Agricultural Irrigation Initiative: Instrumentation and Hardware Best Practices in Precision Agriculture

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Acknowledgments

The authors would like to extend their thanks and appreciation for support in developing the content of this report, with special thanks to the following individuals.

- To the nine growers in the region who graciously permitted access to the evaluation team to approximately thirty-two of their fields and pivots, along with extensive information about their irrigation systems and farm operations.¹ We sincerely appreciate the time they spent with the team, and their invaluable assistance in conducting this research.
- To the team at Ranch Systems, for their extensive technical support and interest in improving customer experience in sensor technology, telemetry design, and data standards.
- To the AgSense team, for both their ongoing support and their leadership in data standards development.
- To the McCrometer technical support team for their assistance in reconfiguring telemetry each season.
- To the team at Obvius Systems for their support in configuring data loggers used to monitor electricity consumption nearly real-time using “smart-meter” technology.
- To the team at ClearRF for assistance in amplifying cellular phone signal strength, permitting telemetry connections in regions with marginal cell phone coverage.
- To Buck Sisson of Soil Water Monitoring Systems and Tom Penning of Irrometer for their assistance in evaluating tensiometers in this study.
- To the teams at Decagon, AquaCheck, HydraSCOUT, and Sentek for their assistance in evaluating capacitive soil moisture probes used in this study.
- To Terry Henderson of FloSonics for his assistance in configuring, using, and troubleshooting GE Panametrics flow meters used in this study.

¹ The growers’ names are being withheld from this report to maintain their privacy.
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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) is an alliance funded by more than 140 Northwest utilities and energy efficiency organizations in Idaho, Oregon, Montana, and Washington working to accelerate the innovation and adoption of energy-efficient products, services, and practices in the Northwest. NEEA structured its Agricultural Irrigation Initiative on the premise that a grower can use integrated, existing technology to make better decisions about when and how much to irrigate, which would result in energy savings and reduce energy intensity. NEEA launched this Initiative with the goal of reducing agricultural irrigation energy use by twenty percent by 2020.

During the course of the demonstrations (the 2012-2014 seasons), NEEA discovered several challenges in integrating equipment into a usable system. The technologies had the basic technical capabilities, but they were challenging to set up, time-consuming to learn, complicated to integrate into the desired configuration, and required significant maintenance to keep operational. NEEA expended a great deal of effort to install, integrate, and utilize these technologies for field demonstrations.

This report documents:

- An overview of instruments deployed in these NEEA demonstrations and how they functioned
- Some of the challenges encountered during the demonstrations and suggestions for improvement
- Specific examples of how members of the Initiative team successfully assembled products into functional solutions

With the objective that the findings can:

- Substantially improve grower experiences by using these technologies
- Improve profitability for the grower
- Identify opportunities for manufacturers and retailers to improve the products they offer, improve their customers’ experiences, and accelerate business growth
- Provide guidance in data standards development, which will improve systems integration
- Result in long-term energy and water savings

This is one in a series of twelve reports on a range of related subjects thoroughly documents NEEA’s experience throughout this Initiative. These reports are available at http://neea.org/reports.
1. Introduction

The Northwest Energy Efficiency Alliance (NEEA) structured its Agricultural Irrigation Initiative on the premise that a grower can use existing technology and optimal irrigation methodology to make better decisions about when and how much to irrigate, which would result in energy savings and reduce energy intensity. This practice can yield both higher profitability and lower energy costs for growers. In order to accelerate market adoption of integrated irrigation solutions, NEEA recruited growers in eastern Oregon and Washington to install and test integrated irrigation solutions on one or more of their fields.

At the onset of NEEA’s Agricultural Irrigation Initiative, two irrigation delivery strategies seemed to offer the greatest amount of potential energy savings. Variable Speed Irrigation (VSI) and Variable Rate Irrigation (VRI) manage water application in a spatially explicit manner. VSI varies the speed of the center pivot as it moves around the field. VRI also varies the pivot speed, but in addition turns on and off valves for groups of sprinklers on the pivot system during its operation. Because of their high potential for driving energy savings, NEEA focused on these two irrigation strategies in 2012 and 2013.

NEEA added Precision Flat Rate (PFR) irrigation into this project in 2014. PFR provides a relatively simpler approach than VSI and VRI by applying a reduced amount of water evenly over a field. While the water and energy savings potential of PFR is less than that of VSI and VRI, NEEA found that PFR technology seems to be more market-ready.

Figure 1 on the next page illustrates a decision support system (DSS) showing the general information flow required to deploy a precision irrigation solution. It shows the manner in which data inputs are processed and presented to support better-informed irrigation decisions for PFR schedules or for advanced VSI or VRI prescriptions. VSI and VRI, in particular, depend heavily on accurate data and instrumentation to support the development of water- and energy-saving irrigation prescriptions.

