USDA-NRCS Conservation Innovation Grants: Final Report

Cover Page

Agreement Number: MSN#134567/144PRJ53AA (USDA, NRCS 69-3A75-11-211)

Project title: Preserving Water Resources in Central Wisconsin

Principal Investigator: Dr. Russell Groves, Department of Entomology, University of Wisconsin, Madison. (Formerly Dr. Alvin Bussan, Department of Horticulture, University of Wisconsin, Madison)

Date of submission: 3/03/2011

Project Duration Oct 1, 2011to Sept 15, 2014 with no-cost extension to Sept 15 2015.

Deliverables achieved:

1) *Wisconsin Irrigation Scheduling Program (WISP 2012* was completed and beta-tested by growers in 2012 and released for general use in 2013. Two UW Extension bulletins, A3600-01, Irrigation management in Wisconsin: the Wisconsin Irrigation Management Scheduling Program, and A3600-02, Methods to Monitor Soil Moisture were released in 2014. Grower training for WISP2012 was conducted in 2013/2014 including on-farm visits. WISP 2012 was modified in 2015 to incorporate canopy development curves for several vegetable crops and matching degree-days. Irrigation system status and energy conservation during peak demand periods were not completed due to proprietary concerns with commercial irrigators.

2) *Groundwater database.* A network of solar powered, continuous monitoring wells were installed in 3 nests of 8 at half mile intervals across each of 3 areas of Central Wisconsin identified as areas of concern for adverse surface water impacts from irrigation pumping. Wells were installed in 2011-2013 and record depth to groundwater at 15 minute intervals which is downloaded and posted on the Wisconsin Institute for Sustainable Agriculture website for use by agencies, modelers, growers and other interest groups. Five additional wells were added in 2015 to assist in ongoing modeling and responsibility for maintaining, downloading and posting the database was assumed by the grower association in 2015.

3) *Framework for evaluating impacts of water use on groundwater levels*. Protocols for monitoring fluctuations groundwater depths in high capacity irrigation wells on private land were developed and a database was established in 2011 which expanded to over 600 wells across 4 counties by 2015. Recordings are made 1-2 times /year and data is held by the grower association and released as needed for modeling and research. Combining GPS-based data on groundwater depths will allow for future GIS analysis of relationships between groundwater fluctuations and land use and cropping patterns which will be needed to create water management evaluation criteria. Funding of this initiative was assumed by the grower association at the conclusion of this project.

4) *Structure for groundwater management*. A white paper "Sustaining Central Sands Water Resources" was completed and released in 2014 which, for the first time, brought together all existing scientific knowledge on the hydrology and agricultural practices of the Central Sands. In-depth studies of the

stratigraphy of sensitive areas and its relationship to the interactions between groundwater and surface water were conducted in 2013-2015 in collaboration with the Wisconsin Geological and Natural History Survey. Data will be crucial for creating decision tools for future ground water management.

5) Management plan for spring runoff and drainage districts in Central Wisconsin. A modeling study was conducted in 2014 in collaboration with WGNHS to examine scenarios involving modifications of the drainage systems in the Central Sands and the potential impacts on groundwater recharge.

6) *Revised nutrient management system*. On-farm demonstrations with cooperating growers to showcase the benefits of slow release fertilizers and manure (digested) as nutrient sources with the potential to reduce nutrient leaching to groundwater were conducted in 2012-2014 on potato, sweet corn, and green beans. Data will be used to revise Nutrient Management Plans to prevent losses.

7) *Perennial cover crop management system*. Commercial scale evaluation alfalfa and sweet clover cover crops grown as companion crops for sweet corn were completed in 2013/2014 and results were communicated to growers and processors.

8) *Modification and creation of NRCS practice standards and technical references*. Results generated in this project will be incorporated into NRCS technical notes in Agronomy (7 – cover and green manure crop benefits to soil quality),Conservation Planning (1 – nutrient management) and practice standards 340 Cover Crop, 449 Irrigation Water Management, 554 Drainage Water Management, and 590 Nutrient Management(includes specific criteria for irrigation, nutrient, and manure management).

9) *Reporting.* Semi-annual reports, final report, new technology fact sheets and other materials were provided.

Table of Contents:

Executive Summary

***a)Designated NRCS priorities*:** Results generated in this project will be incorporated into NRCS technical notes in Agronomy (7 – cover and green manure crop benefits to soil quality),Conservation Planning (1 – nutrient management) and practice standards 340 Cover Crop, 449 Irrigation Water Management, 554 Drainage Water Management, and 590 Nutrient Management(includes specific criteria for irrigation, nutrient, and manure management).

b) Goals and objectives:

Objective 1: Implementation of improved irrigation scheduling programs

Step I: Evaluating soil moisture sensors to improve irrigation scheduling

Step 2: Developing, refining and training users of the Wisconsin Irrigation Scheduling Program (WISP-2012)

Step 3: Refining WISP-2012 to enhance capabilities and broaden potential utility in other regions

Step 4: Reducing water use through deficit irrigation

Step 5: Reducing water use through drip irrigation

Step 6: establishing a baseline of current irrigation practices to identify ways to improve performance

Objective 2: Coordinated Monitoring of depth to ground water and its relationship to stratigraphy and land use patterns

Step 1: Reviewing the research base underlying water resources in the Central Sands

Step 2: Expanding understanding of the interconnection between groundwater and surface water in lakes located in irrigated agricultural areas - Long Lake

Step 3: Establishing a database to document fluctuations in depth to groundwater in the Central Sands

- Water levels in irrigation wells on private lands:
- Water levels in sensitive areas at risk of surface water impacts:
- Consolidating the existing databases recording fluctuations in groundwater depth into a single-source reference to examine potential relationships with climate, irrigation, land use and crop landscapes

Objective 3: Management of water fate from drainage districts

Objective 4: Implementation of nitrogen management strategies that incorporate manure, slow release fertilizers and perennial legume cover crops

c) Accomplishments-summary (by objectives)

Objective 1: Implementation of improved irrigation scheduling programs

Step I: Evaluating soil moisture sensors to improve irrigation scheduling

- 2013/2014, demonstrated commercially available soil moisture sensors to growers in side-by-side comparisons at 2 field days/ year and presented comparison data at state and area grower meetings
- 2013/15, used capacitance sensors to schedule irrigation on multiple crops on the Hancock Experiment station in comparison with WISP-2012 and demonstrated excellent correlation
- 2014, used multiple tensiometers to track soil moisture in a commercial potato field that had been mapped pre-season for differences in moisture-holding capacity and demonstrated excellent correlation with grower-operated irrigation scheduling program (WISP-2012). This is an important step in confirming the potential of pre-season soil conductivity mapping as a basis for variable-rate irrigation.
- 2014, showcased recent advances for monitoring soil moisture at variable depths in real time video presentations to large, mixed agricultural and general public audiences at the 3-day Farm Technology Days in Central Wisconsin.
- 2014, launched a new website, "Understanding Crop Irrigation" in the UW Department of Biological Systems Engineering featuring 2 new UWEX publications: A3600-02; "Methods to Monitor Soil Moisture" and A3600-01, Irrigation Management in Wisconsin, the Wisconsin Irrigation Scheduling Program (WISP-2012). Content updated annually as new information becomes available.
- 2013-15, conducted multiple field days, walking tours, demonstrations and gave presentations at area and statewide educational meetings to promote soil moisture measurement technology with growers.

Step 2: Developing, refining and training users of the Wisconsin Irrigation Scheduling Program (WISP-2012)

- 2013/14, released Wisconsin Irrigation Scheduling Program WISP-2012 for beta-testing with growers in 2013 and, after modification, released for general use in 2014 and made available to commercial software developers in 2015
- 2012-15, demonstrated a close correlation between WISP-2012 predictions of soil moisture and actual soil moisture measured by both capacitance sensors on HARS and tensiometers in a commercial field, confirming the accuracy and utility of WISP-2012
- 2013/14, conducted statewide irrigation workshops for growers and Extension professionals together with on-farm visits to increase adoption of WISP-2012.
- 2014/15, conducted irrigation practices assessment, completed by 90% of growers, to establish a baseline of practices that could be used to promote new practices and measure improvement over time. Currently working with DNR to use practice assessment to incentivize irrigation best management practices.

Step 3: Refining WISP-2012 to enhance capabilities and broaden potential utility in other regions

- 2014/15, developed crop canopy development coefficients for multiple crops and incorporated into WISP-2012 to create greater accuracy and wider applicability through crop-specific WISP modules.
- 2015, correlated heat unit accumulations with canopy development and incorporated into WISP-2012 to streamline crop canopy prediction for growers.

Step 4: Reducing water use through deficit irrigation

- 2012-2014, conducted deficit irrigation studies on green beans, potatoes and sweet corn at HARS by comparing a standard irrigation regime (managed by WISP-2012) with a regime applying 25% less water season long using the same schedule.
- Green bean yields were significantly reduced and deficit irrigation on this short season crop would not be economically feasible
- Potato yields were reduced under deficit irrigation but reductions were less than anticipated, particularly for russet varieties and it was concluded that further research should be conducted on varietal differences, timing of deficits and economic impacts before this practice could be recommended for water conservation on potato
- Sweet corn yields were not negatively impacted by deficit irrigation and many varieties yielded higher, with better recovery, when grown under deficit conditions. It was concluded that deficit irrigation could be implemented on sweet corn in Central Wisconsin to conserve water without economic loss.

Step 5: Reducing water use through drip irrigation

- 2013-14, drip irrigation studies on the HARS demonstrated that potatoes could be grown with up to a 25% reduction in applied water without sacrificing yield or quality by delivering water more efficiently to the root zone and eliminating waste. However, until water becomes more limiting or more highly regulated, it is likely that overall yield rather than irrigation water use efficiency will influence water application rates.

Step 6: establishing a baseline of current irrigation practices to identify ways to improve performance

- 2014/15, an industry-wide assessment of irrigation practices was conducted to identify key drivers of irrigation efficiency and create a baseline of practices that growers are using against which improvements can be measured over time. The assessment was completed by 90% of growers and encompassed 185,000 acres.

Objective 2: Coordinated Monitoring of depth to ground water and its relationship to stratigraphy and land use patterns

Step 1: Reviewing the research base underlying water resources in the Central Sands

- To underpin our research activities in this project, a comprehensive White Paper was written and released in 2014 which, for the first time, brought together all of the relevant hydrological and agricultural science impacting the region into one reference (Kniffin et al 2014, http://wisa.cals.wisc.edu/central-sands-white-paper)

Step 2: Expanding understanding of the interconnection between groundwater and surface water in lakes located in irrigated agricultural areas - Long Lake

- In 2012-2014 a study conducted in collaboration with the Wisconsin Geological and Natural History Survey investigated the hydro-stratigraphy around and beneath Long Lake and its effect on surface water connection to the regional aquifer. This study demonstrated that silt/clay deposits are associated with channel tunnel lakes such as Long Lake and that they can act as aquitards. However, the silt/clay deposits were not continuous and did not impede groundwater connections to the lake.
- In 2014-2015 a more extensive investigation was conducted in collaboration with the WGNHS which used ground-penetrating radar in conjunction with multiple-depth piezometers to examine the distribution of silt/clay deposits across central Wisconsin. Preliminary results indicate that silt/ clay deposits are present throughout the Central Sands with greatest frequency in the southern and western areas. These results were used in a separate, DNR-funded modeling study in the Little Plover River area and are currently being used as an alternative mechanism to measure aquifer recharge.

Step 3: Establishing a database to document fluctuations in depth to groundwater in the Central Sands

Water levels in irrigation wells on private lands:

- In 2011 University of Wisconsin researchers, working in collaboration with the Wisconsin Potato and Vegetable Growers Association launched an initiative to establish a database in which the depth to groundwater was recorded in high capacity irrigation wells. The data base has grown annually as the value of documenting fluctuations in groundwater depth across space and through time was recognized and by 2015 encompassed over 600 high capacity wells across 4 counties. The potential to enhance the accuracy of hydrological modeling and improve the effectiveness of water conservation strategies was evident in the incorporation of private well data into an ongoing WGNHS modeling project for the Little Plover River in Portage County. This study, funded by the Department of Natural Resources, will be instrumental in developing future water management strategies throughout the region.
- In 2014-15, the WPVGA, working with an independent hydrological consulting company, used the database to compare current static water levels in 58 Portage County irrigation wells with the levels that were recorded when they were originally drilled from 2-57 years previously. This study revealed that high capacity well pumping in Portage county has not adversely impacted aquifer storage over extended time periods as the static water levels measured in 2014 were relatively consistent in comparison to levels when they were drilled with 37 wells showing higher static water levels compared to 18 which were lower.

Water levels in sensitive areas at risk of surface water impacts:

- In 2011-2015 a network of 28 monitoring wells was installed in 3 areas where concerns existed over impacts of irrigation on surface water (the Little Plover River, Long Lake and Pleasant Lake) to continuously monitor fluctuations in depth to groundwater. Nests of 8-12 wells were installed in transects across each area and groundwater depths are recorded at 15 minute intervals and posted on the UW Institute for Sustainable Agriculture website (http://wisa.cals.wisc.edu/central_sands_water). Data is used by agencies and researchers for modeling and water management and to increase awareness of growers and concerned citizens. In 2015, at the conclusion of this project, the growers association assumed the responsibility of maintaining this network and posting the data on the public website.

Consolidating the existing databases recording fluctuations in groundwater depth into a single-source reference to examine potential relationships with climate, irrigation, land use and crop landscapes:

- In 2013-15 the project directed resources to consolidate these private and public databases, together with other state and federal data, into a single-source reference which will enable agencies, land owners and researchers to begin to examine the complex inter-relationships between groundwater and surface water fluctuations. A broad palette of potential interacting factors, which may include climate, irrigation, industry, urbanization, agricultural productivity and diversity, crop landscapes, forestation and topography, will be examined using satellite-generated crop and land use data layers which are increasing in scope and accuracy. The grower association assumed funding of this activity at the conclusion of this project.

