Information Support for Groundwater Management in the Wisconsin Central Sands, 2013-2015

A Report to the Wisconsin Department of Natural Resources

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LIST OF ELECTRONICALLY APPENDED MATERIALS

1: Excel file; “Q for Central WI Rivers thru June 2016”

2: Excel file; “Lake Level Data Updated thru 2016”

3. Stream and lake elevation survey (folder)
   - Survey description
   - Shapefile

4. Description of past modeling efforts (folder)

5. Refined stream reach segmentation schema (folder)

1. INTRODUCTION

This report summarizes data and information gathering for 2013 through 2015 that supports groundwater management activities in the Wisconsin central sands. The report supplements the previous work of Clancy et al. (2009) and Kraft et al. (2010, 2012a, 2012b, 2014). These works summarized important hydrologic literature on the central sands, provided documentation for groundwater flow models, and statistically analyzed hydrographs for signs of pumping diversions and drawdowns, concluding that groundwater pumping in the central sands was substantially impacting the region's water levels and streamflows, and that stressed water conditions were not explainable by phenomena such as an unprecedented drought.

The Wisconsin central sands is an extensive (about 2,506 mi^2), though loosely-defined, region characterized by a thick (often > 100 ft) mantle of coarse-grained sediments overlying low permeability rock, and landforms comprising outwash plains and terminal moraine complexes associated with the Wisconsin Glaciation. This and the previous works particularly address the area between the headwater streams of the Fox-Wolf and Central Wisconsin Basins, which contain some 83 lakes larger than 30 acres, and over 600 miles of headwater streams in close proximity to a great density of high capacity wells (Figure 1-1 and Figure 1-2).

The central sands contains Wisconsin's greatest density of high capacity wells, about 2,374[1] in the seven counties that this study area overlaps (Figure 1-3). High capacity well pumping in the region amounted to 28-30% of Wisconsin's total for 2013-2014; 84-87% was used for agricultural irrigation (WDNR 2015). Other uses (municipal, industrial) are small and limited geographically, but can have locally significant surface water impacts (Clancy et al. 2009). Growth in high capacity irrigation well numbers and pumping has been rapid, minimally managed, and, except for a brief period between the *Richfield Dairy* decision in 2014 and Wisconsin Attorney General's opinion in 2016, with minimal regard for impacts on lake, stream, and wetland resources.

Lake levels, groundwater levels, and streamflows associated with irrigated portions of the Wisconsin central sands have been depressed in recent years. For instance, Long Lake near Plainfield, which in recent times covered 45 acres and had a typical depth of about 10 feet, was near dry to dry in 2005-2009, and even the very large rains in 2010-2011 restored only a few feet of water. Low lake levels have apparently provoked more frequent winter fish kills on Portage County's Pickerel Lake. Wolf Lake County Park in Portage County has had its swimming beach closed due to low water levels for 14

[1] High capacity wells for these purposes are defined as wells with a stated maximum pumping capacity of 70 gallons per minute (gpm) or more. Wells with an unknown maximum were also included if the total annual pumping exceeds 365 days, (or 153 days for irrigation wells) of 70 gpm or more.

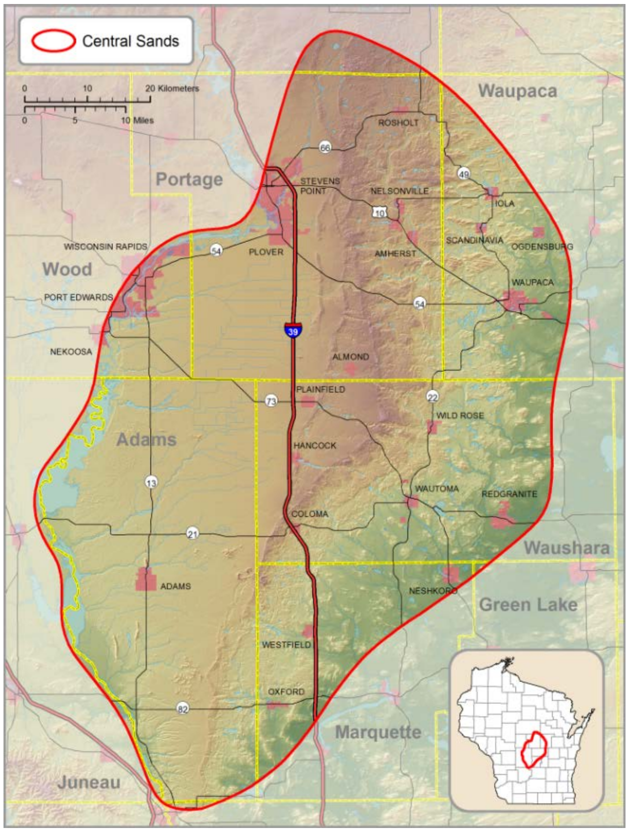


Figure 1-1. The Wisconsin central sands region with selected municipalities and roads.

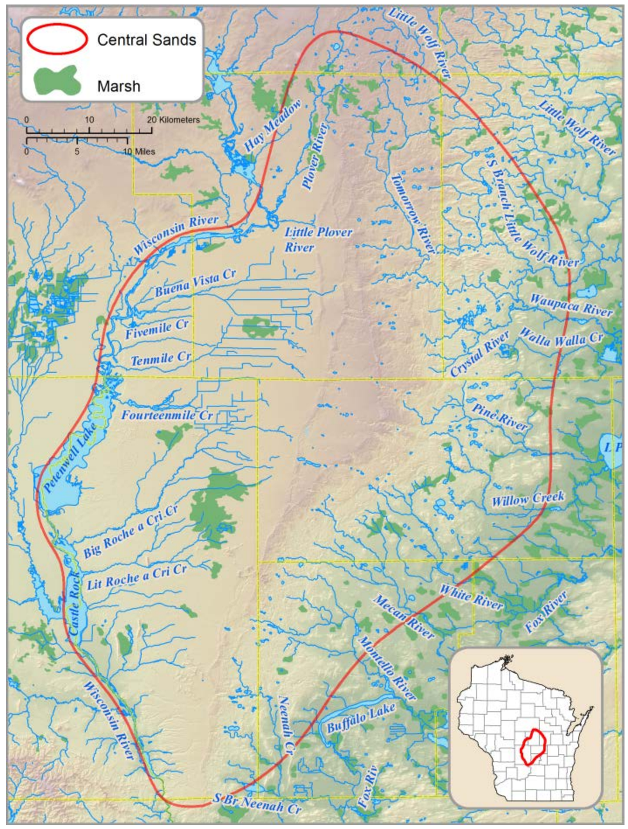


Figure 1-2. Hydrography of the Wisconsin central sands region.

