techs to make sure they collected the key data points on-site.
Navigant will QC the submitted field forms in the iPad data collection software on the morning after the site visit.	Navigant QC'ed the field forms the morning after each site visit.
Navigant will analyze the SIS data from the 2015 program year (PY) to identify any issues with the data prior to the 2016 PY.	Navigant analyzed the 2015 SIS program data in preparation for the 2016 growing season. This proved to be an effective strategy because the irrigation consultants were more comfortable with the data request in 2016; therefore, minimal back and forth was required in 2016.
Navigant will use a tipping rain gauge as the primary method for measuring the actual water use. The tipping rain gauge timestamps when every 0.01 inches of water is applied to the field, which increases the accuracy of the data collection because it gives a full picture of the irrigation events.	Navigant used the tipping rain gauge as the primary source of data collection.
The irrigation consultants will bring blank paper copies of the field forms in case the tablets malfunction on-site.	Navigant advised the irrigation consultants to bring paper copies of the field forms on-site, but they did not need to rely on the paper copies because the iPads never malfunctioned.

Proposed QC Strategy	Implemented QC Strategy
For the tipping rain gauge method, the irrigation consultant will visit the field one time/month to ensure the tipping rain gauge does not clog or get knocked over; for the integrated flow meter method, the irrigation consultant will visit the fields four times/growing season to ensure no data is lost; and for the pressure gauge, the irrigation consultant will visit the field one time/month to download the data and ensure no data is lost.	IRZ and ProAg visited the tipping rain gauge sites and the pressure gauge sites once a month and often more frequently due to a need to remove the equipment for field cuttings or equipment issues. Navigant tracked when the irrigation consultants last visited the field and notified them when they had upcoming site visits and when they were late on site visits. There were no integrated flow meter sites in the sample.
No one will know which SIS fields are in the baseline population versus those that are not, which makes it difficult for the data to be skewed for optimal results.	Navigant ended up using a census of the SIS program data; therefore, this QC strategy was not relevant.
Navigant designed the SIS field data collection protocol to mirror what the irrigation consultants are already doing for SIS fields. If Navigant identifies a QC issue for non-SIS fields then the issue and resolution will likely carryover to the SIS fields as well.	Navigant stayed true to this strategy for the duration of the study. Navigant erred on the side of caution during field work and always consulted with IRZ and ProAg to see how they treated SIS fields to ensure an apples-to-apples comparison between the non-SIS fields and the SIS fields.
While on-site, the irrigation consultant will verify he/she properly installed the equipment required to measure the actual water use, go through the QC checklist, confirm that critical data points have been collected, obtain site contact information, and ensure the contact is aware of future site visits.	Each field form in Fulcrum had a QC checklist to ensure that the field techs collected all of the necessary data on-site.[2] Navigant had a team of six people review the field forms the day after the site visit, referred to as "QC'ers", and they verified that the field techs collected all of key day points on-site.
After going on-site, the field tech will review the field form to ensure he/she has filled out all of the required fields and note any data points that he/she was unable to collect.	Navigant relayed this guidance to the field techs. Navigant QC'ed all of the field forms the day after the site visit to catch any missing or wrong data points immediately after the site visit.
After the site visit, Navigant will verify there is no missing information, review the data to ensure that it is reasonable, and confirm that the irrigation consultant visited the correct field based on the GPS coordinates of the sampled field.	Navigant had a QC team of six people who reviewed the field forms the morning after the site visit was completed. When the QC'ers found items that required follow up they would email the field techs and request a response within 24 hours, which the field techs typically followed through on. Navigant used Google Earth and a software called Solocator to verify the correct field location.

Source: SIS Baseline Research Field Data Collection Protocol

Additional QC Methods

- **Centralized Navigant email:** Navigant developed a centralized email address (BPA.SIS@navigant.com) to communicate with the field techs to minimize confusion. There were six people on the Navigant QC team, and they all used the BPA.SIS@navigant.com email account when communicating with the field techs.

[2] Fulcrum is the data collection software that the field techs used to collect data on-site.

- **Automated logger file download and analysis:** There were over 1,200 site visits completed for the non-SIS fields in the sample, which means there were approximately 1,200 logger files shared between the field techs and Navigant over the course of the study—with the exception of the initial visit. To ensure that the logger files were being saved in the right places, Navigant developed R code to automatically extract the logger files from the BPA.SIS@navigant.com email and save them in a folder for that specific field. In addition, Navigant developed code to generate graphs based on the logger file to make it easier for the QC'er to review the file the next morning.
- **Field summary spreadsheet:** Navigant developed R code to extract information from Fulcrum on an hourly basis to the field summary spreadsheet so that the QC'ers knew when site visits occurred and they could QC the fields the morning after the site visits. Navigant also used this information to verify that the field techs were visiting fields on a monthly basis.
- **SIS program, SIS non-program, and non-SIS data QC:** Navigant received SIS program and SIS non-program data from irrigation consultants involved in SIS in the Columbia River Basin in 2016, which encompassed over 1,300 fields. Navigant developed rigorous QC procedures to ensure that the data received from the irrigation consultants was high quality. In addition to the day-after QC of the non-SIS data, Navigant did a thorough QC of the key data points and communicated with the irrigation consultants to ensure that the data entered into Fulcrum was correct.

Field Data QC

Navigant developed a team of six consultants (QC'ers) to review the field data the morning after the site visits occurred. The QC'ers followed a system of standardized protocols to conduct a thorough review of the data collected by the field techs. This section discusses the field data QC methods, as well as issues and solutions that arose over the course of the study.

Methods

Navigant conducted the field data QC using automated processes, a joint email account, online data collection applications, and an Excel tracking system called the QC Tracker. Navigant staffed the team appropriately to ensure QC was maintained through periods of team member travel, illness, or unavailability. Because this system is susceptible to human error, Navigant implemented additional QC measures on a weekly basis to address any fields that did not receive immediate QC. The sections below detail each step of the field data QC process.

- **QC'er checked for newly uploaded and updated site visits.**

  On his/her designated day, the QC'er copied and resaved the auto-updating field summary spreadsheet into his/her personal documents and opened the document; the personal saving of this document ensured that the automatic updates continued to occur in the original document. From the field summary spreadsheet, QC'ers identified the sites that needed to be reviewed due to a recent visit or an update to the data in Fulcrum. Next, the QC'er opened the QC Tracker to guide him/her through the QC process.

- **The QC process occurred.**

  The QC Tracker was the central database for all QC; it housed data for each field, including field status, equipment serial numbers, and data concerns. Navigant updated the QC Tracker to include dropdown lists and automatic formatting for QC'er ease of use.

  The QC process was broken up between various visit types: Initial, Follow-Up, Ultrasonic, and Retrieval. After completing the QC of a site visit, the QC'er updated the status of the site visit in the QC Tracker to either QC Complete, Follow-Up in Progress, Addressed – Waiting for Additional Data, or Dropped.

  - **Initial Site Visits:** QC'ers used the QC Tracker to enter information the irrigation consultants had already uploaded in Fulcrum. The QC Tracker guided the QC'er through saving the Fulcrum field visit, inserting key Fulcrum details, saving the Solocator photo from the SharePoint websites (one for each of the irrigation consultant firms), using Google Earth to check the Solocator photo location against the expected location, and assigning the visit a status.
  - **Follow-Up and Ultrasonic Site Visits:** QC'ers used the QC Tracker to fill in information from the site visit entered in Fulcrum. During these visits, the QC'er was prompted to visually review the logger file to address data issues swiftly.[3] The QC'er also entered the serial number of the installed equipment provided in Fulcrum, and the QC Tracker reported out a true/false statement to indicate if the serial number matched the initial visit serial number. The serial numbers matched if the consultant was in the correct field, and if the numbers did not match, the QC'ers reached out to the irrigation consultants using the BPA email address to resolve any issues. In addition to follow-up site visits, ultrasonic site visits captured the irrigation type and water flow measurements at the field.
  - **Retrieval Site Visits:** QC'ers used the QC Tracker to verify that logger data was downloaded, confirm equipment was removed, and to retrieve final crop information from the grower. At this visit, the QC'er verified that any outstanding concerns found during the growing were addressed; if not, he/she followed up with the irrigation consultants.

- **Additional QC measures conducted.**

  Each week, one designated QC'er archived a copy of the QC Tracker in case of errors or accidental mishaps. This QC'er then compared the number of site visits in the QC Tracker with the number of site visits in Fulcrum to identify sites that were overlooked in the QC process or were uploaded later than expected by the irrigation consultants. These sites were then assigned to the current QC'er so he/she could address them in a timely manner. Additionally, the project manager received prompt feedback about data concerns or process inefficiencies to enable timely direction and feedback to all parties involved. The project manager also reviewed all of the logger data each week as a double check to make sure that no issues were overlooked. The project manager coordinated with the QC'ers and the field techs as data logger issues arose to make sure they were remedied as soon as possible.

[3] The ultrasonic flow measurement site does not have a logger file—it only has a measurement from the ultrasonic flow measurement.

- **BPA emails.**

  The BPA email address served as the central location for communication between the QC'ers and the field techs. If a QC'er needed to send an email to the irrigation consultants, he/she used the BPA.SIS@navigant.com email address and carbon copied the email address as well, so that all users of the email address could track external conversations.

Data Quality Issues

High quality data is the primary driver for this project. This section identifies the QC issues that arose while collecting the field data as well as the solutions Navigant used to remedy them. It includes graphs, pictures, and secondary details to provide additional context in understanding the problems and solutions.

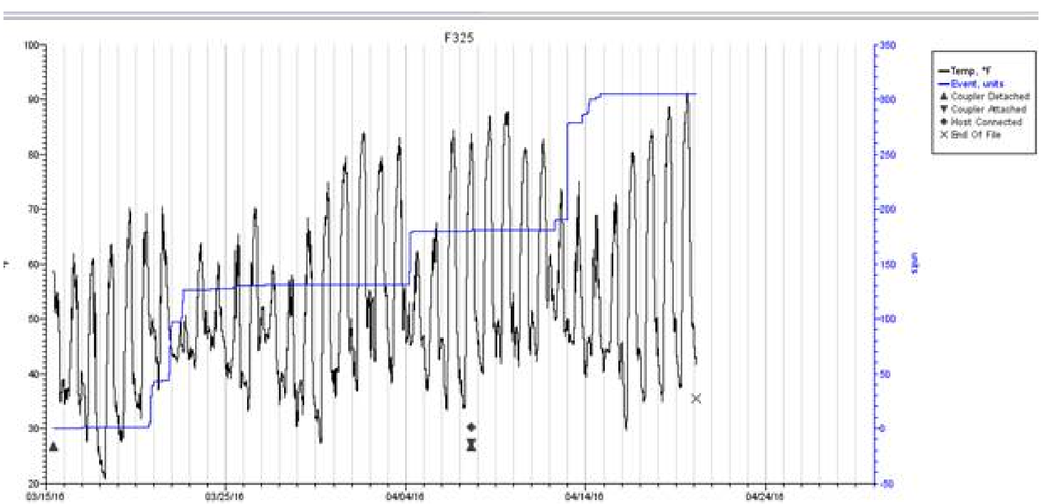
- **Issue:** It was difficult for the QC'er to tell whether the irrigation consultants were temporarily removing field equipment or if they were reinstalling field equipment after a cutting.
  - **Solution:** Navigant updated Fulcrum and asked irrigation consultants to clearly indicate if they were removing or reinstalling equipment. Navigant added a column to the QC Tracker to indicate if the equipment status was "Removed" or "Installed."
- **Issue:** Irrigation consultants delayed uploading data to Fulcrum, which caused QC'ers to overlook sites because they did not have the most up-to-date information.
  - **Solution:** Navigant reminded the irrigation consultants to upload field visits in a timely manner. The lead QC'er began weekly QC checks to ensure that no sites had been omitted, and if sites were omitted, they were immediately QC'ed. In addition, Navigant added a tab to the field summary spreadsheet that showed the recently updated sites in Fulcrum so that it would be easier for the QC'er to identify recently updated sites.
- **Issue:** Tracking old versus new comments in the QC Tracker was difficult because there was little documentation.
  - **Solution:** Navigant implemented a new protocol: A QC'er would initial and date each comment to track the QC'er and the timeline of events.
- **Issue:** The tipping rain gauge did not measure any water applied because the cords were not neatly stored. The cords fell on the tipping mechanism, and the logger did not record any measurements.
  - **Solution:** Navigant reiterated the importance of neatly storing the cords in the tipping rain gauge. Navigant also added a photo field in Fulcrum so that the field tech had to take a picture of their installation, which allowed the QC'ers to respond to any cord concerns immediately. Navigant updated the QC Tracker so that the QC'ers could indicate that they visually verified the tipping rain gauge installation. In Figure 1, the photo on the left shows a messy installation where the cords and rubber band do not allow the tipping mechanism to tip, while the photo on the right shows neatly bundled cords that are not interfering with the black tipping mechanism.

Figure 1: Example of Messy Cords (Left) and Clean Cords (Right) in a Tipping Rain Gauge

Source: Navigant data collection

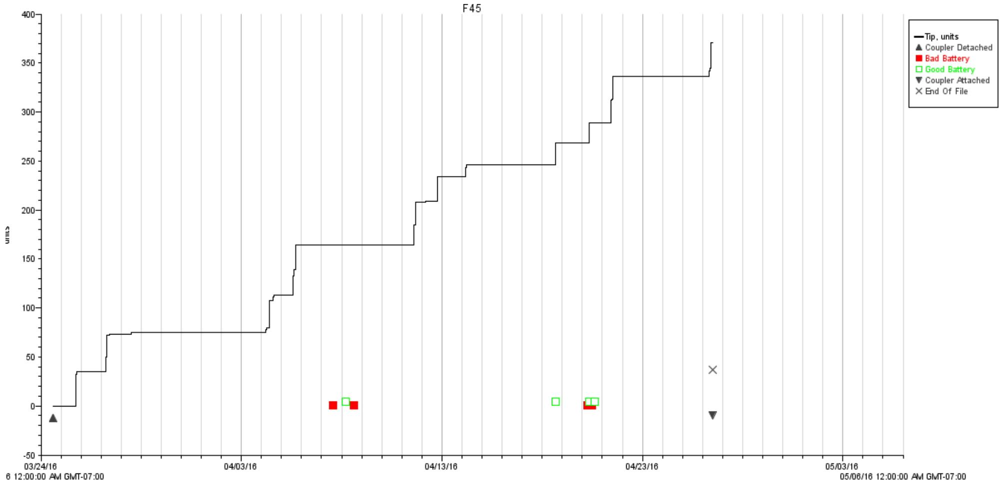
- **Issue:** The logger file for the tipping rain gauge showed good and bad battery signals (see Figure 2). Bad battery signals indicate that the battery malfunctioned and data was lost.
    - **Solution:** Navigant added a battery level column to the QC Tracker so that the QC'er would check the logger file for red and green dots, which indicate battery failure. Figure 2 shows a logger unnecessary recording temperature (black line), which is a quick way to drain the battery. Figure 3 shows a tipping rain gauge with good and bad battery signals, which indicates logger failure.

Figure 2: Tipping Rain Gauge Data Showing Temperature Being Logged (Black Line) When It Should Not Be



Source: Navigant data collection

Figure 3: Tipping Logger File Showing Good and Bad Battery Signals (Red and Green Dots), Indicating Logger Failure



Source: Navigant data collection

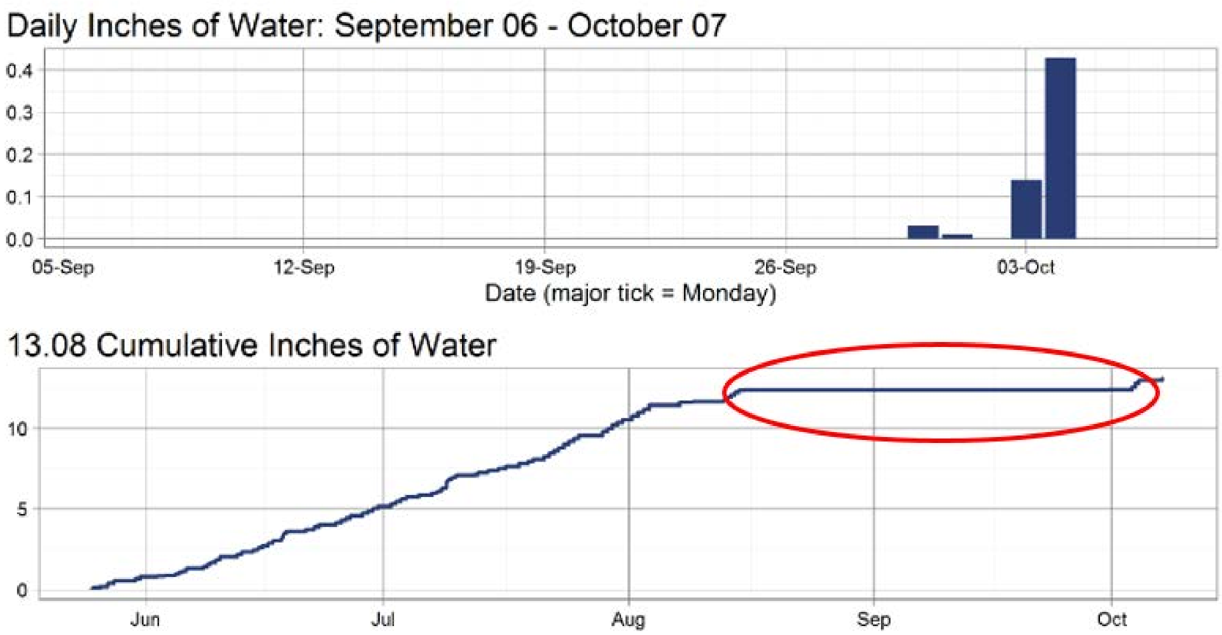
- **Issue**: Field techs sometimes placed the solar panel used to power the pressure sensors in shaded locations, which affected the ability for the U30 battery to stay charged. The QC'ers were able to identify this issue the day after the site visit occurred because the field techs were required to take a picture of the equipment at the site visit.
    - **Solution**: Navigant directed irrigation consultants to reposition the solar panel and/or remove the branches covering the solar panel, as well as to check the battery percentage. Figure 4 shows a partially shaded solar panel.

Figure 4: Example of a Partially Shaded Solar Panel—Could Impact Battery Charge

Source: Navigant data collection

- **Issue:** QC'ers reviewed the logger data and saw that there were weeks where no water was applied.
    - **Solution:** After reviewing the logger data and finding weeks of no water applied, the QC'er would email the irrigation consultants to check for equipment malfunctions or a change in the grower's watering habits. The red circle in Figure 5 denotes a large period with no water applied.

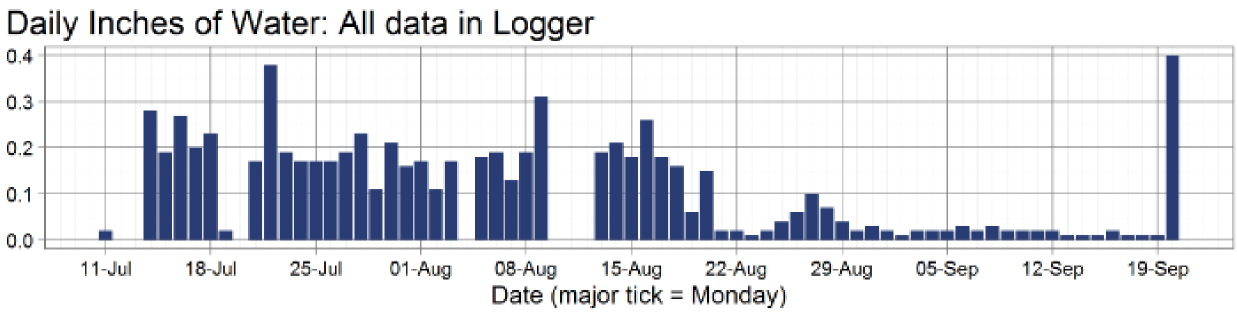
Figure 5: Example of a Tipping Rain Gauge Logger File that Required Follow Up Due to Multiple Weeks Without Water Measurements



Source: Navigant data collection

- **Issue:** Irrigation consultants noted found that the tipping rain gauges were plugged when they visited the field for a follow-up visit.
    - **Solution:** Navigant directed the irrigation consultants to unplug the lid and let the built up water flow through the tipping mechanism to capture the water data applied for that period. In addition, Navigant directed the irrigation consultants to remove any obstructions causing the water to pool up. The tall bar on the far right in Figure 6 indicates that the built up water applied over the month was measured all at once during the follow-up visit.

