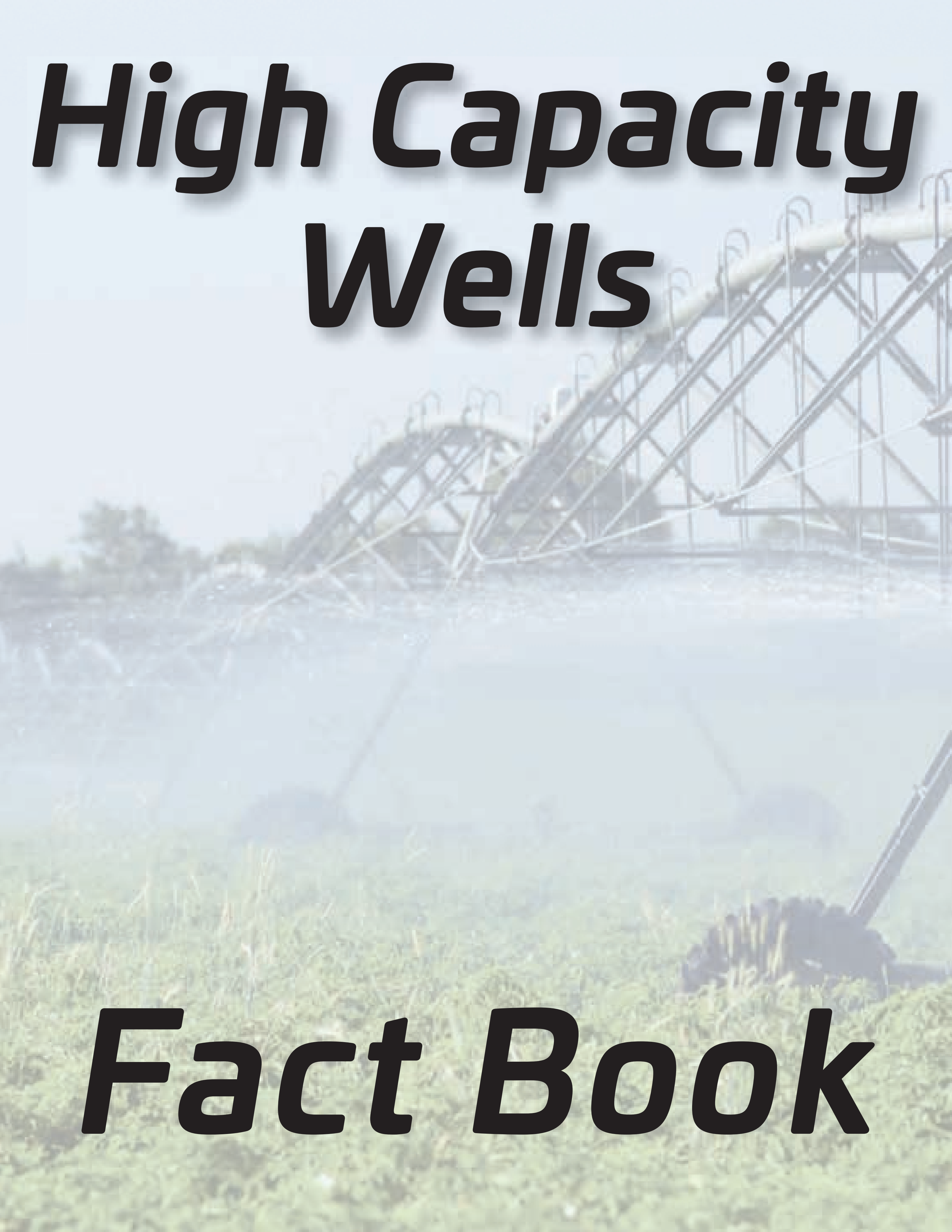
High Capacity Wells

Fact Book



FACT SHEET: High Capacity Well (HCW) Issue

I. **Tab A: Portage County, located north-centrally in a 6 county area consisting of the counties of Portage, Wood, Waupaca, Adams, Waushara, and Marquette, commonly referenced as "Wisconsin Central Sands." Portage County has become the epicenter of the HCW controversy due to its prominence.**

- Largest number of high capacity wells
- Largest producer of irrigated vegetable crops; potatoes, snap peas, green beans, sweet corn, carrots, & red beets.
- Much studied Little Plover River
- Number of seepage lakes currently exhibiting low water levels. (Primarily Waushara County)

II. **Tab B: The relationship of groundwater levels to stream flow, HCW pumpage, and precipitation (rainfall).**

- Scientists have established that annual precipitation maintains the static groundwater levels at maximum height (light blue) and that the excess precipitation (transient water) exits to streams (dark blue).
- Demonstrates that shallow residential wells located within the transient water table (dark blue) can be affected by fluctuating seasonal water levels.

  Note: Shallow well centrifugal pumps have a maximum operational efficiency of 22' under perfect maintenance conditions.

- **Tab C:** Rainfall totals in gallons for HCW pumpage vs. rainfall.
- **Tab D:** Annual rainfall for Portage County in inches and gallons for years 2011, 2012, and 2013.

III. **Tab E: The Golden Sands Dairy (GSD) project, located in the Township of Saratoga, Wood County, Wisconsin application for HCW permits was required to compile an Environmental Impact Report (EIR).**

- The study area comprised approximately 1,015 square miles.
- **Tab F**: The scientific data compiled in the GSD EIR will be analyzed by the Wisconsin Department of Natural Resources (WDNR), upon which it will render its decision in issuing the official Environmental Impact Statement (EIS).

IV. Tab G: On October 10, 2015, the DNR released its methodology for estimating monthly and annual recharge.

- Formula: RECHARGE = precipitation + applied irrigation – actual evapotranspiration (ET).
- To better understand the impacts of irrigation and landcover change in the Central Sands, the Wisconsin Department of Natural Resources employed remote sensing data and a process-based model to quantify annual and monthly recharge rates. Results showed that average annual net recharge rates across the 1,000 square mile study area were similar between forests, grasslands and irrigated agriculture. Results also indicate that the factors controlling recharge such as precipitation, applied irrigation water, and evapotranspiration, can vary throughout any given year and across the study area. These results highlight the need for continued research regarding evapotranspiration rates and incorporating the most detailed model inputs available.
- **Tab H**: Evapotranspiration of various land covers depict that irrigated crops use less water than other land cover such as trees and grassland.
- **Tab I:** RECHARGE to groundwater on an annual basis is greater from irrigated cropland than from land covers such as trees and grassland.
- Greater recharge and lesser evapotranspiration from irrigated cropland than other land covers such as trees and grassland results in greater flow of transient water in streams.
- **Tab J:** Water Cycles, Evapotranspiration and Irrigation

Tab K: Monthly recharge from various land covers due to climate, i.e. rainfall and temperature.

- The effects of climate brings into major question the use of the setting of a stable public rights stage in streams. Plus the current initiative for irrigated agriculture to correct a circumstance which it doesn't cause or having no more control of than the effect of other land cover uses.
- **Tab L:** The minimal effects the GSD project will have on summer flows in Ten Mile Creek beginning in 2017.
- UW-Madison scientists peer-reviewed the DNR's methodology for calculating evapotranspiration (ET) and corrected it by increasing irrigated cropland ET by up to 2" annually. This correction to ET also reduced recharge by a similar amount – these changes are depicted on the charts behind tabs H & I.

V. Tab M: Reforestation and afforestation effects on groundwater recharge: Draft scientific paper by UWSP Professor and Wisconsin Institute for Sustainable Technology (WIST) Director, Paul Fowler

- Growth of forested lands in Wisconsin chronicled over time and resulting effects on groundwater recharge, especially from the largest growth species, namely conifers.

- Cites worldwide scientific community studies and conclusions that trees have a major negative impact on groundwater recharge.
- Cites state of Wisconsin's Policy of Reforestation as a cause, in part.

VI. Tab N: Little Plover River Study Findings

- HCW pumping impacts stream flow and groundwater flow patterns.
- Land use, such as trees, grassland, and agricultural crops, impact recharge rates.
- The model created by the study can be useful in evaluating changes in land use in other areas.
- HCWs nearest to the River have the greatest impacts.
- The impacts of pumping on the River are spread out over time.

Editor's Note: There are extraneous impacts from proximate land, use changes, which need to be calculated in applying the study's findings to achieve a comprehensive assessment of impact to stream flow.

- Accurate calculation of recharge from applied irrigation water, which is redistributed within a 1,300 foot radius of the predominate locations of withdrawal. See Exhibit B.
- The effects of municipal and industrial HCW pumping that distributes pumped water away from the River's recharge area.
- The effects of urbanization and development that has occurred over time and the proliferation of impervious surfaces such as roads, roofs, driveways, parking lots, and the resulting loss of normal recharge exiting the recharge area through storm water drains and runoff.
- The effect on stream flow resulting from the conversion of the headwaters area from wetland to agricultural use by drainage ditches and removal of dams and weirs from the original drainage ditches.
- The effects of the buildup of silt and debris over time constricting the stream bed.

VII. Tab O: Lakes; Plainfield, Long, Huron, Pleasant et al.

- Historically, these lakes have experienced significant high and low water levels, **pre**-large scale HCWs.
- Current geophysical knowledge of these lakes is lacking as to their makeup and the cause of this phenomenon. See Tab P.

Tab P: Study reveals that small seepage lakes (unaffected by outside influences) and water tables are correlated to the Great Lakes water level fluctuations and that water level cycles are caused by macro-continental weather patterns.

- Lakes Superior, Michigan, and Huron water levels have risen and fallen cyclically every 13 years for at least the past 70 years, except for the last decade in which the low levels extended.
- Recent geophysical research has found a connection to these cyclical water levels to macro-climatic conditions similarly affecting water level fluctuation on the Great Lakes and pristine Wisconsin lakes, un-impacted by HCW pumping, runoff, or human influence.
- Wisconsin DNR staff analyzed long-term variation (1951-2014) in annual average lake levels, groundwater levels and stream flows across the state. Results showed that water levels and flows in northeastern and central Wisconsin were strongly correlated with variation in the levels of Lake Michigan and Lake Superior. In the northeast and central region, water levels were above average for a prolonged period from the late 1960's to mid-1990's until declining in recent years. Water levels and flows in the northwestern portion of the state demonstrated a similar prolonged, above average period lasting from the mid-1970's through the early 2000's before declining. By comparison, average water levels and flows in the southern third of Wisconsin increased across the entire period. These results demonstrate that water levels and flows are strongly subject to long-term weather and climate variation and that this variation is not consistent across the entire state. Results from this study will serve as a starting point for understanding the difference between weather induced impacts on water levels and flows from human induced impacts.

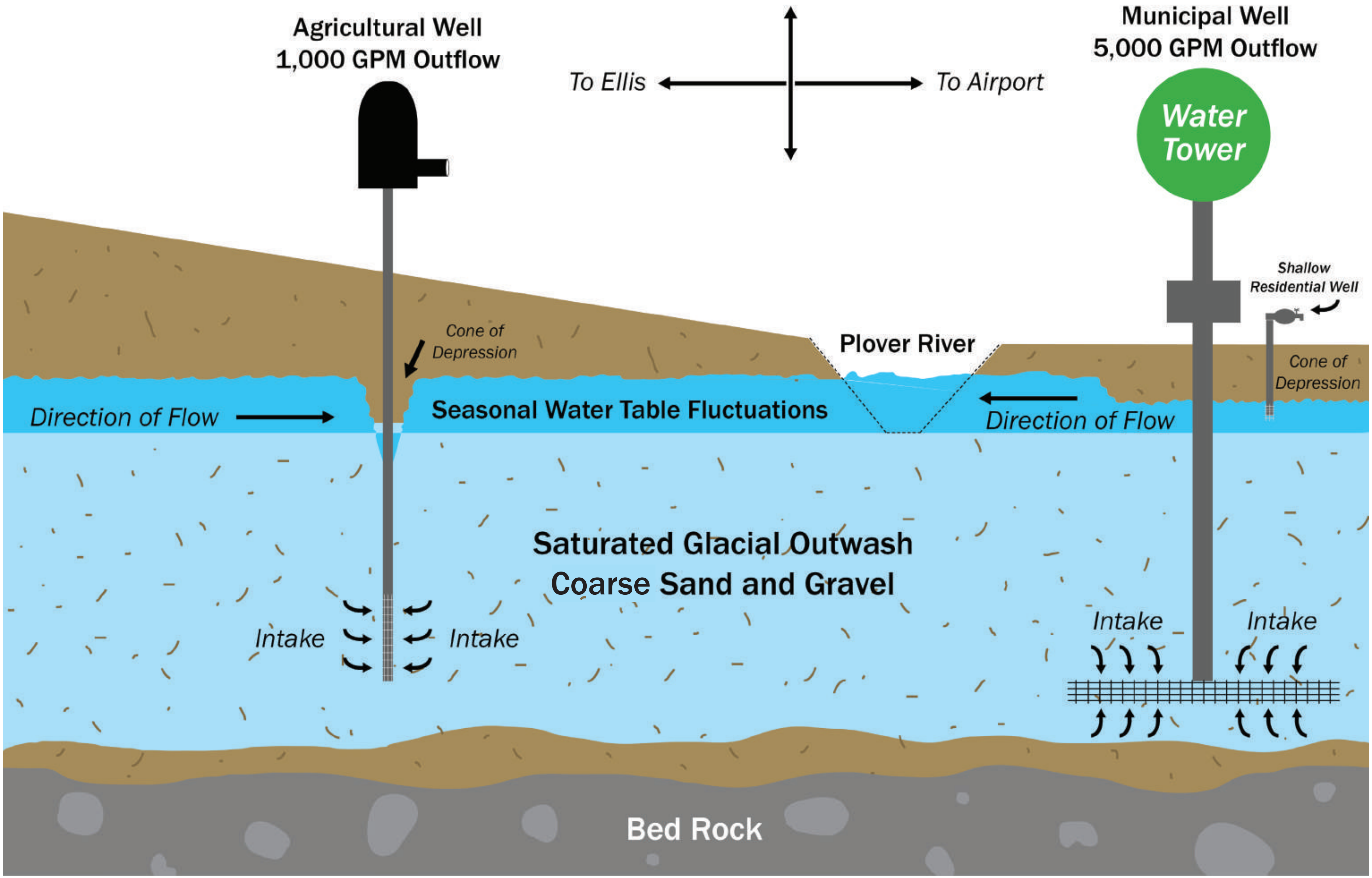
VIII. Tab Q: Economic Impact of Irrigated Vegetable Crops

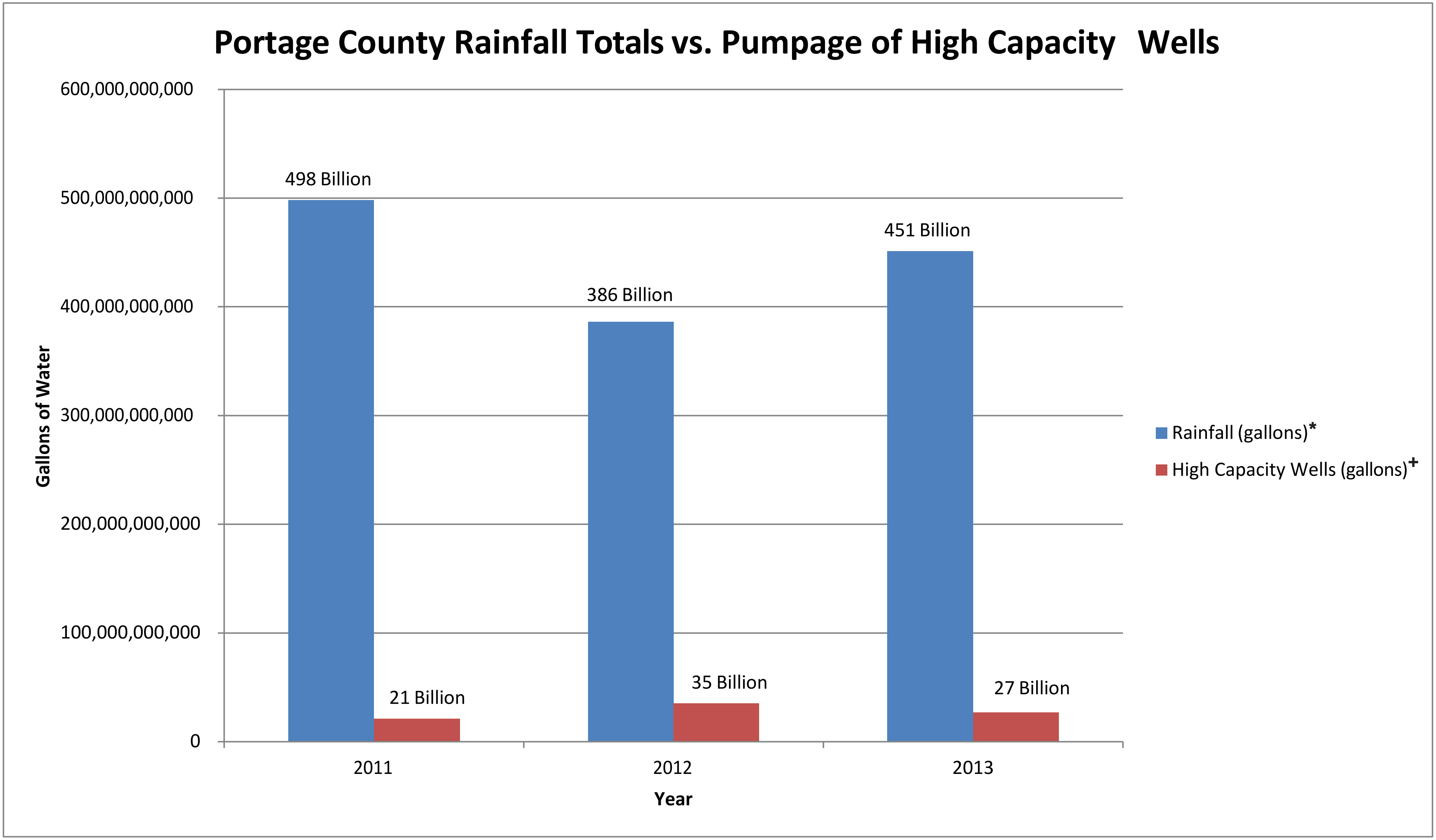
- Economic impact.
- Without consistent, adequate irrigation water, Wisconsin's thriving vegetable industry would collapse. Unlike field crops, vegetable production requires consistent and uniform irrigation water to produce the quality that processors and fresh market buyers require.

IX. Tab R: Wisconsin Potato and Vegetable Growers

- Committed to sustainable agriculture and environment.
- **Tab S:** Water Task Force, Industry cooperation and involvement.

Groundwater




Portage County Rainfall Totals vs. Pumpage of High Capacity Wells
600,000,000,000
500,000,000,000
400,000,000,000
300,000,000,000
200,000,000,000
100,000,000,000
0
Gallons of Water
498 Billion
21 Billion
386 Billion
35 Billion
451 Billion
27 Billion
2011
2012
2013
Year
Rainfall (gallons)*
High Capacity Wells (gallons)+

526,720

total acres in portage county

Annual Rainfall Totals for Portage County*

Year	Rainfall (inches)
2011	34.84”
2012	26.98”
2013	31.52”

Combined Annual Rainfall in Portage County*

Year	Combined Rainfall (gallons)
2011	498,306,254,878 gal.
2012	385,886,990,718 gal.
2013	450,821,273,070 gal.

*Based on monthly rainfall totals for Stevens Point, Wisconsin from 2011-2013.

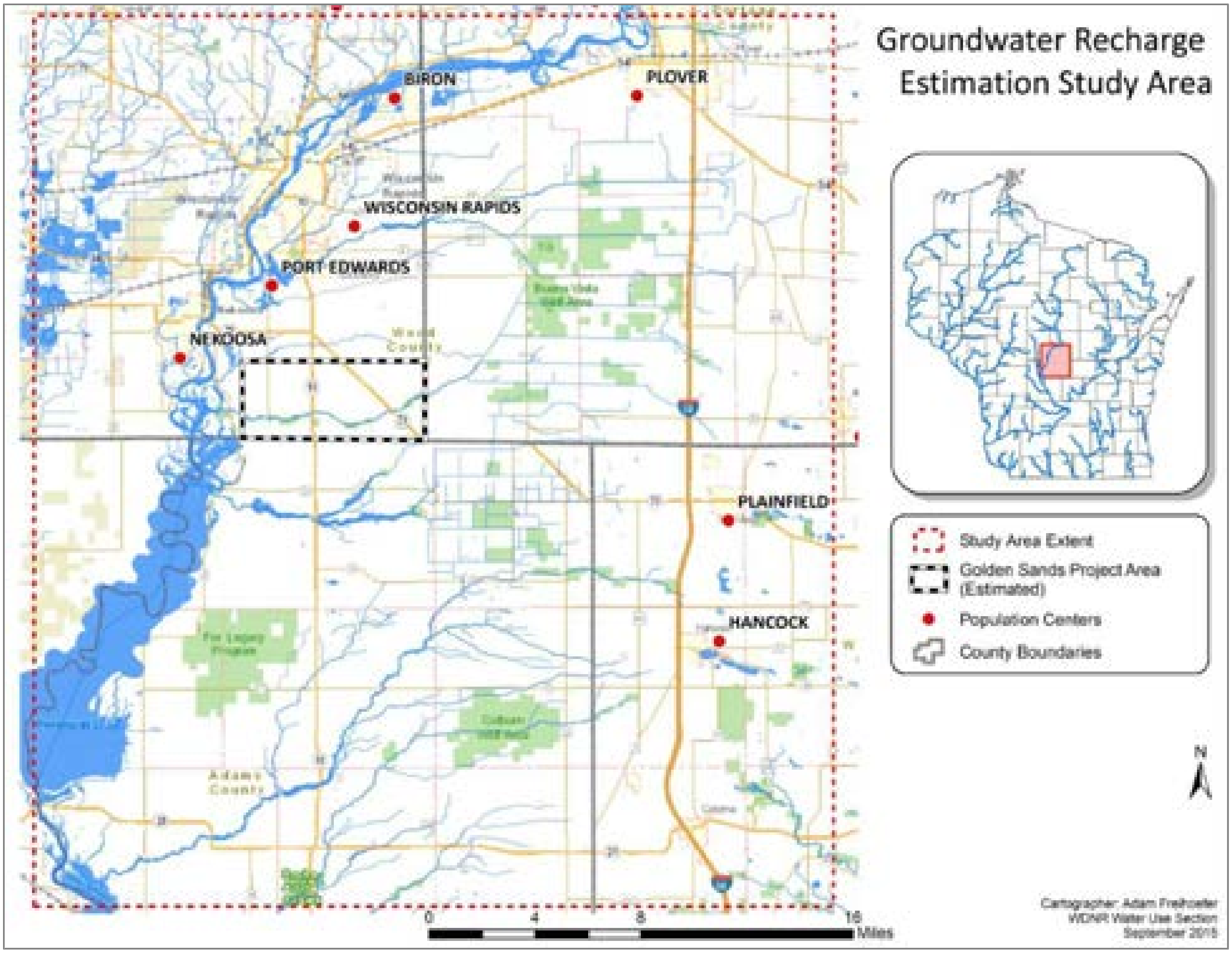


Figure 1: Extent of groundwater recharge study area

S.S. PAPADOPULOS & ASSOCIATES, INC.
Environmental & Water-Resource Consultants

Memorandum

Date: December 2, 2015

From: Charles Andrews

To: Rachel Greve and Adam Freihoefer, Wisconsin Department of Natural Resources

Subject: **Golden Sands Dairy Project**
Groundwater Model Revisions

A groundwater model was developed of the Central Sands by S.S. Papadopulos & Associates, Inc. to evaluate the potential effects of groundwater pumping for the Golden Sands Dairy (GSD) project on groundwater levels and stream flows. The groundwater model and model calculated changes in groundwater levels and stream flows in the vicinity of proposed high capacity wells for the GSD project are described in detail in Appendix D to the "Environmental Impact Report, Golden Sands Dairy, Saratoga Township, Wisconsin" (EIR) dated March 2014. An addendum to the EIR (Addendum) was submitted to the Wisconsin Department of Natural Resources (DNR) in December 2014 reflecting a reduction in the number of high capacity wells and proposed irrigated acreage for the GSD project.

This memorandum updates the calculated changes in groundwater levels and stream flows as described in the EIR based on the revised project scope, and provides additional information on the groundwater model. Information on the groundwater model and calculated changes in hydrologic conditions are also contained in materials submitted to the DNR in response to comments from DNR staff on the EIR and Addendum. These additional materials include: 1) letter to Russell Anderson, DNR, from Anna Wildeman, Michael Best & Friedrich, dated August 19, 2014; 2) memorandum from Charles Andrews to David Crass, Michael Best & Friedrich, dated March 15, 2015 that was sent via email to Rachel Greve, DNR, on March 16, 2015; and 3) letter to Russell Anderson, DNR, from David Crass, Michael Best & Friedrich, dated June 12, 2015.

DNR staff (Adam Freihoefer and Rachel Greve) on September 28, 2015, via telephone conference call, provided additional comments and observations regarding the groundwater model based on their detailed review of the groundwater model and supplemental materials that had been submitted to the DNR. In addition, they provided detailed evaluations of: 1) the spatial extent of the New Rome Member, 2) surface water diversions from the Tenmile and Sevenmile watersheds, 3) stream flows in Tenmile and Sevenmile creeks, 4) precipitation within the model domain, and 5) evapotranspiration (ET) rates within the model domain based on data collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra and Aqua satellites.

In response to comments, observations, and evaluations from DNR staff and at the DNR's request, the groundwater model was revised and recalibrated. The following changes were made to the groundwater model structure and setup:

- The extent of the New Rome Member was revised based on the evaluations conducted by DNR staff. The revised extent of the New Rome Member is shown on revised Figure 2-17.
- The elevation of the base of the Sand and Gravel Aquifer was revised based on a re-evaluation of the available well logs. The largest revisions were made in the eastern part of the model domain. The revised elevation of the base of the Sand and Gravel Aquifer is shown on revised Figure 2-17.
- The model was setup to simulate a normal year followed by two consecutive dry years. The dry years are patterned after climatic conditions in the years 2012 and 2006.
- The model recharge array was modified to explicitly incorporate actual predominate land cover within the model domain. The land cover types represented in the model domain are shown on revised Figure 9.
- Monthly ET rates for each land cover type within the model domain were specified on the basis of MODIS data that were compiled by DNR staff. These rates represent average monthly rates for the period 2000 to 2011. These ET rates were used to calculate monthly recharge rates using a soil water balance approach. This approach is described in detail in Attachment F of Appendix D of the EIR. The monthly ET rates are listed on Table 1-1 and the monthly recharge rates are listed on Table 1-2. Land cover types represented in the model, with average annual recharge rates, are shown on Figure 9. Note that developed land was assigned the same recharge rate as grasslands, cranberry bogs were assigned the same recharge rate as wetlands, and mixed forest was assigned a recharge rate that was the average of rates for coniferous and deciduous forests.
- For a sensitivity analysis, ET rates for irrigated fields were also calculated using a crop coefficient approach and average monthly ET rates (for the period 2000 to 2011) from Hancock Agricultural Research Station as described in Appendix D to the EIR (Table 1-1). For the sensitivity analysis, the maximum ET rate derived from MODIS data or the crop coefficient method was used for each month. This sensitivity analysis is referred to as "MODIS adjusted for irrigated fields" or "MODIS adjusted" analysis. Summer ET rates from the irrigated fields are higher in the MODIS adjusted analysis than in the analysis using MODIS ET rates. The MODIS adjusted monthly ET rates are listed on Table 1-1.
- Existing irrigation pumping was explicitly represented in the groundwater model (previously existing irrigation pumping was represented as the net of pumping minus recharge). The pumping rates used to represent the normal year were based on reported pumping rates for the years 2007 through 2011. The approach used to derive the pumping rate for the normal year is described on page 5 of the March 15, 2015 memorandum from Charles Andrews to David Crass.

- Monthly precipitation rates were specified as the average monthly rates measured at Wisconsin Rapids, Stevens Point and the Hancock Agricultural Research Station during the period 2000 to 2011 (Table 1-1).
- Pumping rates for the first dry year (based on 2012 conditions) in the simulation were specified as the rates reported to DNR for all high capacity wells within the model domain for the year 2012. Pumping rates for 2006 were specified as 1.145 times the rates for the normal year. This factor was calculated to maintain the same irrigation efficiency in 2006 as in the normal year. Irrigation efficiency is calculated as the ratio of monthly ET to total applied water (precipitation plus irrigation water). The factor was calculated based on an irrigation efficiency of 71 percent in July and August.
- The modeling layer structure was modified to eliminate discontinuities in the model layers in the vicinity of the Wisconsin River.
- The hydraulic conductivity estimates derived from specific capacity data were used as conditioning information for developing a continuous hydraulic conductivity distribution in the model calibration process. The hydraulic conductivities derived from specific capacity data are described in Attachment B to the Addendum dated December 2014. The final calibrated hydraulic conductivity distribution is shown on revised Figure 10.

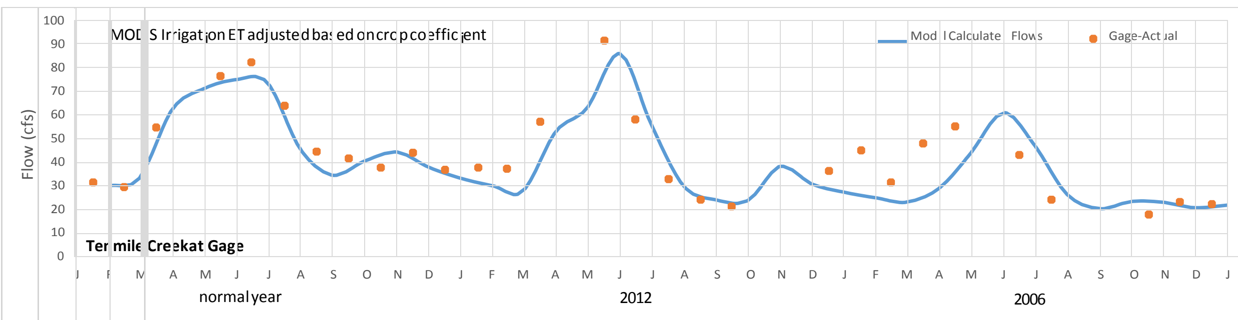
Model Recalibration

The model was recalibrated after the structural changes described above were made. In developing the original groundwater model it was noted that model calculated groundwater levels were relatively insensitive to hydraulic parameters within reasonable ranges. Therefore, model calibration focused on obtaining a good correspondence between model calculated flows and measured flows in Tenmile Creek at the gage, calculated flows and measured flows in Sevenmile Creek, and the average annual calculated and measured flow gains in Tenmile Creek between County U and the gage and between the gage and County Z (just upstream of the mouth)[1]. In the model calibration process, the parameters that were adjusted were the hydraulic conductivity, the monthly distribution of recharge, and the bed elevation of Tenmile Creek. The calculated flow in Sevenmile Creek is very sensitive to the hydraulic conductivity in the vicinity of the creek, the flow in Tenmile Creek at the gage is very sensitive to the monthly distribution of recharge and the magnitude of recharge, and the gain in flow of Tenmile Creek is sensitive to the hydraulic conductivity and the elevation of the bed of Tenmile Creek. Numerous model runs were conducted to evaluate model parameter sensitivity and to select an optimal parameter combination. The calibrated hydraulic conductivity of the Sand and Gravel Aquifer is shown on revised Figure 10

[1] Based on available flow data, it was determined that on an average annual basis Tenmile Creek gains approximately 20 cfs between County U and the gage, and approximately 11 cfs between the gage and County Z.

and the monthly distribution of recharge is listed on Table 1-2. The bed elevation of Tenmile Creek downstream of County U was lowered three feet from the initial estimate of bed elevation in the final calibrated model.

Model calibration was conducted with ET for existing irrigated fields specified as the MODIS adjusted ET. The correspondence between model calculated flows and measured flow in Tenmile Creek at the gage for the calibrated groundwater model, with the MODIS adjusted irrigation ET, is very good as shown on the graph below.

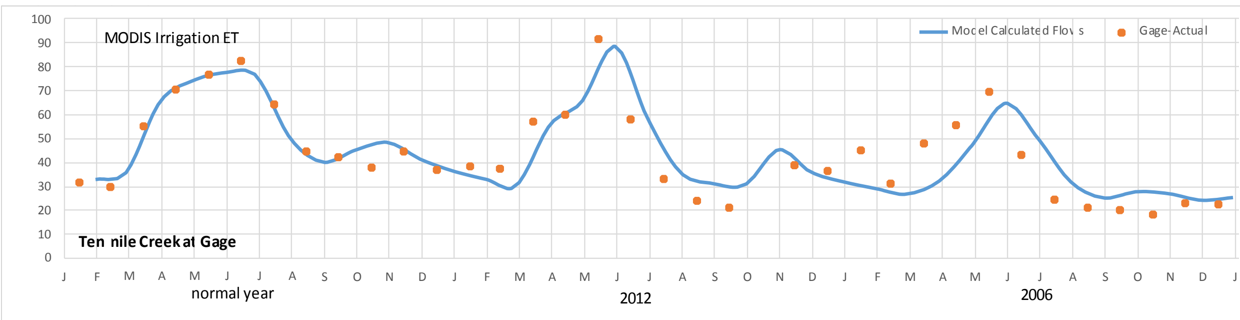


It is important to note that the poor correspondence between model calculated flows and measured flows in the early months of the dry year 2006 results from the fact that antecedent conditions were specified on the basis of 2012 climatic data and not 2005 climatic data.

In the calibrated model, the annual average gain in flow in Tenmile Creek between County U and the gage is 14.3 cfs versus a measured gain of approximately 20 cfs and the average annual gain in flow in Tenmile Creek between the gage and County Z is 8.4 cfs versus a measured gain of approximately 11 cfs. The calculated average annual flows of Sevenmile Creek at Rangeline Road, County Z, and County U are 3.8 cfs, 1.9 cfs and 1.5 cfs, respectively. These flows closely correspond to measured flows.

Considerable effort was expended attempting to understand why the calibrated groundwater model under predicted the gains in flow in Tenmile Creek downstream of County U. No good explanation for the cause of the under prediction was developed. It was noted that in the report by Weeks and Stangland (1971, page 62) that they were also perplexed by a larger than expected gain in flow in Tenmile Creek in the reach downstream of County U.

The correspondence between model calculated flows and measured flows in Tenmile Creek at the gage, with ET from irrigated fields specified based on the MODIS data, is shown on the graph below.



During the summer months, ET from irrigated fields, as estimated from MODIS data, is lower than ET estimated using the crop coefficient method. As a result, the model calculated flows in the summer months, with ET based on MODIS data, are larger than the model calculated flows with ET based on the crop coefficient method.

Calculated Stream Flow Changes from Golden Sands Dairy Project

The recalibrated groundwater flow model was used to calculate potential changes in stream flows and groundwater levels from the GSD project. For these simulations the existing land cover was replaced with irrigated agriculture on the fields that are proposed to be irrigated as part of the GSD project; that is recharge rates for existing land cover were replaced with recharge rates for irrigated fields. The amount of applied irrigation water in these simulations was 11.50 inches in the normal year, 13.20 inches in the dry year based on 2006, and 17.08 inches in the dry year based on 2012. Two simulations were conducted; one in which ET from the GSD fields was specified as the MODIS adjusted ET and the other in which ET from the GSD fields was specified as the MODIS determined ET rate for irrigated fields in the model domain. The results of these simulations are listed on Tables 2-1, 2-2a, and 2.2b; Table 2-1 lists the results of the GSD simulations for the normal year, Table 2-2a lists the results of the simulation of the dry year 2006, and Table 2-2b lists the results of the simulation for the dry year 2012.

The calculated projected stream flow reductions from the GSD project with this revised and recalibrated groundwater model are smaller than those in the EIR and the Addendum. The stream flow reductions are smaller because the increase in ET in converting from the existing land cover to irrigated fields in the revised model is smaller than in the model described in the EIR. In the model described in the EIR, it was specified that conversion of the pine plantation to irrigated agriculture would increase ET in the normal year by 2.1 inches (from 21.8 inches per year for pine plantation to 24.0 inches per year for irrigated fields). In the revised model, with the MODIS adjusted ET from irrigated fields, the increase in ET in converting from existing land cover to irrigated fields is only 0.88 inches per year (from 22.35 inches for existing land cover to 23.23 inches per year). In the revised model, with the MODIS derived ET from irrigated field, the GSD conversion to irrigated agriculture results in a decrease in ET of 1.16 inches per year (from 22.35 inches for existing land cover to 21.19 inches per year for irrigated fields). As a result of a decrease in ET with conversion to GSD irrigated fields, average annual flows in Sevenmile Creek and in Tenmile Creek would increase.

The simulations of the GSD project suggest that flows reductions in Sevenmile and Tenmile Creek will be minimal, even during the summer months. The effects are small, in part, because the high capacity wells are located as far as practical from Sevenmile and Tenmile creeks, which attenuates the effects of high pumping rates during the summer months on stream flows.

The revised and recalibrated model suggest that the results of the simulation of the GSD project described in the EIR and the Addendum represent an upper bound estimate of groundwater level and stream flow reductions potentially caused by the project. In the EIR and the Addendum there are numerous figures depicting groundwater level changes and stream flow changes that potentially will result from the GSD project. No additional similar figures are presented to depict the results of the simulations with the revised and recalibrated model. The original figures depict larger estimates of potential negative changes in groundwater levels and stream flows than are calculated with the revised and recalibrated model. These original figures depict a likely upper bound on potential reductions in flows and groundwater levels. Detailed results of the model simulations are listed on Tables 2-1, 2-2a and 2-2b and these detailed results provide sufficient information to compare these model results to the previous model results described in the EIR and the Addendum.

Calculated Stream Flow Changes with Conversion of Existing Irrigated Fields to Natural Vegetation

At the request of the DNR, the revised and recalibrated groundwater model was used to simulate stream flows and groundwater levels with the conversion of all irrigated fields within the model domain to natural vegetation (assumed to be comprised equally of deciduous trees, coniferous trees and grassland). For this simulation, no irrigation pumping was specified and recharge rates for existing irrigated fields were specified as the average recharge rates for deciduous, coniferous and grassland land cover. The stream flows calculated with this simulation were then subtracted from the stream flows calculated in the simulations of existing conditions to determine the stream flows changes that would result from this conversion (note that there are two sets of existing conditions, one calculated with MODIS adjusted ET from irrigated fields and the other calculated with MODIS ET from irrigated fields). The results of this evaluation are tabulated on Table 2-3 for the normal year, on Table 2-4a for the dry year based on 2006, and on Table 2-4b for the dry year based on 2012.

On an average annual basis, the conversion of irrigated fields to natural vegetation, for the existing condition simulation based on MODIS ET for irrigated fields, results in a decrease in stream flows in the model. This decrease in stream flows occurs because the specified ET rates for the natural vegetation are greater than the ET rates for irrigated fields (refer to Table 1-1). On the other hand, August stream flows generally increase as the result of the conversion due to the cessation of irrigation pumping during the summer months.

Table 1-1

Precipitation and Evapotranspiration

Month	Precipitation (inches)	Evapotranspiration Rates from MODIS (inches)						Irrigation ET Adjusted	ET-Hancock (inches)
		Grasslands	Deciduous	Evergreen	Irrigation	Non-Irr	Wetlands		
Normal Year									
Jan	0.9	0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.2
Feb	1.1	0.7	0.7	0.7	0.6	0.7	0.7	0.6	0.5
Mar	1.6	1.2	1.3	1.2	1.2	1.3	1.3	1.2	1.5
Apr	3.3	1.4	1.4	1.4	1.3	1.4	1.4	1.3	2.8
May	3.9	2.2	2.3	2.3	1.8	2.1	2.3	1.8	4.4
June	4.9	3.5	4.0	3.8	3.3	3.8	4.2	3.3	5.5
July	3.4	4.1	4.7	4.3	4.3	4.5	4.8	5.4	6.4
Aug	3.7	3.4	3.9	3.7	3.7	3.9	4.0	4.7	5.5
Sept	3.5	2.0	2.3	2.3	2.1	2.4	2.2	2.2	3.1
Oct	2.2	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.4
Nov	1.7	0.7	0.7	0.7	0.8	0.8	0.7	0.8	0.4
Dec	1.4	0.5	0.6	0.5	0.6	0.6	0.6	0.6	0.1
Total	**31.6**	**21.3**	**23.4**	**22.5**	**21.2**	**22.8**	**23.8**	**23.3**	**31.6**
Dry Year Based on 2012									
Jan	1.0	0.7	0.7	0.6	0.8	0.8	0.8	0.8	0.3
Feb	1.2	0.9	0.9	0.7	1.0	1.0	0.9	1.0	0.7
Mar	2.7	1.6	1.6	1.5	1.6	1.6	1.6	1.6	2.3
Apr	2.8	1.4	1.4	1.5	1.4	1.4	1.4	1.4	3.3
May	5.7	2.5	2.9	2.8	1.9	2.3	2.9	1.9	5.4
June	1.9	3.5	4.3	3.9	3.1	3.6	4.5	3.4	6.8
July	0.7	3.5	4.3	3.9	4.2	4.1	4.6	6.1	7.1
Aug	3.3	2.7	3.4	3.2	3.3	3.3	3.5	4.6	5.4
Sept	1.8	1.7	1.9	2.0	1.8	2.0	1.8	2.4	3.4
Oct	5.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.3
Nov	1.4	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.4
Dec	1.7	0.6	0.6	0.5	0.5	0.6	0.6	0.5	0.1
Total	**29.2**	**20.8**	**23.6**	**22.3**	**21.3**	**22.4**	**24.4**	**25.3**	**36.4**
Dry Year Based on 2006									
Jan	1.1	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.2
Feb	0.7	0.7	0.8	0.7	0.8	0.8	0.8	0.8	0.5
Mar	1.2	1.3	1.3	1.2	1.3	1.4	1.3	1.3	1.5
Apr	2.3	1.2	1.1	1.3	1.1	1.1	1.1	1.1	3.2
May	5.1	2.3	2.4	2.5	2.0	2.2	2.4	2.0	4.4
June	1.5	3.2	3.8	3.6	3.0	3.5	4.0	3.0	5.6
July	2.6	3.4	4.3	3.7	4.3	4.2	4.5	5.6	6.5
Aug	3.0	3.0	3.6	3.3	3.5	3.6	3.7	4.0	4.7
Sept	3.1	1.8	2.0	2.0	2.0	2.2	1.9	2.0	2.6
Oct	1.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.2
Nov	1.5	0.7	0.7	0.6	0.8	0.7	0.7	0.8	0.4
Dec	2.0	0.6	0.6	0.5	0.7	0.7	0.7	0.7	0.0
Total	**25.9**	**19.9**	**22.3**	**20.8**	**21.1**	**22.0**	**22.8**	**22.8**	**31.0**

Table 1-2

Recharge and Irrigation Rates

Month	Recharge Rates (inches)							Irrigation Rate (inches)
	Grasslands	Coniferous	Deciduous	Wetlands	Non-Irrigated	Irrigation (MODIS adjusted)	Irrigation (MODIS)	
Normal Year								
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Feb	0.4	0.5	0.5	0.4	0.5	0.4	0.4	0.00
Mar	2.6	2.7	2.2	2.5	2.6	2.7	2.7	0.00
Apr	2.0	1.9	2.1	1.8	1.9	1.9	2.0	0.00
May	1.8	1.6	1.6	1.6	1.9	2.3	2.3	0.23
June	1.5	1.2	1.0	0.9	1.3	3.5	3.5	1.86
July	0.0	0.0	0.0	0.0	0.0	2.2	3.2	3.59
Aug	0.1	0.1	0.1	0.1	0.1	1.9	2.8	3.40
Sept	0.7	0.1	0.1	0.1	0.2	2.6	2.7	1.31
Oct	1.0	0.9	0.5	0.4	0.4	1.4	1.4	0.19
Nov	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Annual	**10.4**	**9.1**	**8.2**	**7.9**	**8.8**	**18.9**	**21.0**	**10.58**
Dry Year Based on 2012								
Jan	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
Feb	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
Mar	2.2	3.1	1.6	1.0	2.6	**2.4**	2.4	0.00
Apr	2.2	0.8	1.3	0.8	1.4	**2.3**	2.3	0.00
May	3.2	2.3	1.9	2.2	2.1	**4.1**	4.1	0.23
June	0.2	0.2	0.2	0.2	0.2	**1.1**	1.4	2.65
July	0.0	0.0	0.0	0.0	0.0	**2.5**	4.3	7.90
Aug	0.0	0.0	0.0	0.0	0.0	**1.9**	3.2	3.09
Sept	0.0	0.0	0.0	0.0	0.0	**1.0**	1.6	1.62
Oct	0.6	0.5	0.6	0.6	0.6	**4.3**	4.3	0.19
Nov	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
Dec	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
2012 total	**8.4**	**6.9**	**5.6**	**4.8**	**6.9**	**19.6**	**23.5**	**15.67**
Dry Year Based on 2006								
Jan	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
Feb	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
Mar	0.6	0.0	0.0	0.0	0.0	**2.0**	2.0	0.00
Apr	2.4	2.1	0.8	0.1	0.9	**1.4**	1.4	0.00
May	1.7	1.7	2.3	1.7	1.7	**3.3**	3.3	0.23
June	1.0	1.0	0.2	1.0	1.0	**1.0**	1.0	2.54
July	0.0	0.0	0.0	0.0	0.0	**2.3**	3.6	5.22
Aug	0.0	0.0	0.0	0.0	0.0	**1.7**	2.1	2.62
Sept	0.0	0.0	0.0	0.0	0.0	**2.4**	2.4	1.31
Oct	0.0	0.0	0.0	0.0	0.0	**1.1**	1.1	0.19
Nov	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00
Dec	0.3	0.3	0.3	0.3	0.3	**0.0**	0.0	0.00
2006 total	**6.0**	**5.1**	**3.6**	**3.1**	**3.9**	**15.2**	**16.9**	**12.11**

Table 1-3

Measured and Calculated Flows in Normal and Dry Years

Location	Estimated Base Flow from Measured Data (cfs)	Model Calculated Average Annual Flows (cfs)					
		with MODIS Adjusted ET for Irrigated Fields			with MODIS ET for Irrigated Fields		
		Normal Year	Dry Year (2006)	Dry Year (2012)	Normal Year	Dry Year (2006)	Dry Year (2012)
Big Roche-A-Cri at 1st Ave	9	10.2	6.7	8.2	11.8	8.5	10.1
Chester Creek		4.7	4.1	4.4	4.7	4.1	4.4
Fourteenmile Creek near New Rome	19 to 43	27.3	13.9	20.6	29.5	15.8	22.9
Fourteenmile at mouth		38.9	23.4	31.4	41.2	25.3	33.8
Buena Vista Creek at 100th Rd	31	25.9	16.8	22.6	29.3	20.6	27.1
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	6	4.7	3.4	4.1	5.4	4.2	4.9
Fourmile Creek at 100th Rd	40 to 45	38.7	25.1	33.2	42.4	29.2	38.1
Fourmile Creek at JJ&BB	1	5.5	3.7	4.6	6.5	4.9	5.8
NB Tenmile Cr. at Isherwood/Harding	0.7	2.1	1.2	1.7	2.7	1.7	2.3
Tenmile Cr. Ditch #5 at Taft		6.3	4.2	5.2	7.4	5.3	6.3
Tenmile Creek at Evergreen		23.9	14.3	19.8	25.5	15.9	21.7
Tenmile Creek at County U	~ 31.4	34.3	19.0	27.6	37.6	22.8	31.9
Tenmile Creek at Bell Road		43.7	26.5	36.4	47.2	30.4	40.8
Tenmile Creek near Nekoosa (Highway 13)	51.4	48.5	30.5	40.9	52.0	34.4	45.3
Tenmile Creek at mouth	~62	56.9	37.3	48.7	60.4	41.2	53.1
Sevenmile Creek at Rangeline	~2	1.9	0.5	1.2	1.9	0.5	1.3
Sevemile Creek at Hollywood		3.0	1.3	2.3	3.1	1.3	2.3
Sevenmile Creek at mouth	~4	3.8	1.9	3.0	3.9	1.9	3.0
Fivemile Creek at mouth		12.3	8.4	10.6	12.4	8.4	10.6

Table 2-1

Summary of Calcualted Streamflow Changes from Project
Normal Year

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average Flow in Normal Year (cfs)	Change in Flow in Normal Year with Project		Average Flow in Normal Year (cfs)	Change in Flow in Normal Year with Project	
		cfs	percent		cfs	percent
Big Roche-A-Cri at 1st Ave	10.2	0.00	0%	11.8	0.0	0%
Chester Creek	4.7	-0.01	0%	4.7	0.0	0%
Fourteenmile Creek near New Rome	27.3	-0.01	0%	29.5	0.0	0%
Fourteenmile at mouth	38.9	-0.02	0%	41.2	0.0	0%
Buena Vista Creek at 100th Rd	25.9	0.00	0%	29.3	0.0	0%
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	4.7	0.00	0%	5.4	0.0	0%
Fourmile Creek at 100th Rd	38.7	0.00	0%	42.4	0.0	0%
Fourmile Creek at JJ&BB	5.5	0.00	0%	6.5	0.0	0%
NB Tenmile Cr. at Isherwood/Harding	2.1	0.00	0%	2.7	0.0	0%
Tenmile Cr. Ditch #5 at Taft	6.3	0.00	0%	7.4	0.0	0%
Tenmile Creek at Evergreen	23.9	0.00	0%	25.5	0.0	0%
Tenmile Creek at County U	34.3	-0.01	0%	37.6	0.0	0%
Tenmile Creek at Bell Road	43.7	-0.05	0%	47.2	0.2	0%
Tenmile Creek near Nekoosa (Highway 13)	48.5	-0.13	0%	52.0	0.2	0%
Tenmile Creek at mouth	56.9	-0.67	-1%	60.4	0.0	0%
Sevenmile Creek at Rangeline	1.9	0.12	6%	1.9	0.3	14%
Sevemile Creek at Hollywood	3.0	0.17	6%	3.1	0.4	12%
Sevenmile Creek at mouth	3.8	0.16	4%	3.9	0.4	10%
Fivemile Creek at mouth	12.3	0.01	0%	12.4	0.0	0%

Change in August Base Flow due to Pumping

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average August Flow in Normal Year (cfs)	Change in Flow in Normal Year with Project		Average August Flow in Normal Year (cfs)	Change in Flow in Normal Year with Project	
		cfs	percent		cfs	percent
Tenmile Creek at County U	20.4	-0.02	0%	25.9	0.0	0%
Tenmile Creek at Bell Road	29.8	-0.16	-1%	35.4	0.2	1%
Tenmile Creek near Nekoosa (Highway 13)	34.6	-0.27	-1%	40.1	0.3	1%
Tenmile Creek at Cty Z (mouth)	42.8	-1.00	-2%	48.3	0.0	0%
Sevenmile Creek at Rangeline	1.3	0.11	9%	1.5	0.3	18%
Sevenmile Creek at Hollywood	2.4	0.19	8%	2.6	0.4	16%
Sevenmile Creek at Cty Z (mouth)	3.1	0.18	6%	3.3	0.4	13%

Note: Positive change indicates flow increases as a result of project, negative change indicates flow decreases as a result of project.

Table 2-2a

Summary of Calcualted Streamflow Changes from Project
Dry Year (2006)

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project		Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project	
		cfs	percent		cfs	percent
Big Roche-A-Cri at 1st Ave	6.7	0.00	0%	8.5	0.0	0%
Chester Creek	4.1	-0.02	0%	4.1	0.0	0%
Fourteenmile Creek near New Rome	13.9	-0.01	0%	15.8	0.0	0%
Fourteenmile at mouth	23.4	-0.03	0%	25.3	0.0	0%
Buena Vista Creek at 100th Rd	16.8	0.00	0%	20.6	0.0	0%
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	3.4	0.00	0%	4.2	0.0	0%
Fourmile Creek at 100th Rd	25.1	0.00	0%	29.2	0.0	0%
Fourmile Creek at JJ&BB	3.7	0.00	0%	4.9	0.0	0%
NB Tenmile Cr. at Isherwood/Harding	1.2	0.00	0%	1.7	0.0	0%
Tenmile Cr. Ditch #5 at Taft	4.2	0.00	0%	5.3	0.0	0%
Tenmile Creek at Evergreen	14.3	0.00	0%	15.9	0.0	0%
Tenmile Creek at County U	19.0	-0.04	0%	22.8	0.0	0%
Tenmile Creek at Bell Road	26.5	-0.20	-1%	30.4	0.1	0%
Tenmile Creek near Nekoosa (Highway 13)	30.5	-0.37	-1%	34.4	0.2	1%
Tenmile Creek at mouth	37.3	-1.22	-3%	41.2	-0.1	0%
Sevenmile Creek at Rangeline	0.5	0.11	24%	0.5	0.2	52%
Sevemile Creek at Hollywood	1.3	0.14	11%	1.3	0.4	27%
Sevenmile Creek at mouth	1.9	0.13	7%	1.9	0.4	20%
Fivemile Creek at mouth	8.4	0.01	0%	8.4	0.0	0%

Change in August Dry Year Flow due to Pumping

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project		Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project	
		cfs	percent		cfs	percent
Tenmile Creek at County U	8.8	-0.06	-1%	13.5	0.0	0%
Tenmile Creek at Bell Road	16.4	-0.52	-3%	21.2	-0.1	0%
Tenmile Creek near Nekoosa (Highway 13)	20.4	-0.83	-4%	25.2	-0.1	0%
Tenmile Creek at Cty Z (mouth)	27.2	-2.14	-8%	32.0	-0.7	-2%
Sevenmile Creek at Rangeline	0.5	0.09	19%	0.5	0.2	48%
Sevenmile Creek at Holywood	1.3	0.13	10%	1.3	0.4	28%
Sevenmile Creek at Cty Z (mouth)	1.8	0.12	6%	1.8	0.4	21%

Note: Positive change indicates flow increases as a result of project, negative change indicates flow decreases as a result of project.