Objective 3: Management of water fate from drainage districts –

- In 2014-15 the project collaborated with the WGNHS to evaluate the overall impact of the existing drainage ditches in southeast Portage Co. on the surrounding groundwater-levels using two steady-state groundwater flow models(pre- and post-ditch). A comparison of water-levels simulated by the two models, under 6 scenarios in which varying levels of re-charge and hydraulic conductivity were tested, then provided an indication of the magnitude of potential water-level changes that could be caused by drainage system modifications. The results of the modeling suggest that most of the impact of damming or modifying the ditches would be felt near to the ditches and thus new changes to the system are likely to be felt locally as well. This suggests that any water management strategy intended to change the drainage system in some way should be focused near the area where the change is desired.

Objective 4: Implementation of nitrogen management strategies that incorporate slow release fertilizers and perennial legume cover crops

Slow-release fertilizers:

- Three years of on-farm trials in 2012-2014 demonstrated that slow release N sources such as ESN can be used on sweet corn and field corn to reduce applied N on irrigated sandy soils by replacing soluble N, which can be lost due to leaching, with N released later in the season, without sacrificing crop yield. By protecting N from leaching as a result of early season high rainfall events and releasing N later when the plants need it, slow release N sources can significantly reduce N movement to groundwater and improve water quality. Caution is urged however before applying the majority of N in early season applications of slow release formulations such as ESN to potato because leaching events cannot be predicted and if they do not occur (as seen in 2012), the N need may be overestimated and excess N may be applied resulting in economic loss.

- Studies conducted in 2013-14 demonstrated that timing of N release from slow release formulations was temperature dependent and soil temperatures below 66 degrees decreased the amount of N released in mid-season.
- Studies in 2013-14 also demonstrated that slow release formulations can be damaged during handling and application and can significantly reduce the release period of N and the effectiveness of the formulation.
- Our results indicate that for crops with maturity lengths of 100+ days such as field corn or long season potatoes, slow release formulations can be used effectively if consideration is given to factors that can impact N release rates. For crop maturity lengths of 70-100 days such as short season potatoes or sweet corn, slow release formulations would be best applied at the earliest opportunity, preferably pre-plant, especially if these formulations are incorporated or the field is in no-till. Side-dress application of slow release formulations would still be an option for these crops but its efficacy may be reduced by damage in handling or high soil temperatures. Slow release fertilizers such as ESN are not a good option for crops that mature before 70 days such as green beans or green peas, unless the field is double cropped.

Perennial cover crops:

- In 2013, a perennial cover crop demonstration using alfalfa and sweet clover as pre-season cover crops prior to sweet corn that were carried over as companion crops in the sweet corn, enhanced yields compared to control strips with no cover crop. These data demonstrated that deep rooted, perennial legume cover crops grown as a companion with sweet corn can be an effective way of intercepting N leached below the sweet corn root zone which would improve water quality. Since the legumes also fix N there would be an added benefit to the sweet corn from the N credits which could reduce N rates further.

d) Accomplishment of objectives/barriers

The major goals and objectives of this project were successfully completed with the following exceptions:

- The 2011-12 perennial cover crop with sweet corn was not completed when processor switched fields.
- Center pivot energy monitoring and output were not incorporated into WISP-2012 due to commercial proprietary considerations but space in the program is available for later addition

- Monitoring wells were not installed to monitor the impacts of damming drainage ditches and modeling was substituted
- On- Farm manure trials were not accomplished due to cooperator concerns and emphasis was placed on small scale trials focused on P management in vegetable crop rotations
- PI Dr AJ Bussan left the UW during the grant period causing delays in implementation but Dr Russell Groves assumed the leadership and successfully completed the grant objectives after being granted a 12 month no-cost extension.

e) Completion timeframe

- A 12-month no-cost extension was requested and granted following a change in Principal Investigators.

f) Customers that benefit from grant

- Approximately 80 irrigated vegetable growers farming 150,000 acres of specialty crop potatoes, sweet corn, green beans, peas, carrots, cucumbers and rotation crops (field corn and soybean) in the Central Sands will benefit from this grant. Food processors and several large dairy farms will also benefit.

g) Project funds spending.

- The mid grant change of PIs caused delays necessitating a no-cost extension and resulted in greater allocation of budget to collaborating graduate students and technical assistance in 2014-15 to complete specific objectives. However, overall budget category allocations were maintained.

h) Methods used to demonstrate alternative technology.

- 2012-14: 2 field days/year at Hancock Agricultural Research Station, demonstrating new technologies
- 2012-15: 4-5 presentations/year at local, area and State grower meetings highlighting water conservation
- 2012-15: on-farm demonstrations highlighting slow release fertilizers, manure, cover crops and irrigation technology.
- 2014: Moisture sensor demonstrations at Wisconsin Farm Technology Days
- 2014-15: Small group and on farm training providing hands-on demonstration of irrigation scheduling.
- 2012-15: 1-2 field tours/year to farms, streams and lakes to demonstrate new technology.

i) Quantifiable physical results

The following physical results were obtained for the following objectives

- Objective 1, steps 2-3: the release of WISP-2012 and correlation of predictions with soil moisture
- Objective 1, steps 4.5: yield and quality responses of potatoes, sweet corn and green beans to deficit irrigation
- Objective 1, step 6: a baseline of irrigation practices used by growers.
- Objective 2. Step 1: Release of the white paper reference for hydrology and agricultural research in Central Wisconsin
- objective 2 , step 2: soil cores and ground- penetrating radar showing distribution of silt/clay layers in the Central Sands
- Objective 2, step 3: two databases with actual depth to groundwater over time in irrigation wells and monitoring wells.
- Objective 3, pre drainage and post drainage steady state models of groundwater in the Central Sands
- Objective 4, slow release N: Yields and quality data from potatoes and sweet corn using slow release nitrogen fertilizer; soil temperature and damage impacts on N release from slow release fertilizer.
- Objective 4, Perennial cover crops: sweet corn yield data when grown with alfalfa and sweet clover cover crops.

j) Economic results

- No economic analyses were conducted for this project

k) Federal, state and local programs to implement the project

- Federal: NRCS program staff through modifications in standards and procedures in identified priority areas
- State: University of Wisconsin Extension specialists in conservation and agriculture areas, NRCS State staff
- Local: Extension County Agents, County Conservationists

l) Major recommendations

1) Use WISP-2012 to schedule irrigation

2) Use soil moisture sensors in conjunction with WISP-2012 to track in-field variability in water holding capacity as a prelude to variable rate irrigation

3) Conduct further research on deficit irrigation of potato focusing on deficit timing and variability between varieties

4) Evaluate deficit irrigation of sweet corn in field scale trials to hasten implementation. This practice can conserve water and reduce leaching.

5) Avoid deficit irrigation on short season green beans and peas.

6) Use baseline irrigation practices assessment to identify practices that will increase irrigation efficiency, promote these practices and set goals for continual improvement.

7) Continue monitoring fluctuations in depth to groundwater in high capacity irrigation wells and monitoring wells in sensitive areas and use these databases to increase public awareness, improve modeling , and plan water management strategies.

8) Investigate impacts of damming drainage ditches close to stream headwaters to increase groundwater recharge

9) Implement use of controlled release N in long season crops such as potato and field corn with consideration of factors that can impact release rates such as physical damage during application and soil temperature.

10) Implement use of controlled release N early in the growing season on 70-100 day crops such as sweet corn to increase yield and reduce leaching.

11) Do not use controlled release N on short season crops that mature before 70 days such as green beans unless these are double cropped.

12) Continue field demonstrations of perennial cover crops grown as companion crops with sweet corn.

Introduction

Central Wisconsin contains one of the most productive potato and vegetable growing regions in the United States and around the globe. Within a seven county area, irrigated vegetables are produced on 75,000 to 85,000 ha with approximately 22,000 ha potato, 22,000 ha snap bean, 7,000 ha green peas, 25,000 ha of sweet corn and 3,000 to 5,000 ha of other irrigated vegetables (includes cucumbers, carrots, red beets, and other crops). The Central Sands soils are comprised of stratified sand and gravel and are ideal for producing high quality crops with consistent yield using irrigation. Nearly all of the irrigation water in Central Wisconsin is derived from groundwater contained in an 80 to 200 foot thick aquifer that is easily accessible within 5 to 40 feet of the soil surface.

Recently, the impacts of irrigation on the groundwater aquifer have become increasingly scrutinized. In part, this has been triggered by observed declines in surface water levels in streams and lakes throughout the region and declines in water quality resulting from leaching. Such impacts on the water resources have led to increasing tension and conflicts between agriculture and other users who rely on water for drinking and recreation. These conflicts have escalated politically and the prospect of regulatory action to manage the water resources of the region is imminent.

Maintaining the long term sustainability of the water resources of Central Wisconsin is consequently important for all users. This project was initiated with two primary goals: a) improving the efficiency of irrigation to conserve water by reducing unneeded applications and reducing consumptive water use through deficit irrigation; and b) improving water quality through alternative technologies that can alleviate leaching of nitrogen to groundwater.

The scope of this project included: modeling groundwater systems; developing new computer software; establishing protocols to monitor fluctuations in groundwater depth and maintaining databases for private high capacity wells and continuous monitoring wells in high risk areas; conducting small plot research and large scale, on-farm demonstrations of conservation practices; demonstrating new technologies to farmers and the general public; surveying industry-wide irrigation practices; training growers in adopting new technologies; writing new technical bulletins; and conducting local , area and statewide educational programs.

To address the broad scope of these goals, the resources, expertise and knowledge of the University of Wisconsin was enlisted as follows:

- In hydrology and modeling of groundwater systems, the Civil and Environmental Engineering Department of Water Resources Engineering (Potter), the USGS (Hart), the Wisconsin Geological and Natural History Survey (Bradbury) and graduate students (Kniffin , Sellwood).
- In soil moisture, irrigation technology and computer applications, the UW Department of Soil Science (Bland, Wayne, Kaarakka) and graduate students (Mingwei, Vanderleest), the UW Dept of Biological Systems Engineering (Panuska, Sanford, Newenhouse).
- In soil fertility, UW Dept of Soil Science (Ruark , Naber)
- In Crop science, UW Dept of Horticulture (Bussan, Drilias, Schmitt, Knuteson) and graduate students (Page, Miller), UW Dept of Agronomy (Lower, Conley)
- In monitoring, UW Dept of Soil Science (Naber)
- In management and administration (Wyman, Bussan, Horticulture and Groves, Entomology).

These scientists from the University of Wisconsin academic departments and affiliated programs are all recognized authorities with multiple years of experience, demonstrated expertise and numerous peer-reviewed publications in the hydrogeological and agronomic fields examined in this project.

In addition to the University of Wisconsin, the successful completion of this project was dependent on the active collaboration and participation of the growers of Central Wisconsin through their professional associations, the Wisconsin Potato and Vegetable Growers Association (Houlihan) and the Midwest Food Processors Association (George). These associations actively participated in all phases of this project and supported its goals through the Joint WPVGA/MWFPA Groundwater Task Force.

The long-standing partnership between the University of Wisconsin researchers and extension specialists and the potato and vegetable growers and processors was ideally suited to this project. Growers and processors were actively engaged in all aspects of the project and were essential components in planning, execution, demonstration and implementation phases. The grower and processor associations provided matching funds in the form of cash and in kind contributions without which the project could not have been completed. In addition, the growers directly funded critical research on the hydrology of the Central Sands which was not initially included in the project but which will be essential for future water management activities. Many of the project objectives have been assumed by the growers at the conclusion of this grant to insure that the goals continue to be met.

Background

This project was initiated to focus on 2 primary goals, water quantity (availability and long term sustainability) and water quality. The groundwater aquifer underlying the Central Sands is the essential underpinning for a nationally important potato and vegetable processing industry valued at over $6 billion which relies on the aquifer for irrigation. The groundwater is also connected with surface water streams and lakes which are essential for living, drinking water, recreation, municipal use, rural communities and industries. Therefore, for all of these water users, the long term sustainability of the groundwater and surface water resources is of critical concern. This project was initiated to address the concerns of all user groups by developing approaches to water management which will maintain the long-term sustainability of the aquifer and protect the quality of its water, thereby preserving the thriving agriculture of the region and meeting the needs of all of its citizens.

In the years preceding this project, attempts have been made to bring all of the concerned parties together to discuss potential solutions and arrive at a consensus for directing water management. Four citizen forums were organized in 2010-11 by University of Wisconsin Extension Specialists and held in Central Wisconsin. These were preceded by 4 symposia focused on the science of water management to bring together the existing knowledge in hydrology and irrigated agriculture. The symposia and citizen forums were well attended and agreement was reached that a program was needed that would: protect the surface water and groundwater resources; restore waters that had already been impacted; and maintain a vigorous and productive irrigated agricultural industry. However, the participants failed to reach consensus on how these outcomes could be achieved. The status-quo endured and escalated into the political arena where the Department of Natural Resources was charged with developing protocols for water management. An intensive modeling project was funded and conducted by the Geological and Natural History Survey in the Little Plover River watershed (2014-15) to examine management scenarios that would address concerns which could be adopted across the region.

This CIG project was initiated to expand the hydrological and agricultural knowledge base for the Central Sands that could be used by growers and agency professionals to develop effective water management solutions.

If effective solutions, which address both agricultural and community concerns, are not developed and implemented, the integrity of the groundwater aquifer will be negatively impacted in terms of its quality and long term sustainability, the surface waters will continue to be impacted through reduced lake levels, lowered property values, reduced stream flows and negative impacts on fish populations , and the future productivity of one of the nation’s leading specialty crop production areas will be threatened.

Review of methods and discussion of quality assurance

Methods, procedures and quality assurance are incorporated into the following section of this report, which enumerate the results and findings of the project discussed under specific objectives.

