Irrigation Innovation Consortium Project Summary Report

IIC-supported projects 2018-2022

By: IIC staff and principal investigators

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Introduction

About the Irrigation Innovation Consortium (IIC)

IIC's mission is to accelerate the development and adoption of water and energy efficient irrigation technologies and practices through public-private partnerships in both the agriculture and landscape sectors.

Our leadership, affiliate researchers, staff, and industry stakeholders are dedicated to ensuring that irrigated agriculture and landscape systems stay productive, profitable, and resilient in the face of increasing pressures on the world's freshwater resources.

How research is selected

IIC works to identify and support high-quality research to support the irrigation industry and improve water and energy use efficiency. Through its projects, IIC is advancing knowledge and building collaborative capacity involving university, industry, and other partners.

IIC projects initiated in 2022

Using the Irrigation-Energy Linkage to Estimate Irrigation Water Delivery

University partner: University of Nebraska-Lincoln; Industry partners: Nebraska Water Balance Alliance, Grower Information Services Coop
Principal Investigator: Amy Harsch

Background: This project, which expands on work previously funded by IIC, is focused on using electrical runtime data to accurately estimate water pumped for irrigation in real time. In addition to providing real-time field-level data on water use to farmers via a user-friendly dashboard tool, Harsch's team is providing aggregated data to support local groundwater district and state government agency work on water resource modeling, water budgeting and policy development. The team aims to encourage shifts in awareness and practice related to irrigation management and to scale their impact by engaging with producers and district managers in two Nebraska water management districts.

Developing a data assimilation and integration tool for irrigation management technologies used by California Almond Growers

University partner: University of California Davis; Industry partner: Almond Board of California
Principal Investigator: Nicholas Bambach
Background: This team is developing a dashboard interface for almond growers that will integrate information from various irrigation management tools producers are using to support critical irrigation decisions, with a strong focus on making remote sensing data actionable.
The project will engage with multiple industry partners whose tools will be able to plug into this interface, and will train Extension agents, farm advisors, government field staff and other irrigation stakeholders on how to use this dashboard.

Organizing and analyzing Testing Ag Performance Solutions program data, quantifying productivity and GHG outcomes for corn, grain sorghum, and cotton
University partner: University of Nebraska-Lincoln
Principal Investigator: Dr. Daran Rudnick

Background: The Testing Ag Performance Solutions (TAPS) program, which is designed to reflect real-world, on-farm conditions and circumstances, engages producers in annual competitions to demonstrate and expand their proficiency at managing and marketing commodity crops as efficiently and profitably as possible. Rudnick's team will capitalize on the extensive data gathered over the last five years of the program, including on how growers' use of decision support technologies affects production outcomes, to synthesize and distill a broad range of management implications and inform future research priorities.

Extension Outreach Tools to Improve Adoption of Irrigation Management Technologies in the Texas Panhandle
University partners: West Texas A&M University and Texas A&M AgriLife Extension Service; Industry Partners: Better Harvest Co., Providence Farm
Prinicpal Investigator: David Parker

Background: This team is developing a user-friendly tool to help producers in the Texas Panhandle distribute acres dedicated to irrigated and dryland crops as a strategy for managing declining groundwater resources more effectively and profitably. The team will work closely with crop consultants and producers to support their use of this tool in conjunction with using soil moisture sensors effectively.

IIC-supported projects 2018-2021

Balancing supply and demand of water used to irrigate

With dwindling available irrigation water and increasing demands brought about by climate warming and population increase, the need to increase overall efficiency and conservative practices of irrigation is critical. The key management goal of irrigation is to balance the **supply** of water and **demand** for water. The following list of IIC projects supported starting in 2018 to date is organized below with this principle in mind.

Projects related to water supply and application

Irrigation scheduling using soil water supply and atmospheric evaporative demand, 2021 (active project)

University partner: University of Nebraska-Lincoln; Industry partners: Aspiring Universe Corporation, Arable Labs, HydroInnova LLC, Corteva, and PlanetLabs Inc.
Principal investigator: Trenton Franz

Background. According to the last two decades of USDA farm and ranch irrigation surveys, just a modest percentage (~15% or less) of U.S. producers rely on technology like soil or plant sensors or irrigation schedulers to decide when to irrigate. Meanwhile, remote sensing data is often too complex or opaque to support producers in making real-time irrigation decisions. This project is testing a new irrigation scheduling algorithm, supply-demand dynamics (SDD), that combines cutting-edge remote sensing data, proximal sensing data, and in-situ sensor data to compare how its recommendations pan out compared to traditional irrigation scheduling methods/practices.

Outcomes. The team introduced and trained 80 producers on pivot telemetry, soil moisture sensors, weather stations, and geophysical mapping. They recorded applied irrigation and yield and compared the results with historical trends and control groups. Ninety-five percent of growers keep pivot telemetry for convenience, and just like historical trends, only 10-15% of people kept soil moisture probes and weather stations. This is in spite of the fact that soil moisture probes saved producers 1-4 inches of water with no significant yield differences.

Impacts. If proven to reduce irrigation, the use of satellite-based datasets is scalable and a cost-effective strategy. Moreover, the algorithms can help move towards semi or full automation of irrigation systems. This research will compare satellite and modeling irrigation recommendations vs. other irrigation scheduling methods and provide real-world experiment and proof of concept on this type of automation. Insights from the study may indicate which method offers the most water savings as well as best practices for scheduling irrigation. Satellite and modelling-based irrigation scheduling is more cost-effective and scalable compared to in-situ soil moisture sensors.

Sustainable plasticulture recycling opportunities, 2021 (active project)

University partner: Fresno State University; Industry partners: Jain Irrigation USA, Dow Chemical Company
Principal investigator: Charles Hillyer

Background. The irrigation industry manufactures approximately 250 million pounds of plastic drip tubes, tapes, and emitter lines annually just for the U.S. Some of these products will be actively used in fields or landscapes for a long time (10-30 years), while other products, such as thin-walled drip tapes, are only used for one crop growing cycle (4 months). Only a small percentage of these products are recycled, and much of the non-recycled and even some “recycled” plastic drip products end up in landfills or other non-renewable waste streams. This project is exploring a closed-loop approach to remanufacturing single-use dripline into thick-walled dripline, a potentially valuable proposition for the irrigation industry as it strives to produce products and support production systems more sustainably.

Outcomes. The team has begun work on an economic feasibility study on using recycled plastics from drip irrigation. This study will evaluate burst pressure, emitter uniformity, emitter discharge rates, head loss and plugging susceptibility of recycled drip tape.

Impacts. If successful, this process could support a more sustainable material supply chain for the irrigation industry, reducing waste.