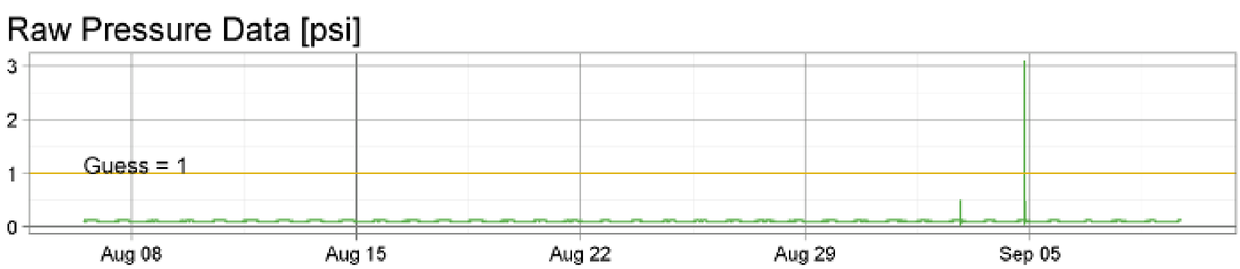
Figure 6: Built Up Water in a Tipping Rain Gauge Measured on September 19, 2016



Source: Navigant data collection

- **Issue:** The QC'er noticed that the pressure gauge logger was not recording any data.
    - **Solution:** Navigant directed irrigation consultants to replace the logger with a new one and request the irrigation system run hours during the period of lost data from the grower. Figure 7 is an example of a pressure gauge logger that did not record any water pressure during an entire month, which is not correct. The green line is the pressure reading, which stays at zero psi for a majority of the month, with only one jump to three psi. Pressure readings should typically reach between 10 and 60 psi multiple times throughout a given month.

Figure 7: Example of Pressure Gauge Not Recording Any Data



Source: Navigant data collection

QC Automation

The SIS project has an especially high demand for accurate data collection and has many moving parts that must interact efficiently. For this reason, Navigant used a high degree of automation to conduct the day-to-day processing of logger data. The main benefits of using automation are that it greatly reduces the potential for human error while performing repetitive tasks, and it creates analysis results almost immediately as data arrives, allowing the QC team to catch issues as quickly as possible.

Methods

Navigant utilized multiple technologies to present data analysis to the QC team without the need for active monitoring by a QC'er. The analysis team developed a series of programs to execute on set schedules, running each discrete step several times per hour at all times. The overall design of the programs was to download logger data, conduct basic QC checks, create data visualization, and report the results of the whole process back to the team to ensure the system continued to run smoothly. This section details each method of the QC automation.

- **Scanned incoming emails from field techs for logger data.**

  Navigant developed a program using the Visual Basic programming language to review emails received by the BPA SIS email account during a set period of time—generally once per day. The team used Visual Basic because of its unique compatibility with MS Office products, particularly with email automation through MS Outlook. The Visual Basic program filtered emails that match certain specifications and then catalogs any attachments from emails that match the data logger file extension names.

- **Exported logger data to raw data form.**

  Navigant received the logger data in a form that could only be directly used by the logger software, HOBOware. To allow a customized analysis of the logger data, Navigant converted the data into a more general form, namely CSV files. To do this, the analysis team incorporated the ability for the scheduled program to open the HOBOware software, specify the file paths to the input data and desired export, and complete the conversion process. The result of this step was data in a form that Navigant could more easily manipulate and analyze as compared to data in the HOBOware software environment.

- **Updated Fulcrum summary outputs.**

  Fulcrum is an online data collection application that the field techs used to record important details on fields in the SIS study. Navigant used results from Fulcrum to track various items such as dates on which irrigation consultants conducted field visits and which logger equipment serial numbers belong to which fields. To create a convenient summary of the Fulcrum information, the analysis team pulled raw data from Fulcrum and summarized the most important results so they could be viewed in one place. This program also ran on a set schedule so the summary output was always as up to date as possible.

  Figure 8 and Figure 9 illustrate how the Fulcrum summary spreadsheet made it easy to monitor fields and ensure that field visits were being conducted at appropriate times.

Figure 8: Screenshot of the Field Summary Spreadsheet Showing Visits to Each Field

	A	B	C	D	E	F	G	H	I	J
1	field_id	irrigation_consultant	crop_type	Mgmt.Categor	approach_for_actual_water_use	visit	follow_up_nun	target	actual	done
2	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	initial		5/5/2016	5/5/2016	TRUE
3	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_1	6/4/2016	6/27/2016	TRUE
4	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_2	7/4/2016		FALSE
5	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_3	8/3/2016		FALSE
6	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_4	9/2/2016		FALSE
7	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_5	10/2/2016		FALSE
8	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_6	11/1/2016		FALSE
9	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_7	12/1/2016		FALSE
10	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	follow_up	follow_up_8	12/31/2016		FALSE
11	F1	IRZ	Peas	Low/Med	Tipping Rain Gauge	retrieval			7/5/2016	TRUE
12	F100	IRZ	Apples	High	Pressure Gauge	initial		4/1/2016	4/6/2016	TRUE
13	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_1	5/6/2016	5/18/2016	TRUE
14	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_2	6/5/2016	6/1/2016	TRUE
15	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_3	7/5/2016	7/6/2016	TRUE
16	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_4	8/4/2016		FALSE
17	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_5	9/3/2016		FALSE
18	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_6	10/3/2016		FALSE
19	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_7	11/2/2016		FALSE
20	F100	IRZ	Apples	High	Pressure Gauge	follow_up	follow_up_8	12/2/2016		FALSE
21	F100	IRZ	Apples	High	Pressure Gauge	retrieval				FALSE
22	F100	IRZ	Apples	High	Pressure Gauge	ultrasonic				FALSE
23	F103	ProAg	Apples	High	Pressure Gauge	initial		3/23/2016	3/23/2016	TRUE
24	F103	ProAg	Apples	High	Pressure Gauge	follow_up	follow_up_1	4/22/2016	4/21/2016	TRUE
25	F103	ProAg	Apples	High	Pressure Gauge	follow_up	follow_up_2	5/22/2016	5/21/2016	TRUE
26	F103	ProAg	Apples	High	Pressure Gauge	follow_up	follow_up_3	6/21/2016	6/25/2016	TRUE
27	F103	ProAg	Apples	High	Pressure Gauge	follow_up	follow_up_4	7/21/2016		FALSE
28	F103	ProAg	Apples	High	Pressure Gauge	follow_up	follow_up_5	8/20/2016		FALSE

Source: Navigant

Figure 9: Screenshot from the Field Summary Spreadsheet Showing Site Visit Dates

	A	B	C	D	E	F	G
1	field_i	approach_for_actual_water_us	crop_type	Mgmt.Categ	irrigati	visit	date
2	F537	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-23
3	F648	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-22
4	F54	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-24
5	F718	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-22
6	F646	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-24
7	F653	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-24
8	F204	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-22
9	F577	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-24
10	F342	Tipping Rain Gauge	Grass (hay)	Low/Med	ProAg	initial	2016-03-24
11	F201	Pressure Gauge	Apples	High	ProAg	initial	2016-03-23
12	F817	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-25
13	F294	Tipping Rain Gauge	Grass (hay)	Low/Med	ProAg	initial	2016-03-24
14	F466	Tipping Rain Gauge	Peas	Low/Med	ProAg	initial	2016-04-18
15	F513	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-22
16	F48	Tipping Rain Gauge	Corn (grain)	Low/Med	ProAg	initial	2016-06-07
17	F45	Tipping Rain Gauge	Grass (hay)	Low/Med	ProAg	initial	2016-03-24
18	F284	Tipping Rain Gauge	Potatoes	High	ProAg	initial	2016-05-05
19	F676	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-22
20	F209	Tipping Rain Gauge	Bluegrass seed	Low/Med	ProAg	initial	2016-03-24
21	F595	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-22
22	F728	Tipping Rain Gauge	Corn (sweet)		ProAg	initial	2016-05-20
23	F485	Tipping Rain Gauge		Low/Med	ProAg	initial	2016-03-24
24	F522	Tipping Rain Gauge	Alfalfa	Low/Med	ProAg	initial	2016-03-23

Source: Navigant

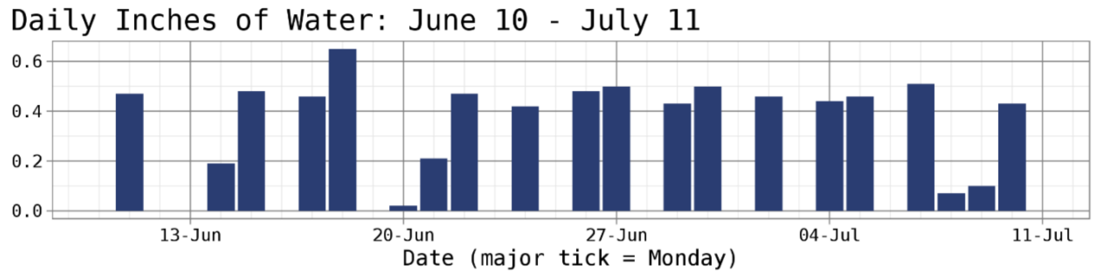
- **Analyzed logger data and create graphics.**

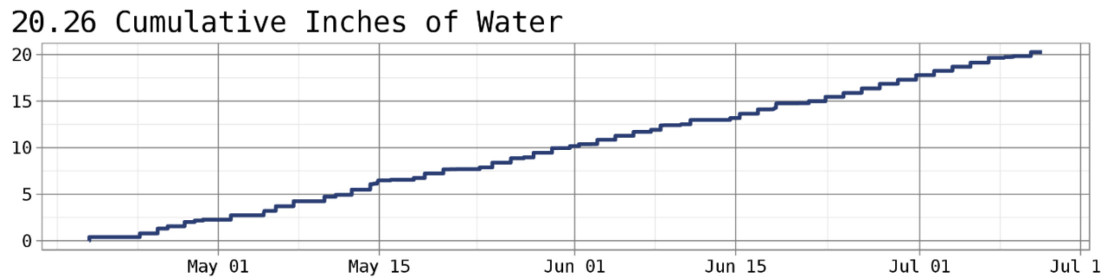
  Once the logger data was ready for analysis and the Fulcrum output was up to date, the analysis team conducted checks on the data's quality. Another automated program began by comparing the logger data to the appropriate field records in the Fulcrum output to ensure that some basic attributes of the data agreed with the expected attributes according to Fulcrum. These checks were primarily to verify that the water collection method agreed with the Fulcrum record and that the equipment serial number matched up with the correct field. The purpose of this step was to prevent the possibility of a field tech mistakenly labeling logger data with an incorrect field ID. In the case that a data logger file was mislabeled, the program would automatically change the field ID and place the results in the correct location for review based on the field ID.

  Once the basic data quality was verified, the program created a series of graphics illustrating the water applied as shown by the data logger and placed the graphics in an appropriate location to be easily reviewed by the QC'ers. The graphics save a lot of time for the QC team, since it was much easier to quickly notice a potential issue from the graphics than it is to identify issues in a large table of data.

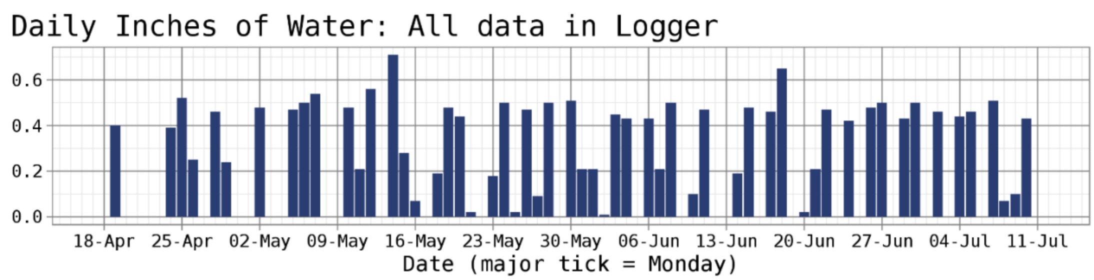
  Figure 10 (blue graphs) shows an example of the graphs that are automatically generated once the BPA SIS email receives a tipping rain gauge file, and Figure 11 (green graphs) shows an example of the graphs that are automatically generated once the BPA SIS email receives a pressure gauge file.

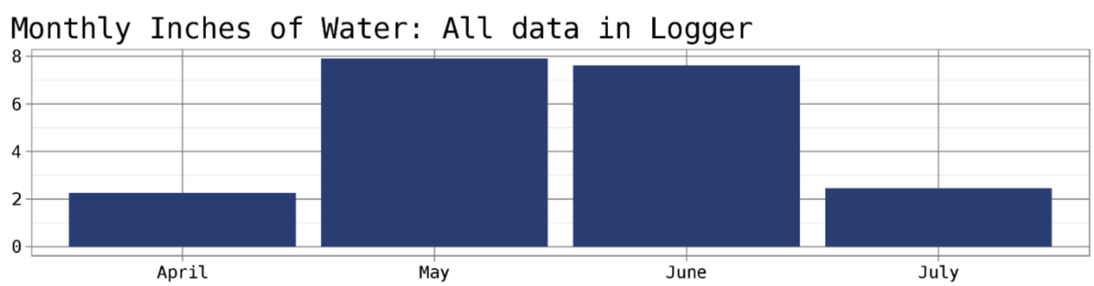
Figure 10: Screenshot of Graphs Automatically Created from a Tipping Rain Gauge Logger File





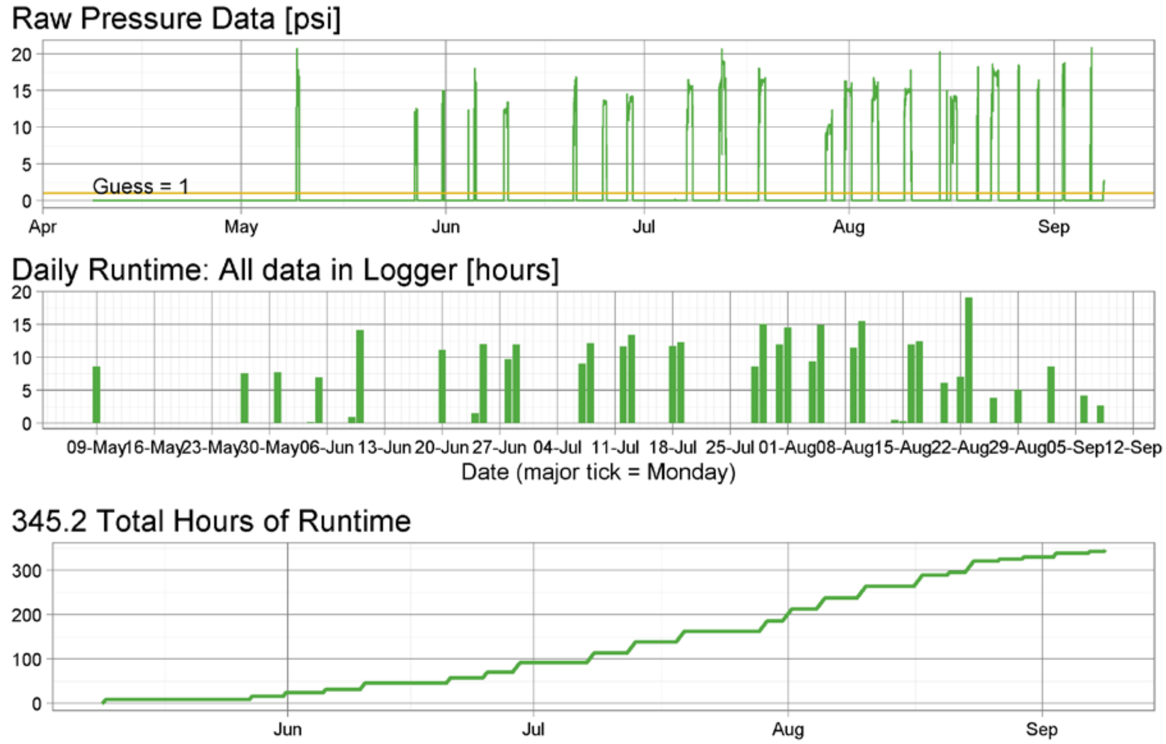
Folder	F372
Filename	F372 2016-07-11_Field Data.cs
Hobo Plottitle	F372
Sensor Serial	10917869
Total Water	20.26 Inches



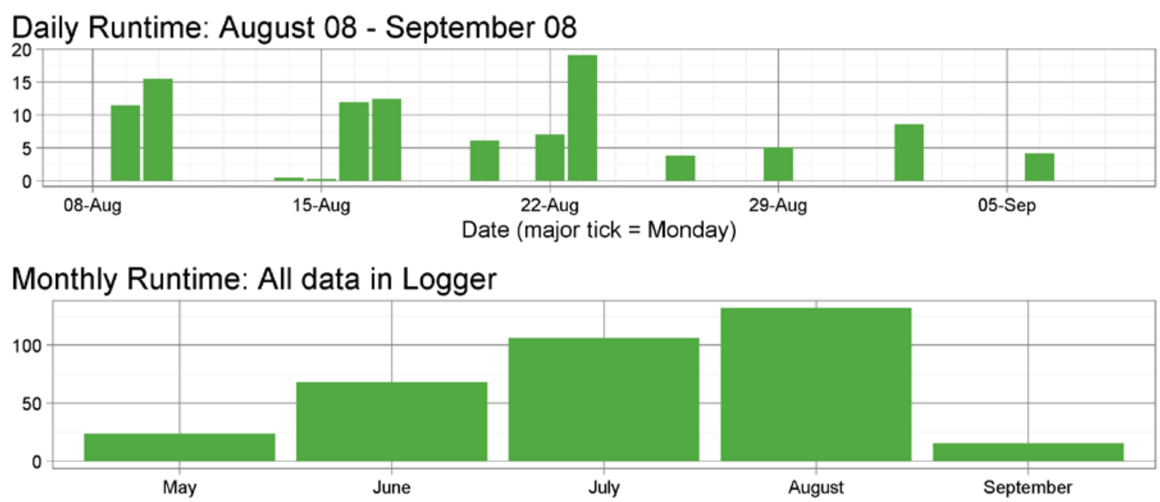


Source: Navigant data collection

Figure 11: Screenshot of Graphs Automatically Created from a Pressure Gauge Logger File



Folder	F290
Filename	F290 2016-09-08_Field Data.csv
Hobo Plottitle	10918118_F290
Sensor Serial	10892797
Total Runtime	345.2 Hours



Source: Navigant data collection

- **Reported log of all automation results.**

  The final step of the scheduled automation program was to report all of the results back to the programmers, highlighting any potential issues or warnings based on the whole process. The program frequently wrote out the progress of each step of the analysis so the programmers could check on results without having to actively monitor the program. If the program encountered a problem at any time, it would automatically send an email to the analysis team, showing what the error was and where it occurred. If there were no errors, the program still sent an email once per day to confirm it was running as expected.

  Figure 12 shows an example of an automated email attachment sent daily to Navigant. In this case, the analysis team could confirm that the program ran every hour; thus, no errors were found.

Figure 12: Automated Email of Data Issues

Message | SIS Main Automation Log 2016-04-23.txt (9 KB) | SIS R Routine Automation Log--2016-04-23.txt (13 KB)

```
At 12:00 AM : Beginning Full SIS Chain Script.
At 12:01 AM : Completed VBS email download.
At 12:01 AM : Completed HoboWare export process.
At 12:01 AM : Completed R analysis.
At 12:01 AM : Full Chain Script Completed.
SUCCESS! No Errors.
At 1:00 AM : Beginning Full SIS Chain Script.
At 1:00 AM : Completed VBS email download.
At 1:01 AM : Completed HoboWare export process.
At 1:01 AM : Completed R analysis.
At 1:01 AM : Full Chain Script Completed.
SUCCESS! No Errors.
At 2:00 AM : Beginning Full SIS Chain Script.
At 2:00 AM : Completed VBS email download.
At 2:01 AM : Completed HoboWare export process.
At 2:01 AM : Completed R analysis.
At 2:01 AM : Full Chain Script Completed.
SUCCESS! No Errors.
At 3:00 AM : Beginning Full SIS Chain Script.
At 3:00 AM : Completed VBS email download.
At 3:01 AM : Completed HoboWare export process.
At 3:01 AM : Completed R analysis.
At 3:01 AM : Full Chain Script Completed.
SUCCESS! No Errors.
At 4:00 AM : Beginning Full SIS Chain Script.
At 4:00 AM : Completed VBS email download.
At 4:01 AM : Completed HoboWare export process.
At 4:01 AM : Completed R analysis.
At 4:01 AM : Full Chain Script Completed.
SUCCESS! No Errors.
```

Source: Navigant

Figure 13 shows a second, more detailed attachment that summarized the data analyzed with each run. The screenshot shows how the attachment helped monitor the data received and provided a warning that the program found a logger file with a mislabeled field ID and corrected it.

