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Agricultural Irrigation Initiative: The Future of Agricultural Irrigation

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) launched the Agricultural Irrigation Initiative with the goal of reducing agricultural irrigation energy use by twenty percent by 2020 NEEA is an alliance funded by more than 140 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.

This report synopsizes a longer document prepared for NEEA by Irrigation for the Future (IFF), an irrigation management company based in Corvallis, Oregon, that provides a Road Map for achieving that goal.

The Road Map characterizes the intrinsic limitations of current technologies, visualizes next-generation technologies and management paradigms based on economic optimization, and suggests strategies for guiding and accelerating development and on-farm adoption of changing technologies.

This report outlines strategic initiatives, concepts and ideas for accelerating technological improvements and summarizes these various strategies for achieving NEEA's twenty-percent agricultural irrigation energy reduction goal under three headings: 1) improving existing technologies; 2) embracing new irrigation management practices; and 3) changing expectations. Not all of the concepts and ideas should be delivered by utilities or NEEA; they could be delivered by the marketplace and agencies that interact with the agricultural community. This report is designed for a wide market focused on long-term directions in agriculture.

This report is one in a series of twelve reports addressing particular areas of NEEA's Agricultural Irrigation Initiative. All twelve reports are available at http://neea.org/reports.

1. Introduction

As part of the Northwest Energy Efficiency Alliance's (NEEA's) Agricultural Irrigation Initiative, two senior irrigation specialists at Irrigation for the Future (IFF) developed a Road Map for Energy and Water Efficiency in Irrigated Agriculture. Several additional leading experts with advanced research and extension experience provided critical review and strengthened the material. This report is a synopsis of an as-yet unpublished longer Road Map report that resulted from the experts' deliberations in 2012 and 2013. Some of its concepts and recommendations may fall outside the roles of utilities and NEEA. It is also one in a series of twelve reports addressing specific areas of this Initiative, all of which are available at http://neea.org/reports.

The Road Map outlines market-based strategies for reducing energy use in irrigated agriculture by increasing water use efficiency. The scope of interventions that would increase water use efficiency is quite broad. Current technologies can be improved to enable more accurate determinations of crop water use and more precise control of irrigation applications. However, irrigators will need altogether new technologies to circumvent the intrinsic limitations of current technologies if they are to approach truly optimal water use efficiencies under common conditions of variability and uncertainty.

In addition, the most effective conservation strategies will involve more than "hard" technologies. Irrigation efficiency is ultimately determined by management, and good management requires comprehensive data collection and integration, sophisticated analytical tools, and other "soft" technologies. Additionally, because prevailing attitudes and institutional policies can either impede or drive technological innovation and adoption, interventions to influence expectations and institutional support are also important. This report summarizes these various strategies in the next section under three headings: 1) improving existing technologies; 2) embracing new irrigation management practices; and 3) changing expectations.

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.

2. Overview of Strategies

The range of strategies and recommendations for increasing irrigation efficiency are described in the following sections. NEEA supports these strategies and recommendations; they are based upon the author's and contributors' experience and backgrounds, and on well-known principles and existing literature. Readers should consider these recommendations advisory/ directional rather than applicable to all precision irrigation technologies and stakeholders.

2.1. 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, significant progress currently underway is 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.

Intellectual property (such as models and software) created by universities, government research centers, and other public institutions that have not yet been actively marketed constitute another promising category of opportunities. The accelerating need for analytical sophistication and reductions in funding for public research efforts drive interest toward two business models for sharing protected intellectual property rights. One is to license intellectual properties developed by public sources to selected private interests to ensure aggressive dissemination and adoption. The second model is increased private development of needed software and services by commercial interests. Specific recommendations are to:

- **Upgrade pivot and linear move irrigation systems:** Reduce or eliminate the use of end guns, convert to Low Energy Precision Application (LEPA) or Low Elevation Spray Application (LESA) systems when appropriate, reduce pressure of systems in general, and improve integration of fertigation /chemigation into irrigation management tools. The *Overview of Center Pivot Irrigation Systems* report details some of these issues.
- **Improve precision irrigation:** Enhance understanding of management zones, integrate wireless sensor networks, and model predictive approaches to adaptive closed-loop control systems. Precision irrigation, while promising, still needs further development. Application techniques have outstripped the field data collection requirements. See the *Irrigation Delivery Systems* report for detailed information on precision irrigation demonstrations.
- **Upgrade regional agricultural weather station infrastructure** with:
    - Increased density of weather stations
    - Second-tier weather stations to monitor only locally-variable wind and precipitation data
    - Doppler-radar precipitation products
    - Software to assimilate and integrate first and second tier weather station data and Doppler observations for field-specific irrigation management and for adjusting other measurements (such as ground-truthing of remote sensing data).

- **Develop commercial pumping efficiency monitoring hardware/firmware** using power metering and flow metering combined with hardware/firmware to output pump efficiency data.
- **Adopt industry-wide data communications standards**, **data format standards, and metadata requirements,** such as those being promulgated through industry organizations such as AgGateway,[1] to facilitate sharing and use of data. These would include weather data standards to enable more aggressive use of weather data for various modeling and other activities and to seamlessly interface with decision support systems (DSS) and instrumentation and control systems.
- **Promote development of intellectual properties:**
    - Evaluate the market potential for intellectual properties proposed in the Road Map (scientific models, analytical programs, software), and explore the relative advantages of open source vs. proprietary technologies on a case-by-case basis.
    - Take an active role in arranging partnerships between academic and commercial entities.
    - Encourage software and service companies to commercialize needed public domain intellectual properties.
- **Develop a low-cost, automated, accurate, reliable system for evapotranspiration (ET) measurements in the field**.
- **Develop practical systems to detect root activity or density**: Upgrade existing technologies (such as ground-penetrating radar and tomography), develop algorithms to automatically interpret high-frequency soil moisture readings from time-domain reflectometers (TDRs) and other sensors to estimate root activity and water uptake. The *Soil Science and the Basics of Irrigation Management* report describes some of these tools.
- **Enhance mobile phone apps to feed back information** on system status (such as on/off status, flow rates, energy use rates, pressures) directly to irrigation managers.
- **Promote conservation tillage and residue management practices** to facilitate capture/utilization of water at the surface and to reduce evaporation losses.
- **Develop algorithms** to integrate multiple sensor data streams representing various properties of the soil-plant-atmosphere continuum, gathered at different time and spatial scales, and extrapolate these sensor data to other areas of a field.

2.2. 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.

[1] AgGateway (http://www.aggateway.org/) is a web-based business network for facilitating the use of information and communication technologies for the agriculture industry.

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. Recommendations include taking steps to:

- **Stimulate routine use of long-lead agricultural weather forecasting**, including two-week ET forecasts, estimated rainfall depths, and error bands associated with such forecasts.
- **Develop cost-effective, high-temporal frequency remote sensing data sources** with design and utilization of automated, dependable, low-altitude pilotless aircraft (unmanned aerial vehicles, or UAV)-based remote sensing systems, coupled with next-generation infrared sensing, for improved monitoring of crop conditions either on a demand basis or regularly-scheduled runs.
- **Develop and disseminate advanced decision support tools,** particularly to address deficit irrigation management and comprehensive analysis of profitability and financial feasibility. Producers faced with the much greater complexity of economically optimal irrigation management will need transparent decision support systems that augment their own experience and judgment. Such systems should facilitate integrating and analyzing more extensive field data, analytical tools, and other diverse information quickly and efficiently and make recommendations tailored to the specific circumstances of individual fields and farms.
- **Develop turn-key mobile labs:** Pre-designed, integrated systems of training modules, test and lab equipment and in-field sensors to be mass-marketed for use by fee-based service providers to provide an infusion of technical assistance and training to facilitate on-farm use of advanced irrigation technology applications.
- **Support development of improved plant-based sensor systems** to monitor plant conditions, such as plant water potentials and canopy temperatures and integrate sensor systems and supporting analytical tools for rapid interpretation and integration of large, diverse datasets to generate best estimates of decision variables and enable week-to-week comparisons of field status.
- **Develop low-cost fiber-optic instrumentation** for distributed soil moisture measurement.
- **Prescribe combinations of long-term management practices,** crop choices, crop rotations, tillage practices and irrigation to better utilize precipitation and irrigation water.
- **Develop statistically explicit analytical tools** (such as Bayesian decision models) to systematically account for uncertainties in field operations, weather, and plant yields.
- **Develop criteria for self-correcting irrigation control loops** based on sensor feedback at multiple scales and time steps that adjust for physical limits and re-parameterize plant and control models (self-learning decision support systems).