Given the industry-specific or scientific natures of some terms used in this report, please refer to the AgGateway AgGlossary (http://agglossary.org/wiki/index.php/main_page) for definitions.

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2 The Irrigation Delivery Systems report provides an in-depth look at how each of these three delivery strategies works.
Figure 1. Integrated Decision Support System
2. Project Findings: Opportunities to Design Market-Ready Solutions

Based upon the challenges during the NEEA demonstrations and actions to mitigate them, the study team developed a number of conclusions addressing both the design of irrigation solutions (in this section) and technology components used in the demonstrations (in Section 3). NEEA supports the conclusions and recommendations in this report. Given that they are based on anecdotal experiences rather than on scientific findings, readers should view the recommendations as advisory.

2.1. Technology Is Less Mature than Originally Assumed
Near the start of NEEA’s Agricultural Irrigation Initiative, the study team identified key technology components of irrigation systems with the intention of providing growers an integrated solution, using existing technologies, for improving irrigation scheduling. The team discovered two key challenges with that approach:

1. Overestimation of the technical maturity of several of these technology components
2. Underestimation of the difficulty of integrating components into a complete and working solution for growers

After experiencing challenges with these barriers in 2012 and 2013, NEEA shifted focus to emphasize collaborative problem-solving with growers rather than focusing on the tools themselves.

2.2. Adopting a Solutions-Based Design Mentality
The modern electronics industry offers growers important technical capabilities, permitting a wide range of remote sensing and machine control capabilities. However, the study team believes that the industry can improve the adoption rate of these individual technologies or products if they are integrated into a “solution.” For example, instrument manufacturers may want to invest in minimizing the learning curve for installing and using new soil moisture sensors with telemetry units. The industry would benefit by providing growers more guidance on integrating new products and solutions into existing farm operations. From a wider perspective, trade associations have the opportunity to educate growers and market the importance of integration among products.

2.3. Strategies for Manufacturers to Accelerate Market Growth
Manufacturers can implement a number of strategies to increase the usefulness of their products to growers, thus increasing their sales while simultaneously accelerating growth in the precision irrigation market. Some of those strategies are outlined below.

- **Ease of Setup:** Taking a “plug-and-play” approach concept familiar to personal computer users could be a major market differentiator for manufacturers who recognize the opportunity. The industry has a long way to go to improve product ease of use, particularly in customizing the node configuration to the specific application. Setup procedures tend to be difficult, confusing, time-consuming, and poorly documented.
• **Ease of Use:** Once the telemetry units are installed and operational, intuitive use of the product and features becomes a significant market differentiator. Some brands have fast, intuitive dashboards to view data and manage farm operations, and some offer apps that allow full-featured access on a grower’s smartphone or tablet.

• **Versatility and Interoperability:** The number of uses for wireless communications on a farm is remarkable. Some brands offer focused solutions in which their controllers only accept sensors of the same brand. While this helps to solve the plug-and-play issue, it vastly limits the ability to build versatile systems. Users currently have difficulties moving data from one brand system to another, suggesting a potential area of focus for the Precision Ag Irrigation Leadership (PAIL)³ project Data Standards development team.

• **Cell Phone Coverage:** If cellular telephone coverage is weak but present, an antenna amplifier may boost the signal to resolve the problem.⁴ Farms tend to experience poor cell coverage; users should test the cell phone signal strength (a feature available from all smartphone carriers) at the location at which they plan to install the base. Most brands also offer satellite modem versions, but the monthly costs tend to be higher.

• **Radio Meshing:** Many units use a spread spectrum radio similar to a PC’s Wi-Fi to communicate with a base station, and the range of these radios is short, one to two miles (1.6 to 3.2 kilometers) at best. Situations in which the nodes can hop signal from one node to another, automatically selecting the best signal and meshing route back to the base station, are ideal.⁵

• **On Board Data-logging:** Models with on-board memory and real-time data-logging avoid loss of data. Many models poll the sensor for data and immediately send the data over the airwaves to the server in the cloud without storing a local copy of the data. During the NEEA demonstrations, interruptions in communication to the server led to the permanent loss of data.

• **Modularity:** A market opportunity exists for manufacturers to create modular systems that are more easily transported, installed, and removed. Installing soil moisture sensors in row crops requires annual installation after planting and removal prior to harvest. Carting the dozen components into the field and assembling the node in-location is both tremendously labor-intensive and challenging to install and decommission.