Figure 13: Automated Email with More Details on Data Issues

Message | SIS Main Automation Log 2016-04-19.txt (13 KB) | SIS R Routine Automation Log--2016-04-19.txt (5 KB)

```
At 11:59 -- Checking for files recieved on 2016-04-19...
        None found.
 At 11:59 -- Checking for files recieved on 2016-04-18...
        FieldID F126 data downloaded. Files already analyzed previously.  WARNING: Original file FieldID is 10898963, but serial number verified FieldID is F126
        FieldID F154 data downloaded. Files already analyzed previously.
        FieldID F41 data downloaded. Files already analyzed previously.
        FieldID F422 data downloaded. Files already analyzed previously.
        FieldID F533 data downloaded. Files analyzed for the first time today.
        FieldID F644 data downloaded. Files already analyzed previously.

 At 11:59 -- Checking for files recieved on 2016-04-17...
        None found.
 At 11:59 -- Daily scan complete. New data recieved on 1 days: 2016-04-18
 The R rountine finished with NO errors.
```

Source: Navigant data collection

In the event that an error did occur, the program recorded what kind of error it was and exactly where in the code the programmers could find the problem (see Figure 14).

Figure 14: Automated Email Describing a Specific Data Issue

Message | SIS Main Automation Log 2016-04-21.txt (14 KB) | SIS R Routine Automation Log--2016-04-21.txt (41 KB)

```
At 12:46 AM : Beginning Full SIS Chain Script.
At 12:48 AM : Beginning Full SIS Chain Script.
At 12:50 AM : Completed VBS email download.
At 12:50 AM : Completed HoboWare export process.
At 12:50 AM : Completed R analysis.
At 12:50 AM : Full Chain Script Completed.
SUCCESS! No Errors.
At 1:00 AM : Beginning Full SIS Chain Script.
At 1:16 AM : Beginning Full SIS Chain Script.
At 1:17 AM : Full Chain Script Completed.

    Error: \\chi1islfls01\energy\BPA\TO 31 SIS Field Work\Code_Master\SIS_autoDownload.vbs(59, 5) Microsoft VBScript runtime error: Object required: 'objoutlook'At \\CHI1ISLFLS01\Energy\BPA\TO 31 SIS Field Work\Code_Master\Logger Analysis Chain.ps1:144 char:1
+ Receive-Job -Name AutoDL -keep
+ ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
```

Source: Navigant data collection

- **Calculated the water requirement.**

  The final step of the automation process was to compile the necessary data to calculate a water requirement for each field. This was the only step not run on a schedule several times per hour—instead it was only needed at the end of the growing season. Navigant utilized an online irrigation scheduling software called AgWeatherNet to determine the water requirement for each field. It was a slow process to enter the field information in for every field—field ID, crop type, soil type, etc. Instead of manually entering all the field information into the AgWeatherNet web interface, Navigant developed code to quickly enter the data from a spreadsheet and pulled the resulting irrigation values directly from AgWeatherNet's backend database. The AgWeatherNet results were presented in daily values, which Navigant used to calculate an individual water requirement for each day of the growing season for each field.

Data Quality Issues

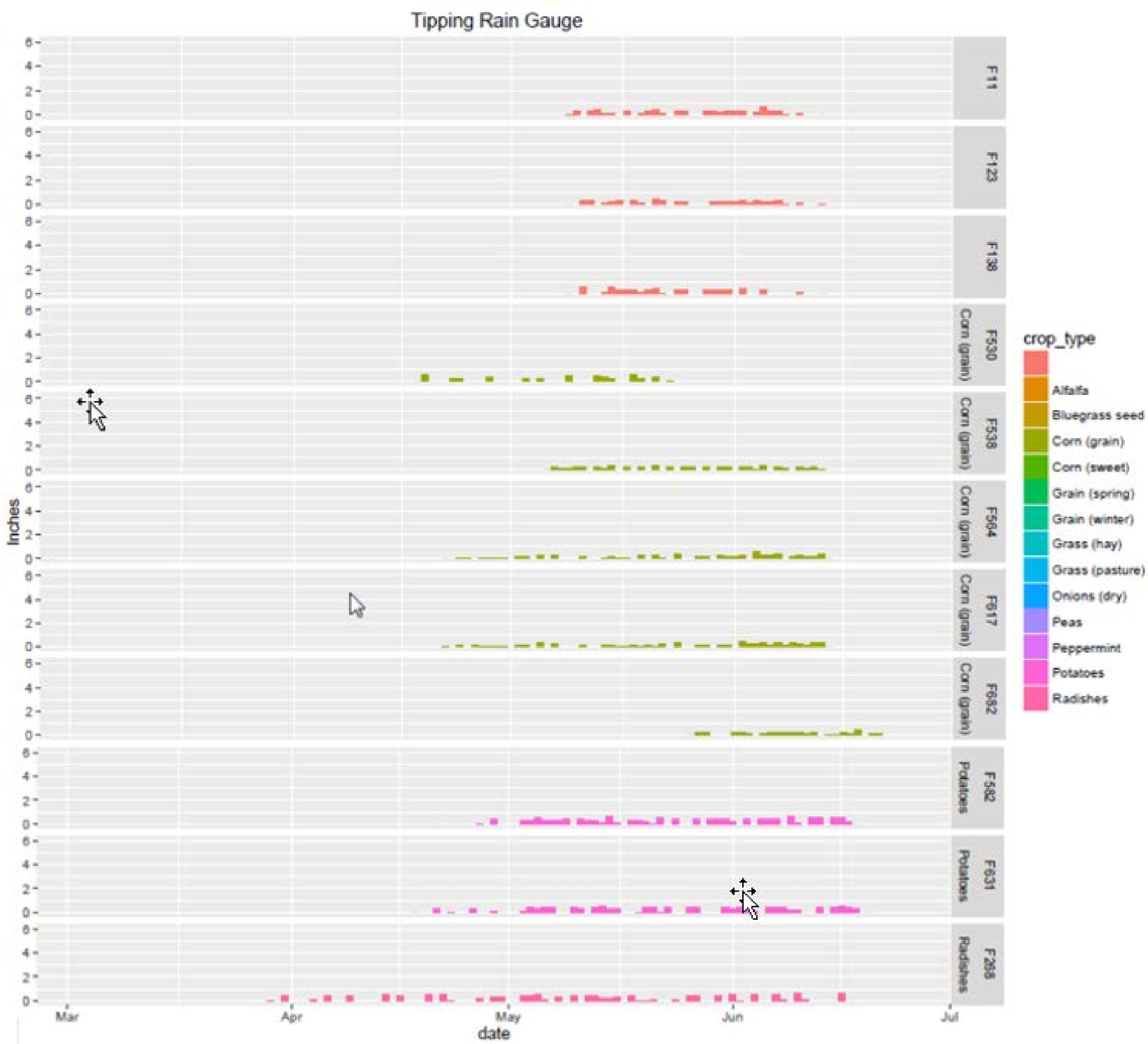
Navigant experienced several obstacles during the automation process and subsequent data QC. The automation level presented some inherent risks, as computers may overlook red flags that a human would more easily spot. The analysis team prepared well for these risks from the beginning of the project, building in protections to highlight potential issues, which made it simple for analysts to monitor results quickly. The QC automation allowed the analysis team to overcome obstacles as they arose and helped make issues less frequent as the project progressed. The rest of this section describes these obstacles and how Navigant overcame them.

- **Issue:** Navigant encountered a few instances where the data logger would need to be replaced in a field due to equipment issues and the field tech replaced it with a piece of equipment that had been previously installed in another field that was done for the growing season. Switching out the equipment with a piece of equipment that had been previously installed in another field created issues with the automated processes. At times, the Fulcrum records did not indicate the change in equipment, so the automated system would flag an incorrect serial number when the serial number was actually correct.
  - **Solution:** The system automation greatly aided Navigant because the program would be unsure of which field ID to use for mismatching serial numbers, which made the problem immediately apparent; therefore, the analysis team was able to make edits to Fulcrum quickly when necessary.
- **Issue:** Navigant used the pressure cutoff point in the pressure gauge data as a proxy to determine when the irrigation system was on or off. It was sometimes difficult, however, to determine the pressure cutoff point using the pressure gauge data. This cutoff can be very different for different systems so a logical estimate had to be made for each individual logger.
  - **Solution:** The automated program made an estimate of the pressure cutoff point based on available data, which was often a reliable indicator but sometimes less so. As the growing season progressed and additional data became available to inform the estimate, there were fewer questionable estimates. In the cases where results appeared odd, the QC'ers would check with the field techs to understand if the results matched up with their expectations.
- **Issue:** Various unpredictable issues could halt the automation program.
  - **Solution:** When an issue did arise, it was typically due to a slight change in the remote server environment on which the program was run or a temporary outage of a certain service component required by the program. Navigant responded by separating the automation program into several pieces, each with its own individual running schedule. This way a temporary error in one section would no longer prevent subsequent sections from continuing normally. Each section could individually send error messages (in the form of emails) so that Navigant could correct the problem as quickly as possible.
- **Issue:** New crop types and inconsistent crop type names entered in Fulcrum.

- o **Solution:** A running list of crop types was kept and compared to the list of eligible crop types in AgWeatherNet. Inconsistent names were mapped to the consistent set of eligible crops, and new crops were flagged for addition to the AgWeatherNet algorithm.

- **Issue:** QC'ers viewed one field at a time and could miss systematic problems or outliers that were not obvious in isolation.
    - o **Solution:** Every week a collection of all data from all loggers was compiled and plotted together to highlight any fields that could have significant issues, as shown in Figure 15. Data from a single field might look fine in isolation, but if it was different from similar fields by an order of magnitude or showed significant irrigation or rainfall that did not align with other similar fields, a QC plot made it easy to spot outliers. Data was grouped by crop type and irrigation type to keep similar fields close together visually.

Figure 15: Example of a QC Plot Generated Weekly



Source: Navigant data collection

SIS Program, SIS Non-Program, and Non-SIS Data QC

Navigant did a top to bottom review of the SIS program (1,300-plus fields), SIS non-program (38 fields), and non-SIS (182 fields) data from the irrigation consultants. The QC methods discussed below for the non-SIS fields are in addition to the day-after QC of the field data.

SIS Program and Non-Program Data QC

Navigant took the following steps to review the data from the irrigation consultants for the 1,300-plus SIS program fields and the 38 SIS non-program fields.

- **Requested and analyzed the 2015 SIS program data in preparation for 2016:** Navigant did a test run of the program data request in 2015 to work out any issues prior to the 2016 growing season. This improved the data quality of program data collected in 2016 because the irrigation consultants were already familiar with the data request spreadsheet and the expectations around the data request.
- **Mapped crop types to AgWeatherNet:** Irrigation consultants often use different nomenclature for the crop types than what is used in AgWeatherNet; therefore, Navigant had to map the crop types from the consultants to the crop types in AgWeatherNet. There were also some crop types in the SIS data that were not in AgWeatherNet. In a majority of situations Navigant was able to identify a crop proxy based on guidance from Troy Peters at Washington State University (WSU), but in some instances, crop types had to be added to AgWeatherNet (e.g., triticale and poplars) when there was not a suitable crop proxy.
- **Conducted a reasonability check on the water-applied numbers:** Navigant reviewed the water-applied data by crop type to identify outliers. There were a few instances where the water-applied numbers were smaller than expected; therefore, Navigant followed up with the irrigation consultants to verify that they entered the correct information.
- **Adjusted all key growing dates in 2015 to be in 2016:** AgWeatherNet can only handle key growing dates in a single year, which is an issue for crops like winter wheat that are planted in the fall and are not harvested until the following summer. Navigant worked with Troy Peters at WSU to adjust the key growing dates in 2015 to 2016. The two dates that often occurred in 2015 that needed to be adjusted to 2016 were the emergence date and the 10% coverage date for crops like winter wheat, timothy hay, and triticale. Per Troy's guidance, Navigant adjusted the emergence date to the break dormancy date and the 10% coverage date to seven days after the break dormancy date.
- **Made sure key growing dates were consecutive:** Key growing dates are a critical input to the water requirement calculation in AgWeatherNet, which is why Navigant did a careful review to make sure they were consecutive (e.g., the 10% canopy coverage data happens before the 70% canopy coverage date). Navigant identified a number of fields with non-consecutive key growing dates and requested that the irrigation consultants review and update them prior to incorporating those fields into the analysis.
- **Made sure key growing dates were unique:** It was common for the irrigation consultants to enter the same data for some of the key growing dates—for example, the initial crop maturation date was often the same as the end of growing season date. Navigant followed up with the

irrigation consultants to address any issues and ensure that all of the key growing dates were unique.

- **Checked for missing data points:** Navigant reviewed the data request spreadsheet for all missing information by filtering the columns for blanks. Navigant followed up with the irrigation consultants for all missing information.
- **Removed fields without all of the required information:** There were a few fields that the irrigation consultants were unable to collect all of the required information for, which Navigant had to exclude from its analysis.
- **Conducted a reasonability check of the key growing dates:** Navigant sorted the fields by crop type and reviewed the key growing dates to make sure they seemed reasonable based on historical knowledge of growing seasons for those crop types. Navigant followed up with the irrigation consultants regarding outliers.
- **Inquired about assumptions for the water applied:** Navigant received SIS data from multiple irrigation consultants, all of whom used varying methods for calculating the water applied. Navigant asked each irrigation consultant how they came up with the water applied so that it would be an apples-to-apples comparison when Navigant merged the SIS data from the various data sources. For example, IRZ included rainfall in all of its water-applied measurements, while ProAg only included rainfall for certain types of water-applied methods. Navigant adjusted all of the water applied numbers so that they would exclude rainfall. Also, each irrigation consultant had varying assumptions for application efficiencies, which Navigant documented so it could back out the application efficiencies from the water applied and apply a consistent method for the application efficiency across all SIS fields.

Non-SIS Data QC

In addition to the day-after QC of the non-SIS field data, Navigant also did a high level review of the non-SIS data to ensure all data was entered correctly into Fulcrum and that the R code was pulling the correct logger files for each site.

- **Compared the key growing dates with the water-applied measurements**: Navigant verified that the key growing dates were entered correctly into Fulcrum and that the equipment captured all of the water applied to the field for the entire growing season by comparing the emergence date to the date of the first water measurement as well as the end of the growing season date to the date of the last water measurement. Navigant flagged any outliers and had the irrigation consultants review them.
- **Requested that the irrigation consultants do a second review of key data points:** Prior to using the data in the analysis and in the grower reports, Navigant asked the irrigation consultants to review the key data points one final time. The irrigation consultants reviewed the following data points: key growing dates, crop type, farm name, utility contact name, address, and email. The key growing dates and crop type were crucial inputs into the water requirement calculation so it was important that these inputs were correct. Also, it was imperative that the grower reports go to the correct person due to data security reasons. Thus, Navigant had the irrigation consultants double check the contact information prior to sending out the grower reports.

- **Visually looked at the logger files for all fields:** There were many logger files associated with each field, and the logger files did not always collect all water-applied information for the entire growing season. Navigant visually inspected the logger files for each field to determine which files needed to be combined to determine the total amount of water applied to the field during the growing season.
- **Mapped crop types to AgWeatherNet:** Irrigation consultants often use different nomenclature for the crop types than what is used in AgWeatherNet; therefore, Navigant had to map the crop types from the consultants to the crop types in AgWeatherNet. There were also some crop types in the SIS data that were not in AgWeatherNet. In a majority of situations Navigant was able to identify a crop proxy based on guidance from Troy Peters at Washington State University (WSU), but in some instances, crop types had to be added to AgWeatherNet (e.g., triticale and poplars) when there was not a suitable crop proxy.
- **Visually inspected water applied vs water required:** Navigant generated PDFs that showed a graph of the water applied and water required over time for each field to make sure the data looked reasonable based on the crop type. Through this visual check, the analysis team identified a trend in wheat and grass fields where the water applied flat lined towards the end of the growing season while the water required kept increasing, which spurred a conversation with the irrigation consultants. In the end the additional review did not result in any adjustments, but it helped to determine what was going on with the data.
- **Checked for missing data points:** Navigant exported the data from Fulcrum to check for any missing data, such as missing key growing dates, and followed up with the irrigation consultants to determine missing information.
- **Conducted a reasonability check of the key growing dates:** Navigant sorted the fields by crop type and reviewed the key growing dates to make sure they seemed reasonable based on historical knowledge of growing seasons for those types of crops. Navigant followed up with the irrigation consultants regarding outliers.
- **Confirmed key growing dates were consecutive:** Key growing dates are critical inputs to the water requirement calculation in AgWeatherNet, which is why Navigant did a careful review to make sure they were consecutive (e.g., the 10% canopy coverage data happens before the 70% canopy coverage date). The analysis team identified a number of fields with non-consecutive key growing dates and requested that the irrigation consultants update them prior to incorporating those fields into the analysis.
- **Confirmed key growing dates were unique:** It was common for the irrigation consultants to enter the same dates for some of the key growing dates—for example, the initial crop maturation date was often the same as the end of growing season date. Navigant followed up with the irrigation consultants to ensure that all of the key growing dates were unique.
- **Adjusted all key growing dates in 2015 to be in 2016:** AgWeatherNet can only handle key growing dates in a single year, which is an issue for crops like winter wheat that are planted in the fall and are not harvested until the following summer. Navigant worked with Troy Peters at WSU to adjust the key growing dates in 2015 to 2016. The two dates that often occurred in 2015 that needed to be adjusted to 2016 were the emergence date and the 10% coverage date for crops like winter wheat, timothy hay, and triticale. Per Troy's guidance, Navigant adjusted the

emergence date to the break dormancy date and the 10% coverage date to seven days after the break dormancy date.

Appendix K – Analysis Methodology

To: Carrie Cobb, Bonneville Power Administration (BPA)

From: Jeff McMillan, Ryan Tanner, and Emily Merchant, Navigant Consulting, Inc. (Navigant)

Date: June 14, 2017

Subject: SIS Baseline Research Study: Analysis Methodology

This memorandum describes the final analysis methodology that Navigant (the research team) used for the Scientific Irrigation Scheduling (SIS) Baseline Research Study. The purpose of this document is to build upon the analysis approach outlined in the SIS Baseline Research Field Data Collection Protocol with the methodology that the research team used in the analysis.[1] This memorandum primarily focuses on the analysis methods used for the water requirement and water applied, as well as a high level discussion of how the field-level results were aggregated to calculate the percent water reduction from the SIS program. Additional information on the aggregation process and the results from the study can be found in the SIS Baseline Research Study Results Memo.

The research team collected data for over 1,500 fields during the 2016 growing season and analyzed the data in early 2017. The data collected included fields across three field study categories that together make up all the fields in the Columbia River Basin, which for the purposes of this memo is referred to as the general market. The three field study categories included fields that received SIS services in 2016 and received an incentive from BPA (SIS program); fields that received SIS services in 2016 and did not receive an incentive from BPA (SIS non-program); and fields that did not receive SIS services in 2016 (non-SIS). The research team randomly sampled 735 fields but ended up getting data for 1,508 fields due to leveraging data collected by the irrigation consultants for the SIS program. Of the 1,508 fields, the research team partnered with irrigation consultants to install equipment on 182 fields not receiving SIS services in 2016 and leveraged data already collected by irrigation consultants through their SIS services for 1,326 fields.

The purpose of the SIS Baseline Research Study was to determine the percent water reduction from the SIS program by calculating the difference in water applied between the general market fields and the SIS program fields. To achieve this goal, the research team worked with irrigation consultants who provided data on how much water the growers applied to the fields and an estimate of how much water the fields required. The research team then aggregated the field-level results to determine the percent water reduction between the general market fields and the SIS program fields.