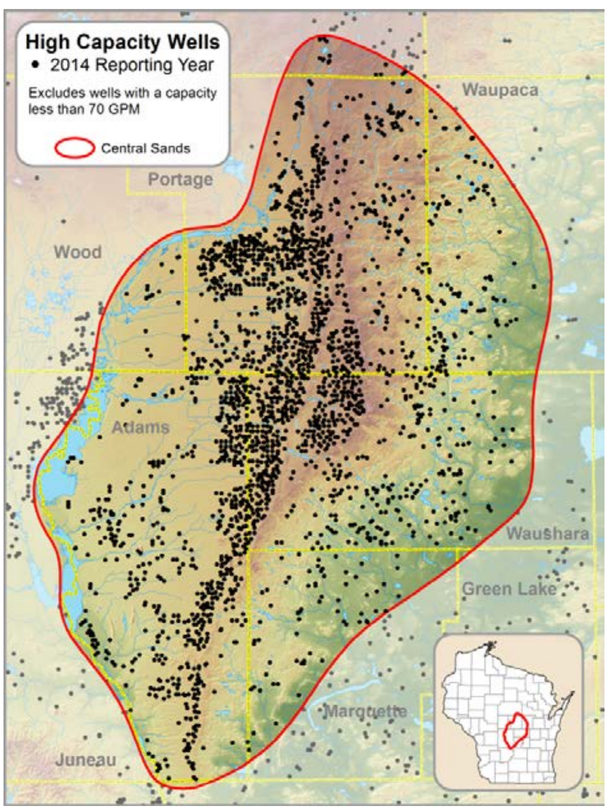


Figure 1-3. Locations of high capacity wells.

years. The Little Plover River, which formerly (1959-1987) discharged at a mean of 10 and a one-day minimum of 3.9 cubic feet per second (cfs) (Hoover Road gauge), now frequently flows at less than the former minimum, and was below the Public Rights Flow (WDNR 2009) 37-53% of the time in 2013.

Objectives of This Effort and Brief Description of How Objectives Were Addressed

The goal of this project is to provide monitoring and modeling support for management and policy processes that address groundwater pumping effects on aquatic resources in the Wisconsin central sands, with these specific objectives:

1. Measure baseflow discharges on select streams and groundwater levels in select wells; provide data to USGS and WDNR for archiving.

Baseflow was measured at 32 stream locations (Chapter 4) and groundwater levels were measured at four. Data have been uploaded to agencies and are provided as electronically appended material.

2. Estimate irrigation rates for crops grown in central Wisconsin for years 2013 and 2014.

Results are provided in Chapter 8.

3. Compile precipitation, groundwater, and lake level data from NOAA, WDNR, County, and USGS data sources for years 2014 and 2015 and merge with previously compiled data. Use the assembled data to provide a context for the relative wetness or dryness of the study period.

Results are provided in Chapter 2.

4. Estimate pumping drawdowns for select monitoring wells and lakes for 2014-2015 by statistical comparisons to reference sites.

Results are provided in Chapters 5 and 6.

5. Run existing groundwater flow models to meet agency and process needs and to explore cause-and-effect relationships of diminished surface waters to groundwater pumping.

This work occurred irregularly through the life of this two-year project with results passed along to agency contacts.

6. Collaborate with Department staff in irrigation rate and modeling analyses.

Results are presented in Chapter 8.

Other

A stream and lake elevation survey, groundwater modeling documentation, and refined stream reach segmentation schema are included as electronic files.

2. WEATHER AND HYDROLOGIC CONDITIONS FOR 2014-2015

Summary

Precipitation in 2014 and 2015, respectively, was greater than average by 4.0 and 8.8 inches at Stevens Point, 4.2 and 0.9 inches at Hancock, and 6.8 and 4.1 inches at Wautoma. The Palmer Drought Index ranged from near normal to unusually moist, and has not fallen below "normal," or average, since the end of 2012. Discharges at reference streams were above average, at the 77th-80th percentile, as were groundwater levels in most areas with few high capacity wells.

Precipitation

2014 and 2015 precipitation

Years 2014 and 2015 were wetter than average, by 4.0 and 8.8 inches at Stevens Point (2014 and 2015 respectively), 4.2 and 0.9 inches at Hancock, and 6.8 and 4.1 inches at Wautoma.

Long term precipitation trends

Precipitation amounts for 1930 through 2015 are displayed in Figure 2-1 and Figure 2-2 for Stevens Point, Hancock, and Wautoma. Stevens Point and Hancock records are virtually complete for the period, but the Wautoma record needed to be inferred through 2008 using the methods of Serbin and Kucharik (2009).

Notable in the long term record is a prolonged dry period that prevailed in 1946 through 1964, when precipitation was less than average by 2.1-2.7 inches/year at the three stations. Hydrographs from monitoring wells, lakes, and streams during this period often express depressed conditions. Precipitation since then has generally increased, consistent with wetter conditions that have prevailed over much of the eastern US, including Wisconsin, since 1970 (Juckem et al. 2008, WICCI 2011). In more recent times, average precipitation at the three stations was 0.2-2.1 inches above the mean during 2000-2009, and 1.2-3.6 inches during 2010-2015.

Drought Index

The Palmer Drought Index (Figure 2-3) is an indicator of weather wetness and dryness based on precipitation and temperature. It is an improvement on precipitation alone as a wet/dry indicator, as it contains an algorithm that uses temperature as a surrogate for evapotranspiration.