Connecting field performance to watershed health: the added power of sharing data, 2020-2021 (active project)

University partners: University of Nebraska-Lincoln; Industry partners: Nebraska Water Balance Alliance, Grower Information Services Cooperative, Olsson
Principal investigators: Dayle McDermitt (2020-2022), Erin Haacker (2022)

Background. This project is building and improving upon a major effort by Nebraska's Twin Platte Natural Resources District (NRD) and five local public power districts to develop an online tool that collects well electrical use data every 15 minutes and converts that information to provide real-time estimates of water delivery at farm-level and watershed scales. The team is: 1) testing the hypothesis that electrical run time informed by electrical power consumption of a pressure-regulated center pivot can be used along with annual flow-test results to accurately estimate water delivery throughout a growing season, even with variable end gun use and other variables; 2) evaluating if and how electrical power consumption per unit of water delivered may be related to aquifer level changes during the growing season; 3) integrating measured water delivery from a population of center pivot irrigation wells that experiences changes in aquifer level during the growing season using groundwater modeling data available through a tool called the Groundwater Evaluation Toolbox; and 4) communicating and sharing the results of this research to irrigators and water managers across the NRD, as well as many other stakeholders in Nebraska and beyond.

Outcomes. The team has made significant progress on all its objectives and will complete a final year of field testing and analysis in 2022. The team developed and implemented an algorithm that can detect and correct for end gun operation. The project has also generated an extensive PostgreSQL database containing electricity run times, computed flow deliveries, measured flow deliveries, well depths, and other data. The team maintains regular contact with growers who have signed up to use this online tool while working with Twin Platte NRD and discussing the potential application or adaptation of this kind of tool with leaders of other water management districts.

Impacts. As the saying goes, "You can't manage what you don't measure." This project is developing scalable results with a tool that accurately provides near real-time knowledge about water use. This information is key to supporting interest and action at the farm or field scale related to improving water-use efficiency and conservation through dynamic irrigation management, crop selection, and other decisions. In addition, when field data is aggregated at the watershed management scale, this information can be used to support effective management by generating accurate regional water volume measurements that can be used as inputs to improve regional water models.

On-site solar-based nitrogen production, 2020

University partner: Fresno State University; Industry partner: Nitricity
Principal investigator: Nicolas Pinkowski

Background. For the past century, fertilizer production facilities have typically been located hundreds to thousands of miles away from farmers requiring fertilizers. Nitrogen fertilizer costs are rising and their production, which typically relies on extensive use of coal or natural gas, is responsible for 1.6% of global CO_2 emissions. This team tested a new technology that can produce nitrogen fertilizer on-farm as a byproduct of energy production using solar panels to evaluate if the system could supply sufficient nitrogen for a small crop of processing tomatoes.

Outcomes. The team successfully applied nitrogen as a by-product of solar energy production. They observed no significant difference in yields or crop quality for tomatoes grown with applied calcium nitrate fertilizer compared to those receiving high-frequency fertigation using solar energy unit-derived nitrate. This was true even though the experimental plots received significantly less N fertilizer due to delay in the solar energy unit becoming operational until later in the growing season.

Impacts. In addition to being a successful proof-of-concept study, the results of this study also support indications that small, continuous nutrient supply can result in better plant uptake. Encouraged by their results, the team has subsequently moved on to designing and testing units to supply field crops of peppers grown at commercial scale with nitrogen, among other applications, garnering high levels of interest from start-up venture companies, government agency staff, and other organizations.

Testing landscape irrigation flow sensors, 2020

University partner: Colorado State University; Industry partner: Irrigation Association
Principal investigator: Brent Mecham

Background. Quality control for irrigation products is evaluated using testing protocols set by objective third-party organizations. Flow sensors were originally designed to monitor flow in real-time, and not necessarily measure the rate of flow, which is the intended use of flow meters. However, flow sensors are often used interchangeably with flow meters by consumers and before this project, flow sensors were tested using the same protocol as flow meters. This project tested and demonstrated a draft protocol proposed for the program Smart Water Application Technologies (SWAT), specifically for flow sensors.

Outcomes. The protocol evaluated flow sensors for accuracy and repeatability of signals, range, pressure loss rating, and durability. The experiment showed that the current protocol is effective but requires fine tuning, as this is the first draft protocol for flow sensors. Recommendations were shared with the SWAT committee.

Impacts. For tools to be accurately evaluated for performance, their intended use must be considered when designing these protocols. This distinction in flow sensors, although similar to, or in some cases incorporated into flow meters, is important for these tools to be effectively used. This project was an essential first step for flow sensors to be properly tested using protocols designed for their intended use.

Field testing new protocol for weather-based irrigation controllers, 2020

University partner: Colorado State University; Industry partner: Northern Water, IIC
Principal investigator: Mark Crookston

Background. Quality control for irrigation products is evaluated using testing protocols set by objective third-party organizations, such as the American Society of Agricultural and Biological Engineers (ASABE). As technology advances, the protocols for testing new products are improved. In the past, manufacturers of weather-based irrigation controllers were evaluated in a 30-day testing period. Controllers were evaluated based on their ability to accurately administer water when the soil became too dry and shut off irrigation when the soil was appropriately wet. The limitation with this previous testing protocol was that during certain parts of the year and in certain climates, one of the main functions of the controllers may not be tested. For example, during a rainy month, the soil may never become dry enough for the controller to administer irrigation, and this function is not evaluated. The alternate testing protocol named ASABE X627 was developed to address this problem by extending the testing period from 30 to 90 days. Northern Water collaborated with IIC to evaluate this new testing protocol.

Outcomes. As of December 2020, the new protocol renamed ANSI/ASABE S627 was approved and now tests controllers in a longer testing period that exposes controllers to more variable weather patterns.

Impacts. On a practical level, these protocols ensure that consumers and irrigation managers have tools that perform to a high standard and increase a manufacturers' credibility in the industry. Better performance of tools such as lawn controllers also equates to more efficient water management among communities and municipalities.

Satellite and UAS imagery use to implement timely irrigation strategies, 2019 (active project)

University partners: Colorado State University, Fresno State University, University of Nebraska-Lincoln, Texas A&M; Industry partners: Lindsay, Farmer's Edge
Principal investigators: José L. Chávez, Florence Cassel, Juan Enciso, Daran Rudnick

Background. Reduced water supply due to drought, urban growth, and industry demand has increased the need for efficient water management. Satellite and UAS platforms equipped with advanced multispectral sensors offer very high spatial and temporal resolution that can be used to support farmers in making effective irrigation management decisions. The main objective of this study was to assess the accuracy of using UASs and satellites (multispectral imagery) to determine crop actual water use or evapotranspiration (ET) and soil water deficit.