Findings and Results

Objective 1: Implementation of improved irrigation scheduling programs

Irrigation of agricultural crops (40%) and municipal public water use (37%) are the primary users of groundwater resources in Wisconsin and while there are many established programs to conserve municipal water use there are few such programs in agriculture. Additionally, the use of groundwater resources to irrigate crops has increased steadily since the 1950s (less than 100 high capacity wells) to the present with over 3000 high capacity wells in operation statewide. 43% of these wells, irrigating potato and vegetable rotations are located in central and north western Wisconsin and therefore developing practices which increase the efficiency of irrigation and use less water and encouraging their adoption by farmers was a primary objective of this project. This objective had 6 interlinked steps:

Step I: Evaluating soil moisture sensors to improve irrigation scheduling

The effectiveness of irrigation scheduling, which seeks to match water availability to crop need, is dependent on the ability of the scheduling tool to predict water availability in the root zone using external atmospheric data and soil characteristics. Directly measuring soil moisture fluctuation in space and time and using this information to refine and improve scheduling decisions is a rapidly expanding technology in agriculture and this project examined several approaches:

- The most widely commercially available soil moisture sensors were compared in side-by-side, season-long comparisons on potato and processing vegetable crops on the Hancock Agricultural Experiment Station (HARS) in 2013-2015 and demonstrated to growers at 2 field days/year. Performance data was shared with growers at multiple area and statewide educational meetings (4-5/year) (Laporte and Panuska, 2015)
- 20 fixed location capacitance sensors were installed in multiple crops (potatoes, green beans, sweet corn, soybeans and field corn) on the HARS and used over 3 years (2013-2015) to schedule irrigation in comparison with the newly released Wisconsin Irrigation Scheduling Program (WISP-2012, see Objective 1, step 2). Data shows that WISP-2012 predictions were highly correlated (within 1-2%) with actual soil moisture measurements. Comparisons were shared with potato and processed vegetable growers at 3-4 educational meetings each year (Wayne and Panuska, 2015)
- In 2014, soil moisture was monitored in a commercial, center-pivot irrigated potato field (Coloma farms) using soil tensiometers (Hortau, Inc) to track moisture fluctuations in areas with differing soil characteristics and comparing actual soil fluctuations to soil depletion and recharge predicted using the WISP-2012 irrigation scheduling program. Sensors were placed in 3 areas of the field which had been designated as "wet, mid or dry" based on electrical conductivity and elevation which were mapped prior to planting to indicate in-field differences in soil water holding capacity (Precision Water Works, Plainfield WI). At each location tensiometers were placed at 15, 30 and 40 cm. Irrigation was scheduled using WISP-2012 (see step 2) moisture predictions and compared with actual soil moisture determined by sensors. Soil moisture content fluctuations were generally in agreement with WISP-2012 predictions providing further proof of the accuracy of WISP-predictive capabilities. At this site, in- field

variability in moisture holding capacity could not be used for site-specific irrigation across the field since the center pivot was not equipped for variable rate applications. Soil samples were taken at harvest from the areas designated as wet, mid and dry using pre- planting soil electrical conductivity measurements and characterized for topsoil thickness, bulk density, texture, carbon concentration and total carbon stock. The soil characteristics, which appeared to be similar by visual estimates between sites, closely matched the pre-season characterizations. Topsoil thickness (25.5cm-26.5cm) did not vary significantly between sites and bulk densities were similar (1.52-1.58Mg/m3) but soil texture, designated as loamy fine sand across the field, was highest in sand (86%) and lowest in silt (6% and clay (8%) in the dry site while the wet site was lowest in sand (79.9%), and highest in silt (11%) and clay (9%). The mid site was intermediate. These soil textures were reflected in carbon concentration with the dry site having significantly less carbon (6g/kg) than the wet site (18g/kg) with the mid site being intermediate (10g/kg). Similar differences were seen in total carbon stock with 23.5, 48.2 and 75.0 Mg/ha in the dry, mid and wet sites, respectively.

- Yields were taken adjacent to each set of sensors to detect plant responses to water availability. Total marketable yield (tubers>4 oz.) in the mid-site was significantly higher (57278kg/ha) than in the dry site (51171kg/ha) and the wet site (41277 kg/ha) where yields were lowest.
- These data clearly showed that differences in soil water holding capacity can vary significantly across a field that looks visually similar and these differences can translate into significant yield differences. The ability to use pre-season soil mapping of water holding capacity using electrical conductivity was effectively confirmed and the differences across the fields could be tracked accurately with soil moisture tensiometers which matched closely with predictions from the irrigation scheduler, WISP-2012. This relationship between remotely sensed, in-field variability and actual moisture level differences across fields is critical to the success of variable-rate irrigation technologies which are being actively pursued by growers in Central Wisconsin. These commercial demonstrations were continued in 2015 and the results will be presented to growers at the 2016 Statewide Potato Educational Meetings in February 2016.
- In August 2014, Wisconsin Farm Technology Days, a statewide agricultural show featuring the latest advances in technology which is visited by a broad cross section of farmers and the general public, was held on a Central Wisconsin potato/vegetable/vegetable farm, presenting the opportunity to showcase recent advances in soil moisture monitoring and irrigation technologies. A comprehensive exhibit featuring a range of soil moisture sensors linked to video displays was presented allowing farmers to track water infiltration through the soil profile in real time. The Aqua Spy sensor recorded fluctuations in moisture at 4 inch intervals to 48 inches and following a significant rain event, viewers were able to follow the rapid infiltration of moisture in sandy soil. An adjacent well installed by the Wisconsin Geological and Natural History Survey showing fluctuations in the groundwater aquifer at 20 feet was able to detect the passage of the soil wetting front recorded by the Aqua-Spy probe at 0-4 feet to the groundwater within 24 hours.
- A new UW Extension website titled “Understanding Crop Irrigation” was completed in 2014 by the Department of Biological Systems Engineering to increase outreach and showcase the

activities of the CIG.(available at: http://fyi.uwex.edu/cropirrigation/). The site was updated with significant data additions in 2015.

- In addition to field days, walking tours, demonstrations and presentations at statewide and area potato and vegetable meetings, a new UW Extension Bulletin and grower guide on using and interpreting soil moisture sensors was released in 2014. Methods to Monitor Soil Moisture, UWEX Publication A3600-02, is available without charge at: Learning Store .uwex.edu (Panuska, etal, 2014). A second UWEX publication titled "Irrigation management in Wisconsin – the Wisconsin Irrigation Scheduling Program WISP", A3600-01, was also updated in 2014 to reflect current technological trends. These new publications are available at: http://fyi.uwex.edu/cropirrigation/soil-moisture-management/

Step 2: Developing, refining and training users of the Wisconsin Irrigation Scheduling Program (WISP-2012)

Wisconsin potato and vegetable growers have relied previously on a long standing, stand-alone irrigation scheduling program (UWEX publication A3600) to schedule irrigation applications and match them to crop need. This manual pencil and paper-based approach, while still effective, was not user friendly, did not employ many of the features of modern irrigation systems and was used by few growers. A complete redesign of the scheduler to incorporate features requested by growers and increase its use was thus a high priority of this CIG.

- In 2012 an on-line version incorporating grower requested features was designed and released by specialists in the departments of Biological Systems Engineering and Soil Science. The new program, Wisconsin Irrigation Scheduling Program (WISP-2012) was beta –tested by several growers in 2012, modified in response to grower comments and released as a fully operational program in 2013 (Panuska and Wayne, 2014). Refinements suggested by growers continue to be incorporated as needed. The program code was made available to commercial software developers (eg AgConnections) for incorporation into existing farm management programs which are widely used by growers but no commercial programs have been released to date.
- In-field performance of WISP-2012 and the correlation of predicted ET and soil moisture depletion with actual soil moisture fluctuation as measured by moisture sensors was tested on multiple crops grown on the HARS over 3 seasons (2013-2015) and demonstrated a close relationship (see Step 1)
- Sharing WISP-2012 with growers to encourage broader use has been accomplished through general grower education meetings, a new irrigation website (http:/fyi/uwex.edu/cropirrigation/) and a series of specific irrigation workshops conducted in 2014. These irrigation workshops were statewide (Hancock, Spooner, Rice Lake, Bloomer and Durant) and attracted over 60 farmers. However, experience indicated that there was still a barrier between classroom training and on-farm use. This was addressed in 2014 by offering growers on-farm training using farmer equipment.
- An assessment of grower irrigation practices conducted in 2014 indicated that, although a majority of growers use some form of irrigation scheduling, WISP-2012 is currently used by only

a small percentage of the industry and the Wisconsin Potato and Vegetable Growers Association is currently seeking ways to increase usage.

Step 3: Refining WISP-2012 to enhance capabilities and broaden potential utility in other regions

WISP-2012 is effective in estimating evapotranspiration from crop canopies when full ground cover is achieved and was designed to follow crop canopy development through the season based on an original model developed for potato and visual estimates provided by growers. Since crop canopy development varies greatly between crops and even between varieties, comprehensive canopy development measurements (based on leaf area index measured with a LI-COR LAI2200) were taken weekly from emergence to full canopy on a range of vegetable and agronomic crops to develop crop-specific canopy coefficients for incorporation into WISP-2012.

- Protocols were developed in 2012 and measurements were taken in 2013 and 2014 at the HARS and in commercial fields. Measurements were taken in potatoes (6 varieties encompassing both short and long season types), green beans (early and late plantings), sweet corn, field corn, soybeans and carrots. Crop-specific canopy cover coefficients were calculated and will be incorporated into WISP-2012 in the very near future. This refinement is intended to increase the accuracy of ET estimation in crops other than potato and broadening the applicability of WISP-2012 to other production areas.
- Crop canopy growth is heat unit-dependent and in 2014 heat unit accumulations were calculated for each crop where leaf area index was measured and canopy development was linked to heat unit accumulation. Degree day-based crop canopy growth functions will be incorporated into WISP-2012 in the very near future. It is anticipated that the degree day growth functions will reduce the need for grower estimation of canopy cover and increase the user friendliness of the program. The processed vegetable industry use degree days to determine planting and harvest dates for green beans, sweet corn and green peas and the linkage to canopy development and ET will be readily adaptable by processed vegetable growers and lead to improved irrigation efficiency.
- Technological advancements in irrigation equipment with variable rate irrigation, remote control of water application, energy conservation, variable rate pumping and others are occurring rapidly. The on-line format of WISP-2012 is flexible and space has been reserved in the program code to add additional parameters to utilize the energy conservation potential of new technologies. These parameters were not added during this project and additional programming time would be required to accomplish this goal. The competitiveness among irrigation companies and the rapid expansion of farm management software pose additional barriers to incorporation of public domain software into WISP-2012.
- A summary of the activities and reports under objective 1, steps 1-3 is appended as Appendix 3.

Step 4: Reducing water use through deficit irrigation

Introduction and procedures. The impacts of different irrigation regimes, where water is withheld at different stages of crop development, differ between crops and even varieties. In potatoes and processing vegetables the timing of reductions in irrigation is considered to be critical with impacts on crop yield and quality greatest when water is reduced during crop maturation and bulking. In this project we examined the impacts of reducing irrigation during post flowering and crop maturation in 2013 and for the whole growing season in 2014 and 2015 for a representative selection of commercial varieties of potato, green bean and sweet corn (Bussan etal, 2014). Plots (4 rows, 15-18 ft) were arranged in a factorial design with 4 replications (reduced to 3 as noted due to crop emergence problems) at the HARS for 3 years (2013-2015)using standard fertility and pest management practices. Two overhead irrigation regimes were examined. "normal irrigation" was managed by WISP-2012 and monitored with capacitance soil moisture sensors. In 2013, deficit irrigation regimes were created on July 24 by re-nozzeling the sprinkler package to deliver 75% of the water volume applied to the normal irrigation plots using the same schedule. The regimes were maintained through vine kill for potato (approximately 6 weeks) and through harvest for green beans and sweet corn. The period of deficit irrigation covered tuber bulking in potato, and the entire season for green beans and sweet corn which were planted later. Yields and quality evaluations were taken at harvest. In 2014 and 2015, the experiment was repeated using the same specifications except for irrigation which again compared normal irrigation with deficit irrigation (75% of normal) but with deficit irrigation applied season- long. This adjustment allowed us to examine the impacts of a greater reduction in water applied over a longer period of time.

2013 results, potato. In 2013, 7 round white chipping varieties (Lamoka, Megachip, Nicolet, Snowden, FL 01, FL 02 and FL 03 and 7 russet types (Bannock, Burbank, Goldrush ,Innovator, Norkotah, Silverton and Umatilla) were compared with planting on May 8, vine kill on Sept. 13 (chipping varieties) and Sept 18 (russets) and harvest on Oct. 8.The impact of a 25% irrigation deficit during tuber bulking (4.5 inches under normal irrigation vs 6.5 inches under deficit) were less than expected from the literature. Round white chipping varieties averaged an 8.3 % decrease in total yield (586 cwt/acre across all varieties) in the deficit irrigation plots and this average yield was significantly lower (5% level). Differences between irrigation regimes among individual varieties were not significant. Nicolet (13% reduction) and Snowden (10%) showed the highest yield reductions in response to deficit irrigation while Megachip (1.9%) and Lamoka (2.6%) were impacted to a lesser extent.

Impacts of deficit irrigation on russet types (which normally mature over longer time frames) was surprisingly lower than chipping types with average reductions in total yield across all varieties of 5.6% compared to normal irrigation plots which averaged 559 cwt/acre. This average reduction across varieties was not significant (5% level). Differences among russet varieties were also not significant but some varieties were impacted to a greater extent than others with Silverton (17%), Innovator (9%) and Norkotah (8.5%) impacted to a greater extent than Burbank (2.8%) and Bannock (3.3%) while Umatilla and Goldrush suffered no yield loss.). Specific gravity was not significantly impacted by deficit irrigation in 2013. Levels of reducing sugars were not significantly impacted in chipping varieties but there was a trend toward significant decreases in bud end glucose in Bannock and Burbank.