The analysis methodology consisted of the following four steps:

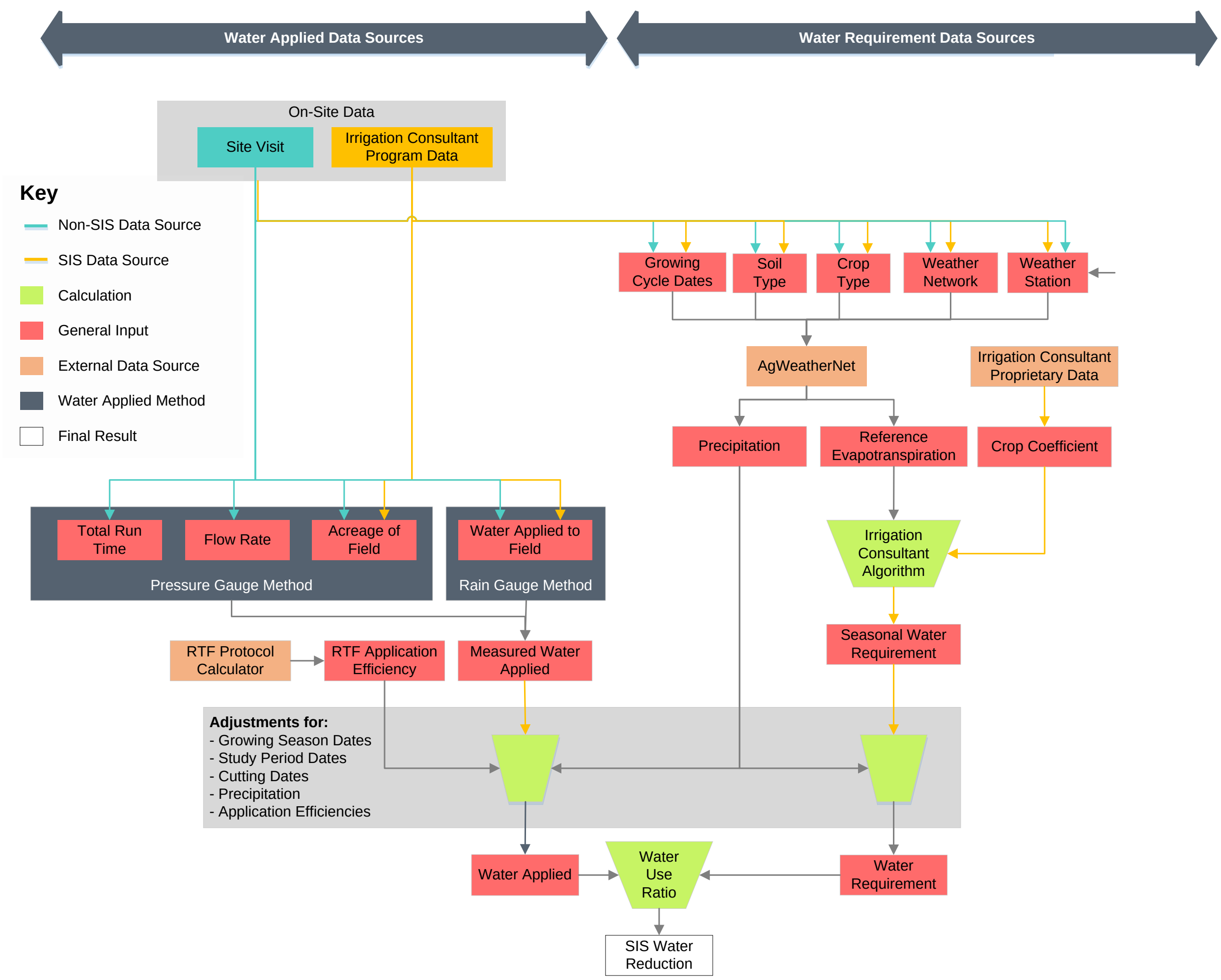
[1] FINAL - AG SIS Baseline Field Data Collection Protocol (Navigant), 2016. https://conduitnw.org/Pages/File.aspx?rid=3389

1. Calculate the water requirement for each field in the study
2. Calculate the water applied to each field in the study
3. Calculate the water use ratio for each of the field study categories and the general market, which is the water applied to the fields divided by the water required by the fields
4. Calculate the percent water reduction from the SIS program, which is the water use ratio of the SIS program fields subtracted from the water use ratio of the general market

This memorandum provides a summary of the data sources for the analysis, then describes the percent water reduction methodology (Step 3 and 4), the water requirement methodology (Step 1), and the water applied methodology (Step 2).

Figure 1 illustrates the detailed flow of data throughout the analysis. The onsite data collection data flow contains nuances because different field types require different data. The blue arrows indicate data from the site visits for non-SIS fields and the yellow arrows indicate data from the site visits for SIS program and SIS non-program fields.

Figure 1: Data Analysis Flow



Source: Research team analysis

Summary of Data Sources

The research team used a variety of data sources to calculate the water requirement, water applied, and water use ratios for each of the field study categories. Table 1 identifies the data sources for each of the field study categories, the parameters used in the analysis, and the role of each parameter in the analysis.

Table 1: Summary of Data Sources

SIS Fields (Program and Non-Program)	**Non-SIS Fields**	**Parameters**	**Role of Parameters in the Analysis**
Irrigation Consultant Data	Site Visit	**All fields:** • Water applied to the field • Field acreage • Growing cycle dates • Crop type • Latitude/longitude of the field • Irrigation system type **Depending on irrigation system type:** • Flow rate and total runtime • Application efficiency assumption	Used as inputs for calculating the water applied and the water requirement The latitude and longitude of the field was used to determine the weather station and weather network associated with each field, which is a required input to AgWeatherNet
AgWeatherNet Irrigation Scheduling Website		• Precipitation • Reference evapotranspiration	Used to calculate the water requirement
Irrigation Consultants' Irrigation Scheduling Software		• Crop coefficient	Used to calculate the water requirement
SIS Calculator from the Regional Technical Forum (RTF)		• Application efficiency	Used to convert gross water applied to net water applied based on inefficiencies in the irrigation system and weather effects
AgriMet and AgWeatherNet Weather Networks		• Weather station • Weather network	Used as an input to AgWeatherNet, which feeds into the water requirement calculation

Source: Research team analysis

Data for the sampled fields came from onsite field measurements gathered in a variety of different ways depending on the field study category. Irrigation consultants provided the research team with the required data for the SIS program and SIS non-program fields at the conclusion of the growing season.[2] In contrast, the research team worked with irrigation consultants to collect data for the non-SIS fields through monthly site visits using loggers that documented key information that the irrigation consultants downloaded and shared with the research team. The equipment used for the non-SIS fields was standard professional grade equipment but it was not the exact same equipment as what the irrigation consultants use for fields receiving SIS services. The reason why these two processes are different is because the

[2] Prior to the start of the growing season the research team asked the irrigation consultants if they could get the water applied data for the SIS fields on a monthly basis and at a more granular level than one number for the entire growing season. The research team received pushback from the irrigation consultants due to the time that it would require to meet that request; therefore, the research team decided to request one seasonal number for the water applied to the SIS fields at the conclusion of the growing season.

research team deemed it unnecessary to install metering equipment in a field that was already being metered by an irrigation consultant who visited the field on a weekly basis to read out the water applied to the field. As a result, the research team focused their metering efforts on the non-SIS fields and submitted a data request to the irrigation consultants for the SIS fields at the conclusion of the growing season. The following subsections provide additional information on each of the data sources shown in Table 1.

Irrigation Consultant Data

Prior to the start of the 2016 growing season the research team provided the irrigation consultants with a spreadsheet template to fill out for a census of SIS program fields and a sample of SIS non-program fields. In addition to the key parameters outlined in Table 1, each consultant provided additional detail on the methodology used to compute the water applied—specifically, the irrigation consultants reported any assumptions made regarding application system efficiency or if precipitation was included in the water applied to the field. The irrigation consultants sent the research team the spreadsheet with the requested inputs for the SIS program and SIS non-program fields at the end of the growing season.

Site Visit Data

All data for the sampled fields was collected by irrigation consultants during site visits to the field. The irrigation consultants conducted site visits to non-SIS fields on a monthly basis to download logger data and document key information, such as crop status and equipment status. In contrast, the irrigation consultants conducted site visits to SIS fields on a weekly basis to document the water applied to the field. The irrigation consultants provided the research team with the data for the non-SIS fields on the day of the visit to the field and waited to provide the research team the data for the SIS fields until the end of the growing season.

AgWeatherNet Irrigation Scheduling Website

AgWeatherNet[3] refers to both a network of weather stations and an irrigation scheduling website developed by Washington State University (WSU). The AgWeatherNet irrigation scheduling website provides essential crop growth information on a daily basis, including daily precipitation amounts, crop water requirements, and several other parameters that the research team found useful for the SIS study. For example, the AgWeatherNet irrigation scheduling website offers table exports based on field-specific inputs from the research team and a database of crop growth algorithms to calculate the daily crop water requirement. The research team exported a spreadsheet from AgWeatherNet for each field and provided the spreadsheets to the irrigation consultants, who then used the daily reference evapotranspiration values as an input to their irrigation scheduling software to calculate the water requirement. The research team also used the daily precipitation output from AgWeatherNet to calculate the water required by the crop from the irrigation system only (i.e., excluding water provided by precipitation), as the water requirement calculated by the irrigation consultants was the total water required by the crop from either the irrigation system or precipitation.

[3] AgWeatherNet website: http://weather.wsu.edu/awn.php?page=irrigation-scheduler

Irrigation Consultants' Irrigation Scheduling Software

The irrigation consultants used their proprietary irrigation scheduling software to calculate the crop-specific evapotranspiration for each field. The irrigation consultants took the daily reference evapotranspiration values from AgWeatherNet and multiplied them by the daily crop coefficient to calculate the daily crop evapotranspiration for each field.[4] The irrigation consultants summed the daily evapotranspiration values between the equipment install date and equipment removal date to determine the seasonal evapotranspiration number for each field. Upon calculating the seasonal crop evapotranspiration for each field, the irrigation consultants sent the research team a spreadsheet with all of the values for each field in the study.

SIS Calculator

The SIS Calculator[5] is a tool developed by the Regional Technical Forum (RTF) to calculate the energy savings from conducting SIS on a specific field. The SIS Calculator provides a list of application efficiencies by irrigation system type and crop type that accounts for the water lost between the irrigation system and the crop due to wind, evaporation, and other factors. The research team needed all of the water applied numbers to be net water applied, which is the amount of water hitting the crop after application losses. However, some of the methods used by the irrigation consultants to measure water applied were measured at the gross level (i.e., before application losses)[6]. In these cases, the research team had to multiply the gross water applied by the application efficiency in the RTF calculator to determine net water applied. Because some of the crop types and irrigation system types provided in the calculator did not match the field categories in the study, the research team mapped the categories in the study to the categories in the SIS Calculator before determining the application efficiencies.

AgriMet and AgWeatherNet Weather Networks

AgriMet and AgWeatherNet are both networks of weather stations throughout the Northwest. For a majority of fields, the research team selected the nearest weather station for each site from the AgriMet and AgWeatherNet weather networks, and entered the weather station name into the AgWeatherNet irrigation scheduling website. For 132 of the 1,501 fields in the study the research team used a different weather station than the closest one to the field due to the irrigation consultants' knowledge of microclimates near the field.

Percent Water Reduction Methodology

This section describes the process for determining the water use ratio and the percent water reduction from the SIS program.

[4] Evapotranspiration is equivalent to the water required by the crop for optimal growth, which can come from irrigation or precipitation.
[5] SIS_Calculator_v2.1: http://rtf.nwcouncil.org/measures/measure.asp?id=184
[6] Examples of water applied methods measured at the gross level include integrated flow meters, hour meters, and pressure gauges.

The **water use ratio** is equal to the amount of water applied to the fields divided by the amount of water required by the fields. The research team calculated a water use ratio for each of the field study categories and for the general market.

The **percent water reduction from the SIS program** is the result of subtracting the SIS program water use ratio from the general market water use ratio.

Water Use Ratio Calculation

The research team calculated the water use ratio for each of the three field study categories by taking the sum of the water applied for all fields in that field study category and dividing by the sum of the water requirement for all fields in that field study category. Equation 1 summarizes the equation used to calculate the water use ratio for each field study category.

Equation 1: Water Use Ratio of Field Study Categories

$$\text{Water Use Ratio}_{\text{Field Study Category, i}} = \frac{\sum_{\text{All fields}}[\text{Water Applied}]}{\sum_{\text{All fields}}[\text{Water Requirement}]}$$

The research team calculated the general market water use ratio by weighting the field study category water use ratios by their relative portion in the general market. The weight of the field study categories was determined by calculating the percentage of fields in each field study category in the sample frame of 735 fields that the research team started recruitment with. For additional information on the weighting and aggregation process, as well as the weights used in the analysis, see the SIS Baseline Research Study Sampling Memo.

Equation 2 demonstrates how the research team calculated the general market water use ratio.

Equation 2: General Market Water Use Ratio

$$\begin{aligned}\text{WUR}_{\text{General Market}} \\ &= \text{WUR}_{\text{SIS Program}} * \text{Weight}_{\text{SIS Program}} + \text{WUR}_{\text{SIS Non-Program}} * \text{Weight}_{\text{SIS Non-Program}} \\ &+ \text{WUR}_{\text{Non-SIS}} * \text{Weight}_{\text{Non-SIS}}\end{aligned}$$

Where:

WUR_i = The water use ratio, which is the water applied divided by the water requirement.

Weight_i = The fraction of the general market that field study category i represents.

Percent Water Reduction from the SIS Program

The research team calculated the percent water reduction from the SIS program to determine the amount of irrigation water that was reduced due to the presence of the SIS program. Equation 3 shows that the SIS program percent water reduction is the difference between the general market water use ratio and the SIS program water use ratio.

Equation 3: SIS Water Reduction

$$\text{SIS Water Reduction} = \text{Water Use Ratio}_{\text{General Market}} - \text{Water Use Ratio}_{\text{SIS Program}}$$

The results from calculating the percent water reduction from the SIS program can be found in the SIS Baseline Research Study Results Memo.

Water Requirement Methodology

The water requirement, expressed in acre inches per acre, which simplifies to inches, is the first component needed to calculate the water use ratio. The research team used a combination of AgWeatherNet and irrigation consultant irrigation scheduling software to determine the water requirement for all the fields in the study.

The AgWeatherNet Process

The research team used the reference evapotranspiration and daily precipitation outputs from AgWeatherNet to calculate the water requirement. AgWeatherNet requires the growing cycle dates, crop type, soil type, year of growing season, weather station, and weather network to determine daily parameters for each field. Table 2 summarizes the required inputs to AgWeatherNet as well as the outputs from AgWeatherNet that the research team used for the water requirement calculation.

Table 2: Inputs and Outputs from AgWeatherNet

<table>
<tr><th colspan="2" rowspan="2">AgWeatherNet Parameters</th><th colspan="2">Source of Data</th></tr>
<tr><th>Non-SIS Fields</th><th>SIS Fields
(Program and Non-Program)</th></tr>
<tr><td rowspan="12">Inputs</td><td>Field ID</td><td colspan="2">Navigant</td></tr>
<tr><td>Year</td><td colspan="2">2016</td></tr>
<tr><td>Weather Network</td><td colspan="2">AgriMet or AgWeatherNet</td></tr>
<tr><td>Crop Type</td><td rowspan="4">Irrigation Consultant Initial Site Visit</td><td rowspan="10">Irrigation Consultant Program Data</td></tr>
<tr><td>Location (Lat/Long)</td></tr>
<tr><td>Weather Station</td></tr>
<tr><td>Soil Type[7]</td></tr>
<tr><td>Date of Emergence</td><td rowspan="6">Irrigation Consultant Retrieval Site Visit</td></tr>
<tr><td>Date Canopy Cover Exceeds 10% of Field</td></tr>
<tr><td>Date Canopy Cover Exceeds 70% of Field</td></tr>
<tr><td>Date of Initial Maturation</td></tr>
<tr><td>Date of End of Growing Season</td></tr>
<tr><td>Cutting Dates (Forage Crops Only)</td></tr>
<tr><td rowspan="2">Outputs</td><td>Reference Evapotranspiration</td><td colspan="2" rowspan="2">AgWeatherNet</td></tr>
<tr><td>Precipitation</td></tr>
</table>

Source: Research team analysis

[7] The soil type is a required input to AgWeatherNet, but it does not affect the reference evapotranspiration or precipitation outputs. The research team used the same soil type for all fields for simplicity purposes.

Irrigation consultants worked with the research team to collect all of the required inputs to AgWeatherNet while onsite. To determine the weather station for each field, the research team used a combination of the closest weather station to the field based on the latitude and longitude coordinates of the field and the irrigation consultants' knowledge about microclimates near the field. For 132 of the 1,501 fields in the study the research team used a different weather station than the closest one to the field due to the irrigation consultants' knowledge of microclimates near the field.

The irrigation consultants used the daily reference evapotranspiration values from the AgWeatherNet output as a key input to their irrigation algorithm to determine the water requirement for each field. The research team also used the daily precipitation output from AgWeatherNet to calculate the water required by the crop from the irrigation system only, as the water requirement calculated by the irrigation consultants was the total water required by the crop from both the irrigation system and precipitation.

Irrigation Consultants' Irrigation Algorithm

The irrigation consultants used the daily reference evapotranspiration values from AgWeatherNet and applied their crop coefficients to determine the crop-specific evapotranspiration for each field. The crop-specific evapotranspiration is equal to the amount of water required by the crop for optimal growth, which can come from irrigation or precipitation. The irrigation consultants summed up the daily evapotranspiration values between the equipment install date and the equipment removal date to determine the seasonal evapotranspiration for each field. The only exception to this calculation was for fields that had cutting dates during the growing season. The irrigation consultants zeroed out the evapotranspiration four days before and seven days after the cutting dates because the metering equipment was removed from the field during this time due to farming equipment actively working in the field. The irrigation consultants zeroed out the evapotranspiration values while the equipment was removed from the field because the water applied data did not include measurements during that time; therefore, it did not make sense to include the water required by the crop for those days. The research team decided to exclude 12 days around the cutting date due to conversations with the irrigation consultants about the average amount of time that the metering equipment is removed from the field during a cutting. This calculation primarily affected alfalfa, grass hay, peppermint, and radish seed fields.

Upon calculating the season crop evapotranspiration values for each field in the study, the irrigation consultants provided the research team with a spreadsheet that included the values for each field in the study, as well as any notes about the calculation.

Water Requirement Calculation

After receiving the crop evapotranspiration information between the equipment install date and the equipment removal date from the irrigation consultants, the research team subtracted the precipitation during the same time period to calculate the water required by the crop from the irrigation system only. Similar to the evapotranspiration calculation, the research team zeroed out the precipitation from four days before to seven days after cuttings to account for the metering equipment being removed from the field. Equation 4 summarizes the equation used to calculate the water requirement for each field in the study.

Equation 4: Water Requirement

$$\text{Water Requirement} = \sum_{\text{Install date}}^{\text{Removal date}} [\text{Reference ET}_{\text{Daily}} * \text{Crop Coefficient}_{\text{Daily}}] - \sum_{\text{Install date}}^{\text{Removal date}} [\text{Precipitation}_{\text{Daily}}]$$

$$= \sum_{\text{Install date}}^{\text{Removal date}} [\text{Crop ET}_{\text{Daily}}] - \sum_{\text{Install date}}^{\text{Removal date}} [\text{Precipitation}_{\text{Daily}}]$$

Where:

Reference ET_{Daily} = The reference evapotranspiration.

Crop ET_{Daily} = The crop-specific evapotranspiration.

Crop $\text{Coefficient}_{\text{Daily}}$ = The coefficient that makes the reference evapotranspiration crop-specific.

$\text{Precipitation}_{\text{Daily}}$ = The precipitation measured by the nearest weather station.

Key Details

See below for additional context and assumptions for the water requirement calculation.

Why the research team subtracted precipitation: The research team subtracted precipitation from the water requirement calculation because the goal of the research study was to identify the impact on the water applied by the irrigation system due to the presence of the SIS program. Subtracting precipitation from the water requirement is also consistent with the water applied calculation, which ensures an apples-to-apples comparison because both the numerator (water applied) and the denominator (water required) of the water use ratio exclude precipitation.

What the water requirement does not account for: AgWeatherNet provides daily outputs from the date of crop emergence to the end of the growing season and aims to estimate how much water the crop needs to grow according to a prescribed crop curve. AgWeatherNet does not account for intentional irrigating before or after the growing season, which farmers may do to improve soil characteristics or to maintain crops during the offseason (e.g., growers often irrigate orchards after harvest to refill the soil profile). The water requirement also does not account for intentional underwatering, which is a strategy to dry out crops intentionally (e.g., growers often underwater wine grapes to increase the sugar content before harvesting and pressing into wine).

Why the water requirement is bounded by the equipment installation period: The research team did not sum the water requirement between the emergence date and the end of growing season date, which is often a longer time period than the equipment installation period, because the water applied calculation is bounded by the equipment installation period. To create an equal comparison between the water required and the water applied, the research team used the equipment installation period for both metrics. The only exception to this was if the equipment install date occurred before the emergence date or the equipment removal date occurred after the end of growing season date. In these instances, the research team bounded the water requirement by the growing season dates instead because the AgWeatherNet output is bounded by the emergence date and end of growing season date. The research team spoke with the irrigation consultants and confirmed that there is often minimal to no water applied when the equipment installation period occurs outside of the bounds of the growing season dates.

Assumed that the crop is unstressed: One of the assumptions that the research team made in the water requirement calculation is that the crop is not stressed. The reason for this assumption was because the research team was interested in the optimal water required by the crop assuming perfect irrigation practices, which means the crop is unstressed.

Assumed that all precipitation is effective precipitation: The research team made an assumption that all precipitation is effective precipitation, which means the precipitation measured at the weather station is the amount of precipitation that is hitting the root zone of the crop and is not lost due to evaporation, runoff, deep percolation, crop interference, etc. The research team made this same assumption for the water applied measurements that required subtracting out precipitation (e.g., tipping rain gauges). The reason for this assumption is that there is so little precipitation in the Columbia River Basin that a majority of precipitation is effective precipitation; therefore, minimal precipitation will be lost due to runoff or deep percolation.[8] While some precipitation is lost due to canopy interference and evaporation, it does not have a significant effect on the result.[9]

Water Applied Methodology

The source of the water applied to the field varies based on the field study category. The research team received the water applied data for the SIS fields from the irrigation consultants at the end of the growing season, whereas the research team worked with the irrigation consultants directly to measure the water applied for the non-SIS fields during the growing season.