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³ PAIL is a project of AgGateway, created to provide a common set of data standards to convert weather, soil moisture, and other data from manufacturers’ hardware and software programs into an industry-wide format for use by irrigation data analysis and prescription programs. [http://www.aggateway.org/eConnectivity/Projects/CurrentOngoing/PrecisionAgIrrigationLeadershipPAIL.aspx](http://www.aggateway.org/eConnectivity/Projects/CurrentOngoing/PrecisionAgIrrigationLeadershipPAIL.aspx)

⁴ Cell phone antenna amplifiers are available from ClearRF ([http://clearrf.com](http://clearrf.com)).

⁵ A sensor node might have multiple paths for the information to hop between nodes over an extended distance to reach the base station. This would enable the connection of nodes to the base station that are many miles away from the base.
3. Project Findings: Technology Components Used in NEEA Demonstrations

The following sections review each technology component used in NEEA’s demonstrations from 2012 through 2014, including advantages and considerations for each.

3.1. Local Weather Stations

Crop water models require accurate weather inputs to calculate water balance, including temperature, relative humidity, solar intensity, wind speed, and rainfall. The station must be in close proximity to the irrigated field due to the high sensitivity of these models to changes in the local microclimate. Figure 2 and Table 1 provide examples of regional weather data services.

**Advantages:** The Internet offers a wealth of local, high-quality weather data. Growers can find their local conditions and forecasts by selecting weather stations close to them through mapping utilities offered by a number of weather networks. If no station is close enough, they can purchase a weather station and either connect into a network such as Weather Underground or view weather on a web-based data server.

Figure 2 illustrates two examples of maps showing locations of weather stations in specific regions. Irrigators can use these maps to identify the weather stations closest to their locations to receive more accurate reports and forecasts.

**Figure 2. Examples of Local Weather Data Availability in Specific Regions**
### Table 1. Weather Services in the Western US

<table>
<thead>
<tr>
<th>Weather Service</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgWeatherNet(^6)</td>
<td>Washington State University</td>
</tr>
<tr>
<td>AgriMet(^7)</td>
<td>US Bureau of Reclamation</td>
</tr>
<tr>
<td>California Irrigation Management Information System (CIMIS)(^8)</td>
<td>State of California</td>
</tr>
<tr>
<td>MesoWest(^9)</td>
<td>University of Utah</td>
</tr>
<tr>
<td>Weather Underground(^10)</td>
<td>The Weather Channel</td>
</tr>
</tbody>
</table>

### Considerations:
Weather data are readily available for public use. Customers and industry could use these data much more easily if standardized data schema formats were in place. The NEEA study team has developed a number of methods for working around the current lack of standardization; however, these methods differed for each weather service and proved cumbersome to implement. The long-term solution to this problem will be actively pursued in Phase Two of the Precision Ag Irrigation Leadership (PAIL) project. The *Data Exchange Standards* report provides more details about PAIL.

### Uses in demonstrations:
For the 2012 and 2013 growing seasons, the study team collected all weather data on dedicated weather stations in close proximity to the fields being studied; they used no weather service data in those seasons. In the 2014 growing season, the study team continued to use the dedicated weather stations for most of the demonstrations, and also successfully used the AgWeatherNet service in the Precision Flat Rate (PFR) irrigation demonstration managed by Washington State University.

### 3.2. Collecting On-Farm Data Using Radio Telemetry
Progressive growers use radio telemetry, a representative technology at the heart of “precision agriculture,” for remote monitoring and control. Telemetry systems employ a wide range of radio, cellular, and satellite communication methods to get the data and instructions to and from each of the nodes in the system.

The example in Figure 3 below shows four nodes deployed in the field communicating with a base station using a form of Wi-Fi. Each node may have multiple sensors attached, or may control multiple outputs. The base station then relays the data to a central cloud-based data server via cellular telephone modem; the grower can then view and manage the data from any computer on the Internet. Nodes can also be connected to center pivot hardware to remotely control farm operations from a grower’s cellular telephone or tablet.

### Advantages:
Many brands and models of radio telemetry are available to help growers monitor microclimate-level weather conditions, in-field real-time soil moisture conditions, control pumps and valves, tank levels, and even to provide video surveillance. The real-time moisture

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8. [http://wwwcimis.water.ca.gov/Stations.aspx](http://wwwcimis.water.ca.gov/Stations.aspx)
9. [http://mesowest.utah.edu](http://mesowest.utah.edu)
10. [http://www.wunderground.com](http://www.wunderground.com)
monitoring facilitated by telemetry allows growers to manage farm operations from their offices, tablets, and/or phones, thus saving them a great deal of time.

Considerations: The selection and installation of telemetry requires attention to a number of considerations:

- **Base Station Cell Phone Signal**: The most common method for connecting farm telemetry to the Internet is via cellular telephone modem. Growers can use alternative methods, such as satellite data communications, for farms located in areas where cellular telephone signal strength is marginal or non-existent.