The Palmer Index in 2014 and 2015 ranged from near normal to unusually moist, and has not fallen below "normal," or average, since the end of 2012.

Discharges on Reference Streams

Long term annual stream discharges provide context for hydrologic conditions. Displayed in Figure 2-4 are the percentile rank of annual streamflows for four streams that surround the central sands: the Wolf River at New London (1914-2015), the Embarrass River at Embarrass (1920-2015 with nine missing years), the Waupaca River at Waupaca (1917-1984 with 20 missing years, plus 2009-2015), and the Wisconsin River between Wisconsin Dells and Wisconsin Rapids (1935-2015 with eight missing years). We term the Wisconsin River between Wisconsin Dells and Wisconsin Rapids as the "Wisconsin River – Central," obtaining discharge values as the difference between Wisconsin Rapids and Wisconsin Dells discharges. Wisconsin River – Central replaced the Wisconsin at Wisconsin Dells and at Wisconsin Rapids in previous reports, which we found to be heavily biased by northern Wisconsin weather. We also left out Ten Mile Creek at Nekoosa, as it has apparently become irrigation pumping affected.

Each of the stream gauges has limitations when used as a reference for the central sands. The Wolf River at New London drains a large basin to the northeast and somewhat distant from the central sands, and hence is subject to differing weather conditions. The Embarrass River at Embarrass is closer and drains a smaller basin (384 mi^2), but is also outside the central sands. The Waupaca River at Waupaca is in the central sands and does not seem overly affected by irrigation pumping at this time, but has a sparse record for 1962 through 2009. The Wisconsin River – Central might be confounded by dam storage and release.

Previously, discharge data from these reference gauges were used to demonstrate significant low flow periods (defined as percentile ranks of 10% or less, which amounts to about a 10 year return frequency) during the past ~ 90 years, which include 1931-1934, 1948-1949, 1957-1959, 1964, 1977, and 1988. The 1930s discharges were the smallest on record, and years 1948-1964 mark a long period when low flows were unusually common (6 of 17 years). In more recent times, years 2000-2004 were about average, while 2005-2009 were somewhat low. Discharges since have mostly been above average, and were at the 80th and 77th percentiles in 2014 and 2015.

Groundwater Levels in Areas with Few High Capacity Wells

Four USGS monitoring wells located in areas with relatively few high capacity wells have been used to provide a context for hydrologic conditions under an assumed small pumping influence (Kraft et al. 2010, 2012a, 2014). These are Amherst Junction (1958 to 2015 record), Nelsonville (1950 to 1998, 2010 to 2015), Wild Rose (1956 to 1998), and Wautoma (1956 to 2015) (Figure 2-5). The record shows groundwater levels were at long term lows in the late 1950s and early 1960s, rose through about 1974, and since have mostly fluctuated cyclically (Kraft et al. 2010, 2012b). Amherst Junction levels were noticeably low in 2007-2010, but Wautoma levels were not. 2014 and 2015 levels continued to rise and

