Not Watered Down: Key Learnings from Center Pivot Irrigation Demonstrations

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ABSTRACT

This paper offers a candid retrospective of three years of field demonstrations and market research as part of the Northwest Energy Efficiency Alliance's (NEEA's) Agricultural Irrigation Initiative, which ran from 2011 through 2014. The Initiative proposed to accelerate agricultural energy efficiency savings opportunities in the Northwest as identified in the Northwest Power and Planning Council's (NPPC's) Sixth Power Plan (NPPC 2010). NEEA set an external goal, developed by and supported across the regional grower community, of reducing agricultural irrigation energy use by 20% by 2020. The original target market for this Initiative focused on corporate and family growers farming 100 or more acres, equipped with pressurized irrigation systems and characterized by center pivot systems.

As part of this Initiative, NEEA conducted three years of large-scale field demonstrations on 74 fields with 22 growers in Oregon, Washington and Idaho. NEEA tested optimal irrigation, a management practice that seeks to maximize the net returns from water; irrigation delivery systems (the manner in which water is delivered to the field); and irrigation technologies that assist in measuring or controlling the application of water.

The paper describes the NEEA Initiative, the strategies from an industry-created roadmap about the future of irrigation, and the nuanced recommendations for conducting agricultural demonstrations. Lessons learned are broken into three categories: Demonstration expectations, demonstration design and management, and the incorporation of technologies in demonstrations. The conclusions offer both practical program management-level suggestions as well as specific technical recommendations for demonstration design.

Introduction

In Q3 2011, NEEA launched the Agricultural Irrigation Initiative with the goal of reducing agricultural irrigation energy use by 20% by 2020, through a series of market activities to test and promote a product solution for center pivots[1] that enabled integrated precision irrigation technology. The main activities that NEEA undertook between 2011 and 2014 included field demonstrations to test the product, some specific technology field tests, infrastructure support (data standards work), the development of a business case and economic modeling, and marketing and outreach.

Mother Nature can trump the best planning. Circumstances such as frozen ground, hail, and heavy wind affected the results of the demonstrations in this Initiative, as did technology challenges (such as lack of communication standards, incompatibility of equipment, installation delays, and limited access to communication links). With such rich learning as a resource, NEEA documented the technical details and nuanced findings from three years of large-scale field demonstrations on 74 fields with 22 growers.

[1] A description of center pivot irrigation systems is available in (Berne 2015a).

This report details combinations of evaluation methods, including objective measurements and tests, subjective field observations, and data analysis assumptions that the researchers used to make recommendations for improvements.[2] Due to the exploratory nature of this work, readers should consider the team's recommendations and the methods and tools described herein as works in progress rather than as fully-vetted applications ready for implementation in the field.

NEEA discontinued funding this Initiative in Q2 2014 with the hope that the market will continue to develop and refine the solutions identified through field demonstrations, data standards work, and collaborative work with industry stakeholders. NEEA will continue to monitor and scan the market and will engage if opportunities arise with which it can help on behalf of the region.

NEEA 2011-2014 Initiative Activities

1. Demonstrations: Conducted field demonstrations for each product tier using the scientific method in order to identify energy savings and non-energy benefits such as increased yield and water savings. The Initiative focused on demonstrating integrated solutions with three main irrigation delivery systems:
    a. Precision Flat Rate irrigation (PFR) – Uniform application of water across a field
    b. Variable Speed Irrigation (VSI) – Varies water application by varying pivot speed
    c. Variable Rate Irrigation (VRI) – Varies water application through pivot speed and individual sprinkler nozzle control
2. Data standards: Provided a common set of data standards through the Precision Ag Irrigation Leadership (PAIL) project to convert weather, soil moisture, and other relevant data from a variety of original equipment manufacturer (OEM) hardware and software programs into an industry-wide format for download and use by an irrigation data analysis and prescription program
3. Business cases: Developed a preliminary business case for growers to adopt the products, and a preliminary business case for vendors to sell and promote the products
4. Outreach and marketing: Developed awareness among industry stakeholders through presentation of results at industry meetings and conferences

The original target market for this Initiative focused on corporate and family growers farming 100 or more acres, equipped with pressurized irrigation systems and characterized by center pivot systems. In addition, the Initiative demonstrations targeted growers with progressive relationships to technology, most likely "pioneers" or "early adopters," with the assumption that the technology would diffuse and find relevant application over time to a much broader spectrum of the market, including smaller farms and growers further down the technology adoption curve.