- **Radio Range and Signal Strength**: The study team faced one of its greatest challenges in maintaining usable signal strength; doing so requires planning and patience. The team observed a maximum useful range between radio transceivers of one to two miles (1.6 to 3.2 kilometers) with good lines of sight between nodes, and perhaps three-quarters of a mile (1.2 kilometers) in tall crops such as corn. While higher power could help to increase signal strength and thus maximum useful range, the Federal Communications Commission (FCC) limits power in the allowed frequencies to one watt. Given that limitation, meshing appears to be the easiest solution, particularly if the grower is using devices that allow multi-hop meshing. Tall flexible whip antennas are useful for getting the radio antennas up over the canopy of tall crops such as corn; they bend aside when the pivot passes overhead (see Figure 4 below).
Figure 4. Whip Antennas Raise the Antenna Well over the Corn Canopy

Note: In this experiment, the field corn grew tall enough to touch the pivot structure, leaving no line of sight to the base for the antenna mounted to the node. The study team developed a prototype whip antenna, illustrated in this image, to regain lines of sight between nodes and the base station. While this solution proved critical to maintaining communications in corn, it had a high failure rate due to poor quality coax extension cables. This method would require more development prior to commercialization.

- **Recurring Costs**: Data plans and software licensing create recurring costs for growers for each device in their networks, which can become significant overhead items. While each brand varies in the way it charges recurring fees, most systems cost about $150 to $200 per year for each node in the system. A few models in the market mesh directly back to the farm office, thus eliminating monthly service fees.

- **Flexibility vs. Complicated Setup**: A few brands of telemetry are easy to install and feature plug-and-play capabilities for specific sensors; at the same time, they tend to be very limited in the range of capabilities that they offer. Conversely, other brands are extremely versatile, but they may be difficult to configure. Manufacturers are continually improving ease of setup and use, but they still have more improvements to make.

- **Exporting Data to Other Systems for Analysis**: While many brands permit data export, few brands make it easy to move data from their servers to other systems. The PAIL team at AgGateway is working to establish data standards that would dramatically improve the transfer of data from one system to another.
Uses in demonstrations: The study team gained substantial experience through the use of telemetry units from different manufacturers, including AgSense, Ranch Systems, McCrometer, and Obvius Systems (some units are shown in Figure 5). The team evaluated a few other manufacturers for comparison purposes. Each brand offers unique benefits, and each may be the best choice for any given application. The following sections describe how the team used each model/brand of telemetry unit in the demonstrations.

3.2.1. AgSense
The study team used AgSense Field Commander controllers on all pivots during the VSI demonstrations. These controllers are installed on the last tower on the pivot and override the control function normally managed by the pivot’s control panel. This functionality provided the study team with real-time and historical irrigation data, as well as machine status. The team found these controllers simple to program with the variable speed prescriptions to the pivot. Their use provides growers the ability to easily monitor and control the pivots from their office computers, tablets, or cell phones.

The team also used AgSense's AquaTrac in the VSI demonstrations to report soil moisture. AquaTrac receives data from moisture sensors and sends the data via the integrated cell phone modem to AgSense's WagNet server for viewing by the grower. AquaTrac has ports for installing a wide range of moisture sensors, as well as a rain gauge. It can accept either SDI-12 inputs or analog inputs, but not both at the same time. Its connectors are all screw-down, and the cabling is clearly marked. The team found it easy to set up the unit in the field, especially given that it was already configured in the software. Even though the unit was placed at a six-foot (1.8-meter) height in eight-foot (2.4-meter) corn, the solar panel kept the battery charged and the cell modem never lost signal. The unit has onboard memory so that when the signal is too poor to send soil moisture data at the appointed time, the unit will still acquire the data and store it until the cell signal is re-established.
3.2.2. Ranch Systems

Ranch Systems provides a highly versatile line of telemetry solutions. Although vineyards constituted its initial target market, the team found its solutions also very well-suited for field crop farms. Its architecture supports a wide range of sensing and control solutions, from soil moisture monitoring, to solenoid valve or pump control, to monitoring storage tank levels. The system can also provide real-time video surveillance. Ranch Systems is on its second generation of telemetry node design, the RS300, which provides even more versatility than the older model (the RS210) that the study team used. Both versions communicate with the base station (the RM210) to deliver sensor data to growers’ cloud-based servers via cell phone or satellite modem.

The data stored in the server are displayed in a dashboard custom-configured to each “property.” The team exported data using standard file transfer protocol (FTP) to Irrinet’s Probe Schedule server, and also exported data in custom comma-separated value (CSV) reports for easy data analysis in spreadsheet programs.

Ranch Systems has recently formed a partnership with OnFarm, an innovator in online farm management applications. Together they have completed the integration of their respective software. Ranch Systems, as an OnFarm Ready Partner, is now plug-and-play compatible with OnFarm’s Grower Dashboard. Growers can now view field data collected by Ranch Systems equipment via the customizable OnFarm user interface.