Table 2-2b

S.S. PAPADOPULOS & ASSOCIATES, INC.

Summary of Calcualted Streamflow Changes from Project
Dry Year (2012)

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project		Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project	
		cfs	percent		cfs	percent
Big Roche-A-Cri at 1st Ave	8.2	0.00	0%	10.1	0.0	0%
Chester Creek	4.4	-0.01	0%	4.4	0.0	0%
Fourteenmile Creek near New Rome	20.6	-0.01	0%	22.9	0.0	0%
Fourteenmile at mouth	31.4	-0.02	0%	33.8	0.0	0%
Buena Vista Creek at 100th Rd	22.6	0.00	0%	27.1	0.0	0%
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	4.1	0.00	0%	4.9	0.0	0%
Fourmile Creek at 100th Rd	33.2	0.00	0%	38.1	0.0	0%
Fourmile Creek at JJ&BB	4.6	0.00	0%	5.8	0.0	0%
NB Tenmile Cr. at Isherwood/Harding	1.7	0.00	0%	2.3	0.0	0%
Tenmile Cr. Ditch #5 at Taft	5.2	0.00	0%	6.3	0.0	0%
Tenmile Creek at Evergreen	19.8	-0.02	0%	21.7	0.0	0%
Tenmile Creek at County U	27.6	-0.04	0%	31.9	0.0	0%
Tenmile Creek at Bell Road	36.4	-0.18	0%	40.8	0.1	0%
Tenmile Creek near Nekoosa (Highway 13)	40.9	-0.31	-1%	45.3	0.2	0%
Tenmile Creek at mouth	48.7	-1.07	-2%	53.1	-0.2	0%
Sevenmile Creek at Rangeline	1.2	0.12	10%	1.3	0.3	20%
Sevemile Creek at Hollywood	2.3	0.18	8%	2.3	0.4	16%
Sevenmile Creek at mouth	3.0	0.17	6%	3.0	0.4	13%
Fivemile Creek at mouth	10.6	0.01	0%	10.6	0.0	0%

Change in August Dry Year Flow due to Pumping

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project		Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Project	
		cfs	percent		cfs	percent
Tenmile Creek at County U	11.1	-0.06	-1%	18.2	0.0	0%
Tenmile Creek at Bell Road	19.7	-0.58	-3%	26.9	-0.1	0%
Tenmile Creek near Nekoosa (Highway 13)	24.2	-0.88	-4%	31.3	-0.1	0%
Tenmile Creek at Cty Z (mouth)	31.7	-2.22	-7%	38.8	-0.9	-2%
Sevenmile Creek at Rangeline	0.8	0.13	16%	0.8	0.2	29%
Sevenmile Creek at Holywood	1.8	0.22	12%	1.8	0.4	22%
Sevenmile Creek at Cty Z (mouth)	2.4	0.21	9%	2.4	0.4	17%

Note: Positive change indicates flow increases as a result of project, negative change indicates flow decreases as a result of project.

Table 2-3

Summary of Streamflow Changes with Conversion to No Irrigation
Normal Year

Average Annual Stream Baseflows and Calculated Changes in Average Base Flow from Conversion to No Irrigation

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average Flow in Normal Year (cfs)	Change in Flow in Normal Year with Conversion to No-Irrigation		Average Flow in Normal Year (cfs)	Change in Flow in Normal Year with Conversion to No-Irrigation	
		cfs	percent		cfs	percent
Big Roche-A-Cri at 1st Ave	10.2	0.5	5%	11.8	-1.0	-9%
Chester Creek	4.7	0.0	0%	4.7	0.0	0%
Fourteenmile Creek near New Rome	27.3	0.9	3%	29.5	-1.3	-4%
Fourteenmile at mouth	38.9	1.2	3%	41.2	-1.0	-2%
Buena Vista Creek at 100th Rd	25.9	-3.0	-12%	29.3	-6.5	-22%
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	4.7	-1.0	-22%	5.4	-1.8	-32%
Fourmile Creek at 100th Rd	38.7	-4.1	-11%	42.4	-7.9	-19%
Fourmile Creek at JJ&BB	5.5	-1.4	-25%	6.5	-2.4	-37%
NB Tenmile Cr. at Isherwood/Harding	2.1	-0.3	-16%	2.7	-1.0	-36%
Tenmile Cr. Ditch #5 at Taft	6.3	-0.3	-5%	7.4	-1.3	-18%
Tenmile Creek at Evergreen	23.9	1.0	4%	25.5	-0.6	-2%
Tenmile Creek at County U	34.3	1.2	3%	37.6	-2.2	-6%
Tenmile Creek at Bell Road	43.7	1.2	3%	47.2	-2.2	-5%
Tenmile Creek near Nekoosa (Highway 13)	48.5	1.3	3%	52.0	-2.2	-4%
Tenmile Creek at mouth	56.9	1.3	2%	60.4	-2.2	-4%
Sevenmile Creek at Rangeline	1.9	0.2	11%	1.9	0.1	7%
Sevemile Creek at Hollywood	3.0	0.2	7%	3.1	0.1	4%
Sevenmile Creek at mouth	3.8	0.2	6%	3.9	0.1	4%
Fivemile Creek at mouth	12.3	0.0	0%	12.4	0.0	0%

Change in August Flows from Conversion to No Irrigation

Location	August Q50 from Regression	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
		Average August Flow in Normal Year (cfs)	Change in Flow in Normal Year with Conversion to No-Irrigation		Average August Flow in Normal Year (cfs)	Change in Flow in Normal Year with Conversion to No-Irrigation	
			cfs	percent		cfs	percent
Tenmile Cr. Ditch #5 at Taft	4.39	5.1	0.3	6%	6.6	-1.2	-18%
Tenmile Creek at Evergreen	15.07	14.6	4.3	30%	17.4	1.6	9%
Tenmile Creek at County U	21.20	20.4	6.1	30%	25.9	0.6	2%
Tenmile Creek at Bell Road	36.85	29.8	6.2	21%	35.4	0.6	2%
Tenmile Creek near Nekoosa (Highway 13)	42.85	34.6	6.2	18%	40.1	0.6	2%
Tenmile Creek at Cty Z (mouth)		42.8	6.2	14%	48.3	0.6	1%
Sevenmile Creek at Rangeline	1.46	1.3	0.7	55%	1.5	0.5	33%
Sevenmile Creek at Holywood		2.4	0.7	30%	2.6	0.5	19%
Sevenmile Creek at Cty Z (mouth)	4.02	3.1	0.7	23%	3.3	0.5	15%

Notes: 1) Positive change indicates flow increases with conversion to no irrigation, negative change indicates flow decreases with conversion to no irrigation. 2) Regression developed by Matthew Diebel, DNR, September 22, 2015 for August Q50 flow.

Table 2-4a

Summary of Streamflow Changes with Converstion to No Irrigation
Dry Year (2006)

Annual Dry Year Baseflows and Calculated Changes in Flows due to Conversion to No Irrigation

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation		Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation	
		cfs	percent		cfs	percent
Big Roche-A-Cri at 1st Ave	6.7	1.5	22%	8.5	-0.4	-4%
Chester Creek	4.1	0.0	0%	4.1	0.0	0%
Fourteenmile Creek near New Rome	13.9	2.3	16%	15.8	0.4	3%
Fourteenmile at mouth	23.4	2.6	11%	25.3	0.8	3%
Buena Vista Creek at 100th Rd	16.8	-2.4	-14%	20.6	-6.3	-30%
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	3.4	-0.9	-26%	4.2	-1.7	-41%
Fourmile Creek at 100th Rd	25.1	-3.1	-12%	29.2	-7.1	-24%
Fourmile Creek at JJ&BB	3.7	-1.2	-32%	4.9	-2.4	-49%
NB Tenmile Cr. at Isherwood/Harding	1.2	-0.1	-7%	1.7	-0.6	-34%
Tenmile Cr. Ditch #5 at Taft	4.2	0.1	3%	5.3	-0.9	-17%
Tenmile Creek at Evergreen	14.3	1.6	11%	15.9	0.0	0%
Tenmile Creek at County U	19.0	2.2	12%	22.8	-1.6	-7%
Tenmile Creek at Bell Road	26.5	2.3	9%	30.4	-1.6	-5%
Tenmile Creek near Nekoosa (Highway 13)	30.5	2.4	8%	34.4	-1.6	-5%
Tenmile Creek at mouth	37.3	2.4	6%	41.2	-1.5	-4%
Sevenmile Creek at Rangeline	0.5	0.0	2%	0.5	0.0	1%
Sevemile Creek at Hollywood	1.3	0.0	1%	1.3	0.0	1%
Sevenmile Creek at mouth	1.9	0.0	0%	1.9	0.0	0%
Fivemile Creek at mouth	8.4	0.0	0%	8.4	0.0	0%

Change in August Flow in Dry Year due to Conversion to No Irrigation

Location	Annual Q90 from Regression (cfs)	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
		Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation		Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation	
			cfs	percent		cfs	percent
Tenmile Cr. Ditch #5 at Taft	1.8	3.1	1.1	35%	4.2	0.0	0%
Tenmile Creek at Evergreen	4.6	7.8	5.5	70%	9.8	3.5	36%
Tenmile Creek at County U	5.2	8.8	8.3	95%	13.5	3.6	26%
Tenmile Creek at Bell Road	17.3	16.4	8.4	51%	21.2	3.6	17%
Tenmile Creek near Nekoosa (Highway 13)	26.4	20.4	8.5	42%	25.2	3.7	14%
Tenmile Creek at Cty Z (mouth)		27.2	8.5	31%	32.0	3.7	11%
Sevenmile Creek at Rangeline	0.7	0.5	0.0	2%	0.5	0.0	1%
Sevenmile Creek at Holywood		1.3	0.0	1%	1.3	0.0	1%
Sevenmile Creek at Cty Z (mouth)	2.6	1.8	0.0	1%	1.8	0.0	0%

Notes : 1) Positive change indicates flow increases with conversion to no irrigation, negative change indicates flow decreases with conversion to no irrigation. 2) Regression developed by Matthew Diebel, DNR, September 22, 2015 for Annual Q90 flow.

Table 2-4b

Summary of Streamflow Changes with Conversion to No Irrigation
Dry Year (2012)

Annual Dry Year Baseflows and Calculated Changes in Flows due to Conversion to No Irrigation

Location	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
	Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation		Average Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation	
		cfs	percent		cfs	percent
Big Roche-A-Cri at 1st Ave	8.2	1.6	19%	10.1	-0.2	-2%
Chester Creek	4.4	0.0	0%	4.4	0.0	0%
Fourteenmile Creek near New Rome	20.6	2.1	10%	22.9	-0.2	-1%
Fourteenmile at mouth	31.4	2.5	8%	33.8	0.1	0%
Buena Vista Creek at 100th Rd	22.6	-2.8	-13%	27.1	-7.4	-27%
Buena Vista Cr. Ditch #2 N.Fork @ Isherwood	4.1	-0.8	-20%	4.9	-1.7	-34%
Fourmile Creek at 100th Rd	33.2	-3.4	-10%	38.1	-8.3	-22%
Fourmile Creek at JJ&BB	4.6	-1.1	-24%	5.8	-2.3	-40%
NB Tenmile Cr. at Isherwood/Harding	1.7	-0.1	-7%	2.3	-0.8	-33%
Tenmile Cr. Ditch #5 at Taft	5.2	0.3	5%	6.3	-0.9	-15%
Tenmile Creek at Evergreen	19.8	1.5	8%	21.7	-0.4	-2%
Tenmile Creek at County U	27.6	2.2	8%	31.9	-2.1	-7%
Tenmile Creek at Bell Road	36.4	2.3	6%	40.8	-2.1	-5%
Tenmile Creek near Nekoosa (Highway 13)	40.9	2.3	6%	45.3	-2.1	-5%
Tenmile Creek at mouth	48.7	2.3	5%	53.1	-2.1	-4%
Sevenmile Creek at Rangeline	1.2	0.1	5%	1.3	0.0	4%
Sevemile Creek at Hollywood	2.3	0.1	3%	2.3	0.0	2%
Sevenmile Creek at mouth	3.0	0.1	2%	3.0	0.0	2%
Fivemile Creek at mouth	10.6	0.0	0%	10.6	0.0	0%

Change in August Flow in Dry Year due to Conversion to No Irrigation

Location	Annual Q90 from Regression (cfs)	MODIS Adjusted ET for Irrigated Fields			MODIS ET for Irrigated Fields		
		Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation		Average August Flow in Dry Year (cfs)	Change in Flow in Dry Year with Conversion to No-Irrigation	
			cfs	percent		cfs	percent
Tenmile Cr. Ditch #5 at Taft	1.8	2.9	1.8	62%	4.5	0.2	4%
Tenmile Creek at Evergreen	4.6	9.1	6.4	71%	12.3	3.2	26%
Tenmile Creek at County U	5.2	11.1	10.1	91%	18.2	3.0	17%
Tenmile Creek at Bell Road	17.3	19.7	10.1	51%	26.9	3.0	11%
Tenmile Creek near Nekoosa (Highway 13)	26.4	24.2	10.2	42%	31.3	3.0	10%
Tenmile Creek at Cty Z (mouth)		31.7	10.2	32%	38.8	3.0	8%
Sevenmile Creek at Rangeline	0.7	0.8	0.0	3%	0.8	0.0	2%
Sevenmile Creek at Holywood		1.8	0.0	1%	1.8	0.0	1%
Sevenmile Creek at Cty Z (mouth)	2.6	2.4	0.0	1%	2.4	0.0	1%

Notes : 1) Positive change indicates flow increases with conversion to no irrigation, negative change indicates flow decreases with conversion to no irrigation. 2) Regression developed by Matthew Diebel, DNR, September 22, 2015 for Annual Q90 flow.

from EIR

3

4D S.S. PAPADOPULOS & ASSOCIATES, INC.

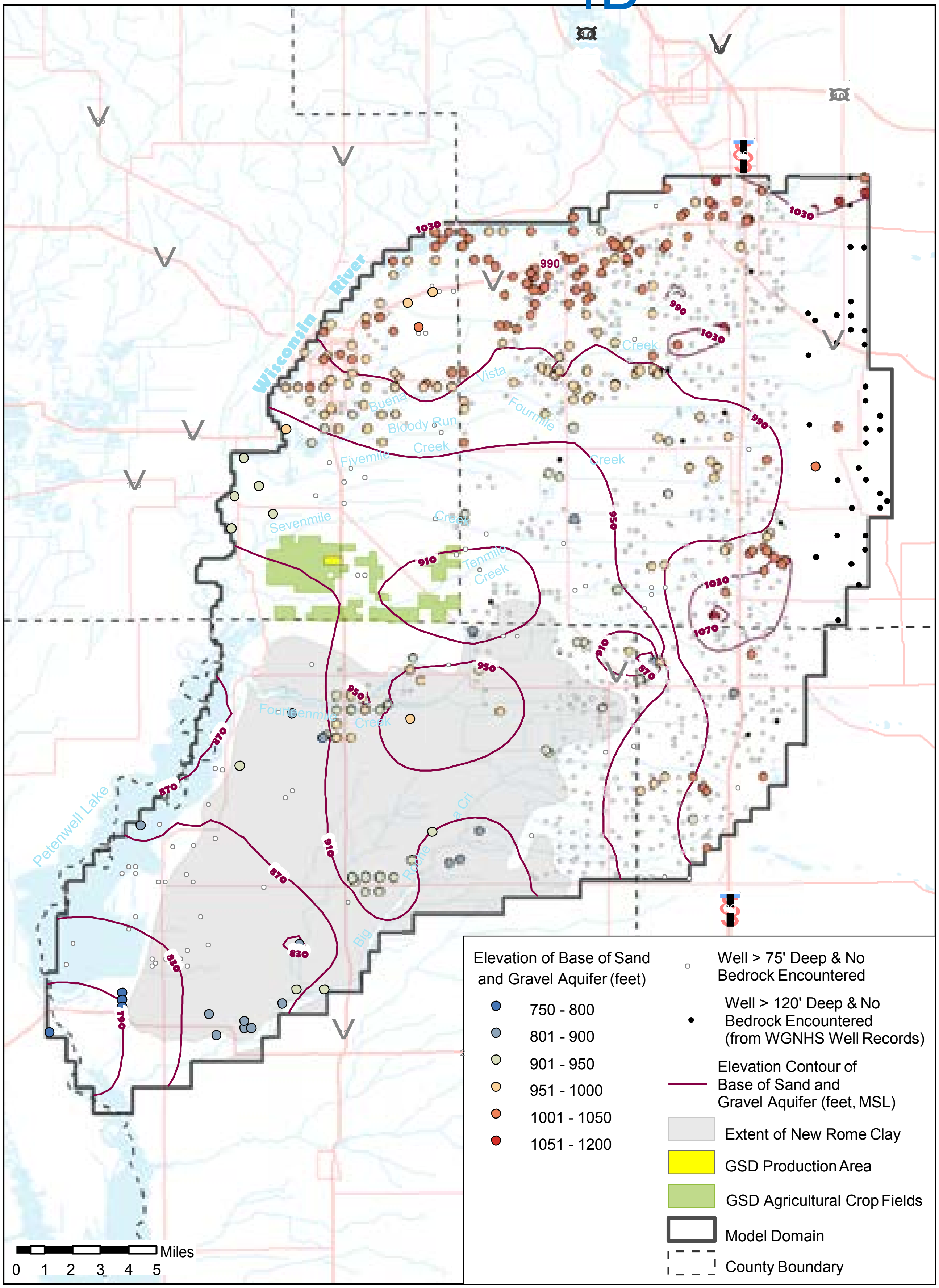


Figure 2-17 Base of the Sand and Gravel Aquifer (Revised 12/2015)

from EIR - Appendix D

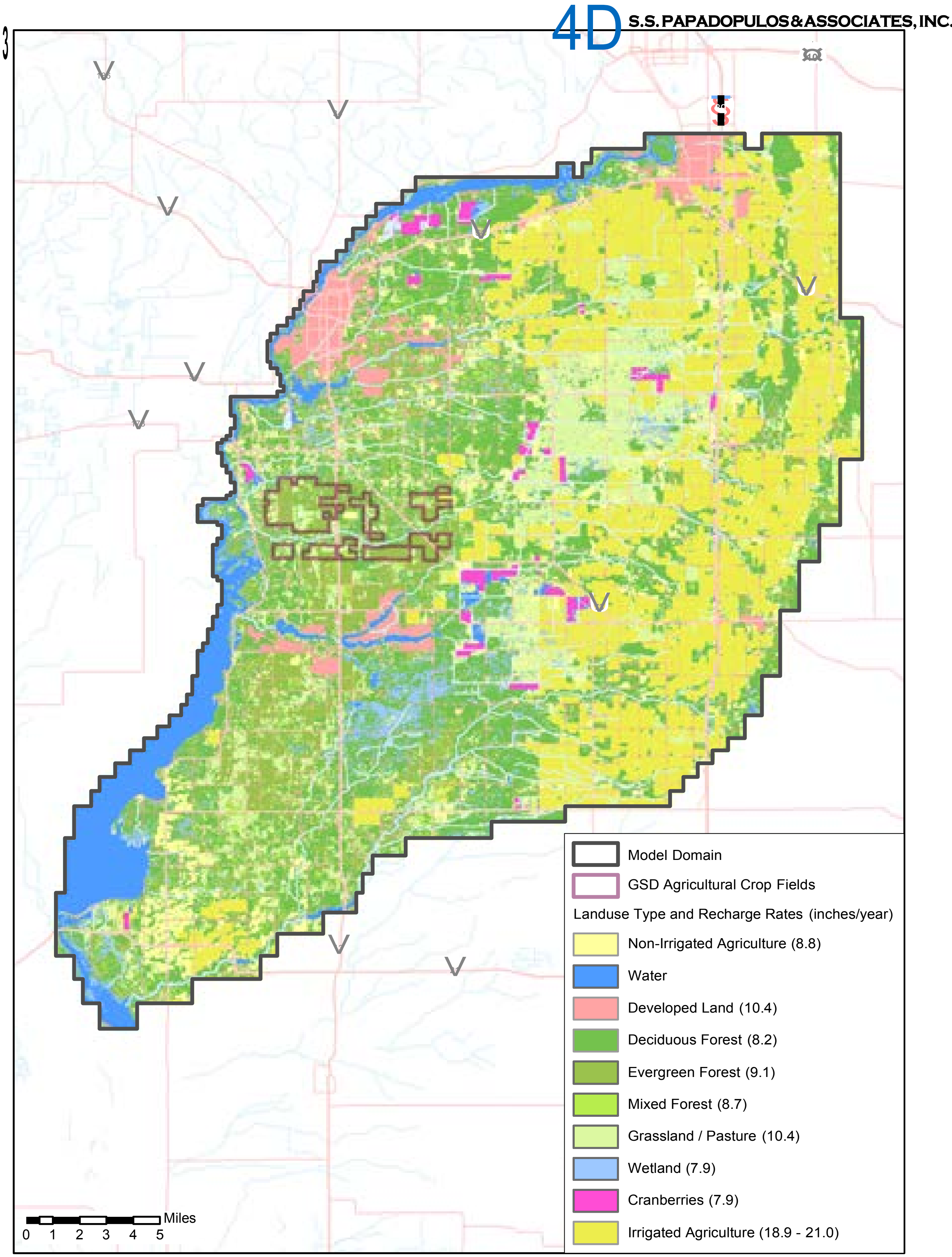


Figure 9 Recharge Rates (Revised 11/30/2015)

S.S. PAPADOPULOS & ASSOCIATES, INC.

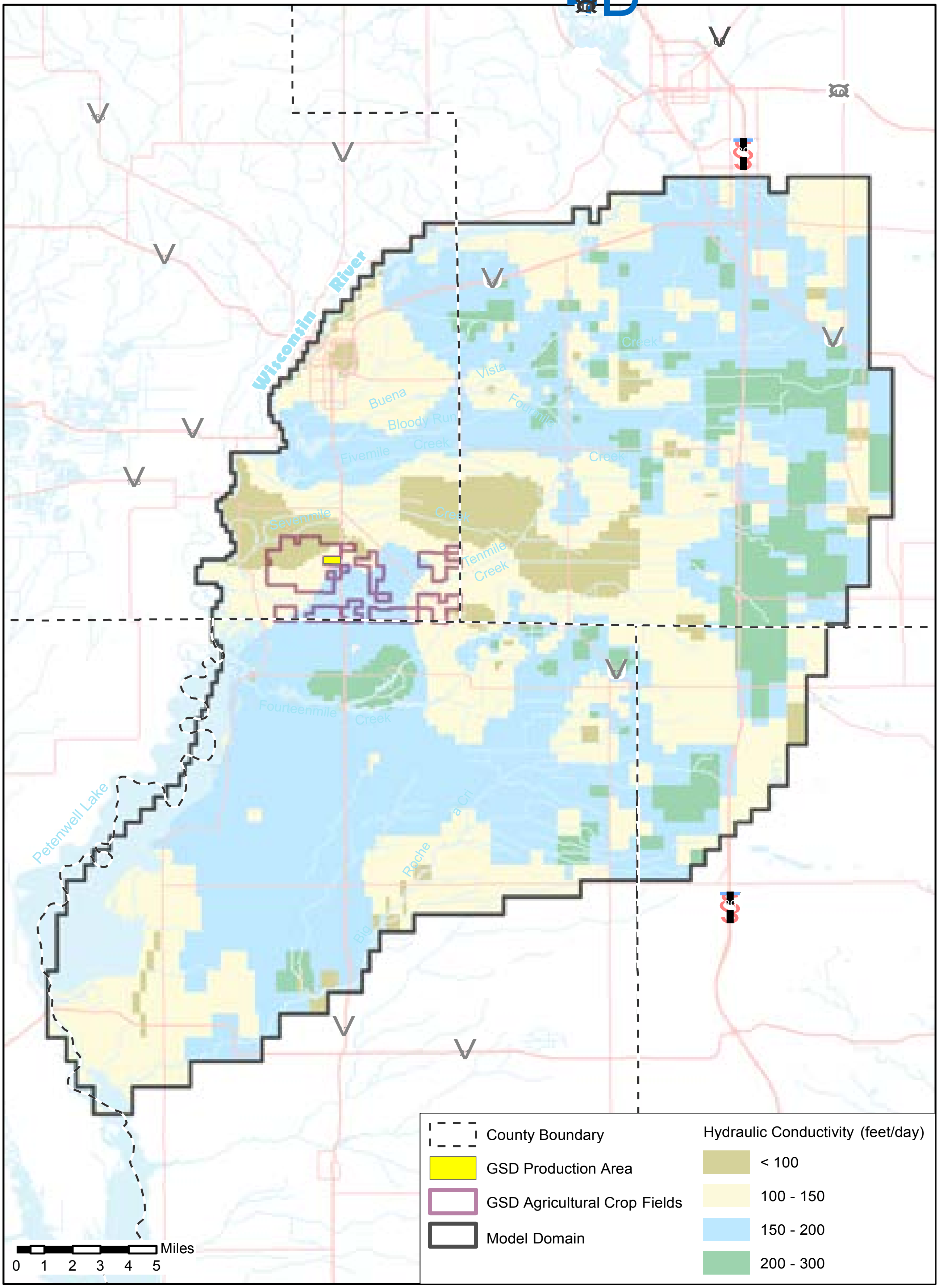


Figure 10 Calibrated Hydraulic Conductivity of Sand and Gravel Aquifer

Estimating Groundwater Recharge in the Central Sands
Abridged Methodology and Results
Adam Freihoefer, Hydrogeologist
Water Use Section, Bureau of Drinking Water and Groundwater
October 30, 2015

This technical brief outlines the methodology used by the Wisconsin Department of Natural Resources (DNR) to estimate groundwater recharge within a portion of Wisconsin's central sands region located in central Wisconsin. A comprehensive technical memorandum describing the approach and results will be provided at a later date. The DNR completed the work to quantify the spatiotemporal variation of recharge in the central sands and validate the recharge array used as a model input for a groundwater flow developed by S.S. Papadopulos & Associates, Inc. (SSPA). The SSPA groundwater model serves as supplemental technical information in support of six high capacity well applications for the proposed Golden Sands Dairy (GSD), south of Wisconsin Rapids, Wisconsin.

1.0 Study Area

The study area is approximately 1,015 square miles and located within central Wisconsin. The study area mirrors the groundwater flow model domain defined by SSPA that contains the GSD property including the proposed dairy production facility and irrigated agricultural fields (Figure 1).

2.0 Recharge Definition

For purposes of this technical memorandum recharge is defined as the water that infiltrates into the subsurface and reaches the groundwater table from a combination of precipitation and applied irrigated water. Groundwater withdrawals (e.g. irrigation pumping) are not considered as that component is incorporated into groundwater flow models separately. The input – output relationship is explained in Equation 1 and can be defined at any time series. This technical memorandum provides an estimation of recharge at the monthly and annual time step.

$$Recharge = Precipitation + Applied\ Irrigation - Actual\ Evapotranspirtaiton + Change\ in\ Soil\ Water\ Storage - Runoff \quad \text{(Eq. 1)}$$

Various inputs and models can be used to estimate the variables described in Equation 1. Sections 2.1 and 2.2 of this technical memorandum describes those the DNR applied.

2.1 Components of Recharge

Recharge can vary across the landscape and is dependent on a number of variables including precipitation, evapotranspiration, land cover and management, soil attributes, and topography. The following subsections briefly describe the individual components that may be used in the estimation of recharge.

2.1.1 Precipitation

To assess climatological variability across the study area daily measurements from climate stations throughout the model domain were acquired. For the precipitation record the DNR accessed the National Climate Data (NCDC) Center database for daily precipitation measurements from stations within the model domain including:

Station Name	Global Historical Climatology Network #	Latitude, Longitude
Wisconsin Rapids Airport, Alexander Field	USW00004826	44.359, -89.836
Wisconsin Rapids	USC00479335	44.388, -89.806
Wisconsin Rapids, Grand Avenue	USC00479345	44.392, -89.829
Wisconsin Rapids 4.6 SSE	US1WIWD0002	44.338, -89.782
Hancock Experimental Farm	USC00473405	44.119, -89.536

To account for variability in measurements between stations, the median of the four Wisconsin Rapids stations was used to calculate the monthly and annual totals between 2000 and 2014. The GSD modeling utilized both normal year and dry year precipitation scenarios. A normal precipitation was calculated using the median monthly and median annual precipitation from the four Wisconsin Rapids climate stations and then calculating the 10-year median from 2002 to 2011. Both 2012 and 2006 represented the dry precipitation years.

Other data sources were also examined to evaluate the variability in the precipitation beyond the Wisconsin Rapids area. Gridded precipitation data from the National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS) (http://water.weather.gov/precip/about.php) provided annual, monthly, and daily observed gridded precipitation based on a multisensor approach (radar, gauge, satellite). The NWS AHPS indicated that between 2005 and 2014 precipitation across the 1,015 square mile study area could vary by as much as 10 inches. As a result of the SSPA groundwater flow model relying on a 10-year median monthly precipitation record to reflect to average recharge, the DNR relied on the median of the four Wisconsin Rapids stations to calculate recharge for their analysis but the DNR does recognize that the variability in precipitation adds to the relative uncertainty in recharge estimates using a single station or area approach.

2.1.2 Actual Evapotranspiration

Mean monthly and annual actual evapotranspiration (ET) rates were estimated using individual moderate resolution imaging spectroradiometer (MODIS) cells developed by NASA and their partners. MODIS data have been collected for over a decade at a spatial resolution of slightly less than 1 km^2. Because of the localized homogeneity in landcover within the study area, the 1 km^2 resolution was deemed acceptable in quantifying land cover specific ET. The ET value is representative of the entire landscape within any specific grid cell meaning that an ET value of 22 inches per year for a grid cell may define the cells majority land cover (irrigated agriculture) but may also include the roads, farm structures, etc. if the field does not make up 100% of the MODIS grid cell.

2.1.3 Land cover and Management

The 2011 United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) cropland data layer (CDL) for Wisconsin was used to depict landcover conditions. The 2011 USDA NASS CDL is a 30-meter grid based GIS coverage that reflects the agricultural extent and crop types grown in 2011, with the 2006 USGS National Land Cover Database defining all non-agricultural lands. The 2011 USDA NASS CDL was selected because that year had improved overall accuracy statistics (91.3 percent) as well as improved accuracy for dominant crops such as corn, soybeans, alfalfa, and potatoes when compared to the other years (2008 - 2013) examined. The DNR made two modifications to the 2011 USDA NASS CDL. The first modification was the merging of a hand digitized extent of cranberry bogs. The second modification was the reclassification of agricultural land cover types as irrigation or non-irrigated. The irrigated extent was defined by identifying the high capacity wells within the study area, buffering each high capacity well with a distance relative to the reported pumping of the well, and intersecting the buffered extent with the 2011 NASS CDL. Any agricultural land that intersected the buffer was considered irrigated. The dominant landcover classifications are deciduous forest (31.2%), irrigated cropland (20.4%), grassland (12.5%), coniferous forest (8.8%), and open water (5.7%) (Figure 2).

2.1.4 Soils

The USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) was used to identify the geospatial extent of soil properties within the study area. The two primary soil attributes that were used in the assessment of recharge were the hydrologic soil group (HSG) and available water capacity (AWC). The HSG is a soil classification to that indicates the minimum rate of infiltration obtained for bare soil after prolonged wetting. A HSG A classification is related to well-drained soil textures such as sand, loamy sand, or sandy loam whereas a HSG D classification relates to poorly drained soil textures such as clay loam, silty clay loam, sandy clay, silty clay, or clay. In some cases soils are assigned a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes. With respect to the study area, the majority of the area was classified with HSG A or B soils. Those with a dual hydrologic group were considered drained due to their proximity to drainage ditches throughout the study area (Figure 3).

The second soil attribute that was obtained from the SSURGO was AWC. AWC is the measure of how much water the soil can hold and make available to plants. AWC it is the difference between the moisture content at field capacity and the moisture content at the permanent wilting point, which are represented in laboratory measurements as the water contents at 33 kPa and 1,500 kPa, respectively. The measure is a dimensionless ratio of the volume of water divided by the volume of soil, where the volumes are often represented as a thickness on a per-square-foot basis (e.g., inches of water per foot of soil). Soils will lower AWC values, such as sand, have the ability to hold less water for plant uptake. The majority of the study area had an AWC of 1.5 inches per foot or les (Figure 3).

2.1.5 Topography

Drainage and overland runoff are important considerations although not dominant components of the water budget in the study area due to the slope and soil textures that facilitate infiltration. A 10-meter digital elevation model (DEM) was used to calculate slope and flow direction for the study area. With the exception of stream corridors and the north-south trending terminal moraine on the eastern side of the study area nearly the entire study area maintains a slope of 3% or less. Portions of the study area that drain into closed depressions, or low topographic features, were defined based on a 10-meter DEM analysis completed as part of the Wisconsin River Total Maximum Daily Load project. The closed depressions likely facilitate recharge by capturing precipitation for subsequent percolation before it can runoff into local surface drainage networks. Approximately 16% of the study area drains to closed depressions.

2.2 Calculating Annual and Monthly Recharge

The DNR implemented a relatively simple methodology to estimate recharge. Beginning with Equation 1 described in Section 2.0, the soil storage and runoff were considered constants resulting in the Equation 2:

$$Recharge = Precipitation + Applied\ Irrigation - Actual\ Evapotranspirtaiton\ (Eq. 2)$$

The precipitation, applied irrigation, and actual evapotranspiration described in Section 2.1 were applied to each 90 m^2 model cell within the model domain. The applied irrigation and MODIS-derived ET inputs were spatiotemporally distributed across the model domain while the precipitation input originated from the four precipitation stations near or within the City of Wisconsin Rapids. The monthly and annual MODIS ET data was extracted for each 90 m^2 cell and averaged by land cover type for the entire model domain. To calculate ET, the types of irrigated crops were averaged into one irrigated agriculture land cover classification to represent the typical irrigated rotation rather than a specific crop since the groundwater flow model was not calibrated to a specific year. The amount of applied irrigation was averaged for all fields per year for the time period water use data was available (2011-2013).

The DNR's approach towards using NASA's MODIS ET dataset was presented and reviewed by University of Wisconsin (UW) agronomy researchers, Dr. Chris Kucharik and Mallika Nocco. The initial reaction of the UW team was that the MODIS ET measurements on agricultural land may be underestimated during the growing season due to the time step (8-day average) that MODIS uses to quantify one of its input parameters, leaf area index (LAI). To verify and quantify any offset within the MODIS ET data the DNR compared MODIS LAI measurements to UW field-level LAI measurements taken within the central sands in 2013 and 2014. The approach is described in Attachment 1. The results indicate the MODIS may underestimate ET on agricultural lands by up to 2 inches, specifically during the growing season. As a result the MODIS-ET, and subsequently recharge, for cropped agriculture in the study area was calculated as a range with the lower ET value representing the raw MODIS-ET and the upper ET value representing the modified MODIS-ET as corrected using field-level measurements. Figure 4 illustrates the monthly variability in recharge from the four dominant land cover classes within the study area. With respect to agriculture, Figure 4 does not include the applied irrigation water and the recharge was calculated using the MODIS-ET value that was modified with field-level data collection from the UW research team.

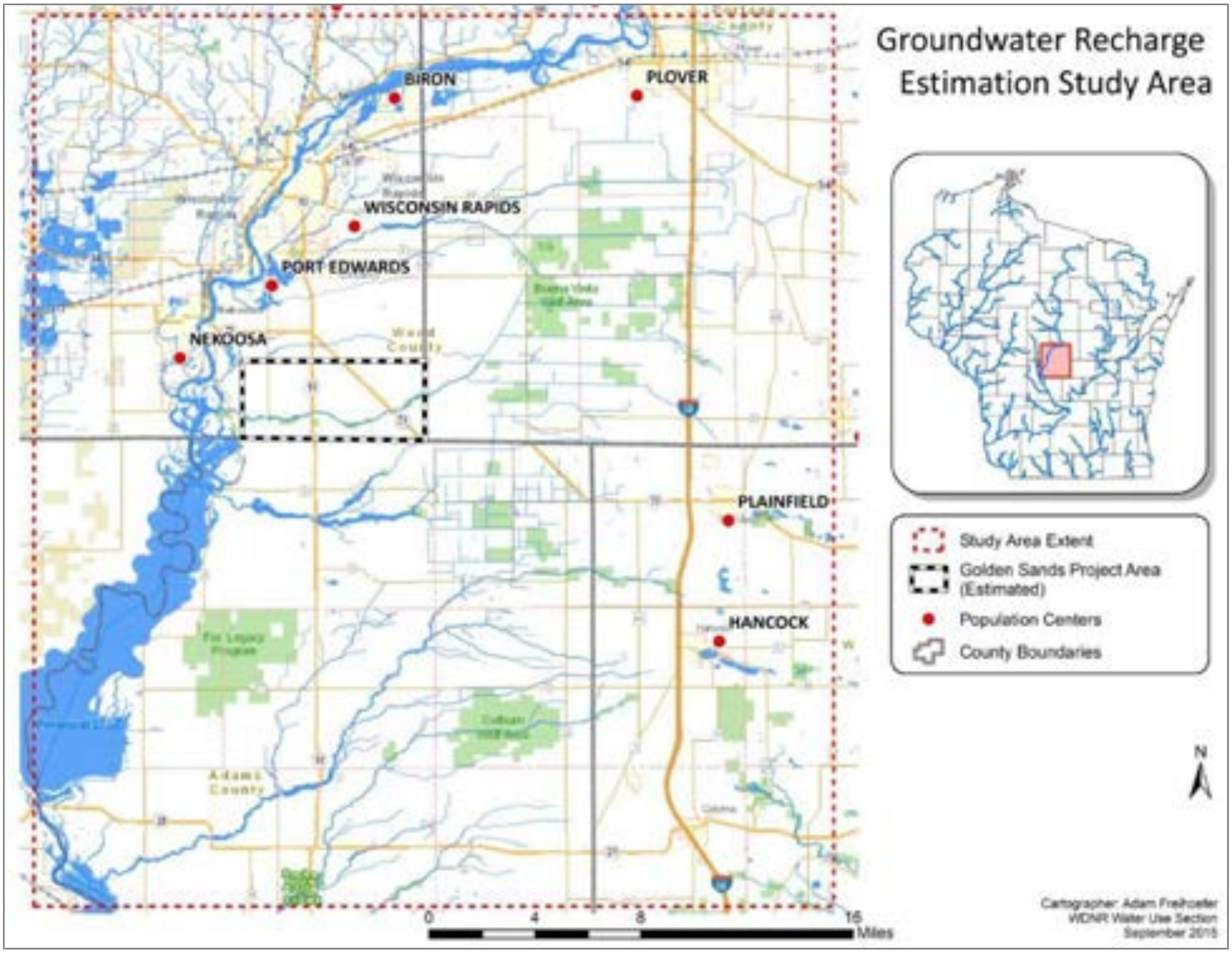


Figure 1: Extent of groundwater recharge study area

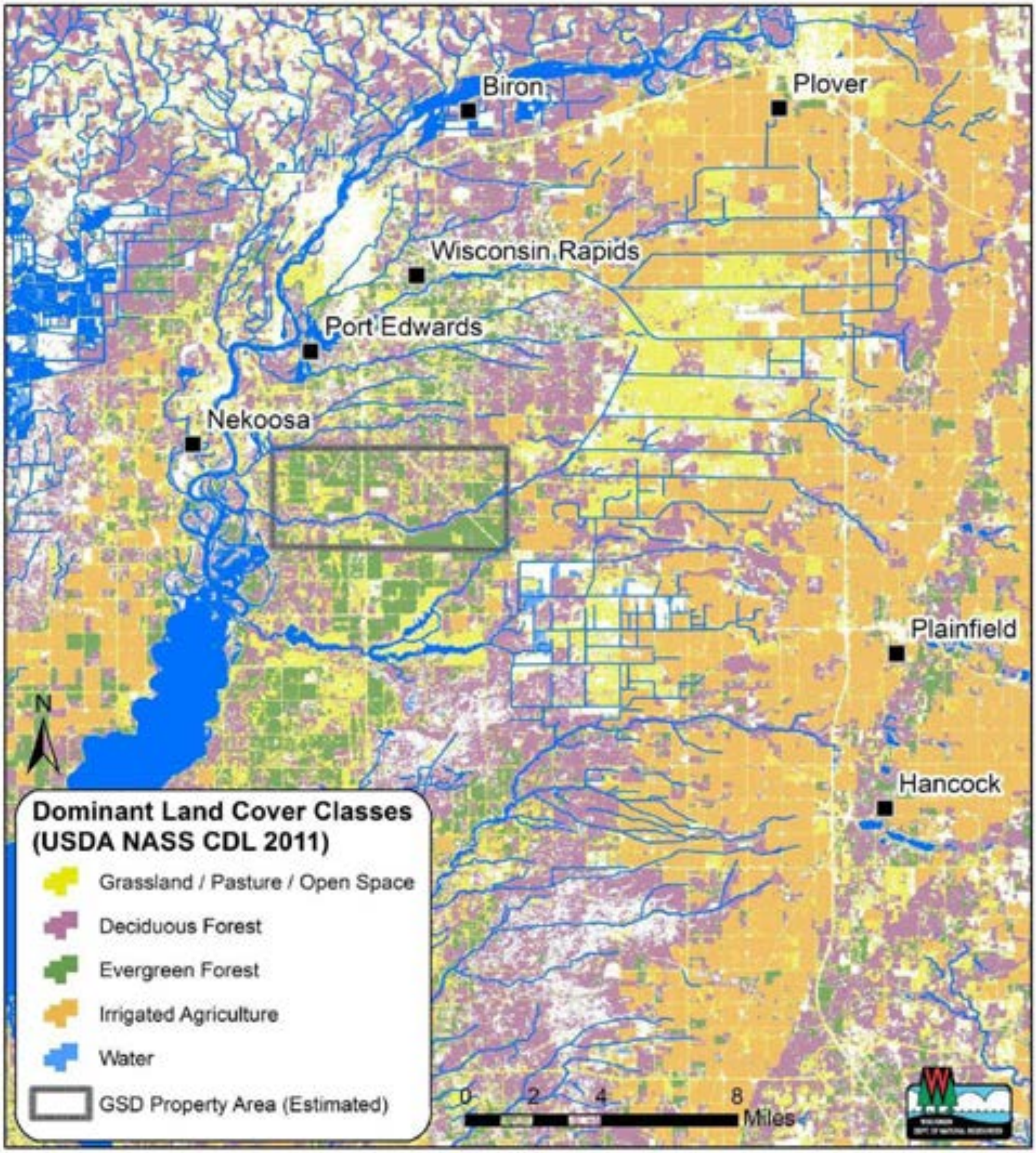


Figure 2: Spatial distribution of dominant land cover classes within GSD model domain

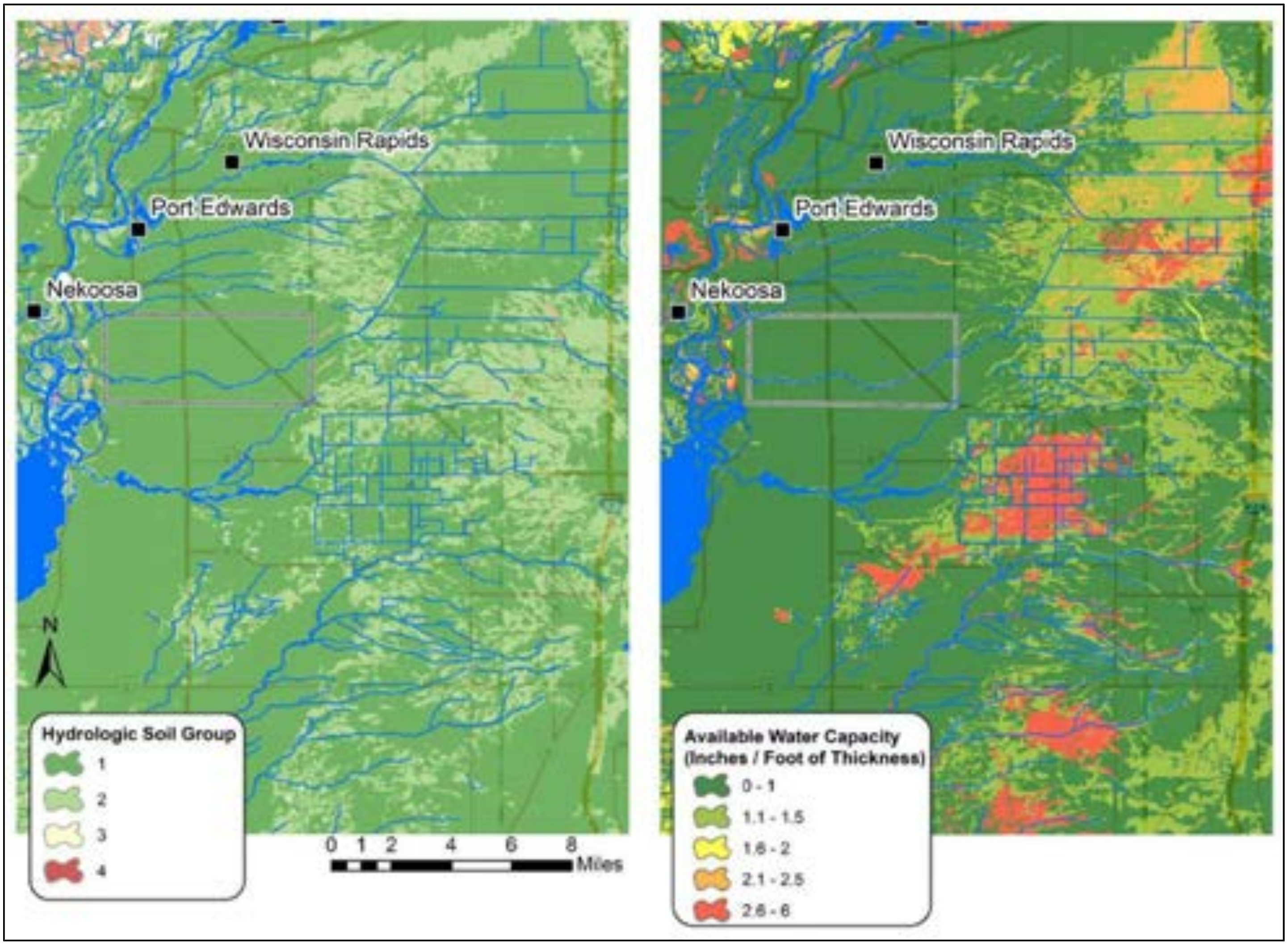


Figure 3: SSURGO hydrologic soil group and available water capacity

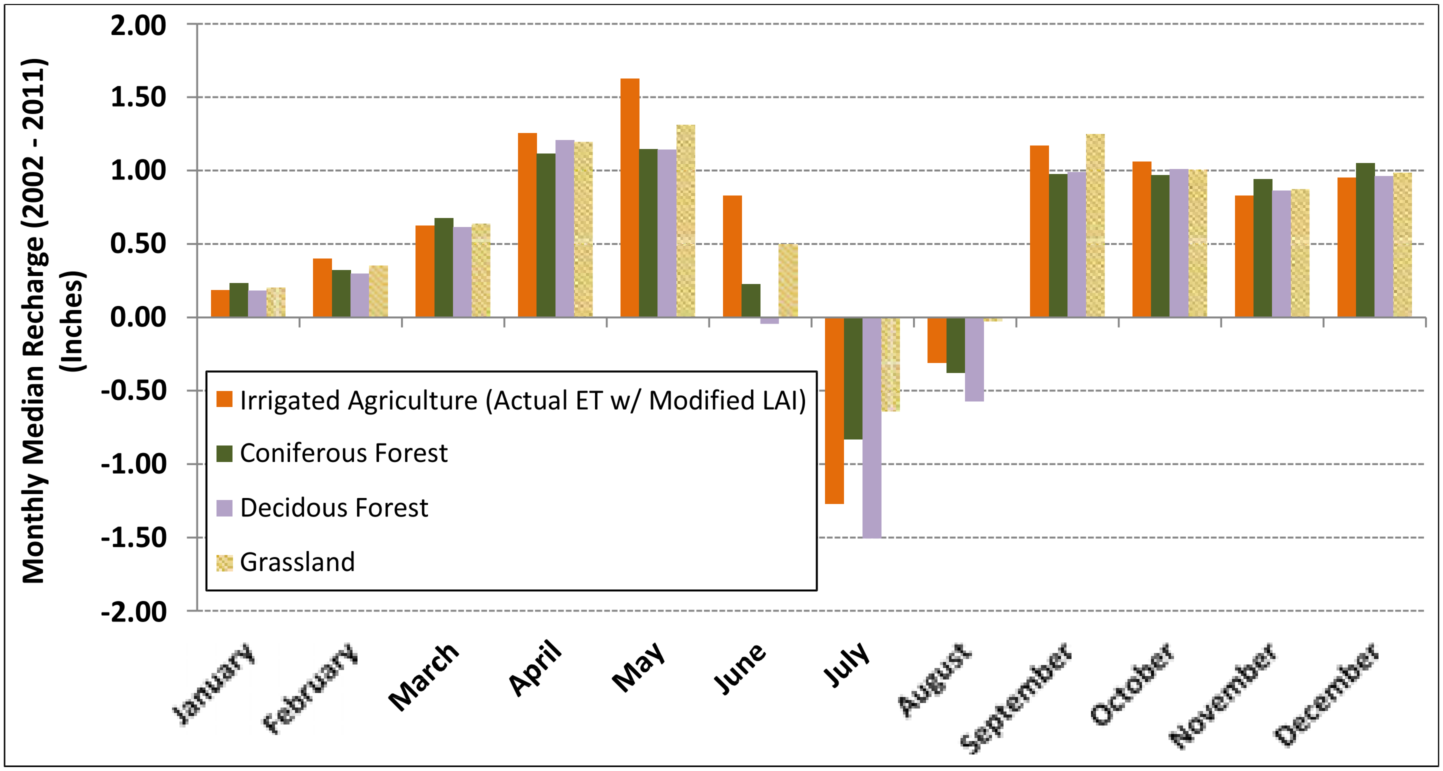


Figure 4: 10-year (2002-2011) monthly median of precipitation – MODIS ET within GSD study area

Attachment 1

Modification of MODIS ET for Agriculture Land Cover

Process to Adjust MODIS Evapotranspiration

Bob Smail, Water Use Section, Wisconsin Department of Natural Resources
October 22, 2015

A draft version of DNR evapotranspiration (ET) and recharge analysis was presented informally to UW staff with expertise in cropping systems and remote sensing analysis. UW staff observed that the MODIS-derived actual ET from agricultural land cover appeared low compared to field measurements the UW project team conducted in a recent research project. It was noted that the difference could be due in part to the fact that remote sensing platforms such as MODIS often underpredict Leaf Area Index (LAI) for row crops. UW researchers provided DNR staff with draft observations they made at several fields approximately 15 mile northeast of the GSD project area. DNR staff then undertook the following steps to compare remotely sensed and directly observed values LAI values:

1. Geolocated each field LAI observation location
2. For each field measurement point, extracted the MODIS LAI observation. The MODIS 8-day average LAI observation was used as it represented the finest temporal resolution. The following datasets were used from MODIS:
   a. 2013 at a 1km grid
   b. 2014 at a 1 km grid
   c. 2013 at a 500 m grid (2014 is not currently available at this grid)
3. Each LAI point-date MODIS observation was then paired with the field observation for the date that most closely matched the 8 day period. Multiple field observations in the same 8 day period were averaged.
4. Each paired MODIS and Field observation point was directly compared indicating that:
   a. 2013 1km (n=36) MODIS LAI was 32% lower than field observed LAI
   b. 2014 1km (n=59) MODIS LAI was 52% lower than field observed LAI
   c. 2013 500m (n=36) MODIS LAI was 11% higher than field observed LAI

These results likely confirm the suspicion that the LAI derived from MODIS at 1km underrepresent field measured LAI. This is likely due in part to the suspected underrepresentation of field crop LAI. However, the 500m MODIS LAI overestimated 2013 field measured LAI. This indicated that part of the incongruity between MODIS and field measurement may be a function of the larger grid capturing greater landscape heterogeneity including non-vegetated landcover. This would be expected to result in an actual LAI averaged across a heterogeneous grid cell being lower than a grid cell that only included vegetated cover. An inspection of imagery in the grid cells associated with each field observation showed that approximately 10% of each MODIS 1km grid cell was covered by a non-vegetated land cover (road, house, barn, etc…) For the MODIS 500km grid cell, 5% was covered by a non-vegetated land cover. A similar result was found in Yang and Wang 2015 wherein increased non vegetated land cover decreased average LAI in a MODIS grid cell.