Outcomes. This study used California, Colorado, Nebraska, and Texas locations. Remote sensing (RS) imagery (0.05 – 5 m pixel size) was acquired over research fields to determine daily crop evapotranspiration (ET) and soil water deficits. Eddy covariance energy balance system and soil water sensors/probes were used to assess remote sensing platform and crop ET model weekly, monthly, and seasonal accuracies. It was found that the reflectance-based basal crop coefficient approach, used to estimate crop transpiration rates, performed similarly or slightly better, in some instances, than the (more complex) adopted single source land surface energy balance method. The performance of the former method resulted better for deficit irrigated corn fields than for fully irrigated fields; perhaps due to the fact that the reflectance based basal crop coefficient method has a limitation regarding capturing (wet) plant and land surface evaporation rates for sprinkler and/or surface irrigated crops. However, a local calibration of this crop coefficient method is recommended to improve their accuracy. Furthermore, the reflectance-based crop coefficient approach was superior to the FAO56 tabulated crop coefficients.

Impacts. The potential to improve crop water management with the remote sensing approach and the development of a decision support system that integrates remote sensing, agricultural weather station, and in-situ data with a database of RS of ETa algorithms is needed. It is suggested that future research include studies pairing PlanetScope images with in-situ surface and air temperature data for use with a larger array of RS of ETa algorithms.

Low pressure and low flow media filtration system, 2019

University partner: Fresno State University; Industry partner: Perigo LLC
Principal investigator: Kaomine Vang

Background. Common media filters require anywhere from 30-50 psi to operate properly. The advent of new irrigation technology and drip tape designs, however, which typically operate in the 8 to 15 psi range, mean that such high-pressure filter ratings both waste energy and can be destructive for drip systems. This project set out to develop, prototype, and test a new filtration device that can perform the same functions of the currently available filter technology while operating at lower pressures.

Outcomes. The team discovered that media compaction and media types affected testing outcomes in interesting ways, leading to some surprising results. After making necessary adjustments, the team was successful at having the filter unit work as planned, aside from the fact that the unit's pressure loss was greater than anticipated.

Impacts. Lower pressure filtration can increase water use efficiency, decrease system internal friction, and lessen contamination of the filtration system by decreasing containment discharge, all factors that have the potential to support drip system optimum function and extend these system's longevity. While this prototype was not successful at achieving all of its goals, further research to perfect this filter device could benefit the irrigation sector.

Irrigation and pumping plant efficiency tool, 2019

University partner: Colorado State University; Industry partners: Electric Power Research Institute, Tri-State Generation and Transmission Association, Inc.
Principal investigator: Joel Schneekloth

Background. Energy represents the largest cost of operating an irrigation system. This project developed a handy online calculator tool for informing irrigators using center pivots about potential maintenance and upgrades they might need to improve their irrigation systems' profitability and efficiency.

Outcomes. The team performed numerous center pivot audits to test the calculator's results and trained the inaugural Colorado Master Irrigator class of 2020 on using the calculator. In addition to audits and training on the calculator, webinars were given on irrigating efficiently. During audits, the team found potential energy savings from 1-27%. Using the calculator, the team was also able to identify specific issues that affect energy use such as flow meter accuracy voltage and amp imbalance, and low system pressures responsible for affecting irrigation application uniformity.

Impacts. This free, simple calculator can be used anytime at a producers' convenience. In some cases, this tool can help a producer identify that a more detailed audit of their system is merited. In addition, the calculator can serve as a useful training tool highlighting common irrigation management issues related to system non-optimization that can be rectified if correctly identified and addressed.

Reducing nutrient runoff in surface-irrigated sugarbeets, 2019

University partner: Colorado State University; Industry partner: Western Sugar Cooperative
Principal investigator: Erik Wardle

Background. Capturing runoff from agricultural fields is the most direct way to evaluate the impact of conservation practices on sediment and nutrient loading into our water bodies. Unfortunately, existing research-grade technology available for edge-of-field (EOF) monitoring can be prohibitively expensive and complex for widespread deployment, especially in semi-arid regions where runoff events from precipitation are infrequent. Thus, the team is developing a new generation of low-cost internet-connected technology, including automated water samplers and infiltrometers, to make EOF monitoring more feasible and economical.

Outcomes. The low-cost sampler developed by the team was compared to a standard sampler. Both samplers were automatically activated when an H flume water height of 0.5 inches was reached. Samples (200 mL) were taken every hour during the irrigation event. The preliminary data from the water level sensor compared to the ISCO bubbler on two irrigation events show comparable results with an R2 = 0.99 and R2= 0.99 for irrigations 1 and 2, respectively.

Impacts. This low-cost technology has the potential to provide similar results and reduce costs of monitoring equipment up to one tenth of the price of standard equipment. A reduced cost makes this equipment widely available to farmers and other interested stakeholders, which results in more informed decision making.

Irrigation scheduling with remote sensing under full and deficit irrigation, 2019

University partner: Colorado State University; Industry partner: Colorado Corn
Principal investigators: José L. Chávez, Allan Andales

Background. Water Irrigation Scheduler for Efficient Application (WISE) is a cloud-based irrigation scheduling tool that relies on the soil-water deficit method, with tabulated crop coefficients (Kc) to estimate crop evapotranspiration (ETc). Evapotranspiration (ET) measurements help farmers evaluate water loss from the root zone and is therefore a critical measurement for irrigation decisions. However, agricultural fields often experience varying ETc rates due to surface and management conditions, in turn making correct irrigation decisions difficult. Remote sensing (RS) techniques could improve irrigation scheduling by accounting for near real-time on-site conditions. This project aims to evaluate the effects of RS-based Kc in improving corn irrigation scheduling within the WISE tool.

Outcomes. Preliminary results indicate that RS-based Kc values improved the estimation of daily ETc when compared to ETc obtained using tabulated Kc values. On average, the land surface energy balance and reflectance-based Kc methods improved the estimation of ETc by 33% and 6%, respectively.

Impacts. Accurate ETc measurements are crucial for water allocation, irrigation management, and understanding the changing climate conditions on the environment. Irrigators rely on accurate data and easy-to-use tools to make real-time management decisions. The WISE tool has practical use applications for agricultural producers, irrigation managers, and research scientists. More research is needed in providing best management practices, irrigation management training, and further tool development that offers recommendations to irrigators.

Improving maize production with subsurface drip irrigation, 2018

University partner: Kansas State University
Principal investigator: Freddie Lamm

Background. In 2017, a field study evaluated the potential for intensification of field corn production with subsurface drip irrigation (SDI). Experimental factors were three irrigation levels (115, 100, or 85% of ET-rain replacement), two high-yielding corn hybrids (Pioneer 1151 or Pioneer 1197), and three elevated plant densities (42,000, 38,000, or 34,000 plants/acre).