3.2.3. McCrometer

McCrometer is a long-time player in the telemetry market. Several years ago, McCrometer acquired Automata, which provided the user interface software for viewing data on its remote server. McCrometer’s greatest advantage is its use of satellite telemetry, which enables growers to utilize telemetry in locations lacking cellular telephone coverage.

3.2.4. Obvius

The NEEA team chose an AcquiSuite EMB7810 data logger from Obvius Systems to collect real-time electric smart meter data. The AcquiSuite counts electrical pulses proportional to the power delivered, and reports the counts through a CradlePoint IBR650 cellular modem to a central server. This process permits nearly real-time monitoring of electric meter data. Since the installation location exhibited weak cellular signal strength, the study team used a ClearRF antenna amplifier to ensure reliable cellular communications.

3.3. Viewing the Data: User Interfaces

The study team used a wide range of tools to view data generated during the demonstrations. The Grower Experience report provides specific recommendations for vendors when designing user interfaces and displaying data on personal computers and mobile devices.
3.4. Soil Moisture Monitoring

The study team performed extensive soil moisture monitoring during the 2012 through 2014 growing seasons on approximately 190 individual field locations. They used three general categories of soil moisture monitoring technology, all of which are well-known in the industry:

- Neutron Probes: A manual process that reports measurements on roughly a weekly basis
- Capacitance Probes: A sensor technology that measures electrical properties of the soil to estimate moisture content, and then uploads the data to a remote server via telemetry, at intervals typically ranging from fifteen to sixty minutes
- Tensiometers: A device that measures how hard the plant has to suck to get water out of the soil, measured in units of pressure – the drier the soil, the more plant suction is required

3.4.1. Neutron Probes

As its name implies, a neutron probe contains a small amount of radioactive material that emits fast neutrons. These neutrons are slowed by hydrogen in the soil, and the number of slow neutrons returning to the sensor correlates extremely well with moisture content. Used with proper procedures, this technology provides an excellent method for accurately monitoring soil moisture with periodic weekly readings.

Advantages: The neutron probe proved to be the most dependable method for quantifying soil moisture levels during the demonstrations. The industry considers it the “gold standard” for soil moisture monitoring. Its use requires periodic visits (generally weekly) from a trained technician to each individual site to record soil moisture. It is typically priced in the range of $400 to $600 per field per year, depending on the farm location and number of fields per farm being monitored, making it a reliable and cost-effective moisture monitoring method for growers. If a grower has problems with telemetry or capacitive sensors, neutron probes offer an excellent alternative for accurately monitoring moisture.

Considerations: Operators need to physically visit each site with a luggable device. The neutron probe must be secured for storage, and its data must be entered into a system to permit communication with a decision support system. Because it utilizes heavily-regulated radioactive material, the neutron probe is strictly a manual instrument that requires handling by a certified operator.

Uses in demonstrations: For the NEEA study, the team selected probe locations at three sites in most fields, representing low, medium, and high soil moisture holding capacity. The researchers placed neutron probe access tubes one foot away from the capacitive sensors at each of these soil moisture sites, allowing side-by-side comparisons of moisture results from multiple technologies.

The team took neutron probe (model CPN503DR) readings on a weekly basis and uploaded the data to the ProbeSchedule.com software, which incorporated the data into the water balance calculations and reported the results to growers. The team took probe readings at six-inch (fifteen-cm) intervals at depths ranging from six inches (fifteen cm) to thirty-six inches (ninety-one cm). The team calibrated the neutron probe to provide soil moisture content in inches per foot for the average soil type in the root zone.
3.4.2. Capacitance Probes

Capacitance probes provide a fast, safe, and relatively inexpensive way to measure the relative permittivity\(^{11}\) of soils, a parameter that can be used to estimate soil moisture content. Capacitance probes come in a wide range of form factors, but all work using the same scientific principle: as soil moisture increases, the output voltage on the sensor increases in a predictable manner. This allows the user to monitor soil moisture nearly real-time and to report those readings to a data server via telemetry.

**Advantages:** The primary advantage of capacitance probes is their ability to report soil moisture real-time without a weekly site visit from a technician. In the NEEA study, data were reported to the central server at fifteen-minute intervals. When growers can remotely and accurately monitor soil moisture real-time, it nearly eliminates the need for them to have sophisticated modeling tools to predict soil moisture; they can act based on the real-time moisture alone.