At this time it is not possible to specifically identify how and to what extent the two sources of error (heterogeneity and row crop underestimation) are each inducing error in the ET observation for each grid cell. However, it may be possible to assume that:

- MODIS observed LAI represents the lower end of actual ET in any cropped cell since it captures non-vegetated area and underestimates row crop LAI.
- Field measurements applied to the entire cell represent the upper end of actual ET since it would ignore non-vegetated areas but accurately represent row crop LAI.

From this we propose a range of ET between the observed MODIS ET and a MODIS ET value adjusted to elevated LAI. The MODIS ET was adjusted through the following steps:

1. MODIS 8 day LAI and ET at 1km were acquired for the growing season (May 25 through September 28).
2. A basic linear regression was completed for each year with MODIS LAI at each field measurement site being used to predict field measured LAI.
3. The slope (m_{LAI}) and intercept (b_{LAI}) for each of yearly comparison were then used to adjust the each year's MODIS LAI dataset so that $LAI_{adjusted} = (LAI_{MODIS}\,x\,m_{LAI}) + b_{LAI}$. This was done at 1253 points with known cropland in the gridcell. The net effect of this adjustment was to raise the average LAI across to MODIS LAI dataset to an average LAI reflecting the field observed LAI.
4. For each year, a linear regression was also identified between MODIS LAI and MODIS ET for each growing season. Although this relationship is known to be logarithmic, it is roughly linear for most of the growing season. This accuracy suffices for the purposes of identify a rough upper bound estimate averaged across the area.
5. The MODIS ET for each point was then adjusted for each year using the slope (m_{ET}) and intercept (b_{ET}) from each regression so that: $ET_{Adjusted} = (LAI_{adjusted}\,x\,m_{ET}) + b_{ET}$.
6. Adjusting the MODIS ET measurements to field measured crop LAI resulted in raising the average MODIS ET to what it would be given the field observed LAI. The following annual increases in ET were predicted for cropland in each year's MODIS dataset:
    a. 2013: Mean = 39 millimeters/yr (1.52 inches), SD = .85 mm
    b. 2014: Mean = 51 millimeters/yr (1.99 inches), SD = .26 mm
7. These observed adjustment falls within the 1mm/day RSME for cropland that MU et al (2011) found when ground validating their MODIS ET algorithm.

The comparison of the field-scale LAI data collected by UW with the MODIS data indicates that the upper end of a range from MODIS-derived ET on agricultural land should be approximately 2 inches above what is currently reported. The 2 inch annual increase in ET should be proportioned across the growing season. This adjustment will be made in the DNR's calculation of recharge on agricultural lands in the in the study area as described in the Monday, October 12, 2015 meeting.

There does not appear to be a similar error present in forested areas. MODIS ET values for the GSD domain align with observed values such as those given in Mu Et al's 2011 algorithm validation and in Sun et al's 2008 forest ET observations in Northern Wisconsin.

References

Mu, Qiaozhen, Maosheng Zhao, and Steven W. Running. "Improvements to a MODIS global terrestrial evapotranspiration algorithm." *Remote Sensing of Environment* 115.8 (2011): 1781-1800.

Sun, Ge, et al. "Evapotranspiration estimates from eddy covariance towers and hydrologic modeling in managed forests in Northern Wisconsin, USA." *agricultural and forest meteorology* 148.2 (2008): 257-267.

Yang, Fei, et al. "Assessment and validation of MODIS and GEOV1 LAI with ground-measured data and an analysis of the effect of residential area in mixed pixel." *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of* 8.2 (2015): 763-774.

Estimating Groundwater Recharge within Wisconsin's Central Sands

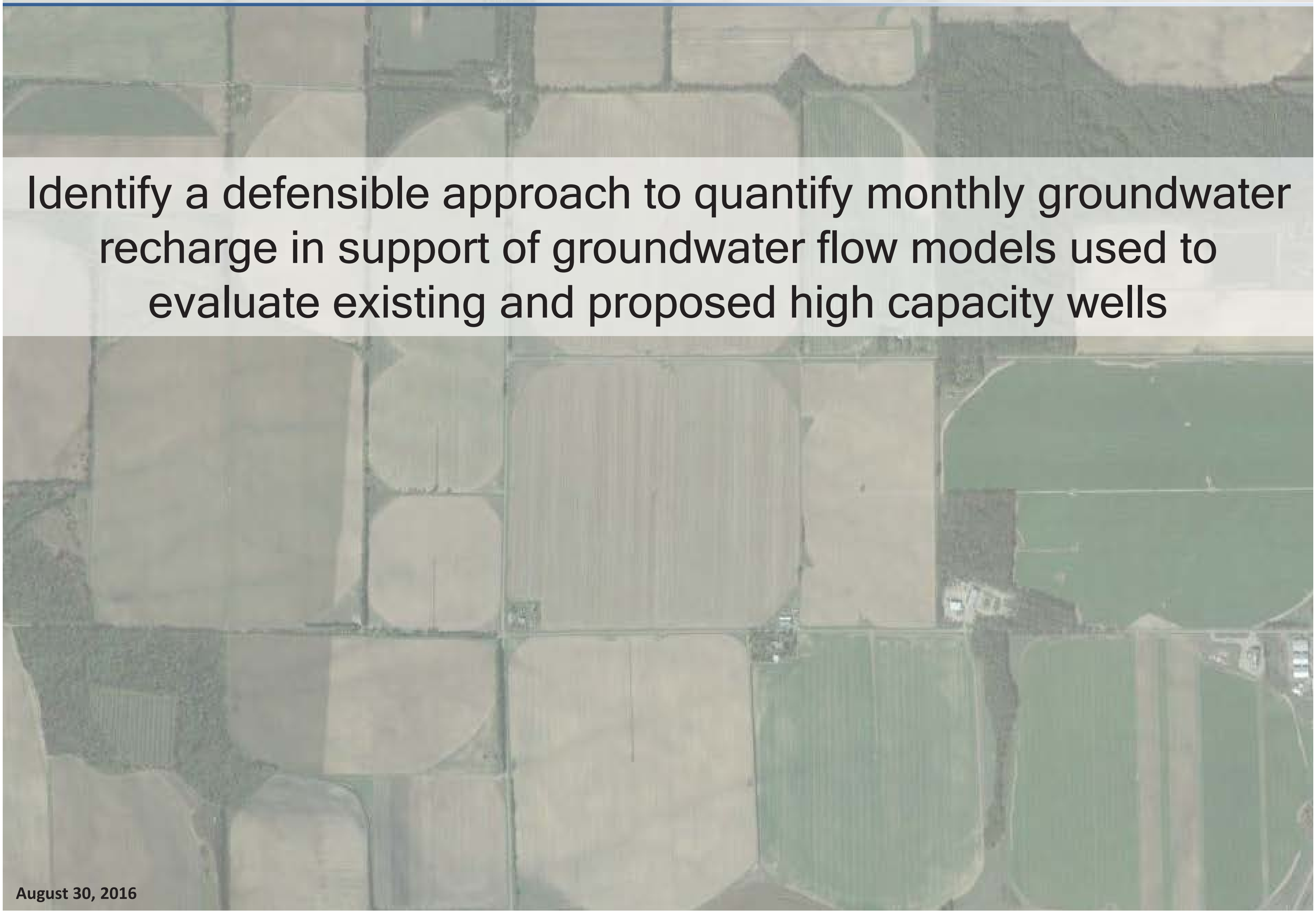
Adam Freihoefer and Robert Smail
Wisconsin Department of Natural Resources
August 30, 2016

[summary]

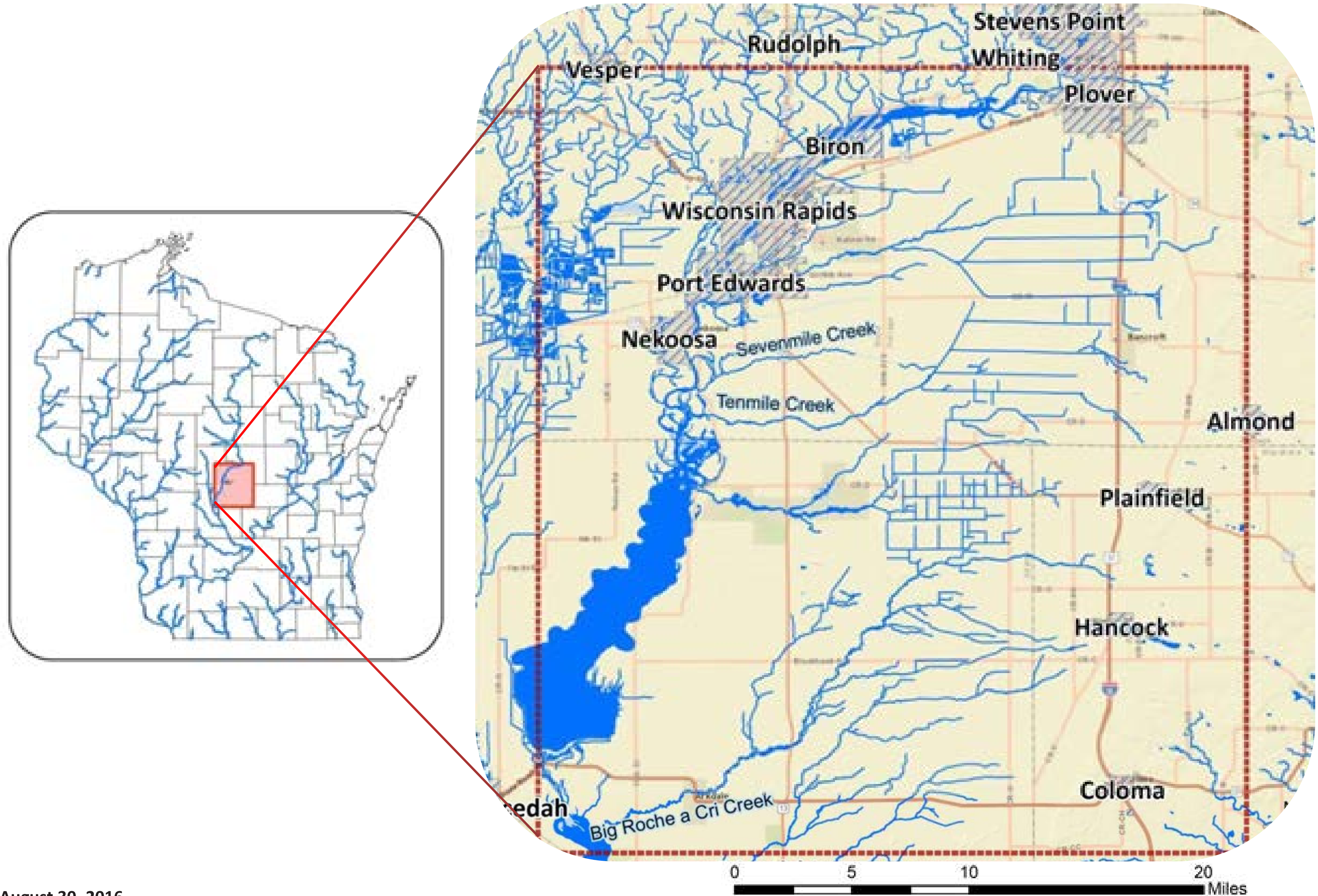
To better understand the impacts of irrigation and landcover change in the . entral Sands, the Wisconsin Department of Natural Resources employed remote sensing data and a process-based model to u antify annual and monthly recharge rates. Results showed that average annual net recharge rates across the 1,000 su are mile study area were similar between forests, grasslands and irrigated agriculture. Results also indicate that the factors controlling recharge such as precipitation, applied irrigation water, and evapotranspiration, can vary throughout any given year and across the study area. These results highlight the need for continued research regarding evapotranspiration rates and incorporating the most detailed model inputs available.

[study objective]

Identify a defensible approach to quantify monthly groundwater recharge in support of groundwater flow models used to evaluate existing and proposed high capacity wells



[study area]



Stevens Point
Rudolph
Whiting
Vesper
Plover
Biron
Wisconsin Rapids
Port Edwards
Nekoosa
Sevenmile Creek
Tenmile Creek
Almond
Plainfield
Hancock
Coloma
Big Roche a Cri Creek
0
5
10
20
Miles

[study considerations]

Timing: *month and annual averages*

Scale: *Landscape*

[central sands water budget]

Deposits

- Precipitation
- Applied Irrigation Water
- Groundwater & Surface Water Inflow

Withdrawals

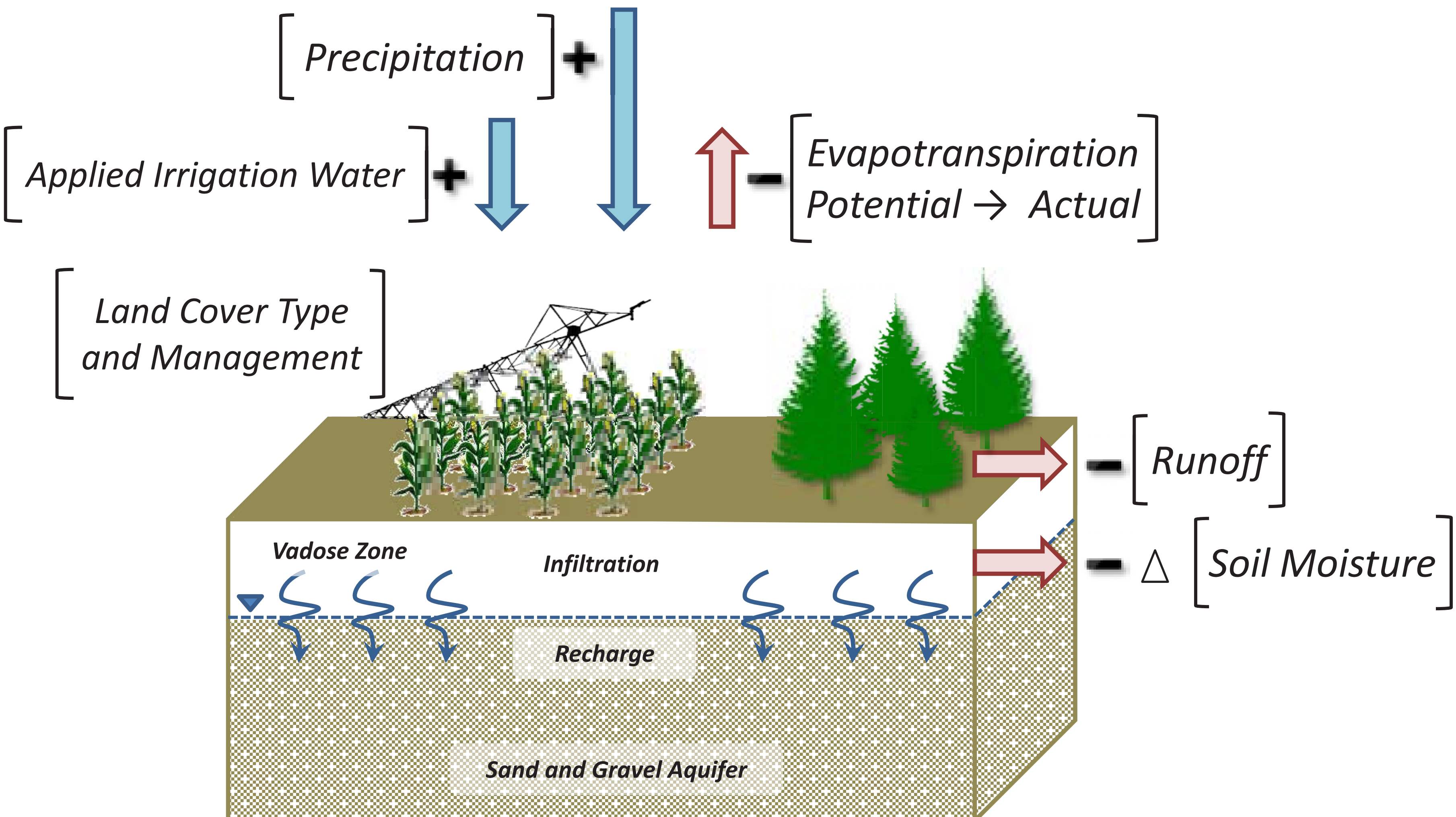
- Evapotranspiration
- Runoff
- Pumping
- Groundwater & Surface Water Outflow

Indices

- Streamflow
- Lake Levels
- Groundwater Levels

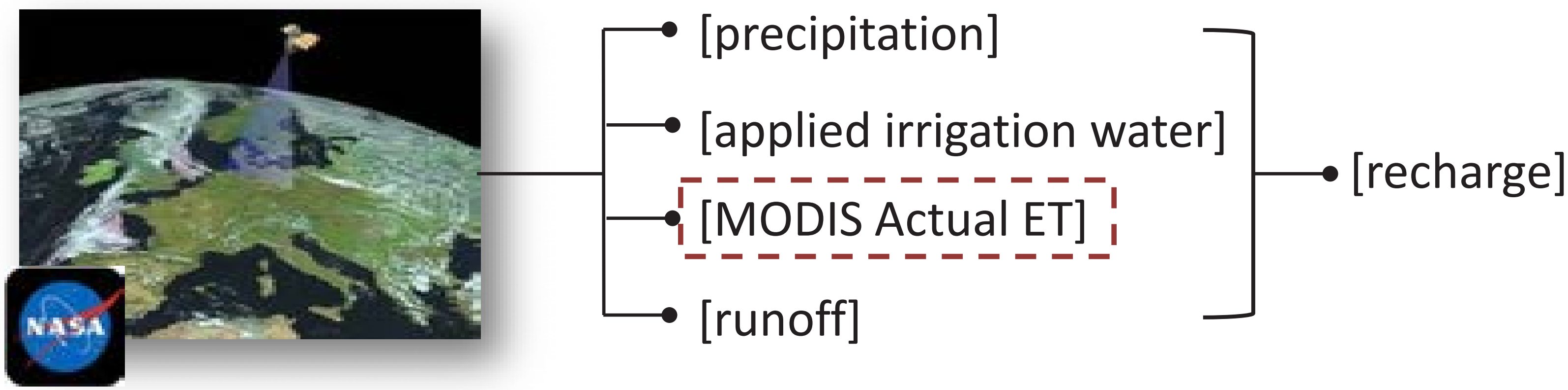
[recharge defined]

The total amount of water that reaches the water table, becoming part of the groundwater system



[recharge estimation technique - MODIS]

MODIS-based Water Budget



[recharge estimation technique - MODIS]

- Moderate Resolution Imaging Spectroradiometer flown by NASA satellites (ET referred to as MODIS 16)

- MODIS ET includes
  - evaporation from wet and moist soil,
  - evaporation from rain water intercepted by the canopy
  - transpiration through stomata on plant leaves and stems.

- 8-day, monthly, and annual time steps between 2000 and 2014

- Grid cells are slightly less than 1 km^2

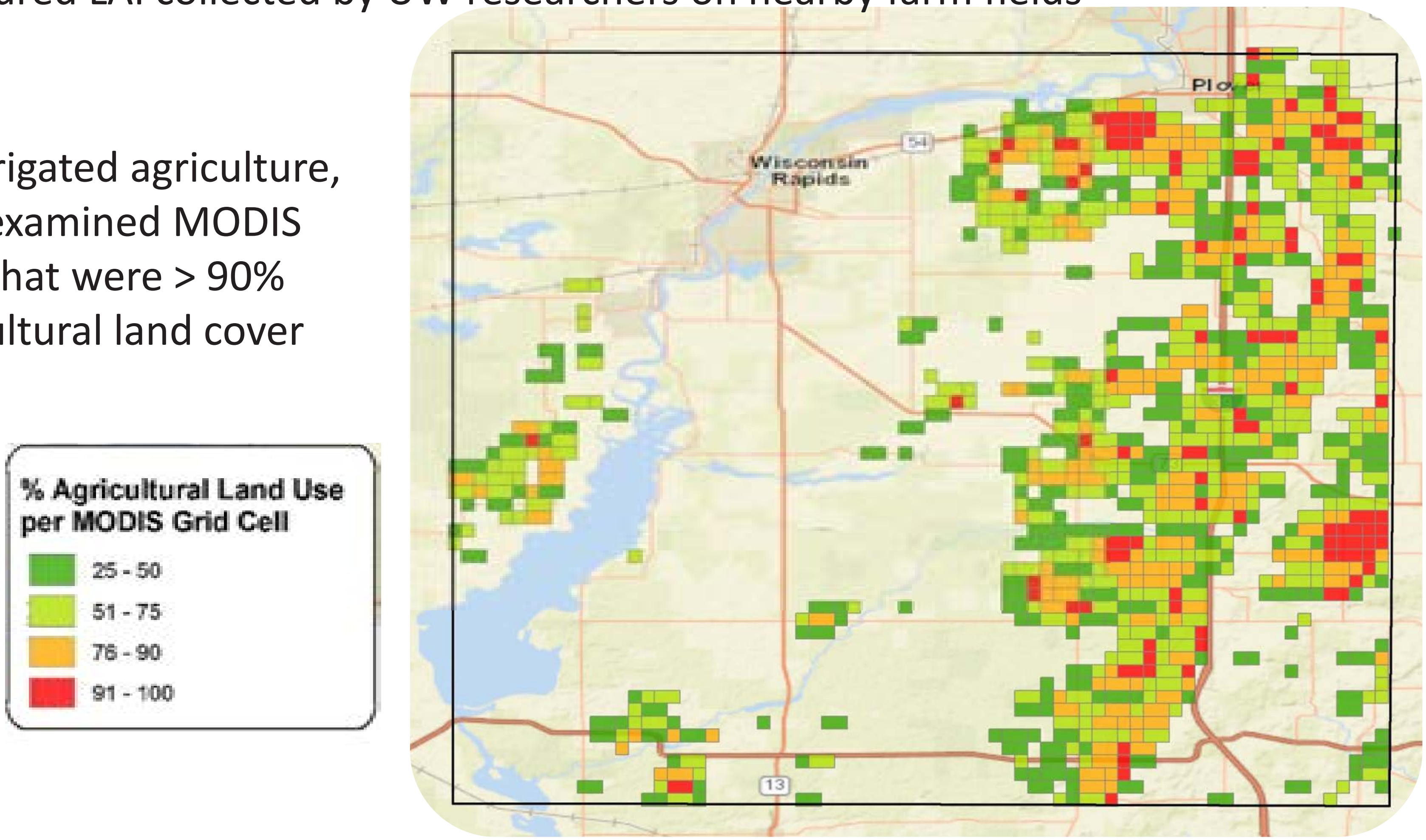
- Values derived using the P-M ET equation with climate data and other satellite acquired information as inputs, and calibrated based on measurements from eddy covariance flux towers

[recharge estimation technique - MODIS]

Modifications to MODIS Budget Approach

1. Increased MODIS Actual ET by 2” across growing season (0.5” per month)
   Why? Acknowledge difference between MODIS 8-day LAI to individual daily measured LAI collected by UW researchers on nearby farm fields

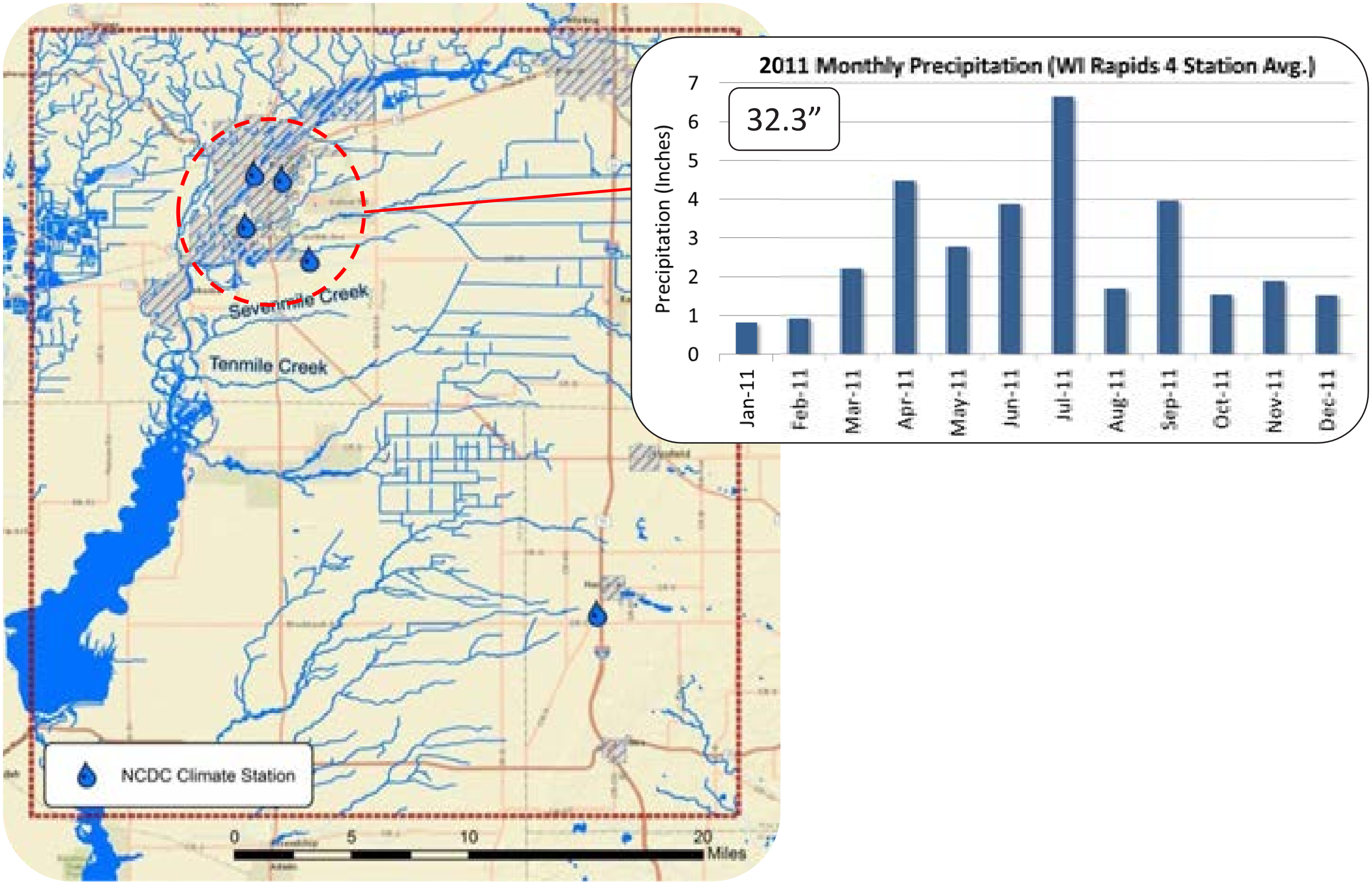
2. For irrigated agriculture, only examined MODIS cells that were > 90% agricultural land cover



[recharge components]

precipitation | irrigation water | land cover | soils | runoff

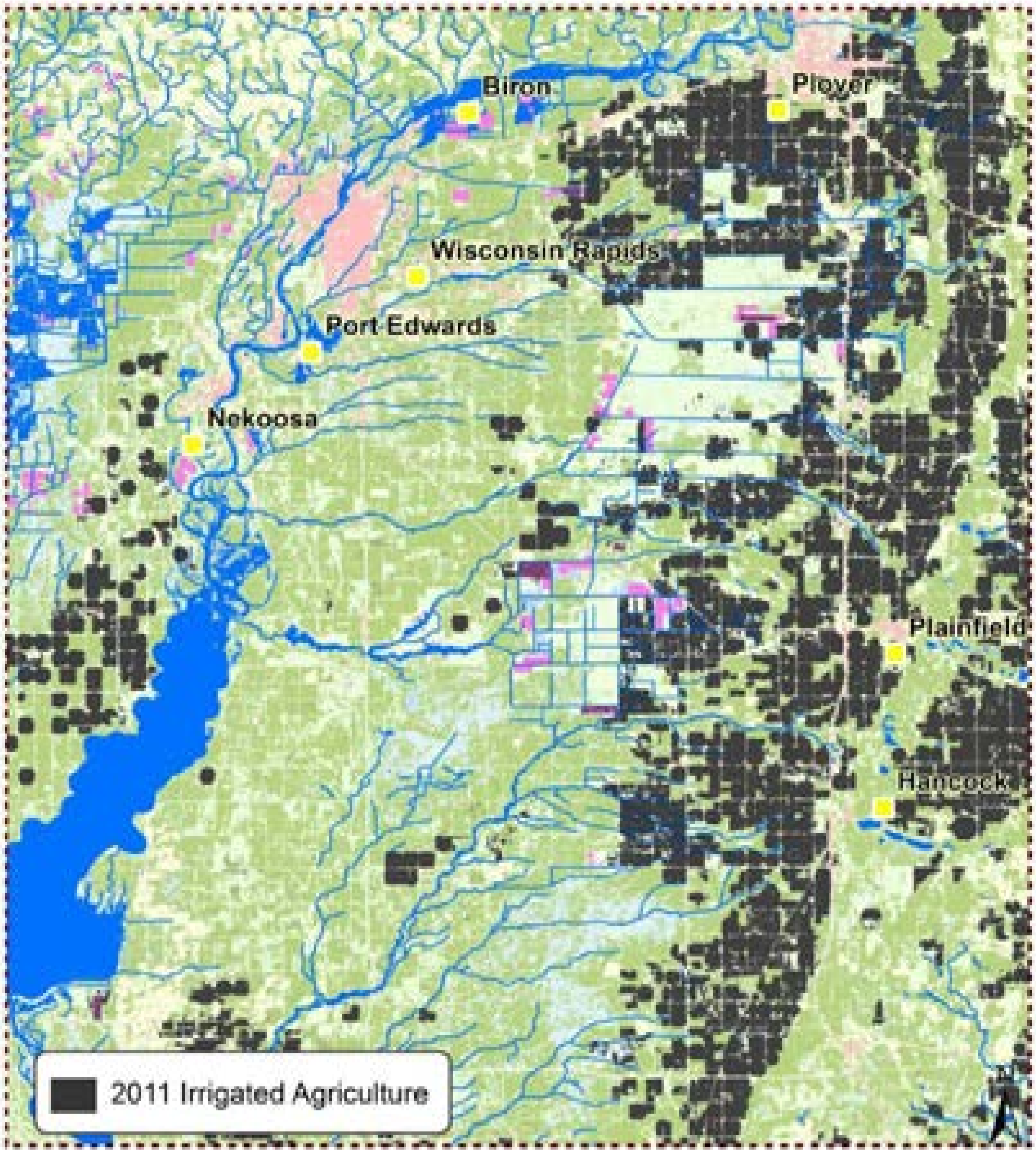
August 30, 2016



[recharge components]

August 30, 2016

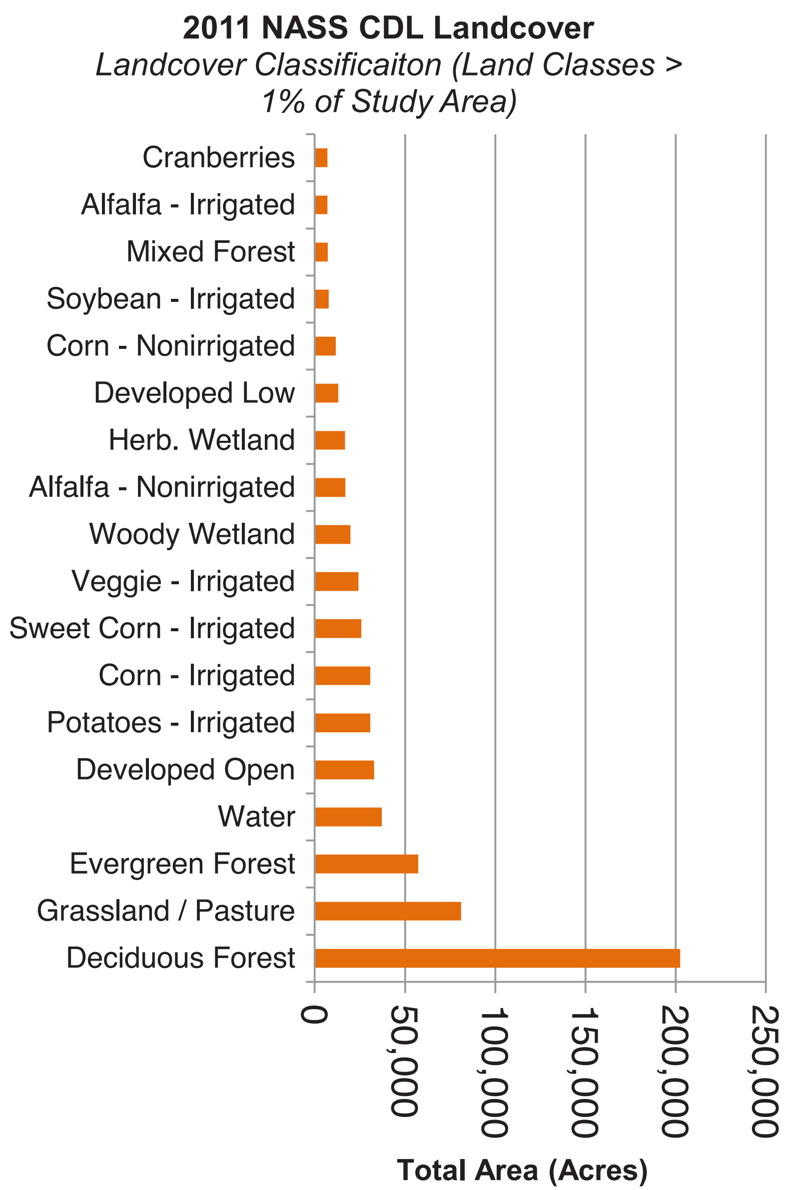
precipitation | **irrigation water** | land cover | soils | runoff

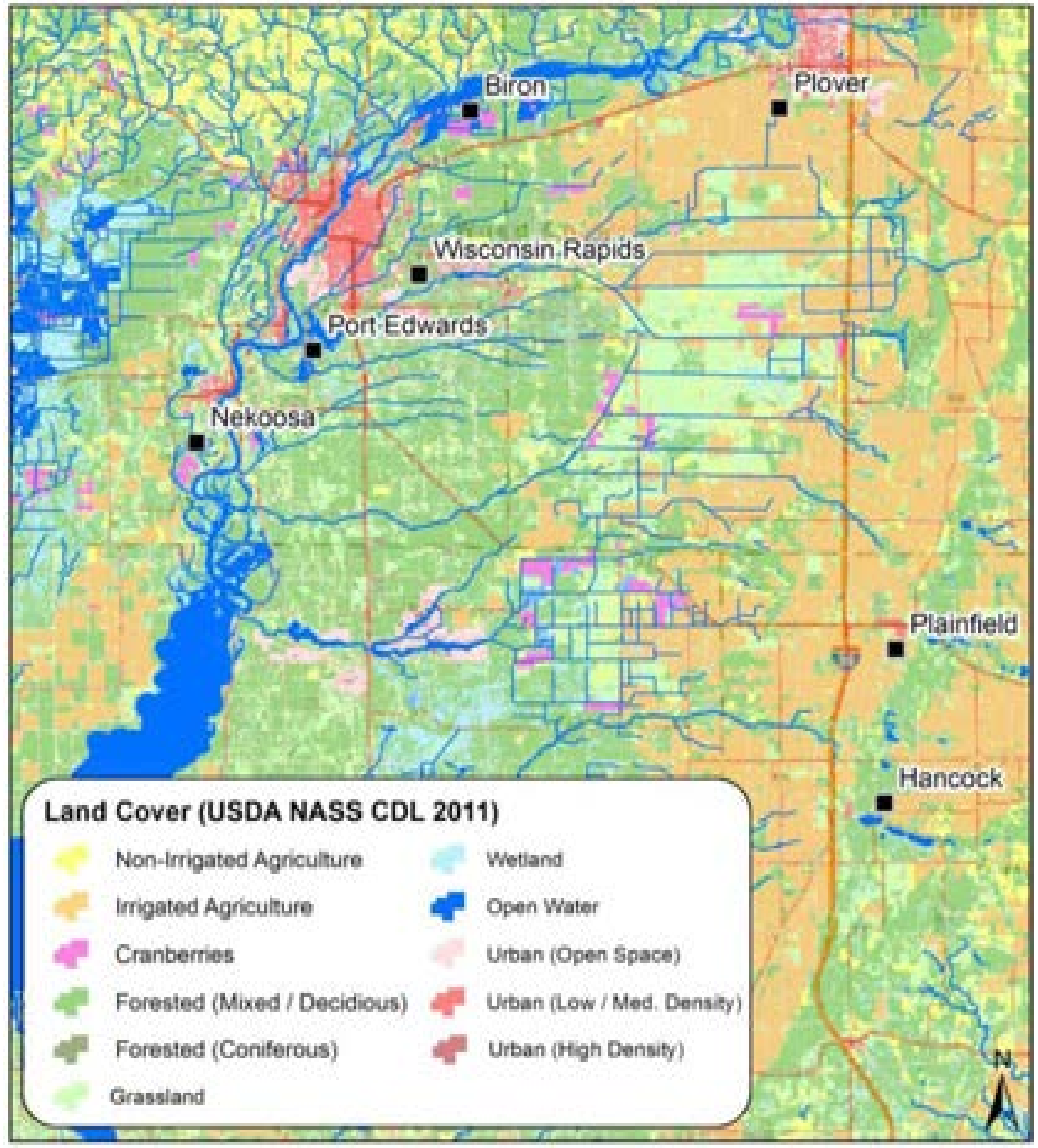


[recharge components]

precipitation | irrigation water | **land cover** | soils | runoff

August 30, 2016

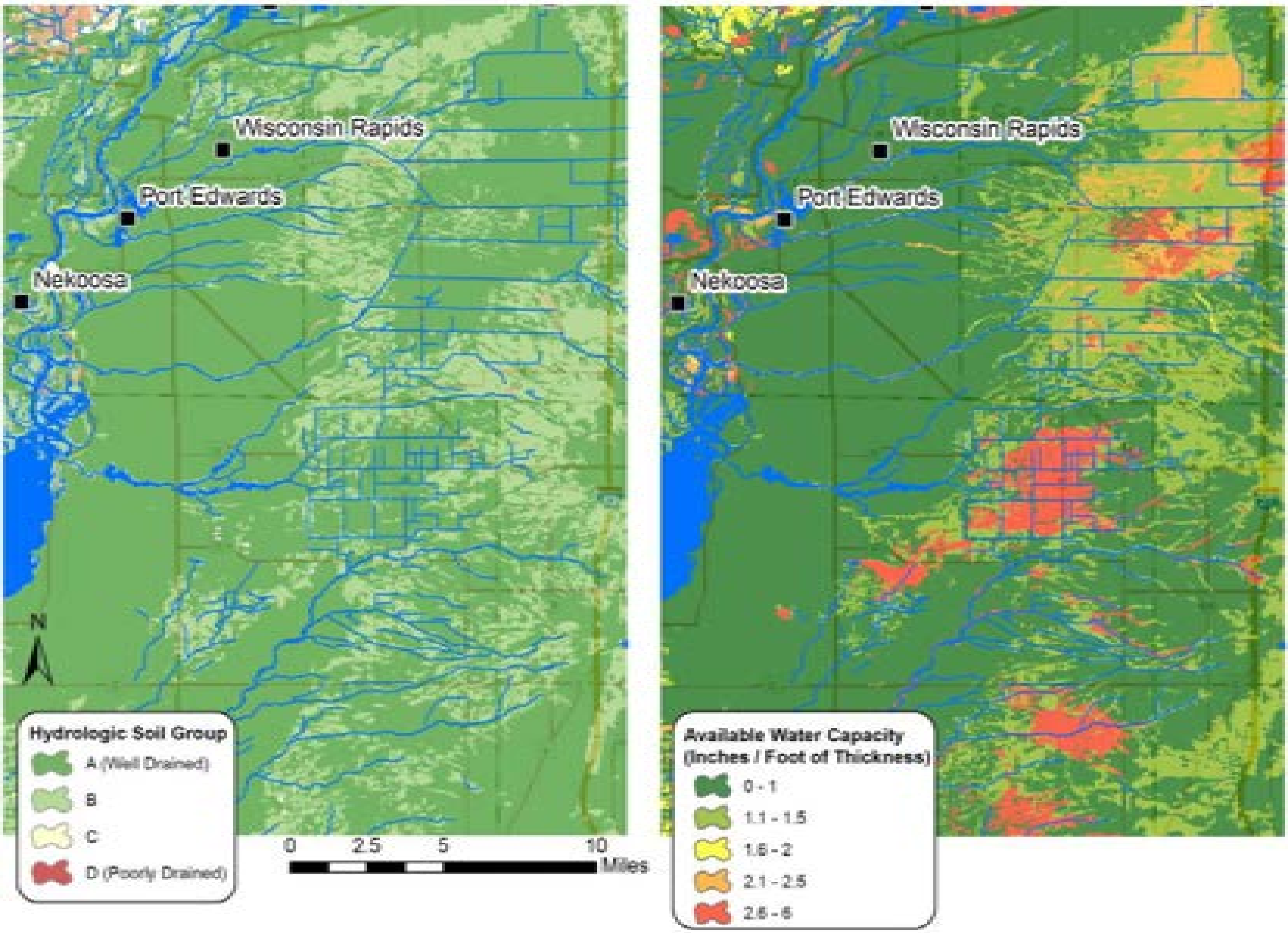




[recharge components]

August 30, 2016

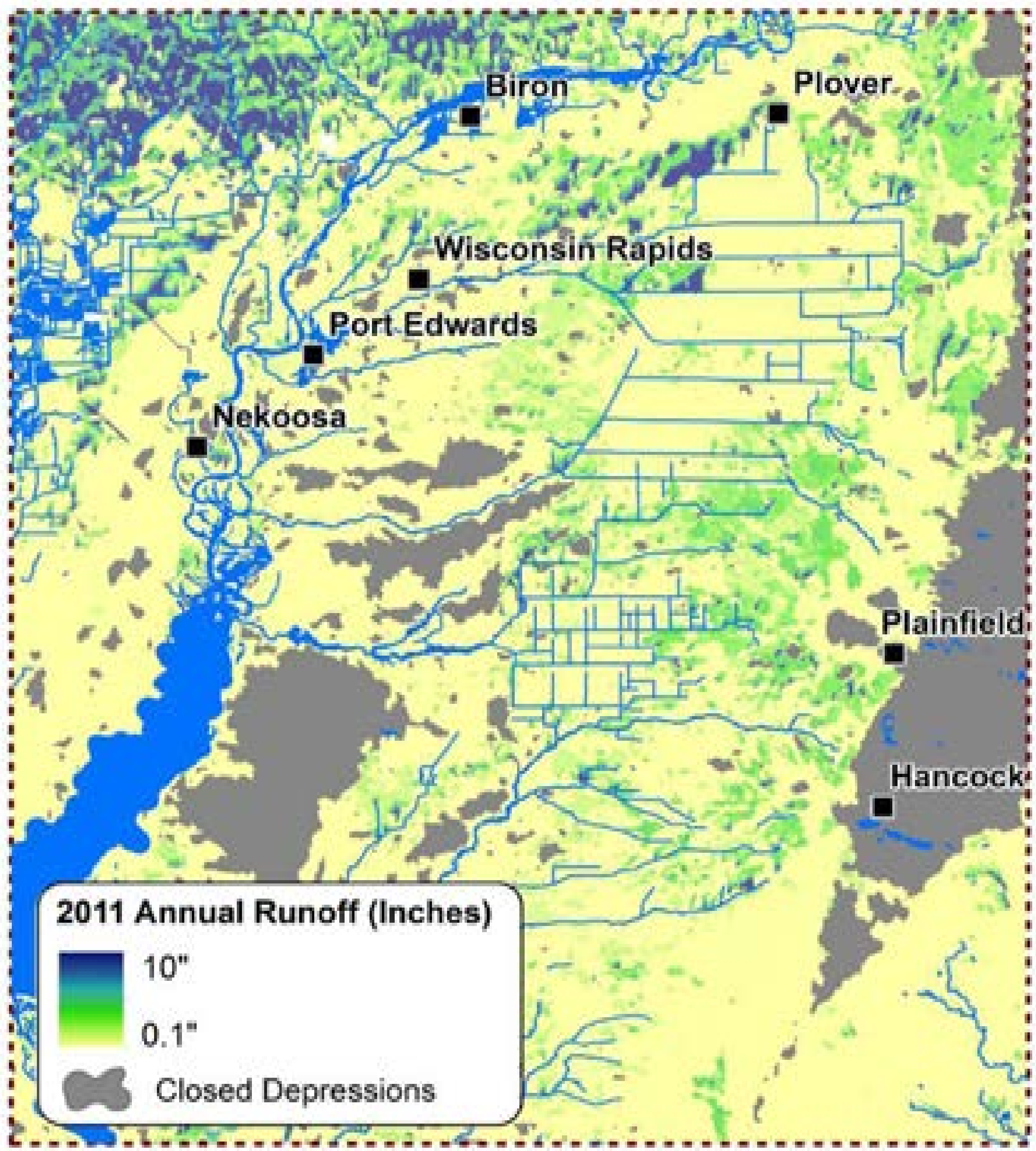
precipitation | irrigation water | land cover | **soils** | runoff



[recharge components]

August 30, 2016

precipitation | irrigation water | land cover | soils | **runoff**



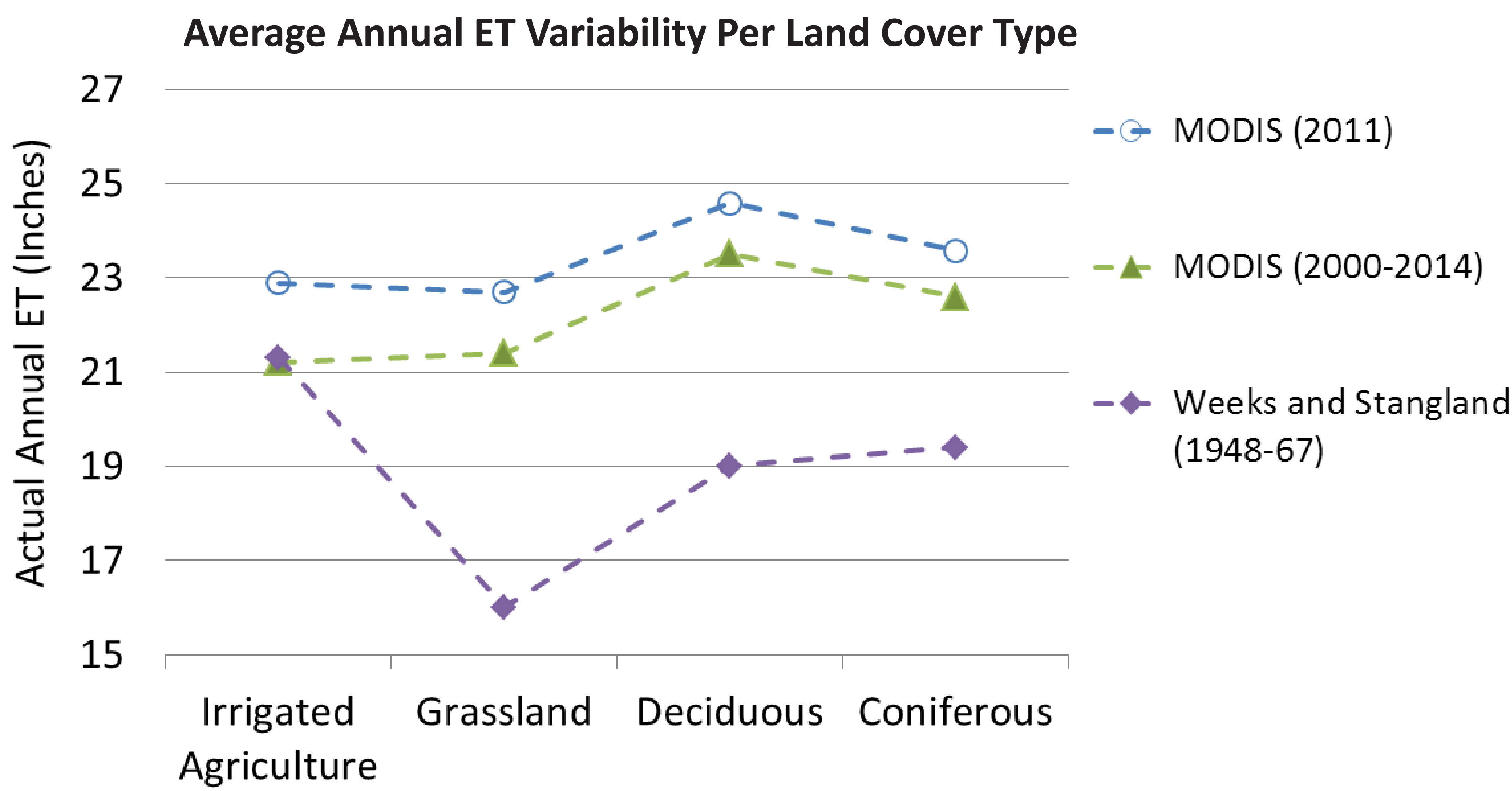
[recharge estimation – putting the pieces together]

Average Annual Water Budget (**2011**) Across Study Area

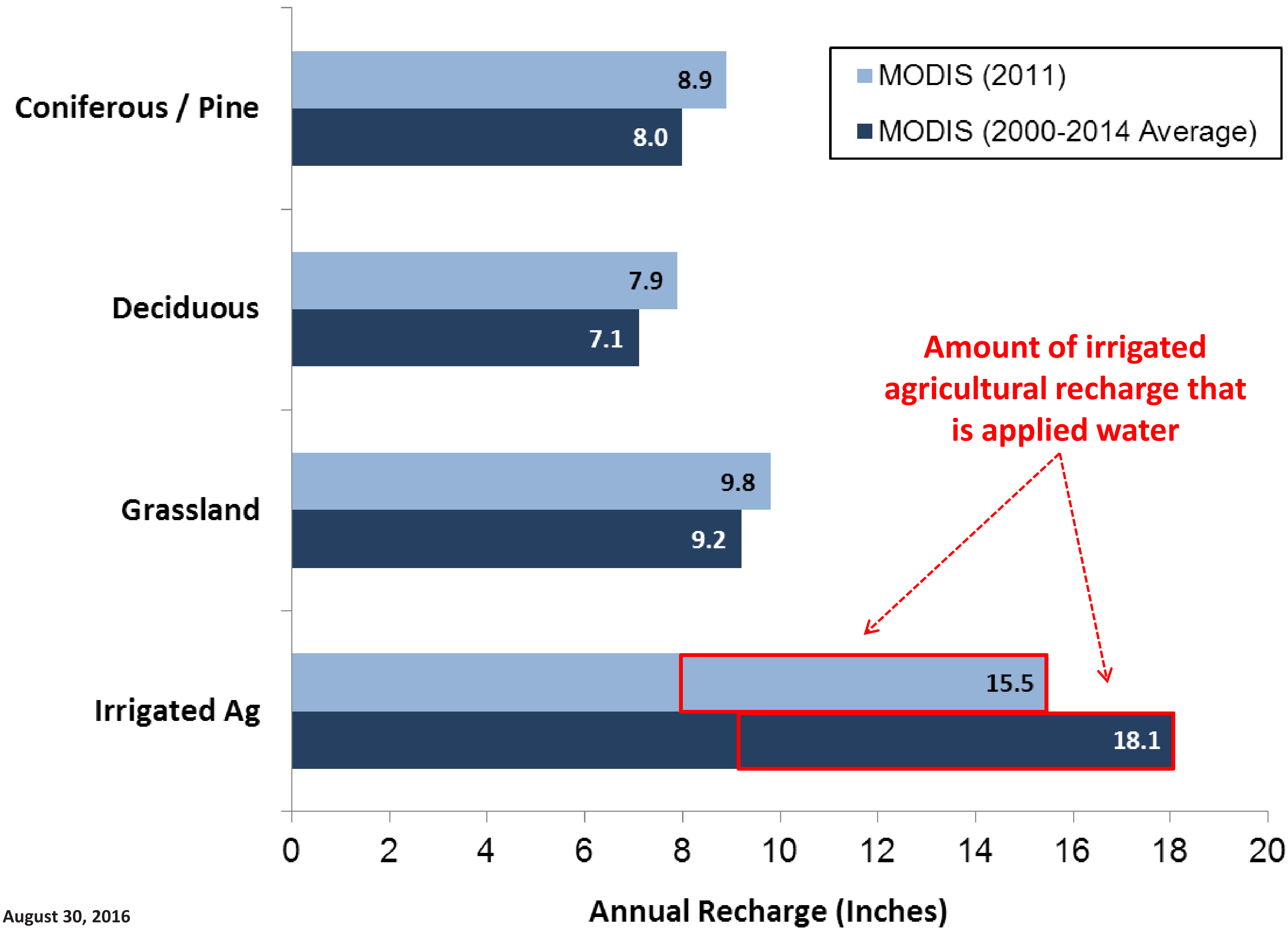
Irrigated Agriculture		(Inches)
Precipitation	+	32.5”
Applied Irrigation	+	7.5”
Actual Evapotranspiration	−	22.9”
Runoff	−	1.7”
Recharge	=	**15.4”**

<u>Insight in Averages</u>

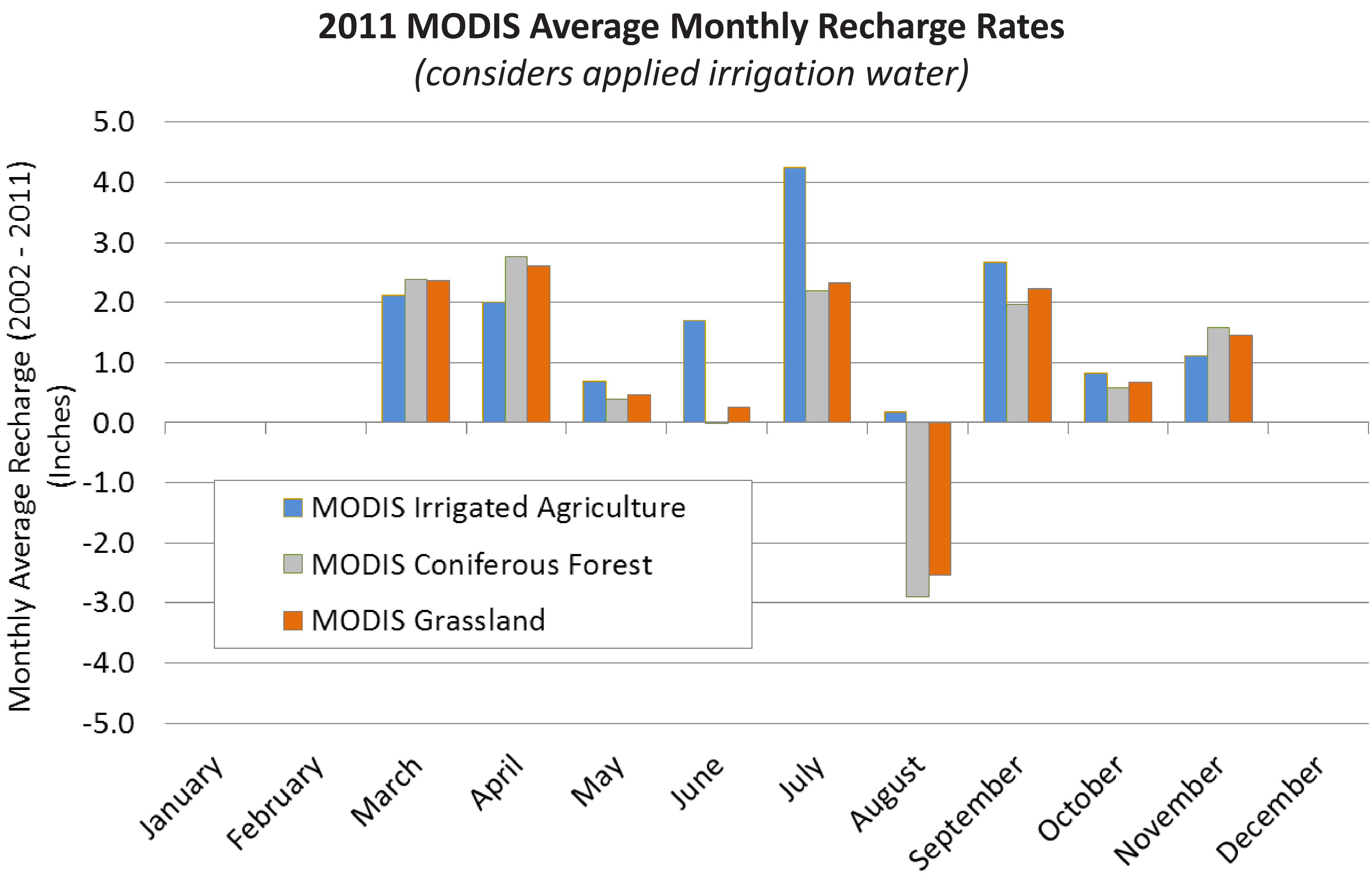
- Variability can exist across the study area (per field / farm) with respect to individual budget components.
- 15.4” represents the average for an entire year, for all irrigated agricultural in the study area.