Since the research team aggregated the fields in the analysis, it was imperative that the research team used a consistent set of assumptions when calculating the water applied to the fields in the study. To achieve this goal, the research team worked with the irrigation consultants to understand the key assumptions each consultant made when metering the water applied. With a full understanding of the assumptions and methodology from each consultant, the research team adjusted the reported water applied values based on application efficiencies and precipitation, as needed. The following description of the water applied methodology is divided into two parts: the first describes how adjustments were made to treat all fields the same, and the second describes the measurements and adjustments made for non-SIS fields.

[8] The research team based this assumption off of a conversation with Troy Peters, a professor at Washington State University, on 9/8/16.
[9] The research team came to this conclusion based on conversations with Troy Peters and with the irrigation consultants.

Adjustments

The research team defines the water applied to be the amount of water hitting the crop from the irrigation system only. In cases where precipitation might be included in a measurement, such as measurements reported by rain gauges, precipitation was subtracted from the measured irrigation. In cases where the water was applied at the gross level (e.g., pressure gauges), an application efficiency was used to adjust gross water applied to net water applied. Gross water applied is the amount of water leaving the irrigation system before application losses due to irrigation system inefficiencies and weather effects. Net water applied is the amount of water hitting the crop after application losses, which is the measurement that the research team was interested in for this study.

For SIS program and SIS non-program fields, irrigation consultants provided one value for the water applied over the metering equipment installation period, as well as flags to indicate whether precipitation was included or if an application efficiency was applied to the reported irrigation values. This allowed the research team to back out any assumptions that the irrigation consultants made to the water applied so that the team could apply a consistent set of assumptions to all fields.

Water Applied for Non-SIS Fields

This section describes the two methods used to calculate the water applied for non-SIS fields. The primary method for measuring the water applied was the tipping rain gauge, and the secondary method, which was used for orchards and vineyards, was the pressure gauge. The tipping rain gauge method was the preferred method, but it was not feasible to use a tipping rain gauge for the drip and micro-sprinkler irrigation systems used in orchards and vineyards, which is why pressure gauges were used as a secondary method. Table 3 summarizes the inputs required by each of the methods for measuring the water applied to non-SIS fields.

Table 3: Methods for Measuring Water Applied to Non-SIS Fields

Input	Non-SIS Fields	
	Source	**Frequency**
Method 1: Tipping Rain Gauge (Primary Method)		
Water applied to field (acre inches per acre)	Site visit	Monthly during growing season to download data
Precipitation (acre inches per acre)	AgWeatherNet	Daily, summed over growing season
Method 2: Pressure Gauge (Secondary Method)		
Total runtime of irrigation system (hours)	Site visit, pressure gauge reading	Monthly during growing season to download data
Flow rate (gallons per minute)	Site visit, ultrasonic flow meter	Once during growing season
Acreage of field (acre)	Irrigation consultant	Once, first site visit

Source: Research team analysis

The research team used an iPad data collection application to transfer data collected at non-SIS fields between the irrigation consultants and the research team. The software housed the data collected during the initial visit, follow-up visits, and the retrieval visit. The most important data points collected with the iPad data collection software were the approach for measuring the water applied, status of the equipment, status of the crop, pictures of the equipment, pictures of the crop, crop type, irrigation system type, soil type, and key growing cycle dates.

Method 1: Tipping Rain Gauge

The tipping rain gauge method is the most direct approach for calculating the water applied because it measures the water hitting the crop and does not require a gross to net water conversion. The research team used the tipping rain gauge method for all irrigation system types except drip and micro-sprinkler systems, where the research team used the pressure gauge method (discussed below).

The irrigation consultants downloaded the data from the tipping rain gauges during each monthly site visit and sent it to the research team for analysis on the same day as the site visit. The tipping rain gauge logs the timestamp of events, which is every time the tipping mechanism receives 0.01 acre inches per acre (i.e., inches) of water from either irrigation or precipitation. The research team converted the events recorded by the tipping rain gauges to acre inches per acre of water by multiplying the number events by 0.01 acre inches per acre.

As the tipping rain gauge measures irrigation and precipitation and the research team is only interested in the water hitting the crop from irrigation, the research team subtracted the precipitation from the tipping rain gauge measurements. The team summed the precipitation measured by the nearest weather station between the equipment install date and removal date, with the exception of four days before and seven days after cutting dates (e.g., alfalfa). The research team then subtracted the sum of the precipitation from the sum of the water applied measurements from the tipping rain gauges to get the water applied by the irrigation system only.

There were many instances where the tipping rain gauges malfunctioned or were damaged and the research team had to install another tipping rain gauge. In those instances, the research team had to combine the water applied data from multiple loggers to determine the seasonal water applied measurements. In other instances, the tipping rain gauges did not measure all of the water applied to the field due to equipment malfunction or the grower tampering with the equipment (e.g., removing equipment from the field without telling the field technician). In those situations, the research team relied on secondary sources (e.g., grower interviews or hour meter data) to make up for the missing data.

Equation 5 summarizes the equation used for the tipping rain gauge method.

Equation 5: Net Water Measured by the Tipping Rain Gauge Method

$$\text{Net Water Applied} = \sum_{\text{All Loggers}} \left[\text{Events} * \frac{0.01 \text{ acre} \frac{\text{inch}}{\text{acre}}}{\text{event}} \right] + \text{Adjustments} - \sum_{\text{Install date}}^{\text{Removal date}} \text{Precipitation}$$

Where:

Event	= Every time the tipping rain gauge receives 0.01 acre inches per acre of water from the irrigation system or precipitation.
Adjustments	= Irrigation data added in after the fact due to the tipping rain gauge not measuring the water applied (e.g., equipment tampering, equipment malfunction).
Precipitation	= Amount of precipitation hitting the field based on data from the nearest weather station.

Method 2: Pressure Gauge with Integrated Data Logger

The research team used pressure gauges to measure the water applied if the irrigation system was a drip system or micro-sprinkler because the tipping rain gauge could not accurately measure the water applied by these irrigation systems. This method required a measurement of the water pressure of the irrigation system for the duration of the growing season, which was used to determine the runtime of the irrigation system. The research team used engineering judgment to determine the pressure threshold that indicated when the irrigation system was on and applying water. In a majority of cases, the research team used a threshold of 10 pounds per square inch gauge (PSIG) or greater as an indication of when the irrigation system was on, while a lower value of 5 PSIG was used for certain fields. The research team determined the pressure threshold on a field-by-field basis depending on the average water pressure of the irrigation system for a particular field. The second input required for the pressure gauge method was a spot measurement of the flow rate so the research team could convert runtime to water applied.

The irrigation consultants downloaded the data from the pressure gauges during each monthly site visit and sent it to the research team for analysis on the same day as the site visit. The team checked for possible overlap in the data file to ensure the total runtime utilized the proper number of minutes when the pressure reading exceeded the irrigation system on-off threshold. Checking the overlap in time guaranteed that the total runtime in minutes was equal to the number of observed pressure readings.

There were a few instances where the pressure gauges malfunctioned and the research team had to install another pressure gauge. In those instances, the research team had to combine the pressure data from both loggers to get the measurements for the entire monitoring period. In other instances, the pressure gauges did not measure all of the water applied to the field due to equipment malfunction or the grower tampering with the equipment. In those situations, the research team had to add in the missed water applied from secondary sources (e.g., grower interviews or hour meter data).

The pressure gauge method also required the research team to take a one-time spot measurement of the flow rate of the irrigation system to convert runtime to water applied. The research team measured the flow rate once during the study period in units of gallons per minute.

Equation 6 is the formula the research team used to calculate gross water applied for the pressure gauge method.

Equation 6: Gross Water Measured by the Pressure Gauge Method

$$\text{Gross Water Applied} = \text{Flow Rate} * \sum_{\text{Minutes}} [\text{When Pressure} > \text{Threshold Pressure}] + \text{Adjustments}$$

Where:

Gross Water Applied = The amount of water leaving the irrigation system before application losses. The gross water applied is measured in gallons.

Flow Rate = The irrigation consultants took a one-time spot measurement of the flow rate of the irrigation system. The flow rate is measured in gallons per minute.

Pressure = The water pressure measured by the pressure gauge. The research team used the pressure data to determine the time (in minutes) that the irrigation system was on.

Threshold Pressure = The research team determined a pressure threshold of when the irrigation system was on past a certain pressure. The most common threshold value was 10 PSIG, but this threshold was set on a field by field basis. Thus, whenever the water pressure was greater than the pressure threshold it was an indicator to the research team that the irrigation system was on.

Adjustments = In some instances the research team had to add water applied data in after the fact due to the pressure gauge not measuring the water applied (e.g., equipment tampering, equipment malfunction).

Equation 6 results in gross water applied in gallons, so the research team converted to net water applied in acre inches per acre using Equation 7.

Equation 7: Net Water Measured by the Pressure Gauge Method

$$\text{Net Water Applied} = \frac{\text{Gross Water Applied} * 3.6827*10^{-5}}{\text{Field Acreage}} * \text{Application Efficiency}$$

Where:

Net Water Applied = This is the water hitting the crop after application losses. It is measured in acre inches per acre.

Gross Water Applied = This is the gallons of water measured during the monitoring period, which was calculated using Equation 6.

Field Acreage = This is the acreage of the field, which was provided to the research team by the irrigation consultants.

$3.6827 * 10^{-5}$ = This is the multiplier that converts gallons to acre inches (one acre-inch = 27,154 gallons).

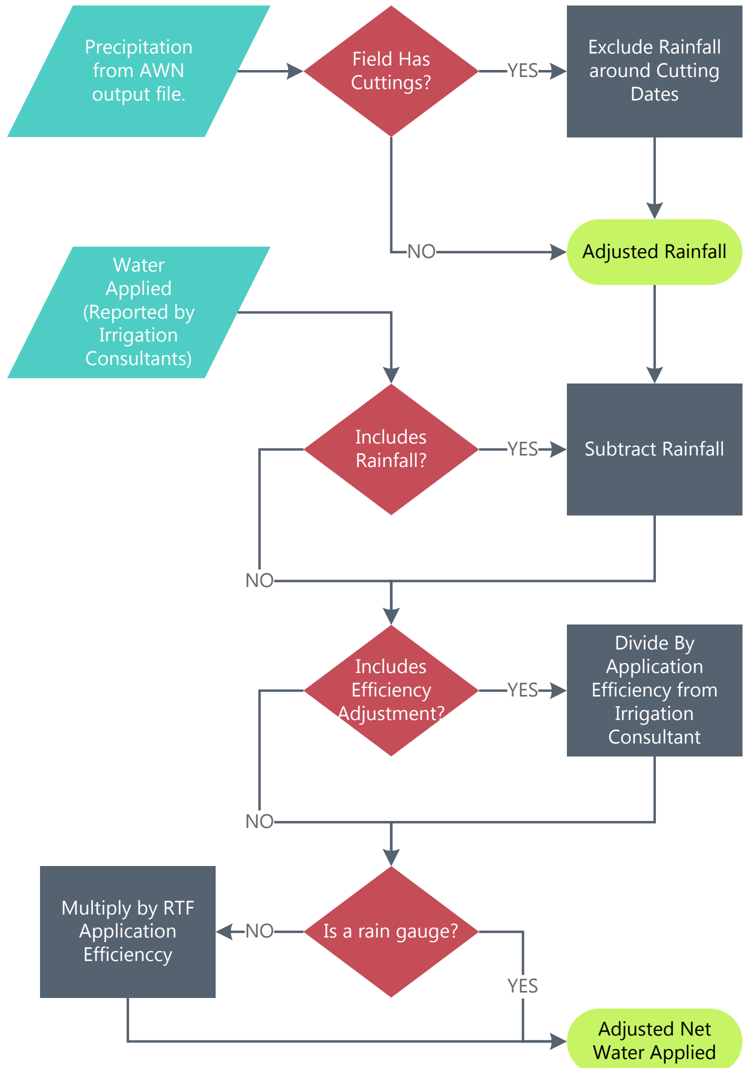
Application Efficiency = This comes from the RTF SIS Calculator. It allowed the research team to convert the gross water applied (pre-application losses) from the pressure gauges to net water applied (post-application losses). The application efficiency varies by crop type and irrigation system type. See Appendix: RTF SIS Calculator Application Efficiencies for a list of the application efficiencies.

Key Details

See below for additional context and assumptions for the water applied calculation.

- **Precipitation and application efficiency:** The research team adjusted the water applied data collected by the irrigation consultants for 1,495 of the 1,501 fields to either apply an application efficiency or remove precipitation to calculate the water hitting the crop by the irrigation system only. If the water applied number included precipitation (e.g., tipping rain gauges) or an application efficiency (e.g., hour meters) then the research team first subtracted out the rainfall to determine the water applied to the crop by the irrigation system only. The research team then divided out the application efficiency assumed by the irrigation consultant, and then applied the RTF application efficiency. The research team only applied an application efficiency if the water applied was measured at the gross level (e.g., hour meters, flow meters, pressure gauges) and needed to be converted to net water applied. Figure 2 summarizes the process that the research team used to adjust for application efficiencies and precipitation.

Figure 2: Application Efficiency and Precipitation Adjustments



Source: Research team analysis

- **Ultrasonic flow measurements:** The pressure gauge method required a one-time spot measurement of the ultrasonic flow measurement so that the research team could convert from gross water applied to net water applied. In an ideal scenario, the research team would have taken multiple spot measurements of the flow rate of the irrigation system because it can vary over time. However, due to time and budget restrictions, the research team had to rely on a one-time spot measurement.

  In some instances, the research team had to use a different ultrasonic flow measurement than what was measured by the irrigation consultant due to unrealistically low values for the water applied.[10] The team worked with the irrigation consultants on these adjustments based on the

[10] The research team determined from conversations with the irrigation consultants that the unrealistically low water applied values stemmed from erroneous ultrasonic flow measurements. This likely occurred because the grower gave the irrigation consultants the wrong information on where to take the ultrasonic flow measurement of the irrigation system.

irrigation consultants' knowledge of the irrigation system and information from the grower on how much water they applied during the growing season. In most instances the irrigation consultants were able to leverage secondary sources of information from the grower (e.g., hour meter data) to determine how much water was applied.

- **Growing dates versus equipment installation dates:** In many cases the rain gauges or other equipment for monitoring irrigation could not be installed until after the growing season had started or had to be removed before the end of the growing season due to practical reasons (e.g., it might get run over by a tractor). The consequence was that any irrigation that occurred before equipment was installed or after it was removed was not included in analysis. Conversely, the growing season could start after the equipment was installed, in which case irrigation or precipitation might be recorded before the growing season, which would then need to be excluded from analysis. If the install date occurred before the emergence date, then the research team bounded the water requirement by the emergence date. Conversely, if the equipment removal date occurred after the end of growing season date then the research team bounded the water requirement by the end of growing season date. In all other instances the research team bounded the water requirement by the equipment install and removal dates.

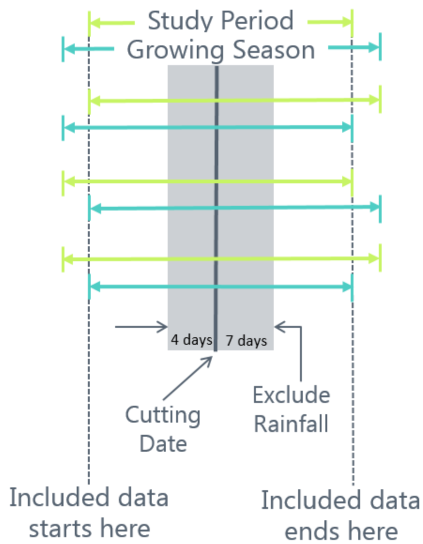
  Figure 3 provides a visual depiction of the potential difference between dates used to compute the water applied and water required based on the equipment install and removal dates. It is important to note that there is often a minimal amount of water applied between the emergence date and equipment install date and between the end of season date and the equipment removal date.

Figure 3: Key Growing Dates and Study Period Dates

Source: Research team analysis

- **Precipitation around cutting dates:** Forage crops like alfalfa often have several cutting dates throughout the growing season. Because monitoring equipment must be removed to allow for farming equipment to cut the crops, irrigation and precipitation were missed for several days before and after each cutting. To account for this, the research team did not subtract precipitation from the water applied on or between four days before and seven days after the cutting date. For example, if a cutting date was on July 10, the research team did not subtract the precipitation that fell on or between July 6 and July 17 from the water applied. Figure 4 provides a graphical representation of how the research team handled precipitation around cutting dates.

Figure 4: Cutting Dates and Data Cutoff Dates



Note: Only one cutting date is shown, but some fields had up to five cutting dates (e.g., alfalfa fields).
Source: Research team analysis

Appendix: RTF SIS Calculator Application Efficiencies

The research team used the RTF application efficiencies to convert gross water applied to net water applied, when applicable. The application efficiency depends on the irrigation system type and the crop type, as seen in Table 4.

Table 4: Application Efficiencies

RTF Crop Type	Center Pivot/Linear Move	Drip/Micro	Furrows/ Rills/ Corrugations	Other Surface Methods	Solid Set	Traveling Big Gun	Wheel Line/ Hand Lines
Alfalfa	0.8	-	0.63	0.58	0.75	0.7	0.75
Beans	0.75	0.8	0.55	0.35	0.7	0.6	0.65
Canola	0.8	0.8	0.55	0.45	0.75	0.65	0.75
Field Corn	0.75	-	0.55	0.45	0.73	0.62	0.73
Grass Seed	0.8	0.8	-	-	0.75	0.65	0.7
Hops	0.85	0.85	-	-	0.8	0.75	0.8
Mint	0.8	0.8	-	-	0.75	0.65	0.7
Onions	0.75	0.8	0.55	0.35	0.7	0.6	0.65
Orchard	-	0.85	0.75	0.7	0.85	-	0.85
Other	0.78	0.82	0.57	0.45	0.45	0.64	0.73
Pasture	0.75	-	0.55	0.5	0.7	0.62	0.7
Peas	0.75	0.8	0.55	0.35	0.7	0.6	0.65
Poplars 1st	-	0.85	-	-	0.8	-	0.8
Poplars 2nd	-	0.85	-	-	0.8	-	0.8
Poplars 3rd	-	0.85	-	-	0.8	-	0.8
Potatoes	0.75	0.8	0.55	0.35	0.7	0.6	0.65
Shepody Potatoes	0.75	0.8	0.55	0.35	0.7	0.6	0.65
Spring Wheat	0.75	-	0.55	0.5	0.7	0.62	0.7
Sugar Beets	0.8	0.8	0.55	0.45	0.75	0.65	0.75
Sweet Corn	0.8	0.8	0.55	0.45	0.75	0.65	0.75
Wine Grapes	0.85	0.85	-	-	0.8	0.75	0.8
Winter Wheat	0.75	-	0.55	0.5	0.7	0.62	0.7

Source: RTF SIS Protocol Calculator, Version 2.1 – Revised 4/15/2015. *http://rtf.nwcouncil.org/measures/measure.asp?id=184*.

Appendix L – Analysis Results

To: Carrie Cobb, Bonneville Power Administration (BPA)

From: Emily Merchant, Navigant Consulting, Inc. (Navigant); Elizabeth Daykin, Cadeo Group

Date: June 14, 2017

Subject: SIS Baseline Research Study: Results

This memorandum discusses the methods that Navigant and Cadeo Group (the research team) used to aggregate the field-level results from the Scientific Irrigation Scheduling (SIS) Baseline Research Study and the results from the study. During the 2016 growing season the research team worked with irrigation consultants to collect water applied data for 1,508 fields. The data collected included fields across three field study categories that together make up the general market. The combination of the three field study categories make up all the fields in the Columbia River Basin, which for the purposes of this memo is referred to as the general market. The three field study categories included fields that received SIS services in 2016 and received an incentive from BPA (SIS program), fields that received SIS services in 2016 and did not receive an incentive from BPA (SIS non-program), and fields that did not receive SIS services in 2016 (non-SIS). This document discusses how the research team used the water applied and water required data for each of the fields to determine the percent water reduction from BPA's SIS program, as well as the associated statistics.

To determine the percent water reduction from BPA's SIS program, the research team used a metric called the water use ratio, which is the amount of water applied to the field divided by the water required by the field. The team took the difference between the water use ratio of the general market and the SIS program fields to determine the percentage of water reduced by BPA's SIS program. The methods for determining the water use ratio for the SIS program fields and the general market fields is summarized in the weighting and aggregating the results sections.