2014, 2015 procedures and results, potato. In 2014 and 2015. Experimental design was identical to 2013 with the exception of the length of the deficit irrigation period which was extended to season-long to create a greater water savings. In 2014, plots were planted on May 5, vine-killed on Sep 12 (chipping) and Sep 17 (russets) and harvested on Oct 2. Prior to vine kill in 2014 14.7 inches of water was applied to the normal irrigation plot and deficit plots received 11.0 inches (75%) for a season deficit of 3.7 inches. In 2015 the chipping breeding lines FL01, 02, and 03 were not evaluated. Plots were planted on May --, vine killed on September (chipping) and September (russets) and harvested on Sep 28. 15.5 inches of water was applied to the normal irrigation plots prior to vine-kill in 2015 and deficit plots received 11.6 inches for a season deficit of 3.9 inches.

In 2014, yield reductions in chipping varieties were again lower than expected, even with a greater deficit, applied season long. Average yields over all chipping varieties were reduced 7.2% under deficit irrigation compared to the average yield of 683cwt/acre across the same varieties under normal irrigation. This was a significant reduction (5% level) but across all varieties was less than that experienced in 2013 when the deficit only covered tuber bulking. Differences among chipping varieties in 2014 were variable with greatest reductions seen in Nicolet (20%) and Snowden (12.7%). These reductions were significant (5% level) and larger than those seen in 2013. Megachip (4.1) and Lamoka (6.3 %) were again the least impacted chipping varieties although differences were nor significant.

Yield reductions caused by season-long deficit irrigation on russet varieties in 2014 were also lower than expected and similar to the trends seen in 2013 when deficits were lower. Across varieties the average total yield reductions in deficit irrigated plots was 3.1% compared to normal irrigation which averaged 641cwt/acre. This yield reduction was not significant (5% level) and was less than seen in 2013 even with a larger deficit applied season long. Among russet varieties, Goldrush was unusual with 17.4% lower total yield under season-long deficit compared with no reduction from a lower deficit in 2013. Other russet varieties showed little (less than 3%) or no reduction in yield when less water was applied season long with the exception of Norkotah where total yield was again reduced by over 5% under deficit irrigation. As in 2013, Umatilla, Burbank and Bannock were the least impacted by deficit irrigation. Unlike 2013 when deficits were applied only during bulking, specific gravities were significantly lower for all chipping and russet varieties grown under season-long deficit irrigation. Levels of reducing sugars were not recorded in 2014.

In 2015, yields in both chipping and russet entries were lower than experienced in 2014 and responses to deficit irrigation were more variable. Average yields over all chipping varieties were reduced 10.6% compared to normal irrigation which averaged only 402.7 cwt/acre in 2015 vs 683 cwt/acre in 2014. Differences among chipping varieties in 2015 were variable with greatest reductions seen in Nicolet (17%). Lamoka (2.8%) was again the least impacted chipping variety. Across the 3 year study Nicolet (17% reduction) and Snowden (9.5% reduction) were impacted most severely by a 25% irrigation deficit while Pinnacle averaged a 4.4% increase in yield under deficit irrigation.

Yields of russet varieties in 2015 were lower than in previous years (442 cwt/acre across all varieties under normal irrigation in 2015 vs 641cwt/acre in 2014) and impacts of deficit irrigation were more severe with an average yield reduction of 13.3% across all varieties compared to 3.1 % in 2014 and 5.6%

in 2013. In 2015, Burbank (18%) and Umatilla (16.4%) suffered relatively large yield reductions under deficit which was in contrast to previous years when Burbank yields were reduced 1.9% and Umatilla was not impacted. When averaged across 3 years Bannock was also relatively tolerant of deficits with (3.3% reduction) while Silverton 13.4%) was impacted most severely. Impacts of deficit irrigation on russet varieties was less than anticipated in this trial with Bannock, Burbank, Goldrush, Innovator, Norkotah and Umatilla being under 10% when averaged over 3 years.

Conclusions, potato. Irrigation research on potato throughout the country and across different irrigation systems has repeatedly shown that deficit irrigation during tuber bulking can result in substantial yield and quality responses ranging from 15% to over 30% and yield reductions can be even greater if deficits occur during tuber initiation and early bulking. In our research over 3 years the impact of deficit irrigation were generally less than anticipated. This was seen for both chipping varieties and russet types but was particularly evident in russets where some widely grown varieties such as Burbank, Bannock and Umatilla consistently maintained yields under deficit irrigation that were close to and even higher than those under standard irrigation. Since close to 50,000 acres of potatoes are grown in Central Wisconsin and potatoes normally receive 15-19 inches of water/ acre, saving 3-4 inches of water/acre by widespread application of deficit irrigation would substantially reduce groundwater withdraws. It is recommended that further research be conducted with deficit irrigation to examine when deficits are economically feasible and identify varieties and breeding lines that need less water.

A summary of 2013-14 results with analysis is appended as Appendix 4. 2015 final results are not available at this time.

Green bean, procedures and results. Green beans have a significantly shorter growing season than other vegetable and agronomic crops with 55-60 days from planting to harvest and less than 30 days from flowering to mature pods. Thus it was anticipated that reducing water without impacting yield and quality would present a greater challenge than with other longer season crops. To test this hypothesis an experiment was conducted on the HARS for 3 years (2013-2015) comparing the impact of standard irrigation and deficit irrigation regimes on 3 commercial green bean varieties and 5 advanced breeding lines. Plots (4 rows, 15-18 ft) were arranged in a factorial design with 3-4 replications at the HARS using standard fertility and pest management practices. Two overhead irrigation regimes were examined. "Normal irrigation" was managed by WISP-2012 and monitored with capacitance soil moisture sensors. Deficit irrigation conditions were created from planting to harvest using a sprinkler package to deliver 75% of water applied to the normal irrigation plots using the same schedule. Green bean varieties Caprice, Huntington, Hercules (2015 only) and Accelerate (2015 only) and breeding lines BA0999, BA1001, DMC04-88, DMC04-95 and SV1098G were compared. In 2013, plots were planted on June 12 and harvested on Aug. 7 and received 8.35 inches of water in normal irrigation plots and 6.2 inches in deficit plots for a season-long deficit of 2.1 inches In 2014, plots were planted on June 28 and harvested on Aug. 28, however, germination and emergence were poor and erratic and no results were recorded. In 2015, plots were planted on June 5 and harvested on Aug. 3 and received 9.0 inches of water in normal irrigation plots and 6.75 inches in deficit plots for a season-long deficit of 2.25 inches.

As anticipated, in 2013 deficit irrigation reduced yields of green beans significantly with greatest reductions seen in DMC04-88 (32%), BA0999 (25%), Huntington (23%) and DMC04-95 (22%). Yields in other lines and varieties were reduced by 9-20% but were not statistically significant. In 2015 all lines and varieties were adversely impacted in total yield with an average reduction across all lines of 15.5%. Greatest yield reductions were seen in Accelerate, BA0999, Caprice, Huntington and SV1098GV which were all over 20%.

Conclusions, green beans. These results confirmed that reducing water inputs by 25% season-long in green beans using deficit irrigation would result in economically unsustainable yields and is not a viable option to conserve water. Using smaller deficits earlier in the growing season may be an alternative but the operational window of less than 30 days from emergence to flowering would present challenges in timing. Results and analysis of the green bean response to deficit irrigation are appended in Appendix 6.

Sweet corn procedures and results. Deficit irrigation studies with sweet corn were also conducted over 3 years (2013-2015) at the HARS comparing full and deficit regimes. Sweet corn, with a growing season of 90-100 days, is intermediate between short season crops such as green beans and peas and long season crops such as potatoes and field corn. Our hypothesis was that sweet corn would be more tolerant of water deficits than green beans with which it is often rotated. To test this hypothesis an experiment was conducted comparing the impact of standard irrigation and deficit irrigation regimes on 3 commercial sweet corn varieties (Overland, Rocker and Protégé) and 6 advanced breeding lines (DM21-84, GH 4927, GSS 1453, GSS 1477, SV 1365 and SV 1514 SK). Plots (4 rows, 15-18 ft) were arranged in a factorial design with 3-4 replications at the HARS using standard fertility and pest management practices. Two overhead irrigation regimes were again examined. "normal irrigation" was managed by WISP-2012 and monitored with capacitance soil moisture sensors while deficit irrigation conditions were created from planting to harvest using a sprinkler package to deliver 75% of water applied to the normal irrigation plots using the same schedule. In 2013 plots were planted on June 22 and harvested on Sep. 20 and received 16.65 inches of water in normal irrigation plots and 12.48 inches in deficit plots for a season-long deficit of 4.17inches. In 2014, plots were planted on June 5 and harvested on Aug. 28 and received 13.3 inches of water in normal irrigation plots and 9.98 inches in deficit plots for a season-long deficit of 3.3 inches. In 2015, plots were planted on May 27 and harvested on Aug. 25 and received 12.3 inches of water in normal irrigation plots and 9.2 inches in deficit plots for a season-long deficit of 3.1 inches.

Total yields were taken at harvest and corn was cut from cobs and weighed to determine recovery. In 2014, single ear leaves were removed and analyzed for total nitrogen using standard soil lab procedures to determine if reducing water by deficit irrigation would result in greater nitrogen uptake by the plants.

In 2013, season long deficit irrigation had little impact on sweet corn yields. Across all lines and varieties, total yield was 7% higher in deficit plots with yields ranging from 9-13 tons/acre. Although not statistically significant, 7 of the 9 lines and varieties tested yielded higher under deficit irrigation than under normal irrigation.

In 2014, when total yields averaged 11-13 tons/acre, a similar trend was seen where 7 of 9 lines and varieties yielded higher under deficit irrigation than under standard and the average yield across all entries was 10% higher in deficit plots. Although not statistically significant, these trends were consistent for both 2013 and 2014.

Essentially all sweet corn grown in Central Wisconsin is processed and recovery of cut corn from harvested ears is an important statistic. In 2013 and 2014, harvested ears were husked and cut using techniques similar to commercial processing to determine whether deficit irrigation impacted recovery. In both years % recovery (40.8% vs 39.0% from deficit plot vs standard irrigation in 2013 and 38.8 vs 38.7% in 2014) was essentially the same under both normal and deficit irrigation when averaged across all entries and there were no significant differences among individual entries.

Reducing irrigation water by 25% with deficit irrigation could potentially reduce movement of water through the soil profile and reduce potential leaching of nutrients such as nitrogen and make soil N more available for plant uptake. To test this hypothesis, in 2014 ear leaves were removed at harvest and analyzed for % nitrogen using standard soil lab protocols. Across all entries, % nitrogen in ear leaves was 10% higher in deficit irrigated plots (2.80%) than under standard irrigation (2.55%). This difference was not statistically significant but it was consistent among all varieties and breeding lines. Although germination differences prevented repeating this analysis in 2015, the 2014 data support the hypothesis that using less water through deficit irrigation could potentially also increase nitrogen availability to the plants.

In 2015, the uneven germination experienced with green beans in 2014 was reflected in the same plot areas in sweetcorn, suggesting a soil contaminant was present which did not impact the potatoes grown in that area in 2013 but adversely impacted sweet corn and green beans in subsequent years. As a result, sweet corn yields were erratic in 2015 and although an average yield of 9-12 tons/acre was seen, the impacts of deficit irrigation were unclear. In contrast to2013 and 2014 total yields across all entries were reduced by 25% in 2015 but since 3 entries averaged over 30%, the results were skewed and no conclusions could be drawn from the 2015 data.

Sweet corn conclusions. Although the results from 2015 were inconclusive due to poor germination the data from 2013 and 2014 strongly suggest that deficit irrigation on sweet corn could be implemented in Central Wisconsin without adverse impacts on yield or quality. In these trials we examined a 3-4 inch water deficit applied season long. Over 60,000 acres of sweet corn are grown in Central Wisconsin and if a 3.5 inch/acre reduction in irrigation water were implemented widely, groundwater withdraws could be significantly reduced. It is recommended that further research be conducted with sweet corn to refine the impacts of timing water deficits during the season in order to maximize the potential savings.

Results and analysis of the 2013-14 sweetcorn deficit irrigation studies are appended as Appendix 5

Step 5: Reducing water use through drip irrigation

Nearly all potato and vegetable producers in the Central Sands area of Wisconsin use center pivot, overhead sprinkler irrigation systems to deliver water to crops using high capacity wells to extract groundwater from the extensive aquifer underlying the area. Groundwater and surface water are strongly tied due to the unconfined structure of the glacial aquifer and relatively small withdraws due to pumping can have consequences in surface water lake levels and stream flows. The need to conserve water resources by increasing water use efficiency has led growers to explore alternative irrigation water delivery systems which could potentially achieve the same productivity using less water.

Drip irrigation is widely used in many parts of the world but concerns over economic cost and difficulties in incorporating it into current growing practices have precluded its adoption in Wisconsin and limited it to very small acreage specialty crops. Drip irrigation has been shown on many vegetable crops in arid climates to achieve water savings through better localization of moisture in the root zone and providing a more consistent supply of water to the plant with less evapotranspiration than overhead sprinkler systems. Concomitant benefits from drip irrigation which include reducing the hydrophobic "dry zone" in potato hills, reducing water loss to furrows, reducing canopy humidity for disease management and providing a precise delivery mechanism for pesticides and nutrients, would also accrue.

A 2-year trial was conducted on the HARS to evaluate the yield and quality of 3 widely grown potato varieties, Russet Burbank, Russet Norkotah and Snowden as influenced by irrigation type and rate (Page et al 2014). Irrigation types were standard overhead center pivot irrigation supplying 100% of crop evaporation demand and drip irrigation supplied by emitter tapes laid on the hill surface prior to emergence. Drip irrigation treatments used different emitter spacing's to deliver 100%, 86% and 75% of the overhead irrigation rate producing irrigation deficits of 0%, 14% and 25%, respectively. The experimental design was a modified split plot with 3 replications. Since the 3 trial varieties are processed into fries (russets) and chips (Snowden), in addition to yield, the study also evaluated quality parameters , including fry color and reducing sugar content, petiole nitrate levels, soil moisture and temperature levels that could impact internal tube defects and irrigation water use efficiency.