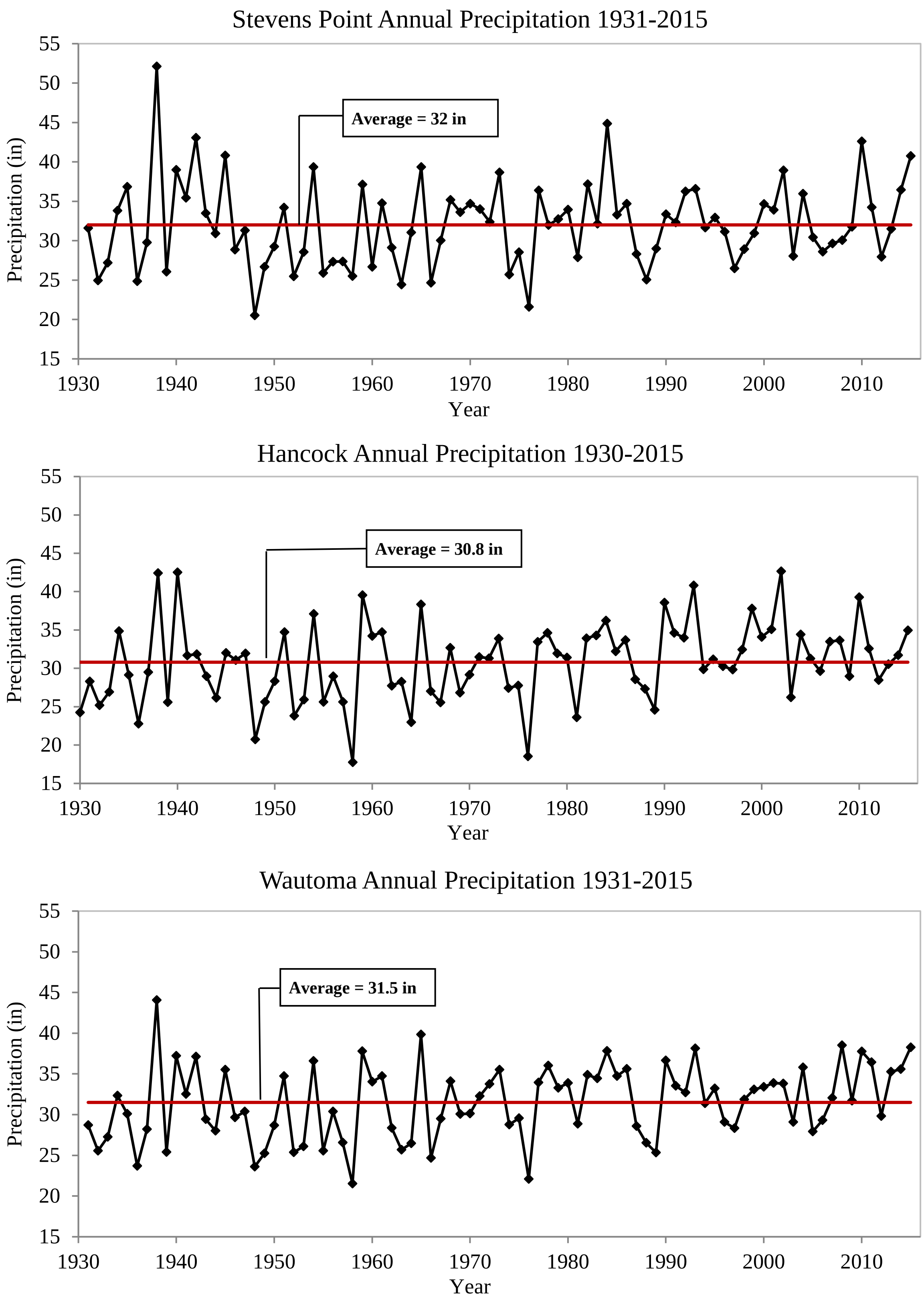


Figure 2-1. Annual precipitation at Stevens Point, Hancock and Wautoma.

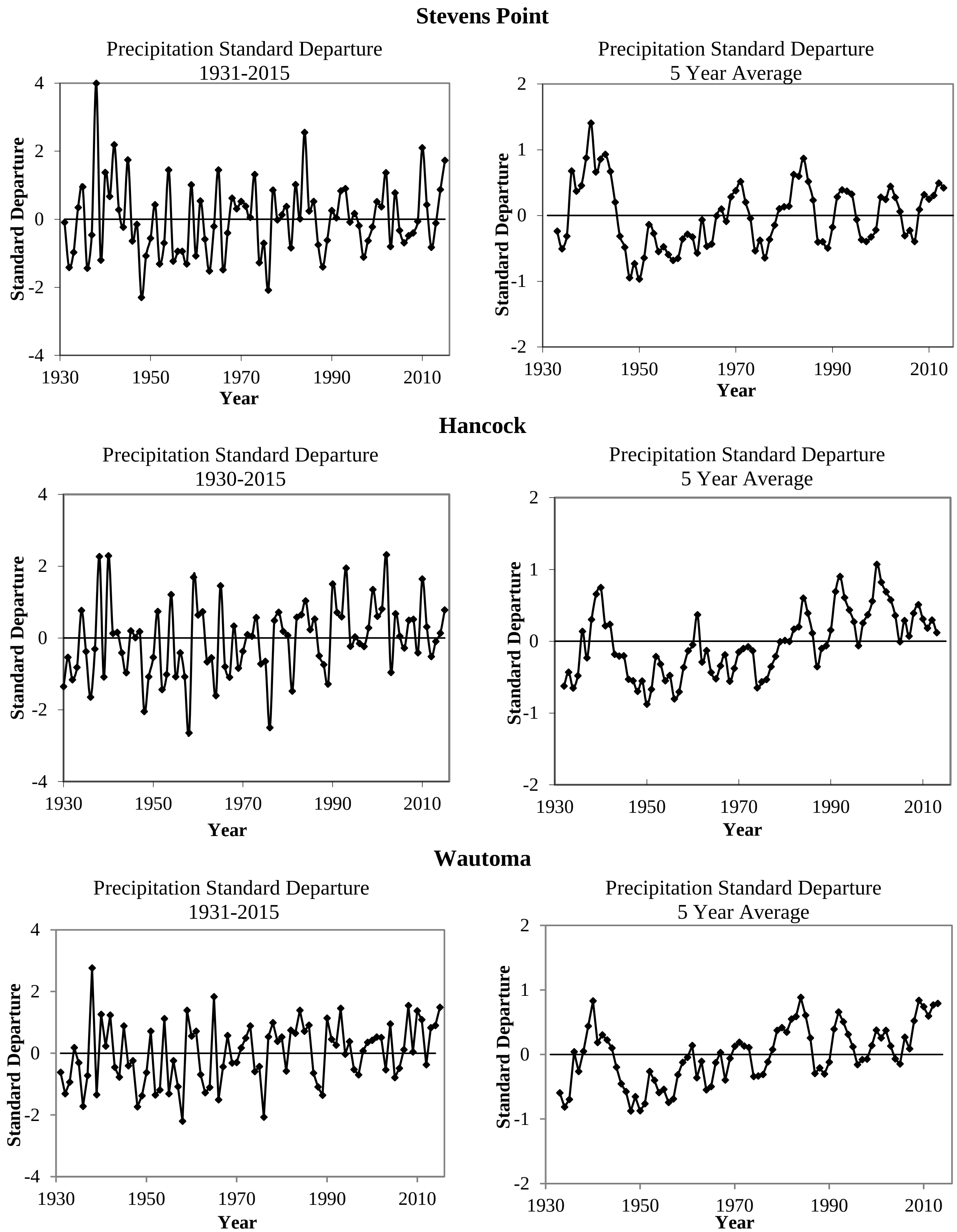


Figure 2-2. Standard departure of annual precipitation and five year average of the standard departure for Stevens Point, Hancock, and Wautoma.