Road Map for Energy and Water Efficiency in Irrigation Agriculture

As part of the Initiative, Irrigation for the Future (IFF) developed a Road Map for Energy and Water Efficiency in Irrigated Agriculture (English 2015). The Road Map outlines market-

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

based strategies for reducing energy use in irrigated agriculture by increasing water use efficiency. These various strategies fall under three headings: 1) improving existing technologies; 2) embracing new irrigation management practices; and 3) changing expectations. These strategies were the foundation for the market transformation theory and consequentially, the demonstration design that NEEA used from 2011-2014.

Improve and utilize existing technologies more effectively. Significant gains in efficiency are achievable with both existing technologies that are not fully utilized even where economically justified, and with nascent technologies with proven capabilities but limited market penetration. As an example, progress currently underway is significantly closing the gaps among sensor technologies, ease of access, and timeliness of information. While sensors have experienced rapid technological progress in recent decades, most sensors in use today are not adequate, a condition that represents an important class of opportunities.

Embrace new irrigation management practices. Irrigation management is the ultimate determinant of water use efficiency. NEEA's goals cannot be attained without at least limited adoption of new approaches to irrigation management that include regulated deficit irrigation, explicitly accounting for crop responses to applied water and for the costs and revenues of irrigation strategies. Adoption of new approaches will require new decision support systems that fully engage individual producers in management decisions in order to adequately address their objectives, experience, and constraints.

Higher-density field instrumentation and high-frequency, full-field monitoring of crop water availability to deal with spatial variability will be essential. Decision makers will need long-range forecasts of water requirements to better allocate limited resources. Decision tools to deal with these issues will involve significantly increased analytical complexity to accurately model the specific physical circumstances of soils, crops, and irrigation systems for individual farms. Managing that complexity will require advanced software engineering to streamline the computationally-intensive analysis of alternative irrigation strategies.

Change expectations. Some opportunities outlined in the Road Map are significant departures from current practice. Overcoming resistance to change within the irrigation community will require building a compelling economic case for producers and fostering a better understanding of the economic legitimacy of these practices within supporting financial services and governmental agencies. Regulatory agencies, federal agencies, and other institutions can motivate and guide technological development, remove regulatory barriers, and finance research, education, and outreach. Universities and commercial entities can provide technical support that will be essential for more intensive irrigation management if producers are to effectively manage the increased flow of data and the more complex web of decision factors involved in optimizing irrigation water use.

Because some technologies outlined in the Road Map are largely comprised of invisible systems of rules, informational modules, analytical tools, and decision support systems, the common extension practice of working with leading producers to demonstrate new technologies to neighboring communities may be ineffective. Increasing awareness of new technologies and management practices will require direct outreach and training.

Theory of Market Transformation

NEEA believes that the integration of data from current weather systems, moisture sensors, and soil mapping techniques, in conjunction with optimal irrigation management, will lower energy costs for growers and yield higher profitability through reduced labor, lower fertilizer and chemical intensity usage, improved crop uniformity and quality, and potentially increased yield. The integrated use of these technologies would provide an exact analysis and facilitate recommendations for when, where, and how much water to apply, defined as "precision irrigation."

NEEA's hypothesis for market transformation was that an integration of current and new irrigation efficiency technologies would provide an attractive value proposition to large growers worried about water availability, under pressure to reduce inputs (labor, fertilizers), and with the time demands of managing larger enterprise operations. Once these large growers demonstrated the benefits of water and energy reductions and the technologies dropped in price, growers with smaller farms would be attracted to the increased profit potential and would adopt the products, thus accelerating market adoption (Berne et al. 2015b).