Average Annual ET Variability Per Land Cover Type
Actual Annual ET (Inches)
27
25
23
21
19
17
15
Irrigated Agriculture
Grassland
Deciduous
Coniferous
MODIS (2011)
MODIS (2000-2014)
Weeks and Stangland (1948-67)

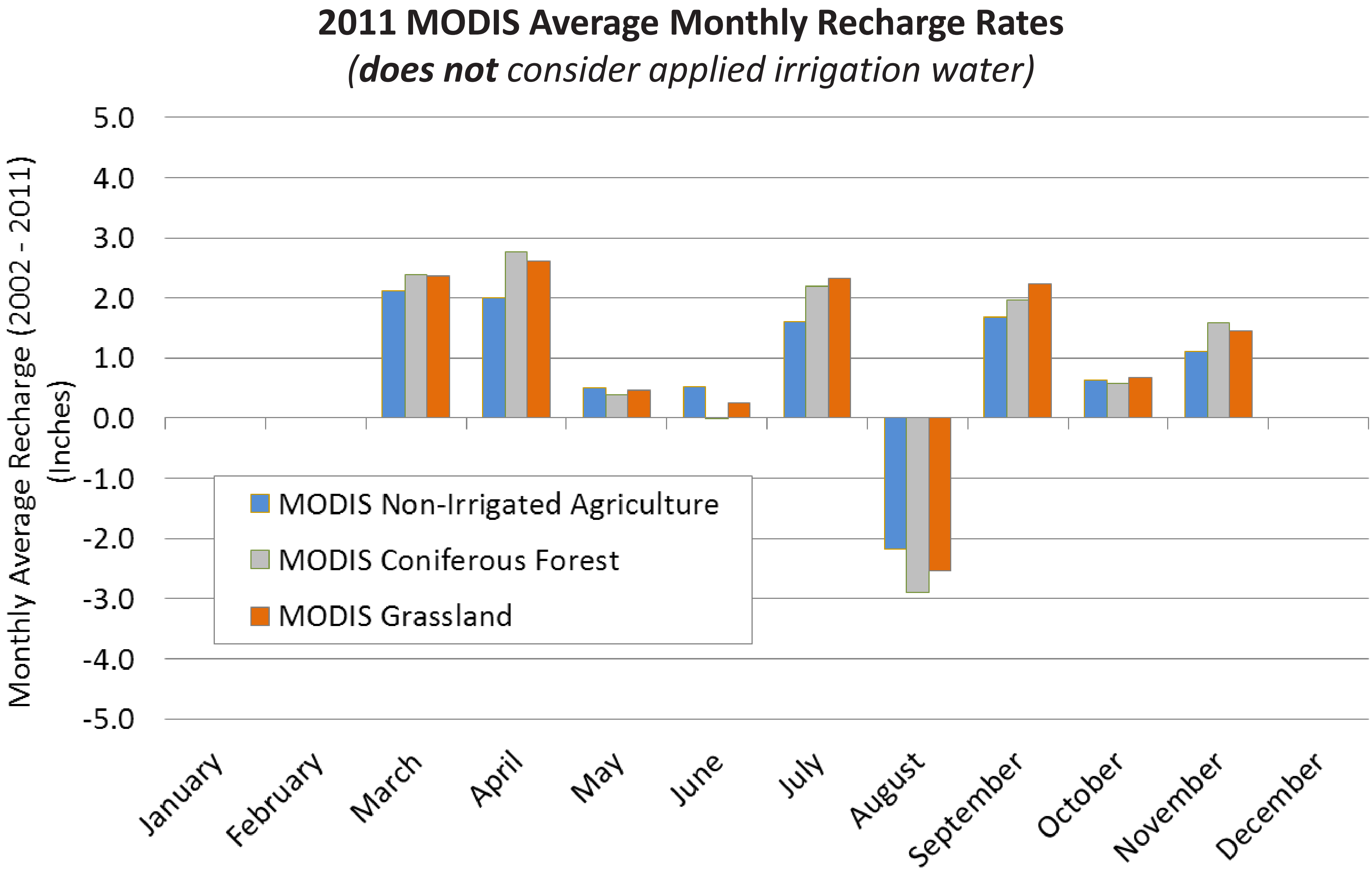
[recharge estimation – comparing annual recharge]



[recharge estimation – comparing monthly recharge]

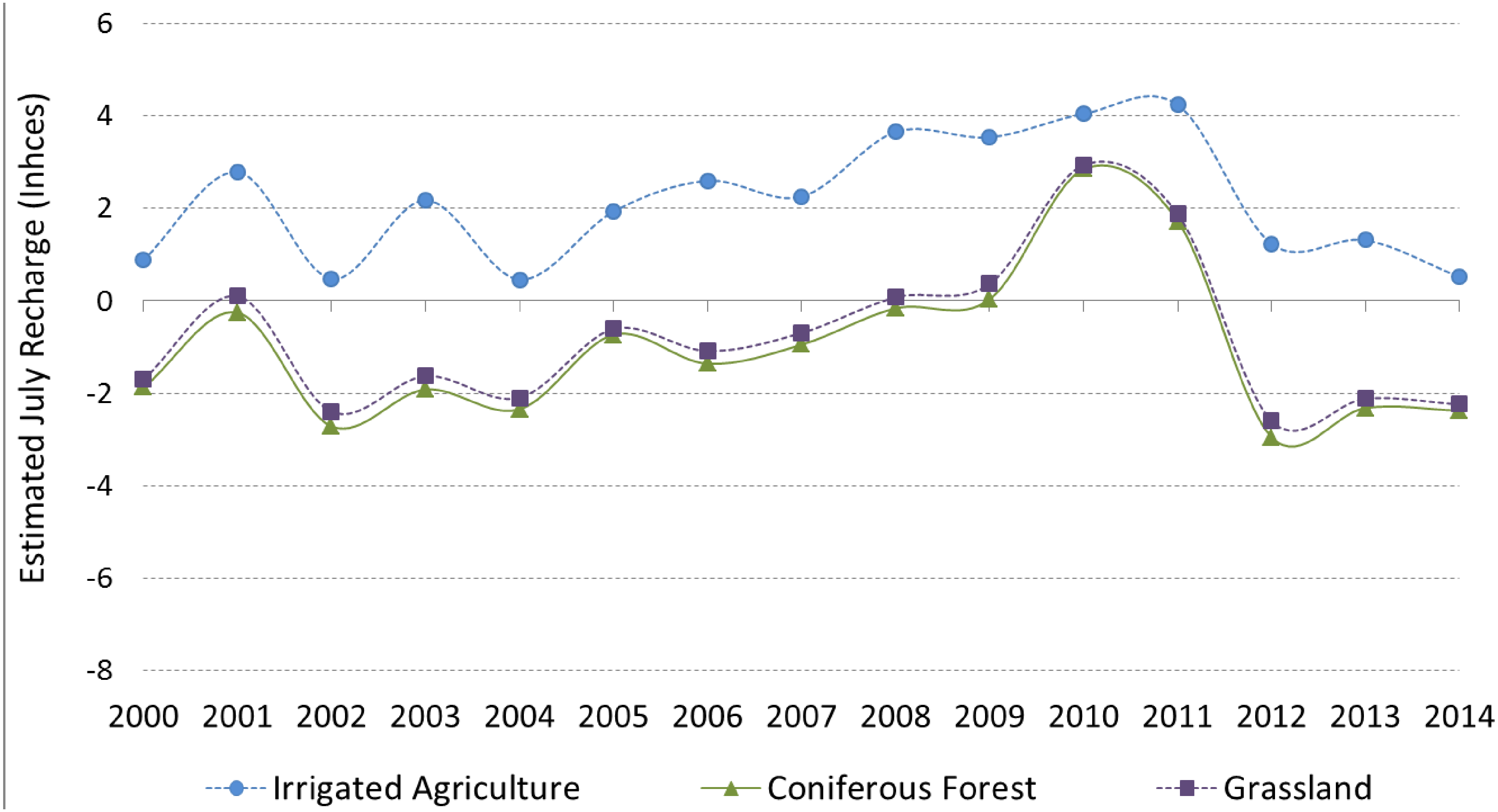


[recharge estimation – comparing monthly recharge]



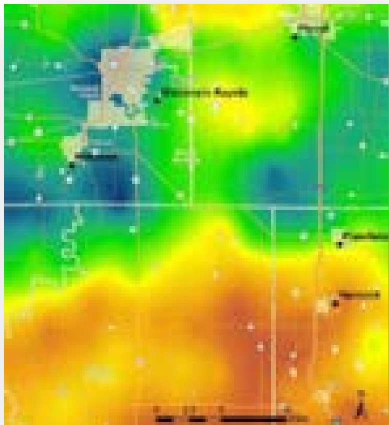
[recharge estimation – comparing monthly recharge]

Variation in Estimated July Recharge (2000 - 2014)

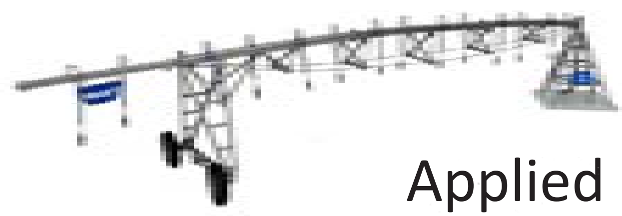


[recharge estimation – input variability and uncertainty]

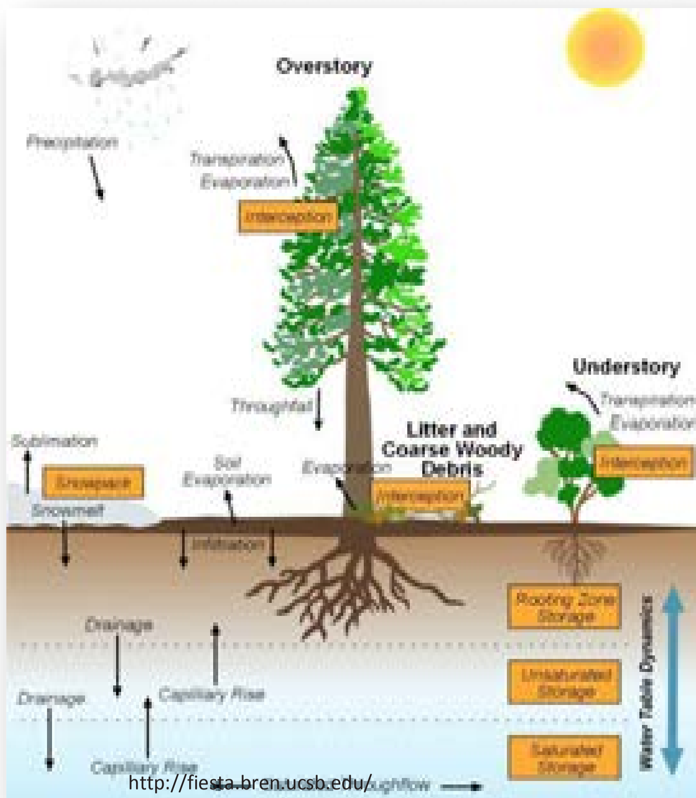
Spatiotemporal Variation



Precipitation



Applied water distribution



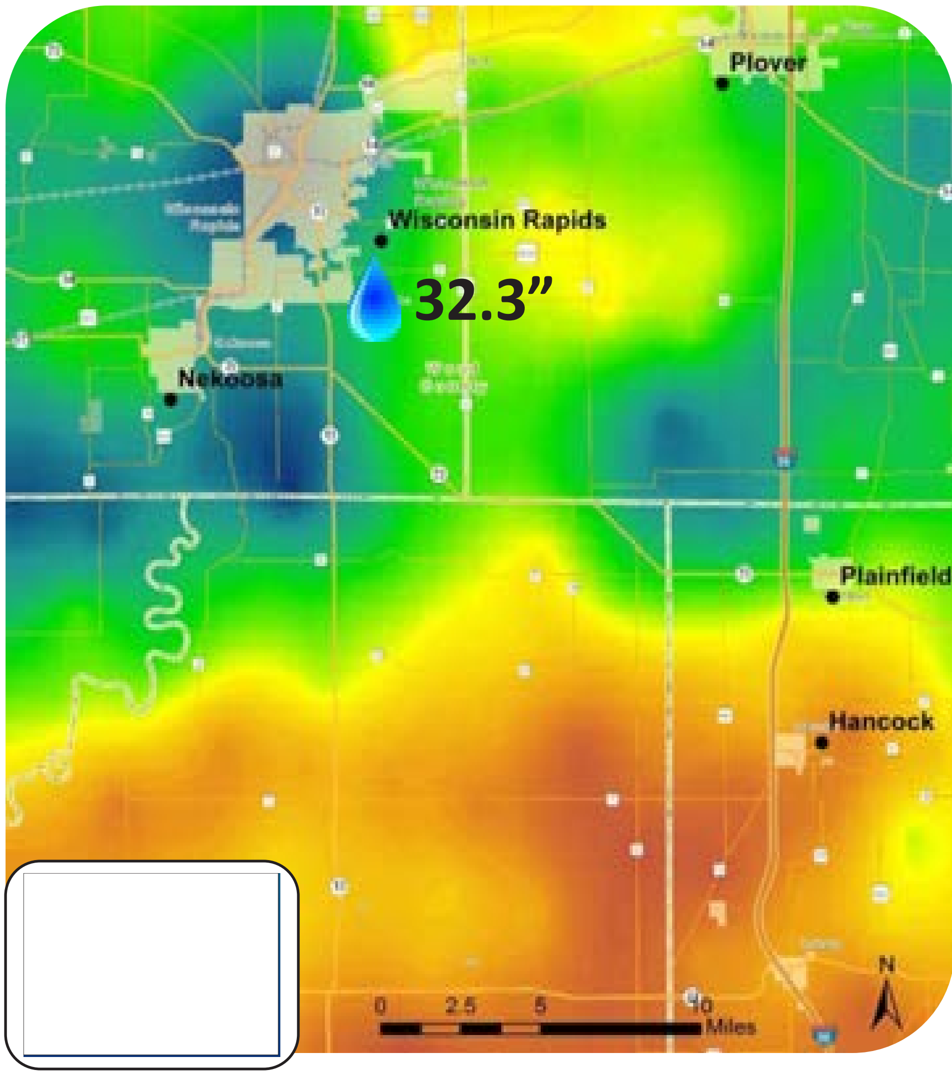
http://fiesta.bren.ucsb.edu/

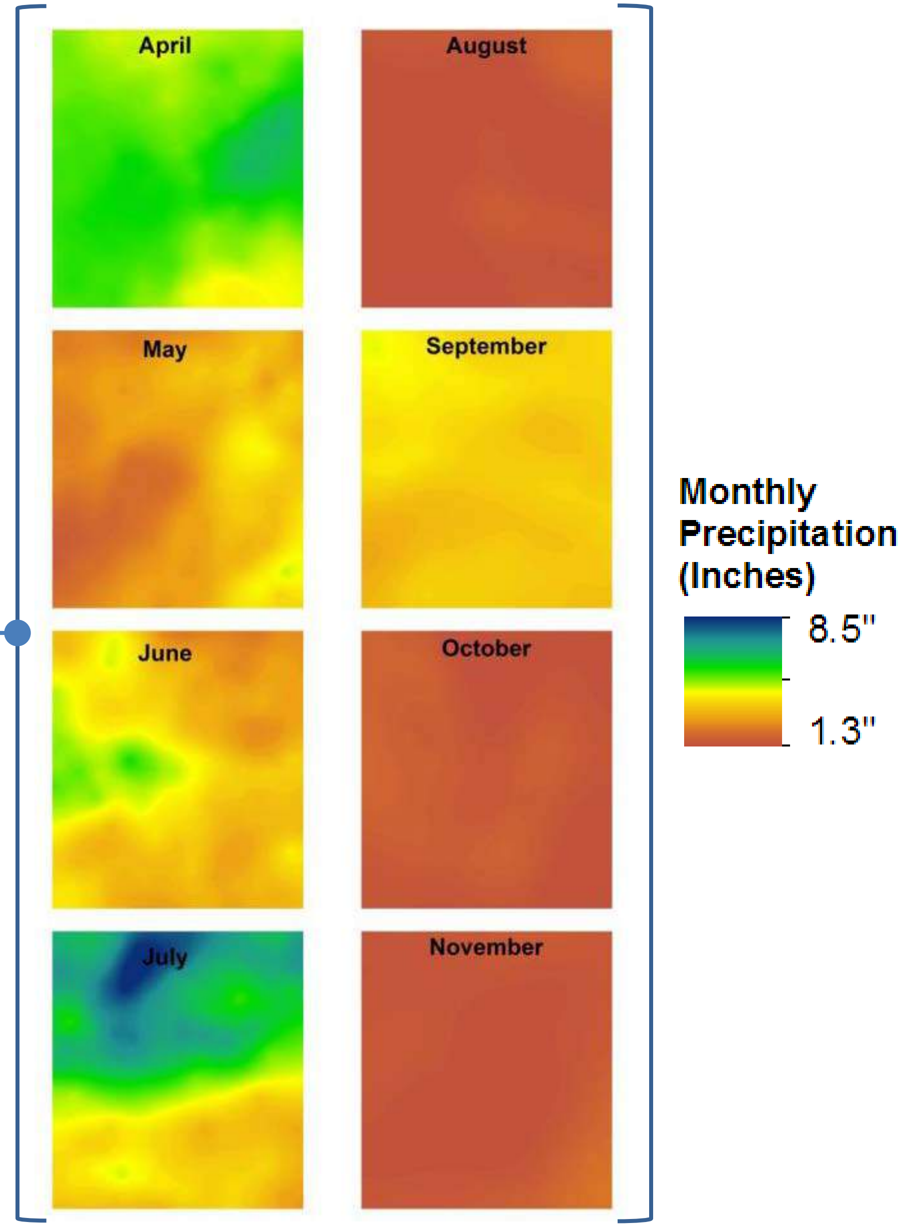
Actual ET Model

[recharge estimation – input variability and uncertainty]

2011 Gridded Annual Precipitation

NOAA Advanced Hydrologic Prediction Service

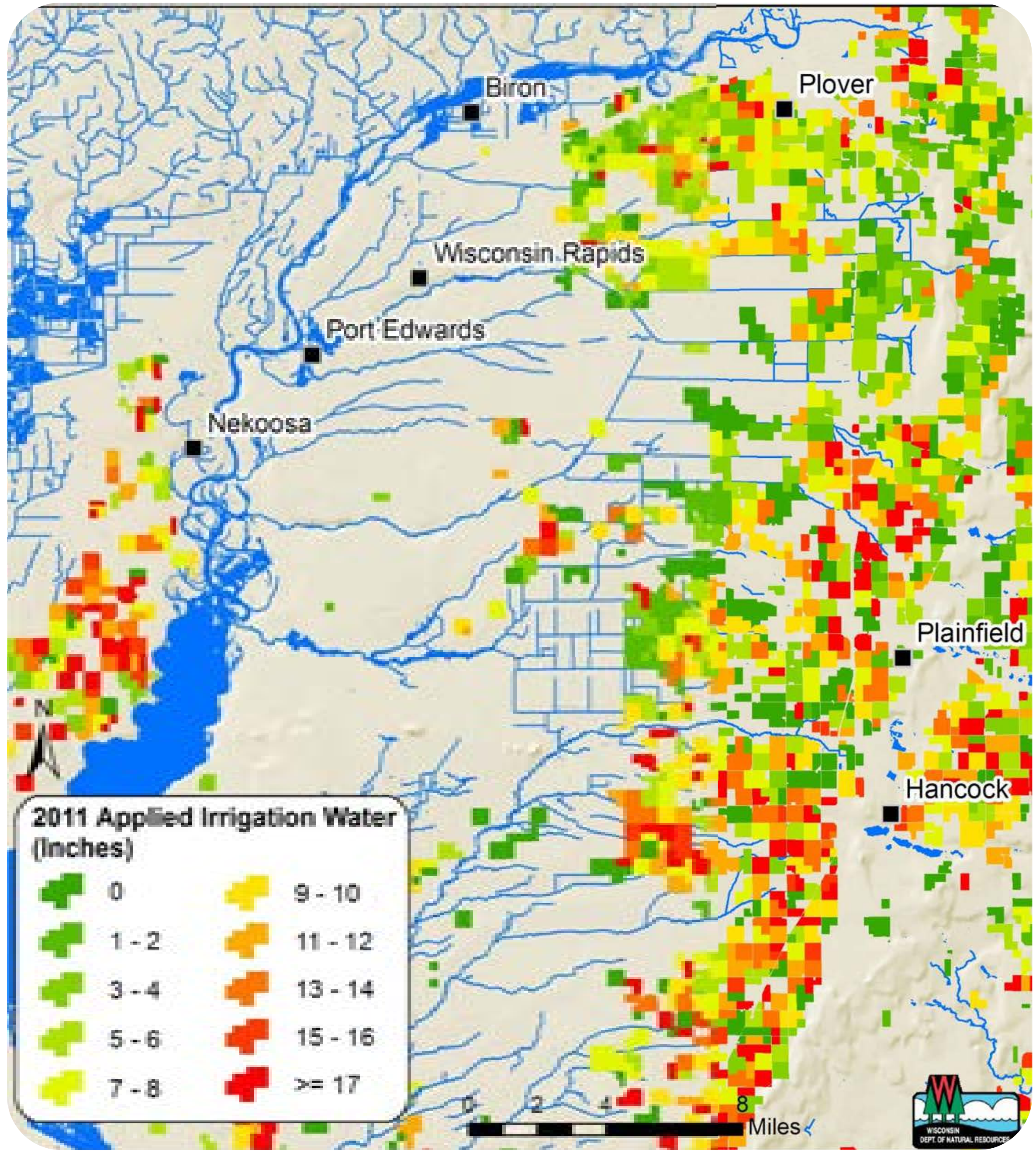




[recharge estimation – input variability and uncertainty]

2011 Applied Irrigation Water

Derived from Reported Water Use Information, Well Location, and Acreage

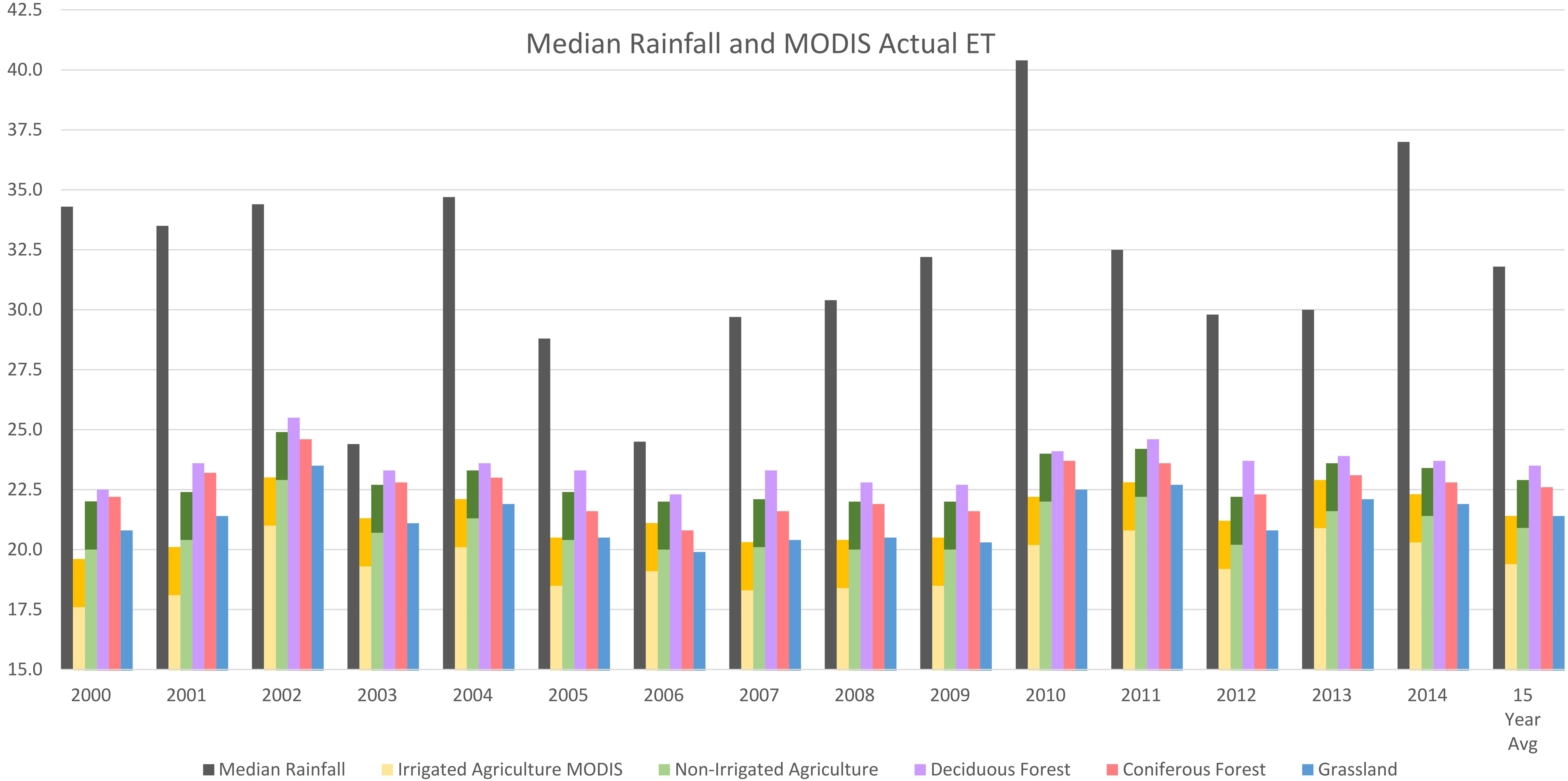


[wrap up]

- In any given year, recharge varies based on spatiotemporal variation of rainfall
- Linking recharge to resource impacts requires an examination of not just land cover type, but land management practices such as irrigation withdrawals
- Even a monthly assessment of recharge may not capture the variability of rainfall and the associated demand of the irrigated crop (e.g. June’s rain falls in beginning of month, water is needed by plant at month’s end)
- The MODIS approach is less time intensive if all other data products are readily available (runoff, applied water)
- Future work is needed including establishing better calibration datasets to calculate actual ET (e.g. eddy covariance towers)

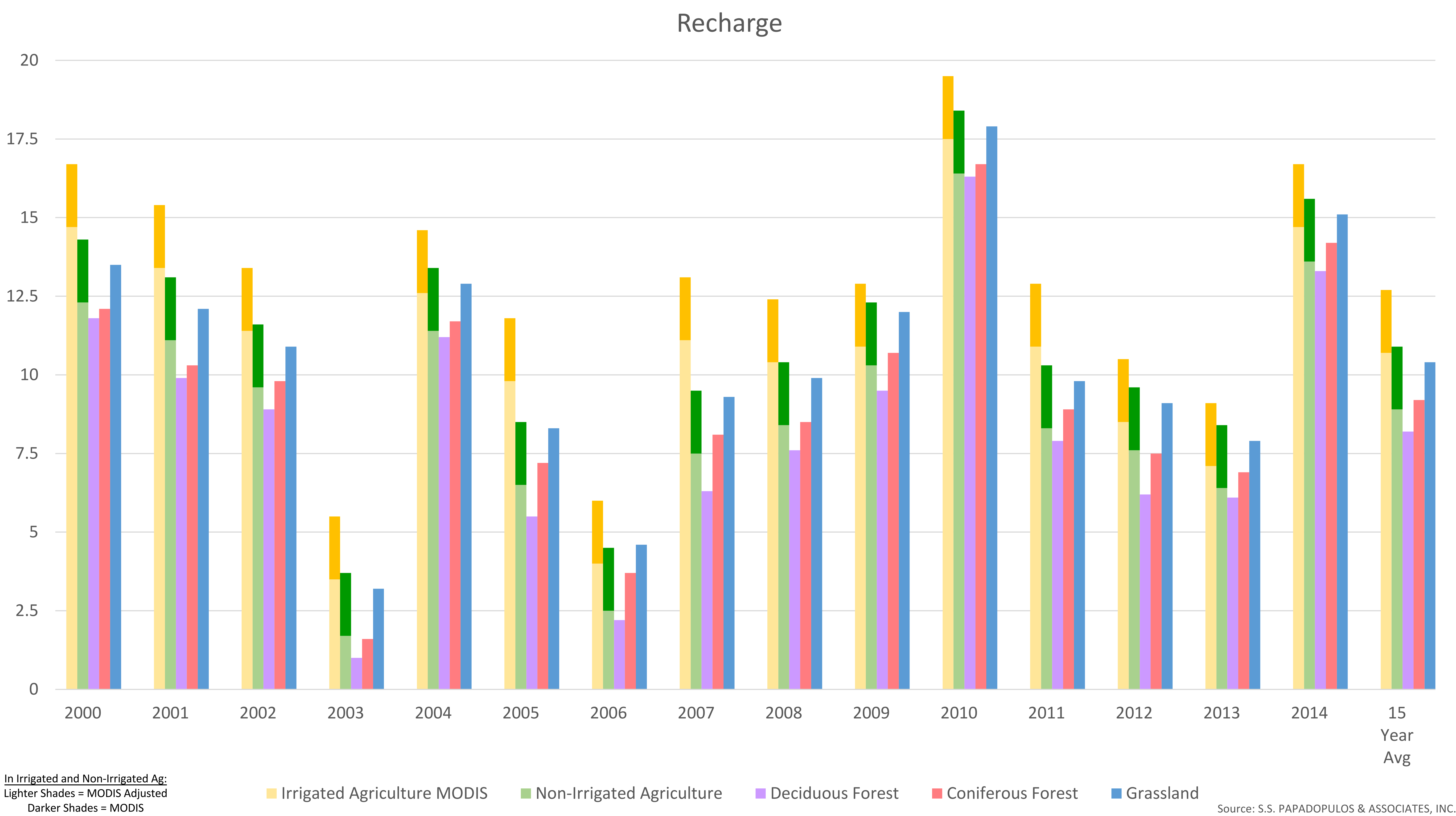
Questions?

Adam Freihoefer (adam.freihoefer@wi.gov)
Robert Smail (robert.smail@wi.gov)



In Irrigated and Non-Irrigated Ag:
Lighter Shades = MODIS
Darker Shades = MODIS Adjusted

Source: S.S. PAPADOPULOS & ASSOCIATES, IN


Recharge
20
17.5
15
12.5
10
7.5
5
2.5
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
15 Year Avg
In Irrigated and Non-Irrigated Ag:
Lighter Shades = MODIS Adjusted
Darker Shades = MODIS
Irrigated Agriculture MODIS
Non-Irrigated Agriculture
Deciduous Forest
Coniferous Forest
Grassland
Source: S.S. PAPADOPULOS & ASSOCIATES, INC.

The Increasing Trends in Base Flow in Wisconsin since the Early 1900s.

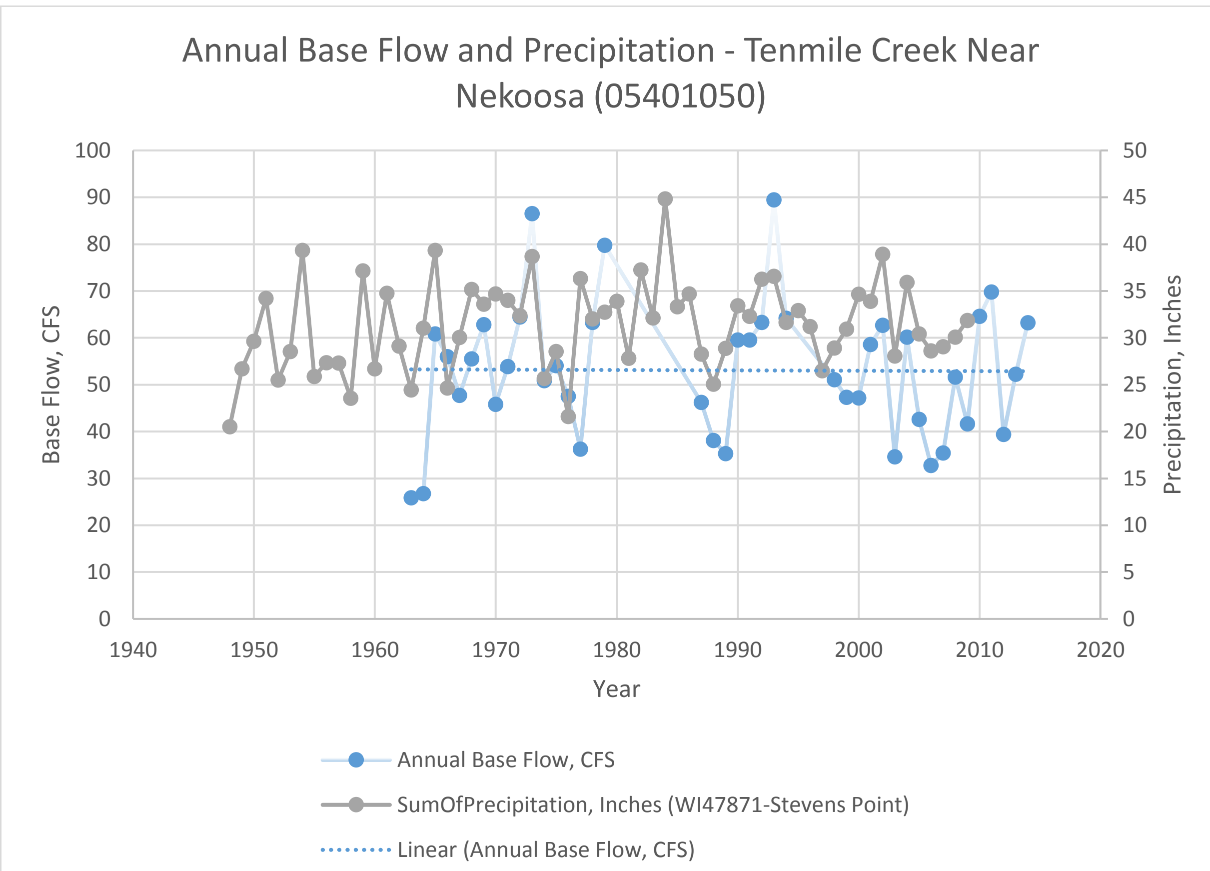
[**Bold** values indicate statistically significant trends in baseflow for the period of record (Gebert and others, 2007)]

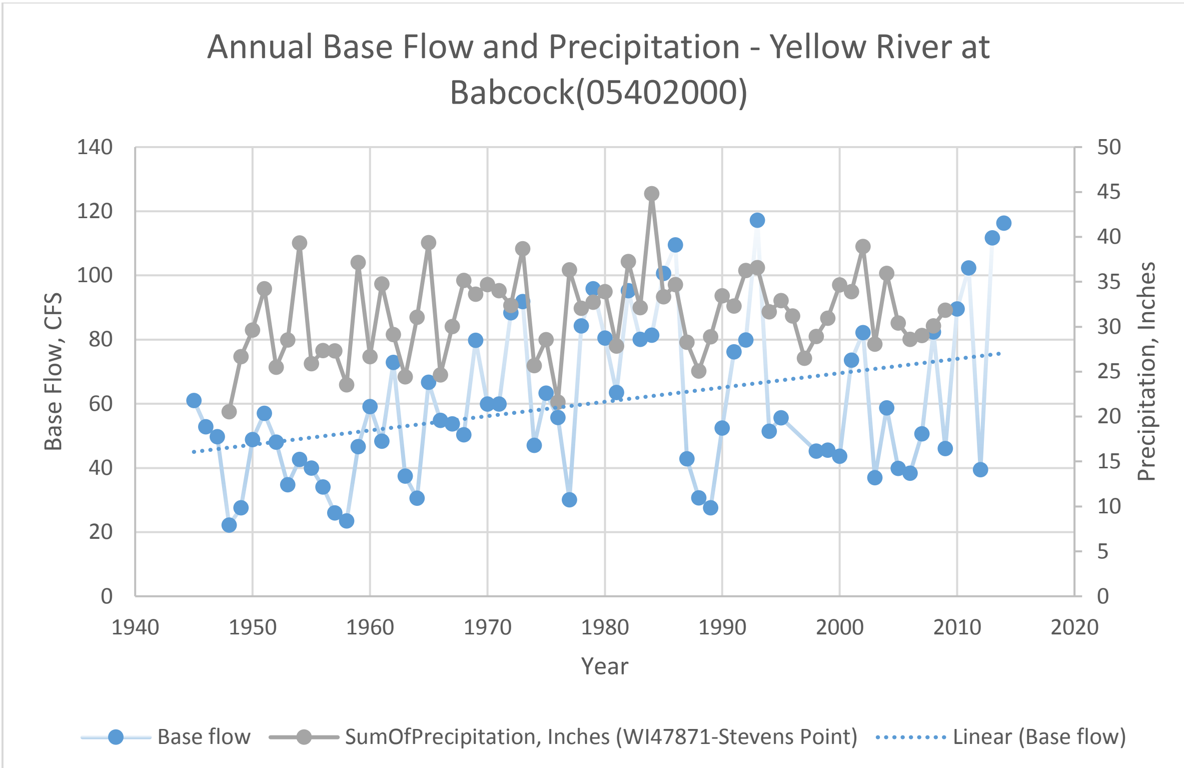
Station number	Station name	Period of record	Length of record (years)	Average annual baseflow (cubic feet per second)		
				Full record	1970–99	Percent difference
04025500	Bois Brule River – Brule	1943–99	57	149	152	2.0
04063700	Popple River – Fence	1964–99	36	69.7	68.5	-1.7
04069500	Peshtigo River – Peshtigo	1954–99	46	566	604	6.7
04073500	Fox River – Berlin	1900–99	100	941	1,130	**20.1**
04074950	Wolf River – Langlade	1967–99	33	349	351	.6
04086000	Sheboygan River – Sheboygan	1917–99	83	122	146	**19.7**
04087000	Milwaukee River – Milwaukee	1915–99	85	209	290	**38.8**
05362000	Jump River – Sheldon	1916–98	83	173	190	9.8
05368000	Hay River – Wheeler	1951–98	48	232	263	**13.4**
05379500	Trempealeau River – Dodge	1915–99	85	327	404	**23.5**
05381000	Black River – Neillsville	1906–99	94	162	201	**24.1**
05394500	Prairie River – Merrill	1915–99	85	115	114	-.9
05397500	Eau Claire River – Kelly	1915–99	85	127	134	5.5
05399500	Big Eau Pleine River – Stratford	1915–99	85	30	32	6.7
05405000	Baraboo River – Baraboo	1915–99	85	219	271	**23.7**
05406500	Black Earth Creek – Black Earth	1955–98	44	29.1	32.2	**10.7**
05408000	Kickapoo River – LaFarge	1939–99	61	123	144	**17.1**
05413500	Grant River – Burton	1935–99	65	111	137	**23.4**
05414000	Platte River – Rockville	1935–99	65	65.1	78.5	**20.6**
05426000	Crawfish River – Milford	1932–99	68	229	271	**18.3**
05432500	Pecatonica River – Darlington	1940–99	60	121	143	**18.2**
05436500	Sugar River – Brodhead	1915–99	85	234	297	**26.9**

- Gebert and others (2007) examined temporal trends in base flow for the period of record for 22 gaging stations in Wisconsin, and found the average base flow for the 1970-99 period increased as compared to the average annual base flow for the entire record for the majority of the gaging stations.
- Gebert (1996, 2007) indicated that agricultural practices are the likely driver for the increasing trend, and basins containing more agriculture by area are more likely to show increases in base flow over time. In addition, climate is also a primary factor.

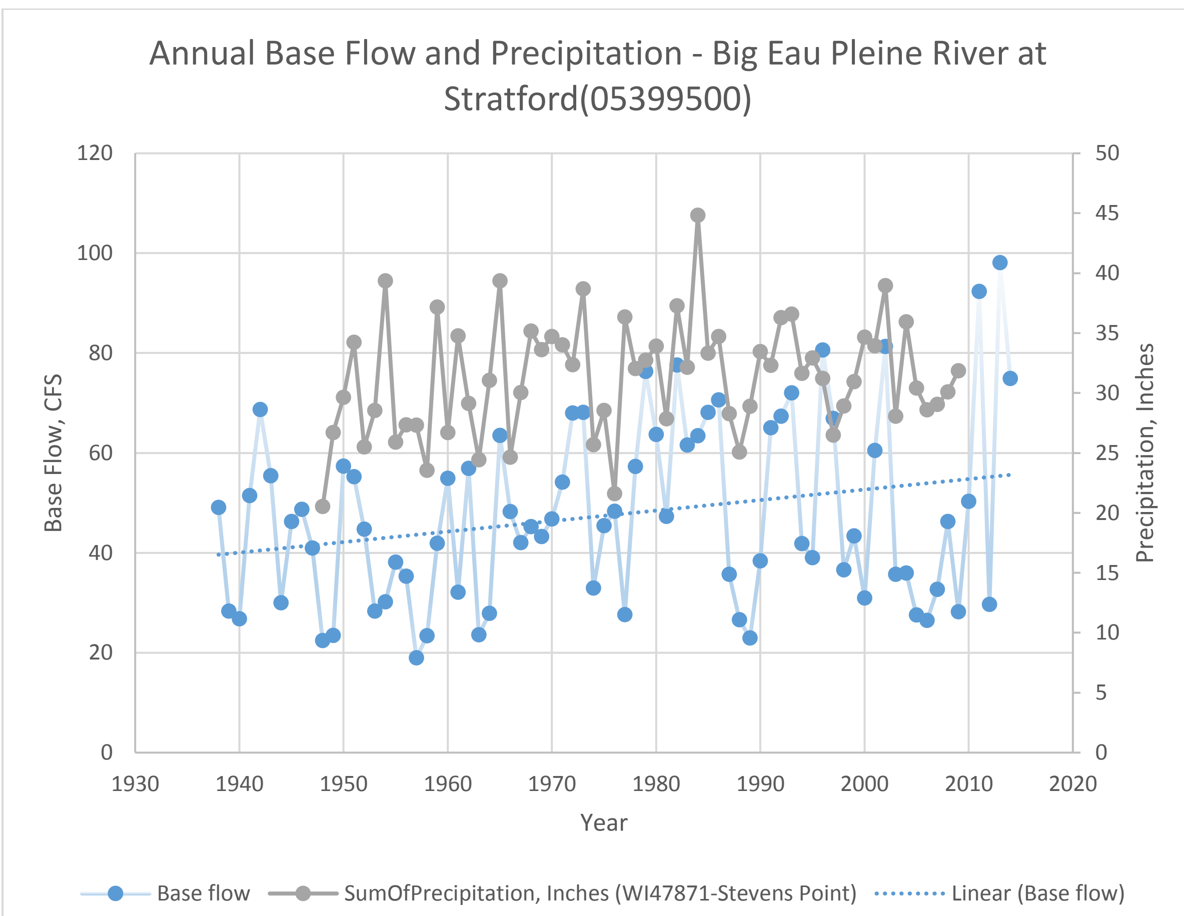
Historical Base Flow Data in Central Wisconsin

- Historical base flow were evaluated for select gaging stations in Central Wisconsin, where long term stream flow data are available. The annual base flow data are plotted with annual precipitation data at Stevens Point.
- Increasing base flow trends are observed at the gaging stations at Yellow River at Babcock, and Big Eau Pleine River at Stratford, where streamflow data from the 1930/1940 to 2015 are available.
- No significant trend is observed at the Tenmile Creek at Nekoosa gaging station, where streamflow data from 1964 to 2013 are available. It is important to note that no streamflow data prior to 1964 are available.
- Comparison of the base flow time series plot to the precipitation history indicates that the base flow generally fluctuates with that of precipitation, and precipitation is the primary driver for base flow changes.

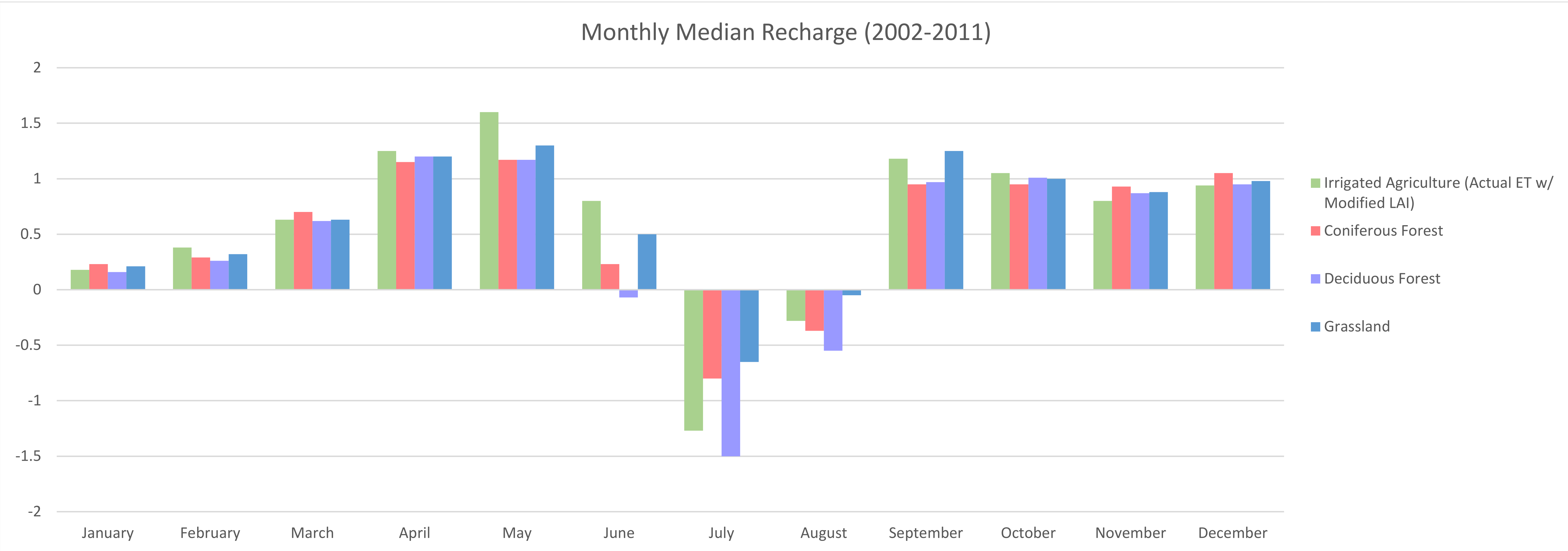




Annual Base Flow and Precipitation - Yellow River at Babcock(05402000)
Base Flow, CFS
Precipitation, Inches
Year
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
35
40
45
50
1940
1950
1960
1970
1980
1990
2000
2010
2020
Base flow
SumOfPrecipitation, Inches (WI47871-Stevens Point)
Linear (Base flow)



Annual Base Flow and Precipitation - Big Eau Pleine River at Stratford(05399500)
Base Flow, CFS
Precipitation, Inches
Year
0
20
40
60
80
100
120
0
5
10
15
20
25
30
35
40
45
50
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Base flow
SumOfPrecipitation, Inches (WI47871-Stevens Point)
Linear (Base flow)



Source: S.S. PAPADOPULOS & ASSOCIATES, INC.

BEFORE THE

DEPARTMENT OF NATURAL RESOURCES

In the Matter of the Establishment of Public Rights Stage(s) / Flow(s) for the Little Plover River, Portage County.	)))	IP-WC-2009-00223

FINDINGS OF FACT AND ORDER

The Department, under the authority granted pursuant to s. 31.02, Stats., and in response to a request of the following conservation groups; River Alliance of Wisconsin, Wisconsin Wildlife Federation and Trout Unlimited, herein establishes a minimum Public Rights Flow(s) (PRF) for the Little Plover River (LPR) located in Portage County, whereby the PRF may not be lowered, with exception to natural changes in precipitation (droughts). The PRF is that water quantity or level necessary to protect public rights and interests in the LPR.