**Considerations:** While capacitance probes worked quite well in some of the fields in the NEEA study, they on several occasions delivered unusable data. In 2013, the team carefully studied the correlations between neutron probe measurements and readings from the Decagon 10HS and AquaCheck capacitance probe sensors (described below under “Uses in demonstrations”). The team considered strong correlations (assumed for this study to be greater than \(r = 0.9\))\(^{12}\) to indicate that neutron probes and capacitance probes yielded soil moisture readings that strongly correlated with one another. Based upon these assumptions, the study team observed strong correlations in moisture readings for the two types of probes only about forty percent\(^{13}\) of the time, as illustrated in Figure 6. Since the team members tested each brand of capacitance probe independently against the neutron probe, they determined that the problem was clearly brand-independent.

\(^{11}\) A measure of the ability of a material to interact with an electric field and become polarized by the field, so that the field within the material is weaker than the field in the absence of the material

\(^{12}\) A perfect positive correlation is \(r = 1.0\), meaning that one variable exactly predicts the value of the other variable

\(^{13}\) The approximate percentage of correlations of neutron probes with Decagon 10HS and AquaCheck probes (averaged for the two) that exceeded \(r = 0.9\)
The team is still trying to identify the root cause of this difficulty and suspects that it is related to soil chemistry, specifically to high base saturation of the soils in the NEEA study sample. High base saturation alters the typical electrical properties of the soil, and overrides the effects of water on soil conductivity and capacitance. Although high base saturation is not extremely common in soils, it was prevalent in many field sites in the NEEA study. This fact suggests that a simple and inexpensive soil test could screen out potentially problematic locations for using capacitance probes, and merits future research. By prescreening the probe locations for base saturation, growers could dramatically improve their confidence levels in the capacitance probe data. More information on the scientific effects of base saturation on electrical properties of soil is available in the *Using Soil Electrical Conductivity Mapping for Precision Irrigation in the Columbia Basin* report.

**Uses in demonstrations:** The NEEA demonstrations used the four brands of capacitance probes shown below in Table 2 and Figure 7.

The Decagon 10HS is an individual analogy sensor that is easy to install. Decagon originally developed these sensors for use in greenhouses, and they are also well-suited for general soil moisture measurement. Because of their relatively low costs, the NEEA team installed three 10HS sensors at different depths at each node in the VRI demonstrations. The study team selected sites in each field with low, medium, and high soil moisture holding capacity in lighter soils in order to bracket the impact of irrigation on different soil types present in that field.
The AquaCheck, HydraSCOUT, and Sentek probes all have sensors that report soil moisture located at multiple depths in the soil profile. The sensor data are delivered to the telemetry node via a serial interface port. All three brands have similar installation methods. The NEEA study team normally installed these probes at locations in the field with the majority soil type.

<table>
<thead>
<tr>
<th>Test</th>
<th>Probe(s) Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decagon</td>
<td>AquaCheck</td>
</tr>
<tr>
<td>VSI Demonstrations</td>
<td>X</td>
</tr>
<tr>
<td>VRI Demonstrations</td>
<td>X</td>
</tr>
<tr>
<td>Data Standards Alpha Test</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 7. Capacitance Probes Used in Demonstrations

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3.5. Tensiometers

A tensiometer measures how hard the plant needs to pull to get water out of the soil. A tensiometer is a very simple instrument consisting of a porous ceramic tip attached to a water-filled tube with a suction dial (negative pressure) gauge at the top. The ceramic tip is installed in the root zone of plants; as the plant extracts water from the soil, the soil extracts water from the instrument, registering the same suction that the roots experience. Tensiometers produce a water retention curve,\(^{15}\) which is a helpful reference for determining soil properties.

Advantages: Many agronomists still regard the tensiometer as the best direct measure of the amount of stress the plant experiences.

Considerations: The models tested require weekly attention to maintain the fluid levels inside the devices.

Uses in demonstrations: The NEEA team tested two brands of tensiometers: an Irrometer tensiometer (see Figure 8) and a prototype of the “Torpedo” by Soil Water Monitoring Systems, LLC (see Figure 9).

A typical tensiometer can be fitted with a pressure gauge such as that shown in Figure 8, or with a pressure transducer that allows the instrument to connect to telemetry.

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\(^{15}\) See the *Soil Science and the Basics of Irrigation Management* report for an example of a water retention curve.
The Torpedo prototype used in this study functioned well in the lower suction range but lost contact and all its water at tensions above 70 kPa. This finding potentially limits the range of crops for which it is suitable.

### 3.6. Flow Meters

Flow meters proved extremely useful during the demonstrations in quantifying water and energy savings. Few of the pivots were outfitted with flow meters, so the study team installed General Electric Panametrics’ AquaTrans AT868 flow meters (shown in Figure 10), which use ultrasonic pulses to measure flow rate, on many pivots. The AT868 acts as the data logger and records flow rate (analogous to a speedometer) and cumulative gallons (analogous to an odometer). The study team strapped UTXDR Ultrasonic Flow Transducers to the risers and connected the transducers to the AT868.