NEEA identified key market barriers as well as interventions that could encourage market adoption of precision irrigation solutions, summarized in Figure 1.

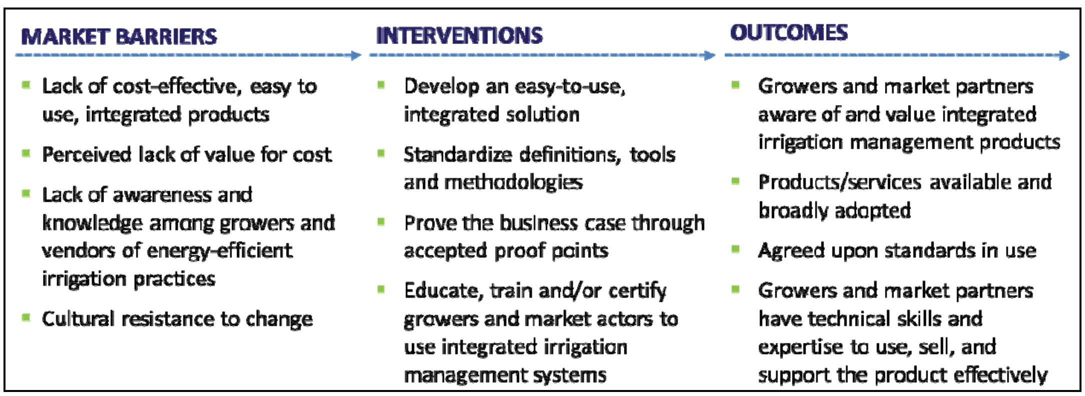

Figure 1. NEEA agricultural irrigation theory of market transformation

Demonstrations

The methodologies for assessing energy savings through improvements in irrigation management fall loosely into three categories. NEEA was testing all of the following:

1. Optimal Irrigation: A management practice that seeks to maximize the net returns from water
2. Irrigation Delivery Systems: The manner in which water is delivered to the field (PFR, VSI, and VRI as described earlier). Table 1 summarizes NEEA's demonstration projects and Figure 2 highlights their locations.
3. Irrigation Technologies: Specific devices, tools or methods that assist in measuring or controlling the application of water

Table 1. NEEA 2012-2014 demonstration projects

Type	Year	Team Lead	# Fields	Locations
PFR	2014	CropMetrics	8	Idaho
PFR	2014	WSU	20	ID, WA,
PFR	2014	Irrinet	2	OR, WA, ID
VSI	2014	CropMetrics	6	ID
VSI	2013	CropMetrics	8	ID, WA
VRI	2012-2013	OSU	4	OR, WA, ID
VRI	2014	Irrinet	3	OR, WA, ID

Note: This table does not include reference fields (control group)