FINDINGS OF FACT

1. On April 24, 2007, River Alliance of Wisconsin, Wisconsin Wildlife Federation and Wisconsin Trout Unlimited, submitted a petition to the Wisconsin Department of Natural Resources (WDNR) requesting the WDNR establish PRF(s) for the LPR to preserve and protect public rights and interests in said waterway. Their petition also requested the Department to establish an interim emergency PRF equivalent to the 7-day, 10 year low flow, $Q_{7,10}$.

2. The WDNR established a minimum healthy flow for the LPR through informal file memo. This flow of 4 cubic feet per second, (cfs), at Eisenhower Road (CTH R) was developed by the WDNR to establish a goal for the LPR Workgroup efforts to restore a healthy flow in the LPR. This data and analyses were the base information used to establish the public rights flow.

3. The LPR is located in Sections 13, 14, 15 and 24, T23N, R8E, and in Sections 18 &19, T23N, R9E, (Towns of Plover and Stockton, Village of Plover) in Portage County.

4. The LPRhas been declared a navigable water body pursuant to s. 30.10, Stats.

5. The LPR is classified as a Class I Trout stream as identified in s. NR 1.02(7)(b)1., Wis. Adm. Code. "A class I trout stream is a stream or portion thereof with a self-sustaining population of trout. a. Such a stream contains trout spawning habitat and naturally produced fry, fingerling, and yearling in sufficient numbers to utilize the trout habitat, or b. Contains trout with 2 or more age groups, above the age of one year, and natural reproduction and survival of wild fish in sufficient numbers to utilize the available trout habitat and to sustain the fishery without stocking."

6. The LPR is defined as an "Area of Special Natural Resource Interest" pursuant to s. 30.01(1am)(b), Stats., and NR 1.05(3)(b), Wis. Adm. Code.

7. LPR flows are primarily dependent on ground water discharge, particularly during normal base flow conditions.

8. The United States Geological Survey (USGS) maintained a stream flow monitoring gage on the LPR at Hoover Road from 1959 to 1987 and at Kennedy Road from 1959 to 1975.

9. The Department's Bureau of Fisheries Management guidance for streams with 10 cfs or less, average summer flow (June 1 – September 30), identifies the minimum stage, PRF, for fishery interests is the ordinary high water mark (OHWM) of the stream. For intermediate streams from 10 cfs to 25 cfs average summer flow, the fisheries interest stage is below the OHWM level and must be established by the fish manager. Average summer flow for the LPR, as calculated by the USGS gage data at Hoover Road, from 1959 to 1987 is 9.975 cfs.

10. Historic Department PRF determinations on navigable streams do not allow the flows to be less than the 7-day, 10 year low flow($Q_{7,10}$). The $Q_{7,10}$ flow in streams is used to determined wasteload allocations for WPDES dischargers and is a minimum flow that must be in a stream to protect water quality. Although water quality is the determining factor for compliance with discharge permit conditions it does not take into account the available fish and wildlife habitat present at that particular flow. The following are USGS calculated 7-day, 10 year low flows at Hoover Road, I39, Eisenhower Road and Kennedy Road; Low-Flow Characteristics of Streams in the Central Wisconsin River Basin, Wisconsin. Water Resources Investigations Open-File Report 81-495.

Location	$Q_{7,10}$ flow
Kennedy Road	1.2 cfs
Eisenhower Rd., (CTH R)	2.2 cfs
I39	4.2 cfs
Hoover Road	4.8 cfs

11. The Public Rights Flow should be of sufficient volume and depth to protect fish and wildlife (including aquatic life), and their respective habitats. One method used to determine this flow is the Montana (Tennant) method *Instream Flows for Riverine Resource Stewardship, Revised Edition*, The Instream Flow Council,2004. According to the Montana Method the minimum flows required to maintain good habitat for aquatic life was 30 % of the minimum flow should be between 30 and 60 percent of the annual flow (maf). For LPR locations:

Location	maf	30% maf	60% maf	$Q_{7,10}$
Kennedy Road	4.03	1.21 cfs	2.42 cfs	1.2 cfs
Eisenhower Road	No gage at this location, no data to support a maf			2.2 cfs
I39	No gage at this location, no data to support a maf			4.2 cfs
Hoover Road	10.26 cfs	3.08 cfs	6.16 cfs	4.8 cfs

12. Department Fish Managers have determined through stream monitoring, that the minimum low flow of the LPR to prevent Trout mortality relating to temperature at CTH R is 4 cfs. Assessment of the Brook Trout Population in the Little Plover River, Final Report, May 2007. Tom Meronek, Fisheries Biologist.

13. Department Fish Managers have determined through stream survey and analysis, that the minimum flows in the LPR necessary to utilize available aquatic habitat in the vicinity of CTH R/Eisenhower Road to be 3 cfs. Department of Natural Resources, West Central Region, 2006 Habitat Modeling. Provost, Meronek.

14. Department Fish Managers have determined that targeting biomass levels of 75 to 125 is desirable and allows trout recruitment to fluctuate normally. According to published studies (Hunt 1979), this correlates to flows of 4 cfs., at CTH R. Assessment of the Brook Trout Population in the Little Plover River, Final Report, May 2007. Tom Meronek, Fisheries Biologist.

15. University of Wisconsin, Stevens Point, Center for Watershed Science and Education, College of Natural Resources, collected stream flow data at Hoover, CTH R (Eisenhower Road) and Kennedy roads during the periods of 2005 to 2008. Data collection of flow values over time has enabled UWSP to calculate a regression analysis relating flow values at Kennedy, Eisenhower (CTH R), I39 and Hoover. From the regression analysis, flows at Eisenhower (CTH R) of 4.0 cfs correlate to flows of 2.2 cfs at Kennedy, 5.8 cfs at I39, and 6.8 cfs at Hoover. Technical Memorandum #15, Little Plover River Discharge at Eisenhower and Relation to other Stations. Clancy, Kraft, Mechenich, Macholl.

CONCLUSIONS OF LAW

The department has authority under Section 31.02 (1), Wis. Stats. to regulate and control the levels and flow of water in the interest of public rights in navigable waters, and in accordance with the foregoing Findings of Fact, to issue an order establishing a public rights flow(s) for the Little Plover River.

The Department has complied with Section 1.11, Wis. Stats., Wisconsin's Environmental Policy Act and chs. NR 102, 103 and 1.95, Wis. Adm. Code.

ORDER

THE DEPARTMENT THEREFORE, ORDERS:

The public rights flow for the Little Plover River at Kennedy Road is 1.9 cfs.
The public rights flow for the Little Plover River at CTH R is 4.0 cfs.
The public rights flow for the Little Plover River at I39 is 5.8 cfs
The public rights flow for the Little Plover River at Hoover Road is 6.8 cfs.

NOTICE OF APPEAL RIGHTS

If you believe that you have a right to challenge this decision, you should know that the Wisconsin statutes and administrative rules establish time periods within which requests to review Department decisions shall be filed.

To request a contested case hearing pursuant to Wis. Stat. § 227.42, you have 30 days after the decision is mailed, or otherwise served by the Department, to serve a petition for hearing on the Secretary of the Department of Natural Resources, P.O. Box 7921, Madison, WI, 53707-7921.

A request for contested case hearing must follow the service requirements found in Wis. Admin. Code §NR 2.03 and the form prescribed in Wis. Admin. Code §NR 2.05(5), and must include the following information:

1. A description of the Department's action or inaction which is the basis for the request;
2. The substantial interest of the petitioner which is injured in fact or threatened with injury by the Department's action or inaction;
3. Evidence of a lack of legislative intent that this interest is not to be protected;
4. An explanation of how the injury to the petitioner is different in kind or degree from the injury to the general public caused by the Department's action or inaction;
5. That there is a dispute of material fact, and what the disputed facts are;
6. The statute or administrative rule other than s. 227.42, Wis. Stats., which accords a right to a hearing.

This determination is final and judicially reviewable. For judicial review of a decision pursuant to ss. 227.52 and 227.53, Wis. Stats., you have 30 days after the decision to file your petition with the appropriate circuit court and to serve the petition on the Secretary of the Department of Natural Resources. The petition must name the Department of Natural Resources as the respondent.

Reasonable accommodation, including the provision of informational material in an alternative format, will be provided for qualified individuals with disabilities upon request.

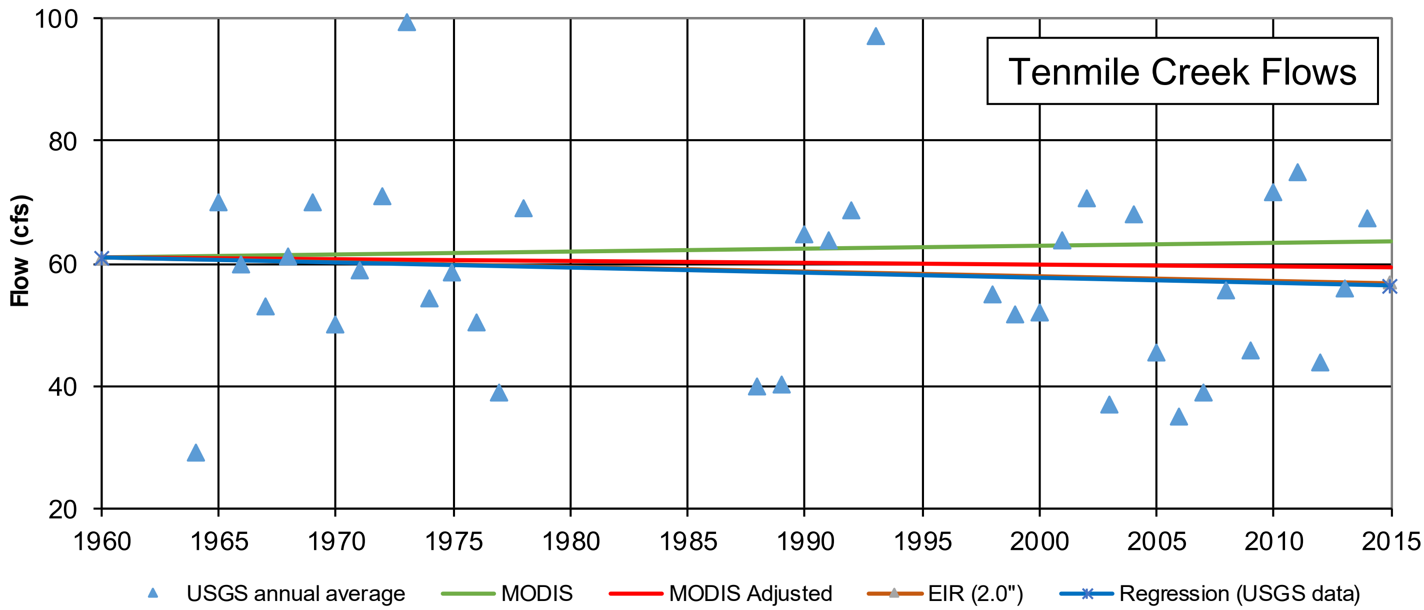
Dated at Eau Claire, WI, March 23, 2009

STATE OF WISCONSIN DEPARTMENT OF NATURAL RESOURCES
For the Secretary

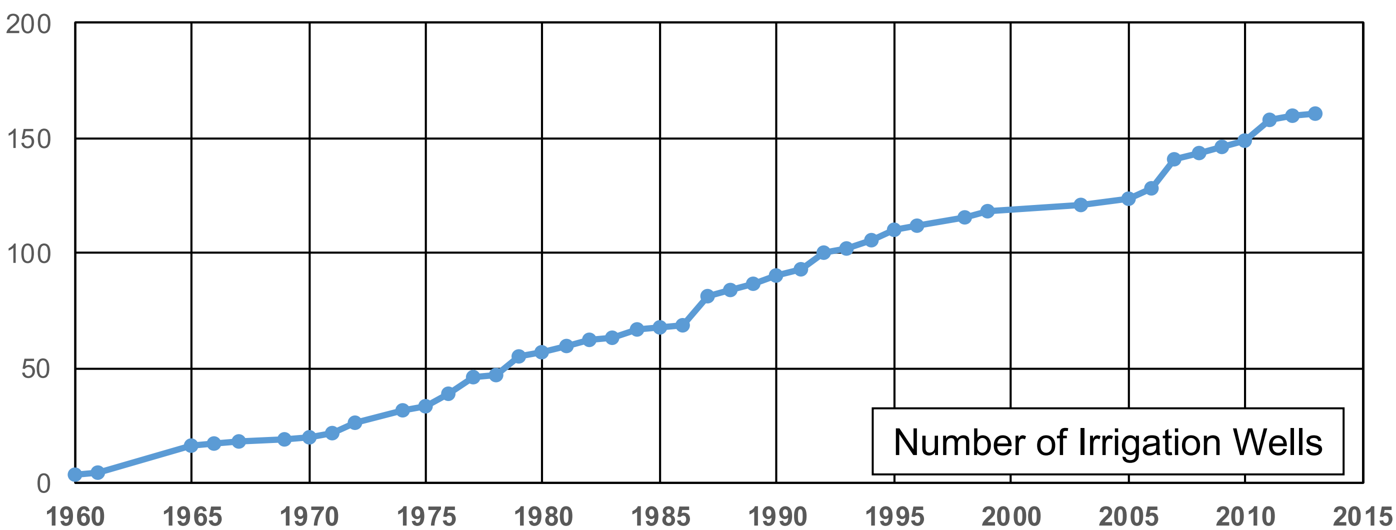
By ______________________

Daniel G. Baumann, P.E.
Regional Water Media Leader

Comparison of Average Annual Flows in Tenmile Creek and Number of Irrigation Wells in Watershed



*Regression and EIR lines run together on the chart



Note: On the upper graph is plotted (as dots) the average annual measured flows in Tenmile Creek, and the graph displays the following depictions of estimated change in average annual flow through time: 1) calculated change in flow from 1960 based on model simulation with irrigation ET specified as that derived from MODIS analysis, 2) calculated change based on model simulation with irrigation ET specified as that derived based on MODIS analysis adjusted for crop coefficients, 3) calculated change based on model simulation with irrigation ET based on net change in ET from pre-existing conditions of 2” per year, and 4) linear regression of USGS daily flow data.

Short Communication

On the Question of Agricultural Water Use in Central Wisconsin

Paul Fowler, Wisconsin Institute for Sustainable Technology, University of Wisconsin-Stevens Point

Corresponding author: paul.fowler@uwsp.edu

Wisconsin Institute for Sustainable Technology (WIST), College of Natural Resources, University of Wisconsin, Stevens Point, WI 54481, USA

Abstract

Water use by agriculture has become an issue in many areas where groundwater levels have dropped. Because the impact of agricultural water use is a driver of water use policy it is important to understand other factors that may also be impacting groundwater. This paper reports an examination of scientific literature on water use by trees compared to water use by vegetable crops. Evapotranspiration by trees results in significant water loss and interception of precipitation by forest canopy also impacts groundwater recharge. Studies in different geographical areas, including the U.K. and Northern Wisconsin, have shown water use by trees on an annual basis that exceeds the amount used to grow potatoes. Studies in China, the U.K and South Africa predicted that reforestation and afforestation would reduce water available for surface flow or aquifer recharge by as much as 56%. The analysis focuses particularly on Wisconsin, where a six-county area ranks as one of the top vegetable-growing regions of the U.S. and where groundwater levels have become an issue. Reforestation has increased significantly in this area. The researcher concludes that while agricultural water use has undoubtedly increased in Wisconsin over the past 50 years, it may not be either the sole or major source of groundwater depletion and reduced stream flow.

Keywords:
Agricultural water use
Evapotranspiration
Groundwater impacts
Reforestation
Water use policy

1. Introduction

Much has been made in both the scientific literature (Kraft et al., 2012; Weeks and Stangland, 1971) and the media (FOX11 NEWS, 2014; Prengaman, 2013) of the impact of agriculture on groundwater levels in Wisconsin's Central Sands, so named for the defining geomorphological feature of the region, a broad plain that is a remnant of the last glaciation. Much of the area is underlain by the Central Wisconsin Sand and Gravel Aquifer (CWSGA), a contiguous area east of the Wisconsin River where groundwater is stored in sand and gravel deposits more than 50 feet deep. The aquifer covers approximately 1.5 million acres in parts of Adams, Marquette, Portage, Waupaca, Waushara and Wood counties.

Models arising from the scientific work are being used to drive Wisconsin water-use policy and regulation (Wisconsin Department of Natural Resources [WDNR], 2014). The basis for arguing the negative impact of agriculture on groundwater are relationships established and data measured over the past 50 years between the number of high capacity wells in use in the state and a lowering of groundwater levels.

Whilst this argument is persuasive, it is almost certain that other factors are at play. This paper presents an analysis of Forest Inventory Assessment data to demonstrate that the same period also coincides with some dramatic changes in growing stock volume of major tree species and postulates that groundwater levels are impacted by forest population.

2. Materials and methods

Forest area and forest type group was acquired in acres from the Forest Inventory and Analysis databases using the Forest Inventory Data Online portal for the survey years 1996, 2013 and 2014. Data for the following forest type groups: white/red/jack pine, spruce/fir and exotic softwoods were aggregated as 'softwood'. Oak/hickory, elm/ash/cottonwood, maple/beech/birch, aspen/birch were aggregated as 'hardwood'. Data for the entire state of Wisconsin was accessed 19 March 2015. Data for the six counties of Adams, Marquette, Portage, Waupaca, Waushara and Wood was accessed April 28, 2015.

3. Results

The area of forested land in Wisconsin has been steadily increasing in recent decades and currently stands at approximately 17.1 million acres (Table 1), representing over 50 percent of the State's total land area.

Table 1

Area in acres of forest land in Wisconsin by stand age in 1996 and 2013.

	Stand age		
Year	0–59 years	60–200+ years	Total acres
1996	9,804,288	6,158,659	15,962,947
2013	8,236,679	8,864,485	17,101,164

Wisconsin now has more forested land than at any time since the first Forest Service forest inventory in 1936. The greatest volume gains in the last 14 years have been the softwood species, eastern white pine (+67%) and red pine (+60%) (WDNR, 2012). The period also coincides with a sharp increase in the area of stands that are over 60 years old (44%).

The data for the entire state is largely reflected in the six county area comprising Wood, Portage, Waupaca, Adams, Waushara and Marquette counties (Table 2) which approximately coincide with the area designated as Wisconsin's Central Sands and underlain by the Central Wisconsin Sand and Gravel Aquifer. Thus, analysis of this six county area shows a 15% increase in forestland from 1,047,018 acres in 1996 to 1,207,770 in 2014. In that same period the softwood acreage increased by 50% - from 224,880 acres in 1996 to 337,785 acres in 2014. That softwood acreage became more mature too in the period with 27% of the acreage comprising trees aged between 40 and 99 years in 1996 compared with 58% in 2014.

Table 2. Area in acres by forest type by county in the Central Sands region in 1996 and 2014.

	Year					
	1996			2014		
County	Forest type			Forest type		
	Softwood	Hardwood	Total	Softwood	Hardwood	Total
Adams	78,414	174,959	253,373	76,220	178,477	254,697
Marquette	13,465	82,319	95,784	37,148	96,830	133,978
Portage	34,360	137,229	171,589	55,417	127,212	182,629
Waupaca	31,934	151,345	183,279	55,654	163,069	218,723
Waushara	33,323	94,330	127,653	61,507	123,363	184,870
Wood	33,384	181,956	215,340	51,839	181,034	232,873
Total	224,880	822,138	1,047,018	337,785	869,985	1,207,770

4. Discussion

4.1. Impact of forest type, age and area

The results tabulated above are significant for the following reasons:

(1) softwood species maintain high levels of interception (in which rainfall reaches surfaces of branches, leaves, and trunks but then evaporates rather than reaching ground) over all four seasons whereas hardwood species that shed their leaves intercept less during the winter months.

(2) mature tree stands have well-developed canopies that intercept very significant amounts of rainfall, in some cases up to 45%, meaning that only 55% may be available for aquifer re-charge, *before* any account is made for transpiration; forest age has been demonstrated to be a significant factor in determining streamflow response (Webb and Kathuria, 2010).

(3) greater reforestation and afforestation will increase rainfall interception at the expense of groundwater recharge.

(4) evapotranspiration by trees is shown in a number of studies to be greater than that of grass, crops or vegetables (Hall et al., 1996; Huang and

Gallichand, 2006; Jimenez-Martinez et al., 2010; O'Brien et al., 2004; Tanner, 1981).

4.2. Water use of tree versus vegetables

Evapotranspiration is a widely used measure to quantify the use of water by plants and that use is reported in millimeters over a period of time. The bigger the number, the greater the water use and the less water available for groundwater recharge. Herbaceous plants including vegetables generally transpire less than woody plants including trees because they usually have less extensive foliage and additionally losses by vegetables are limited by their short crop cycle. Furthermore, softwood forests tend to have higher rates of evapotranspiration than hardwood forests, particularly in the dormant and early spring seasons. This is primarily due to the enhanced amount of precipitation intercepted and evaporated by conifer foliage during these periods (Swank and Douglass, 1974).

Studies in the UK have shown that between 25 and 45% of annual rainfall is typically loss by interception from softwood stands compared with 10-25% for hardwoods (Calder et al., 2003). These percentages remain remarkably constant over a wide range of total rainfall. Taken together softwoods may be expected to use some 550–800 mm of water (Nisbet, 2005) compared with 370–430 for potatoes (Hall et al., 1996). Tanner (1981) reported potato evapotranspiration in Wisconsin was between 293 and 405 mm. In Wisconsin where annual rainfall varies from 719 to 923 mm (averages based on weather data collected from 1981 to 2010 for the NOAA National Climatic Data Center), red pine plantations can tap significant water stored in the subsurface soil and where roots are within a couple of meters of the water table may be net depleters of ground water.

Relevant research that has evaluated evapotranspiration from red pine plantations include Weeks and Stangland (1971), and Sun et al. (2008). Weeks and Stangland (1971) estimated average evapotranspiration from pine trees at 493 mm. The study by Sun et al. (2008) estimated annual evapotranspiration from red pine plantations on sandy soils in Northern Wisconsin in the range of 574 to 594 mm per year. More recently Mao and Cherkauer (2009) studied evapotranspiration in a range of vegetative land covers throughout the Great Lakes region. They concluded that average evaporation from softwood forest was about 569 mm.

4.3. Reforestation and Afforestation

While State of Wisconsin policy encourages reforestation and afforestation through its Department of Natural Resources Reforestation Program, other nations are being more circumspect. Indeed, the United Kingdom's Forestry Commission in 2002 commissioned work to investigate the impact of reforestation on ground water sources. The investigators noted that in softwood species recharge is predicted to be about one quarter that under grass and essentially non-existent in years with average or below average rainfall (Calder et al., 2002).

Similar concerns about groundwater quantity were investigated in Australia. A study carried out by Sinclair Knight Merz (2008) predicted that land use change from commercial agricultural to a high forestry scenario would reduce water available for surface flow or aquifer recharge by 56%. Further modeling indicated that no-flow months could increase in frequency from very much less than 1% of months to as much as 30% of months under a high forestry regime.

A study in China suggested that the average water yield reduction as a result of forestation may vary from about 50 mm per year (50%) in a semi-arid region in northern China to about 300 mm per year (30%) in the tropical southern region (Sun et al., 2006).

In South Africa, since 1999, forest plantations have been categorized as stream flow reduction activities and required to be licensed and to pay water charges (Department of Water Affairs and Forestry, 1999). The National Water Act is based on conclusive findings that forest plantations established in former natural forests, grasslands, or shrub land areas consume more water than the baseline vegetation, reducing water yield (stream flow) as a result (Albaugh et al., 2013, and references therein).

5. Conclusions

Whilst agricultural water use has undoubtedly increased in Wisconsin over the past 50 years, we suggest that it may not be either the sole or major source of groundwater depletion and reduced streamflow. Concerns in other nations regarding the impact of forested land on water availability coupled with the fact that Wisconsin currently has the largest forested land area with the most mature stands since pre-European settlement times leads us to contemplate that reforestation and afforestation may have as large a part to play as agriculture in the impact on groundwater inventory. We suggest that a program of research be undertaken to study these matters further.

6. References

Albaugh, J.M., Dye, P.J., King J.S., 2013. Eucalyptus and Water Use in South Africa. International Journal of Forestry Research 2013, 1–11.

Calder, I.R., Reid, I., Nisbet, T., Armstrong, A., Green, J.C., Parkin G., 2002. Study of the Potential Impacts on Water Resources of Proposed Afforestation. Loughborough University, viewed 4 October 2015, http://randd.defra.gov.uk/Document.aspx?Document=WT01008_2051_FRP.pdf.

Calder, I.R., Reid, I., Nisbet, T., Green, J.C., 2003. Impact of lowland forests in England on water resources – application of the HYLUC model. Water Resour. Res. 39, 1319–1328.

Department of Water Affairs and Forestry. 1999. Water-Use Licensing: the Policy and Procedure for Licensing Streamflow Reduction Activities. Pretoria, South Africa, 1999.

FOX11 NEWS 2014, television broadcast. Ground water debate in central Wisconsin, 22 July. Presented by Robert Hornacek.

Hall, R.L., Allen, S.J., Rosier, P.T.W., Smith, D.M., Hodnett, M.G., Roberts, J.M., Hopkins, R., Davies, H.N., Kinninurgh, D.G., Goody, D.C., 1996. Hydrological effects of short rotation coppice. Institute of Hydrology report to the Energy Technology Support Unit, ETSU, ETSU B/W5/00275/REP, viewed 4 October 2015, http://core.ac.uk/download/files/79/63213.pdf.

Huang, M., Gallichand, J., 2006. Use of the SHAW model to assess soil water recovery after apple trees in the gully region of the Loess Plateau, China. Agric. Water Manage. 85, 67–76.

Jimenez-Martinez, J., Candela, L., Molinero, J., Tamoh, K., 2010, Groundwater recharge in irrigated semi-arid areas: quantitative hydrological modeling and sensitivity analysis. Hydrogeol. J. 18, 1811–1824.

Kraft, G.J., Clancy, K., Mechenich, D.J., Haucke, J., 2012. Irrigation effects in the Northern Lake States: Wisconsin Central Sands revisited. Ground Water, 50, 308–318.

Mao, D.Z, Cherkauer, K.A., 2009. Impacts of land-use change on hydrologic responses in the Great Lakes Region. J. Hydrol. 374, 71-82.

Nisbet, T., 2005. Water Use by Trees, Forestry Commission, April 2005, viewed 4 October 2015, http://www.northlandnemo.org/images/Water%20Use%20by%20Trees.pdf.

O'Brien, R., Keller, C.K., Strobridge, D.M., 2004. Plant cover effects on hydrology and pedogenesis in a sandy vadose zone. Geoderma 118, 63–76.

Prengaman, K. 2013, 'Groundwater war pits Wisconsin farms against fish', WisconsinWatch.org, 21 July, viewed 4 October 2015, http:// http://wisconsinwatch.org/2013/07/groundwater-war-pits-wisconsin-farms-against-fish-2/.

Sinclair, Knight, Merz. 2008. Water and Land Use Change in the Catchment of the Crawford River Bendigo, Victoria, Australia, viewed on 4 October 2015, http://www.ghcma.vic.gov.au/imageandfileuploads/SKM%20WatLUC%20Crawford%20R%20case%20study_final.pdf.

Sun, G., Noormets, A., Chen, J., McNulty, S.G., 2008. Evapotranspiration estimates from eddy covariance towers and hydrologic modeling in managed forests in Northern Wisconsin, USA. Agr. Forest Meteorol. 148, 257-267.

Sun, G., Zhou, G., Zhang, Z., Wei, X., McNulty, S.G., Vose, J.M., 2006. Potential water yield reduction due to forestation across China. J. Hydrol. 328, 548–558.

Swank, W., Douglass, J., 1974. Streamflow greatly reduced by converting deciduous hardwood stands to pine. Science 185, 857–859.

Tanner, C.B,. 1981, Transpiration efficiency of potato. Agron. J. 73, 59–64.

United States Department of Agriculture, Forest Service 2015, Forest Inventory Assessment Data, viewed 19 March 2015, http://apps.fs.fed.us/fia/fido/index.html.

Webb, A.A., Kathuria, A., 2010. Response of streamflow to afforestation and thinning at Red Hill, Murray Darling Basin, Australia. J. Hydrol. 412-413, 133–140.

Weeks, E.P.; Stangland, H.G. 1971. Effects of irrigation on streamflow in the Central Sand Plain of Wisconsin. US Geological Survey Open-File Report. Reston, Virginia viewed 4 October 2015, http://wi.water.usgs.gov/pubs/OFR-sandplain/OFR-sandplain.pdf.

Wisconsin Department of Natural Resources, 2012, Forest Health 2012 Annual Report, viewed 4 October 2015, http://fhm.fs.fed.us/fhh/fhh_12/WI_FHH_2012.pdf.

Wisconsin Department of Natural Resources, 2014, Wisconsin Administrative Code, Groundwater Protection, Chapter NR 820, March 2014, viewed 4 October 2015, http://docs.legis.wisconsin.gov/code/admin_code/nr/800/820.

PROJECT REVIEW

Key findings of the Little Plover River groundwater flow modeling project in Wisconsin's Central Sands region

Wisconsin Geological and Natural History Survey | 2016

Summary

A state-of-the-art groundwater flow model was developed as a tool for understanding the interactions between groundwater withdrawals and streamflow in the Little Plover River basin in Wisconsin's Central Sands region.

Background

Wisconsin's Central Sands region is home to abundant streams, rivers, and lakes as well as a thriving agricultural industry. In 2013, in response to concerns about the growing number of high-capacity wells and their impacts on surface waters, the Wisconsin Department of Natural Resources funded a project to construct a groundwater flow model for the Little Plover River basin in Portage County. The project was carried out jointly by the Wisconsin Geological and Natural History Survey and the U.S. Geological Survey.

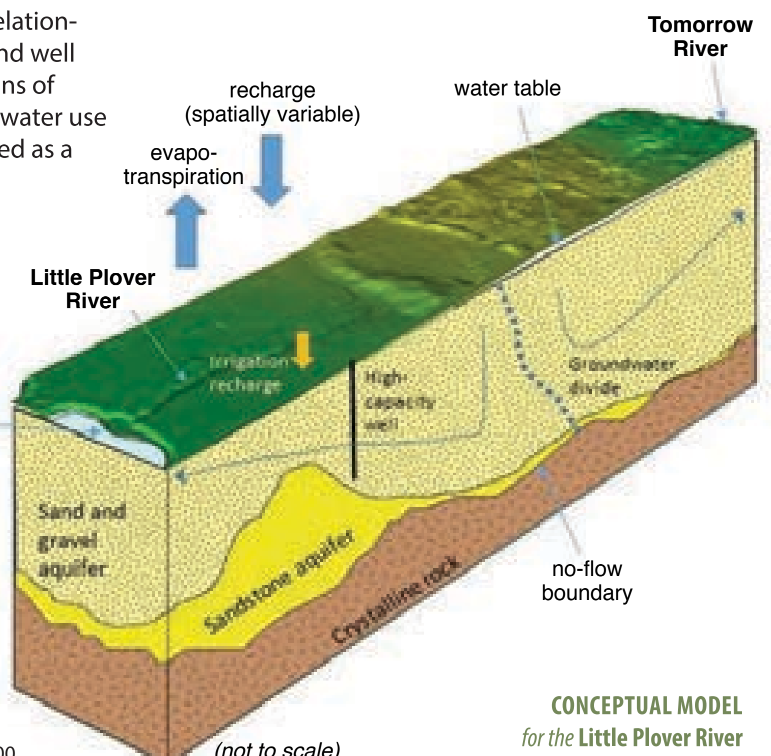
The model can be used to demonstrate the relationships between groundwater, surface water, and well withdrawals. Models allow "what-if" evaluations of possible decisions involving management of water use or land-use changes. The model was developed as a pilot project with the following goals:

1. **To provide scientific support** for future water- and land-use management decisions in the Little Plover River basin.
2. **To evaluate modeling techniques** that might later be expanded to the entire Central Sands region.
3. **To serve as an educational tool** for fostering science-based discussion for both the public and the technical community.

Model construction

The groundwater system in the Little Plover River basin is simulated using a three-dimensional groundwater flow model. The model incorporates knowledge about the area's geology, wells, and surface water locations, and is calibrated (adjusted) so that simulated groundwater levels and stream flows closely match measured values. In this model, horizontal layers represent the sand and gravel aquifer and the underlying sandstone bedrock.

A soil-water balance model was used to estimate groundwater recharge by calculating the amount of precipitation and irrigation that infiltrate through the soil to replenish the groundwater system. This estimated recharge, that varies both in space and time, provided data for the groundwater flow model.



CONCEPTUAL MODEL *for the* **Little Plover River groundwater flow model**

Wisconsin Geological and Natural History Survey
3817 Mineral Point Road • Madison, Wisconsin 53705-5100
608.263.7389 • WisconsinGeologicalSurvey.org
Kenneth R. Bradbury, *Director and State Geologist*

The model simulates high-capacity wells, with pumping rates varying monthly. Base flow, the groundwater component of streamflow, is simulated for the Little Plover River. The model can simulate both long-term average conditions ("steady-state") as well as how seasonal variations in pumping and recharge affect water levels and base flow throughout the year ("transient").

Key findings

- The Little Plover River is closely connected to the groundwater system, making it vulnerable to impacts from nearby pumping.
- Water use in the basin varies through the year. About 80% of the total annual water use comes from irrigation pumping, which occurs primarily during the growing season.
- Land use and crop patterns affect recharge rates, which in turn impact groundwater levels and stream flows. The model can be used to evaluate the effects of changing land use.
- Pumping and land-use changes have altered the natural groundwater flow pattern. The area of the landscape contributing groundwater to the river (the capture zone) is smaller now than it was before human settlement.
- Wells outside the capture zone can still have a major impact on base flow.
- There can be a delay of weeks to months between changes in pumping and impacts on the river, depending on the distance between the pumping well and the river.
- A well's impact on the river depends primarily on its proximity to the river. For example, removing about 15 wells nearest the river would increase base flow substantially in an average year.
- The concept of depletion potential, the percentage of pumped groundwater that otherwise would have supplied flow to a river or lake, can help evaluate the relative impact of each well. This analysis method shows promise as a guide for balancing water use with environmental needs.

What is the project status?

The model and report have undergone extensive peer review and are currently being revised. We anticipate making the model and an accompanying user's manual publicly available later this year and the report documenting the model construction will follow. Once the model is available, we will host a workshop or webinar demonstrating how to use it.

What's next?

The model can be used to evaluate the potential impact of proposed wells and to simulate different management scenarios to support future decision making in the Little Plover River basin. Potential uses of the model include evaluating the hydrologic impacts of changing pumping rates, land use, crop types, or irrigation practices in specific areas.

The modeling techniques evaluated for this pilot project are readily transferrable to model construction in the remainder of Wisconsin's Central Sand Plains, although significant data collection would be needed to extend the model to a larger area.

Who can I contact for more information?

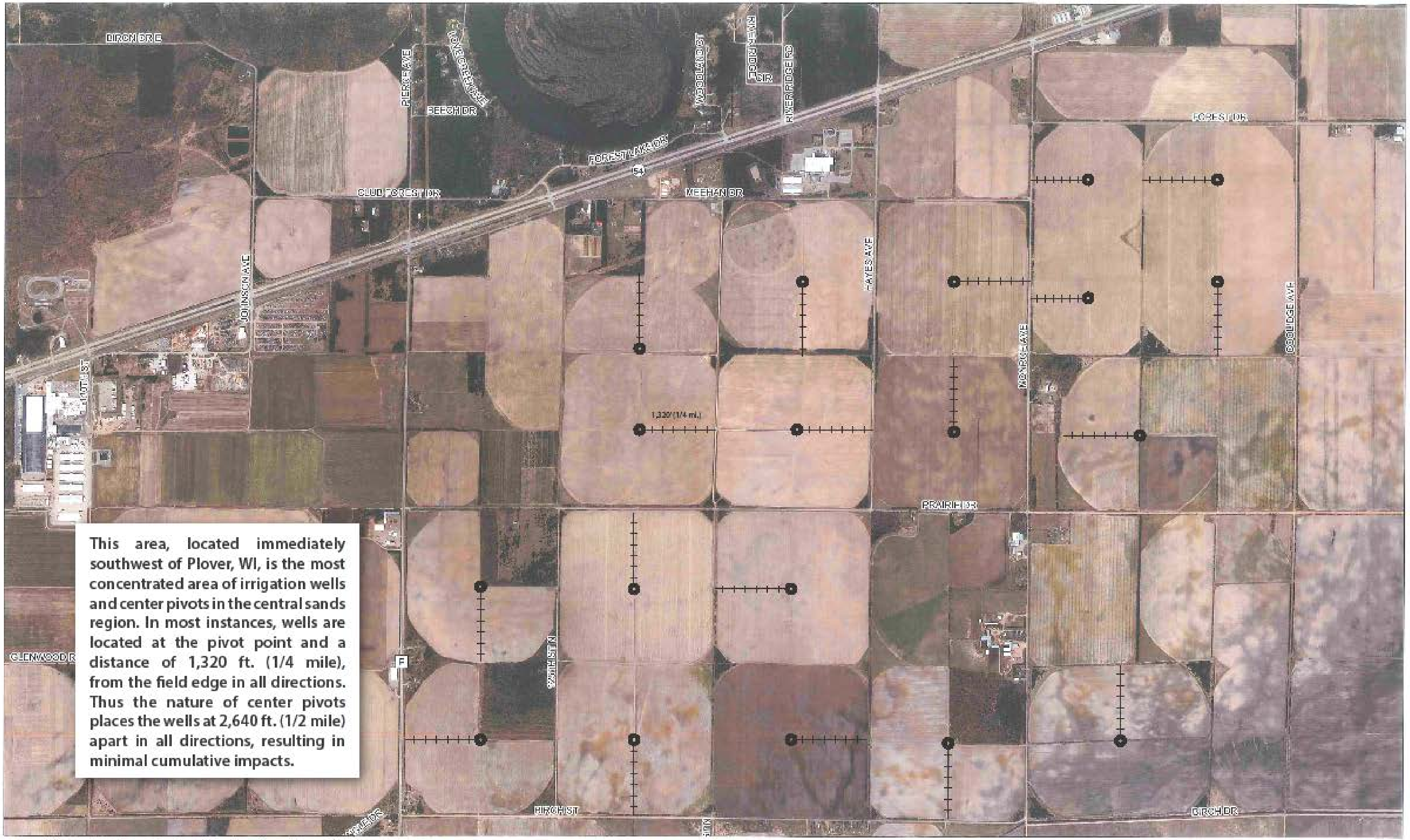
Wisconsin Dept of Natural Resources
Dan Helsel
daniel.helsel@wisconsin.gov

UW Extension — University of Wisconsin-Extension
Kenneth Bradbury
ken.bradbury@uwex.edu

USGS — science for a changing world
Michael Fienen
mnfienen@usgs.gov

See also **http://fyi.uwex.edu/littleplovermodel/**

Exhibit B



N

This map shows the approximate relative location of property boundaries but was not prepared by a professional land surveyor. This map is provided for informational purposes only and may not be sufficient or appropriate for legal, engineering, or surveying purposes.
Prepared by Portage County Planning & Zoning (Sutter) July 25, 2016

Key

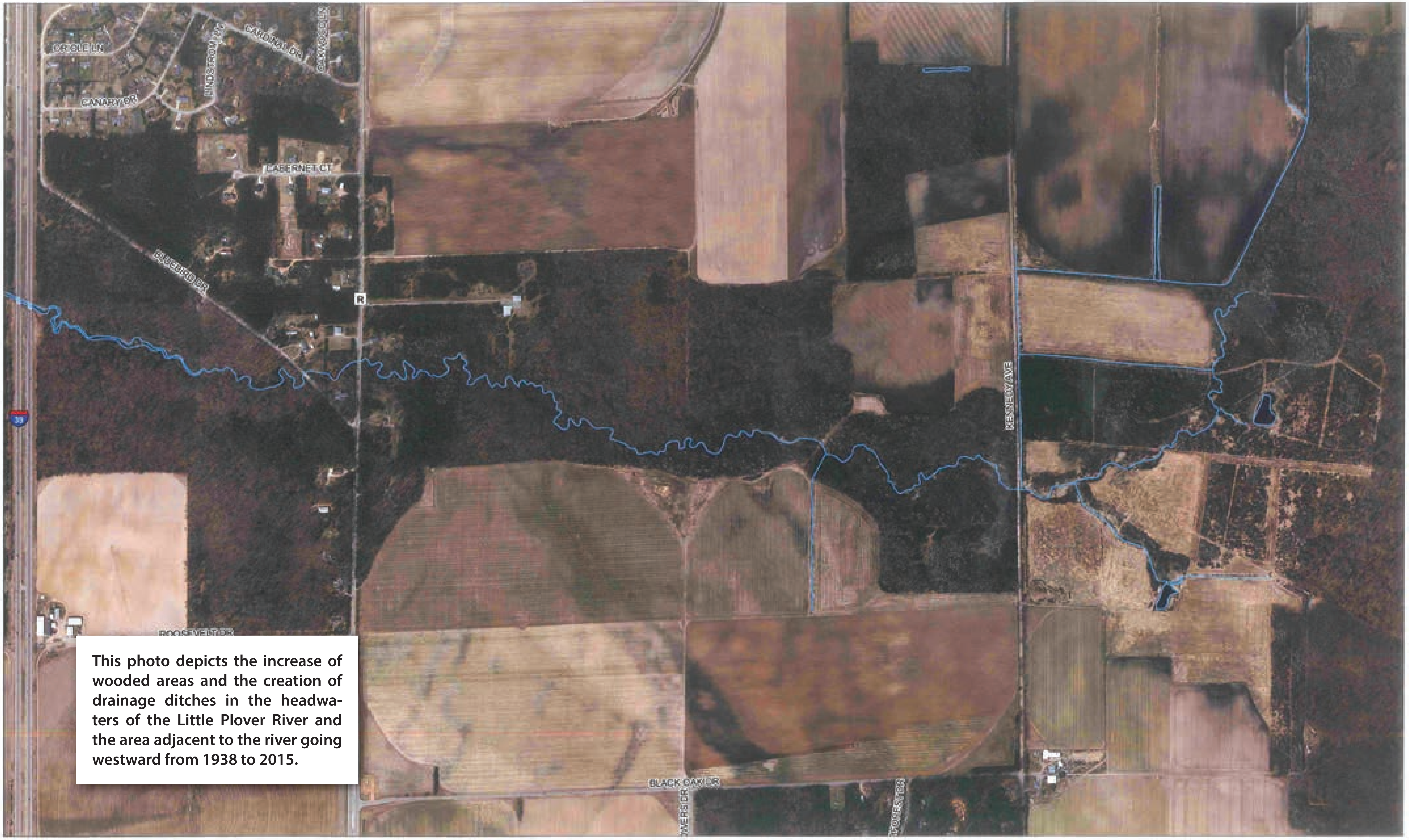
●	High Capacity Well
┼┼┼	Irrigation System

0 500 1,000 2,000 Feet

Date of Photography: Spring, 2015

This depicts the Little Plover River Area showing the land coverage as it appeared in 1938.

Source: Portage County Planning and Zoning Records



This photo depicts the increase of wooded areas and the creation of drainage ditches in the headwaters of the Little Plover River and the area adjacent to the river going westward from 1938 to 2015.

This map shows the approximate relative location of property boundaries but was not prepared by a professional land surveyor. This map is provided for informational purposes only and may not be sufficient or appropriate for legal, engineering, or surveying purposes.
Prepared by Portage County Planning & Zoning (Sutter) July 25, 2016

Date of Photography: Spring, 2015

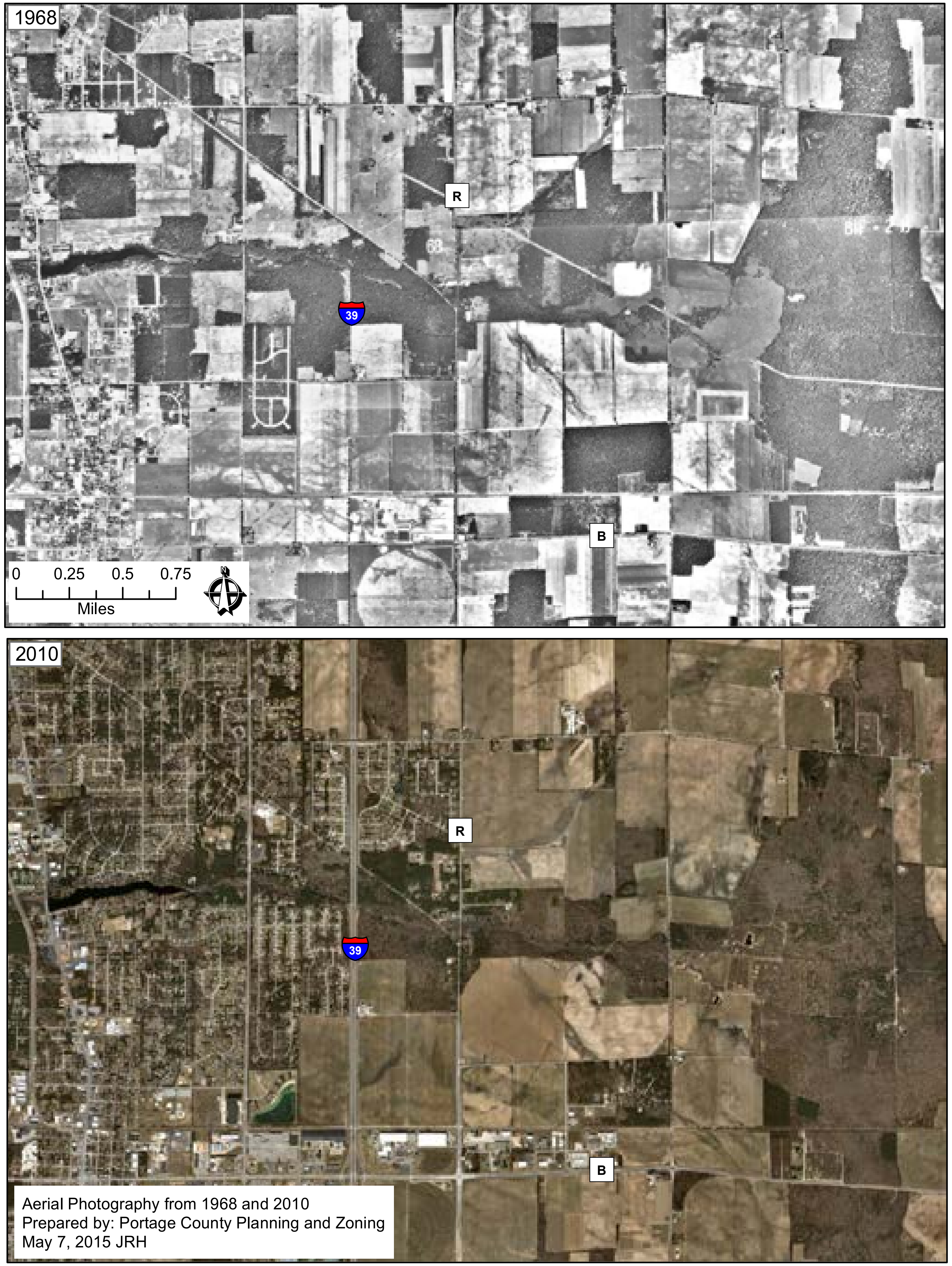
This photo depicts the surface-water drainage way that the village created to provide an outlet for surface water runoff. The runoff was a result of urbanization and the creation of impervious surfaces.

N

This map shows the approximate relative location of property boundaries but was not prepared by a professional land surveyor. This map is provided for informational purposes only and may not be sufficient or appropriate for legal, engineering, or surveying purposes.
Prepared by Portage County Planning & Zoning (Sutter) July 25, 2016

0 200 400 800 Feet

Date of Photography: Spring, 2015



Aerial Photography from 1968 and 2010
Prepared by: Portage County Planning and Zoning
May 7, 2015 JRH

1971

<u>Center Pivot</u>
24 in area

<u>Lakes Status (from north to south) – Plainfield/Hancock/Coloma</u>

Bass:	(West) side of Bass is dry (East) side of Bass has water
Yanke:	Appears about the same as in 1964, with west 1/3 largely dry/some small improvement in west 1/3
Kowalski:	Same as in 1964 – West 1/3 dry
Plainfield:	West ½ looks to have fully resumed East ½ is still largely dry
Long:	Appears full, but with somewhat expanded beach on north, west and east sides
Deer:	Still dry as in 1964
Horsehead:	Now has about 50% water
Weymouth:	Mostly has water – somewhat enlarged beaches
Huron:	Looks good – as it did in 1964
Sand:	
Herrick:	Beach has receded from 1964 but still stressed
Pine:	
Fish:	West half is full
Crooked:	About the same as 1964 – west end is dry
Bohn:	Improved over 1964
Pleasant:	

Conclusion: Most of the lakes of focus (Long, Huron, Fish, Pine and Pleasant) are full. Deer Lake is still dry. There are now 24 high capacity wells in the area but, the lakes have substantially recovered from the 1960s dry period.

Note: Observations made at the State Historical Society and are undergoing verification.

1964

Center Pivot Irrigation
2 Units in this area

Lakes Status (from north to south) – Plainfield/Hancock/Coloma

Bass (west):

Bass (east):

Yanke: Appears that west ½ is dry

Kowalski: West 1/3 dry

Plainfield: West ½ is dry
East ½ shows only 2 patches of water

Long: Largely dry – with 3 small patches of water

Deer: Dry

Horsehead: Mostly dry

Weymouth: West pond dry
East pond has water

Huron: Looks full

Sand: Dry

Herrick: Holding up but with expanded beach

Pine: North half of lake going dry

Fish: East half o flake going dry, west is okay

Crooked: West end dry but 2/3 Okay

Bohn: About ½ dry but has water in the middle

Conclusion: Nearly all the Waushara County lakes (Plainfield, Hancock) are dry. Except for 2 center pivots located about 1 – 2 miles south of full lake Huron, there is no irrigation in evidence that could have produced this result.

1957

Center Pivot
None

Lakes Status (from north to south) – Plainfield/Hancock/Coloma

Bass (west): Has sizeable shore reduction by about 30%

Bass (east): Look full with very little beach

Yanke: Looks full, bur with sizeable beach

Kowalski: Looks full with moderate beach

Plainfield: Looks full but moderate beach on north and east

Deer: Full

Long: Is full of water with some beach on north side

Horsehead: Full

Weymouth: Full

Huron: Full

Sand:

Herrick: Full

Pine:

Fish: Full – both east and west portions

Crooked: 90% full

Bohn: Full

Pleasant:

Conclusion: In 1957 all Waushara County lakes of interest are full or nearly full. There is no center pivot irrigation in evidence at this time.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER
10.1002/2013GL058679

Key Points:
- A climatically driven decadal oscillation dominates the regional water cycle
- The oscillation is governed by ($P-E$) and a stage-dependent runoff flux
- A recent change in oscillation may mark the onset of a new hydroclimatic regime

Supporting Information:
- Readme
- Relationship between total evaporation (May-November) and summer evaporation (June, July and August) for the in-lake evaporation pan.
- Spectral analysis (FFT) of the time-series for: annual water level (A), annual change in water level (B), annual precipitation minus evaporation (C), annual precipitation (D), annual evaporation (E), annual water level pre-1998 (F), annual water level post-1998 (G) in the NHLD. (data detrended; cs2Hann window; PSD SSA: power spectral density as sum squared amplitude) Horizontal lines indicate the 50% (yellow), 90% (green), 95% (blue) and 99% (red) significance levels (white noise model). (H) Detrended time-series for annual NHLD water level, post-1998 data only. We note that power spectra were also generated for the Lake Michigan-Huron, Lake Superior and the modelled NHLD water level time-series (cf. Figs. 2B and 3D). The results for all three annualized time-series indicated prominent but not statistically significant signals with a period of 12y to 13y. Further FFT results for Lake Michigan-Huron using monthly data from Fig. 2B indicated highly significant peaks (99.9%) that correspond to periods of 12.7y and 1y.
- Analysis of time lag and integration window effects (both in years) on the relationship between annual ΔS and annual (P-E) for the aggregated NHLD dataset.
- Time-series for water levels in 27 NHLD lakes over the time period 2008-2013. Data are the weekly grand mean ± standard deviation for a suite of 15 seepage lakes, 10 drainage lakes and 2 drained lakes. Source: Anne Kretchmann, North Lakeland Discovery Center, Manitowish Waters, WI (unpublished data).