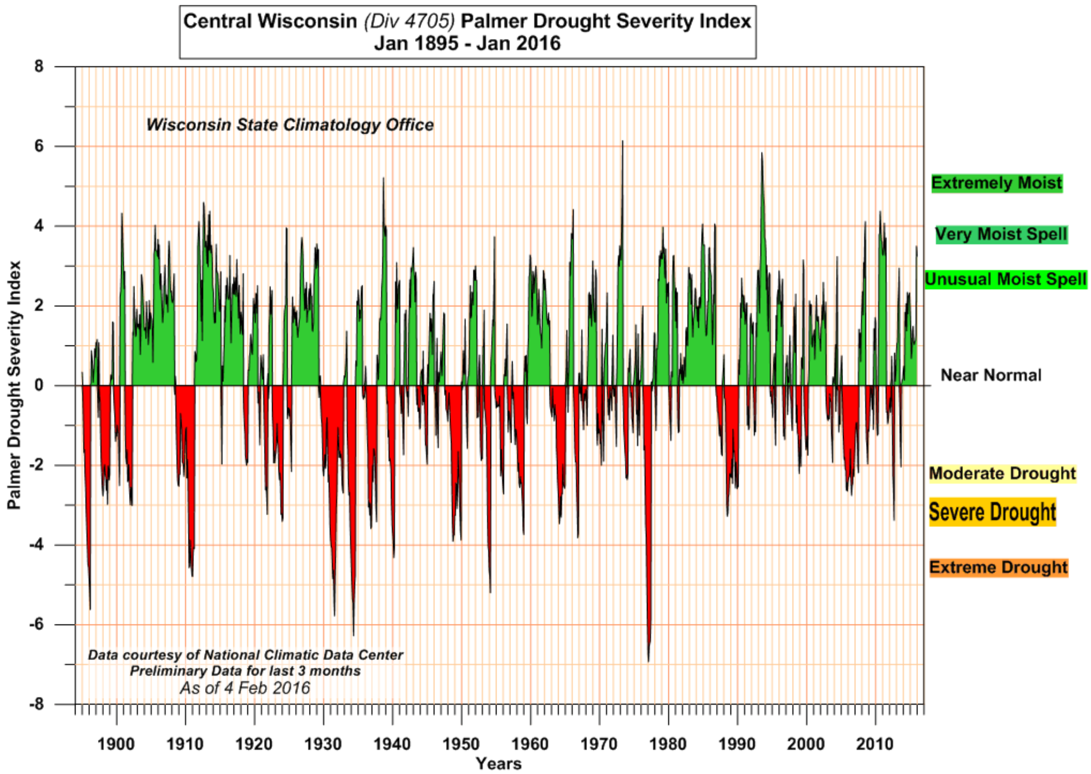


Figure 2-3. Palmer Drought Index graph for central Wisconsin ending January 2016 produced by the Wisconsin State Climatology Office (2016). Note that the post-2000 period is not substantially droughty compared to the historical record.

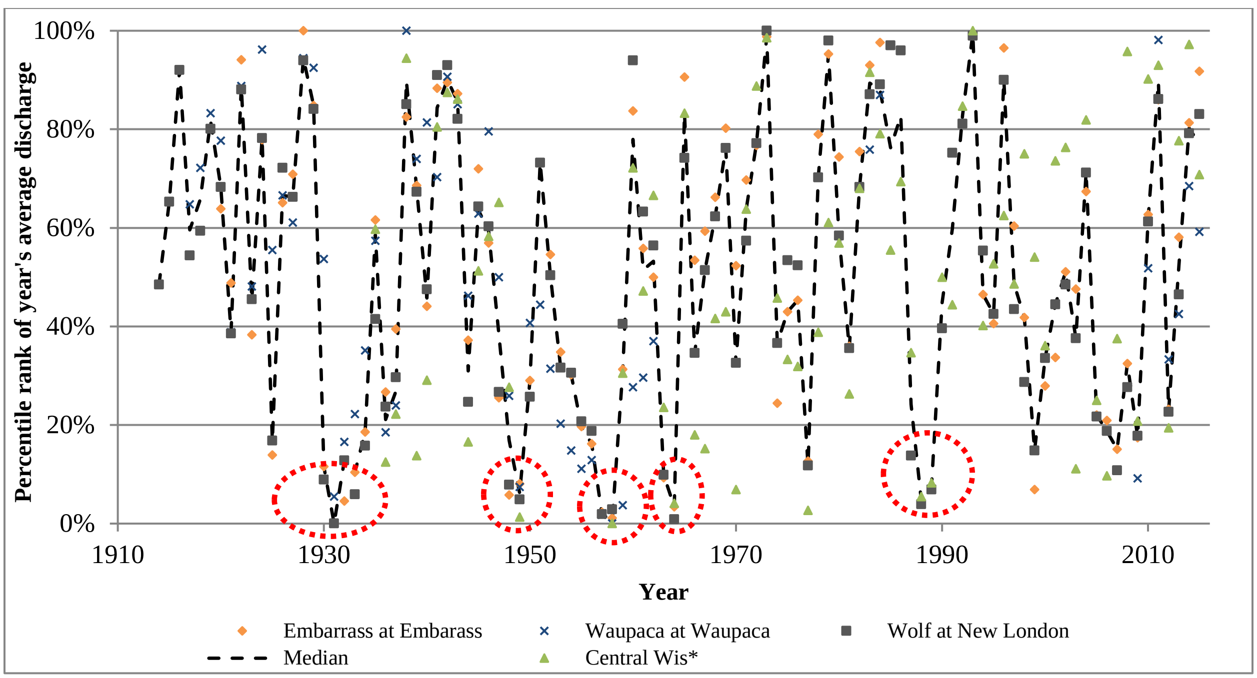


Figure 2-4. Percentile rank of streamflows by year ending 2015. Connecting line is for the median percentile rank. Significant dry periods (median of percentile rank <10%) are highlighted by red circles. "Central Wis" is the difference in Wisconsin River discharges between Wisconsin Rapids and Wisconsin Dells.