2.3. 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. Specific recommendations are to:

- **Establish an ad hoc communication organization** to build personal contacts with legislative and administrative leaders, media, and industry, and to provide trusted expertise regarding the merits and technical feasibility of proposed interventions.
- **Increase financial support for germination of new technologies,** such as an expansion of small business innovation research (SBIR) and the use of innovation calls focused on first-stage commercial development of irrigation-specific innovative ideas.
- **Stimulate increased adoption** of improved technogies by: 1) publicizing the costs and benefits of various initiatives; 2) making equipment vendors more aware of financial support programs, management tools, and outreach sources; and 3) publicizing parallel efforts by other agencies.[2] An unpublished report describing these steps is available upon request from NEEA.[3]
- **Establish rapid response commercial water markets** to motivate water conservation and to provide flexibility for on-farm water management without the cost of on-farm water storage.
- **Undertake outreach activities** directed at funding institutions to increase farmer access to financing for system improvements and alternative management practices for irrigators in the Pacific Northwest.
- **Campaign for revisions to state water law to:** 1) enable rapid response water markets (see above); 2) revise laws that discourage implementation of conservation practices; 3) establish efficiency standards for irrigation water and energy use; and 4) require advanced electronic flow metering on wells and irrigation systems.

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[2] Bonneville Power Administration (BPA), the United States Department of Agriculture-Environmental Quality Incentives Program (USDA-EQIP), and other programs support best design and best management practices for improved, more energy-efficient pumping stations (such as Variable Frequency Drives (VFDs)), flow meters, advanced water emission devices, and improved water distribution systems.

[3] Contact Geoff Wickes at NEEA (info@neea.org<mailto:info@neea.org>) for a copy of the unpublished report *"Electrical Energy Efficiency and Emerging Technologies in Northwest Agriculture"*

- **Establish energy buy-back incentives** to create opportunity costs for conserved energy.
- **Provide direct financial support for selected on-farm system improvements** to reduce capital costs and financial risk.
- **Upgrade irrigation district rotation delivery schemes** to allow irrigators greater flexibility in managing the rate, frequency, and duration of water use.
- **Promote research in targeted challenge areas** by public and private entities:
    - Improve physiological modeling of effects of water stress on crop physiology, root development, crop growth, and final yield; fund a public domain version of the AquaCrop yield model calibrated for Pacific Northwest crops and integrated into irrigation management DSS.
    - Increase accuracy **of ET modeling based on the American Society of Civil Engineers (ASCE) Standardized Equation** of reference ET by: 1) deriving region-specific crop coefficients; 2) modifying the Standardized Equation to account for ET under low soil moisture conditions; 3) adjusting crop coefficients to account for weather variations, soil salinity, no-till cultural practices, sub-surface drip irrigation (SSDI), and varietal differences; and 4) using field data feedback for in-season updating of crop coefficients.
- **Encourage public-private partnerships (PPPs).** Examples of limited forms of public-private partnerships include licensing of intellectual properties by public agencies, and targeted research partnerships between public institutions and private entities. Public agencies can often guarantee continuing support of a program that a private entity might not undertake. A private partner can make the partnership more nimble and responsive and may be better able to finance and initiate a program. Some have argued that PPPs are an effective mechanism for procurement, life cycle analysis, and performance-based contracting.
- **Facilitate commercialization of intellectual properties**: formulate standards and protocols for dissemination, maintenance, and control of open-source software, and address the liability problems that come from delivering faulty advice or services.
- **Develop and disseminate the following:**
    - **Guidelines, tools, and specialized training** in hardware, software, and advanced agronomic principles to enable growers, consultants, dealers, technicians, and other personnel to define management areas and to write advanced guidelines for irrigation and other farming operations. For example, irrigation guidelines to establish deeper rooting patterns can increase capture of precipitation, reduce losses from non-uniformity, and allow more flexible irrigation schedules.
    - **Design procedures** for determining optimal combinations of wireless sensors for integration of distributed and mobile sensor networks and other types of remote sensing for dynamic closed-loop adaptive control.
    - **Procedures/databases for on-farm documentation** of life cycle analysis and sustainability issues.
    - **Education, training, and technical assistance** to help farm advisors address growers' reluctance to change established practices or to incur the expense of changing farm equipment.