Outcomes. Intensification of corn production with SDI appears to be a promising approach to improving the use of our limited land and water resources. Corn yields were not affected by irrigation level and significantly greater crop water productivity (CWP) was obtained by the lower 85% ET-rain irrigation treatment. There were significant differences between hybrids with Pioneer 1197 averaging nearly 9% more grain yield, primarily due to a greater number of kernels per ear. Increasing plant density from 34,000 to 38,000 or 42,000 plants/acres increased grain yield by 4% (10 bushels/acre). Seasonal profile soil water was relatively stable across irrigation treatments and plant densities, further indicating that the 85% ET-rain irrigation treatment was sufficient for this corn production intensification study. These results suggest that crop intensification with SDI can increase crop water productivity

Impacts. Though SDI in corn production led to enhanced corn yields, the implementation of this technology must be carefully considered. Benefits of using SDI include more efficient water and energy use, increased uniformity and plant health, and better management of fertilizer and pesticides. The disadvantages include greater irrigation system cost, system maintenance, and system longevity. Increasing crop water productivity, while reducing irrigation water use, will be an important factor in feeding the growing world.

Predictive modeling of delivered water utilizing power consumption data, 2018

University partner: Fresno State University; Industry partners: REDtrac, Madera Pumps, McCrometer
Principal investigator: David Zoldoske

Background. Working with numerous vendors, growers, and irrigation districts in the San Joaquin Valley, this team instrumented a variety of wells to support comprehensive monitoring and improve model estimations of water and energy use and engage in outreach about the data generated. The central goal was to help irrigators better understand the relationship of energy demand and pump performance.

Outcomes. The team encountered significant grower resistance to allowing researchers to gather data from their wells. Historically, California water users have not been required to monitor wells located on private property. The team was able to find willing participants located in the southern San Joaquin Valley and 10 additional wells were equipped at Fresno State. More irrigation districts planned to work with the team to equip additional wells in nearby areas.

Impacts. Data insights generated from this project can help pump manufacturers better predict the longevity of their product and help growers to make timely, cost-effective decisions related to pump maintenance. Faced with managing significant energy consumption costs and increasing regulatory pressures due to California’s Sustainable Water Management Act and other water board provisions, trying this approach again may result in stronger grower participation interest.

Projects related to water demand

Precision irrigation on golf courses with soil moisture sensors and mapping, 2021 (active project)

University partners: Texas A&M, University of Minnesota; Industry partners: The Toro Company, U.S. Golf Association
Principal investigator: Chase Straw

Background. The golf course industry is under increasing pressure to reduce management inputs, especially irrigation. Fairways account for an average of 28 irrigated acres on each of the 15,000+ golf courses in the United States. Annual median water use per acre of these areas is between approximately 250,000 and 1,250,000 gallons, depending on the region (Golf Course Superintendents Association of America, 2015). Unfortunately, current adoption of soil moisture sensors and mapping technologies for precision irrigation is minimal on golf courses. Furthermore, minimal on-site precision irrigation research has been conducted to demonstrate the water savings potential from precision irrigation implementation.

Outcomes. The team compared golf course fairway water consumption in Minnesota and Texas using a precision irrigation approach and conventional irrigation scheduling methods. Preliminary results show that precision irrigation technology consumed 46% less water than ET treatment, and 24% less than conventional scheduling methods. In addition, 105 golf superintendents completed a nationwide survey on the driving forces and barriers of precision irrigation technology adoption in 2022. Preliminary findings show that 89% have adopted precision irrigation technologies on their golf courses. The most adopted precision irrigation technologies include individual head irrigation control systems (68%), handheld soil moisture sensors without GPS (58%), and evapotranspiration weather stations (41%). The top three driving forces of precision irrigation adoption include: reducing water use (87%), increasing playability (68%), and increasing turfgrass aesthetics (68%). Among the survey respondents the most common barrier to adoption of precision irrigation technology included high initial cost (77%), need for higher administrative approval (36%) and lack of information on the effectiveness of irrigation technology (28%). Survey data analysis was still ongoing as of December 2022.

Impacts. Precision irrigation is a viable strategy to achieve reductions in water consumption by making irrigation applications only where, when, and in the amount needed. Precision irrigation is likely best implemented using a combination of soil moisture sensor and mapping technologies, along with individual irrigation head control, to program an irrigation system for more precise, site-specific applications that could lead to significant water reductions beyond conventional irrigation scheduling methods. Surveys such as the one from this study are essential to understanding the behavior, motivations, and hesitations of irrigation managers, and for guiding future research and development on precision irrigation and related technologies, which could help conserve substantial amounts of water and reduce costs.

Quantifying irrigation water savings of agrivoltaics, 2021 (active project)

University partners: Colorado State University, University of Arizona; Industry partners: National Renewable Energy Laboratory, Jack's Solar Garden
Principal investigator: Jordan Macknick

Background. "Agrivoltaics" is the term used to describe the integration of agriculture and electricity produced using ground-mounted solar photovoltaic (PV) technologies. Solar projects can take up large areas of land. Under certain configurations, particularly when solar panels are elevated, agricultural activities can take place around and under the panels. This project is focused on characterizing the irrigation water requirements and potential irrigation savings in agrivoltaic systems. The team is evaluating the impacts of different panel heights on microclimate and soil conditions, how different vegetation types (with different root structures and water requirements) affect irrigation needs, and how irrigation requirements differ underneath and around solar panels. Prior work by the team in Tucson, Arizona, showed the partial shade of the solar panels led to a doubling of yield while requiring 30% less water than an open-air adjacent plot. Moreover, as the efficiency and generation of PV panels is dependent upon temperature, the cooler microclimate created underneath the PV panels from vegetation led to a ~2% increase in annual solar output, when compared to an adjacent PV installation that had non-vegetated groundcover. This research is exploring if and how such findings for agrivoltaic systems located on Colorado's Front Range may be similar or different.

Outcomes. The team was able to establish different field experiment elements and install a new irrigation system (with retention pond) in spite of significant COVID-induced delays. Ultimately, they established (i) 16 different crop types across Jack's Solar Garden's food producing plots, (ii) 4 separate seed mixes across two pollinator habitat study areas that include irrigation, (iii) an experimental design to study the impacts of mowing on native grass mixes, and (iv) plots for studying non-irrigated grass regeneration. The researchers partnered with the Colorado Agrivoltaic Learning Center, which is affiliated with Jack's Solar Garden, and conducted outreach on research goals/aims alongside this group. Researchers have given tours to visitors, delivered educational talks to tour groups, and have distributed information about the ongoing research.

Impacts. The team generated multiple datasets in this first season. These datasets include (i) timeseries data collected by dataloggers and sensors instrumented within the crop production portions of the site, (ii) observational data about plant growth, development, and yield, and (iii) spatially distributed data on soil carbon and water efflux. Data from the 2022 growing season will contribute to understanding the efficacy and cost benefits of agrivoltaics, which will contribute to more efficient land use and potential water savings in these microclimates.