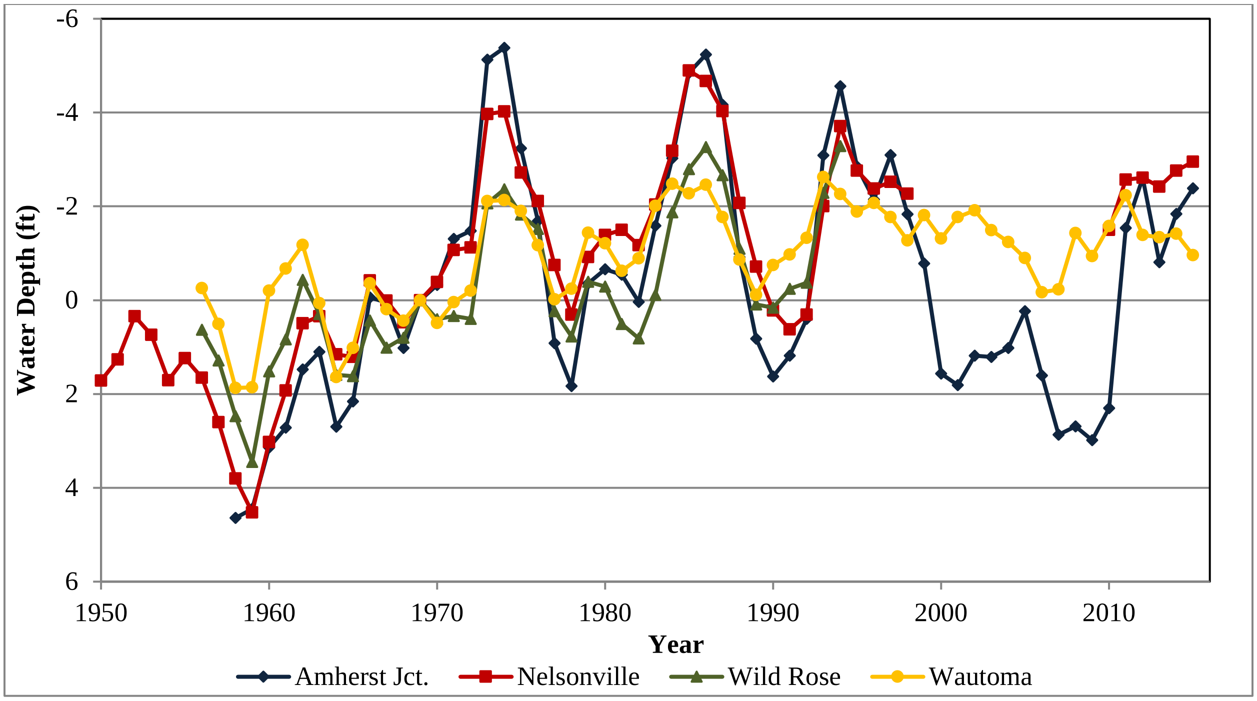


Figure 2-5. Annual average depth to water in four long term USGS monitoring wells located in areas with fewer high capacity wells. Water levels were adjusted so that 1969 values were zero for display purposes.

were high at Amherst Junction (75th and 79th percentile for 2014 and 2015, respectively), and at Nelsonville (85th and 86th percentile), but were about average at Wautoma (47th and 64th percentile).

Though the three stations currently producing water level data (Amherst Junction, Nelsonville, and Wautoma) are in areas with relatively few high capacity wells, they are still somewhat influenced by pumping. Groundwater flow modeling suggests that pumping may lower water levels at these locations by 0.4 to 0.76 feet on average (Kraft et al. 2012b). Haucke (2010) found the somewhat low water levels at Amherst Junction following 2000 could not be explained by precipitation alone, and could be consistent with a pumping effect. The revived Nelsonville well, which has less pumping influence than Amherst Junction, may prove to be a better reference location in the future as more data accumulate.

3. CENTRAL SANDS HIGH CAPACITY WELLS AND GROUNDWATER PUMPING SUMMARY FOR 2013 AND 2014

High Capacity Well Numbers, Uses, and Growth

The central sands had 2,374 active high capacity wells listed in the WDNR database as of October 2015 (WDNR 2015), mostly in Portage, Waushara, and Adams Counties (Figure 3-1). The region contains 28% of all Wisconsin high capacity wells, with most (86%) used for irrigation (Table 3-1). High capacity well numbers have been growing rapidly during the last decade or so, increasing from 1,772 in year 2000 to 2,067 in 2010, and 2,374 as of October 2015 (Figure 3-2).

2013 and 2014 High Capacity Well Pumping

High capacity well pumping in the central sands was 72 billion gallons in 2013 and 61 billion gallons in 2014 (Table 3-2, Figure 3-3). Portage, Adams, and Waushara Counties were the top three groundwater pumping counties in Wisconsin in 2013 and ranked first, third, and fourth in 2014, accounting for a quarter of all the groundwater pumped in Wisconsin.

Central sands high capacity well groundwater pumping was dominated by irrigation, amounting to 84-87% of the total in 2013 and 2014 (Table 3-2).

Table 3-1. Central sands high capacity wells, total and by use as of October 2015.

	Total	Irrigation		Industrial		Public		Other Ag		Other / Unknown	
All Central Sands	2,374	2,052	86%	42	2%	72	3%	30	1%	178	7%
------------- Central Sands Portion of Each County ------------											
Adams	608	540	89%	2	<1%	14	2%	7	1%	45	7%
Marathon	15	11	73%							4	27%
Marquette	76	39	51%	4	5%	2	3%	13	17%	18	24%
Portage	939	817	87%	32	3%	20	2%	4	<1%	66	7%
Waupaca	114	96	84%	1	1%	12	11%			5	4%
Waushara	604	540	89%	2	<1%	18	3%	6	1%	38	6%
Wood	18	9	50%	1	6%	6	33%			2	11%