- Total and US#1 yields were similar for Russet Burbank and Snowden between drip and overhead irrigation and no yield reduction was seen with water deficits of 14 or 25%. The 100% drip irrigation yields were lower indicating that some nutrient leaching may have occurred but differences were not significant. Russet Norkotah yields were higher under overhead irrigation relative to drip in 2013 but not in 2014.
- Tuber internal physiological measurements to detect potential impacts on processing were inconsistent but there was little irrigation treatment effect on stem and bud end glucose or sucrose concentrations and no negative treatment interactions occurred for fry color. Petiole nitrate levels did not differ between varieties and the impact of irrigation on petiole nitrate levels was minimal and did not impact crop nitrate status.
- Soil moisture measurements in the hill and under the furrow indicated that there was a large variation in moisture at 10cm in the hill regardless of irrigation treatment. At 20 cm in the hill there was a higher moisture content in the drip treatments than in the overhead irrigation treatments. This corresponded to higher moisture levels under the furrow in overhead treatments relative to drip irrigation and demonstrated that water from overhead irrigation was diverted into the furrow and lost from the root zone. Plant wilting was observed in the drip irrigation plots during periods of high air and soil temperatures (which were often higher in drip

irrigated plots) indicating that plant stress was occurring under drip irrigation but this did not result in reduced yield or quality.

- Water use efficiency as measured by yield/unit of water applied was greatest in the drip irrigation plots with a 25% deficit with significantly greater efficiency than drip irrigation with a 14% deficit, drip irrigation with no deficit and overhead irrigation.

These data clearly demonstrated that potatoes could be grown with up to a 25% reduction in applied water without sacrificing yield or quality. However, until water becomes more limiting or more highly regulated, it is likely that overall yield rather than irrigation water use efficiency will influence water application rates.

A complete report of drip irrigation studies is appended as Appendix 7 and can be accessed at http://www.agroecology.wisc.edu/documents/page thesis 5 2015.pdf

Step 6: establishing a baseline of current irrigation practices to identify ways to improve performance

Water is a vital resource for the potato and vegetable industry in Central Wisconsin and the long-term sustainability of the groundwater aquifer is the industry's highest priority. As a result, there has been increasing pressure to manage irrigation more efficiently and reduce unneeded water use. We believe that potato and vegetable growers have already adopted many of the practices that will address this need and are actively exploring new technologies to achieve further improvements. However, until 2014 no up-to-date information existed to document what practices are commonly used by the industry The establishment of a baseline would provide a yard-stick against which future improvements could be measured.

In the fall of 2014 an initiative to develop a comprehensive irrigation practices baseline was implemented by growers, their industry associations, irrigation professionals and University specialists who collaborated in the development of a simple, online assessment tool to document the adoption of practices which impact irrigation efficiency (Wyman and Knuteson, 2015). The assessment tool was diverse and included questions pertaining to irrigation equipment, irrigation operations, predicting and measuring water, water management, water conservation at the farm and landscape levels and grower beliefs on how water resources should be managed in the future.

The assessment tool was deployed online and data was managed by the grower associations to provide confidentiality while growers could retain their individual answers for future comparison with industry averages. Data was received from 71 completed assessments (around 90% of the total number of growers who irrigate and were members of the association) from across the state, which represented 185,375 irrigated acres. Data was collected from potatoes, green beans, peas, carrots, alfalfa, field corn, sweet corn and many other specialty and small acreage crops.

Highlights of the assessment (presented below as the percentage of growers using practices that are contributing to more efficient water use and conservation) were incorporate into a publication that was distributed to growers throughout the state (http://wisa.cals.wisc.edu/appendix items):

- ***Equipment used***
  - 99% use center pivot systems with 25% also using travelling guns
  - 49% use drop nozzles with 82% of those operated at low- medium pressure
  - 96% are monitored while in operation
- ***Accuracy***
  - 64% have checked flow rates in the last 5 years
  - 53% have checked application uniformity in the last 2 years
- ***Energy conservation***
  - 83% irrigate at off-peak hour when possible (avoids ET loss)
  - 59% have variable frequency motors
- ***Record keeping***
  - 82% record water applications by field
  - 62% maintain records at least 3 years (18% for 10 yrs, 15% longer than 10 years.
- ***Factors determining how often growers irrigate***
  - ***Crop need*** (at least 5 factors considered)
    - 73% use predicted or estimated evapotranspiration (ET)
    - 96% consider growth stage; 84% variety; 75% canopy; 67% rooting depth
  - ***Rainfall***
    - 97% monitor in-field rainfall; 89% use short-range forecasts; 41% long range
  - ***Soil moisture, whole field applications***
    - 89% monitor individual fields
    - 77% monitor daily using the following methods:
      - 83% hand feel; 64% visual (wet/dry areas); 40% soil probes
  - ***Soil moisture, site-specific (variable rate) applications***
    - 30% use site-specific application, based on:
      - 48% use soil maps or visual to determine moisture holding capacity.
      - 23% use visual, high/ low spots
      - 10% can turn sprinklers on/off with zone controls
  - ***Irrigation Scheduling*** (Using crop need, canopy, ET, rain, soil moisture)
    - 47% use an irrigation scheduling aid:
      - 12% WISP (8% on-line); 25% check book method, 3% commercial software
- ***Water conservation practices***
  - ***In-Field (at least 6 approaches used)***
    - 82% limit compaction to encourage deeper rooting and more efficient water use
    - 70% plant cover crops to hold water for recharge
    - 61% use conservation tillage to increase organic matter
    - 60% added organic matter to increase water holding capacity

        - 24% used deficit irrigation to promote deeper rooting
        - 22% used in row surfactants
    - ***Whole farm (at least 4 approaches used)***
        - 55% used crop rotations that require less water
        - 50% planned plantings to avoid areas of concern (high/low spots)
        - 25% planted varieties that use less water
        - 14% used natural features (e.g. wetlands) to increase recharge
    - ***Landscape***
        - 34% measured static depth to groundwater at least twice /year
        - 10% measured depth to groundwater annually
        - 27% coordinated with neighbors/stakeholders on water issues
        - 62% familiar with geology and groundwater flow on farm
        - 45% familiar with relationship between groundwater and surface water on farm
- ***Outreach/education***
    - 70% attended educational meetings that included water issues
    - 21% worked on resource issues with community
    - 19% conducted on-farm research

The data shown demonstrates that a high percentage of growers are using practices which encourage increases in irrigation efficiency and water conservation advancements. Detailed analysis of the data was performed to show the industry variation in practices. This analysis uses Principal Component Analysis (PCA) with a Data Envelopment Analysis (DEA) to identify key drivers of sustainability (Dong etal, 2015), and graphically represent the breadth of advancements within the industry.

Across the whole industry, there was remarkably little variation among growers in adoption and use of irrigation practices with all growers grouped within a 2.0% frequency range. This data suggests that all growers are using similar practices and indicates that educational programs would have a high probability of influencing which irrigation practices could be adopted to improve performance across the grower spectrum.

The PCA and DEA analyses pinpointed several practices which would have the greatest impact on irrigation efficiency and the assessment demonstrated that there is potential to increase the percentage of growers adopting these practices. Technologies used by growers to determine the need for irrigation provide a good example of the potential for improvement through greater adoption of identified practices. The analysis identified the use of lysimeters to measure field water content as a high priority and yet only 40% of growers are currently using soil probes to collect this information (19% as in-place and 21% portable). In irrigation scheduling, an encouraging 72% of growers are using an estimate of ET to schedule water applications and yet only 12% are using a computer-based scheduling program and only 4% are using WISP-2012 which was developed through this grant program. This demonstrates a high potential to improve irrigation efficiency by promoting WISP-2012 and educating growers in its use. These programs were developed in this project, and are currently being implemented (objective 1, step 2).

The irrigation assessment final report is appended as Appendix 8

<u>Objective 2: Coordinated Monitoring of depth to ground water and its relationship to stratigraphy and land use patterns</u>

The potato and processing vegetable industries in the Central Sands of Wisconsin are important components of the US food supply with production ranking in the top three nationally for potatoes, sweet corn, green beans, green peas, carrots and several other specialty crops. The Central Sands is a stratified sand and gravel area encompassing all or parts of seven counties which is underlain by a groundwater aquifer that is 80 to 200 feet deep and often resides within 5 to 20 feet of the surface. The productivity of this important growing region stems directly from the continuing availability of groundwater for irrigation which is drawn from the aquifer.

Fortunately, in the Central Sands groundwater is a renewable resource which is replenished annually by precipitation. While there is no likely scenario which would significantly draw down this aquifer to unsustainable levels, increasing withdraws for irrigation prompted by increasing productivity and climate changes which have extended growing seasons, have resulted in temporal and spatial fluctuations in the depth to groundwater. These fluctuations have been linked to impacts on surface water which are seen in reduced lake levels and stream flows at higher elevations. Adverse impacts on surface waters have led to increasing conflicts between farmers and other user groups which rely on groundwater for recreation and drinking water.

Maintenance of the groundwater table at levels which do not impact surface water lakes and streams is an important goal of this project that will require improved monitoring of ground water depths over time to follow seasonal fluctuations and through space to follow local variations due to sub-surface stratigraphy and land use patterns. Improving our understanding of the hydrology of the Central sands area governing groundwater fluctuation was an underlying component of this objective. Objective 2 was divided into 3 linked sub objectives.

Step 1: Reviewing the research base underlying water resources in the Central Sands

Wisconsin's Central Sands evolved rapidly after the introduction of center pivot irrigation in the 1950s which transformed an unproductive and undeveloped area of the state into one of the most productive agricultural areas in the nation over the next half century. During this time the area was the locus for numerous agricultural, hydrological and geological scientific studies but unfortunately these studies were never compiled into a single resource to guide development and conservation activities. To underpin our research activities in this project, a comprehensive White Paper was written and released in 2014 which, for the first time, brought together all of the relevant science impacting the region into one reference (Kniffin et al 2014, http://wisa.cals.wisc.edu/central-sands-white-paper) This report is a pre-publication version released for public use in 2014 and included in this report as Appendix 1. The report will be released as an official University of Wisconsin Extension publication in 2016. The executive summary of this White Paper follows:

Over the last two decades, stakeholder concerns over how climate and human-induced land use changes, such as groundwater pumping, have affected the surface and groundwater resources in the Central Sands region of Wisconsin have been increasing. This document was written to provide a common framework and language for dialogue regarding the state of water resources science and future management of Central Sands water resources. The first several sections of the document investigate the geological, ecological, climate and land use factors affecting water resources. The document then examines long-term changes in groundwater levels, lake levels and stream baseflows and their causes. Finally, the document explores water resource management strategies and frameworks that have been implemented in other regions of the United States and throughout the world that have potential to inform practices to mitigate the effects of human groundwater use on lake and streams and their associated ecosystems, while supporting a thriving agricultural economy.

Water is a dynamic resource that has affected the evolution of the terrestrial and aquatic landscape in the Central Sands region and will continue to affect its future evolution. In the 1800's, lakes, streams and wetlands were interspersed amongst prairies, savannahs and open forests. The influence of settlement and agricultural expansion transitioned the landscape to the agricultural, forest plantation and urban areas found today. The Central Sands aquifer enabled this transition by making water resources available for agricultural production and processing, human water supply, industrial use and stock supplies. Meanwhile, streams throughout the region are predominantly baseflow-fed and lakes are often flow-through (seepage) lakes that receive groundwater inflow and discharge water to the surrounding aquifer. Streams and lakes experience annual and interannual fluctuations dependent on climate conditions.

Studies have documented long-term changes in climate throughout the Central Sands region. From 1948 to 2006, average annual temperatures throughout the region increased 1 to 2°C and growing seasons lengthened by 15 to 20 days. During the same time period, one study found that regional, long-term trends in precipitation increased between 5 and 15 cm. Another study showed that precipitation increased in the southern portion in the Centrals Sands, while precipitation trends in the northern portion of the Central Sands showed no long-term trend. However, this study showed that the composite annual increase in precipitation across all stations was 8.7 cm between 1955 and 2005. Regional, long-term trends in annual precipitation minus evapotranspiration (often used as a surrogate for recharge) have been estimated to increase between 5 and 10 cm between 1948 and 2006. No studies have shown that climate-driven variables have caused long-term declines in recharge throughout the region.

Studies showed or predicted regional, long-term influences of groundwater pumping. Studies found that groundwater levels, lake levels and baseflow in streams have declined in areas near numerous irrigation wells over the last several decades. Groundwater flow models showed that long-term declines in groundwater and associated surface water levels are a result of a net reduction in recharge (and increase in evapotranspiration) estimated between 4.5 and 14.2 cm per year and depend on the location in the Central Sands aquifer as well as the proximity to pumping wells. Studies also showed that groundwater pumping for short periods of time (i.e. days) near streams reduces streamflows.

Annual evapotranspiration has been estimated for a number of different vegetation types. In general, irrigated crops, phreatophytes (plants that have access to and can use groundwater) and evergreens were estimated to contain the highest annual evapotranspiration; prairie, unirrigated row crops and bare ground contained the least; and deciduous forest and grasslands were in between. Studies noted that evapotranspiration depends greatly on irrigation scheduling, crop density, residue management, microclimates and other dynamic land cover and land use factors.

Drainage ditches in the region are directly connected to groundwater and serve to lower groundwater levels beneath adjacent lands. Drainage ditches also interrupt regional groundwater flow paths. Many drainage ditches are former streams that have been deepened and channelized. The total impact of drainage ditches on the regional water budget has not been documented in literature.