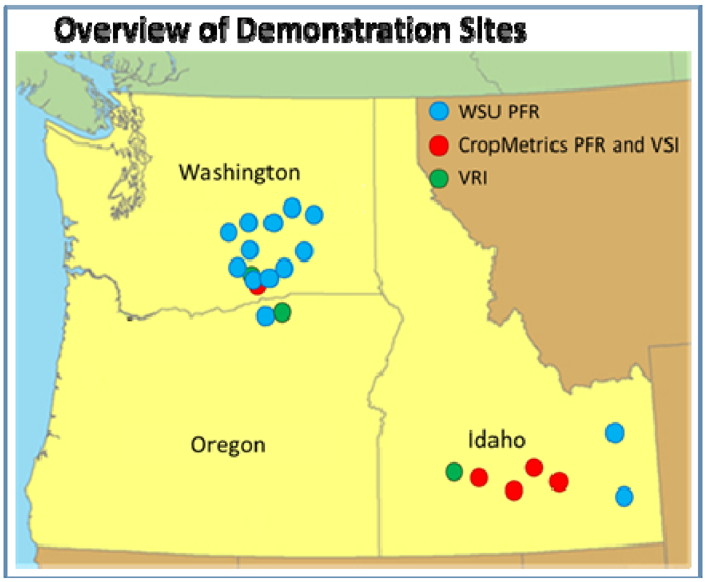

Figure 2. NEEA Agricultural Irrigation Initiative demonstration sites

Lessons Learned

Demonstration Expectations

Grower technology adoption is slower than that in other industries. NEEA learned that growers (even early adopters and pioneers) take a minimum of three years to adopt a new technology – the first year for watching other case studies, the second for trying a small demonstration, and the third for scaling to include multiple pivots (Berne, Valenti, and Whitty 2015f). This duration affects the length of time necessary to conduct a demonstration, the realistic objectives for one growing season, and the time span for scaling a utility incentive program. If demonstrations don't go as planned, the length of time until adoption can stretch out even further.

Qualitative findings often trump quantitative. NEEA found that no matter what our sample size was as the beginning of the season, many variables led to a substantially smaller sample size for quantitative energy savings at the end of the season. However, the team was able to document great anecdotal evidence and market transformation. An example:

- 2014 VSI demonstration: Barley grower. This is a medium-sized, family-owned and operated farm growing a wide range of crops. The grower and NEEA team member agreed that 2014 was among the best crops of barley that they had ever seen. Harvest began on schedule, and yield monitors registered an average 210 bushels per acre, compared to the grower's previous record of 185 bushels per acre, representing a 13.5% improvement. This sample constituted about 15% of the harvest on that field. Sadly, the farm experienced four inches of rain the morning after the crop had been swathed, and several more inches in the following days, which virtually destroyed the remainder of the harvest and made yield monitoring for the remainder of the harvest impossible.

Demonstration Design and Management

Contractor selection and coordination. NEEA worked with a number of contractors with varying management skills throughout the demonstrations. It became clear that the best irrigation demonstration contractors have excellent project management skills, subject matter expertise, and local knowledge and relationships. As building trust in the grower world is crucial, NEEA found that the best practice is to work within existing distribution channels such as consultants, university extension offices, and utilities to establish grower relationships. In addition, field conditions and weather are constantly changing, so regular communication and coordination among all field contractors helps to leverage time-sensitive information, get better demonstration results, and avoid miscommunications and missteps with growers.

Adjust timeline to begin demonstration sooner. Through this Initiative, NEEA learned how to schedule planning, contracts, and decisions to work within the natural cycles that drive all agricultural work, including planting, harvest, and preparation (Berne et al. 2015b). Ideally, NEEA would develop contracts or agreements in the summer prior to the following growing season, then recruit growers with the assistance of consultants and utilities for demonstrations in the fall, incorporating appropriate contractual agreements and relationship-building. This would allow the demonstrations to run for the entire next growing season(s) with all systems working properly from the beginning of the season.

Precision irrigation requires IT proficiency. NEEA observed that the farming operations with in-house IT skillsets and aptitudes are able to troubleshoot, implement continuous improvements, and maximize the capabilities of precision irrigation technology. This is a great selection criterion to assess during the grower selection phase, and to discuss when making an agreement with a grower at the start of the season.

Earning grower trust differs from other markets. Growers have unique motivations and barriers to adopting energy-efficient technology. NEEA learned first-hand the importance of building personal trust within grower communities when working to accelerate the adoption of a new product. Developing this trust is key to working effectively within the grower culture. Local consultants and regional utilities with strong local customer relationships can be NEEA's biggest allies in building this trust.

Determine plan to measure energy savings at the outset. NEEA has not yet demonstrated a cost-effective, reliable way of measuring water and energy savings in complex, variable agricultural systems such as a large center pivot operation. Recommendations for future work include development of a vetted pre-season plan with both primary and backup savings measurement processes. This is challenging work for which solutions must be developed and deployed.

Design controls so growers feel empowered. NEEA found that growers need to be empowered to maintain control over their irrigation systems and decisions. Technologies, solutions, and demonstrations must be tailored to ensure that the grower is in command (Berne, Valenti, and Whitty 2015f).