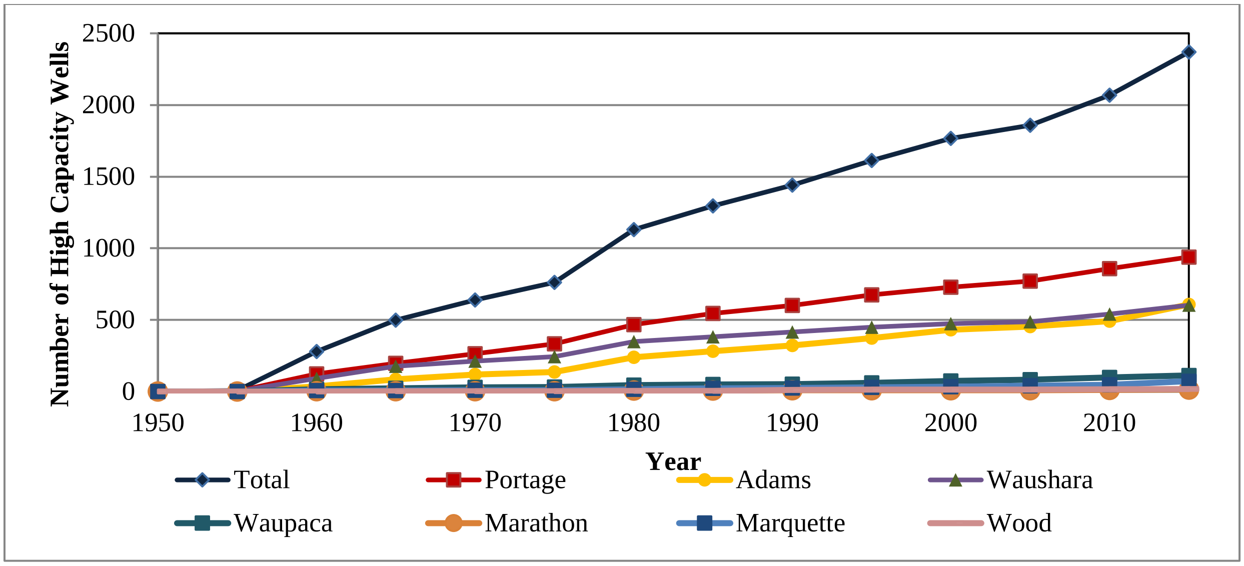


Figure 3-1. Growth of high capacity wells in the central sands, total and by county through October 2015.

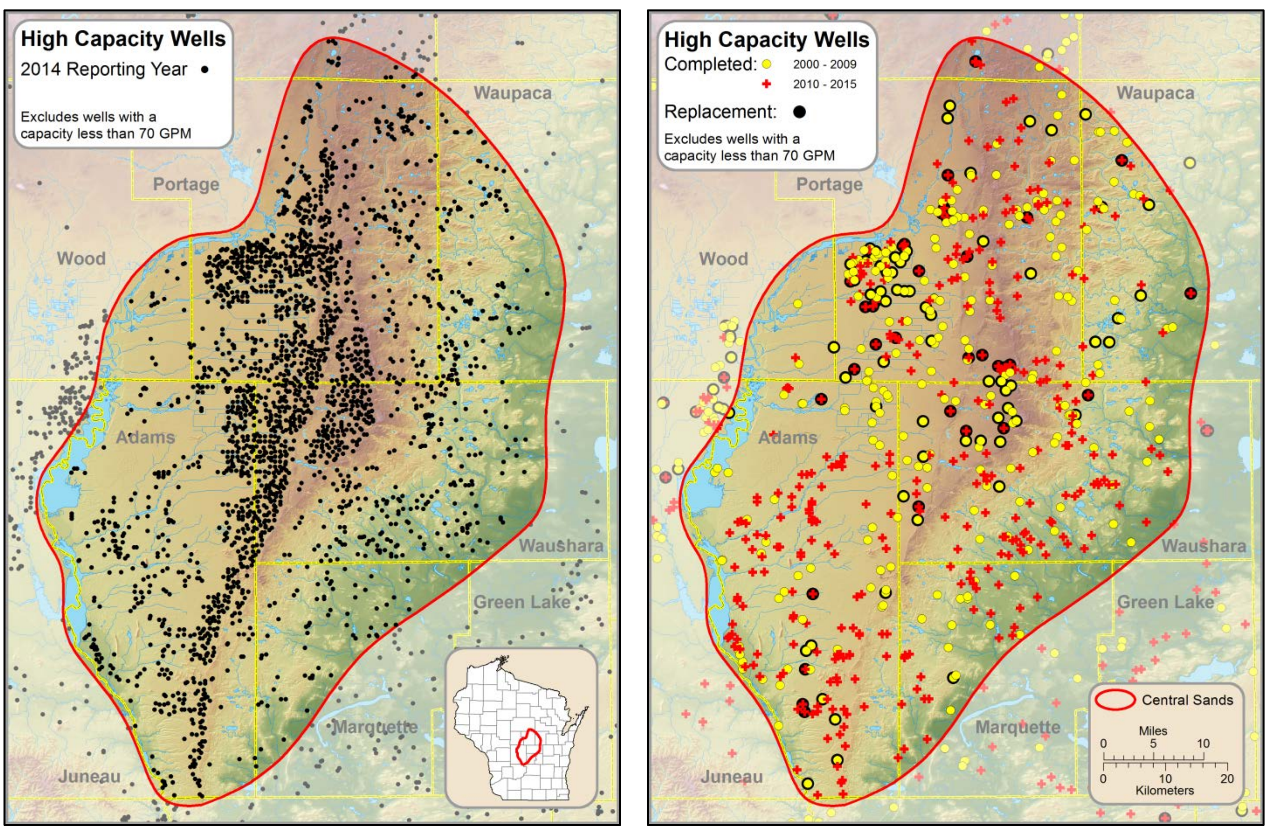


Figure 3-2. High capacity wells in the central sands (left), and their growth since 2000 (right).

Table 3-2. Central sands high capacity well pumping, total and by county, for 2013 and 2014, billions of gallons.

2013

	Total	Irrigation		Industrial		Public		Other Ag		Other/ Unknown	
All Central Sands	72.08	62.82	87%	2.15	3%	4.63	6%	2.4	3%	0.07	<1%
-------------- Central Sands Portion of Each County -------------											
Adams	20.14	19.67	98%	0.02	<1%	0.28	1%	0.14	1%	0.04	<1%
Marathon	0.12	0.12	100%	0	0%	0	0%	0	0%	0	0%
Marquette	1.98	1.03	52%	0.1	5%	0.001	<1%	0.84	42%	0.001	<1%
Portage	26.84	22.14	82%	2.01	7%	2.64	10%	0.05	0%	0.0017	<1%
Waupaca	2.64	1.89	72%	0.024	1%	0.72	27%	0	0%	0	0%
Waushara	19.49	17.87	92%	0.003	<1%	0.21	1%	1.37	7%	0.03	<1%
Wood	0.87	0.1	11%	0.001	<1%	0.77	89%	0	0%	0	0%