Key elements that can help develop strategies for groundwater and surface water management specific to the region include comprehensive modeling that can test alternative land use and land management strategies; further investigation of land management influences on rates of evapotranspiration; continued groundwater level, lake level and stream flow data monitoring and collection; and discussions about ecosystem valuation. Modeling should be conducted on transient time scales to accommodate annual and inter-annual variations in weather and dynamic land management practices.

The document explores a portfolio of potential strategies for water resources management. Strategies were grouped into three main types: technological adaptation , such as precision agriculture, deferred or deficit irrigation, and drip irrigation; landscape-level water resource management, such as drainage ditch management, low evapotranspiration landscapes, and comprehensive irrigation management plans; and regional or local water transfer projects. Strategies range in potential impact on water resources, uncertainty of potential impact and difficulty of implementation.

A water resources management planning framework is needed to implement any strategy or set of strategies. Authors recommend choosing a framework that incorporates structured stakeholder participation along with comprehensive and dynamic computer modeling to develop and implement management strategies. Authors also recommend building upon and learning from previous stakeholder engagement efforts. Three stakeholder-identified goals for water resource management were identified during stakeholder meetings. These include: 1) maintaining healthy waters and ecological resources in the Central Sands region during future water development; 2) restoring healthy waterways in the Central Sands region that have been compromised; and 3) promoting and maintaining a vibrant agriculture industry.

Site specific objectives for each goal will need to be identified. Water resource management success will depend up the ability of water resource management strategies to response to stakeholder-identified interests and concerns. Strategy evaluation and selection will be a critical component of a structured process and will ultimately require adaptive management.

Given the comprehensive review of the state of water resources science in the Central Sands, the context and cultural background of the landscape along with potential strategies, and a framework for implementing potential strategies, this document aims to inform future strategic planning and implementation of water resources management in the Central Sands of Wisconsin.

Step 2: Expanding understanding of the interconnection between groundwater and surface water in lakes located in irrigated agricultural areas - Long Lake

Long Lake is a 52-acre shallow lake located in an area of irrigated vegetable production in northwestern Waushara County in the Central Sands. Long Lake is illustrative of a series of tunnel channel lakes formed when glaciers receded in the Central Sands. These lakes have experienced periodic episodes of low water levels which have often been attributed to groundwater withdraws for irrigation. Long Lake is located within 5 miles of 40 high capacity irrigation wells and has experienced consecutive years of low water levels in the 1970s and 1980s and more recently in the 2000s.

These low water levels have increased public concerns over the impact of irrigation on surface water lakes and resulted in Long Lake being designated as one of 4 areas of concern in the Central Sands. Long Lake has been historically characterized as a groundwater flow-through lake which is directly connected to the groundwater aquifer and typically exhibits lake level fluctuations which increase in early spring in response to recharge of the water table and subsequently decrease in summer and fall when evapotranspiration exceeds precipitation. Long lake is located in the Plainfield-Huron tunnel channel which also contains Plainfield Lake, Second Lake, Weymouth Lake, Fiddle Lake Shumway Lake and Lake Huron.

Well drilling logs for residential properties surrounding Long Lake show deposits of silt/clay materials at varying depths and of varying thicknesses characterized as “New Rome” clay. It has been hypothesized that these deposits could be acting as aquitards which were impacting normal connections between groundwater and surface water and contributing to lake level fluctuations in this and similar lakes. A study was thus conducted in 2012-2014 in collaboration with the Wisconsin Geological and Natural History Survey to examine the stratigraphy of the soil and subsoil profiles associated with Long Lake and determine the connection between the lake and the underlying groundwater aquifer and the potential role of silt/clay deposits in impacting lake levels. An abstract of this study follows and a final report is attached as Appendix 2.

Consecutive years of low water levels in Long Lake – Oasis, Waushara County, Wisconsin have increased public concern about the impact of high capacity irrigation pumping and climate change on Long Lake water levels. This study investigated the hydrostratigraphy around and beneath Long Lake and its effect on surface water connection to the regional aquifer from July 2012 to July of 2014. Research methods included sediment core sampling, well construction report analysis, geophysical investigations and surface and groundwater level monitoring. Within the study area, sediment cores and well construction reports revealed that fine sediments are present beneath Long Lake and are uncommon outside the Plainfield-Huron lake tunnel channel. Sediment and geophysical analyses showed that sands, gravels and fine sediments were deposited in layers. Fine sediment layers beneath Long Lake ranged from a few millimeters to several meters in thickness and were not continuous throughout the lakebed.

Groundwater level monitoring from July of 2012 to July of 2014 revealed downward vertical groundwater head gradients between deep (<40 ft) and shallow (<10 ft) piezometers on the north (LL-N), east (LL-E) and west (LL-W) side of the Long Lake lakebed, except in LL-W in November 2012. Throughout the same time period, vertical groundwater gradients between deep and shallow piezometers on the south (LL-S) side of the Long Lake lakebed contained no vertical gradient. Horizontal groundwater gradients measured between July of 2012 and July of 2014 showed that shallow groundwater (<10 ft deep) flowed southeast, while deep groundwater (>40 ft) flowed southwest. Study results indicate that Long Lake is connected to the regional aquifer and is affected by changes in regional groundwater elevation. Long-term surface water levels in Long Lake may be challenging to maintain given their sensitivity to groundwater pumping and close proximity to the groundwater divide

This study demonstrated that silt/clay deposits are associated with channel tunnel lakes such as Long Lake and that they can act as aquitards. However, the silt/clay deposits were not continuous and did not impede groundwater connections to the lake. Long term surface water levels in Long Lake and similar channel tunnel lakes in the Central Sands may be challenging given their sensitivity to groundwater fluctuation and these results will be valuable in designing water management strategies.

In 2014-2015 a more extensive investigation was conducted in collaboration with the WGNHS which used ground-penetrating radar in conjunction with multiple-depth piezometers to examine the distribution of silt/clay deposits across central Wisconsin. These studies were conducted in three areas which have been designated as sensitive sites where surface waters have been impacted negatively by agricultural use for irrigation: The little Plover river watershed, in Portage Co., Long Lake in Waushara Co. and Pleasant Lake in Adams Co.. This study is still in progress at this time but preliminary results indicate that silt/ clay deposits are present throughout the Central Sands with greatest frequency in the southern and western areas. These deposits were shown to act as aquitards that can impact connections between groundwater and surface water but deposits are not continuous and impacts vary with deposition pattern. These results were used in a separate, DNR-funded modeling study in the Little Plover Ricer area and are currently being used as an alternative mechanism to measure aquifer recharge.

Step 3: Establishing a database to document fluctuations in depth to groundwater in the Central Sands

As the understanding of the Central Sands stratigraphy and hydrology expands the potential to develop models to aid in the management of ground water and surface water resources also improves. Historic, present and future groundwater level, lake level and streamflow monitoring data drives our understanding about how surface water and groundwater systems interact and have changed over time. A lack of historic data and gaps in available data sets have limited our capacity to analyze trends in the surface and groundwater flow system, as has been illustrated in the reviewed literature (step 1). For this region, present and future data collection tracking fluctuations in groundwater levels and associated surface water lake levels and stream flows will be increasingly important for system and trend analyses and the construction and validation of groundwater flow models. In this project we focused resources in

2 areas to address this need: 1) working with cooperating growers to monitor groundwater levels in high capacity irrigation wells on privately owned lands (data which is rarely available for public use); and 2) on tracking fluctuations in groundwater depths using continuous monitoring wells in areas of the Central Sands which have been designated as sensitive areas for surface water impairment.

Water levels in irrigation wells on private lands: Much of the land area in the Central Sands is privately owned and a high proportion of the irrigation wells in the state are operated by potato and vegetable producers in the area. These wells are dispersed over a 7 county area with varying topography, groundwater depth, agricultural density and crop landscapes which create significant spatial and temporal variability in the region. Growers annually report irrigation pumping as a component of the Department of Natural Resources permit requirements for high capacity wells but until this project was initiated, no coordinated data base documenting fluctuations in groundwater in private wells existed, presenting a serious impediment to the state's ability to model and manage the ground water resource. In 2011 University of Wisconsin researchers, working in collaboration with the Wisconsin Potato and Vegetable Growers Association groundwater task force, launched an initiative to establish a database in which the depth to groundwater was recorded in high capacity irrigation wells. Specifications for equipment and protocols for measuring depth to the water table and elevation of the wells were established with the Wisconsin Geological and Natural History Survey to ensure accuracy and measurements were taken annually at a minimum and, in many cases, 2-4 times/year. The data was consolidated into a commercial software package (Conservis) and held and managed by the WPVGA to preserve confidentiality. Procedures were established to facilitate access to the data base for scientific uses including on-going modeling programs in the Central Sands.

The data base has grown annually as the value of documenting fluctuations in groundwater depth across space and through time was recognized and by 2015 encompassed over 600 high capacity wells across 4 counties. The potential to enhance the accuracy of hydrological modeling and improve the effectiveness of water conservation strategies was evident in the incorporation of private well data into an ongoing WGNHS modeling project for the Little Plover River in Portage County. This study, funded by the Department of Natural Resources, will be instrumental in developing future water management strategies throughout the region.

The WPVGA, working with an independent hydrological consulting company (GeoEnvironmental Inc.), recently used the database to compare current static water levels in 58 Portage County irrigation wells with the levels that were recorded when they were originally drilled from 2-57 years previously (Faivre, 2015). This study revealed that high capacity well pumping in Portage county has not adversely impacted aquifer storage over extended time periods as the static water levels measured in 2014 were relatively consistent in comparison to levels when they were drilled with 37 wells showing higher static water levels compared to 18 which were lower. While this data does not address the potential impact of groundwater fluctuations on surface water stream flows and lake levels, it does reinforce the recognized assessment that the groundwater aquifer in the Central Sands is a renewable resource which is not being depleted. This is in contrast to groundwater aquifers in other parts of the US where ground water sustainability is in question.

Water levels in sensitive areas at risk of surface water impacts: Prior to this project, University of Wisconsin Extension specialists convened a series of 4 forums in the Central Sands at which scientists, environmental groups representing lake owners, fishing and recreational water users, farmers, food processors, local communities and concerned citizens came together to discuss concerns and explore potential strategies to address them. These forums were unable to reach consensus but it was agreed that there were localized areas in the Central Sands where surface waters were already experiencing adverse impacts that were attributable to groundwater withdraws and these areas were designated as high risk where resources should be directed to seek solutions. The areas were the Little Plover River in Portage County which had experienced reduced stream flows and fish kills in recent years, Long Lake in Waushara County, where low lake levels were impacting recreation and property values and Pleasant Lake in Waushara County where new high capacity wells to supply large dairy operations in the area were causing concern.

To address these areas of concern, we focused on documenting fluctuations in groundwater depth over time in the 3 high risk areas and increasing the awareness of concerned end users by publishing water depths in real time on the University of Wisconsin Institute for Sustainable Agriculture website, http://wisa.cals.wisc.edu/central_sands_water. (Naber et al, 2013)

This was achieved by installing nests of 8 solar powered monitoring wells capable of monitoring groundwater depth at 15 minute intervals in transects (at half to one mile intervals) across each sensitive area. Wells (2 inch PVC) were professionally drilled (Onsite Environmental Services, Sun Prairie, WI) in the spring and summer of 2012 and 2013 and varied in depth from 10 feet to 60 feet reflecting the variability of surface topography, Elevations of each well head were taken with TDK instruments with accuracy of 2-4 cm. Each well was equipped with a pressure transducers (CS450-LI00-SA-29-NC) to record water table depth at 15 minute intervals ^ hour intervals were used in the study to reduce data load), a datalogger (CR200X) to store data, a rain gage (TE525-L10) to record rainfall at each well site and a 5W solar panel (SP5-L10) to maintain battery power. (Equipment was acquired through Campbell Scientific, Logan, UT). Water table data was downloaded from each site at 3 week intervals staggered between locations and up loaded to the WISP web site where it was presented as raw data (6-hour intervals) and graphs of water depth over time. Staggered downloads between sites ensured that all data on the website was updated every 3 weeks.

This data set was maintained by project personnel while this project was operational and data collection has since been assumed by the WPVGA through an independent hydrologist to ensure that the database continues to expand through time and remains available to the public and agencies for use in water management.

This data can be networked with other existing groundwater monitoring stations, (maintained by state and federal agencies) and provides a valuable verification capability for the private irrigation well database. The value of this data was illustrated in 2014-15 when the monitoring well data in the Little Plover River watershed was incorporated into ongoing hydrological modeling exercises being conducted by the WGNHS and the DNR. In the course of this modeling project it was determined that needed groundwater depth data was not available from the south-southeast transect of the watershed and the

WPVGA, in collaboration with this CIG project, installed an additional 5 wells in 2015 to generate the data to enhance the model.

These activities, which were initiated by the NRCS-CIG in collaboration with growers who cost shared the project, and are now being continued and expanded by those growers alone, clearly illustrate the value of collaborations between federal agencies and the private sector in providing funds and focusing resources to initiate and foster programs to address broad issues.

Consolidating the existing databases recording fluctuations in groundwater depth into a single-source reference to examine potential relationships with climate, irrigation, land use and crop landscapes:

The activities outlined above, which were created initially by the NRCS CIG in collaboration with grower groups and are now continuing with grower support alone have created two independent databases on groundwater depth and fluctuation through space and time that will be a valuable assets in designing water management strategies based on hydrologic models. In 2013-15 the project directed additional resources to begin to consolidate these private and public databases, together with other state and federal data, into a single-source reference. This continually expanding resource will enable agencies, land owners and researchers to begin to examine the complex inter-relationships between groundwater and surface water fluctuations and a broad palette of potential interacting factors which may include climate, irrigation, industry, urbanization, agricultural productivity and diversity, crop landscapes, forestation and topography. Examining these interrelationships is now possible through the public availability of satellite-generated crop and land use data layers which are increasing in scope and accuracy.