Upon aggregating the field-level results, the research team determined that the percent water reduction from the SIS program, as measured in absolute terms, is 0.5%. To put this in perspective, the last time the percent water reduction from BPA's SIS program was analyzed was in 2005 by Quantec, and they found that the percent water reduction from the SIS program was 10%.[1] The primary driver behind the difference in savings between the two studies is likely due to significant advances in irrigation practices since 2005, as well as differences in approach between the two studies. The Quantec study calculated the savings by comparing the water consumption of SIS program fields to non-SIS fields, whereas this study compared the water consumption of SIS program fields to general market fields (SIS program, SIS non-program, and non-SIS fields). Also, the magnitude of this study was significantly larger than the Quantec

[1] *A Study of Irrigation Scheduling Practices in the Northwest* – Phase II: Measurement of Water and Electricity Impacts. Quantec. 2005.

study. The Quantec study included metered data for 38 fields, whereas this study included metered data for 1,501 fields.

Table 1 and Table 2 summarize the high level results and associated statistics from analyzing the percent water reduction from BPA's SIS program in 2016. The reason why the percent water reduction in Table 1 is positive and not negative is because the percent water reduction, i.e. delta, is measured in absolute terms. This means that regardless of whether the difference between the general market water use ratio and the SIS program water use ratio is positive or negative, the percent water reduction is presented as a positive value.

Table 1: Summary of Results

Metric	SIS Program	Market
Water Use Ratio	0.760	0.755
% Water Reduction from BPA's SIS Program	0.5%	
Absolute Precision	±2.53%	
90% Confidence Bounds	-2.1%	3.0%

Source: Metered data

Table 2: Statistics of Field Study Category Water Use Ratios

Category	Water Use Ratio	Standard Error	CV
SIS Program	0.760	0.001	0.303
SIS Non-Program	0.945	0.030	0.204
Non-SIS	0.730	0.021	0.383
General Market	0.755	0.015	N/A

*CV stands for coefficient of variation.

Source: Metered data

Analysis Approach

This section discusses the methods that the research team used to aggregate the field-level results to determine the percent water reduction from BPA's SIS program. This section also describes which fields the research team included in the analysis, as well as how the team weighted the data collected from each of the field study categories to determine the general market water use ratio.

Fields Included in the Analysis

The research team used two datasets for the analysis: the dataset of 735 fields used to characterize the population and the dataset of 1,508 fields to perform the water use ratio analysis. Due to reasons discussed below, the research team did not include all the fields in the analysis for which the team received data.

Dataset Used for Weighting

As the population frame for the irrigated fields in the Columbia River Basin is unknown, the research team needed to estimate the percentage of the population that falls into each of the field study categories of interest: SIS program, SIS non-program, and non-SIS. As a proxy, the research team used a random geospatial sampling technique to select 735 fields on irrigated land, which the team used as a starting point for recruiting fields into the study. Because the research team selected these fields randomly without any known bias associated with irrigation techniques, the category percentages (i.e., weights) demonstrated by these 735 fields were assumed to be representative of the population at large. Additionally, because these percentages heavily impact the results, the research team had the irrigation consultants call the growers at the beginning of the growing season to see which field study category and crop management type the sampled field fell into; the consultants also followed up with the growers again at the end of the growing season to confirm the information.

The research team excluded 35 fields from the dataset of 735 fields for the field study category weighting calculation because the fields were either not irrigated in 2016 or they were sampled twice. The team did not include unirrigated fields in the weighting calculation because one of the requirements for a field to be included in the study was that it needed to be on irrigated land. The team excluded duplicate fields from the weighting calculation because the dataset of 735 fields was supposed to be representative of the population of irrigated fields in the Columbia River Basin; therefore, it did not make sense for the same field to occur twice in the population. Duplicate fields showed up in the dataset because of the way the research team randomly sampled fields—by selecting latitude and longitude coordinates in a field. A duplicate field would occur if two sample points landed in the same field. If this happened, the research team only counted that field once in the field study category weighting calculation.

The research team had to assume a field study category for 99 of the 700 fields included in the field study category weighting calculation as the irrigation consultants were unable to get ahold of the grower. For the purposes of weighting, the team placed these fields into the non-SIS category because they were confident that more than 50% of these fields were likely to be non-SIS. The irrigation consultants stated that if these fields were utilizing SIS techniques, they would likely be aware. Given that information, the research team concluded that categorizing the 99 fields as non-SIS would introduce less bias than if these fields were excluded entirely from the weighting calculation due to a lack of information.

The research team excluded 162 of the 735 fields in the dataset for the crop management weighting calculation because the irrigation consultants were unable to get ahold of the grower to confirm if the grower grew a high management crop or a low/medium management crop in 2016. The reason why the irrigation consultants could confirm the field study category and not the crop management type for the field is because of their knowledge of the region and which growers participate in SIS services. Growers change their crop rotation so frequently that it is more difficult for the irrigation consultants to monitor which crops are grown on a given field than whether SIS is conducted on a given field.

Dataset Used for the Analysis

The research team collected data for 1,508 fields but only used 1,501 fields in the final analysis. The list below describes the reasons why some fields were excluded from the dataset of fields used in the analysis.

- **Excluded non-SIS fields due to equipment malfunction or tampering (35 fields):** The research team installed equipment in 217 non-SIS fields at the beginning of the growing season and ended up with usable data for 182 fields. The research team excluded 35 fields from the analysis for one of the following reasons: loss of data due to equipment malfunction or tampering, the grower decided to receive SIS services partway through the growing season or the grower did not end up irrigating their field in 2016.
- **Grower did not want to participate in the study (2 fields):** Part of the reason why the research team collected data for 1,508 fields and only used 1,501 fields in the study was because one grower decided not to include their fields in the study after they had already provided their data to the irrigation consultants. The research team had to delete two fields at the request of the irrigation consultant because the grower did not want their fields to be included in the study.
- **Water requirement was negative (5 fields):** The third reason the research team collected data for 1,508 fields and only included 1,501 fields in the analysis was because the water requirement for five fields was negative. This occurred because the water required by the field was so small due to a shorter than average growing season length that after the research team subtracted the seasonal precipitation from the water requirement it resulted in a negative water requirement from the irrigation system. A negative water requirement means that the water needs of the crop was so small that it could be met (and exceeded) by the rainfall it received, thus no irrigation was needed. Fundamentally it did not make sense for a grower to remove water from a field, which they would have to do to achieve a negative water requirement. Thus, the research team excluded the five fields with a negative water requirement from the analysis.

Approach to Ensure an Apples-to-Apples Comparison

The research team collected data from multiple irrigation consultants with varying approaches for data collection; thus, the research team made a significant effort to ensure that the irrigation consultants used similar assumptions for the water applied and water requirement calculations so the team could aggregate the fields in the analysis. At the beginning of the study, the research team held multiple meetings with various stakeholders from all ranges of the spectrum, including university professors, BPA program managers, and irrigation consultants, to get a sense for how irrigation consultants perform SIS services in the region. The research team conducted this exercise so it could design a field data collection protocol that was representative of how SIS services are performed in the Columbia River Basin. At the beginning of the study, stakeholders expressed concern that the research team would be working with irrigation consultants in real time to collect data for non-SIS fields, but the team would have less oversight over how the irrigation consultants collected data for SIS fields. To combat this concern, the research team designed the field data collection protocol for the non-SIS fields to mirror the way that the irrigation consultants collected data for the SIS fields. In addition, because the irrigation consultants were the same people collecting data for the non-SIS fields as the SIS fields, the research team is confident that the water applied data was collected in a similar method across all field study categories.

One of the other ways that the research team ensured the irrigation consultants collected field-level data in a consistent manner was to have them include their assumptions for precipitation and application efficiencies in the SIS program data. For example, in the water applied data that the irrigation consultants provided at the end of the growing season, some consultants included precipitation in their estimate for the water applied and others did not. As the research team was interested in the water applied by the irrigation system only, the research team subtracted out precipitation in any cases where it was added in by the irrigation consultant.[2] In addition, some of the irrigation consultants included an application efficiency adjustment in their water applied estimate. In those instances, the research team divided out the application efficiency assumed by the irrigation consultant and applied a consistent set of application efficiencies across all fields that needed the water applied converted from gross to net water applied (e.g., orchards and vineyards).

Weighting

To determine the percent water reduction from BPA's SIS program as compared to the general market, the research team had to weight the field-level data to determine the water use ratio of the general market fields. The general market water use ratio is a weighted average of the water use ratios of each of the three field study categories (SIS program, SIS non-program, and non-SIS).

The research team worked with irrigation consultants to collect the water applied data and the inputs required for the water requirement calculation for the sampled fields. Through these efforts, the team achieved a near census, approximately 100%, for the SIS program participants and data for over 200 fields in the remaining groups (non-SIS and SIS non-program fields). Since the data that the research team collected from the irrigation consultants was not representative of the overall population proportions of these field study categories, the team applied weights to the field study categories. The research team calculated the field study category weights from the sample frame of 735 fields that the team used to recruit fields into the study.[3]

Table 3 shows a breakdown of the characteristics of the 735 fields included in the sample frame, as well as the resulting weights of each field study category. The research team excluded 35 fields from the population weighting due the reasons discussed in the dataset used for weighting section.

[2] The research team confirmed that they used the same method as the irrigation consultants for identifying the weather station and calculating the precipitation. The purpose of this exercise was to ensure that the research team subtracted the same rainfall as what the irrigation consultants added to the water applied. The research team confirmed that the irrigation consultants summed up the precipitation based on the monitoring period and used the weather station closest to the field, except for 132 fields in the study where the irrigation consultants used a different weather station due to their knowledge of microclimates near the field. In those 132 instances, the research team used the weather station the irrigation consultants used to ensure an apples to apples comparison.

[3] Additional information on how the research team developed the sample frame is available in the Sample Design, Approach, and Selection memo, which the team developed in May 2017.

Table 3: Sample Frame by Field Study Category

Category	Number of Fields in the General Market	Percentage of Fields in the General Market
Non-SIS	510	69%
SIS Program	125	17%
SIS Non-Program	65	9%
Excluded Fields	35	5%
Total	**735**	**100%**

Source: Interviews of growers

Table 4 provides the weight that each field study category made up in the population frame—i.e., the general market. The research team used the weights summarized below to determine the general market water use ratio, which was calculated by taking the water use ratio of each field study category and multiplying it by the weight of that field study category relative to the general market.

Table 4: Field Study Category Weights

Category	Number of Fields in the General Market	Percentage of Fields in the General Market
Non-SIS	510	72.9%
SIS Program	125	17.9%
SIS Non-Program	65	9.3%
Total	**700**	**100%**

Source: Interviews of growers

The research team also determined the breakdown of crop management types within each field study category. It is important to note that the team designed the sample with the intention of weighting the results only by field study categories and did not design the sample to also weight the results by crop management type. This is because the research team would have needed to meet unrealistic sampling targets to achieve the necessary confidence and precision targets. The research team developed crop management weights by splitting out the fields into two categories:

- **High crop management**, which are typically higher value crops like onions and cherries
- **Low/medium crop management**, which are typically lower value crops such as alfalfa and corn

The crop management type weights, presented in Table 5, used the same exclusion rules as the field study category weights (e.g., duplicate fields and non-irrigated fields). Additionally, the research team excluded 162 fields from the crop management weighting calculation because the irrigation consultants were unable to get ahold of the grower to confirm the crop type, making the crop management type unknown.

Table 5: Crop Management Type Weights

Category	Crop Management Intensity	Number of Fields in the General Market	Percentage of Fields in the General Market
Non-SIS	Low/Medium	242	63%
Non-SIS	High	142	37%
SIS Program	Low/Medium	77	62%
SIS Program	High	48	38%
SIS Non-Program	Low/Medium	34	53%
SIS Non-Program	High	30	47%

Source: Interviews of growers

The research team also explored weighting fields by their probability of selection—i.e., weighting by the size of the field. However, the field size already affected the probability of selection in the sample because the larger fields had a greater probability of being selected in the dart method sampling approach. The research team sampled fields using the ArcGIS Sampling Design Tool, which plotted fields on a map within a pre-determined area and then put the points in a random order; this allowed the research team to sample fields in an unbiased manner. As there was a higher likelihood that the sampling tool would randomly assign a point in a larger field than a smaller field, applying a probability of selection weighting would have overly biased the results toward larger fields. The research team excluded duplicate fields from the weighting calculation, which occurred when two sample points landed in the same field. The dataset of 735 fields was intended to represent the population, therefore including the same field more than once would have created an inaccurate population.

Aggregating the Results

The research team aggregated the field-level data to determine the percent water reduction from the SIS program as compared to the general market. To determine the percent water reduction, the team first needed to calculate the water use ratio for each of the field study categories. Equation 1 summarizes the equation used to calculate the water use ratio for each of the field study categories, which was accomplished by summing the water applied to all the fields in each field study category and dividing it by the sum of the water required by all the fields in each field study category.

Equation 1: Field Study Category Water Use Ratio

$$\text{Water Use Ratio}_{\text{Field Study Category,i}} = \frac{\sum_{\text{All fields}}[\text{Water Applied}]}{\sum_{\text{All fields}}[\text{Water Required}]}$$

The next step that the research team used to calculate the percent water reduction from the SIS program was to calculate the water use ratio of the general market. The research team accomplished this by using Equation 2, which involves weighting the water use ratios of the field study categories and taking the sum.

Equation 2: General Market Water Use Ratio

$$\text{Water Use Ratio}_{\text{GeneralMarket}} = \sum_{\substack{\text{All field study}\\ \text{categories}}} [\text{Water use ratio}_{\text{Field study category,i}} * \text{Weight}_{\text{Field study category,i}}]$$

The research team could have calculated the water use ratios for the field study categories by calculating a water use ratio for each field and taking a simple average of the water use ratios within each field study category. The research team did not use this approach because it did not account for the fact that the team was estimating the ratio of two values (i.e., the water applied and the water required).

The research team calculated the water use ratios for the crop management types using the same approach as the field study categories, which involved taking the ratio of the water applied to water required for each crop management and field study category combination. The team applied the weights in Table 5 to determine the percent water reduction from the SIS program as compared to the general market.

The water applied and water required values for less than 10% of the fields had more than three significant digits. To avoid overstating the accuracy of the results, the research team rounded the water applied and water required values to three digits for all calculations.

Results

This section discusses the statistical analysis results from aggregating the field-level data to determine the percent water reduction from the SIS program. This section includes the savings estimate from aggregating the results by field study category, as well as from aggregating the results by crop management and field study category. In addition to providing the numerical results, this section includes visual representations of the results.

Statement of Results

The research team provides the following three metrics for each field study category and the general market in Table 6, which sets the stage for the statistical validity of the results presented in Table 7.

- **Water use ratio.** The ratio of the water applied to the water required, calculated as described in the aggregating the results section.
- **Standard error.** The measure of dispersion around the mean. Because the SIS program population was known, the research team used the finite population correction (FPC) factor to calculate the standard error for the SIS program fields. The assumed population was 1,289 SIS program fields because the team got a near census of the program participants. The research team did not make a FPC adjustment for the SIS non-program and non-SIS fields because those populations were unknown.
- **Coefficient of variation (CV).** Unit-less measure of variability relative to the mean, which is often expressed as a percentage.

Table 6: Water Use Ratios by Field Study Category

Category	Water Use Ratio	Standard Error	CV
SIS Program	0.760	0.001	0.303
SIS Non-Program	0.945	0.030	0.204
Non-SIS	0.730	0.021	0.383
General Market	0.755	0.015	N/A

Source: Metered data

It is important to note that the standard error in Table 6 does not include the percent error in the equipment used to measure the water applied to the fields. The research team acknowledges that there is a small percent error associated with the equipment used in the study, but it is so negligible that the team did not take it into account. For example, the tipping rain gauge, which was the primary method used for the non-SIS fields, has a percent error of plus or minus one percent. The research team assumed that the percent error in the equipment across all field study categories was similar and, therefore, it falls out in the analysis and does not affect the result.

Table 7 summarizes the percent water reduction and the associated statistics from comparing the water use between the SIS program fields and the general market fields. As discussed in the Sample Design, Approach, and Selection memo, the research team designed the sample to detect a difference of at least 10% (or 10% absolute precision) and a targeted level of 90% confidence.

In addition to the water use ratio for each group, Table 7 provides the following:

- **Percent water reduction from BPA's SIS program.** The absolute difference between the SIS program water use ratio and the general market water use ratio.
- **Absolute precision.** The difference in water use ratios between SIS program fields and the general market fields that the research team can discern with confidence. As discussed in the Sample Design, Approach, and Selection memo, the research team designed the sample to detect a difference of at least 10% (or 10% absolute precision).
- **90% confidence bounds.** The interval estimate of the delta. As discussed in the Sample Design, Approach, and Selection memo, the research team used a sample design with a target level of 90% confidence, which is the standard statistical confidence in energy efficiency evaluations and indicates 90% confidence that the true delta falls within that interval.

Table 7: Field Study Category Savings Estimate

Metric	SIS Program	Market
Water Use Ratio	0.760	0.755
% Water Reduction from BPA's SIS Program	0.5%	
Absolute Precision	±2.53%	
90% Confidence Bounds	-2.1%	3.0%

Source: Metered data

Table 8 provides the water use ratio, standard error, and CV by crop management category and field study category. As discussed previously, the research team is showing these metrics for informational purposes only because the team did not design the sample with the intent of breaking out the results by crop management type.

Table 8: Water Use Ratios by Crop Management Type

Crop Management	Category	Water Use Ratio	Standard Error	CV
High	SIS Program	0.727	0.017	0.571
	SIS Non-Program	1.040	0.067	0.294
	Non-SIS	0.683	0.054	0.635
	High Management Total	**0.731**	**0.015**	**N/A**
Low/Medium	SIS Program	0.791	0.017	0.564
	SIS Non-Program	0.844	0.074	0.382
	Non-SIS	0.760	0.034	0.490
	Low/Medium Management Total	**0.772**	**0.016**	**N/A**

Source: Metered data

Table 9 shows the savings estimate for the high management crops, and Table 10 shows the savings estimate for the low and medium management intensity crops. As seen below, calculating the savings by crop management type does not produce a significantly different result than calculating the savings for all crop management types together. Aggregating the results by field study category or by field study category and crop management type both show a minimal percent water reduction due to the presence of the SIS program.

Table 9: Savings Estimate for High Management Crops

Metric	SIS Program	Market
Water Use Ratio	0.727	0.731
% Water Reduction from BPA's SIS Program	0.5%	
Absolute Precision	±3.77%	
90% Confidence Bounds	-3.3%	4.2%

Source: Metered data

Table 10: Savings Estimate for Low/Medium Management Crops

Metric	SIS Program	Market
Water Use Ratio	0.791	0.772
% Water Reduction from BPA's SIS Program	1.9%	
Absolute Precision	±3.84%	
90% Confidence Bounds	-2.0%	5.7%

Source: Metered data

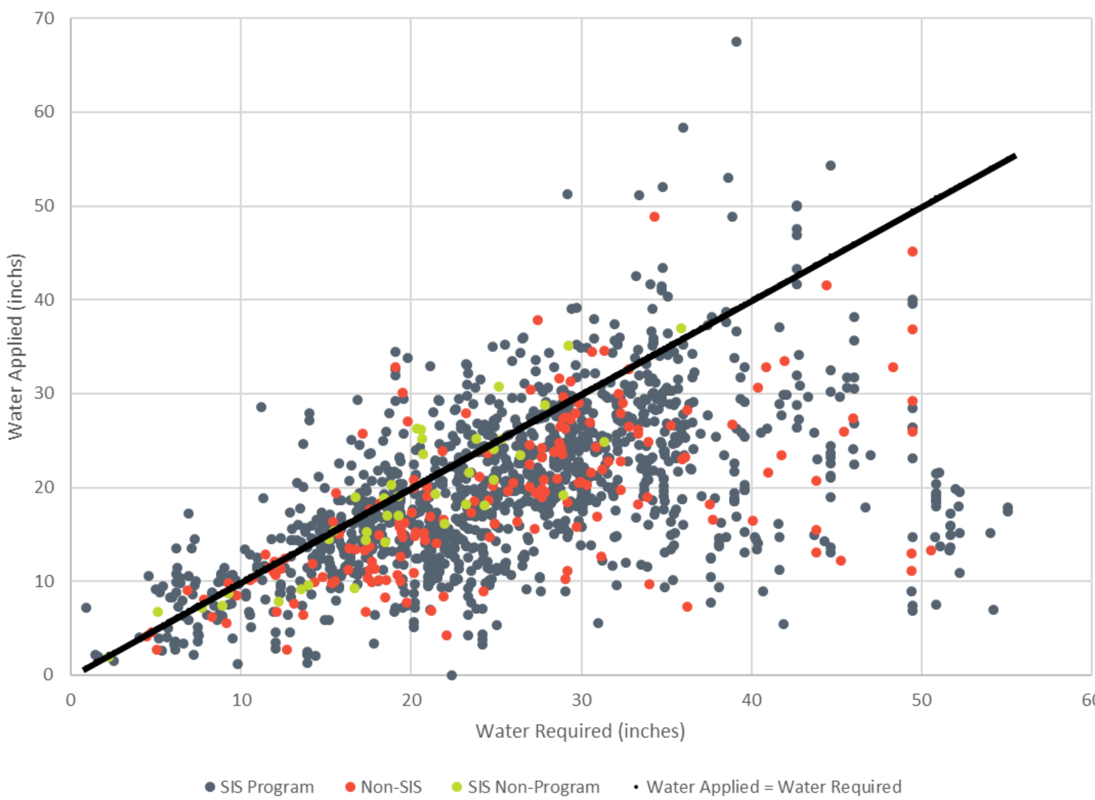
While the SIS program is likely resulting in higher water savings on certain fields more than others, as well as for certain crop types more than others, when aggregating the results the research team found that the SIS program results in close to zero water savings. Growers participating in the SIS program may be applying less water at certain times, but overall they are applying similar amounts of water to their fields as growers who are not participating in the SIS program. Growers participating in the SIS program could be experiencing higher crop yields due to more closely monitoring their irrigation practices, but the research team was unable to collect data on crop yield as part of this study; therefore, the research team is unable to back up this claim with data.