- **Promote long-term funding for the following:**
  - **User training in understanding and using long-term weather forecasts**.
  - **Academically rigorous analyses** to determine reasonable expectations of energy conservation, water savings, and economic outcomes from new or alternative technologies.
  - **An intensive and persistent public information program** to raise awareness within supporting technical and financial institutions on the merits of proposed conservation strategies.
  - **A web-based repository of applications** for: 1) enhanced open-source development and a common forum for feedback and discussion of options and improvements; and 2) public domain decision support systems.

3. Risks and Challenges

In addition to offering substantial efficiency gain opportunities, implementation of strategies outlined in this report present some risks and challenges.

3.1. Risks

- New, efficient technologies may not be readily adopted by growers. The extension practice of working with producers to demonstrate new technologies to irrigators may be ineffective given that some technologies outlined in this report are largely comprised of invisible systems of rules, informational modules, analytical tools, and decision support systems.
- Precision irrigation needs communication protocols and standards (see the *Data Exchange Standards* report) to enable the increasing volume of data so that it is turned into actionable information. Communication standards and protocols to enable the next generation of products and users to save water, energy, and resources may not be in place when needed.
- Providing management advice and decision support systems for use in new management techniques such as deficit irrigation and other unconventional practices will often involve substantial uncertainty, entailing liability risks for consultants.
- While partial irrigation (deficit irrigation) offers potentially greater net income for producers, it also leaves less room for error or uncertainty.

3.2. Challenges

- The technology is not yet available; most sensors currently in use for irrigation management are inadequate for maximizing energy and water efficiencies.
- Precision irrigation application techniques have outstripped field data collection requirements.
- Use of field data for calibration of sensor systems and analytical models.
- Management of spatially variable fields.
- The increasing complexity of economically optimal irrigation management will necessitate transparent decision support systems that augment producers' own experience and judgment.
- To mitigate resistance to change, NEEA and other industry stakeholders (US Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), utilities, and the supply chain) must provide both producers and supporting financial services and governmental agencies with a compelling economic case.
- Increasing awareness of new technologies and management practices will require direct outreach and training.

4. Lessons Learned, Next Steps, Value of Findings

4.1. Lessons Learned

- The most effective conservation strategies will involve “soft” technologies, such as comprehensive data collection and integration and sophisticated analytical tools, in addition to “hard” technologies.
- Given that prevailing attitudes and institutional policies can either impede or drive technological innovation and adoption, interventions to influence expectations and institutional support are important.

4.2. Next Steps

- NEEA will publish the full Road Map report upon which this synopsized report was based.
- While NEEA currently has no explicit plans currently in Emerging Technologies to implement any of the strategies in this report, its Emerging Technology group will review these recommendations to identify potential further actions.
- NEEA should support the AgGateway communication protocols to completion and turn over the project to the American Society of Agricultural and Biological Engineers (ASABE).

4.3. Value of Findings

The recommendations in this report provide an array of strategies for further advancing energy and water efficiency in irrigated agriculture. The wide-ranging variety of the strategies presented maximizes opportunities for implementing one or more that will complement any set of circumstances and constraints.