**Advantages:** Ultrasonic transducer-style flow meters mount on the outside of a section of pipe. This is a key advantage in that it eliminates the need to drill holes in the pipe and interrupt irrigation operations. The AT868 is a very rugged, high-quality instrument that can be configured for a wide range of pipe sizes and materials. Properly configured, the AT868 provided accurate real-time readings for both flow and total gallons.

**Considerations:** The flexibility offered by the AT868 meant that its initial configuration proved to be moderately complicated. The study team needed a significant amount of time to learn how to configure it.

The AT868 can be ordered only in either a 12-volt direct current (DC) or a 120-volt (alternating current) AC version, not both at the same time. The AT868 draws 0.7 amps, so it would require a large solar panel and a large 12-volt battery. For that reason, the study team chose to wire them to 120-volt AC power sources in locations with continuous availability of 120 volts.
Out of the more than fifty pivots tested with AT868 flow meters during the demonstrations, three pivots had a rusty scale on the inside of the pipe sufficiently thick that it eliminated the feasibility of using ultrasonic transducers.

The AT868 supporting documentation is not well-organized, which increased the time necessary for the study team members to learn how to configure, install, and connect to telemetry.16

Uses in demonstrations: To obtain accurate measurements, the transducer should be attached to a sufficiently long section of pipe to avoid turbulent flow, as defined in the documentation and literature.

For applications for which the team members needed only cumulative total volume data over the season, they mounted the AT868 on the riser of the pivots and the neutron probe technicians recorded the accumulated number of gallons on the AT868 display during their normal weekly rounds.

When the team members needed real-time flow data, they connected the flow meter through a Ranch Systems RS210 node to allow the uploading of real-time data to the Ranch Systems server. The team configured the node to count pulses from the AT868, with one pulse equaling one hundred gallons. The team then configured the Ranch Systems server to report flow (gallons) and flow rate (gallons per minute) as a function of time.

During the pivot evaluations,17 the team needed a portable flow meter to measure the flow rate going through the riser of the pivot. General Electric offers a portable version of the AT868, but for budgetary reasons, the study team mounted existing AT868 flow meters into inexpensive Craftsman tool boxes and powered each unit with a battery and an inverter.

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16 The team developed additional documentation, available upon request
17 See the Pivot Evaluation Best Practices report for more information
Figure 10. AquaTrans AT868 Flow Meter
4. Recommendations for Assembling a Soil Moisture Monitoring System

Based on its experience in conducting three years of demonstrations for the Agricultural Irrigation Initiative, the NEEA study team offers the following suggestions\(^\text{18}\) to growers in assembling soil moisture monitoring systems:

- **Slow and steady wins the race:** Start small, and build out the telemetry system gradually. Conduct small-scale demonstrations for a few years before committing to larger-scale systems. As growers learn what works well in their operations, they can invest more wisely. Purchase products with proven track records of operating together, and experiment to see what works in a particular situation. Growers who start too big may discover problems faster than they can fix them, or may get stuck with a brand they don’t like.

- **Don’t let the complexity of new technology get in the way of improving irrigation scheduling:** Soil moisture monitoring can dramatically improve the precision of irrigation. As growers are gradually building their experience in automation and remote sensing, they can rapidly improve their irrigation scheduling using weekly neutron probe data.

- **Carefully consider where to place sensors in the field:** Growers can use several different approaches, each requiring a different method of interpreting the data. Examples include:
  - One sensor at the lowest holding capacity of the field (driest)
  - One sensor placed in the most typical soil type
  - One sensor placed at both the lowest and highest holding capacities to bracket moisture levels
  - Combinations of the above locations

- **Make sure sensor readings make sense:** The study team strongly recommends validating the accuracy of capacitance probe moisture readings for the first year or two, preferably by using a neutron probe for every probe site. If the soil on a farm doesn’t lend itself to capacitive probe measurements, the grower can rely on neutron probe data.

- **Use care when installing probes:** Improper installation can cause probes to report inaccurate readings. For example, air pockets around the sensors will cause artificially low readings. Carefully following manufacturer’s installation procedures will significantly improve growers’ odds of success.

- **Watch for PAIL-certified products:** The AgGateway Data Standards team is currently developing data standards that will improve the ability of products to move data from one system to another. In the near future, products that comply with these standards will be labeled accordingly, and should be easier to integrate.

- **Pay close attention to radio signal strength in laying out a wireless network:** Wi-Fi networks really need lines of sight from nodes to base stations; problems with signals frequently start at about the one-mile range. Ensure that antennas are tall enough to get over the canopy.