Toward pivot automation with proximal sensing in the Great Plains, 2020-2021 (active project)

University partner: University of Nebraska-Lincoln; Industry partners: Valmont Industries, USDA-ARS
Principal investigator: Derek Heeren

Background. More producers might use irrigation scheduling to dynamically manage irrigation in response to crop water demand if it was automated and reliable. This project's four main objectives are to: 1) evaluate the accuracy of pivot-mounted multispectral and infrared thermometer sensors compared to data from stationary sensors and sensors deployed using unmanned aircraft; 2) compare maize and soybean crop health in terms of vegetative indices and crop water stress in relation to variable soil water content levels; 3) develop thermal indices thresholds to trigger irrigation calibrated for the sub-humid climate of the eastern Great Plains; and 4) compare outcomes and effectiveness of using an existing patented system (ISSCADA) integrated with data from pivot-mounted sensors to schedule irrigation to traditional irrigation scheduling methods, looking at crop yields.

Outcomes. The team's effort to develop new thermal index (iCWSI) indices that trigger an irrigation event in subhumid environments has been successful. They also determined that the integration of pivot mounted sensors with the ISSCADA irrigation system works. Additionally, the team identified that thermal indices data might also be able to be used to signal the need to intervene before non-yield-limiting stress becomes yield-limiting. Field work continues in 2022 to further evaluate this system.

Impacts. This project has advanced a labor-saving precision irrigation technology that will likely be attractive to growers and help encourage them to try this mode of supported, dynamic irrigation management and move beyond the more common practice of turning pivots on and leaving them on for the most part throughout the growing season. This project has also informed best management practices (BMPs) related to triggering needed irrigation events in eastern Nebraska. This is important given that producers are investing in new installations of more center pivot irrigation systems in this area and need this kind of guidance. Rain-fed agriculture has historically been more typical in this area, however, changing weather patterns have shifted precipitation amounts and timing, so more producers are installing center pivot systems in order to mitigate crop production risks.

Developing the Parallel 41 Flux Network, 2018-2021 (active project)

University partners: University of Nebraska-Lincoln, Kansas State University; Industry partners: LI-COR, Climate Corporation
Principal investigators: Christopher Neale, Eduardo Santos

Background. Evapotranspiration (ET) is a critical parameter that is commonly used to assess plant water stress, measure crop water use, support irrigation management decisions, monitor drought, and calculate water balance and productivity. This project, active since IIC's launch in 2018, has established and augmented the "Parallel 41" network of latest-generation, smart eddy covariance flux stations across the Central Plains of the U.S. The team is working to interrelate in-field, real-time actual evapotranspiration measurements with satellite-based spatial data to provide constantly updated and accurate ET information that will be made accessible to agricultural crop managers in the network's participating states though an online platform. In Kansas, the team is currently evaluating the feasibility of using existing flux gap-filling protocols to provide real-time ET estimates when atmospheric conditions are not suitable for eddy covariance measurement.

Outcomes. The network was partially established using funding in 2018 and 2019 from the IIC, with 10 towers located in Iowa (3), Nebraska (5), Kansas (1), and Colorado (1). 2020 funding made possible the installation and operation of five additional towers that was delayed due to the pandemic and related supply chain and logistics issues. The team will work to install more towers in 2022. Data collected by the

Parallel 41 Network consists of quality controlled, gap-filled, and continuous measured ET, daily reference ET, daily crop coefficient (Kc), and cumulative measured ET.

Impacts. The Parallel 41 Network's collection of high-quality measured ET data has supported basin-wide water balance analysis by state and water district leaders, validated spatial remote sensing ET datasets, and has engaged many end-users, including Natural Resource District (NRD) staff and producers across the Great Plains.

Precision mobile drip for specialty crop vegetable production in the Texas High Plains, 2020 (active project)

University partner: Texas A&M; Industry partners: Dragon-Line, Dynamax, Valmont
Principal investigator: Charles Rush (2020-2021), Qingwu Xue (2022)

Background. Today, approximately 4.5 million acres of cropland in the Texas High Plains, mostly planted to cotton or corn, are irrigated using 30,000+ center pivot systems. Due to increasing groundwater scarcity and increased pumping costs, growers are looking for ways to maintain and improve their operations' profitability, including switching to growing high-value crops such as watermelon, cantaloupe, tomatoes, and peppers. Center pivot sprinkler irrigation, however, can negatively impact specialty crop quality; using drip irrigation is preferable. This project is exploring the potential of converting existing irrigation infrastructure to mobile drip and targeting water applications dynamically throughout the growing season.

Outcomes. Texas A&M AgriLife, in collaboration with USDA-ARS and additional industry partners, integrated the use of mobile drip irrigation (MDI) and the Irrigation Scheduling and Supervisory Control and Data Acquisition (ISSCADA) plant/soil water feedback system to produce watermelons for fresh market sales in the Texas Panhandle region. This integrated system will be compared against conventional center pivot irrigation with low elevation sprinkler application (LESA) and traditional surface drip (DI), to evaluate crop yield and quality, water use and water use efficiency, and total economic return. The team deployed soil water sensors, neutron access tubes, and infrared thermometers.

Impacts. Conversion of LESA center pivot irrigation systems to MDI has great potential for those interested in including high-value specialty crops in their cropping systems. The preliminary study showed that melons grown under MDI yielded equal to those grown with traditional surface drip irrigation and significantly better than those grown under LESA. Planting flat and not on beds has the potential to further increase total biomass and yields under MDI. This, along with reduced weed pressure, could reduce input costs and further increase total profit from the production of high-value specialty crops with MDI.

Optimizing irrigation of turfgrass with precision technology, 2020

University partners: Colorado State University, Kansas State University, Texas A&M; Industry partners: The Toro Company, Aexonis
Principal investigators: Jay Ham, Cathie Lavis, Dale Bremer

Background. Improving turf and landscape irrigation management systems using Internet of Things (IoT) sensors, machine learning, and cloud-based systems can make technologies cheaper and more user friendly. The overall goal of this project was to conserve water by accelerating widespread use of soil moisture sensors (SMS) for landscape irrigation control by reducing costs and complexity in their use. The team worked to complete the following objectives: 1) evaluating irrigation trigger thresholds by measuring turf canopy responses to soil moisture using SMS; and 2) comparing SMS-based irrigation scheduling effectiveness among several SMS types and with traditional and ET-based irrigation scheduling.

Outcomes. The project will comprise three field studies, two under rainout shelters and a third in a larger, uncovered area and will be conducted on three turfgrasses. The new, low-cost SMS with internet of things (IoT) connectivity (wireless underground sensor network, or WUSN), developed by Dr. Ham, CSU, will also be evaluated in our proposed studies. The team's new low-cost SMS measures water content, soil temperature, and contains a novel temperature-controlled chamber that quantifies thermal response. The sensor was successfully calibrated against gravimetric samples on fairways at three golf courses over the summer season and will be tested in different settings in 2021. A novel IoT cellular carrier board reads the soil moisture sensors and sends the data to the cloud via a LoRa network installed with the help of industry partner Aexonis. The team invested considerable effort to make the system low power so it can operate all spring, summer, and fall on a small battery pack – no solar panel required. The entire carrier board system has been designed to fit in a small 6-inch valve box normally used in irrigation system installation.