Presentation of Results

This section includes a few graphics that the research team developed using the field-level results from the study to provide a visual representation of the results.

Figure 1 is a graph of the water applied (y-axis) versus the water required (x-axis) for all the fields included in the analysis, with each dot representing a field. The black line represents the hypothetical scenario that the water applied to the field is equal to the water required by the field. As seen below, most of the fields fall below the black line, which means that most of the growers applied less water to their fields than what was required for optimal crop growth. This figure also provides a visual representation of why the research team determined minimal water savings between the SIS program and the general market. If there were more water savings, the SIS program fields would have been below the black line and the non-SIS and SIS non-program fields would have been above the black line.

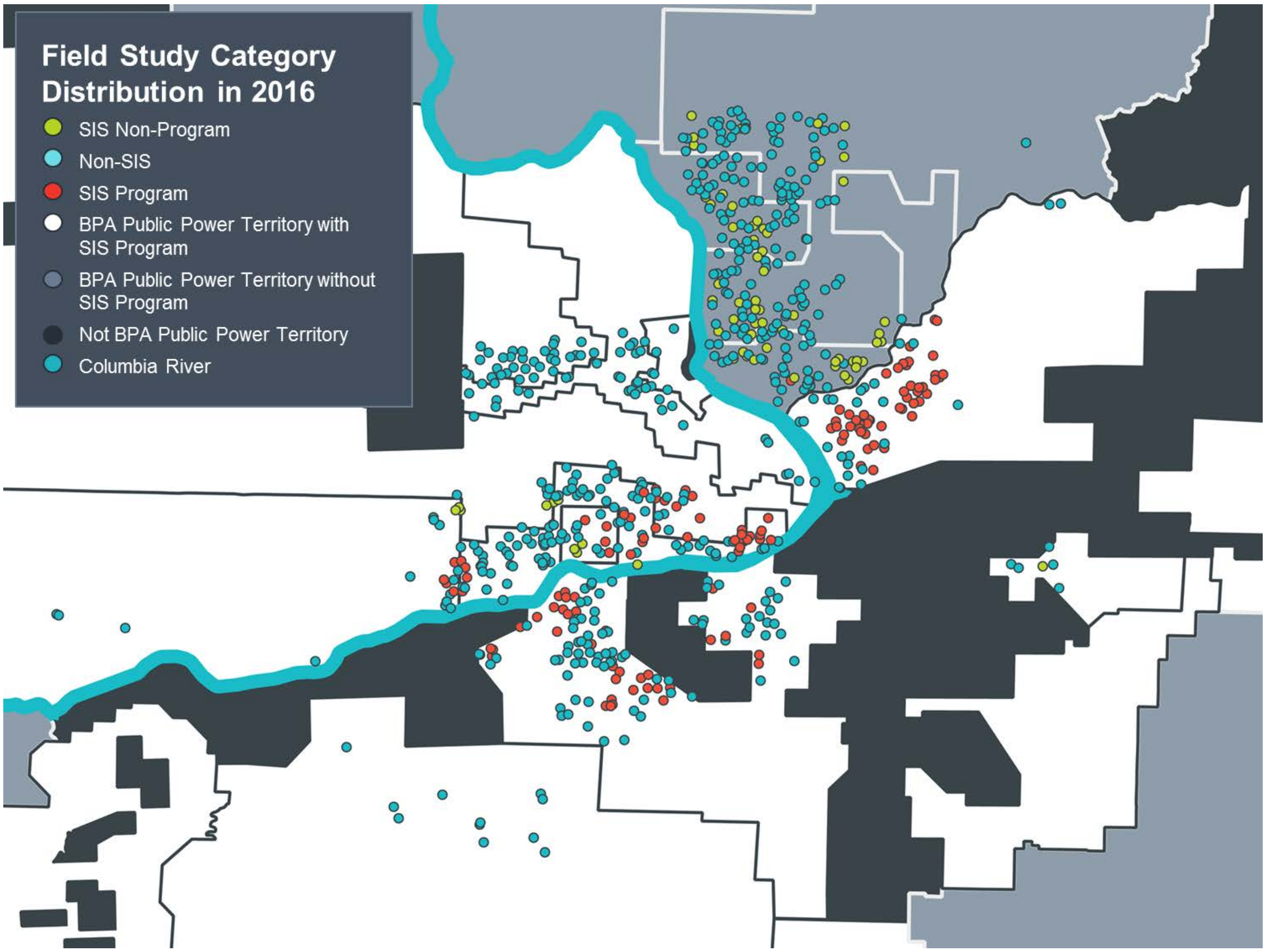
Figure 1: Water Applied vs. Water Required for All Fields in the Study



Source: Metered data

Figure 2 shows the distribution of the field study categories for the fields included in the study, with each dot on the map representing a field. As seen below, most of the SIS non-program fields were in the top of the map, where a SIS program is not offered. The SIS program fields are predominately located in the right part of the map, center of the map, and bottom of the map.

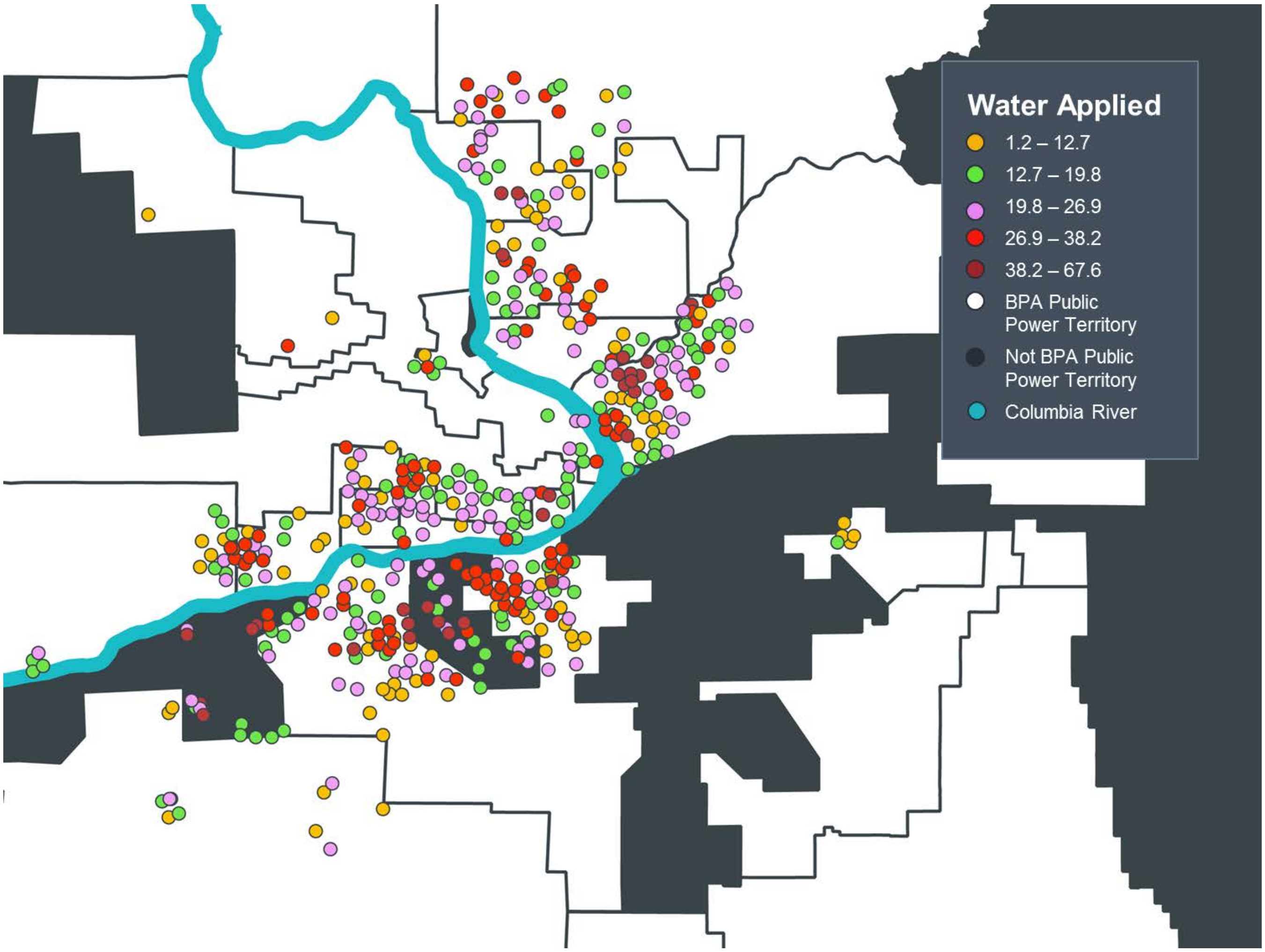
Figure 2: Distribution of Field Study Categories in the Study



Source: Interviews of growers

Figure 3 shows the water intensity of the fields in the study. The darker dots mean the grower applied more water to their field, and the lighter dots mean the grower applied less water to their field. The higher water intensity pockets on the right of the map are poplar fields and on the top of the map are apple fields. The lower water intensity pockets on the left of the map are wine grape fields and on the bottom of the map are winter wheat fields.

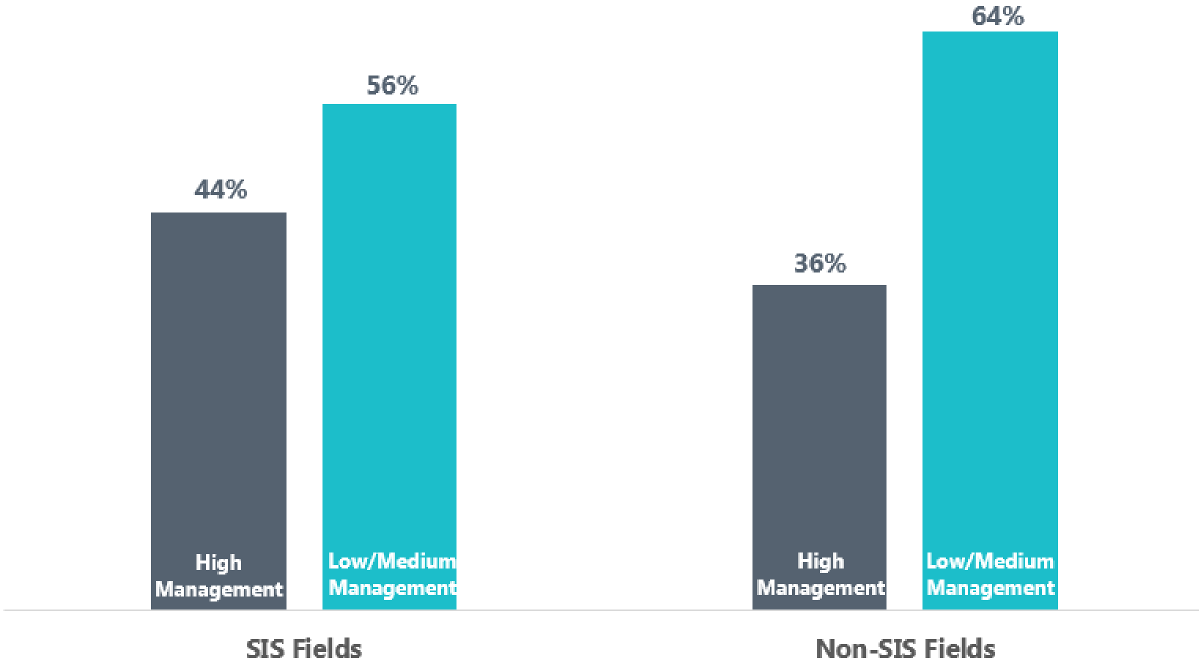
Figure 3: Water Applied to the Fields in the Study



Source: Metered data

Figure 4 compares the breakdown in crop management types between SIS fields and non-SIS fields. As seen below, there is not a significant difference in the crop management types between SIS fields and non-SIS fields. Both SIS fields and non-SIS fields are predominately low or medium management crops.

Figure 4: Comparison of Crop Management Types Between SIS Fields and Non-SIS Fields



Source: Interviews of growers

Research Portfolio – Appendix Documents

Appendix Documents

M. Recruitment Communication Materials – FAQ

N. Recruitment Communication Materials – Recruitment Flyer

O. Field Guide

P. Grower Report Template

Appendix M – Recruitment Communication Materials – FAQ

FAQs for Participants of Scientific Irrigation Scheduling Research

Q: What is the purpose of the Scientific Irrigation Scheduling study?

This study is being conducted to determine energy savings associated with Scientific Irrigation Scheduling. In order for utilities to continue to be able to offer incentives for participating in the Scientific Irrigation Scheduling program, we need data to prove Scientific Irrigation Scheduling practices save energy. Studies like this one allow Northwest utilities to continue to provide energy-saving programs.

Q: Who is sponsoring this study?

A: This study is sponsored by Bonneville Power Administration in partnership with your local utility. Bonneville Power Administration conducts studies like this every few years to evaluate energy efficiency program opportunities. Past studies are available on the Bonneville Power Administration website located at http://www.bpa.gov/EE/Sectors/agriculture/Pages/SIS.aspx.

Q. Is there a cost to participate?

A: No. Participants will not be responsible for any costs associated with participating in this study. Any equipment used on site will be provided by Bonneville Power Administration or participating study partners.

Q: How do participants sign up?

A: Fields are randomly selected using generated GPS coordinates. If your field is randomly selected to participate in the study, a utility-approved irrigation consultant will contact you this fall/winter (Mid-Oct – January). Irrigation consultants will determine your eligibility and enroll participants in the study over the phone.

Q: How are participants selected for this study?

A: All fields were selected using randomly generated GPS coordinates. Fields were not chosen for any reason relating to crops, growing practices, energy use, or water use.

Q: How will my information be kept secure?

A: During the course of this study, all personal information, water use, energy use, and growing practice information will be protected on a secured website. All research data will be presented in aggregate, and no reports published internally or externally will contain any personally identifiable information.

Q: Who is the primary contact for this study?

A: The primary contact throughout the study period will be a local irrigation consultant. Irrigation consultants will contact participants by phone first and then will schedule in-person site visits over the 2016 growing season.

Q: Does this study provide advice on optimal water usage?

A: The purpose of this study is to establish how much water is saved by Scientific Irrigation Scheduling practices. For the 2016 growing season, the study will collect data on current water usage. After the growing season, when the study is complete, an irrigation consultant can answer additional questions about specific water techniques appropriate to your field.

Q: What are the benefits of participating?

A: Participants will be assisting in a very important study that will help to identify energy reduction strategies. At the end of the study period, growers who do not currently practice Scientific Irrigation Scheduling will be provided with a water usage report from the selected field. This report may provide watering guidance for future growing seasons.

Q: Will the study measure water usage on entire farms or just one field?

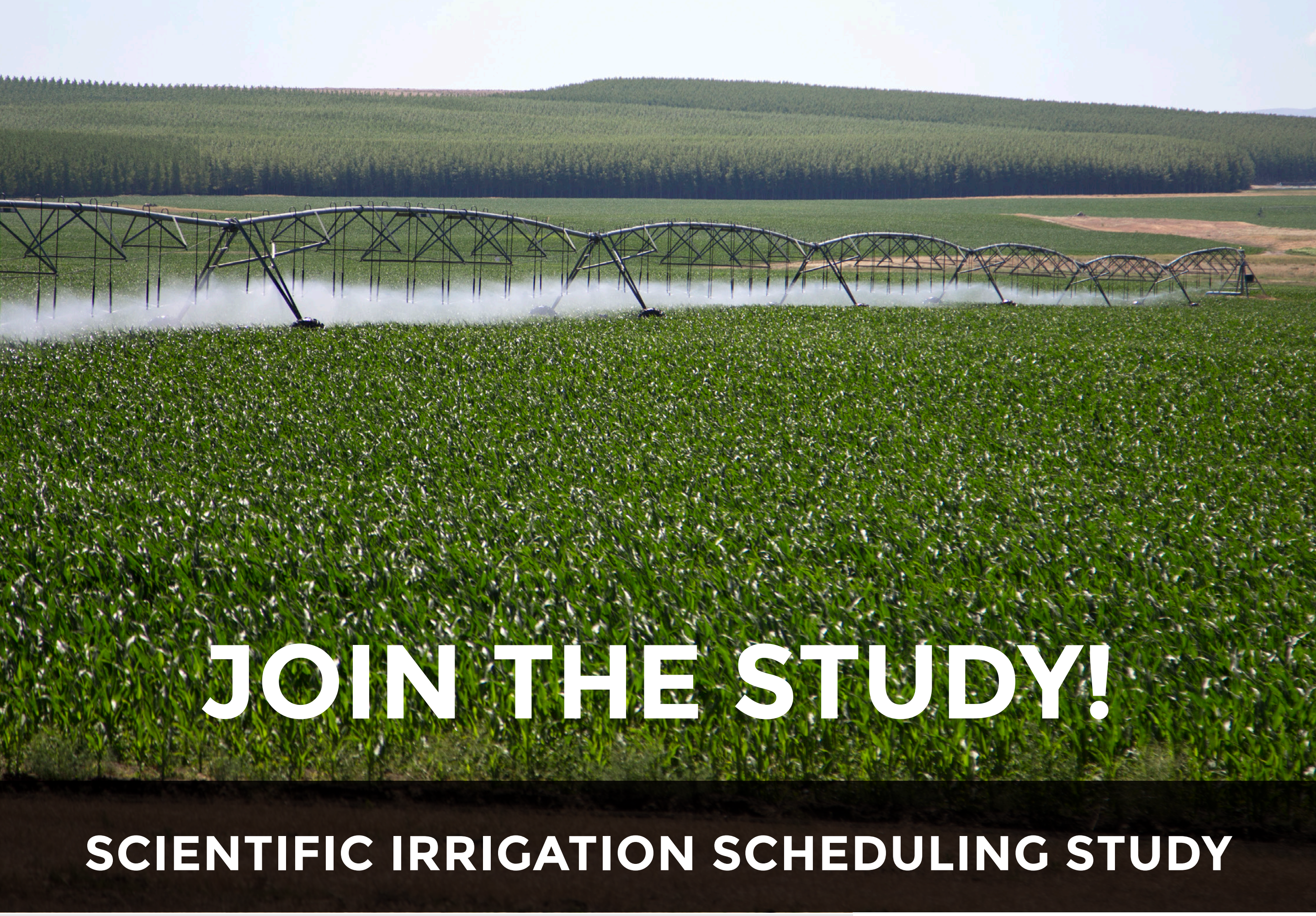
A: For the purpose of this study, data will only be collected on the water usage of the field that was randomly selected by GPA coordinates. The irrigation consultant will describe the exact field location.

Q: Can I volunteer to participate if I was not selected for the study?

A: Unfortunately, no. Since this is a randomized study, only growers whose fields were randomly selected using GPS coordinates will be invited to participate.

Q: What if the selected field is not being cultivated or irrigated?

A: To be eligible for this study, fields must be irrigated, and the crop must be managed to maximize output.



JOIN THE STUDY!

SCIENTIFIC IRRIGATION SCHEDULING STUDY

OVERVIEW:

The Bonneville Power Administration (BPA), in partnership with your local utility, is conducting an important research study to determine how much irrigated water Northwest growers can save through Scientific Irrigation Scheduling. The study will take place during the 2016 growing season.

Fields for this study have been randomly selected using generated GPS coordinates and represent both growers who do and do not practice Scientific Irrigation Scheduling. If your field is selected to participate in this study, you will be contacted by your local utility.

STUDY PARTICIPATION INCLUDES:

- An initial phone interview to confirm participation
- Scheduled site visits by an irrigation consultant during the 2016 growing season to measure water application (non-SIS fields only)
- A water use report provided at the end of the growing season showing optimal water use compared to the measured application (non-SIS fields only)

CONTACT YOUR LOCAL UTILITY WITH QUESTIONS.