Precision agriculture requires innovative incentives. NEEA observed that growers (as customers) are not price-sensitive in the same way that a residential customer would respond to an incentive for an energy efficient refrigerator. While cost is a consideration, complexity, ease of use, and yield are big drivers for growers' considerations of a complex pivot system upgrade (Berne, Seavert, and Whitty 2015e). NEEA paid for initial soil mapping and lab analysis of soil samples, ongoing soil moisture monitoring services, and the expertise and regular input from irrigation consultants throughout the season (which varied in each demonstration). NEEA was able to get some equipment donated by manufacturers for use in limited demonstration sites. For future and large-scale demonstration design, NEEA's early findings and anecdotal information point to possible upstream incentives through retailers, and training and rewards offered by vendors.

Incorporation of Technologies in Demonstrations

Solve connectivity issues first. All precision irrigation is reliant on good data connections, whether Internet, satellite, or line of sight radio communication. NEEA ran into all kinds of challenges implementing fully functional on-farm wireless networks, courtesy of both the natural world and of technical issues related to wiring connections, signal strength, and other challenges around communication protocols. The presence or absence of a solid data connection at the start of the season can make or break a demonstration (Low, le Roux, and Whitty 2015c).

Use extra scrutiny to ensure adequate and fluid installation of new technologies. Technology installations are a critical point of contact with growers for building trust in their products or services (Berne, Valenti, and Whitty 2015f). NEEA identified many areas for improvement in the installation processes for many technologies, including the need to develop a shorter, easier process and to provide good documentation and support (know the audience, language, and their levels of IT expertise).

Regular pivot evaluation and maintenance is crucial. Throughout the demonstrations, NEEA learned that few growers have a regular cadence for pivot and sensor calibration (Low et al. 2015b). NEEA commissioned a specific study to prototype a cost-effective approach for evaluating and improving pivot performance (much like building commissioning) on 31 pivots in the Northwest.

Not all pivot systems perform as specified or designed, which leads growers to overwater. Pivot maintenance is a precursor for deeper efficiency and supports long equipment life and any upgrades. The implementation of pivot evaluations creates an opportunity that could potentially drive significant energy savings in the region. Utilities could include pivot evaluations as a requirement in existing downstream incentive programs. Findings from the pivot evaluation study include:

1. Improving distribution uniformity enables growers to reduce the amount of water they pump to meet minimum crop requirements across the entire field
2. Selecting the appropriate sprinkler head designs can reduce evaporative losses
3. Servicing worn parts such as leaky pipes, regulators, sprinkler heads, and worn or broken gear boxes enables the grower to irrigate more uniformly and to improve crop yield
4. Optimizing system pressure benefits the grower in multiple ways:
    a. Improves yield and quality of yield
    b. Reduces energy costs in cases with pressures originally too high
    c. Decreases other inputs such as fertilizers, pesticides, and other chemicals

Soil mapping is important, and not all soils are created equal. A particular soil characterization solution doesn't always meet the conditions of a particular field; for example, apparent electrical conductivity (EC_a) soil mapping, one means of characterizing soil, isn't effective for all soils (Higgins et al. 2015b).[3] VRI and VSI applications require accurate maps of soil water-holding capacity as inputs to the applied water prescription generation process. Thus, determining accurate soil variability information and conducting soil mapping are necessary steps toward successful implementation of precision irrigation.

These accuracy requirements are typically not satisfied by freely-available soil survey data. The 2013 NEEA VRI demonstrations mapped 17 fields, some multiple times, and found inconsistent levels of performance for apparent electrical conductivity (EC_a) soil mapping techniques. As a result, NEEA commissioned the Oregon State University (OSU) Department of Biological and Ecological Engineering to perform a soil mapping assessment on three of those fields to identify field conditions that can confound the soil EC_a mapping process, which involved re-mapping those three fields, simultaneously taking more than 125 geo-located soil samples from each field, and analyzing 26 properties that describe the soil composition and chemistry.