Impacts. A lower-cost design with a longer battery life increases scalability while lowering the labor cost of these soil moisture sensors. This allows irrigators to employ a larger number of sensors which would help them make more accurate irrigation decisions through the field. Additionally, advances to carrier boards may have future unknown benefits as potential data points in soil health and moisture become more accessible and more easily measured to transmit the information. The team channeled the knowledge gained from three years of work into establishing a new company called SoilSignal (www.soilsignal.com).

Precision irrigation water management with remote sensing in California orchards, 2020 (active project)

University partner: Fresno State University; Industry partners: WiseConn USA, Irrometer
Principal investigator: Dilruba Yeasmin

Background. In 2013, California growers from 18 counties responded to a survey on their perceived changes in irrigation water use due to adopting precision agriculture technology such as soil moisture sensors as part of a study conducted by California Institute of Technology (CIT) and Fresno State, funded by Pacific Gas & Electric. That study indicated significant opportunities to improve irrigation efficiency by adopting technologies, such as soil moisture sensors. This project generated a series of datasets, maps, and tables to evaluate crop water status for orchards located in 18 California counties. This data was used for a new study to identify where targeted efforts to encourage adoption of more precision ag technologies might be most beneficial. Additionally, 55 growers were surveyed following up from the 2013 study to see how their perspectives on adopting precision irrigation technology had changed.

Outcomes. Of the 55 growers surveyed all participants responded “yes” when they were asked about using precision Ag technology in their fields for irrigation monitoring and management. Almost all of the participants listed some sort of irrigation monitoring equipment or systems that includes: Tensiometer, Puresense, Soil Moisture Monitor, FloraPulse in Tree Sensor, Cimis Weather Station, Soil Moisture Probes, Jain Logic (PureSense), Hortau Jain Logic, Semios McCrometer, and Ceres Imaging. 77% respondents noticed some level of positive changes in their irrigation water management after adopting precision agriculture technology. The participants noted:

1) Water reduction not only came from sensors but also irrigation practices (drip only establishment, substitute farming etc.)

2) Just adopting a precision ag technology by itself does not ensure improved water use efficiency. Growers did observe that in some cases where water savings or improved water use efficiency was not achieved that they had more uniform, improved yields.

3) Producers who used soil moisture sensors in combination with understanding the function of different soil types in their orchards were able to benefit from being more strategic about their irrigation decisions.

Additionally, a general conceptual model was developed to support researchers working with orchard growers in the future on understanding water stress over time.

Impacts. Critical orchard areas in California were identified from analyzing multiyear satellite imagery based vegetation indices that can help to understand where improved irrigation technology can be adopted. A model was developed that can be adopted by growers, industry or researchers to identify these critical orchard areas. In addition, the growers’ survey revealed how growers’ perceptions are changing over time toward adopting improved irrigation management technologies. Overall, this research outcome may work as a bridge to reduce the gap between irrigation technology developers and consumers ,as well as of grower communities toward the overall goal of improving water use efficiency through innovative and improved irrigation technology.

Wireless sensors for modeling crop evapotranspiration, 2020

University partner: Colorado State University
Principal investigator: Matthew Lurtz

Background. Monitoring evapotranspiration (ET) offers important controls and feedback for local, regional, and global climate and water resource systems. Developing innovative tools for evaluating ET in natural systems is critical for more effective management strategies. This project served as an important first step to developing a cost-effective ecosystem-monitoring network.

Outcomes. In this study, the team designed a monitoring station that measures: 1) within-canopy temperature; 2) soil moisture at varying depths; and, 3) green-leaf temperature using a contactless infrared thermometer. The team also incorporated non-water-limited and limited irrigation management schedules along with high-frequency nanosatellite imagery to bolster the data driven approach. The field analysis took place at an agricultural monitoring site in plots of corn that are fully irrigated and drought-stressed in eastern Fort Collins, CO. Preliminary results suggest that simplified estimations of ET using a DIY sensor network are an acceptable alternative to more sophisticated methods of measuring ET.

Impacts. This work supports creating accurate, cost-effective tools that make gathering data more accessible and consistent. This is crucial to developing evidence-based best practices and policies.

Measuring crop water use with a novel IoT sap-flow system, 2020

University partner: Colorado State University
Principal investigator: Maria Cappurro

Background. Monitoring crop water requirements can improve irrigation efficiency and sustainability of irrigated agriculture. Sap flow gauges can aid in its quantification and assessment. The objective was to develop an innovative Internet-of-Things (IoT) Sap-Flow System to measure plant transpiration in real time and incorporate an advanced decision making and diagnostic tool for irrigation management.

Outcomes. A new type of sensor, logger and algorithms were developed to measure the water flow through plant stems just like one might measure water flow through a pipe. The sap flow gauges measure water flow rate indirectly using the Heat Pulse technique. The gauges allowed tracking of transpiration responses to dynamic changes in weather variables and soil water.

Impacts. All the information can be seen in real time from any online device from any place in the world. Results will improve our ability to predict corn water use, better manage irrigation and water resources. Instructions on how to build these new sensors and a printed circuit board (PCB) design for the microcontroller components, including a data storage module, will be published for others to benefit from this low-cost, open-source, IoT-based technology.

Calibration and evaluation of a multi-scale spatially distributed ET algorithm, 2020 (active project)

University partner: Colorado State University; Industry partner: Northern Water
Principal investigators: José L. Chávez, A.J. Brown

Background. The objectives of this study include: 1) evaluating the effect of different remote sensing (RS) platform pixel spatial resolutions (scales) on the estimation of different types of data needed for estimating actual crop water use or evapotranspiration (ETa) on hourly, daily, and weekly timeframes (e.g., vegetation/crop height, leaf area index, fractional percent cover, surface aerodynamic resistance, sensible and latent heat fluxes); 2) developing a calibration protocol and standards for the (seamless) use of different imagery spatial resolutions (scales) in RS of ETa algorithms; and 3) determining the accuracy (uncertainty) of calibrated/standardized imagery and resulting ETa rates (from selected RS of ETa algorithms) on irrigation decisions in experimental fields.

Outcomes. Preliminary results indicate that the size of the image pixel, acquired with satellites and unmanned aerial systems, affects the accuracy of the estimation of water use by plants. It seems that the use of imagery with smaller pixel sizes better characterize reflectance energy from vegetation targets and derived crop water use rates. However, some satellites require additional imagery calibration. Further, methods of estimating crop water use that utilize both vegetation reflectance and temperature data proved to be more robust than methods only using reflectance data.