\(^{18}\) NEEA supports these suggestions. They are based on unforeseen challenges experienced by study team members across the three years of NEEA demonstrations, and on their actions to mitigate those challenges. Readers should view them as advisory.
- **Keep the data stored securely for future analysis**: These data will help to identify optimal operational practices so the grower can improve productivity and profits year to year.
- **Conduct periodic maintenance to ensure smooth operations**:
  - Keep solar panels clean
  - Service rain buckets
  - Use spike strips to deter birds from soiling equipment or damaging the wiring
  - Monitor data regularly for errors
  - Decommission equipment for the next year and disconnect the battery
  - Store in a cool, dry place
  - Bench-test and configure nodes in the shop and perform repairs before installing in the field
5. Risks and Challenges

Properly implementing modern instrumentation into modern farm operations can enable dramatic improvements in crop quality, yields, and growers’ profits. The study team experienced first-hand the substantial challenges that growers face in adopting and integrating solutions that improve farm operations.

On one hand, some growers might find these challenges sufficiently daunting that they are slow to adopt the modern practices crucial for them to remain profitable and competitive. Giving up on new technology is not a good option for growers.

On the other hand, the challenges documented in this report can offer industry partners valuable insights into opportunities to improve their customers’ experiences, to accelerate market growth, and to increase their market share. The insights may also help growers to adopt new technologies with higher success rates.

5.1. Risks

- If growers experience too much frustration with new systems, they may defer system development for multiple seasons.
- If manufacturers and dealers neglect focused improvements in customer experience, sales and profits may not materialize.
- If growers don’t ground-truth sensor technology, they could make bad decisions without realizing it until they observe serious crop stress occurring.

5.2. Challenges

- **Incomplete product solutions**: The industry makes fine equipment, but it doesn’t always provide solutions that growers can seamlessly integrate into their normal agronomic processes. Industry could accelerate sales by increasing its emphasis on improving customer experience and by “designing with the end in mind.”
- **Capacitance probe data quality**: Ground-truthing moisture probe data, preferably with a neutron probe, is an important action for growers in assessing the quality of such data.
- **Telemetry signal strength**: Radios have an effective range of about one mile with a good line of sight. Automatic multi-hop mesh networking and improved antenna designs appear to be the best solutions for extending this range.
- **Data standards**: AgGateway is actively developing standardized data schemas, an important first step in improving system integration.
- **Telemetry not highly interoperable**: No single brand of telemetry offers a set of features complete enough for accomplishing the entire irrigation management process. Growers currently must mix brands to have a complete irrigation management solution.
- **Technology advances quickly**: Keeping informed about the rapidly-changing technology landscape and how to get the most from their investments is difficult for growers.
6. Lessons Learned, Next Steps, Value of Findings

6.1. Lessons Learned
• Improving irrigation scheduling is more about helping growers solve problems and save time than it is about installing nifty hardware.
• Not all technologies perform as advertised, and they sometimes require field adjustments.
• Creating an on-farm wireless network is very technically challenging. The few plug-and-play telemetry solutions tend to offer very narrow ranges of features.

6.2. Next Steps
• Share brand-specific insights with each manufacturer.
• Work with industry partners to improve customer experience.
  o Push for plug-and-play solutions as the norm rather than the exception
  o Improve ease of setup and ease of use
  o Push for solutions to signal strength problems
  o Drive PAIL data standards development consistent with improving interoperability
• Identify the root cause of erroneous capacitance probe data, and identify mitigation methods.

6.3. Value of Findings
For Growers
• Growers can save time and improve production through the use of remote sensing and machine controls.
• Manufacturers are introducing products with new features and more functionality at a rapid pace; growers should keep scanning the market for new solutions as they become available.
• While manufacturers still have a way to go in refining usability improvements, they do offer highly-capable systems today.
• Keep the eye on the prize; workarounds do currently exist for problems encountered. Focus on getting the necessary information without getting frustrated by technology.
• Slow and steady wins the race.

For Manufacturers
The most effective ways to generate market growth and accelerate sales are through investments in improving customers’ product experience and by providing complete and integrated solutions that are easy to fold into existing farm operations to solve real problems. Manufacturers can use the findings of this report to help them develop solutions to address specific technical barriers, including:

• Mitigating poor signal strength that hampers data transmission
• Improving moisture probe technology and techniques so they work well in all soils
Based on these experiences, the NEEA team has taken two major steps to help industry accelerate market penetration of these important technologies:

- Worked closely with several of the industry partners to shift their development emphases toward improving the usability of their products and making it easier for growers to integrate these solutions into farm operations. The study team observed substantial progress toward improved usability with some of these industry partners.
- Initiated the development of data standards though AgGateway to enable improved system integration, making substantial progress in establishing standardized means of sending and receiving data. Details of this work and outcomes are available in the *Data Exchange Standards* report.