CONTACT YOUR LOCAL UTILITY WITH QUESTIONS.

Scientific Irrigation Scheduling helps growers know exactly when to irrigate crops and how much water to apply through a system that monitors weather and soil moisture data. Past annual water and energy savings from Scientific Irrigation Scheduling have been estimated at 10 percent. The goal of this study is to review current practices and update savings estimates.

Benefits to growers:
At the end of the study period, fields without SIS will be provided with a report showing the measured water application on the study field. The report may provide optimal watering guidance for future years.

No cost to growers:
Growers will not be responsible for any costs associated with participating in this study. Any equipment used on site will be provided by BPA or its affiliates.

Selection process:
All fields were chosen using randomly generated GPS coordinates. Growers were not chosen for any reason relating to crops, growing practices, energy use, or water use.

Information security:
During the course of this study, all personal information, water use, energy use, and growing practice information will be protected on a secured website. All research data will be presented in aggregate, and no reports published internally or externally will contain any personally identifiable information.

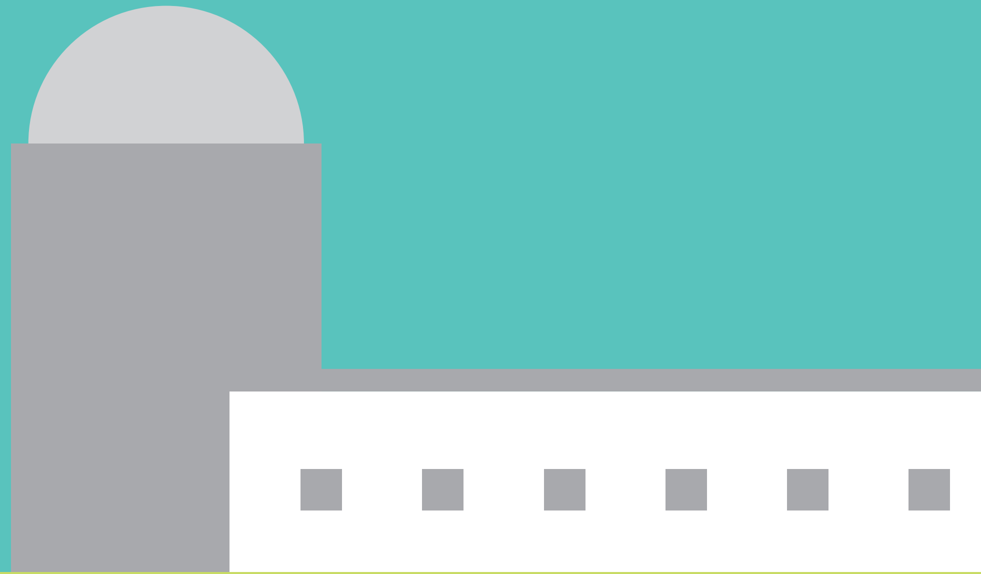
Primary contact:
The primary contact throughout the study will be a local irrigation consultant. The irrigation consultant will schedule the site visits and meet with growers in person during the 2016 growing season. For more information on the SIS research study, please contact your local utility.

LOGO HERE

Utility name
phone number
email

BPA SIS Baseline Research Study

Field Guide



1 IDENTIFY THE TYPE OF IRRIGATION SYSTEM USED

- Center pivot
- Wheel line
- Hand line
- Set move
- Solid set
- Drip line
- Micro-sprinkler

2 CHOOSE METHOD TO MEASURE WATER USE

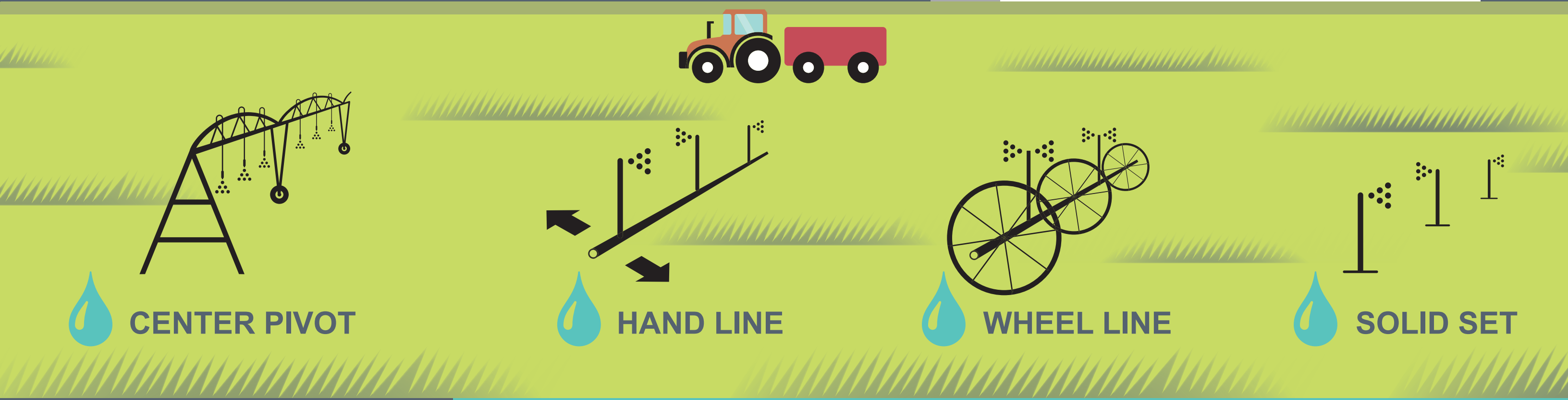
- Tipping rain gauge
  (1 visit per month)
- Pressure gauge
  (1 visit per month)
- Integrated flow meter
  (4 visits per growing season)

3 COLLECT DATA AND LOG IT INTO FULCRUM APP

- Find the field in SharePlus
- Link to Fulcrum
- Collect data in Fulcrum
- Sync Fulcrum & SharePlus

Choose Method

BASED ON TYPE OF IRRIGATION SYSTEM



SITE VISITS

Initial Visit

Interview Customer

Install Equipment

Take photo in Solocator app
Then Upload & Sync to SharePlus

Record Water Use
Flow meter method only

Follow-up Visits

Record Water Use
Download logger data for tipping rain gauge & pressure gauge methods

Ultrasonic Flow Measurement

Record Measurement
Pressure gauge method only

Retrieval Visit

Record Water Use
Download logger data for tipping rain gauge & pressure gauge methods

Remove Equipment
Not applicable for flow meter method

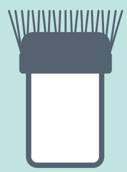
Interview Customer

Get Growing Cycle Dates

TIPPING RAIN GAUGE METHOD

REQUIRED EQUIPMENT:
Tipping rain gauge, Bird-B-Gone Strip, USB base station, laptop with HOBOware and tablet.

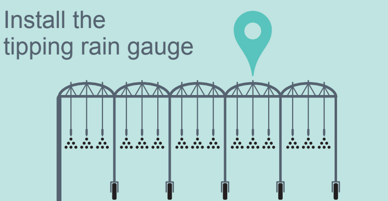
1



Install the bird-b-gone strip with zip ties

2

Install the tipping rain gauge



CENTER PIVOT

Put the rain gauge near the 2nd tower from the end, do not put it in the first three towers

OTHER SYSTEMS

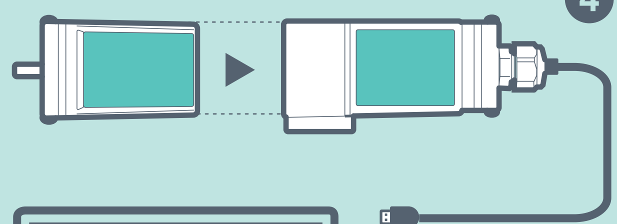
Put the rain gauge evenly spaced between the sprinklers. For hand lines and wheel lines put the rain gauge halfway between sprinklers and 1/3 away from a line

3

Insert the logger inside the rain gauge into the coupler

Plug the USB connector into computer

4



5

Open HOBOware

6

To Launch...Device > Launch
To Readout ....Device > Readout > Plot > Save
To Check Status......................................Device > Status
> Select Don't Stop Logging
(unless it's a retrieval, then click Stop Logging).
> Save logger files as "FXXX_2016-MM-DD"
& send to BPA.SIS@navigant.com

CLEANING INSTRUCTION

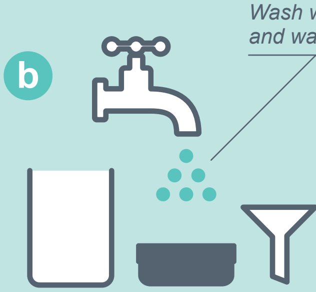
a

Tipping bucket assembly

Remove the metal screen by opening the spring clip from inside the rain gauge

b

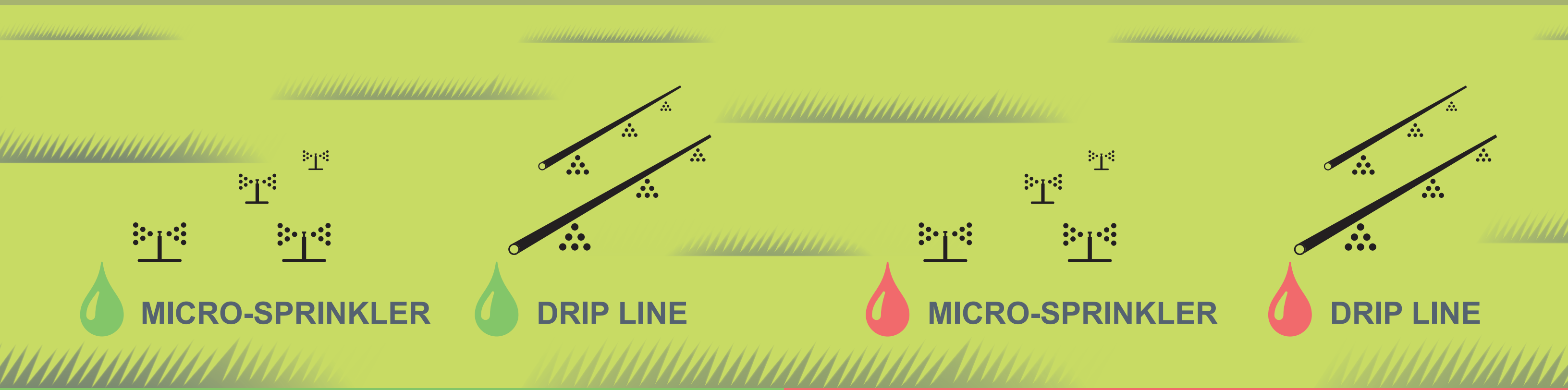
Wash with soap and water



Clean the funnel, tipping bucket, and filter screen with soap and water using a cotton swab

WITHOUT
INTEGRATED FLOW METER

WITH
INTEGRATED FLOW METER



PRESSURE GAUGE
METHOD

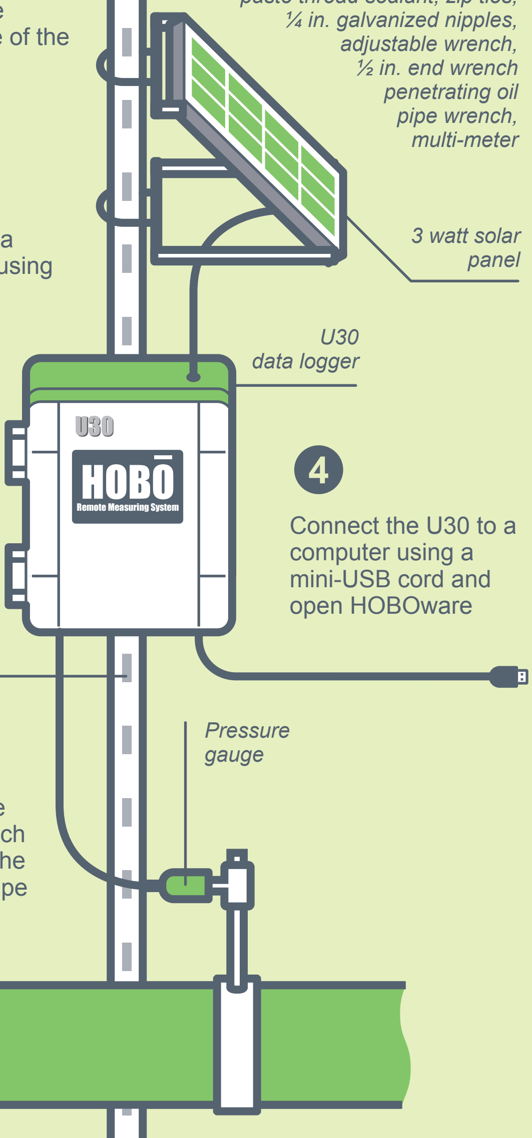
REQUIRED EQUIPMENT :

Steel T post, ¼ in, brass ball valves, ¼ in. galvanized tees, post driver, paste thread sealant, zip ties, ¼ in. galvanized nipples, adjustable wrench, ½ in. end wrench penetrating oil pipe wrench, multi-meter

1. Mount the solar panel on the stake using the U-bolts on the side of the mounting bracket

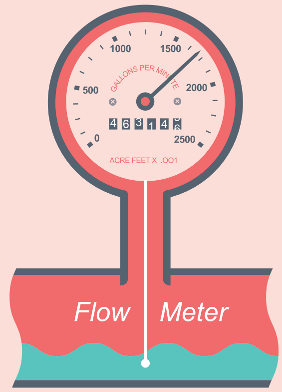
2. Mount the U30 data logger to a T-post using the U-bolts on the backside of the enclosure

3. Install the pressure gauge using a 1-inch wrench and wrap the ends with Teflon tape or pipe dope



4. Connect the U30 to a computer using a mini-USB cord and open HOBOware

INTEGRATED
FLOW METER
METHOD



No additional equipment is required

4 SITE VISITS DURING GROWING SEASON

> Initial site visit, two times during the growing season, and the retrieval visit
> Alert grower to tell us if the flow meter malfunctions during the growing season

5 CONFIGURE THE ANALOG SENSOR PORT:

Device > Configure
Moules/Ports > Channel 1
> Configure > Load
> Select T-ASH-G2-100-U30
> Continue

6 TO LAUNCH LOGGER

Device > Launch > Select: Channel 1 (pressure), Logger's Battery Voltage, 1 minute logger interval > Start

7 TO CHECK STATUS OF THE LOGGER

Device > Status

Do this after launching & reading out the logger. Make sure the status says "logging"

8 TO READOUT THE LOGGER

Device > Readout > Plot > Save

> Select Don't Stop Logging (unless it's a retrieval, then click Stop Logging)
> Save the file as "FXXX_2016-MM-DD" & send to BPA.SIS@navigant.com

Before going on-site login and sync the tablet in Fulcrum and SharePlus

After each site visit sync Fulcrum and SharePlus
(Requires cell service or WiFi)

Data Collection Tips

SharePlus

Solocator

Fulcrum

Access Site Details

> Open SharePlus
> Select "Sites"
> Select Your Company under "Portals", Select Your Company Site Visits
> Filter by Site ID

Always sync SharePlus at the beginning & end of each day by selecting the circular arrow (requires cell service or WiFi)

How to Take Solocator Photo & Upload to SharePlus at Initial Visit

> Open Solocator app
> Take photo of equipment serial # & "FXXX" on post it note
> Open SharePlus
> Search for field ID
> Select field
> Click wrench icon in top right
> Select "Edit Properties"
> Click "Add"
> Find photo in photo library
> Save image as "FXXX"
> Click Save
> Sync SharePlus by clicking the circular arrow

Logging in to Fulcrum

Click on the Fulcrum icon to open the app and login

Email
Password
Cancel / OK

It's not necessary to log in & out when passing tablets between field techs, just make sure someone is logged in

If using desktop - visit:
https://web.fulcrumapp.com

Overview of Fulcrum Field Forms

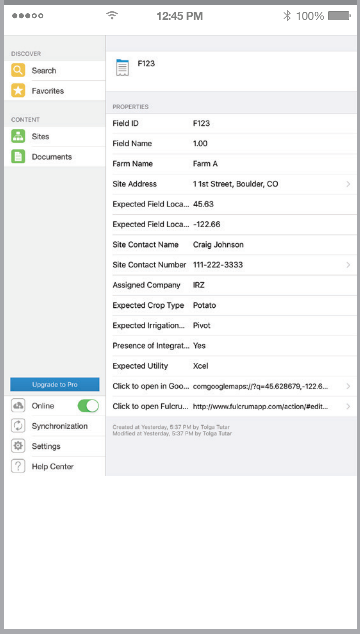
Initial Visit
Fill out at the first site visit to record equipment details and ask customer questions.

Follow-up Visit
Create a new follow-up visit form for each follow-up visit to the field.

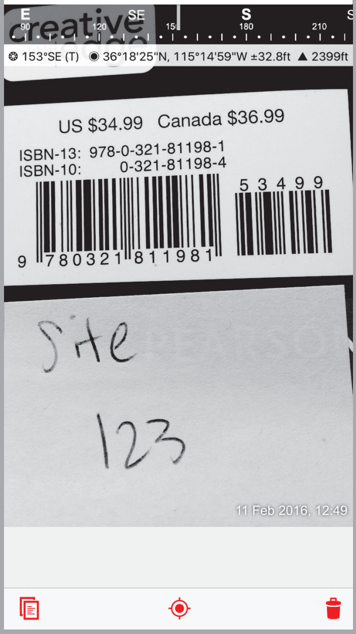
Retrieval Visit
Fill out at the end of the season for the final measurements and customer interview.

Ultrasonic Flow measurement
Complete this form once for the pressure gauge method only.

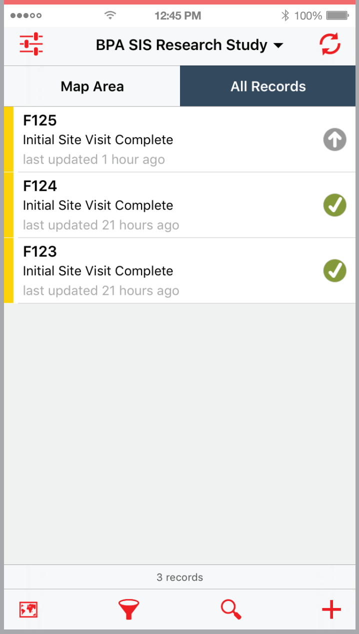
SharePlus Screenshot



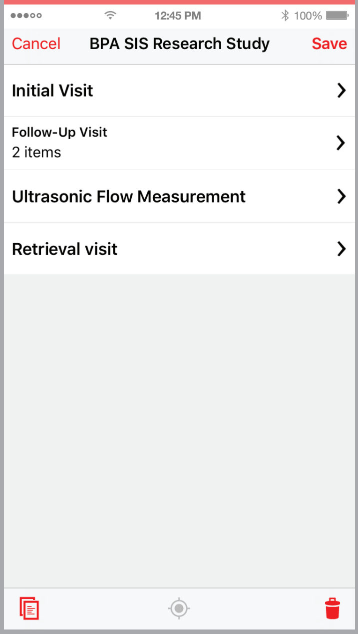
Solocator: Photo Example



Fulcrum: Overview of Sites



Fulcrum: Field Forms



2016 SCIENTIFIC IRRIGATION SCHEDULING BASELINE STUDY

Bonneville
POWER ADMINISTRATION

Field Data Collection Report

Thank you for participating in the Bonneville Power Administration (BPA) Scientific Irrigation Scheduling (SIS) study. BPA, in partnership with your local utility, conducted a research study to determine how much irrigated water Northwest growers can save through SIS. This report contains study findings specific to your farm. Your field was randomly selected to participate.

FARM NAME

CROP TYPE

FIELD LOCATION

SIS helps growers know exactly when to irrigate crops and how much water to apply through a system that monitors weather and soil moisture data. Past annual water and energy savings from SIS have been estimated at 10%. If you are interested in learning more about SIS, please contact your local utility.

Findings

The graph shows the actual water applied to the crop compared with the estimated crop water use throughout the growing season. The estimated crop water use is based on weather conditions and the growing cycle of the crop. Towards the end of the growing season the estimated crop water use may increase while the water applied stays the same because the crop water needs are being met by the water in the soil and not irrigation.

Actual Water Applied vs Estimated Crop Water Use

Source: Navigant Field Data Collection and Washington State University AgWeatherNet
Note: The Actual Water Applied and the Estimated Crop Water Use does not include rainfall.

Actual Water Applied vs. Estimated Crop Water Use Table

Source: Navigant Field Data Collection and Washington State University AgWeatherNet
Note: The Actual Water Applied and the Estimated Crop Water Use does not include rainfall.

Bonneville
POWER ADMINISTRATION

Developed for the Bonneville Power Administration • www.bpa.gov

Developed by Navigant Consulting, Inc.

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