Impacts. While datasets are still being gathered and analyzed, the team expects that users will be able to appropriately monitor the actual spatially distributed crop water use and therefore be able to optimize the use of their water and nutrient resources. Providing users with guidelines on how to properly use RS imagery of different pixel spatial resolution (in ETa algorithms) will facilitate the adoption and application of the technology and algorithms. Therefore, this project has the potential to help users improve their irrigation management, document actual crop water use (e.g. water rights purposes, evaluation of efficiencies), conserve water, nutrients, soil, chemicals, and make irrigated agriculture more profitable and/or sustainable.

Artificial neural network model, 2019

University partner: Fresno State University; Industry partners: WiseConn, AgMonitor, AgH2O, Dynamax, Jain Irrigation USA, Irrometer
Principal investigator: Fayzul Pasha

Background. Relying on evapotranspiration to determine the amount of irrigation to apply is a common practice but can result in over- or under-irrigating. Identifying which other parameters are most important to estimating crop water requirement is useful to help apply water more accurately in real time. This team conducted a study to check the feasibility of developing an artificial intelligence (AI)-based model to successfully capture and better understand the general pattern and dynamics of the crop water requirement.

Outcomes. A brute force method was applied to identify the number of combinations to observe the lag and cumulative effects of weather variabilities. A total of 1,211,040 combinations were run to observe different impacts on Plant Water Intake (PWI). Results show that some of the weather variables are highly correlated with the PWI at lower lag days. As the lag day increases, the correlation decreases; and after a certain number of lag days, the correlation does not change. Results also show that the correlation increases with the increase of number of independent variables in a combination to predict the PWI. The approach was applied to an olive field at the University Agricultural Lab (UAL) located at California State University, Fresno, identifying the significant water savings potential with this method.

Impacts. The preliminary results suggest the use of artificial neural network (ANN) modeling as decision support for predicting crop water requirements may save growers 15% on their amounts of water and energy usage compared to status quo practices. The development of a model analyzing this high number of variables is significant and may encourage the development of future tools to help farmers use this model in easy-to-use software.

Vertical irrigation solutions with machine learning, 2019

University partner: Colorado State University; Industry partner: Vertical Irrigation, LLC
Principal investigator: Joshua Craver

Background. Lighting accounts for 40-60% of input costs in indoor agriculture. This project studied the effects of far-red supplemental lighting strategies on microgreens quality and identified best-management approaches to supplementing far-red light during key growth stages.

Outcomes. The study showed that the effects of far-red light on the quality of microgreens are species-specific. In general, far-red light boosted fresh and dry microgreens weight and increased hypocotyl length (facilitating ease of cutting). The team observed: 1) a 40% increase in fresh and dry weight and a 34% increase in height in kohlrabi microgreens; and 2) a 40% increase in dry weight and a 15% increase in height of mustard microgreens. No notable growth or quality differences in far-red light applications between 40 and 80 µmol•m-2•-1 FR (a measurement of far-red light intensity).

Impacts. Currently, the cost of energy use limits the sustainability and profitability of vertical agriculture irrigation systems. Defining dynamic lighting strategies for improved microgreens quality will help growers more efficiently and effectively manage their production costs. More research is needed on the timing of far-red light applications and how dynamic lighting impacts water-use efficiency. This research could be used to inform machine learning applications for controlling management conditions.

New soil moisture technology for improving landscape irrigation management, 2019

University partners: Colorado State University, Kansas State University, Texas A&M
Industry partner: The Toro Company
Principal investigators: Cathie Lavis, Dale Bremer, Jack Fry, Jared Hoyle, Jay Ham, Tony Koski, Yaling Qian, Benjamin Wherley, Ambika Chandra

Background. Improving turf and landscape irrigation management systems using internet-of-things (IoT) sensors, machine learning, and cloud-based systems can make technologies cheaper and more user friendly. The overall goal is to conserve water by accelerating widespread use of soil moisture sensors (SMS) for landscape irrigation control by reducing costs and complexity in their use. Our proposed objectives are to: 1) evaluate irrigation trigger thresholds by measuring turf canopy responses to soil moisture using SMS; and 2) compare SMS-based irrigation scheduling effectiveness among several SMS types and with traditional and ET-based irrigation scheduling

Outcomes. The project will comprise three field studies, two under rainout shelters and a third in a larger, uncovered area and will be conducted on three turfgrasses. The new, low-cost SMS with internet of things (IoT) connectivity (wireless underground sensor network, or WUSN), developed by Dr. Ham, CSU, will also be evaluated in the proposed studies. The team's new low-cost soil sensor measures water content and soil temperature and contains a novel temperature-controlled chamber that quantifies thermal response. The sensor was successfully calibrated against gravimetric samples on fairways at three golf courses over the summer season and will be tested in different settings in 2021. A novel IoT cellular carrier board reads the soil moisture sensors and sends the data to the cloud via a LoRa network installed with the help of industry partner AeXonis. The team invested considerable effort to make the system low power so it can operate all spring, summer, and fall on a small battery pack – no solar panel required. The entire carrier board system has been designed to fit in a small 6-inch valve box normally used in irrigation system installation.

Impacts. A lower cost design with a longer battery life increases scalability while lowering the labor cost of these soil moisture sensors. This would allow irrigators to deploy a larger number of sensors. The findings from this research directly impacted the shape and scope of a previously mentioned 2020 project, *Optimizing irrigation of turfgrass with precision technology*, which led to the patent of the sensor and the development of the company, SoilSignal.

Radio wave moisture sensing technology, 2018

University partner: Fresno State University; Industry partner: Digital Springs, LLC
Principal investigator: David Zoldoske

Background. Equipping growers with real-time accurate data on soil water status across large areas of agricultural cropland is of critical importance. This project tested a radio wave-based platform using remote measurements to accurately access soil moisture content in discrete areas and depth, prototyping a small, wheeled cart to cover small areas of measurement. If successful, the technology would allow data to be collected on large areas and provide growers with accurate information on soil/water status in their fields.

Outcomes. The Radio Wave Water Sensing Technology team designed a test protocol based on the EPA WATERSENSE and Irrigation Association (IA) SWAT protocol. This first prototype was a soil probe based on radio wave technology. The prototype has evolved into a mobile unit that can remotely sense water moisture in soils. The team believes it can detect water moisture in soil down to 12 feet. However, further development and refinement is needed. The team established that radio wave technology can detect water content in different soil types.

Impacts. Growers are often hesitant to adopt sensing technology because products are not cost-effective or scalable for their operation. Developing a mobile probe that accurately measures soil moisture inside the root zone in multiple soil types could allow farmers to invest in a smaller number of products and thereby lower the threshold to adoption.