Correspondence to:
C. J. Watras,
cjwatras@wisc.edu

Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: Hydroclimatic implications

C. J. Watras[1,2], J. S. Read[3], K. D. Holman[4], Z. Liu[5,6], Y.-Y. Song[6], A. J. Watras[7], S. Morgan[8], and E. H. Stanley[2]

[1]Wisconsin Department of Natural Resources, University of Wisconsin-Madison Trout Lake Research Station, Boulder Junction, Wisconsin, USA, [2]Center for Limnology, University of Wisconsin-Madison, Madison, Wisconsin, USA, [3]Center for Integrated Data Analytics, U.S. Geological Survey, Middleton, Wisconsin, USA, [4]Center for Climatic Research, University of Wisconsin-Madison, Madison, Wisconsin, USA, [5]Department of Atmospheric and Oceanic Sciences and Center for Climatic Research, University of Wisconsin-Madison, Madison, Wisconsin, USA, [6]Department of Atmospheric and Ocean Sciences, Peking University, Beijing, China, [7]Department of Electrical and Computer Engineering, University of Wisconsin-Madison, Madison, Wisconsin, USA, [8]Wisconsin Valley Improvement Company, Wausau, Wisconsin, USA

Abstract We report a unique hydrologic time series which indicates that water levels in lakes and aquifers across the upper Great Lakes region of North America have been dominated by a climatically driven, near-decadal oscillation for at least 70 years. The historical oscillation (~13 years) is remarkably consistent among small seepage lakes, groundwater tables, and the two largest Laurentian Great Lakes despite substantial differences in hydrology. Hydrologic analyses indicate that the oscillation has been governed primarily by changes in the net atmospheric flux of water ($P-E$) and stage-dependent outflow. The oscillation is hypothetically connected to large-scale atmospheric circulation patterns originating in the midlatitude North Pacific that support the flux of moisture into the region from the Gulf of Mexico. Recent data indicate an apparent change in the historical oscillation characterized by an ~12 years downward trend beginning in 1998. Record low water levels region wide may mark the onset of a new hydroclimatic regime.

1. Introduction

Hydrologic responses to contemporary climate change in North America are uncertain in part because instrumental records are generally short, sparse, and often confounded by direct human influence, such as dredging, diversion, impoundment, and withdrawal. Among the longest instrumental records are those for the Laurentian Great Lakes, which date back to the 1860s. Several studies have identified decadal to multidecadal oscillations in these records (or in geological proxies such as coastal ridges) that imply climatic forcing [*Cohn and Robinson*, 1976; *Thompson and Baedke*, 1997; *Polderman and Prior*, 2004; *Hanrahan et al.*, 2009]. In recent years, sharply declining water levels in the upper Great Lakes have focused attention on hydrologic drivers and their potential connection to large-scale climatic modes [*Assel et al.*, 2004; *Sellinger et al.*, 2008; *Hanrahan et al.*, 2010]. The recent declines have been attributed to multiple factors, including channel dredging and changes in precipitation and evaporation [cf. *Stow et al.*, 2008; *Hanrahan et al.*, 2010; *Egan*, 2013a]. The question of potential drivers has hydroclimatic, economic, social, and political dimensions [*Egan*, 2013b].

The complexity of water budgets for very large systems like the Laurentian Great Lakes complicates mechanistic investigation. In their simplest form, water budgets can be expressed as $S_t = S_{t-1} + (P - E + Q)$ where S is storage (water level or stage), t is time, P is precipitation, E is evaporation, and Q comprises all other inflows and outflows. For the upper Great Lakes, Q can be decomposed into at least five inflow terms (fluvial inflow, groundwater inflow, surface runoff, diversion in, and connecting channel inflow) and four outflow terms (fluvial outflow, groundwater outflow, diversion out, and consumptive use).

To facilitate analysis, we focus instead on the historical water level fluctuations of small, relatively undisturbed systems with simpler hydrologic budgets that can be written as $S_t = S_{t-1} + (P - E + G_{net})$ where G_{net} (the net groundwater flux) is the only substantial component of Q. Compiling instrumental data from several sources, we report a unique 70 years time series comprising two small seepage lakes and two sets of groundwater monitoring stations that are within the upper Great Lakes region but outside the Great Lakes basin. We compare this time series to

Citation:
Watras, C. J., J. S. Read, K. D. Holman, Z. Liu, Y.-Y. Song, A. J. Watras, S. Morgan, and E. H. Stanley (2014), Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: Hydroclimatic implications, *Geophys. Res. Lett.*, *41*, doi:10.1002/2013GL058679.

Received 15 NOV 2013
Accepted 11 DEC 2013
Accepted article online 16 DEC 2013

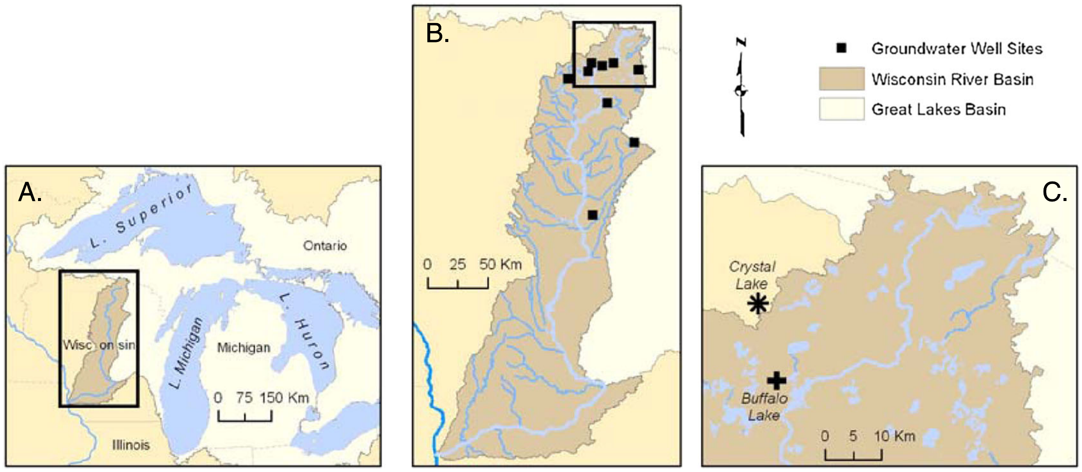


Figure 1. Map of the study area. (a) Laurentian Great Lakes region, showing upper Great Lakes basin (Lake Superior and Lake Michigan-Huron) and Wisconsin River drainage (flowing south to the Mississippi River). (b) Wisconsin River drainage, showing location of nine groundwater monitoring wells. (c) Location of Buffalo Lake (45°52′N, 89°33′W, area 56 ha, maximum depth 8 m) and Crystal Lake (46°0′N, 89°36′W, area 34 ha, maximum depth 20 m) within the NHLD.

analogous data for the two largest Laurentian Great Lakes over the time period 1942–2011. We use contemporaneous time series for precipitation and evaporation to investigate the importance of proximate hydrologic drivers. We then explore relations with global atmospheric variables using correlations with global geopotential height (GPH) at 500 hPa and sea level pressure (SLP). Our findings indicate that a climatically driven near-decadal oscillation has dominated water levels across the upper Great Lakes region for most of the past century, and they suggest that a change in the historical oscillation may have occurred during the past two decades.

2. Study Sites and Data

The region under study is shown in Figure 1. Lake Superior and Lake Michigan-Huron are the two largest freshwater lakes in the region (world), with a total catchment area of 5.8×10^5 km^2. Crystal Lake and Buffalo Lake are small seepage lakes (<60 ha) located adjacent to the Great Lakes Basin in the northern Chippewa River drainage and the upper Wisconsin River drainage, respectively (both of which flow southward to the Mississippi River) (Figures 1b and 1c). As seepage lakes, they have no inflowing or outflowing streams and receive negligible surface runoff from their small terrestrial catchments. Both lakes lie within the Northern Highland Lake District (NHLD) of Wisconsin, an area which contains thousands of poorly integrated lakes and wetlands situated in deep glacial tills (30–60 m) and outwash sands that were formed as the Wisconsonian glacial period ended roughly 10 kyr B.P. [*Magnuson et al.*, 2006].

Historical water levels of Buffalo Lake (arbitrary datum) and a set of nine groundwater monitoring wells distributed across the upper Wisconsin River basin were obtained from the Wisconsin Valley Improvement Company (WVIC) which manages flow in the Wisconsin River (Figure 1b). Weekly observations were made in Buffalo Lake from 1942 to 1989, and monthly observations were made in the wells from 1942 to 1995 (reported here as the ensemble mean anomaly for all nine wells). Historical water levels (1981–2012) of Crystal Lake and 10 adjacent groundwater monitoring wells were obtained from the North Temperate Lakes Long-Term Ecological Research (NTL-LTER) Program, Center for Limnology, University of Wisconsin-Madison (http://lter.limnology.wisc.edu/). The LTER protocol entailed biweekly readings of a referenced (mean annual sea level) staff gauge in the lake and manual measurements of water levels in the groundwater wells each month. Groundwater elevations for this well set are also reported as an ensemble mean. Monitoring wells were situated in shallow, unconfined aquifers within the deep glacial till and outwash sand.

Annual precipitation totals for the NHLD (1937–2011) were obtained from the WVIC as the monthly average of 10 to 12 weather stations in the upper Wisconsin River drainage extending northward from Wisconsin Rapids, WI, into Vilas and Oneida counties. Monthly evaporation totals for the approximate ice-free period (May–November, 1937–1993) were obtained from WVIC based on data from an in-lake evaporation pan. To accommodate missing *E* pan data for some months, annual evaporation totals were estimated from values for summer months using

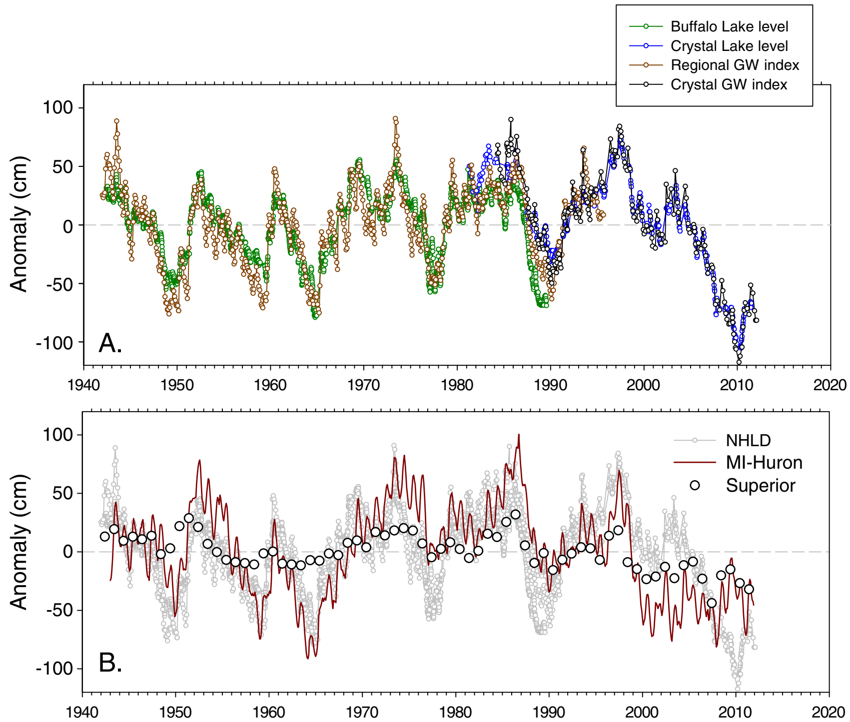


Figure 2. Near-decadal oscillation of regional water levels, 1942–2011. (a) Time series for Crystal Lake, Buffalo Lake, and the both sets of groundwater monitoring wells. (b) Time series for Lake Michigan-Huron (red line) and Lake Superior (circles) superimposed on the time series for the NHLD (grey).

the empirical relationship $E_{\text{May–Nov}} = 1.33 \cdot E_{\text{Jun–Aug}} + 8$ ($r^2 = 0.78$) which was derived for all years with complete records (Figure S1 in the supporting information). For the time period 1989–2011, annual evaporation totals for Crystal Lake were estimated using a Bowen ratio energy balance (BREB) method that uses a whole-lake energy budget to estimate evaporative fluxes (E) [*Lenters et al.*, 2005; *Read*, 2012]. For the BREB method, yearly simulations of E began on first day of open water (ice free) and ended on the last day of open water. To reconstruct a time series for evaporation during the approximate ice-free season for the period 1937–2011, we combined the WVIC data (1937–1993) with the BREB data (1994+). We note that during the brief period of overlap, mean estimates of E differed by ~16% between methods (paired $t = 2.78$, $p = 0.07$).

Monthly water levels for Lake Superior and Lake Michigan-Huron (International Great Lakes Datum (IGLD) 1985) were obtained from the Watershed Hydrology Branch of the U.S. Army Corps of Engineers in Detroit, MI. Lake Superior elevations were based on a network of gauges in Duluth, MN; Marquette, MI; and Pt. Iroquois, Thunder Bay, and Michipicoten, Ontario. Lake Michigan-Huron elevations were based on a network of gauges in Harbor Beach, Mackinaw City, and Ludington, MI; Milwaukee, WI; and Tobermory and Thessalon, Ontario.

3. Water Level Oscillations

The time series of water level anomalies for Crystal Lake, Buffalo Lake, and NHLD groundwater tables is shown in Figure 2a. Visual inspection indicates strong coherence and suggests that a near-decadal oscillation has dominated water levels in the NHLD for at least seven decades. The amplitude of oscillation ranges approximately ±0.7 m, dwarfing the well-known annual cycle. To aggregate the NHLD data, we interpolated daily values for the time series in Figure 2a and we used the interpolated values for 1 January of each year to estimate annual water levels. Spectral analysis (fast Fourier transform) of the annualized water level data indicates a dominant periodicity of ~13 years (99% significance level, Figure S2a). Consistent with the findings of *Ault and St. George* [2010], spectral analysis did not indicate statistically significant oscillations for related variables, such as precipitation, evaporation, or the annual change in water level—except for a very low frequency signal in annual evaporation that reflects a gradual decreasing trend until 1970 and a gradual increase thereafter (Figures S2b–S2e).

The NHLD data are compared to analogous time series for Lake Michigan-Huron and Lake Superior in Figure 2b. The graphical comparison shows that the oscillation of Lake Michigan-Huron has been remarkably similar to the oscillation observed in the NHLD despite large differences in hydrology. Lake Superior has oscillated with a similar periodicity but with damped amplitude. The damping may be due to regulatory structures that control outflow through the Saint Mary's River within limits set by the International Lake Superior Board of Control. With this caveat, temporal coherence among these hydrologic systems indicates that the near-decadal oscillation is a general characteristic of the regional water cycle.

4. Hydrologic Mechanisms Underlying the Near-Decadal NHLD Oscillation

To investigate hydrologic mechanisms potentially driving the near-decadal water level oscillation, the NHLD water budget was expressed as $\Delta S = (P - E) + (G_{in} - G_{out})$ where ΔS is the change in stage (water level) over a specified time period and $(P - E)$ approximates the net atmospheric flux of water, all in L/T. The variability of P and E over annual time scales has been comparable for the time period 1937–2011 (means 79 and 51 cm yr^{-1}, coefficients of variation 12% and 15%, respectively). As expected for a humid region, P and E are negatively correlated (Figure 3a). The correlation implies a dual effect: increased P is associated with decreased E and the converse, thus amplifying the impact of dry and rainy years on water levels.

We estimated ΔS for the aggregated NHLD data over windows ranging from 1 to 4 years. These estimates were correlated with analogous values for $(P - E)$ over a series of yearly lags. The results indicated that a 1 year integration window with no lag in $(P - E)$ explained the most variance in observed ΔS (Figure S3). The best fit indicates that annual $(P - E)$ can account for 65% of the variability in ΔS from year to year (Figure 3b). The intercept implies a missing flux of −38 cm/yr (±3.7 cm, standard error (SE); $p < 0.001$), which hypothetically constitutes regional groundwater loss (G_{net}). The residuals were not correlated with time, but there was a correlation with stage, which suggests that the average groundwater flux (−38 cm/yr) was an underestimate when stage was high and an overestimate when stage was low.

Given the results from Figure 3b and the dependence of the NHLD groundwater flux on stage, we used a recursive model to estimate the aggregate stage for a given year (t) as $S_t = S_{t-1} + m(P_t - E_t) - G_t$, where P_t and E_t are yearly total precipitation and evaporation and G_t is a stage-dependent groundwater flux term, given by $G_t = (b \cdot S_{t-1} - c)$. The constants "$m$," "$b$," and "$c$" were derived from the fit in Figure 3b, where "m" and "c" are the slope and intercept of the original fit and "b" is the slope of the residuals fit to stage. The initial stage (S_{1942}) and the stage dependence coefficient (b) were optimized to minimize the mean square error (MSE) between the modeled and observed stages (bounding possible values for b within its 95% confidence window). For the aggregated NHLD data, the model was able to explain 70% of the variability in annual ΔS over the time period 1943−2010 (Figure 3c). The time series for modeled stage (S) tracked the observed time series reasonably well ($r^2 = 0.62$, Figure 3d), confirming the importance of $(P - E)$ as a governing factor and the importance of a stage-dependent groundwater flux as a contributing factor.

5. Connection With Large-Scale Atmospheric Circulation Patterns

The similar near-decadal oscillation of NHLD and Great Lakes' water levels suggests that a common governing mechanism(s) has operated across the region despite large differences in the hydrology of individual systems. Since connections to large-scale climate modes have been suggested by *Ghanbari and Bravo* [2008], *Hanrahan* [2010], and *Hanrahan et al*. [2009, 2010] for the upper Great Lakes, we investigated the correlation between monthly changes in NHLD water levels and 500 hPa geopotential height and sea level pressure from the National Centers for Environmental Prediction-National Center for Atmospheric Research reanalysis data set for the 63 year period of 1948–2010. Because warm-season precipitation dominates the annual cycle in this region (data not shown), our correlation analysis focuses on monthly changes in stage between April and September, where each month has an associated change in stage (e.g., the April 1948 change in stage is the difference in stage between 1 May 1948 and 1 April 1948). The seasonal cycle was removed from all time series prior to correlating. This included removing the seasonal cycle from the change in stage time series and from the 500 hPa geopotential height and sea level pressure fields at each grid cell separately.

The correlation map between monthly change in stage and 500 hPa geopotential heights indicates that warm-season changes in stage are associated with a large-scale atmospheric wave train that extends from the central North Pacific, across central North America, and over western North Atlantic (Figure 4a). This wave train anomaly

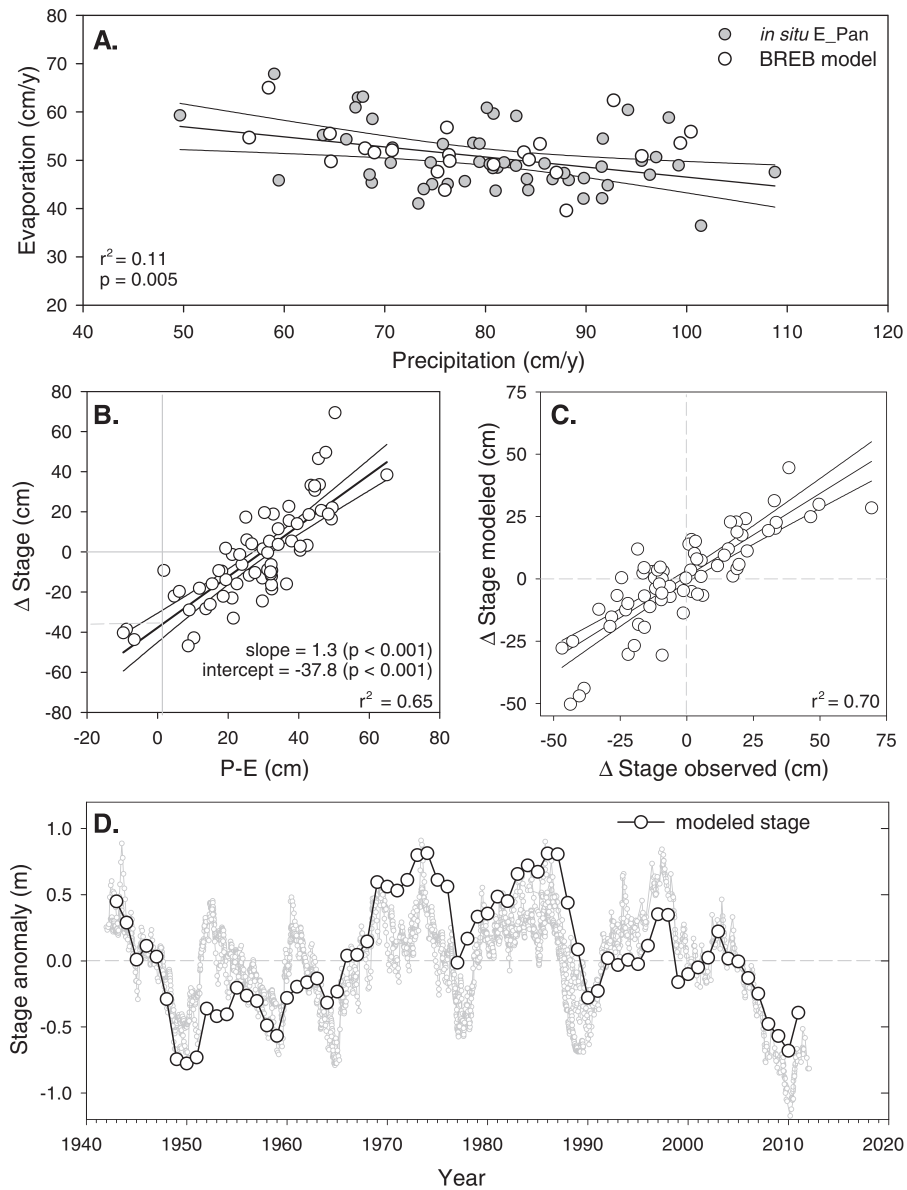


Figure 3. Relationship between NHLD water levels, precipitation, and evaporation, 1942–2010. (a) Negative relationship between *P* and *E*, (b) regression of annual ($P - E$) on the annual change in stage (ΔS) using aggregated water levels, (c) comparison of observed ΔS to the predicted ΔS, based on recursive model with a stage-dependent groundwater flux (see section 4), and (d) time series for observed and modeled water levels.

pattern resembles the circumglobal teleconnection (CGT) pattern that propagates along the westerly waveguide [*Branstator*, 2002; *Ding and Wang*, 2005]. This is similar to the findings from *Small et al.* [2010], which suggest that the CGT influences regional hydrology across the United States and Canada during fall months. We surmise that the CGT enables upstream conditions, such as those over the North Pacific, to influence climate and climate variability across North America. We present the correlation map between monthly change in stage and sea level pressure to illustrate the relationship with atmospheric conditions near the surface (Figure 4b). Correlations in Figure 4b show that positive changes in lake stage are associated with a high-pressure anomaly near the Gulf of Alaska and near the southeast coast of the United States, along with a low-pressure anomaly near the central United States. The inferred flow regime based on the sea level pressure correlation map suggests that positive changes in lake stage are correlated with south-southwesterly winds into the Great Lakes region, possibly originating over the Gulf of Mexico. South-southwesterly surface winds from the Gulf of Mexico are often associated with warm temperatures and increased atmospheric moisture content,

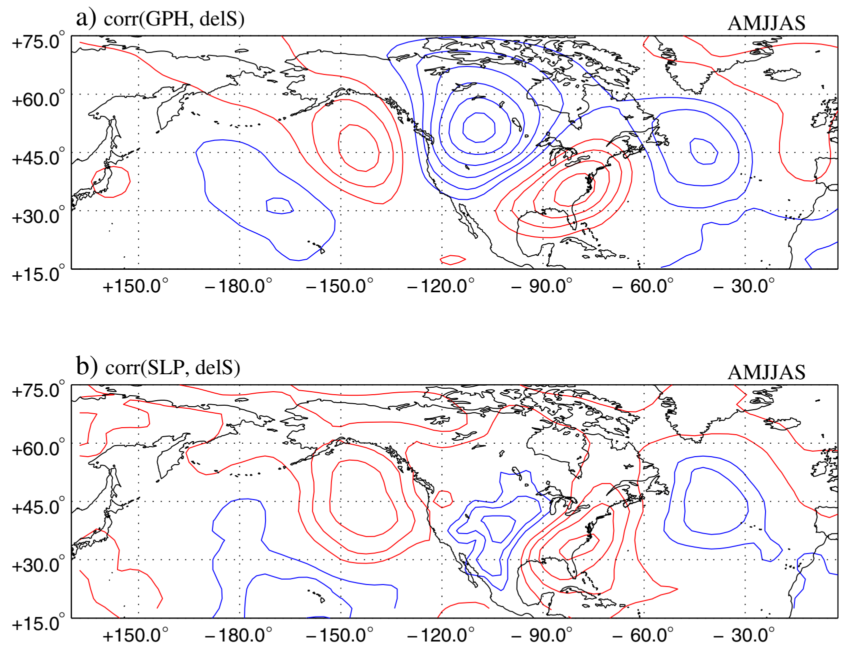


Figure 4. One-point correlation maps between monthly NHLD change in stage (delS) and (a) 500 hPa geopotential height (GPH) and (b) sea level pressure (SLP) during each month between April and September from 1948 to 2010. Red (blue) contours indicate positive (negative) correlation values. The contour interval is 0.05. The zero line is omitted. Values above/below ±0.11 are significant at the 99% contour interval based on Student's *t* test.

which may reduce stability in the region and also act to suppress surface evaporation. It should be noted that the correlation analysis presented in Figure 4 does not explicitly isolate the mechanism for the 13 year oscillation in NHLD and upper Great Lakes' water levels. Instead, the analysis provides a potential explanation of large-scale atmospheric circulations that influence warm-season hydrology across the upper Great Lakes region.

6. Potential Hydroclimatic Implications

The strong coherence among small NHLD lakes, groundwater, and the two largest Laurentian Great Lakes is surprising, but it is consistent with reports for other lakes in the region over shorter time spans [*Magnuson et al*., 2006; *Stow et al*., 2008; *White et al*., 2008]. A common oscillation among dissimilar systems seems to imply a common governing factor, and our data suggest that the common factor is ($P - E$). Until recently, evaporation has been considered a negligible factor in the near-decadal oscillation of the upper Great Lakes due to its relative constancy over most of the historical record [*Hanrahan et al*., 2009]. Recent correlations between a longer ice-free period, increased water temperature, and increased evaporation suggest a stronger influence of E on water budgets across the region [*Magnuson et al*., 2000; *Austin and Colman*, 2007; *Desai et al*., 2009; *Hanrahan et al*., 2010; *Mishra et al*., 2011].

During the past decade, unusually low water levels have been observed in both the NHLD and the upper Great Lakes. Following a peak in 1998, NHLD water levels have trended downward for roughly 12 years—reaching a record low elevation in 2010 (Figure 2a). Similarly, the water level of Lake Michigan-Huron recently dropped at a rate not seen since the 1930s megadrought [*Assel et al*., 2004; *Sellinger et al*., 2008]. Both Lake Superior and Lake Michigan-Huron have been consistently below average level for the longest sustained period in their historical records [*International Lake Superior Board of Control*, 2012], and in January 2013, Lake Michigan-Huron reached an all-time low water level (U.S. Army Corps of Engineers, unpublished data, 2013).

To assess an apparent change in the historical oscillation, spectral analysis was applied to the pre-1998 and post-1998 segments of the NHLD time series after trends were removed (Figures S2f and S2g). The results indicate a near-decadal oscillation in both detrended segments (13 years and 11 years, respectively), but the major spectral peak for the post-1998 segment is not statistically significant due to its relatively short length. Although speculative, this result suggests that a downward trend was superimposed on the historical oscillation beginning around 1998. The data also suggest that the amplitude of oscillation (if real) has decreased (Figure S2h). Ancillary data for a suite of 27 small NHLD lakes are consistent with this latter finding. Over the 5 year time period spanning 2008–2013, the 27 lake time series has been dominated by low-amplitude (±0.30 cm) seasonal and interannual fluctuations around a lower mean water level (Figure S4). Similarly low-amplitude fluctuations have characterized the time series for Lake Michigan-Huron during recent years (Figure 2b).

At least three future hydroclimatic scenarios seem possible for this midcontinental region: (1) the historical water cycle may resume in a few years, with the time period 1990–2012 as an aberration in the historical record; (2) the recently altered cycle may propagate through future time as an amplified oscillation around the historical mean water level; or (3) a step change (or series of step changes) to new mean water levels may occur. Because of the magnitude of past oscillations, it remains challenging to predict which scenario is most likely [*Meehl et al*., 2009]. However, as future climatic conditions evolve over time, small isolated lakes and water tables may prove to be useful sentinels of hydrologic change.

Acknowledgments
We thank Tim Meinke, Ken Morrison, and Aaron Stephenson for technical assistance; Janel Hanrahan, Tim Kratz, and Noah Lottig for insightful discussions; Keith Kompoltowicz and Melissa Kropfreiter for providing data for the two Great Lakes; and Anne Kretchmann for providing the 27 lake NHLD data set. Support was provided by the Wisconsin Department of Natural Resources, the Wisconsin Focus on Energy Program, and by the U.S. National Science Foundation (NTL-LTER Program, DEB-0822700). This paper is a contribution from the Trout Lake Research Laboratory, Center for Limnology, University of Wisconsin-Madison.
The Editor thanks two anonymous reviewers for their assistance in evaluating this paper.

References

Assel, R. A., F. H. Quinn, and C. E. Sellinger (2004), Hydroclimatic factors of the recent record drop in Laurentian Great Lakes water levels, *Bull. Am. Meteorol. Soc.*, *85*(8), 1143–1151, doi:10.1175/bams-85-8-1143.

Ault, T. R., and S. St. George (2010), The magnitude of decadal and multidecadal variability in North American precipitation, *J. Clim.*, *23*, 842–850, doi:10.1175/2009JCLI3013.1.

Austin, J. A., and S. M. Colman (2007), Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: A positive ice-albedo feedback, *Geophys. Res. Lett.*, *34*, L06604, doi:10.1029/2006GL029021.

Branstator, G. (2002), Circumglobal teleconnections, the jet stream wave guide and the North Atlantic oscillation, *J. Clim.*, *15*, 1893–1910, doi:10.1175/1520-0442(2002)015<1893:CTTJSW>2.0.CO;2.

Desai, A. R., J. A. Austin, V. Bennington, and G. A. McKinley (2009), Stronger winds over a large lake in response to weakening air-to-lake temperature gradient, *Nat. Geosci.*, *2*, 855–858, doi:10.1038/NGEO693.

Cohn, B. P., and J. E. Robinson (1976), A forecast model for Great Lakes water levels, *J. Geol.*, *84*(4), 455–465 [Available at http://www.jstor.org/stable/30066062].

Ding, Q. H., and B. Wang (2005), Circumglobal teleconnection in Northern Hemisphere summer, *J. Clim.*, *18*, 3483–3505, doi:10.1175/JCLI3473.1.

Egan, D. (2013a), Does Lake Michigan's record low mark the beginning of a new era for Great Lakes?, *Milwaukee J. Sentinel*, 28 July 2013. page 1A [Available at http://www.jsonline.com/news/wisconsin/levelsmain1-b9941593z1-216428651.html].

Egan, D. (2013b), Great Lakes panel still waiting for legislative action on lake levels, *Milwaukee J. Sentinel*, 10 September 2013. page 1A [Available at http://www.jsonline.com/news/wisconsin/great-lakes-panel-still-waiting-for-legislative-action-on-lake-levels-b9994414z1-223041351.html].

Ghanbari, R. N., and H. R. Bravo (2008), Coherence between atmospheric teleconnections, Great Lakes water levels, and regional climate, *Adv. Water Resour.*, *31*, 1284–1298, doi:10.1016/j.advwatres.2008.05.002.

Hanrahan, J. L., S. V. Kravtsov, and P. J. Roebber (2009), Quasi-periodic decadal cycles in levels of lakes Michigan and Huron, *J. Great Lakes Res.*, *35*(1), 30–35, doi:10.1016/j.jglr.2008.11.004.

Hanrahan, J. L., S. V. Kravtsov, and P. J. Roebber (2010), Connecting past and present climate variability to the water levels of Lakes Michigan and Huron, *Geophys. Res. Lett.*, *37*, L01701, doi:10.1029/2009gl041707.

Hanrahan, J. L. (2010), Connecting past and present climate variability to the water levels of Lakes Michigan and Huron, PhD dissertation, Univ. of Wisconsin–Milwaukee.

International Lake Superior Board of Control (ILSBC) (2012), Semi-annual progress report to the International Joint Commission, International Lake Superior Board of Control, http://www.ijc.org/rel/boards/Lake_superior/Superior-SAR-Mar12.pdf.

Lenters, J. D., T. K. Kratz, and C. J. Bowser (2005), Effects of Climate variability on lake evaporation: Results from a long-term energy budget study of Sparkling Lake, northern Wisconsin (USA), *J. Hydrol.*, *308*, 168–195, doi:10.1016/j.jhydrol.2004.10.028.

Magnuson, J. J., et al. (2000), Historical trends in lake and river ice cover in the Northern Hemisphere, *Science*, *289*(5485), 1743–1746, doi:10.1126/science.289.5485.1743.

Magnuson, J. J., T. K. Kratz, and B. J. Benson (Eds.) (2006), *Long-term Dynamics of Lakes in the Landscape*, pp. 400, Oxford Univ. Press, New York.

Meehl, G. A., et al. (2009), Decadal prediction, *Bull. Am. Meteorol. Soc.*, *90*(10), 1467–1485, doi:10.1175/2009bams2778.1.

Mishra, V., K. A. Cherkauer, and L. C. Bowling (2011), Changing thermal dynamics of lakes in the Great Lakes region: Role of ice cover feedbacks, *Global Planet. Change*, *75*(3-4), 155–172, doi:10.1016/j.gloplacha.2010.11.003.

Polderman, N. J., and S. C. Pryor (2004), Linking synoptic-scale climate phenomena to lake level variability in the Lake Michigan-Huron basin, *J. Great Lakes Res.*, *30*(3), 419–434.

Read, J. S. (2012), Physical processes in small temperate lakes, PhD dissertation, Dep. of Civ. and Environ. Eng., Univ. of Wisconsin-Madison.

Sellinger, C. E., C. A. Stow, E. C. Lamon, and S. S. Qian (2008), Recent water level declines in the Lake Michigan-Huron system, *Environ. Sci. Technol.*, *42*(2), 367–373, doi:10.1021/es070664+.

Small, D., S. Islam, and M. Barlow (2010), The impact of a hemispheric circulation regime on fall precipitation over North America, *J. Hydrometeorol.*, *11*(5), 1182–1189, doi:10.1175/2010JHM1273.1.

Stow, C. A., E. C. Lamon, T. K. Kratz, and C. E. Sellinger (2008), Lake level coherence supports common driver, *Earth Ocean Sci.*, *89*, 389–390.

Thompson, T. A., and S. J. Baedke (1997), Stand-plane evidence for late Holocene lake-level variations in Lake Michigan, *Geol. Soc. Am. Bull.*, *109*(6), 666–682, doi:10.1130/0016-7606(1997)109<0666:SPEFLH>2.3.CO;2.

White, M. S., M. A. Xenopoulos, K. Hogsden, R. A. Metcalfe, and P. J. Dillon (2008), Natural lake level fluctuation and associated concordance with water quality and aquatic communities within small lakes of the Laurentian Great Lakes region, *Hydrobiologia*, *613*(1), 21–31, doi:10.1007/s10750-008-9469-y.

Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

Bob Smail
Wisconsin DNR – Water Use Section
WPVGA - Water Task Force Meeting
Plover, WI

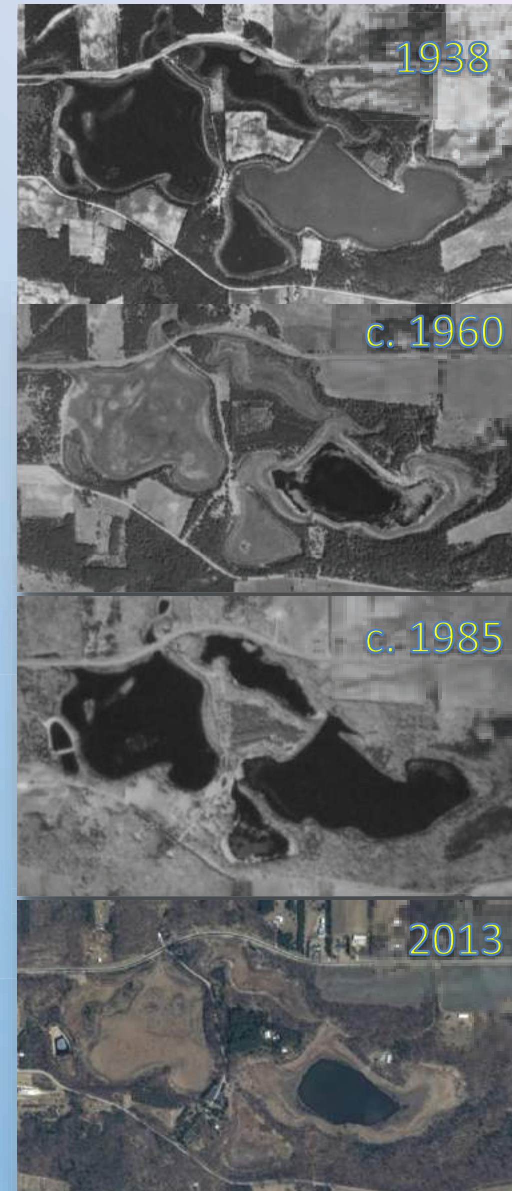
August 30, 2016

Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

Wisconsin DNR staff analyzed long-term variation (1951-2014) in annual average lake levels, groundwater levels and stream flows across the state. Results showed that water levels and flows in northeastern and central Wisconsin were strongly correlated with variation in the levels of Lake Michigan and Lake Superior. In the northeast and central region, water levels were above average for a prolonged period from the late 1960’s to mid-1990’s until declining in recent years. Water levels and flows in the northwestern portion of the state demonstrated a similar prolonged, above average period lasting from the mid-1970’s through the early 2000’s before declining. By comparison, average water levels and flows in the southern third of Wisconsin increased across the entire period. These results demonstrate that water levels and flows are strongly subject to long-term weather and climate variation and that this variation is not consistent across the entire state. Results from this study will serve as a starting point for understanding the difference between weather induced impacts on water levels and flows from human induced impacts.

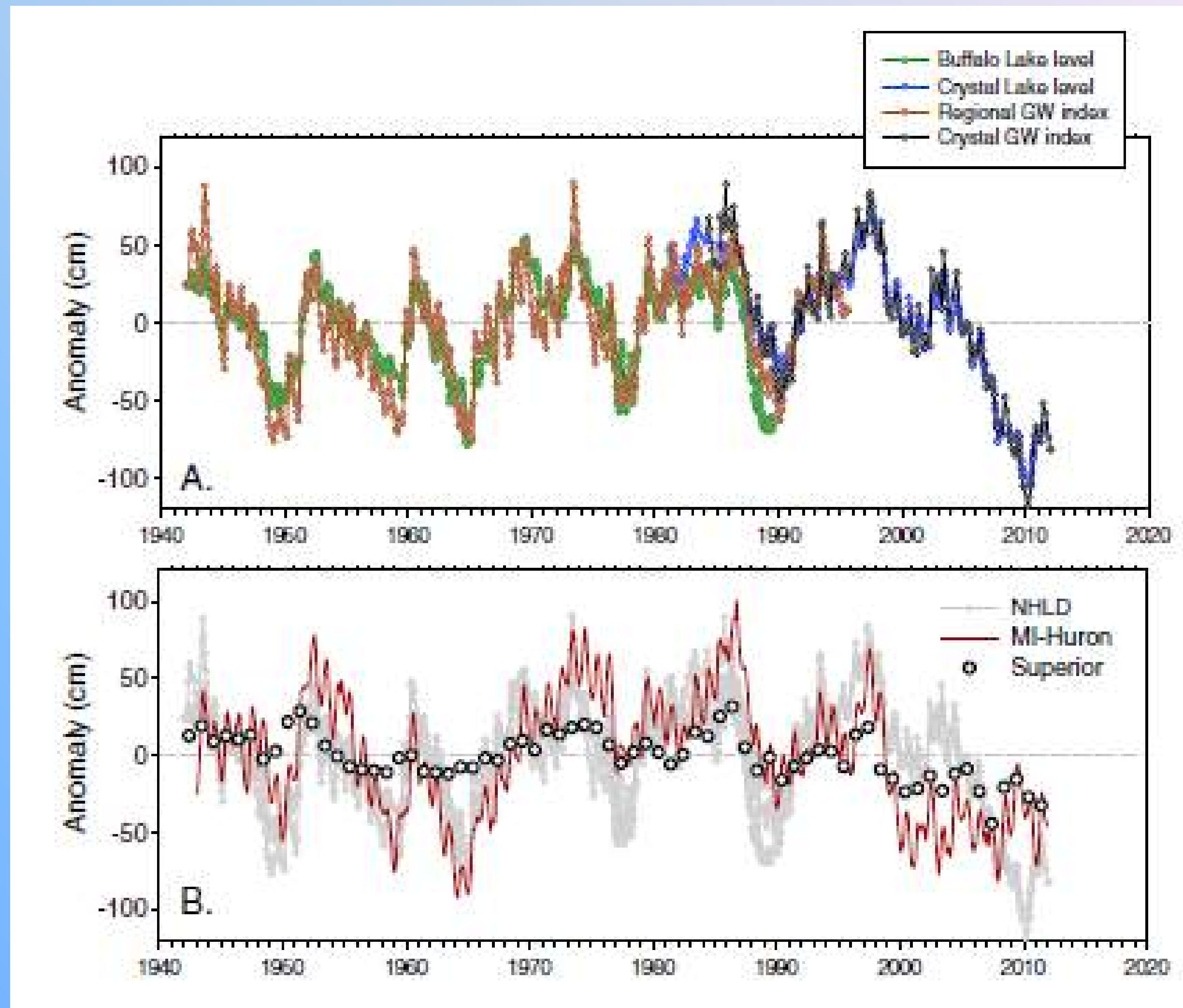
Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

The challenge of managing for "normal" water levels?



Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

Recent research has shown synchronicity between water levels in different locations.

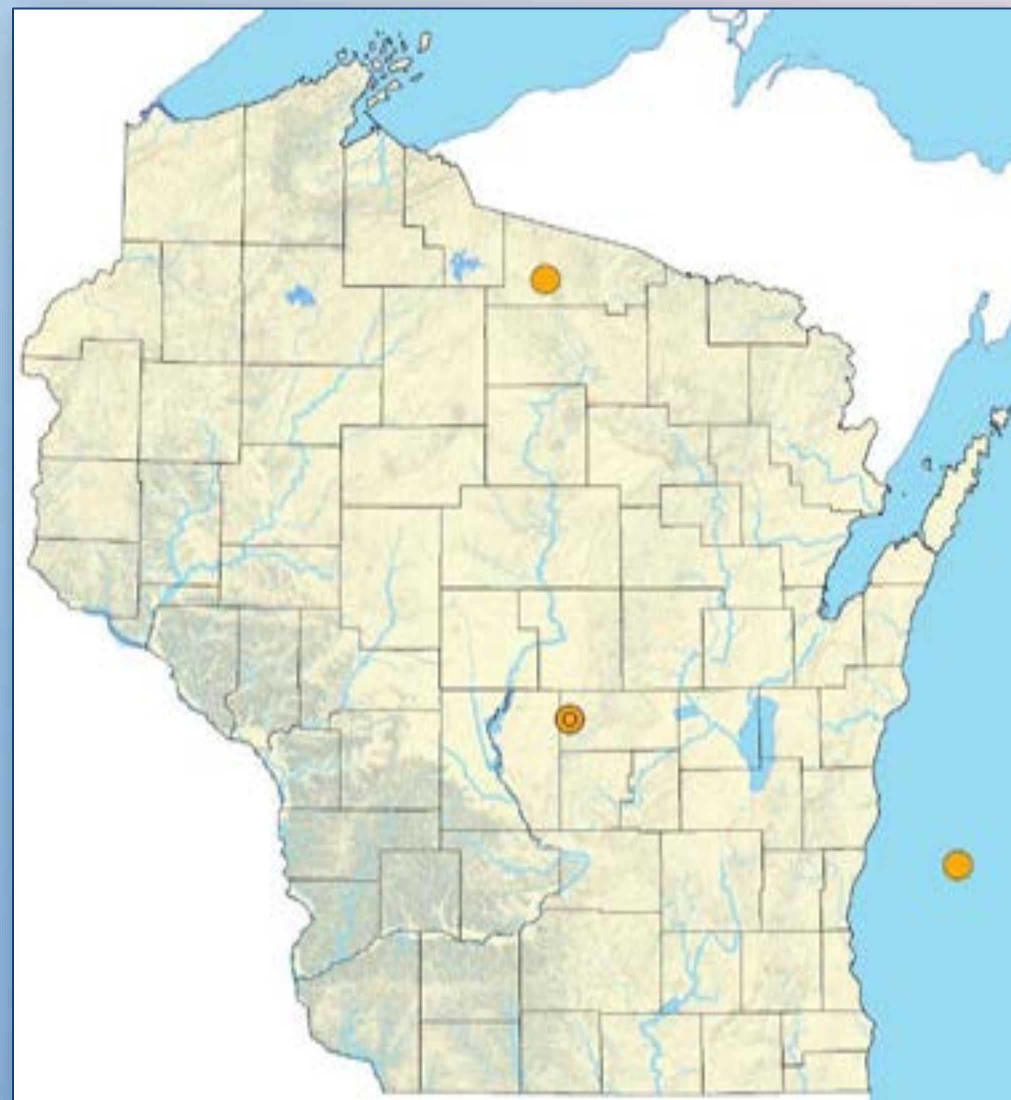


Watras et al. 2013. Decadal oscillation of lakes and aquifers in the upper Great Lakes region of North America: Hydroclimatic implications. Geophysical Research Letters. 10.1002/2013GL058679

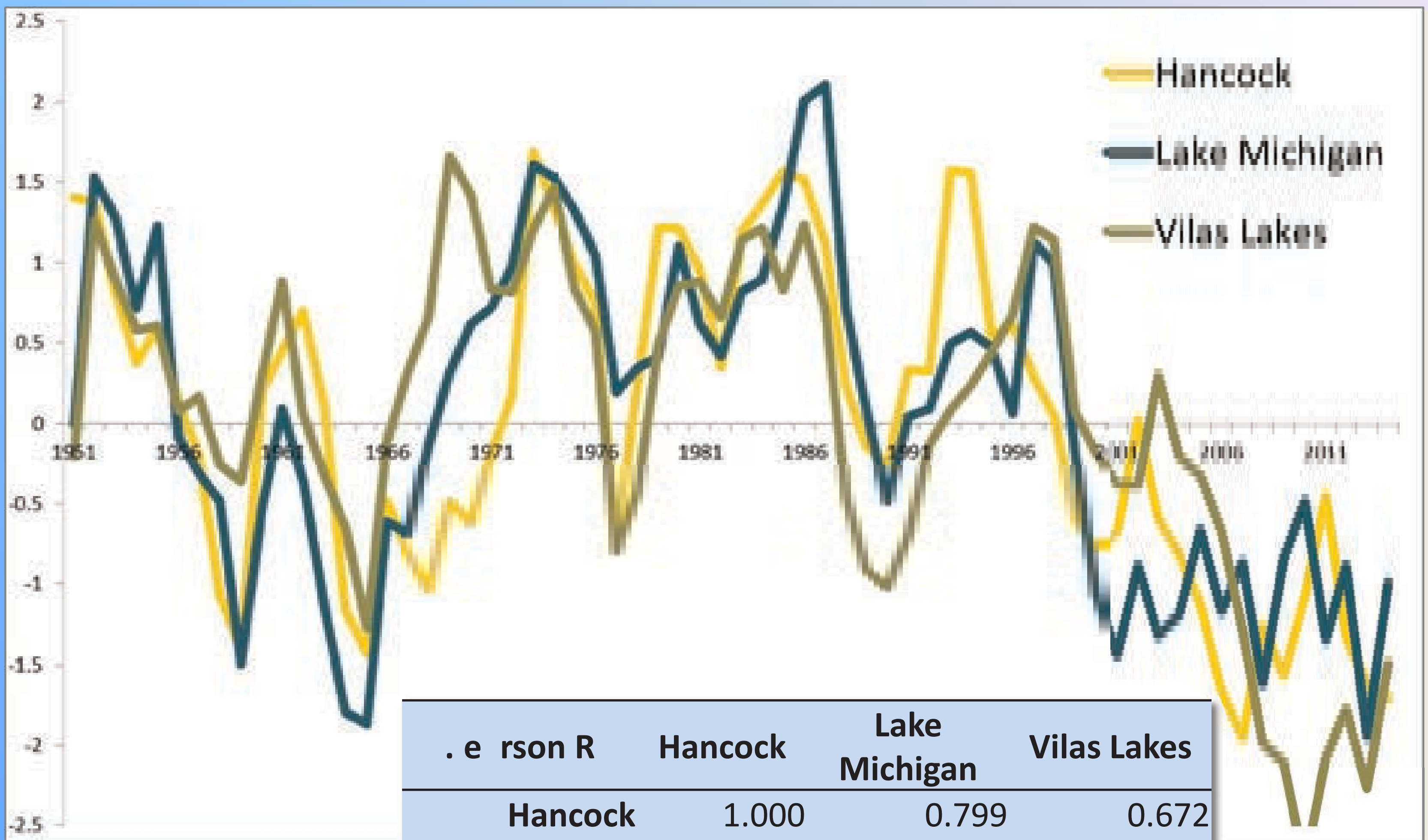
Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

- Three observations initially compared
  - Vilas Lakes aggregated average anomaly (Watras et al)
  - Lake Michigan mean elevation (NOAA- GLERL)
  - Hancock depth below land surface (USGS)

- Z-scores calculated to normalize different measurement types

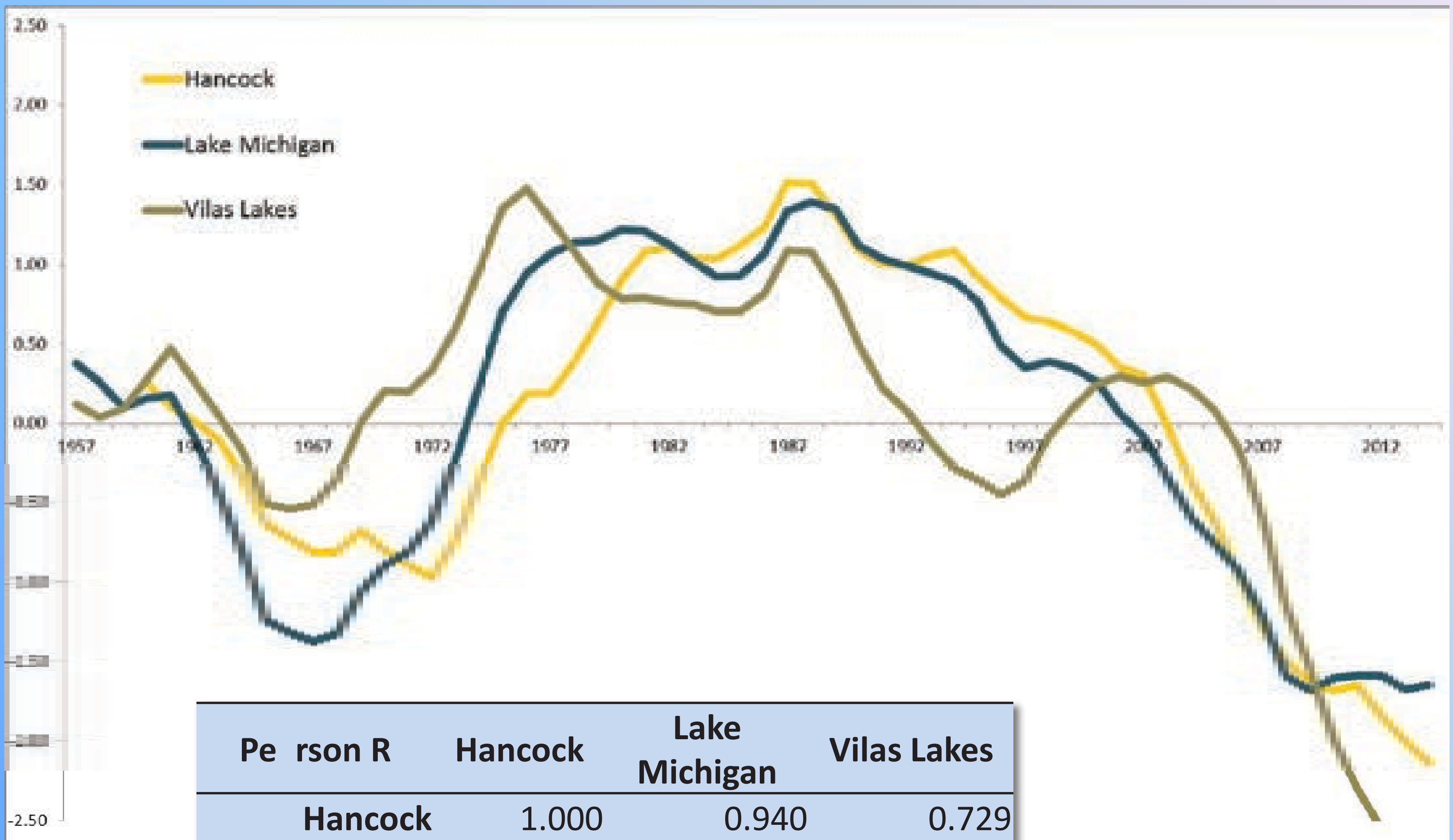


Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation



. e rson R	Hancock	Lake Michigan	Vilas Lakes
Hancock	1.000	0.799	0.672
Lake Michigan	0.799	1.000	0.739
Vilas Lakes	0.672	0.739	1.000