This project began the process of consolidating the water depth databases in 2014-15 by engaging the expertise in GIS technology at the University of Wisconsin and funding an undergraduate student to merge the existing databases, check well elevations for accuracy, determine where data is lacking, examine the relationship between current water levels and historical drilling data and relate water table depth to known groundwater flow patterns in watersheds and sub-watersheds. In 2016 research will focus on examining the relationships between groundwater fluctuations and land use patterns, crop landscapes, climate, intensity of irrigated agriculture and other factors that may be impacting groundwater/surface water interaction using satellite data. This research was initiated by NRCS CIG funding and has now been assumed by growers providing a further example of the value of federal/private partnerships in addressing long term research needs.

<u>Objective 3: Management of water fate from drainage districts</u>

When the Central Sands was first considered for conversion from undeveloped pine and oak forests intermixed with wetlands into potential farmland, many parts of the region had groundwater levels above or within a few feet of the soil surface and could not be farmed. Natural drainage occurred through a network of streams flowing from the higher elevations in the moraines flanking the eastern edge of the region, in an east-west direction, to discharge into the Wisconsin River on the western edge. To develop the area into productive agricultural land, a new drainage system was installed in the early 1900s that used natural streams that were often straightened and deepened, in combination with new drainage ditches to accelerate water discharge into the Wisconsin River. This system was effective in lowering the water table several feet and opening thousands of acres for agricultural production. As center pivot irrigation became available in the 1950s, vegetable production expanded rapidly and the density of high capacity wells and groundwater withdraws continued increasing into the 2000s. However, impacts of groundwater withdraws on surface waters, reflected in lower lake levels and reduced stream flows, created conflicts between agriculture and groups who use water for recreation.

To address these issues we must explore the potential for slowing the discharge of water into the Wisconsin River and diverting it for irrigation. Strategies that involve the damming or diversion of drainage ditches and streams to create retention areas that would increase recharge to the groundwater or hold spring runoff water until it can be pumped to higher elevations for use in irrigation, need to be evaluated. Modeling provides an effective means to evaluate the impact of different approaches to water management on depth to groundwater and in this project we collaborated with the Wisconsin Geological and Natural History Survey to use a modeling approach to examine the impact of hypothetical ditch and stream modifications on stream flows and water levels in lakes at higher elevations.

The drainage ditches in question are located in the area of the central sands where Portage, Wood, Adams, and Waushara Counties meet, with most of the ditches lying within the southwest To evaluate the overall impact of the drainage ditches to the surrounding groundwater-levels two steady-state groundwater flow models were developed. The first model (pre-ditch model) represented groundwater conditions in the ditched region of the central sands prior to installation of the ditches while the second model (post-ditch model) represented groundwater conditions after installation of the ditches. A comparison of water-levels simulated by the two models, under 6 scenarios in which varying levels of re-charge and hydraulic conductivity were tested, then provided an indication of the magnitude of potential water-level changes that could be caused by drainage system modifications. The pre- and post-ditch differences in water levels could then be used to predict the potential impacts that modifications in present day ditch systems would have. The post-ditch model was intended to simulate conditions in the years after ditching, but prior to development of irrigation, in order to evaluate the effects of the ditches only. No attempt was made to account for pumping or land use changes in the area, and as a result, post-ditch water-levels are not representative of current water-levels. In addition, the models were not calibrated to real-world observations and, therefore, they do not reproduce real-world conditions. Instead they were used to test the response of the groundwater system to potential drainage system modifications under hypothetical conditions.

Corner of Portage County. The area of interest is approximately 150,000 feet in the east-west direction and approximately 106,000 feet in the north-south direction, and for modeling this was discretized into cells having dimensions of 500 feet by 500 feet. All modeling was completed using the United States Geological Survey (USGS) groundwater modeling code MODFLOW-2005 (Harbaugh, 2005), using Groundwater Vistas (ESI, 2011) as a pre- and post-processor.

Pre-ditch and post-ditch water-levels were compared for six different combinations of recharge and hydraulic conductivity values. For each scenario the pre-ditch model was run to produce simulated water-levels for the model domain. Those simulated water-levels were then used as initial water-levels in the post-ditch model. The post-ditch model was then run to produce simulated water-levels for the model domain with the ditches present. The net effect of installing the ditches is a lowering of the water table. This lowering of the water table is called drawdown. The amount of drawdown caused by ditching is determined by subtracting the post-ditch water-levels from pre-ditch water-levels.

To quantify changes in water-levels and the amount of drawdown for the various simulated scenarios, water-levels and drawdown values were compared at the model locations coinciding with the locations of two lakes; Bass Lake and Long Lake. Bass Lake is located in southern Portage County with an elevation of 1,090 ft and Long Lake is located in northwest Waushara County at the same elevation.

The modeling results show that the magnitude of drawdown potentially caused in the lake area of the modeled region as a result of installing drainage ditches was approximately 3 feet or less. The simulated drawdown at the two lake locations was relatively insensitive to variations in recharge and hydraulic conductivity, with all simulations producing lake drawdown in the range of 1 to 2.9 feet. These results suggest that returning the system to a condition similar to the pre-ditch condition could potentially affect water-levels in the eastern portion of the modeled area by approximately the same magnitude of 1 to 3 feet. However, returning the system to the pre-ditch condition would result in thousands of acres of currently arable land potentially becoming too wet to farm again. Any smaller scale change to the system, such as damming an individual ditch or small subset of ditches, would be expected to have a smaller effect on water-levels than a change to the whole ditch system. The subject models are steady-state and therefore do not assess the amount of time required for the aquifer to respond to changes.

The simulation results show that development of the ditch network might have affected water-levels and lake levels in the eastern part of the modeled area by up to 1 to 3 feet, with larger changes occurring near the ditches themselves. This result suggests than any modification to the ditch system has the potential to affect water-levels in the eastern portion of the modeled area by similar amounts or less, depending on the proposed modification, while water-level changes near the ditches will be greater.

The goal of this research was to help understand the effects of the ditches on the aquifer system as a way to evaluate potential water management strategies involving the ditches. The results of the modeling suggest that most of the impact of the ditches would be felt near to the ditches and thus new changes to the system are likely to be felt locally as well. This suggests that any water management strategy intended to change the drainage system in some way should be focused near the area where the change is desired.

The full report of this modeling exercise to examine the impact of drainage system modifications on water levels is attached as appendix 11.

This research will be used in developing coordinated approaches to water management and modeling their potential impacts across the Central Sands. The finding that damming a stream would elevate water levels to the greatest extent close to the modification is currently being evaluated as a scenario to improve stream flows in the Little Plover River by installing a dam close to its headwaters. This would create a retention area that could be used to increase recharge locally and hold water during periods of high stream flow for release when stream flows are low. This approach is an important component of a proposed conservation area for the Little Plover headwaters being developed by the Village of Plover and the WPVGA.

Objective 4: Implementation of nitrogen management strategies that incorporate manure, slow release fertilizers and perennial legume cover crops

Mitigating impacts of vegetable production and processing on water quality in Central Wisconsin will require improvements in nutrient use efficiency and retaining nutrients within the root zone during crop and non-crop production periods of the growing season (Ruark, 2013). Nitrogen fertility is the largest concern due to frequent leaching events that move nitrates to groundwater. Increased nitrogen use efficiency requires maintenance of plant available nitrogen in the root zone during critical crop production stages while concurrently minimizing risk of nitrate movement through the soil during leaching events. Preventing movement of nitrates beyond the root zone will require revised cropping systems with deeper rooting patterns and maintenance of green tissue throughout the entire calendar year. In this project we investigated 3 approaches, slow-release fertilizer, manure and perennial cover crops, using on-farm trials with cooperating growers.

Slow release fertilizers are now available in affordable formulations and could be used to deliver plant available nitrogen at times that match crop demand in mid to late season while also minimizing risk of nitrate movement through the soil during earlier leaching events. ESN (Environmentally Sound Nitrogen) has been evaluated in potato and field corn under irrigation in small plot research and it was shown in 3 of 4 trials that ESN applied at 20% lower rates than standard nitrogen fertilizer resulted in similar yields in both potatoes and field corn, demonstrating improved nitrogen use efficiency. ESN is used as a primary nitrogen fertilizer source for majority of potatoes grown in Minnesota and North Dakota (Hyatt et al 2010) Demonstration of cost efficiency and reduced environmental impacts of ESN could provide incentives to Wisconsin potato and vegetable growers to implement use of slow release fertilizer within their production systems (Naber et al, 2013).

Large dairy herds are being established in Central Wisconsin providing another alternative nutrient source for vegetable crops. Appropriate means of utilizing manure with regard to nutrient management rules (NRCS 590 standard), food safety, and minimal impact on water quality will be critical for integration of the dairy industry into Central Wisconsin (Ruark et al, 2013). Sweet corn has long been managed with manure, but manure cannot be applied immediately prior to short season pea or snap bean crops due to potential contamination of the harvested crop and occurrence within canned product. Small plot research has shown that manure (raw and digested) use in potato and processed vegetable rotations can provide an excellent source of N although concerns still persist over the ability to use P in crops following potato, which is a high P user (Ruark et al, 2013, Ruark et al 2014). Field scale demonstrations will be crucial for educating potato and vegetable growers on the appropriate and optimal use of manure as a nutrient source in multiple crops with minimal water quality impacts and no food safety risks (Naber etal, 2014). In addition, demonstration trials will be crucial for making sure manure is utilized in a manner that complies with Wisconsin 590 nutrient management standards (NRCS 2011).

Cover cropping has been a means for capturing nutrients prior to leaching in numerous cropping systems. On sand soils of Central Wisconsin, planting annual rye after potato or field corn harvest failed to capture fertilizer nitrogen applied during the growing season even though 50 to 65% of the nitrogen remained in the field after harvest. Maintaining legume cover crops perennially may prevent nitrate leaching and fix atmospheric nitrogen, especially if they grow under the vegetable canopy as companion crops. Red clover and alfalfa are deep rooted crops with known ability to scavenge for nitrates in the soil and for nitrogen fixation. Growing these crops as perennial covers could therefore reduce fertilizer requirements in subsequent crops and decrease impact of vegetable production systems on groundwater quality. Field demonstrations were conducted to allow growers to optimize management practices and evaluate risks and benefits of these systems.

Vegetable growers already split apply fertilizers, tissue test, and take multiple steps to optimize nutrient use efficiency. New techniques using slowly released nutrients, manure and perennial groundcover are necessary to further reduce nitrate leaching. These trials were initiated to facilitate grower incorporation of these practices into their farm systems.

During 2012, 2013 and 2014 field trials were conducted with cooperating growers to demonstrate the impact of using controlled release nitrogen (ESN) and manure on yields of field corn, sweet corn and potatoes (Naber and Ruark, 2015). Summaries of these trials are as follows:

- In 2012, trials were conducted with cooperating growers to demonstrate the potential effectiveness of a slow-release nitrogen source (ESN) in sweet corn, field corn and potatoes. Trial designs and procedures are described in Naber etal, 2013. Growers used split fields to compare standard fertility programs (which included starter N at planting, side-dress N and supplemental N applied through irrigation as called for by N levels in petiole samples) with ESN-based programs applied earlier in the season with no supplemental N (starter, pre-plant and side-dress).
- The 2012 growing season was unusual compared with recent years in Central Wisconsin which typically receive large rainfall events (3-6”) early in the growing season leaching N from the root zone and necessitating supplemental applications of N through mid-late season. In contrast 2012 had lower than average rainfall with no large rainfall events and no supplemental N was required. This led to lower total N rates in the standard fertility regimes (180, 198 and 206lbs/acre for sweet corn, field corn and potatoes, respectively), compared to ESN regimes (198, 241 and 275 lbs/acre). No significant yield differences were detected between standard and ESN regimes although yields were higher in the standard regimes for all crops (8.8 vs 8.2 tons/ acre for sweet corn; 197 vs 185 bu/acre for field corn; and 441 vs 397 cwt/acre for potatoes).
- These results demonstrated that, while ESN did not impact yield significantly, its use in years when no large precipitation events cause N loss through leaching and standard fertility regimes

require no supplemental N, ESN rates which are applied in early season may exceed crop N needs and become economically costly.

- Field experiments with perennial cover crops established in the prior season and maintained as a companion crop to retain N, were established with a cooperating grower in 2011 in expectation that a following sweet corn crop would be planted in 2012. Unfortunately, processing crop contracting difficulties resulted in the field being planted to short season green beans which were unsuited to a perennial cover crop and no data was taken.
- Small plot trials with manure applications were initiated with field corn on the Hancock Agricultural Research Station in 2011 and continued in 2012 to address the examine the utility of manure (liquid and solid) as an N source prior to planting and to address concerns that P levels in soil for following processed vegetables would exceed NRCS 590 standards (Ruark et al, 2013). These trials were supportive of the objectives of this project but were not the primary focus and are not included in this report.
- In 2013 on-farm trials were established with growers to evaluate alternative N management practices using ESN and manure on potatoes and sweet corn. Experimental designs and procedures are reported in Naber et al, 2014.
- In the potato trials a standard fertility regime (including starter N, side-dress N and supplemental N through fertigation, totaling 470 lbs actual N/acre) was compared with an ESN-based regime (where N was applied early as pre-plant and side-dress applications totaling 340 lbs/acre N).
- In contrast to 2012, a significant rainfall event of 4 inches, occurred in early season (June 22 and 24) which resulted in significant N loss through leaching, necessitating several supplemental N applications in the standard regime field.
- Marketable potato yields were significantly higher in the ESN-treated half of the field with 767cwt/ acre compared to 646 lbs/acre in the standard regime. The yield advantage from ESN was evident in increased percentages of larger size grades which are more valuable. This was greatest in the 6-10 oz grade with 130 cwt/ acre more in the ESN field but also seen in 4-6 oz, 10-13 oz, and 13-16 oz grades which were all over 20 cwt/ acre more in the ESN field.
- The effectiveness of the ESN regime in holding N in the potato root zone through delayed release which avoided the leaching in early season, was striking in terms of both yield and quality increases but also would significantly reduce N movement to groundwater and improve water quality
- For sweet corn in 2013, 3 fields were used where ESN was the primary N source applied as a side-dress at V4 using rates of 0, 75 and 150 lbs N/acre and supplemented with 93 lbs /acre by fertigation. Half of each field also received liquid manure applied in the spring (22 lbs N/acre) and immediately incorporated (Naber et al, 2014). In this case study the largest yields (15 tons/acre) were achieved using both ESN at 150 lbs/acre with manure, compared to 13.3 tons/acre with ESN alone, indicating a positive interaction between these 2 N sources. Yields in fields where ESN rate was reduced were similar (12.8 and 13.6 tons/ acre from O and 75lbs/acre vs 13.3 tons/acre from 150 lbs/acre)
- In a second case study on sweet corn in a split pivot one half received a total of 200 lbs of N as a standard regime (two top-dress applications of ammonium sulfate and urea and 1 fertigation

application with 32%N) while the other half received 32 lbs/acre less total N (168 lbs/acre) in an ESN-based regime (a single top-dress application of ESN and 1 fertigation application of 32%). Yields of 9.2 and 9.1 tons/acre in the standard vs the ESN regimes, which received 32 lbs less N, again indicated that ESN was a suitable N source as a delayed release formulation in years where significant rain events occur in early season.