Remote sensing-based decision support with micro-satellites & ground-based data, 2018

University partner: Colorado State University; Industry partner: Lindsay Corporation
Principal investigator: José L. Chávez

Background. Reduced water supply due to drought, urban growth, and industry demand has increased the need for efficient water management. Satellite and unmanned aircraft systems (UAS) platforms equipped with advanced multispectral sensors offer very high spatial and temporal resolution that can be used to support farmers in making effective irrigation management decisions. Researchers tested the accuracy of UAS combined with satellite images to determine actual water needs or evapotranspiration (ET) and soil water deficit, for both full and deficit irrigation management.

Outcomes. A total of seven UAS missions were performed: 1) multispectral imagery were pre-processed and calibrated; 2) ground-based radiometry and soil water content were collected; 3) field and weather data were processed to estimate corn water used at the USDA ARS Limited Irrigation Research Farm (LIRF); and 4) actual crop water use (ET) algorithm was coded using MATLAB. A large difference on corn water use was determined for the full and limited sub-surface drip irrigated treatments, with better ET model performance for larger rates of corn ET.

Impacts. Historically, remote sensing and satellite imagery were more commonly used to help researchers and policy makers by supporting the development of hydrologic models, water demands and return estimates, etc. Advancements in UAS have made it possible for individual growers to also benefit from this technology, and projects such as this help the industry move towards the adoption of using advanced multispectral imagery technology to inform irrigation decisions. The UAS ET algorithm was shown to have the potential to be used in variable rate irrigation (VRI) to produce irrigation prescription maps. The team also believed that a combination of ground-based sensors and UAS-based multispectral imagery may be an approach to produce more accurate VRI prescription maps. This project also helped inform designs of future UAS projects funded by the IIC in later years.

Underground wireless networks for soil moisture sensing and irrigation water management, 2018

University partners: Colorado State University, Kansas State University, Texas A&M; Industry partner: The Toro Company
Principal investigators: Jay Ham, Kathy Lavis, Benjamin Wherley

Background. The goal of this study is to design and fabricate a low-cost buried sensor network that can quantify soil moisture by measuring radio signal attenuation within the soil profile. The core technology is low-cost wireless sensor nodes that communicate by radio through the soil (vs. through the air), eliminating the need for aboveground infrastructure and greatly simplifying the logistics of instrumenting a field with IoT sensors. Once installed, the sensor network detects real-time changes in soil moisture and communicates the results to an aboveground cellular gateway and the cloud.

Outcomes. A new type of soil moisture sensing technology was developed based on a low-cost, battery-powered, underground radio-transceiver network. Custom software was developed that uses a unique communication protocol and minimizes power consumption, allowing for a long battery life. Preliminary field and laboratory tests showed the system could measure changes in soil moisture between adjacent nodes using radio attenuation and data packet reception metrics. A provisional patent was filed on this technology via CSU Ventures. The patent was approved in 2021.

Impacts. Data gathered from this project could be integrated into other models and tools, such as the WISE Evaluation tool, allowing for more informed irrigation scheduling. Additionally, this project has the potential for lower labor costs and higher scalability as less materials and an efficient energy method via battery power are used. This research was expanded upon in future years and led to the development of a new company, SoilSignal in 2021.

Special Projects

Irrigation industry research needs assessment and survey, 2021

University partners: IIC founding universities; Industry partner: Irrigation Association
Principal Investigator: Inge Bisconer

Background. The Irrigation Innovation Consortium (IIC) partnered with the Irrigation Association to conduct interviews and a survey of wide-ranging irrigation industry stakeholders to identify their research needs and interests related to the development and adoption of water and energy efficient irrigation technologies. The team also worked to determine what kind of public-private collaboration on research, training, and demonstrations would be most welcome and beneficial.

Outcomes. The survey received a total of 414 valid responses from 40 states, with a quarter coming from CA and notable runner's up being AZ, CO, FL, and TX. A number of important trends and themes were revealed through this study, some of which include:

1. Survey respondents and interviewees expressed how important it is to know the water and energy footprint of irrigated agriculture and landscapes.
2. The industry faces a number of irrigation technology-related challenges including lack of awareness, incorrect use, and lack of affordability.
3. More irrigation technology-related research is needed.
4. More agronomic and systems integration research is needed.
5. Water and energy efficient practices and tools research is needed to support innovative irrigation training and integration.
6. Standards and curriculum development, and programming to improve workforce development is needed.
7. Research to track water sustainability targets, develop carbon footprint data, and support potential shifts in water and energy pricing policies is needed.

Impacts. Industry stakeholders indicated through surveys and interviews multiple areas in dire need of research and innovation. Interviewees unanimously expressed the need to understand the water and energy footprint of irrigated agriculture and landscapes, and survey respondents indicated a need to focus on 1) Innovation in technology transfer, adoption and integration, including workforce training, standards and curriculum development, and 2) Agronomic research to better connect irrigation's role within the plant/water/soil/climate nexus to quantify potential ecosystem services, production system benefits and ROI, and 3) Irrigation technology research to improve irrigation system uniformity, performance, longevity and sustainability; to improve precision irrigation including automation, sensing and control; to track water and energy sustainability targets and support potential shifts in water and energy pricing policies.

An economic impact study of the irrigation industry, 2020

University partners: IIC founding universities; Industry partners: Irrigation Association, Headwaters Corp.
Principal investigator: George Oamek

Background. Back in 2010, the Irrigation Association led a study that confirmed the size and importance of the irrigation industry but contained little analysis about the important economic drivers and other value-added aspects of irrigation for society. A decade later this project conducted a study update to attempt to quantify how much the irrigation sector adds to the U.S. and regional economies and provide additional insights related to predicting future demand for irrigation goods and services. Such information is valuable and necessary for the industry to target research gaps and identify sound directions and opportunities meriting company attention and investment.

Outcomes. Study results show that the irrigation industry is healthy and growing, generating almost $9 billion in direct economic impacts and an additional $23.3 billion in indirect economic impacts. The industry directly supports an estimated 70,000 jobs, which jumps to ~167,000 jobs if including secondary impacts. For agriculture, commodity prices explain most growth and variability in crop irrigation equipment sales over time, although local conditions and changing weather patterns also play an important role at regional levels. In contrast, single-family housing starts are the main macro driver of landscape irrigation equipment sales and services.

Impacts. Understanding the size and growth trajectories of the irrigation industry is beneficial for everyone influenced by the industry. It also helps key players in the business to plan and prepare for the expected (e.g., cyclical recessions) and unexpected (e.g., public health crisis) events. Knowledge and understanding of the predicted impacts of climate change are anticipated to continue to incentivize the adoption of irrigation systems to mitigate risk and related water conserving technologies because of evolving regulations and policies. Increasingly variable water supply availability in certain areas is anticipated to impact decisions about the kinds of irrigation systems and water-conserving technologies that crop producers, housing developers, and households will choose to invest in.