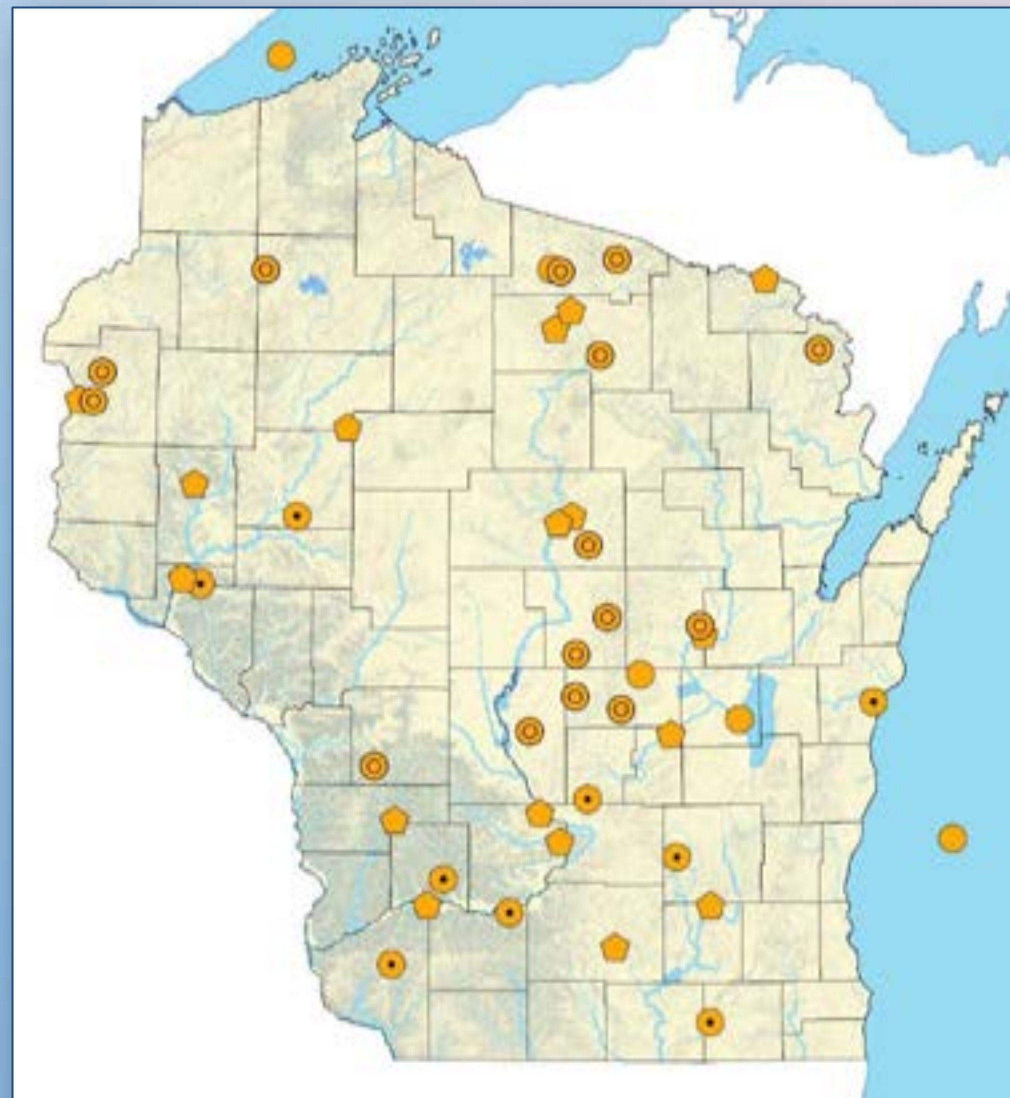
Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation



Pe rson R	Hancock	Lake Michigan	Vilas Lakes
Hancock	1.000	0.940	0.729
Lake Michigan	0.940	1.000	0.762
Vilas Lakes	0.729	0.762	1.000

Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

- 47 Observations locations statewide
- Continual (nearly) from 1968 to present
- Some observations dated back to 1800's
- Started analysis at 1951 when 2/3 of observations started



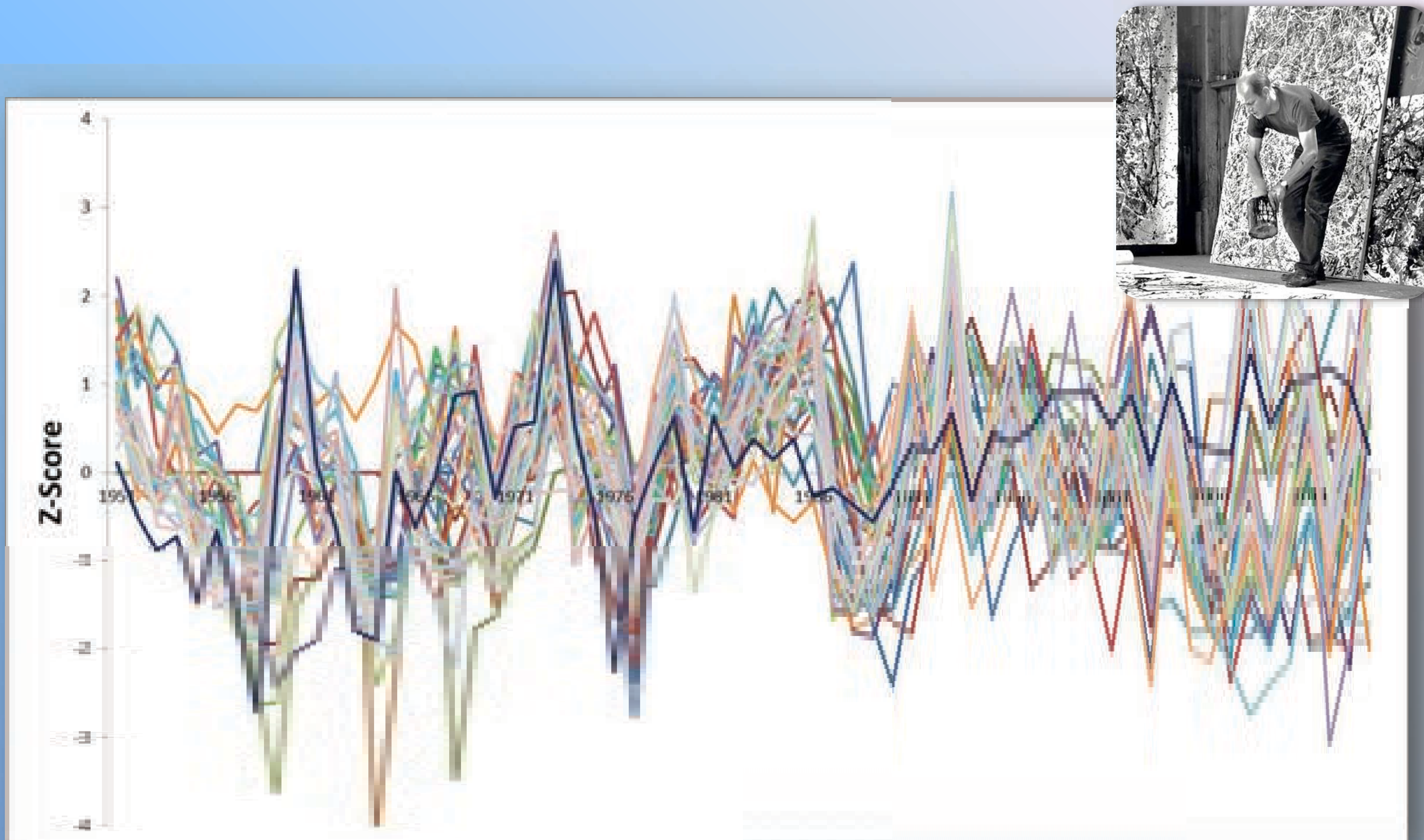
Bedrock Well

Lake Level

River Flow

Sand and Gravel Well

Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation



Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

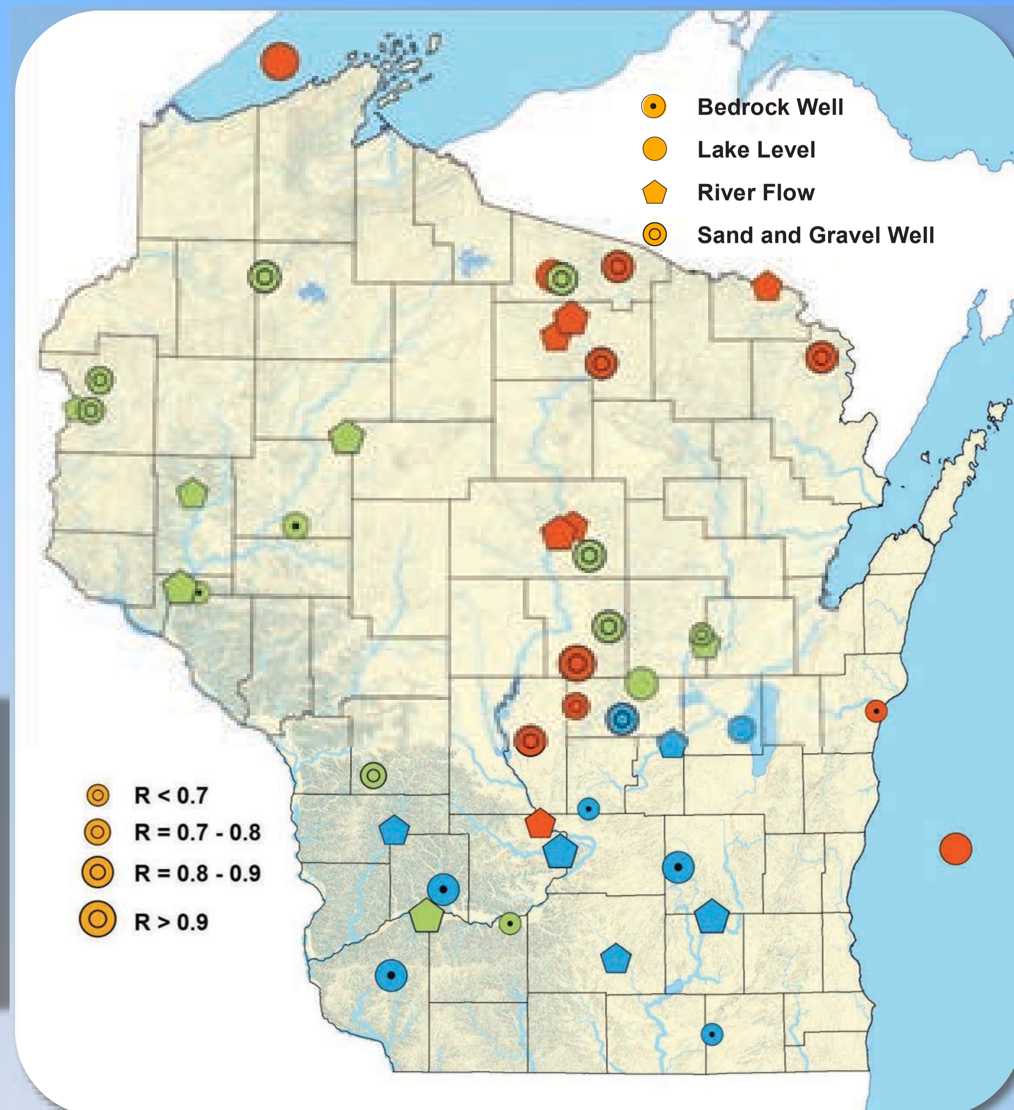
- Three identified as optimal number by Principal Component Analysis
- K-Means cluster used to identify clusters

West Cluster - 18 Sites

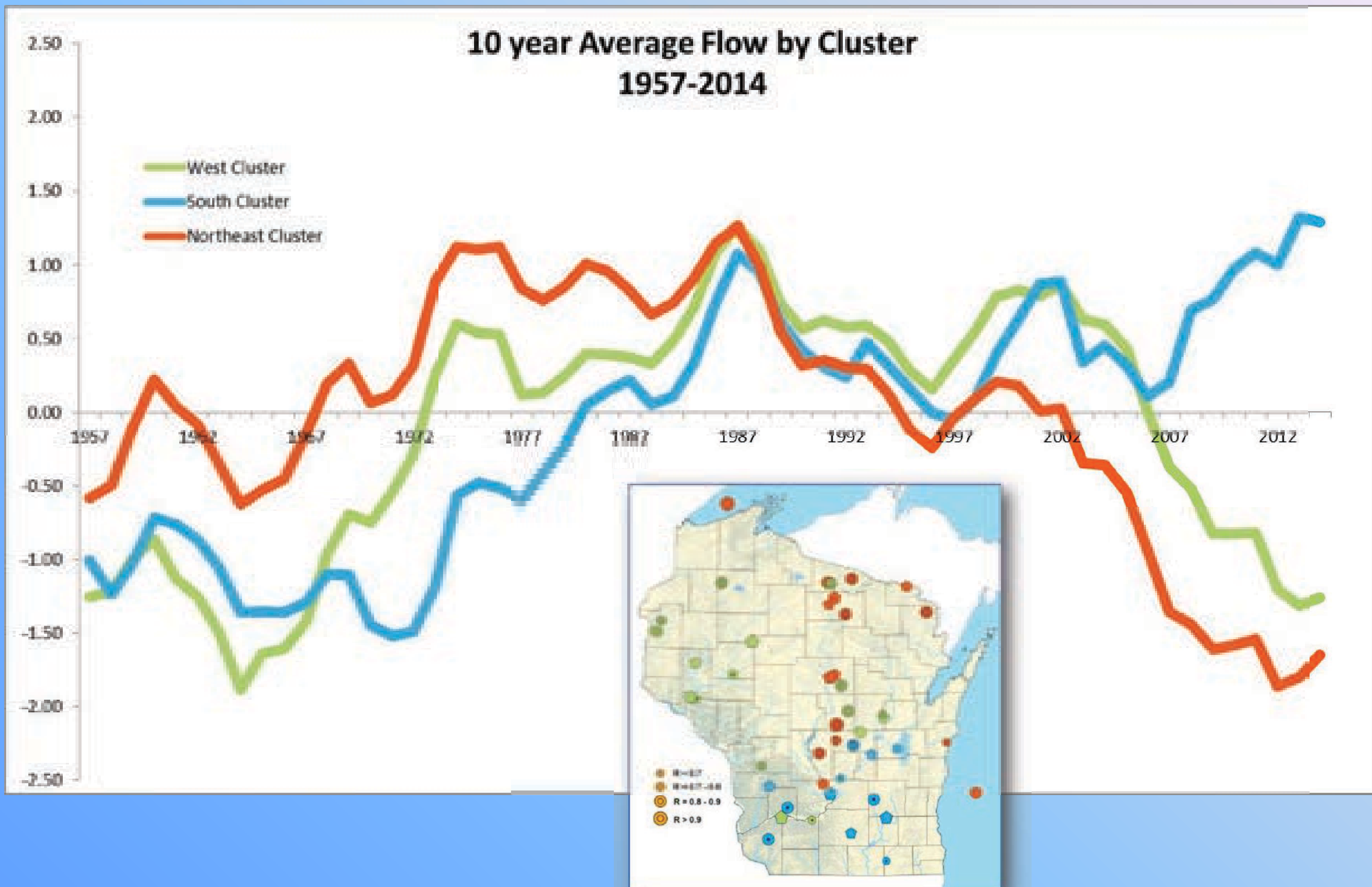
South Cluster - 12 Sites

Northeast Cluster - 16 Sites

Mean Corre ation e twee Cluste and St es in e ch Cluste		Cluster West	South	Northeast
Sites	West	0.81	0.27	0.52
	South	0.33	0.81	-0.17
	Northeast	0.58	-0.16	0.86

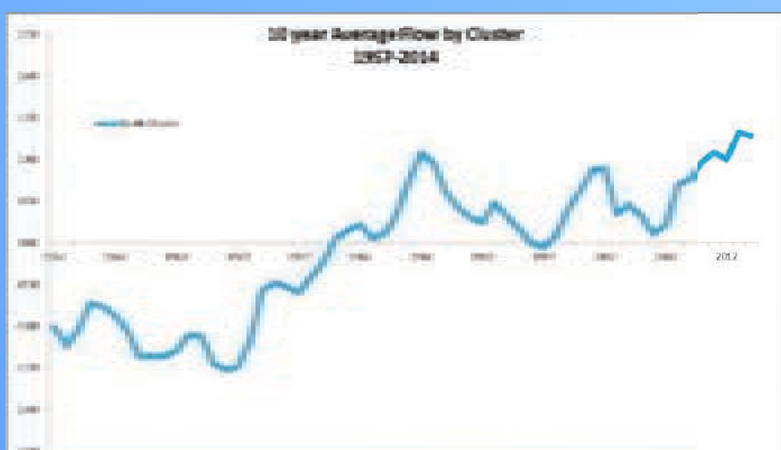


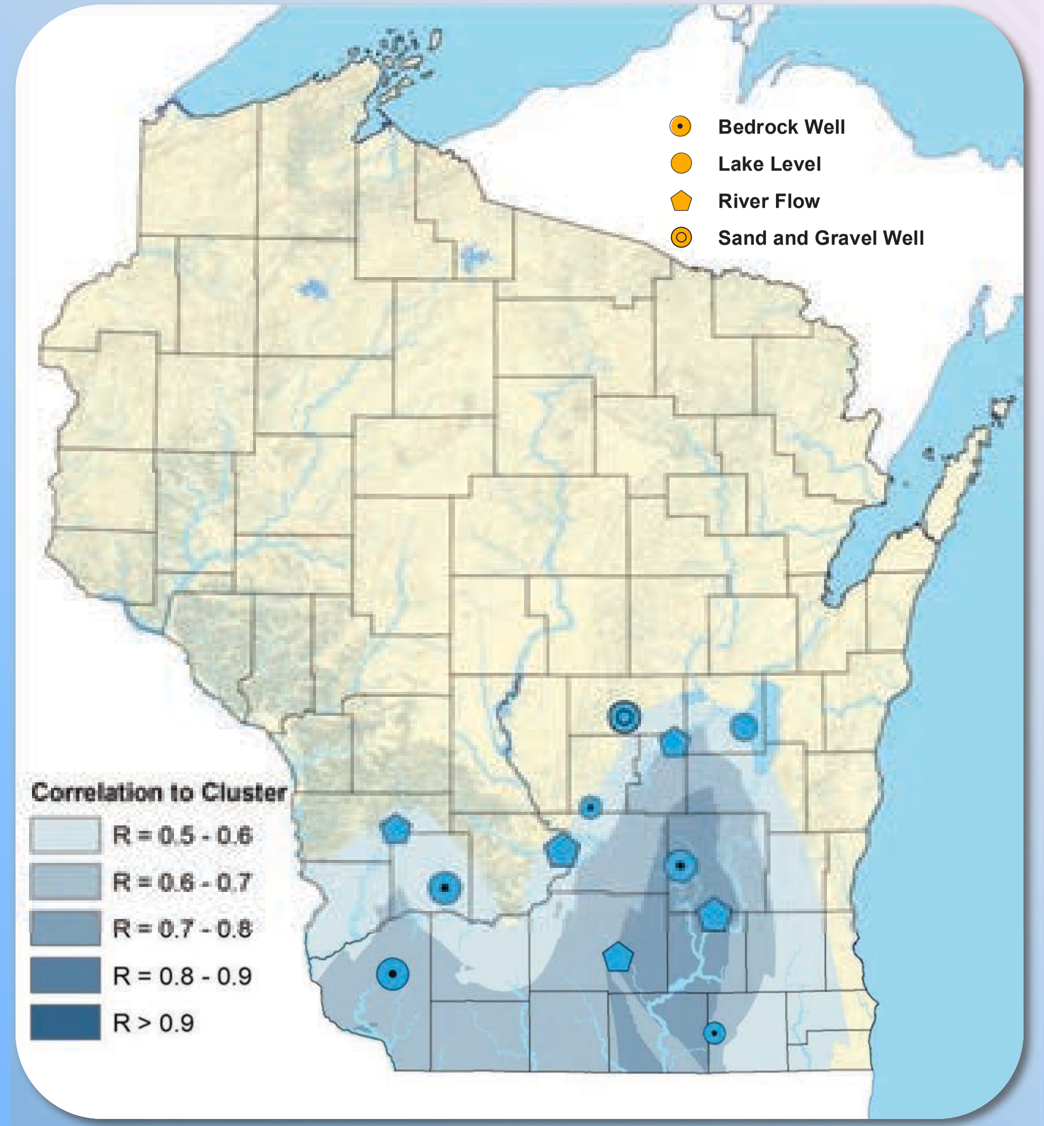
Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation



Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

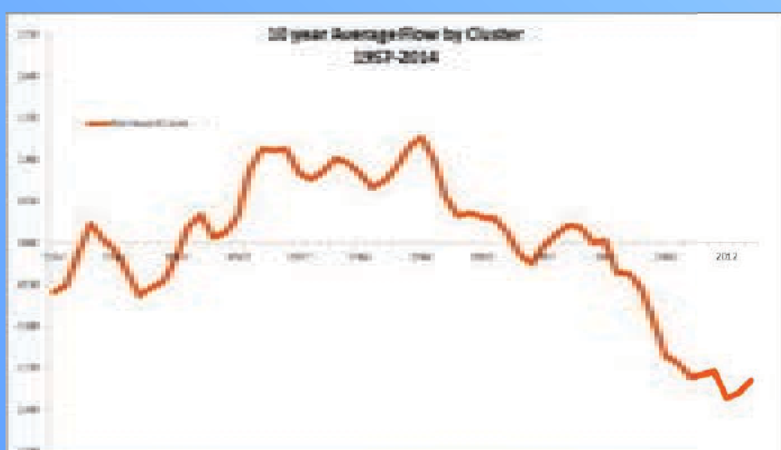
- 12 Sites
  - 1 Sand and Gravel Wells Levels
  - 5 Bedrock Well Levels
  - 1 Lake Level
  - 5 River Flows
- Correlation to cluster mean range:
  - 0.98 Rock River at Watertown
  - 0.54 Bedrock Well at Endeavor
  - 0.81 Mean Correlation

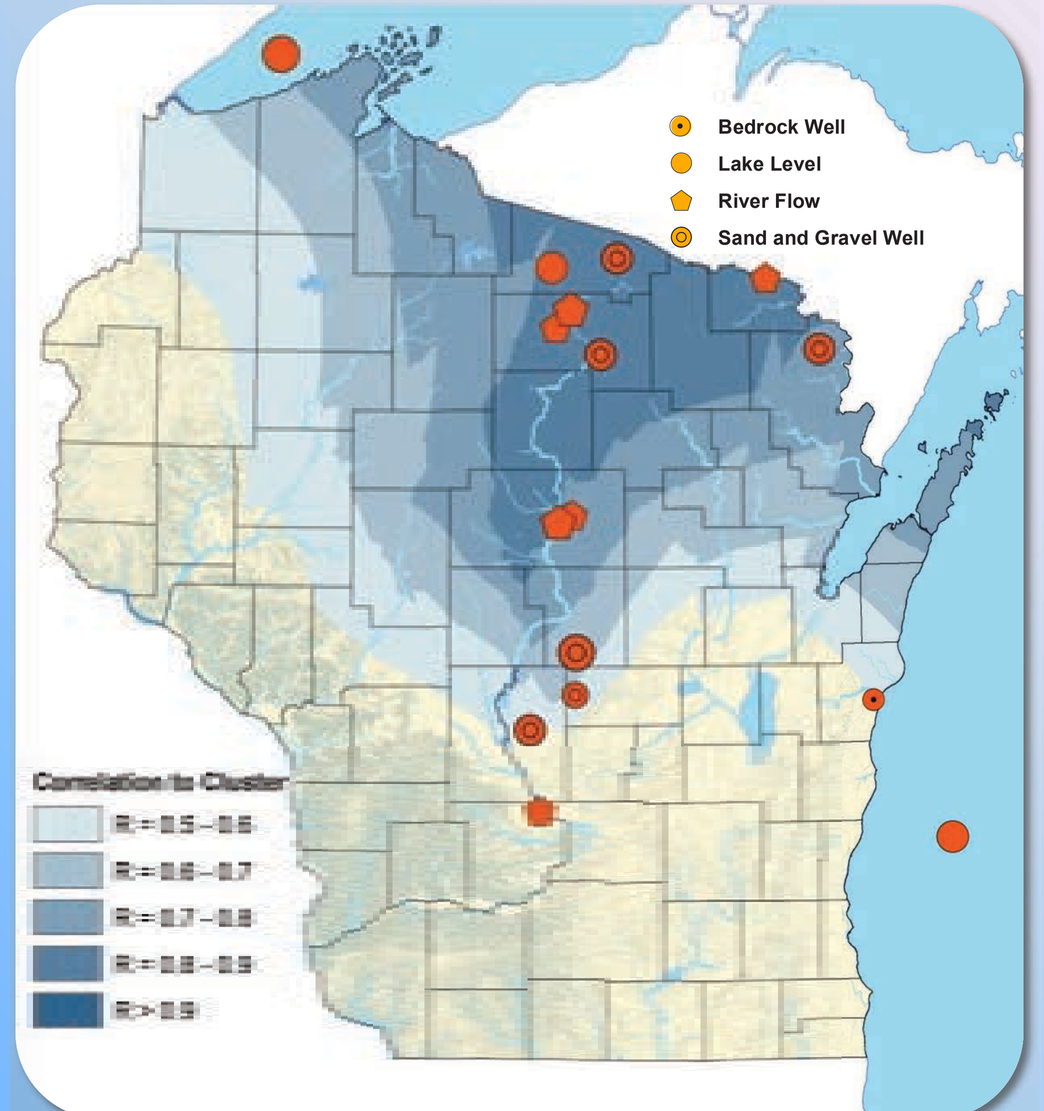




Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

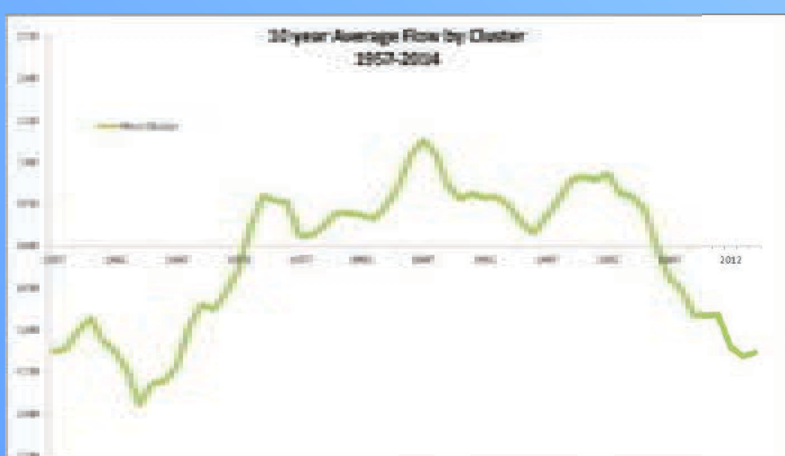
- 16 Sites
  - 6 Sand and Gravel Wells Levels
  - 1 Bedrock Well Level
  - 3 Lake Levels
  - 6 River Flows
- Correlation to cluster mean range:
  - 0.94 WI River at Rothschild
  - 0.60 Manitowoc Bedrock Well
  - 0.86 Mean Correlation

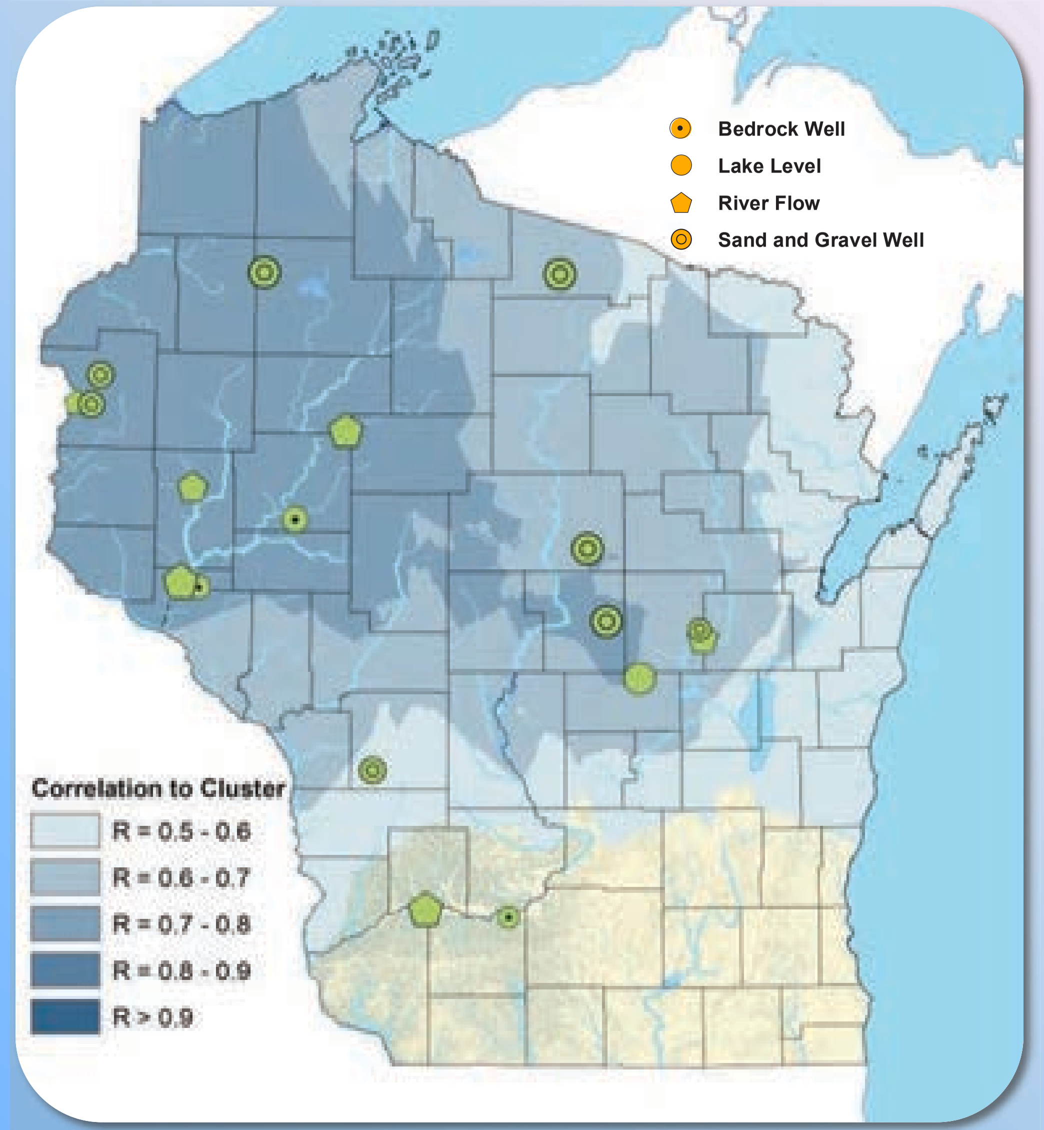




Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

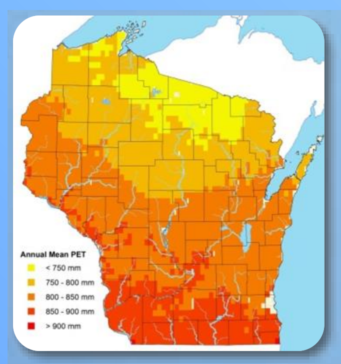
- 18 Sites
  - 8 Sand and Gravel Wells Levels
  - 3 Bedrock Well Levels
  - 1 Lake Level
  - 6 River Flows
- Correlation to cluster mean range:
  - 0.91 Chippewa River at Durand
  - 0.64 Durand Bedrock Well
  - 0.81 Mean Correlation



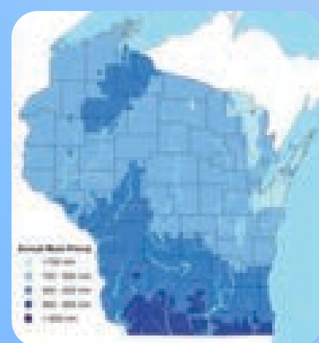


Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

Annual variation in flows and water Level were compared to expected surplus of water determined by annual precipitation minus annual potential evapotranspiration.

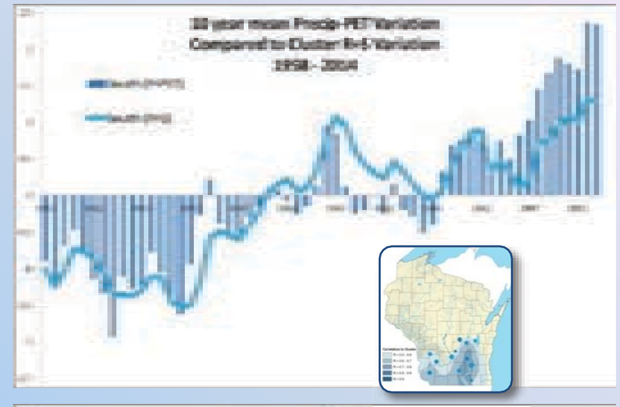


-

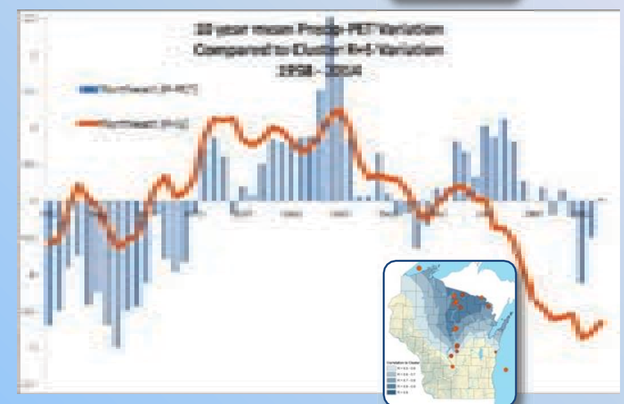


Weather variables were a strong predictor in the south, but less reliable in the north and west.

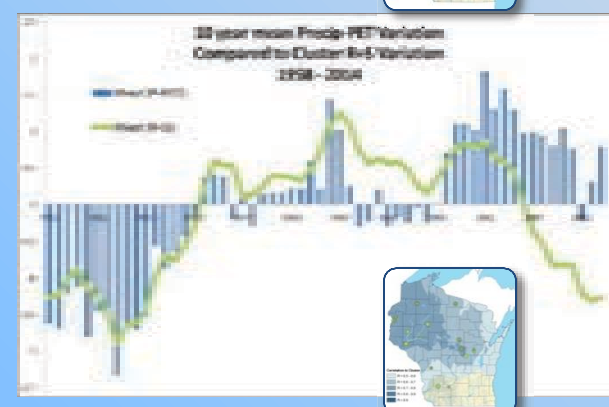
r= 0.90



r= 0.23



r= 0.68



Gridded Precipitat on Data:

- 1948-2007 PET and Precip Data from Nocco & Kucharik
- 2000-2014 NOAA/NWS Prism Precip Data
- 2000-2014 MODIS PET Data (Mu & Running)

Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

p ats

- Water levels vary regionally but not always in direct conjunction with weather.
- Changes in *ACTUAL* evapotranspiration make a difference to water levels… possibly a very big difference.
- Water budgets can be described simply, but the components are highly complex and dynamic.
- Instantaneous water level observations alone are not evidence of impacts… or lack of impacts.
- Great Lakes levels do not determine levels in northern and central WI… they are just determined by similar climatic factors.

Wisconsin Water Levels and Flows
Long Term Synchronicity and Variation

Next Steps

- Supporting research projects to improve understanding of actual evapotranspiration
- Integrating new NASA, NWS and USDA remote sensing products into department analyses.
- Supporting collaborative (WDNR, UW, USGS, WGNHS) project to build historical record of water level variation and create an integrated dataset to monitor change through time.
- Expanding ground and surface water monitoring.
- Exploring potential for future long-term evapotranspiration research and monitoring.
- Integrating new and emerging data into modeling efforts.

ECONOMIC IMPACT OF SPECIALTY CROP PRODUCTION AND PROCESSING IN WISCONSIN

Ashleigh Arledge Keene (907-209-8386, arledge@wisc.edu)
Paul D. Mitchell (608-265-5414, pdmitchell@wisc.edu)
Agricultural and Applied Economics, University of Wisconsin, Madison, WI October 2010


WI Potato and Vegetable Growers Association

Production and processing of specialty crops in Wisconsin are important to both state and national agricultural and manufacturing industries. Wisconsin ranks 7th among US states for farmgate vegetable sales and 8th for farmgate fruit and tree nut sales. While a portion of these sales enter fresh markets (grocery stores, restaurants, farmers markets, etc.), a significant amount of Wisconsin farmgate sales go to processors for freezing, canning, drying and pickling. As a result, Wisconsin ranks 2nd among US states for both harvested acreage and total production of processing vegetables and 3rd for production value. Key processing crops in Wisconsin include potatoes, sweet corn, green beans, green peas, carrots, cucumbers, and onions, with cranberries by far the leading fruit. In addition, Wisconsin is a world-renowned producer of ginseng, most of which is exported to Asia.

ECONOMIC IMPACT OF SPECIALTY CROPS

Production and processing of Wisconsin specialty crops benefit the statewide economy in multiple ways. In a direct sense, each sector creates economic activity and jobs within its own industry. However, both crop production and processing also benefit nearly every other Wisconsin industry. For example, growers purchase equipment and fertilizers from local suppliers, pay farm workers, and invest earnings in local banks. In turn, farm workers use their earnings to pay for housing, groceries and other personal expenditures. In this way, one dollar received by a Wisconsin farmer for producing and selling a specialty crop creates more than one dollar in value as the dollar is spent and re-spent in the statewide economy. The *total economic impact* of specialty crop production and processing in Wisconsin captures this ripple effect in statewide spending.

TOTAL ECONOMIC IMPACT

Specialty crop production and processing together account for about $6.4 billion in economic activity (3% of Wisconsin's overall economy) and nearly 35,000 jobs (1% of jobs statewide), including both indirect and induced impacts.

Total Impact of Specialty Crop Production and Processing[1] Industries in Wisconsin
(Economic activity in $ millions per year)

	Total Economic Activity	Total Jobs
Vegetable & Fruit Production	**$1,092**	**9,900**
Potatoes	$349	2,770
Cranberries	$300	3,400
Sweet Corn	$83	660
Green Beans	$63	490
Green Peas	$26	200
Carrots, Cucumbers & Onions	$28	220
Ginseng	$16	130
Specialty Crop Processing	**$5,268**	**24,800**
Total Impact	**$6,360**	**34,700**

[1]Production estimates based on 2006-2008 average farmgate values; processing estimates based on 2007 Economic Census values. Note: Sum of impacts may not equal total impact due to rounding.

ECONOMIC IMPACT OF SPECIALTY CROP PRODUCTION

- There are roughly 1,200 large scale vegetable growers statewide, with annual sales averaging $510 million[1].
- About 1,700 large scale growers produce fruit in Wisconsin, with annual sales averaging $240 million[2].
- Wisconsin ranks 3rd among US potato-producing states, with half of Wisconsin **potatoes** used for processing (chips, frozen fries, dehydrated) and about half sold for fresh consumption.

WI State Cranberry Growers Association

- **Cranberries** constitute 85% of fruit production in Wisconsin and the state produces over half of all cranberries in the US.
- For major processing crops (sweet corn, green beans and green peas), Wisconsin ranks 2nd among US states for both harvested acreage and total production and 3rd for production value.
  - Wisconsin's processing **green beans** account for more than two-fifths of US production.
  - Processing **sweet corn** and **green peas** each account for about one-fifth of US production.
- **Carrots, cucumbers, and onions** contribute significantly to Wisconsin's vegetable processing industry. Wisconsin ranks 2nd in the US for production of processing carrots, 4th for production of pickling cucumbers and 13th for onion production.
- Wisconsin leads the nation in **ginseng** production, accounting for 95% of US production.
- Specialty crop production directly contributes an estimated $745 million in economic activity and more than 6,100 jobs (full-time, part-time or seasonal) to Wisconsin's economy. Spending from this economic activity generates an additional $350 million in economic activity and nearly 3,800 additional jobs.
  - Of this additional activity, $200 million and an associated 2,400 jobs are *indirect* activity stemming from farm spending in other industries, such as for farm equipment, inputs, and land.
  - $150 million and 1,400 jobs are *induced* activity from in-state spending by farm employees (example: housing, groceries, taxes, etc).
- **The total impact of Wisconsin specialty crop production is an estimated $1.1 billion in economic activity and nearly 10,000 jobs statewide.**

---

[1] Only growers with 25 acres or more included. Annual sales based on 2006-2008 average values.

[2] When possible, only growers with 25 acres or more were included. Annual sales based on 2006-2008 average values.

Economic Impact of Specialty Crop Processing

- Throughout Wisconsin, approximately 80 companies process vegetables and fruit.
- In-state processing of specialty crops annually generates an estimated $3.1 billion in economic activity and roughly 9,700 jobs. Spending from this economic activity spurs an additional $2.2 billion in economic activity and 15,100 jobs.
    - Of this total, $1.6 billion and an associated 9,600 jobs are indirect activity from companies spending in other Wisconsin industries.
    - $580 million and 5,500 jobs are induced activity from in-state spending by company employees.
- **The total impact of specialty crop processing in Wisconsin is approximately $5.3 billion in economic activity each year and 24,800 jobs statewide.**

Midwest Food Processors Association

Impact of Specialty Crop Production and Processing[1] Industries in Wisconsin
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Production[1]					
Economic Activity	$745	$201	$146	$1,092	1.47
Jobs	6,100	2,400	1,400	9,900	1.61
Processing[2]					
Economic Activity	$3,063	$1,629	$576	$5,268	1.72
Jobs	9,700	9,600	5,500	24,800	2.57
Total Impact					
Economic Activity	$3,808	$1,830	$722	$6,360	1.67
Jobs	15,800	12,000	6,900	34,700	2.19

[1]Production estimates based on 2006-2008 average farmgate values; processing estimates based on 2007 Economic Census values.
Note: Sum of impacts may not equal total impact due to rounding.

Vegetable and fruit processing data is not available for individual crops. Furthermore, because some crops produced in Wisconsin is processed out-of-state and some non-Wisconsin grown crops are imported into the state for processing, it is very difficult, and beyond the scope of this publication, to estimate the per-crop impacts of processing in Wisconsin.

Economic Impact of Potato Production

WI Potato and Vegetable Growers Association

- Nationally, Wisconsin ranks 3rd in potato production.
- In 2008, roughly 140 Wisconsin growers[1] produced 2.6 billion pounds of potatoes, half of which were used for processing.
- Production value has grown substantially in recent years, increasing 66 percent in value between 2004 and 2008.
- Wisconsin's potato production directly contributes an annual average of $240 million in economic activity and more than 1,620 jobs to the statewide economy[2]. Spending from this economic activity results in an additional $109 million in economic activity and 1,150 jobs.
    - $66 million and an associated 730 jobs of this additional activity are indirect impacts stemming from farm spending in other Wisconsin industries.
    - $43 million and 420 jobs are induced impacts from in-state spending by farm employees.
- **The total impact of Wisconsin's potato production is estimated at $349 million annually in economic activity and over 2,770 jobs statewide.**

Impact of Potato Production[1] in Wisconsin
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$240	$66	$43	$349	1.45
Jobs	1,620	730	420	2,770	1.71

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.

WI Potato and Vegetable Growers Association

[1] Only growers with 25 acres or more included.
[2] Based on 2006-2008 average values.

Economic Impact of Cranberry Production

- Cranberries are Wisconsin's largest fruit crop, accounting for almost 85% of the total value of fruit production in the state in 2008.

WI State Cranberry Growers Association

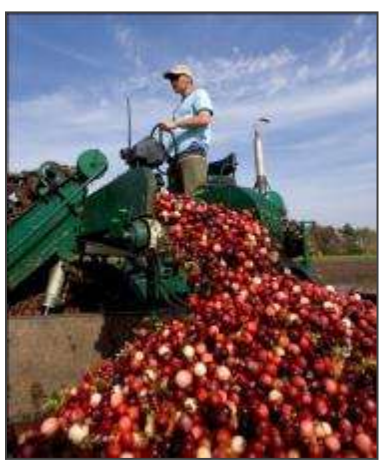
- 260 growers produced nearly 4.6 million barrels of cranberries in 2008, a record volume and over half of US cranberry production that year.
- Most of Wisconsin's cranberry production is used for processing, but a small portion is sold in fresh markets.
- Wisconsin's cranberry production directly contributes an annual average of $199 million in economic activity each year and more than 2,300 jobs to the statewide economy[1]. Spending from this economic activity generates an additional $101 million annually in economic activity and 1,100 jobs.
    - $55 million and an associated 700 jobs of this additional activity are indirect impacts stemming from farm spending in other Wisconsin industries.
    - $46 million and 400 jobs are induced impacts from in-state spending by farm employees.

- **The total impact of Wisconsin's cranberry production averages $300 million each year in economic activity and roughly 3,400 jobs statewide.**

Impact of Cranberry Production[1] in Wisconsin
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$199	$55	$46	$300	1.51
Jobs	2,300	700	400	3,400	1.48

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.



WI State Cranberry Growers Association

[1] Based on 2006-2008 average values.

ECONOMIC IMPACT OF SWEET CORN PRODUCTION

Midwest Food Processors Association

- Wisconsin ranks 2nd in the US for production of processing sweet corn, accounting for one-fifth of national production.
- Roughly 700 Wisconsin growers[1] produced 652,000 tons of processing sweet corn in 2008, valued at $81 million.
- On average, Wisconsin's production of processing sweet corn directly contributes $57 million in economic activity annually and 390 jobs to the statewide economy[2]. Spending from this economic activity results in an additional $26 million in economic activity and 270 jobs.
    - $16 million and an associated 170 jobs of this additional activity are indirect impacts stemming from farm spending in other Wisconsin industries.
    - $10 million and 100 jobs are induced impacts from in-state spending by farm employees.
- **The total impact of processing sweet corn production in Wisconsin is estimated at $83 million annually in economic activity and over 660 jobs statewide.**

Impact of Processing Sweet Corn Production[1] in Wisconsin
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$57	$16	$10	$83	1.46
Jobs	390	170	100	660	1.69

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.

WI Potato and Vegetable Growers Association

[1] Only growers with 25 acres or more included.
[2] Based on 2006-2008 average values.

ECONOMIC IMPACT OF GREEN BEAN PRODUCTION

- Wisconsin ranks 1st in the US for production of processing green beans, accounting for two-fifths of national production.
- Over 400 Wisconsin growers[1] produced 327,000 tons of processing green beans in 2008, valued at $62 million.
- Wisconsin's production of processing green beans directly contributes an annual average of $43 million in economic activity roughly 290 jobs to the statewide economy[2]. Spending from this economic activity results in an additional $20 million in economic activity and approximately 200 jobs.
    - $12 million and an associated 130 jobs of this additional activity are indirect impacts stemming from farm spending in other Wisconsin industries.
    - $8 million and 70 jobs are induced impacts from in-state spending by farm employees.
- **The total impact of Wisconsin's processing green bean production averages $63 million annually in economic activity and nearly 490 jobs statewide.**

Impact of Processing Green Bean Production[1] in Wisconsin
(Economic activity in $ millions)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$43	$12	$8	$63	1.47
Jobs	290	130	70	490	1.69

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.

WI Potato and Vegetable Growers Association

WI Potato and Vegetable Growers Association

[1] Only growers with 25 acres or more included.
[2] Based on 2006-2008 average values.

ECONOMIC IMPACT OF GREEN PEA PRODUCTION


WI Potato and Vegetable Growers Association

- Wisconsin ranks 3rd in the US for production of processing green peas, accounting for one-fifth of production nationally.
- Nearly 400 Wisconsin growers[1] produced 76,000 tons of processing green peas in 2008, valued at $20 million.
- On average, Wisconsin's processing green pea production directly contributes $18 million in economic activity annually and more than 120 jobs to the statewide economy[2]. Spending from this activity results in an additional $8 million in economic activity and 80 jobs.
    - $5 million and an associated 50 jobs of this additional activity are indirect impacts stemming from farm spending in other Wisconsin industries.
    - $3 million and 30 jobs are induced impacts from in-state spending by farm employees.
- **The total impact of Wisconsin's processing green pea production is estimated at $26 million annually in economic activity and over 200 jobs statewide.**

Impact of Processing Green Pea Production[1] in Wisconsin
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$18	$5	$3	$26	1.44
Jobs	120	50	30	200	1.71

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.


Midwest Food Processors Association

[1] Only growers with 25 acres or more included.
[2] Based on 2006-2008 average values.

ECONOMIC IMPACT OF CARROT, CUCUMBER AND ONION PRODUCTION

WI Potato and Vegetable Growers Association

- Carrots, cucumbers and onions contribute significantly to Wisconsin's vegetable industry. Wisconsin ranks 2nd in the US for production of processing carrots and 4th for production of pickling cucumbers. Wisconsin ranks 13th for onion production, with most of the onions produced here sold in fresh markets.

- Wisconsin growers produced 77,000 tons of processing carrots, 39,000 tons of pickling cucumbers and 33 million pounds of onions in 2008.

- Production of carrots, pickling and fresh cucumbers, and onions directly contributes an annual average of $19 million in economic activity and more than 130 jobs to the statewide economy[1]. Spending from this activity generates an additional $9 million in economic activity each year and 90 jobs.
  - $5 million and an associated 60 jobs of this additional activity are indirect impacts stemming from farm spending in other Wisconsin industries.
  - $4 million and 30 jobs are induced impacts from in-state spending by farm employees.

- **The total combined impact of producing processing carrots, cucumbers and onions in Wisconsin is estimated at $28 million each year in economic activity and over 220 jobs statewide.**

Impact of Carrot, Cucumber and Onion Production[1] in Wisconsin
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$19	$5	$4	$28	1.47
Jobs	130	60	30	220	1.69

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.


WI Potato and Vegetable Growers Association


WI Potato and Vegetable Growers Association

[1] Based on 2006-2008 average values.

ECONOMIC IMPACT OF GINSENG PRODUCTION

- Wisconsin growers produce nearly the entire US ginseng crop (95%).
- In 2007, 569,000 pounds of ginseng were produced by growers throughout the state.
- Wisconsin's ginseng production directly contributes an annual average of $11 million in economic activity and approximately 75 jobs to the statewide economy[1]. Spending from this economic activity generates an additional $5 million in economic activity and 55 jobs.
    - $3 million and an associated 35 jobs of this additional activity were indirect impacts stemming from farm spending in other Wisconsin industries.
    - $2 million and 20 jobs were induced impacts from in-state spending by farm employees.
- **The total impact of Wisconsin's ginseng production averages $16 million annually in economic activity and over 130 jobs statewide.**

Impact of Wisconsin's Ginseng Production[1]
(Economic activity in $ millions per year)

	Direct	Indirect	Induced	Total	Multiplier
Economic Activity	$11	$3	$2	$16	1.45
Jobs	75	35	20	130	1.73

[1]Production estimates based on 2006-2008 average farmgate values.
Note: Sum of impacts may not equal total impact due to rounding.


Ginseng Board of WI


Ginseng Board of WI

[1] Based on 2007-2008 average values.

2014

AGRICULTURE – WORKING EVERY DAY FOR WISCONSIN

Portage County Agriculture: Value & Economic Impact

Agriculture works hard for Portage County every day. Family-owned farms, food processors and agriculture-related businesses generate thousands of jobs and millions of dollars of economic activity while contributing to local income and tax revenues.

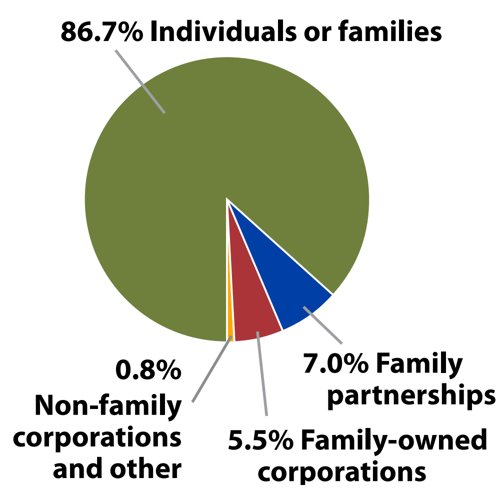
Portage County is located in the heart of the Central Sands region of Wisconsin. With over 50 percent of the harvested cropland under irrigation, high value vegetable crops dominate the landscape. Portage County ranks first in the production of potatoes, processed snap beans and sweet corn and leads the state for market value of agricultural crops sold.