- In 2013 a perennial cover crop demonstration on sweet corn as established in a full pivot (160 acres) in Portage County. In 2012 alfalfa was established in half of the field following mid-season green bean harvest and Red clover was established in the other half. A strip with no cover crop was left in each field half as a control. In 2013, the perennial cover crops were treated with glyphosate and disked to achieve partial kill and sweet corn was planted in both field halves.
- The cover crops were allowed to regrow as a companion crop under the sweet corn canopy and the sweet corn was harvested at maturity. Yields in the red clover cover crop (10.67 tons/acre) were slightly higher than in the control with no cover (9.7 tons/acre) but did not differ significantly. Similar results were seen in the alfalfa cover crop (10.6 tons/acre) compared to its no cover control (8.97 tons/acre).

These data demonstrated that deep rooted, perennial legume cover crops grown as a companion with sweet corn can be an effective way of intercepting N leached below the sweet corn root zone which would improve water quality. Since the legumes also fix N there would be an added benefit to the sweet corn from the N credits which could reduce N rates further.

Further small plot studies with manure were again conducted in 2013 with determine if previously applied manure would alter the optimum P rate for potatoes (Ruark et al, 2014). These studies were related to the objectives of this project but were not the primary focus and are not reported here.

In 2014, on-farm trials with growers were confined to evaluation of ESN on potatoes with experimental design and procedures presented in Naber and Ruark, 2015. Two commercial fields planted with Russet Burbank potatoes (bulk 1 and bulk 2) were treated as determined by cooperating growers with a blend of ESN and standard N sources with ESN comprising 30% of planned N applied at hilling with additional N to be applied as fertigation using petiole and leaflet tissue samples to guide subsequent application amounts. A 3-acre wiper operating in bulk 1 was used as a N check and received N only at planting.

The Bulk 2 field received an additional application of ammonium nitrate and vine growth and tuber bulking were extended. Yields determined as field averages by the grower were 469 cwt/ acre for bulk 1 and 575 cwt/acre for bulk 2 which received the additional N application. The check field which received no supplemental N died early at 86 days and yielded only 359 cwt/ acre.

Discussion: considerations for use of slow release N sources

Three years of field scale trials in 2012-2014 have shown that slow release N sources such as ESN can be used on field corn and sweet corn to reduce applied N on irrigated sandy soils by replacing soluble N , which may be leached from the root zonein early season with slow release N which is released later, while maintaining yields. By protecting N from leaching as a result of early season high rainfall events and releasing N later when the plants need it, slow release N sources can significantly reduce N movement to groundwater and improve water quality.

Caution is urged however before applying the majority of N in early season applications of slow release formulations such as ESN to potato. The rate of N applied early in the season at hilling assumes that some N will be lost due to a large leaching event. Slow release N is protected against large loss of N during at such times and would be a valuable contributor to water quality. However, leaching events cannot be predicted and if they do not occur, the N need may be overestimated. This was seen in the 2012 trials when below average rainfall was experienced. As a result, the ESN regime, which anticipated some loss due to leaching, over-applied N by over a third compared to a standard regime in which supplemental N applications were not required. Yields were not impacted but the unneeded N in the ESN regime added to the total N budget and presented growers with an economic loss. Pre-season fertility plans for potato are nearly always adjusted during the season in response to field conditions. The potential for a dryer-than-average year and lower-than-average N applications reduces the potential reward for a single large application of slow release fertilizer early in the growing season.

The timing of N release from slow release formulations is a critical component in how they can be used successfully (Ruark etal, 2015). Pre-plant and side-dress are the industry standard times to apply these formulations which will then assure that sufficient N is released during tuber bulking. In this project field studies were conducted in 2013 and 2014 to define an N release curve in relation to field conditions (Ruark etal, 2013). Using accepted protocols to measure N release, nylon bags containing ESN were buried in potato fields and retrieved at intervals to measure N loss over time. In 2013 N release was monitored for 70 days at which point only 60% of the N had been released. In 2014 however, N release was monitored for 75 days and, at that point, 90% had been released. Based on data collected in 2013 and 2014, soil temperatures below 66 F reduced N release rate. Consideration of factors that impact soil temperatures such as solar radiation, irrigation, and canopy cover therefor need to be considered in determining how long N will be released in mid-late season.

It is also important to point out that slow release formulations can be damaged during handling and application. Such damage can significantly reduce the release period of N and the effectiveness of the formulation. Studies conducted in 2013 and 2014 using a standard 24 hour water tests to estimate damage and release rates from samples collected from applicators in the field showed that a 5-10% loss in mass indicated no damage while a 10-20% loss indicated probable damage and losses greater than 20% indicated significant damage and a likely change in release rates. In 2013 samples were taken of different blends of ESN and soluble formulations and 3 of 4 samples showed some evidence of damage while the 4th sample was significantly damaged. In 2014, release rates from damaged samples reached 80% at 30 days prior to undamaged samples.

Our results indicate that for crops with maturity lengths of 100+ days such as field corn or long season potatoes, slow release formulations can be used effectively if consideration is given to factors that can impact N release rates. For crop maturity lengths of 70-100 days such as short season potatoes or sweet corn, slow release formulations would be best applied at the earliest opportunity, preferably pre-plant, especially if these formulations are incorporated or the field is in no-till. Side-dress application of slow release formulations would still be an option for these crops but its efficacy may be reduced by damage in handling or high soil temperatures.

Slow release fertilizers such as ESN are not a good option for crops that mature before 70 days such as green beans or green peas, unless the field is double cropped.

Growers typically use petiole samples to determine the N status of potatoes and make decisions on the need for supplemental N applications in mid to late season. Growers and researchers have informally observer lower than expected petiole values for potatoes fertilized with slow release formulations compared to similar N rates using soluble fertilizers. In 2014, petiole results were in line with UW recommendations 30 days after and were then below for every subsequent collection while petiole levels from the check without ESN were in line with those expected at 50 and 74 days. These results indicate that growers using a significant proportion of a slow release such as ESN formulation early in the growing season would not be able to accurately assess the N needs of a crop in mid to late season and determine if supplemental N applications are needed. Studies were conducted in 2014 to determine if leaflet total nitrogen would provide a more accurate assessment of N need in potatoes fertilized with slow release fertilizers but results are preliminary and UW Extension currently does not have recommendations for using leaflet total nitrogen.

Conclusions and recommendations

The primary goals of this project in addressing water availability were firstly to increase the efficiency of irrigation and reduce waste through improved scheduling of applications in conjunction with improved monitoring of soil moisture conditions and secondly to reduce consumptive water use through deficit irrigation.

The development of a new computer-based irrigation scheduling program, WISP-2012, which incorporates specific modules for canopy development for a range of vegetable crops that are also linked to heat unit accumulations, was an important foundational step in achieving the first of these goals. The demonstration that WISP-2012 predictions of soil moisture, using remote sensing of atmospheric conditions, plant canopy and soil characteristics, was closely correlated with actual soil moisture (and thus irrigation need), as measured by the two primary types of moisture sensors , in multiple crops over 3 years, confirmed that growers could confidently use WISP-2012 to schedule irrigations only when these are needed and eliminate waste.

On-farm demonstrations linking pre-season, field mapping of moisture holding capacity using electrical conductivity, with actual soil moisture, measured with tensiometers, and predicted soil moisture from WISP-2012, clearly showed that differences in soil water holding capacity can vary significantly across fields that are visually similar and that these differences can translate into significant yield differences. This relationship between pre-mapped, in-field variability in moisture holding capacity and actual moisture level differences across fields is critical to the success of variable-rate irrigation technologies which are being actively pursued by growers in Central Wisconsin. The ability of WISP-2012 to closely track actual soil moisture in the field and interact with the variable-rate irrigation technologies of the future is an important achievement. New educational materials and training provided by this project will allow vegetable growers in Central Wisconsin to quickly rapidly adopt more efficient irrigation practices

Our second goal of using deficit irrigation to actually reduce consumptive water use by withholding water during non-critical growth stages has set the stage for growers in Central Wisconsin to begin to reduce the amount of water currently used in vegetable systems. Data from 2013 and 2014 strongly suggest that deficit irrigation on sweet corn could be implemented in Central Wisconsin without adverse impacts on yield or quality. These trials examined a 3-4 inch water deficit applied season long. Over 60,000 acres of sweet corn are grown in Central Wisconsin and if a 3.5 inch/acre reduction in irrigation water were implemented widely, groundwater withdraws could be significantly reduced. It is recommended that further research be conducted with sweet corn to refine the impacts of timing water deficits during the season in order to maximize the potential savings. Reducing the water applied to sweetcorn also increased the nitrogen concentration in ear leaves indicating that less leaching and greater nitrogen uptake could result in both environmental and economic gains.

While increasing irrigation efficiency and reducing overall water use were critically important goals to address current needs, preserving the sustainability of Central Wisconsin's groundwater and surface water resources for the long term was of equal importance in this project. Developing a comprehensive White Paper which, for the first time, brought together all of the existing hydrological and agronomic knowledge assembled over the last half century and carefully examined the interaction of physical and biological factors that could impact water management in the region, provided the foundation for ongoing work in this and related projects.

Our research, in collaboration with the Wisconsin Geological and Natural History Survey, examined the interaction of groundwater and surface water in several lakes and streams in Central Wisconsin where lower lake levels and reduced stream flows have been associated with irrigation. The resulting improved understanding of the interaction between groundwater, agriculture and surface water has made important contributions to ongoing modeling projects in the Little Plover River watershed in the northern Central Sands and will be invaluable as these models are adapted to aid in water management across the region.

The network of continuous monitoring wells installed by this project in each of 3 areas where surface water impacts have been linked to irrigation, is providing a continual public record of fluctuations in groundwater depth in these areas. This database provides data on both temporal and spatial variability in groundwater fluctuations in critical areas which will be an important component of future water management approaches. As an indication of the importance of this database and their commitment to the future, the grower association assumed responsibility for maintenance and public posting of the data at the conclusion of the CIG.

A broader commitment to monitoring fluctuations in groundwater depth between years and across the Central Sands is being provided by the grower-led initiative to monitor fluctuations in high capacity irrigation wells. Initiated in 2011, this network has now expanded to over 600 wells across 4 counties which is providing unprecedented information on groundwater fluctuation. The database is maintained by the grower association and can be accessed for research, modeling and management purposes. The database is already being consolidated with other public databases to begin to examine potential interactions between groundwater fluctuation and climate, agricultural density, crop and non-crop landscapes and other factors that must be considered in water management.

Water quality is also a critical concern in the long term sustainability of the aquifer underlying the Central Sands with leaching of nutrients , pesticides and manure all potentially impacting the quality of its water. In this project we focused resources on nutrients with specific studies and field demonstrations on slow release nitrogen fertilizer and manure.

Three years of on-farm trials in 2012-2014 demonstrated that slow release N sources such as ESN can be used on sweet corn and field corn to reduce applied N on irrigated sandy soils by replacing soluble N applied in early season, which can be lost due to leaching, with N released later in the season, without sacrificing crop yield. By protecting N from leaching as a result of early season high rainfall events and releasing N later when the plants need it, slow release N sources can significantly reduce N movement to groundwater and improve water quality. In long season potatoes caution is urged however before applying the majority of N in early season applications of slow release formulations such as ESN because leaching events cannot be predicted and if they do not occur (as seen in 2012), the N need may be overestimated and excess N may be applied resulting in economic loss. Studies conducted in 2013-14 demonstrated that timing of N release from slow release formulations was temperature dependent and soil temperatures below 66 degrees decreased the amount of N released in mid-season.

Overall, our results indicate that for crops with maturity lengths of 100+ days such as field corn or long season potatoes, slow release formulations can be used effectively if used as side dress applications. For crop maturity lengths of 70-100 days such as short season potatoes or sweet corn, slow release formulations would be best applied at the earliest opportunity, preferably pre-plant, especially if these formulations are incorporated or the field is in no-till. Slow release fertilizers such as ESN are not a good option for crops that mature before 70 days such as green beans or green peas, unless the field is double cropped.

Large scale dairy operations are increasing in Central Wisconsin and the integration of manure into vegetable cropping systems is an important consideration. In this CIG project we worked with growers to demonstrate that manure can be an effective source of nitrogen on sweet corn, field corn and potatoes that has the potential to reduce leaching and improve soil moisture holding capacity. However, when used in vegetable crop rotations, the impact of increased P concentrations on rotation crops is of concern in developing nutrient management plans.

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