Through the use of detailed statistical and data reductionist methods, the team identified the soil chemical property "base saturation" (increased calcification in the makeup of the soil) as the confounding factor for accurate soil EC_a mapping in the Columbia Gorge region. The findings indicated that soils with base saturations of 90% or higher did not produce viable soil maps. Based upon those findings, the OSU team advised that growers and mapping service providers perform a low-cost base saturation test prior to EC_a mapping a field, and then determine whether to proceed with mapping. NEEA recommends that service providers incorporate a planned "self-consistency check" into their mapping operations, and that they conduct mapping operations at times when they can avoid large changes in ambient temperatures.

[3] Additional information on soil and irrigation management fundamentals is available in (Low 2015a).

Right-size the management zone for "precise" precision irrigation. Designing irrigation prescriptions to accurately apply water in a field using VRI requires dividing the field into reasonable management zones (Higgins et al. 2015a). The NEEA research team led by OSU performed an extensive catch-can test, also called a precision water application test, which collected the actual water applied under a pivot and created a map to show the difference between the irrigation prescription and the actual water applied. The researchers identified a minimum size of a management zone of 23 meters (75 feet); in other words, any area within a VRI prescription smaller than 23 meters (75 feet) along any edge will not be managed independently. The result informs the formation of VRI prescriptions and supports the utility of creating sprinkler "banks" that are sufficiently large.

Understand that available technology may still necessitate special considerations in implementation. NEEA's integrated irrigation solution relied on more than ten hardware and software applications that needed to interface effectively. Not all technologies performed as advertised, and sometimes they required field adjustments. Researchers can mitigate these challenges through actions such as using multiple brands of equipment for a given function, isolating demonstrations of individual technologies, and conducting demonstrations on smaller pivots (Low, le Roux, and Whitty 2015c).

Watch for integrated solutions and support data standards. While individual irrigation-related technologies can themselves substantially improve energy efficiency, the holistic approach of integrating all the various irrigation-related technologies holds the most promise for maximizing performance, profits, and impacts for growers and vendors alike. Integrated solutions include technologies from the pumps at the river to the emitters on the pivots, as well as all the instrumentation that monitors all the static and dynamic variables.

Vendors' continued collaborations to design and market integrated, easy-to-use solutions will improve the grower experience and help to accelerate market adoption. This developing vertical integration of the supply chain can be attributed to the creation of industry-wide data standards and their widespread adoption by the manufacturers (Berne, Hillyer, and Whitty 2015d).

NEEA brought together industry stakeholders to develop an agreed-upon set of data standards for the transmission of data necessary to develop, execute, and record a precision irrigation plan. Together with NEEA, the industry stakeholders initiated a data standards development project called Precision Ag Irrigation Leadership (PAIL) within AgGateway, a national organization devoted to e-business in agriculture. This work will continue through funding from NEEA Codes and Standards. NEEA will evaluate it for impact and results on a regular basis.

Conclusions

NEEA has demonstrated the existence of an opportunity to save energy and water in the agricultural irrigation sector through more precise irrigation practices. Results have been anecdotal at this point but the information looks promising. However, many of the technologies are not yet mature enough for market introduction of a fully-integrated system.

The climate for precision irrigation is rapidly changing, and industry is responding to the new needs and demands. NEEA believes that the need for continued innovation and efficiency improvements will remain. Frequently drought-stricken markets such as California and Australia can be prime exemplars to the Northwest in demonstrating precision irrigation solutions.

NEEA established that growers require at least three years to test and adopt new technologies. The Northwest has the opportunity to invest in testing, refining, and promoting regionally-appropriate precision irrigation technologies many years prior to the actual need for the efficiency promised by the new technologies. NEEA's support of the data standards (PAIL's part of the AgGateway effort leading to ASABE standards) development work will help to provide the necessary infrastructure for future market intervention opportunities.

This expanding industry requires collaboration among competitors, shared risk, shared learning, and experimentation. While the three-year NEEA Agricultural Irrigation Initiative has ended, NEEA has discovered some potential interventions, such as regular evaluations of pivot systems, that may present solid opportunities for utilities to engage with growers and to help them achieve higher levels of energy efficiency. NEEA will continue to scan, research, and fund agricultural energy efficiency opportunities.

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