Non-irrigated land supports the production of cash grains and forages which feed the thriving dairy and livestock industries. Vegetable and dairy processing plants support a broad range of farms and provide significant employment in the County.

How important is agriculture?

- Agriculture provides **jobs for 5,448** Portage County residents.
- Agriculture accounts for **$1.1 billion in economic activity**.
- Agriculture contributes **$386 million** to the county's total income.
- Agriculture pays **$22.0 million in taxes**. This figure does not include all property taxes paid to local schools.

Who owns the farms?



Agriculture provides 12% of Portage County's jobs

Portage County **agriculture provides 5,448 jobs**, or 12.5 percent, of the county's workforce of 43,535. Production jobs include farm owners and managers and farm employees. Agricultural service jobs include veterinarians, crop and livestock consultants, feed, fuel and other crop input suppliers, farm machinery dealers, barn builders and agricultural lenders, to name a few. Processing jobs include those employed in food processing and other value-added industries that support food processors. Every job in agriculture generates an additional 0.78 jobs in the county.

Agriculture contributes $386 million to county income

Portage County **agriculture accounts for $386.5 million**, or 10.9 percent, of the county's total income. This includes wages, salaries, benefits and profits of farmers and workers in agriculture-related businesses. Every dollar of agricultural income generates an additional $0.77 of county income.

Agriculture pumps $1.1 billion into local economy

Portage County **agriculture generates $1.17 billion in economic activity**, about 17 percent, of the county's total economic activity. Every dollar of sales from agricultural products generates an additional $0.36 of economic activity in other parts of the county's economy.

Here's how agriculture stimulates economic activity:

- The direct effect of agriculture equals $795.6 million and includes the sale of farm products and value-added products.
- Purchases of agricultural and food-processing inputs, services and equipment add another $150.0 million in economic activity. For example, this includes business-to-business purchases of fuel, seed, fertilizer, feed and farm machinery, as well as veterinary services, crop and livestock consultants and equipment leasing.
- This business-to-business activity then generates another $134.5 million in economic activity when people who work in agriculture-related businesses spend their earnings in the local economy.

Agriculture pays $22.1 million in taxes

Economic activity associated with Portage County farms and agriculture-related businesses **generates $22.1 million** in local and state taxes. This figure does not include all property taxes paid to support local schools. If it did, the number would increase dramatically.

Table 1. Taxes paid by agriculture

Sales tax	$4.8 million
Income tax	$7.6 million
Property tax	$6.5 million
Other	$3.1 million
Total	**$22.1 million**

Table 2. Portage County's top commodities (sales by dollar value, 2012)

1. Vegetables	$167.7 million
2. Milk	$47.7 million
3. Grain	$31.4 million
4. Cattle & calves	$31.0 million
5. Fruits, tree nuts & berries	$7.7 million

Ken Schroeder

www.kbur.com

Agricultural processing is a key Portage County industry

Agricultural processing is the major agricultural industry in Portage County. Portage County agricultural processors contribute $669.2 million to the county's economy. The processing of vegetables accounts for $606.6 million. The processing of milk into dairy products accounts for another $62.6 million. Every dollar of sales of processed products generates an additional $0.30 of economic activity in other parts of the economy.

Vegetable production is a very important part of Portage County's agriculture. In 2012, the market value of vegetable crops was $167.7 million, or 57 percent of the total market value of all agricultural products sold in the county. There are over 72,000 acres of vegetables, including potatoes, sweet corn, snap beans, and peas, raised in Portage County.

- Processing accounts for $174.8 million of income in the county.
- Portage County's agricultural processing accounts for 2,611 jobs. Vegetable processing accounts for 2,442 jobs and dairy processing accounts for another 169 jobs.

Horticulture contributes to Portage County diversity

Portage County sales of Christmas trees, fruits and vegetables, greenhouse, nursery and floriculture products total $177.3 million. Landscape and grounds maintenance businesses create additional full-time jobs and many seasonal jobs.

Local food sales add $652,000 to economy

More and more Portage County farmers sell directly to consumers from roadside stands, farmers' markets, auctions and pick-your-own operations, with 112 farms generating $652,000 in local food sales.

©USDA NRCS

Farmers are stewards of about half the county's land

Portage County farmers own and manage 278,673 acres, or 54.4 percent, of the county's land. This includes cropland, rangeland, pasture, tree farms and farm forests. As stewards of the land, farmers use conservation practices, such as crop rotation, nutrient management and integrated pest management, to protect environmental resources and provide habitat for wildlife.

UW Extension

University of Wisconsin-Extension

University of Wisconsin-Extension is part of the local and statewide network of organizations and agencies that support Wisconsin's $88.3 billion agriculture industry. A recent statewide survey of nearly 1,000 agricultural service providers from throughout Wisconsin found that UW-Extension helps enhance economic impact by improving agribusiness services to farmers, increasing agribusiness or farm profitability, expanding agribusiness networks, and helping to reduce agribusiness or farm environmental impacts.

Produced in 2014 by:
University of Wisconsin-Extension
Wisconsin Milk Marketing Board
Wisconsin Department of Agriculture, Trade, and Consumer Protection

Economic data (2012) provided by:
Steven C. Deller, Professor, Department of Agriculture and Applied Economics, University of Wisconsin-Madison, and Community Development Specialist, Universityof Wisconsin–Extension.

Other economic data from:
USDA 2012 Census of Agriculture

For more information, contact:

Portage County UW-Extension
Courthouse Annex Building
1462 Strongs Avenue, Stevens Point, WI 54481-2947
715-346-1316 • http://portage.uwex.edu/

Adams County Agriculture: Value & Economic Impact

©Wisconsin Milk Marketing Board

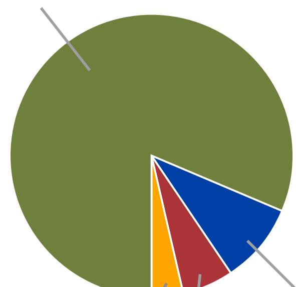
Agriculture works hard for Adams County every day. Family-owned farms, food processors and agriculture-related businesses generate thousands of jobs and millions of dollars of economic activity while contributing to local income and tax revenues.

Adams County is part of the Central Sands region of Wisconsin. Flat topography, sandy soils and abundant groundwater combine to make irrigated vegetable production the major agricultural enterprise. Adams County consistently ranks among the top five Wisconsin counties in the production of potatoes, sweet corn and snap beans. One-half of the harvested cropland in Adams County is irrigated.

How important is agriculture?

- Agriculture provides **jobs for 1,136** Adams County residents.
- Agriculture accounts for **$171 million in economic activity**.
- Agriculture contributes **$83 million** to the county's total income.
- Agriculture pays **$4.8 million in taxes**. This figure does not include all property taxes paid to local schools.

Who owns the farms?



Agriculture provides 13% of Adams County's jobs

Adams County **agriculture provides 1,136 jobs**, or 13 percent, of the county's workforce of 8,805. Production jobs include farm owners and managers and farm employees. Agricultural service jobs include veterinarians, crop and livestock consultants, feed, fuel and other crop input suppliers, farm machinery dealers, barn builders and agricultural lenders, to name a few. Processing jobs include those employed in food processing and other value-added industries that support food processors. Every job in agriculture generates an additional 0.60 jobs in the county.

Agriculture contributes $83 million to county income

Adams County **agriculture accounts for $83.5 million**, or 14.8 percent, of the county's total income. This includes wages, salaries, benefits and profits of farmers and workers in agriculture-related businesses. Every dollar of agricultural income generates an additional $0.64 of county income.

Agriculture pumps $171 million into local economy

Adams County **agriculture generates $171.4 million in economic activity**, about 17 percent, of the county's total economic activity. Every dollar of sales from agricultural products generates an additional $0.43 of economic activity in other parts of the county's economy.

Here's how agriculture stimulates economic activity:

- The direct effect of agriculture equals $120.2 million and includes the sale of farm products and value-added products.
- Purchases of agricultural and food-processing inputs, services and equipment add another $23.4 million in economic activity. For example, this includes business-to-business purchases of fuel, seed, fertilizer, feed and farm machinery, as well as veterinary services, crop and livestock consultants and equipment leasing.
- This business-to-business activity then generates another $27.7 million in economic activity when people who work in agriculture-related businesses spend their earnings in the local economy.

Agriculture pays almost $5 million in taxes

Economic activity associated with Adams County farms and agriculture-related businesses **generates $4.8 million** in local and state taxes. This figure does not include all property taxes paid to support local schools. If it did, the number would increase dramatically.

Table 1. Taxes paid by agriculture

Sales tax	$1.0 million
Income tax	$2.0 million
Property tax	$1.4 million
Other	$0.46 million
Total	**$4.8 million**

Table 2. Adams County's top commodities (sales by dollar value, 2012)

1. Vegetables	$61.5 million
2. Grain	$22.7 million
3. Cattle & calves	$9.0 million
4. Fruits & berries	$7.0 million
5. Milk	2.9 million

Vegetable production and agricultural processing impacts in Adams County

Vegetable production is the largest part of Adams County's agriculture. In 2012, the market value of vegetable crops was $61.5 million, or 58 percent of the total market value of all agricultural products sold in the county. Potatoes, snapbeans, sweetcorn, and peas are the main vegetables raised in Adams County. Agricultural processing is also an important part of Adams County's agriculture. Adams County agricultural processors contribute $20.2 million to the county's economy. Potatoes are the main product processed.

- Every dollar of sales of processed products generates an additional $0.26 of economic activity in other parts of the economy.
- Processing accounts for $5.2 million of income in the county.
- Adams County's agricultural processing accounts for 58 jobs.

©USDA Peggy Greb

Horticulture contributes to Adams County diversity

Adams County sales of Christmas trees, fruits and vegetables, greenhouse, nursery and floriculture products total $68.9 million. Landscape and grounds maintenance businesses create additional full-time jobs and many seasonal jobs..

Local food sales account for $178,000 to economy

More and more Adams County farmers sell directly to consumers from roadside stands, farmers' markets, auctions and pick-your-own operations, with 20 farms generating $178,000 in local food sales.

Farmers are stewards of 29% of the county's land

Adams County farmers own and manage 118,393 acres, or 28.7 percent, of the county's land. This includes cropland, rangeland, pasture, tree farms and farm forests. As stewards of the land, farmers use conservation practices, such as no-till, cover crops, crop rotation, nutrient management and integrated pest management, to protect and improve environmental resources and provide habitat for wildlife.

UW Extension

University of Wisconsin-Extension

University of Wisconsin-Extension is part of the local and statewide network of organizations and agencies that support Wisconsin's $88.3 billion agriculture industry. A recent statewide survey of nearly 1,000 agricultural service providers from throughout Wisconsin found that UW-Extension helps enhance economic impact by improving agribusiness services to farmers, increasing agribusiness or farm profitability, expanding agribusiness networks, and helping to reduce agribusiness or farm environmental impacts.

Produced in 2014 by:
University of Wisconsin-Extension
Wisconsin Milk Marketing Board
Wisconsin Department of Agriculture, Trade, and Consumer Protection

Economic data (2012) provided by:
Steven C. Deller, Professor, Department of Agriculture and Applied Economics, University of Wisconsin-Madison, and Community Development Specialist, University of Wisconsin-Extension.

Other economic data from:
USDA 2012 Census of Agriculture

For more information, contact:

Adams County UW-Extension
569 N. Cedar Street, Suite 3, Adams, WI 53910
608-339-4237 • http://adams.uwex.edu/

2011


©Wisconsin Milk Marketing Board

Juneau County Agriculture: *Value & Economic Impact*

Agriculture works hard for Juneau County every day. Family-owned farms, food processors and agriculture-related businesses generate thousands of jobs and millions of dollars of economic activity while contributing to local income and tax revenues.

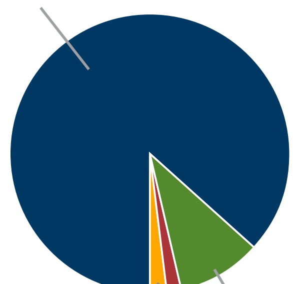
Juneau County is located along Interstate 90/94 in central Wisconsin. Although dairy most notably generates the highest annual income of all agricultural commodities, Juneau County has about 800 farms and is very diversified. Dairy, beef, sheep, bison, goat and emu farms complement forage and grain production. The county also boasts a number of specialty crops, such as cranberries, potatoes, grapes, blueberries, apples and Christmas trees.

Today's consumers want to know where their food comes from. In Juneau County this has led to increased interest in sustainable food production, more locally grown food and more food produced organically.

How important is agriculture?

- Agriculture provides **1,578 jobs** in Juneau County.
- Agriculture accounts for about **$246 million in business sales**.
- Agriculture contributes **$70 million** to county income.
- Agriculture pays about **$6 million in taxes**.

Who owns the farms?



Agriculture provides 14% of county's jobs

Juneau County **agriculture provides 1,578 jobs**, or 14 percent, of the county's workforce of 11,264. Jobs include farm owners and managers, farm employees, veterinarians, crop and livestock consultants, feed, fuel and other crop input suppliers, farm machinery dealers, barn builders, agricultural lenders and other professionals, to name a few. It also includes those employed in food processing and other value-added industries. Every job in agriculture generates an additional 0.34 jobs in the county.

Agriculture pumps about $246 million into economy

Juneau County **agriculture generates $245.6 million**, almost 18 percent, of the county's total business sales. Every dollar of sales from agricultural products generates an additional $0.26 of business sales in other parts of the county's economy.

Here's how agriculture stimulates business activity:

- The direct effect of agriculture equals $195.3 million and includes the sale of farm products, processed and other value-added products.
- Purchases of agricultural and food-processing inputs, services and equipment add another $39.1 million in business sales. For example, this includes business-to-business purchases of fuel, seed, fertilizer, feed and farm machinery, as well as veterinary services, crop and livestock consultants, and financial services.
- This business-to-business activity then generates another $11.2 million in sales when people who work in agriculture-related businesses spend their earnings in the local economy.

Agriculture contributes $70 million to income

Juneau County agriculture **accounts for $70.3 million**, or almost 12 percent, of the county's total income. This includes wages, salaries, benefits and profits of farmers and workers in agriculture-related businesses. Every dollar of agricultural income generates an additional $0.48 of county income.

Agriculture pays about $6 million in taxes

Economic activity associated with Juneau County farms and agriculture-related businesses **generates $5.8 million** in local and state taxes. This figure does not include all property taxes paid to support local schools. If it did, the number would be much higher.

Table 1. Taxes generated by agriculture

Sales tax	$1.3 million
Property tax	$1.7 million
Income tax	$0.79 million
Other	$2.1 million
Total	**$5.8 million**

Table 2. Juneau County's top commodities (sales by dollar value, 2007)

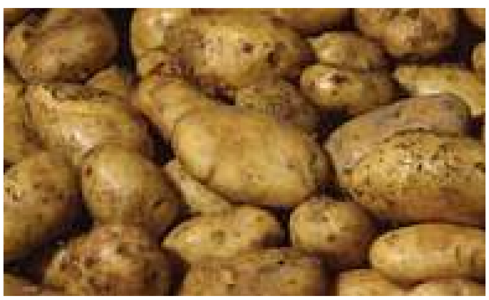
1. Milk	$33.6 million
2. Fruits & berries	$21.3 million
3. Grains	$19.8 million
4. Cattle & hogs	$6.6 million
5. Misc. livestock & other crops	$8.5 million

Dairy is a key Juneau County industry

Dairy farming is the major agricultural industry in Juneau County. On-farm milk production generates $45.5 million in business sales. Processing milk into dairy products accounts for another $58.9 million.

- Five plants process dairy products in Juneau County.
- On-farm milk production accounts for 383 jobs, and dairy processing accounts for 170 jobs.
- At the county level, each dairy cow generates $3,475 in on-farm sales to producers.
- At the state level, each dairy cow generates about $21,000 in total sales.

UW-Extension



Horticulture contributes to Juneau County diversity

Juneau County sales of Christmas trees, fruits and vegetables, greenhouse, nursery and floriculture products add up to $21.4 million. Landscape, grounds maintenance and tree-care businesses create additional full-time jobs and many seasonal jobs.

Direct-marketing sales add $195,000 to economy

More and more Juneau County farmers sell directly to consumers through roadside stands, farmers' markets, auctions and pick-your-own operations. In all, 51 farms generate $195,000 in direct-marketing sales.

Farmers are stewards of 37% of the county's land

Juneau County farmers own and manage 181,046 acres, or 37 percent, of the county's land. This includes cropland, pasture, tree farms, farm forests and wetlands. As stewards of the land, farmers use conservation practices, such as crop rotation, nutrient management and integrated pest management, to protect environmental resources and provide habitat for wildlife.

UW Extension
Cooperative Extension

Produced in 2011 by:
University of Wisconsin-Extension, Cooperative Extension

Economic data (2008) provided by:
Steven C. Deller, professor of agricultural and applied economics, College of Agricultural and Life Sciences, University of Wisconsin-Madison; and community development specialist, University of Wisconsin-Extension, Cooperative Extension.

Other economic data from:
USDA 2007 Census of Agriculture

For more information, contact:
Juneau County – UW Extension
Juneau Office Building
211 Hickory St.
Mauston, WI 53948
608-847-9329
http://juneau.uwex.edu/

2014

AGRICULTURE – WORKING EVERY DAY FOR WISCONSIN

Marquette County Agriculture: Value & Economic Impact

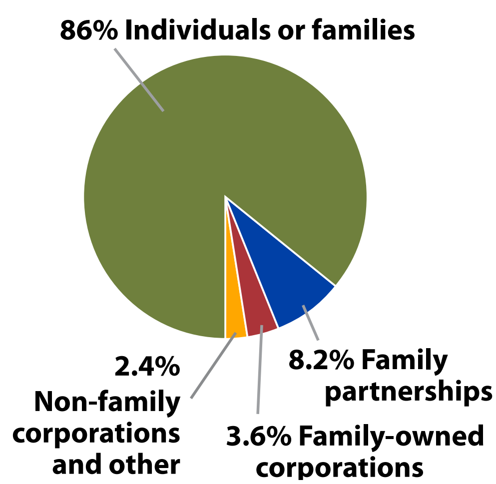
Agriculture works hard for Marquette County every day. Family-owned farms, food processors and agriculture-related businesses generate thousands of jobs and millions of dollars of economic activity while contributing to local income and tax revenues.

Located in the Central Sands region of Wisconsin, Marquette County has a diversity of agricultural communities and practices. It has 478 farms with an average farm size of 251 acres. The diversity of Marquette County agriculture is ranges from primarily small-scale livestock and dairy farms to cash cropping, vegetable production, and Christmas tree farming. Managed rotational grazing is a key practice for the success of many livestock farmers in Marquette County. It has also historically been in the top five counties for mint oil production. Well-known for its abundant lakes, rivers, and woodlands, Marquette County offers unique recreational opportunities for the whole family.

How important is agriculture?

- Agriculture provides **jobs for 2,386** Marquette County residents.
- Agriculture accounts for **$154 million in economic activity**.
- Agriculture contributes **$593 million** to the county's total income.
- Agriculture pays **$7.3 million in taxes**. This figure does not include all property taxes paid to local schools.

Who owns the farms?



Agriculture provides 43% of Marquette County's jobs

Marquette County **agriculture provides 2,386 jobs**, or 42.9 percent, of the county's workforce of 5,556. Production jobs include farm owners and managers and farm employees. Agricultural service jobs include veterinarians, crop and livestock consultants, feed, fuel and other crop input suppliers, farm machinery dealers, barn builders and agricultural lenders, to name a few. Processing jobs include those employed in food processing and other value-added industries that support food processors. Every job in agriculture generates an additional 0.47 jobs in the county.

Agriculture contributes about $154 million to county income

Marquette County **agriculture accounts for $153.7 million**, or 43.4 percent, of the county's total income. This includes wages, salaries, benefits and profits of farmers and workers in agriculture-related businesses. Every dollar of agricultural income generates an additional $0.60 of county income.

Agriculture pumps $593 million into local economy

Marquette County **agriculture generates $593.3 million in economic activity**, 66 percent, of the county's total economic activity. Every dollar of sales from agricultural products generates an additional $0.31 of economic activity in other parts of the county's economy.

Here's how agriculture stimulates economic activity:

- The direct effect of agriculture equals $452.9 million and includes the sale of farm products and value-added products.
- Purchases of agricultural and food-processing inputs, services and equipment add another $110.9 million in economic activity. For example, this includes business-to-business purchases of fuel, seed, fertilizer, feed and farm machinery, as well as veterinary services, crop and livestock consultants and equipment leasing.
- This business-to-business activity then generates another $29.4 million in economic activity when people who work in agriculture-related businesses spend their earnings in the local economy.

©Wisconsin Milk Marketing Board

Agriculture pays $7.3 million in taxes

Economic activity associated with Marquette County farms and agriculture-related businesses **generates $7.3 million** in local and state taxes. This figure does not include all property taxes paid to support local schools. If it did, the number would increase dramatically.

Table 1. **Taxes paid by agriculture**

Sales tax	$1.6 million
Income tax	$2.1 million
Property tax	$2.2 million
Other	$1.4 million
Total	**$7.3 million**

Table 2. **Marquette County's top commodities** (sales by dollar value, 2012)

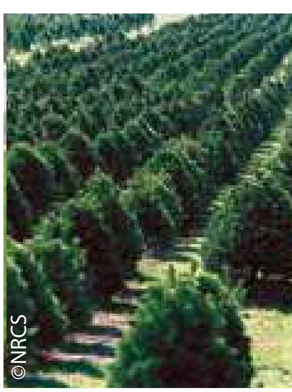
1. Milk	$25.4 million
2. Grain	$20.4 million
3. Vegetables	$10.1 million
4. Other crops & hay	$4.4 million
5. Cattle & calves	$3.9 million

©USDA

Agricultural processing is a key Marquette County industry

Agricultural processing is the major agricultural industry in Marquette County. Marquette County agricultural processors contribute $486.8 million to the county's economy. The processing of chicken accounts for the majority of the processing impacts. There is also the processing of mint for oil.

- Every dollar of sales of processed products generates an additional $0.31 of economic activity in other parts of the economy.
- Processing accounts for $107.6 million of income in the county.
- Marquette County's agricultural processing accounts for 1,419 jobs.



©NRCS

Jeff Sindelar

©USDA Peggy Greb

Horticulture contributes to Marquette County diversity

Marquette County sales of Christmas trees, fruits and vegetables, greenhouse, nursery and floriculture products total $13.5 million. Landscape and grounds maintenance businesses create additional full-time jobs and many seasonal jobs.

Local food sales account for $73,000 to economy

More and more Marquette County farmers sell directly to consumers from roadside stands, farmers' markets, auctions and pick-your-own operations, with 36 farms generating $73,000 in local food sales.

©USDA NRCS

Farmers are stewards of 41% of the county's land

Marquette County farmers own and manage 120,185 acres, or 41.2 percent, of the county's land. This includes cropland, rangeland, pasture, tree farms and farm forests. As stewards of the land, farmers use conservation practices, such as crop rotation, nutrient management and integrated pest management, to protect environmental resources and provide habitat for wildlife.

UW Extension

University of Wisconsin-Extension

University of Wisconsin-Extension is part of the local and statewide network of organizations and agencies that support Wisconsin's $88.3 billion agriculture industry. A recent statewide survey of nearly 1,000 agricultural service providers from throughout Wisconsin found that UW-Extension helps enhance economic impact by improving agribusiness services to farmers, increasing agribusiness or farm profitability, expanding agribusiness networks, and helping to reduce agribusiness or farm environmental impacts.

Produced in 2014 by:
University of Wisconsin-Extension
Wisconsin Milk Marketing Board
Wisconsin Department of Agriculture, Trade, and Consumer Protection

Economic data (2012) provided by:
Steven C. Deller, Professor, Department of Agriculture and Applied Economics, University of Wisconsin-Madison, and Community Development Specialist, University of Wisconsin-Extension.

Other economic data from:
USDA 2012 Census of Agriculture

For more information, contact:

Marquette County UW-Extension
Marquette County Service Center
P.O. Box 338, 480 Underwood Ave., Montello, WI 53949
608-297-3141 • http://marquette.uwex.edu/

2014

AGRICULTURE – WORKING EVERY DAY FOR WISCONSIN

Waupaca County Agriculture:

Agriculture works hard for Waupaca County every day. Family-owned farms, food processors and agriculture-related businesses generate thousands of jobs and millions of dollars of economic activity while contributing to local income and tax revenues.

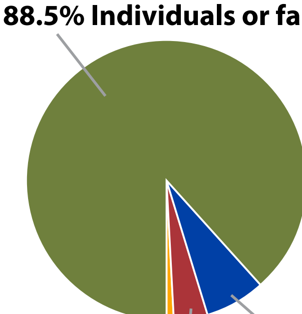
While Waupaca is known for abundant natural resources, tourism and manufacturing, agriculture continues growing as a key economic leader in the county. Dairy, beef, alfalfa, corn and soybeans still account for the vast majority of full-time farms and farm-product sales.

Today, 50 percent of the 1,145 farms in Waupaca County identify farming as their primary occupation; 26 percent have a payroll, and 10 percent have women as the principal operator.

How important is agriculture?

- Agriculture provides **jobs for 5,415** Waupaca County residents.
- Agriculture accounts for **$1.35 billion in economic activity**.
- Agriculture contributes **$355 million** to the county's total income.
- Agriculture pays **$16.4 million in taxes**. This figure does not include all property taxes paid to local schools.

Who owns the farms?



Agriculture provides 20% of Waupaca County's jobs

Waupaca County **agriculture provides 5,415 jobs**, or 20.3 percent, of the county's workforce of 26,617. Production jobs include farm owners and managers and farm employees. Agricultural service jobs include veterinarians, crop and livestock consultants, feed, fuel and other crop input suppliers, farm machinery dealers, barn builders and agricultural lenders, to name a few. Processing jobs include those employed in food processing and other value-added industries that support food processors. Every job in agriculture generates an additional 0.82 jobs in the county.

Agriculture contributes $355 million to county income

Waupaca County **agriculture accounts for $354.8 million**, or 21.4 percent, of the county's total income. This includes wages, salaries, benefits and profits of farmers and workers in agriculture-related businesses. Every dollar of agricultural income generates an additional $0.94 of county income.

Agriculture pumps $1.35 billion into local economy

Waupaca County **agriculture generates $1.35 billion in economic activity**, 31.6 percent, of the county's total economic activity. Every dollar of sales from agricultural products generates an additional $0.39 of economic activity in other parts of the county's economy.

Here's how agriculture stimulates economic activity:

- The direct effect of agriculture equals $973.7 million (72% of total) and includes the sale of farm products and value-added products.
- Purchases of agricultural and food-processing inputs, services and equipment add another $306.9 million (23% of total) in economic activity. For example, this includes business-to-business purchases of fuel, seed, fertilizer, feed and farm machinery, as well as veterinary services, crop and livestock consultants and equipment leasing.
- This business-to-business activity then generates another $71.4 million (5% of total) in economic activity when people who work in agriculture-related businesses spend their earnings in the local economy.

Agriculture pays $16 million in taxes

Economic activity associated with Waupaca County farms and agriculture-related businesses **generates $16.4 million** in local and state taxes. This figure does not include all property taxes paid to support local schools. If it did, the number would increase dramatically.

Table 1. **Taxes paid by agriculture**

Sales tax	$3.4 million
Income tax	$5.0 million
Property tax	$4.6 million
Other	$3.4 million
Total	**$16.4 million**

Table 2. **Waupaca County's top commodities** (sales by dollar value, 2012)

1. Milk	$90.0 million
2. Grain	$42.7 million
3. Cattle & calves	$18.3 million
4. Other crops & hay	$3.9 million
5. Vegetables	$3.4 million

Dairy is a key Waupaca County industry

Dairy farming is the major agricultural industry in Waupaca County. On-farm production and milk sales account for $126 million. Processing milk into dairy products generates another $701.9 million.

- Six plants process dairy products in Waupaca County.
- On-farm milk production accounts for 784 jobs, and dairy processing accounts for 1,807 jobs.
- At the county level, each dairy cow generates $4,506 in on-farm sales to producers in milk, calf, and cull cow sales.
- At the state level, each dairy cow generates over $34,000 in total on-farm and processing sales.

©Wisconsin Milk Marketing Board

2014

WAUPACA COUNTY

©USDA Peggy Greb

©USDA NRCS

Horticulture contributes to Waupaca County diversity

Waupaca County sales of Christmas trees, fruits and vegetables, greenhouse, nursery and floriculture products total $4.0 million. Landscape and grounds maintenance businesses create additional full-time jobs and many seasonal jobs.

Local food sales account for $907,000 to economy

More and more Waupaca County farmers sell directly to consumers from roadside stands, farmers' markets, auctions and pick-your-own operations, with 94 farms generating $907,000 in local food sales.

Farmers are stewards of about half the county's land

Waupaca County farmers own and manage 215,330 acres, or 45 percent, of the county's land. This includes cropland, rangeland, pasture, tree farms and farm forests. As stewards of the land, farmers use conservation practices, such as crop rotation, nutrient management and integrated pest management, to protect environmental resources and provide habitat for wildlife.

UW Extension

University of Wisconsin-Extension

University of Wisconsin-Extension is part of the local and statewide network of organizations and agencies that support Wisconsin's $88.3 billion agriculture industry. A recent statewide survey of nearly 1,000 agricultural service providers from throughout Wisconsin found that UW-Extension helps enhance economic impact by improving agribusiness services to farmers, increasing agribusiness or farm profitability, expanding agribusiness networks, and helping to reduce agribusiness or farm environmental impacts.

Produced in 2014 by:
University of Wisconsin-Extension
Wisconsin Milk Marketing Board
Wisconsin Department of Agriculture, Trade, and Consumer Protection

Economic data (2012) provided by:
Steven C. Deller, Professor, Department of Agriculture and Applied Economics, University of Wisconsin-Madison, and Community Development Specialist, University of Wisconsin-Extension.

Other economic data from:
USDA 2012 Census of Agriculture

For more information, contact:
Waupaca County UW-Extension
Courthouse
811 Harding Street, Waupaca, WI 54981-2087
715-258-6230 • http://waupaca.uwex.edu/

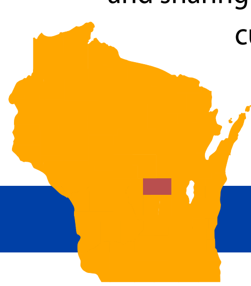
2014

AGRICULTURE – WORKING EVERY DAY FOR WISCONSIN

Waushara County Agriculture: Value & Economic Impact

Agriculture works hard for Waushara County every day. Family-owned farms, food processors and agriculture-related businesses generate thousands of jobs and millions of dollars of economic activity while contributing to local income and tax revenues.

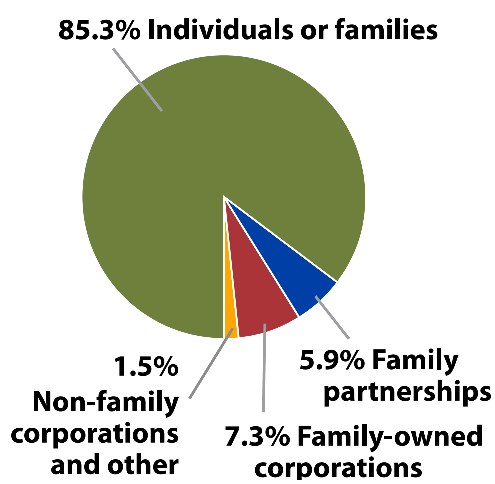
The diversity of agriculture of Waushara County reflects the diversity of the soil in the county. The eastern end of the county, with its richer and heavier soils, is primarily where farms focusing on dairy and cash crops are found. The center of the county, with hills and poorer soils, is home of many of the county's Christmas tree producers. The western end of the county, with its sandy soil and flat surface, is well known for its irrigated vegetable crop production; for both commercial processing and farm market sales. The Hancock Agricultural Research Station has assisted local producers by cooperatively conducting and sharing research for potatoes, cucumbers and snap beans production and harvest.



How important is agriculture?

- Agriculture provides **jobs for 1,785** Waushara County residents.
- Agriculture accounts for **$323 million in economic activity**.
- Agriculture contributes **$120 million** to the county's total income.
- Agriculture pays **$6.7 million in taxes**. This figure does not include all property taxes paid to local schools.

Who owns the farms?



Agriculture provides 20% of Waushara County's jobs

Waushara County **agriculture provides 1,785 jobs**, or 19.5 percent, of the county's workforce of 9,153. Production jobs include farm owners and managers and farm employees. Agricultural service jobs include veterinarians, crop and livestock consultants, feed, fuel and other crop input suppliers, farm machinery dealers, barn builders and agricultural lenders, to name a few. Processing jobs include those employed in food processing and other value-added industries that support food processors. Every job in agriculture generates an additional 0.57 jobs in the county.

Agriculture contributes $120 million to county income

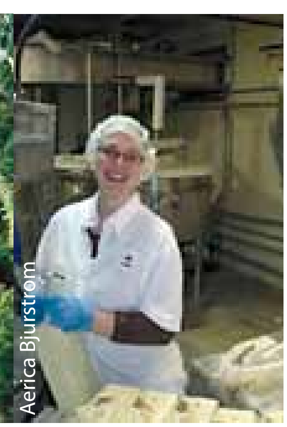
Waushara County **agriculture accounts for $119.5 million**, or 20.6 percent, of the county's total income. This includes wages, salaries, benefits and profits of farmers and workers in agriculture-related businesses. Every dollar of agricultural income generates an additional $0.64 of county income.

Agriculture pumps $323 million into local economy

Waushara County **agriculture generates $322.6 million in economic activity**, about 27 percent, of the county's total economic activity. Every dollar of sales from agricultural products generates an additional $0.37 of economic activity in other parts of the county's economy.

Here's how agriculture stimulates economic activity:

- The direct effect of agriculture equals $236.2 million and includes the sale of farm products and value-added products.
- Purchases of agricultural and food-processing inputs, services and equipment add another $50.5 million in economic activity. For example, this includes business-to-business purchases of fuel, seed, fertilizer, feed and farm machinery, as well as veterinary services, crop and livestock consultants and equipment leasing.
- This business-to-business activity then generates another $35.9 million in economic activity when people who work in agriculture-related businesses spend their earnings in the local economy.



Agriculture pays almost $7 million in taxes

Economic activity associated with Waushara County farms and agriculture-related businesses **generates $6.7 million** in local and state taxes. This figure does not include all property taxes paid to support local schools. If it did, the number would increase dramatically.

Table 1. Taxes paid by agriculture

Sales tax	$1.5 million
Income tax	$2.3 million
Property tax	$2.0 million
Other	$0.86 million
Total	**$6.7 million**

Table 2. Waushara County's top commodities (sales by dollar value, 2012)

1. Vegetables	$67.1 million
2. Grain	$29.8 million
3. Milk	$18.5 million
4. Cattle & calves	$5.6 million
5. Other crops & hay	$3.0 million

Mike Rankin

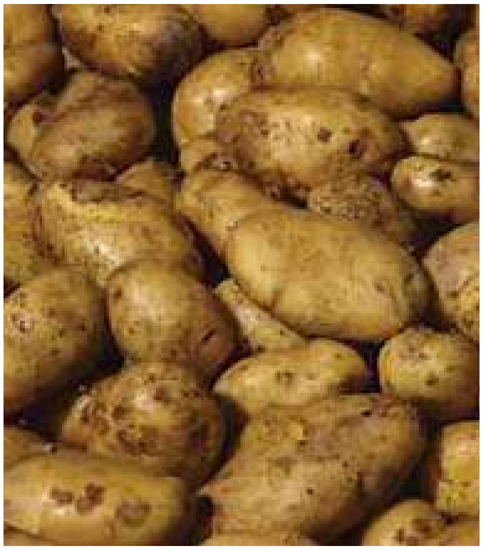
Ken Schroeder

Vegetable production and agricultural processing impacts in Waushara County

Vegetable production is the largest part of Waushara County's agriculture. In 2012, the market value of vegetable crops was $67.1 million, or 50 percent of the total market value of all agricultural products sold in the county. There are 8,372 acres of potatoes, 7,547 acres of sweetcorn, 7,030 acres of snapbeans, and 2,682 acres of peas raised in Waushara County.

Agricultural processing is also an important part of Waushara County's agriculture. Waushara County agricultural processors contribute $132.5 million to the county's economy. Potatoes, snapbeans, sweetcorn, and peas are the main products that are processed.

- Every dollar of sales of processed products generates an additional $0.30 of economic activity in other parts of the economy.
- Processing accounts for $25.0 million of income in the county.
- Waushara County's agricultural processing accounts for 340 jobs.



©USDA NRCS

Horticulture contributes to Waushara County diversity

Waushara County sales of Christmas trees, fruits and vegetables, greenhouse, nursery and floriculture products total $70.3 million. Landscape and grounds maintenance businesses create additional full-time jobs and many seasonal jobs.

Local food sales account for $628,000 to economy

More and more Waushara County farmers sell directly to consumers from roadside stands, farmers' markets, auctions and pick-your-own operations, with 52 farms generating $628,000 in local food sales.

Farmers are stewards of 36% of the county's land

Waushara County farmers own and manage 145,210 acres, or about 36 percent, of the county's land. This includes cropland, rangeland, pasture, tree farms and farm forests. As stewards of the land, farmers use conservation practices, such as crop rotation, nutrient management and integrated pest management, to protect environmental resources and provide habitat for wildlife.

UW Extension

University of Wisconsin-Extension

University of Wisconsin-Extension is part of the local and statewide network of organizations and agencies that support Wisconsin's $88.3 billion agriculture industry. A recent statewide survey of nearly 1,000 agricultural service providers from throughout Wisconsin found that UW-Extension helps enhance economic impact by improving agribusiness services to farmers, increasing agribusiness or farm profitability, expanding agribusiness networks, and helping to reduce agribusiness or farm environmental impacts.

Produced in 2014 by:
University of Wisconsin-Extension
Wisconsin Milk Marketing Board
Wisconsin Department of Agriculture, Trade, and Consumer Protection

Economic data (2012) provided by:
Steven C. Deller, Professor, Department of Agriculture and Applied Economics, University of Wisconsin-Madison, and Community Development Specialist, University of Wisconsin-Extension.

Other economic data from:
USDA 2012 Census of Agriculture

For more information, contact:
Waushara County UW-Extension
Courthouse
209 S. St. Marie, PO Box 487, Wautoma, WI 54982-0487
920-787-0416 • http://waushara.uwex.edu/

Irrigation and Conservation Practices Used by Wisconsin Potato and Vegetable Growers

Highlights from a baseline assessment – November, 2014

Irrigated vegetable production in Wisconsin is an important component of the agricultural economy. Wisconsin is ranked in the top five nationally in production of potatoes, sweet corn, green beans, peas, carrots and many other processed vegetables. The Central Sands area, where much of this production is centered, is one of the most productive growing areas in the U.S.

This high level of productivity is dependent on our ability to irrigate, and water is a vital resource for the potato and vegetable industry. The Central Sands is underlain by an abundant groundwater aquifer that is recharged annually by precipitation. In recent years, however, increases in irrigated acreage, changing weather patterns, and an extended growing season have combined to stress this important resource.

The future of our irrigated vegetable industry is ultimately dependent on our ability to balance long term conservation of our water resources with the continuing productivity that is needed for economic survival. Increasing the efficiency of our irrigation practices and adopting conservation practices that use less water are key components to achieving this balance.

To determine a baseline of the irrigation and conservation practices used by Wisconsin growers, an online assessment was conducted in November 2014. The Wisconsin Potato and Vegetable Growers Association (WPVGA) led this process in collaboration with University of Wisconsin Specialists, using a sustainability model developed by FieldRise. Data was collected from 90% of irrigated vegetable growers representing 185,375 acres. This information helps recognize existing grower achievements and determines where changes can be made to continue improvement over time.

Data highlights

A summary of the percentage of growers using practices that are contributing to more efficient water use and conservation efforts.

Equipment used

99% use center pivot systems (**25%** also use traveling guns)

49% use drop nozzles with **82%** of those operated at low or medium pressure

58% of pivots can be operated remotely

96% are monitored during 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 during off-peak hours

59% have variable frequency drive 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)

Irrigation: factors growers use to determine how often to irrigate

1 Crop water need

73% use predicted or estimated evapotranspiration (ET) rates

96% consider growth stage, **84%** variety, **75%** canopy, **67%** rooting depth

2 Rainfall

97% monitor in-field rainfall; **89%** use short-range forecasts, **41%** long-range

3 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

4 Soil moisture, site-specific (variable rate) applications

30% use site-specific application

48% use soil maps or visual methods to determine moisture holding capacity

23% use landscape observation (high/ low spots)

10% turn sprinklers on/off with zone controls

5 Irrigation Scheduling (using crop need, canopy, ET, rain, soil moisture)

47% use an irrigation scheduling aid:
12% WISP (**8%** online), **25%** paper checkbook method, **3%** commercial software

Water conservation practices

In-Field

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% add organic matter to increase water holding capacity

24% use deficit irrigation to promote deeper rooting

22% use in-row surfactants to limit nutrient loss

Whole farm

55% use crop rotations that require less water

50% plan plantings to avoid areas of concern (high/low spots)

25% plant varieties that use less water

14% use natural features (e.g. wetlands) to increase recharge

Landscape

34% measure static depth to groundwater at least twice /year

10% measure depth to groundwater annually

27% coordinate with neighbors/stakeholders on water issues

62% have knowledge of geology and groundwater flow on farm

45% are familiar with the relationship between groundwater & surface water on farm

Outreach/education

70% attend educational meetings that include water issues

21% work on resource issues with community

19% conduct on-farm research

What Participating Growers are Saying about Water and Irrigation

Conservation

"Water conservation is important to our farm because we believe in promoting a sustainable environment, both for our farm as a whole and for the community around us."

"The more water we conserve now, the higher availability in the future."

"Water conservation is important so we don't … waste groundwater, which everyone depends upon."

Production and economics

"Irrigation is a significant expense, and as such it only makes sense to use it wisely."

"It's important for our farm and every farm in the Central Sands area. Without irrigation, we couldn't grow vegetable crops."

Long term sustainability

"This is important to us all. We need to be stewards of the resources, so we can continue for generations to come."

"Sustainability is always an important goal on a family farm."

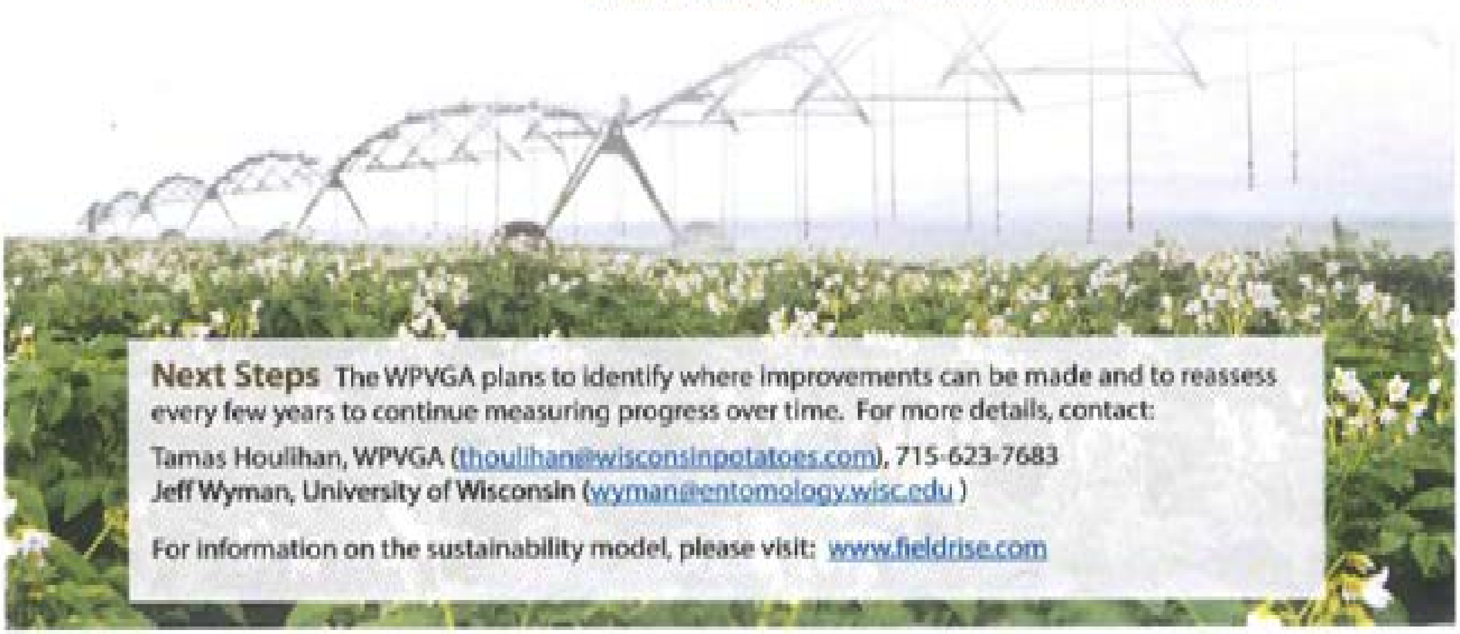
Using new technologies

"Use variable frequency electric motors and run our diesel motors at lower rpm."

"… using deficit irrigation."

"… variable rate irrigation with mapping."

"Turn end guns off when not needed, minimize over watering."



Next Steps The WPVGA plans to identify where improvements can be made and to reassess every few years to continue measuring progress over time. For more details, contact:

Tamas Houlihan, WPVGA (thoulihan@wisconsinpotatoes.com), 715-623-7683
Jeff Wyman, University of Wisconsin (wyman@entomology.wisc.edu)

For information on the sustainability model, please visit: www.fieldrise.com

Wisconsin Potato and Vegetable Growers Association Groundwater Task Force:

Accomplishments **2012-2014**

Executive Summary

Background: The Wisconsin Potato and Vegetable Grower Association (WPVGA) Groundwater Task Force was formed in 2009 in response to growing concerns over the potential impact of irrigated agriculture, climate, urbanization, and other factors on the groundwater aquifer and surface waters of the Central Sands. The focus of the Task Force is to bring together resources and expertise to foster the sustainable use of water resources.

The group meets monthly and has a diverse membership that includes: representatives of 14 potato and vegetable farms from all parts of the Central Sands; 3 major potato and vegetable processors (McCain Foods, Del Monte Foods and Seneca Foods); rural communities (Village of Plover); University of Wisconsin Research and Extension Specialists from the Departments of Soils, Horticulture, Entomology, Plant Pathology, Biological Systems Engineering, the Nelson Institute, Wisconsin Geological and Natural History Survey and the Wisconsin Institute for Sustainable Agriculture; and support expertise from WPVGA, Wisconsin Public Service, USDA-Natural Resources Conservation Service, irrigation and drainage companies and other groups that are called on as needed. The Task Force is chaired by Nick Somers (Plover River Farms Alliance) and Jeremie Pavelski (Heartland Farms Inc.).

Task Force Goals:

1. *Be an advocate for responsible water use practices and informed, science-based public policy that will protect the Central Sands groundwater aquifer and its associated streams, lakes and wetlands.*
2. *Promote and maintain a sustainable agricultural industry.*
3. *Foster vibrant rural communities*.

Objectives and Accomplishments:

Objective 1: Consolidate and build on the extensive existing knowledge-base related to the hydrogeology of the Central Sands and the potential impacts of water use, drainage, climate and other factors on the groundwater aquifer and associated surface water bodies.

- Released a White Paper (*Sustaining Central Sands Water Resources*) bringing together all of the relevant hydrological and agronomic studies in the Central Sands as a foundation for future study. http://wisa.cals.wisc.edu/central-sands-white-paper
- Established a network of growers to monitor groundwater elevations in privately owned irrigation wells in the Central Sands currently consisting of 479 wells across 4 counties sampled 2-3 times/year.
- Installed 3 groups of 8 monitoring wells to track fluctuations in groundwater at 6 hour intervals in transects across 3 areas designated as high risk for surface water impacts (Little Plover River, Long Lake, Pleasant Lake). Groundwater elevations are posted at (http://wisa.cals.wisc.edu/central_sands_water/csw-monitoring-wells) every 3 weeks.
- Conducted a study of the hydrogeology of Long Lake by the Wisconsin Geologic and Natural History Survey to improve understanding of the formation of tunnel- channel lakes and the impact of clay layers deposited in their formation on groundwater/surface water interaction.
- Initiated a study by WGNHS to examine the geophysics and stratigraphy of the Little Plover River Basin and enhance the DNR-funded modeling project in the area.
- Initiated a project to model the potential impacts of drainage system modifications on water retention and groundwater recharge.
- Engaged an independent hydrogeologist to assess strengths and weaknesses of ongoing Task Force activities.

Objective 2: Identify, implement and evaluate strategies to increase the efficiency of irrigation.

- Beta- tested and released a new irrigation scheduling program, WISP-2012, in 2013.
- Conducted statewide training sessions, small group workshops and on farm visits to increase use of WISP-2012 throughout the industry. Released program to commercial software developers for incorporation into farm management software.
- Initiated crop canopy development studies in 6 potato varieties, field corn, sweet corn, soybeans, snap beans and carrots to create crop-specific versions of WISP-2012.
- Evaluated soil moisture sensors for use with WISP-2012 and started an on-farm trial to examine site-specific irrigation based on variability of soil type and moisture holding capacity across fields.
- Conducted a multi-year trial to evaluate whether water can be withheld at early growing stages to increase rooting depth and increase water use efficiency without harming yield. Initial results show that deferred irrigation can save water for some long season crops such as soybean (3 inches) without negative yield impacts, but that careful timing is essential for shorter season crops.
- Demonstrated that drip irrigation is an efficient delivery system for irrigation of potatoes which conserves water (15% less) and can be used for precise fertilization and pest management.

Objective 3: Investigate evapotranspiration from crops, natural landscapes and bare soil and its relationship to climate, irrigation, recharge, and fluctuations in groundwater.

- Collaborated in on-farm trials investigating year-round water consumption of irrigated crops, natural vegetation, and bare soil and initiated a water/nitrogen balance experiment on the Hancock Experiment Station with sweet corn.
- Developed digital maps to track the distribution of crops, natural plant communities, woodland and urban areas across the Central Sands to identify changes in cropping patterns, examine relationships to groundwater fluctuations and plan crop landscapes that require less water.

Objective 4: Communicate Task Force activities and accomplishments to the farming community, State and federal agencies, the citizens of the Central Sands, and the people of Wisconsin, and seek broad input from all concerned parties to determine potential solutions to water issues.

- Continued to increase the science base of task force activities which now include 8 UW Departments, centers and institutes and assembled information into a multidisciplinary White Paper.
- Conducted 3 on-farm tours in 2013 for farmers and state and federal agency water specialists from DNR and NRCS increase understanding of farm operations and achievements in water conservation.
- Conducted 4-5 local and state-wide educational meetings and 2 field days per year with growers and processors to expand their understanding of water issues and increase participation in water conservation activities throughout the industry.
- Expanded press and social media messaging with weekly releases detailing accomplishments and promoting the sustainability of the potato and vegetable industry.
- Conducted industry-wide assessments on Wisconsin potatoes (57,000 acres) and midwestern processing sweetcorn and snap bean (45,000 acres) to determine baseline sustainability, document achievements and identify areas for potential improvement.

Did you know?

- Every drop of irrigation applied to our crops is based on science. We develop sophisticated scheduling programs that take into account exactly how much water each crop needs at each stage of its growth, how much water the soil can hold and how the weather will impact supply.

- We're good neighbors and good stewards. Water is only applied to match the precise crop need, and only when it is necessary.

- Our farmers invest millions of dollars to enhance the long-term sustainability of Wisconsin's environment and its precious resources.

- Wisconsin farmers rely on and help maintain a healthy environment to feed the world.

HOME GROWN WISCONSIN POTATOES

Wisconsin Potato & Vegetable Growers Association
www.WisconsinFarmers.org

Did you know?

- More than 99% of Wisconsin's farms are family-owned.
- Potato production requires consistent and uniform irrigation water to produce the quality you deserve and that processors and produce buyers require.
- Our farmers are acutely aware of the need to balance the water that is withdrawn from the aquifer for irrigation with the water that is returned to it in the form of precipitation that recharges the system annually.
- We regularly commission environmental studies and invest in new technologies to ensure the long-term quality and sustainability of Wisconsin's water supply.
- Our product, livelihood, heritage and legacy demands that we be mindful stewards of our environment.

HOME GROWN WISCONSIN POTATOES

Wisconsin Potato & Vegetable Growers Association
www.WisconsinFarmers.org