2014

	Total	Irrigation		Industrial		Public		Other Ag		Other/ Unknown	
All Central Sands	61.47	51.88	84%	2.13	3%	5.02	8%	2.42	4%	0.03	<1%
-------------- Central Sands Portion of Each County -------------											
Adams	17.94	17.53	98%	0.01	<1%	0.25	1%	0.14	1%	0.01	<1%
Marathon	0.06	0.06	100%	0	0%	0	0%	0	0%	0	0%
Marquette	1.97	1	51%	0.12	6%	0.001	<1%	0.84	43%	0	0%
Portage	21.12	16.53	78%	1.98	9%	2.56	12%	0.05	<1%	0	0%
Waupaca	2.67	1.87	70%	0.01	<1%	0.79	30%	0	0%	0	0%
Waushara	16.36	14.72	90%	0.003	<1%	0.23	1%	1.39	8%	0.02	<1%
Wood	1.36	0.17	13%	0	0%	1.19	88%	0	0%	0	0%

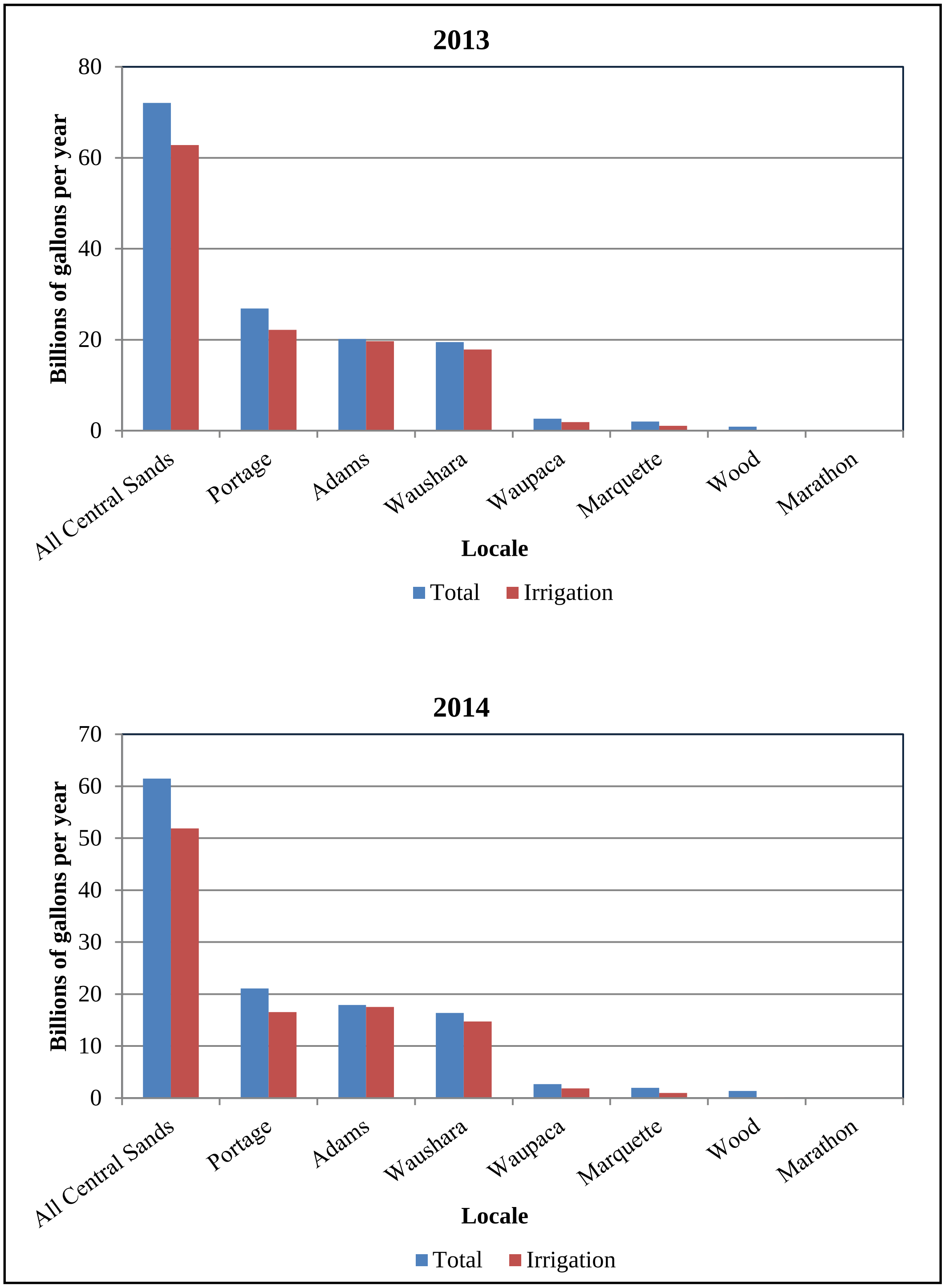


Figure 3-3. Total and irrigation high capacity well pumping in the central sands, total and by county, 2013 and 2014.

4. BASEFLOW DISCHARGES ON SELECT STREAMS – UPDATE

Baseflow discharge measurements continued at 32 of 42 stream locations (Figure 4-1, Table 4-1) previously measured by Kraft et al. (2010). Discharges were measured monthly through the study period except in January and April of 2013. Most of the 32 sites had discharge histories that predated Kraft et al. 2010. Thirteen were at or near current and former USGS daily discharge sites, and eight were at USGS miscellaneous or "spot" sites that had one or more occasional measurements. Thirteen sites, including eight USGS sites, were gauged as part of the Fox-Wolf project in 2005-2006 (Kraft et al. 2008) (Table 4-1). Data for locations with both UWSP and USGS histories are summarized and compared in Table 4-2. Complete data are included with this report as electronic media in a spreadsheet entitled "Q for Central WI Rivers thru June 2016.xlsx." Data collected through June 2016 were sent to USGS to be archived in their database.

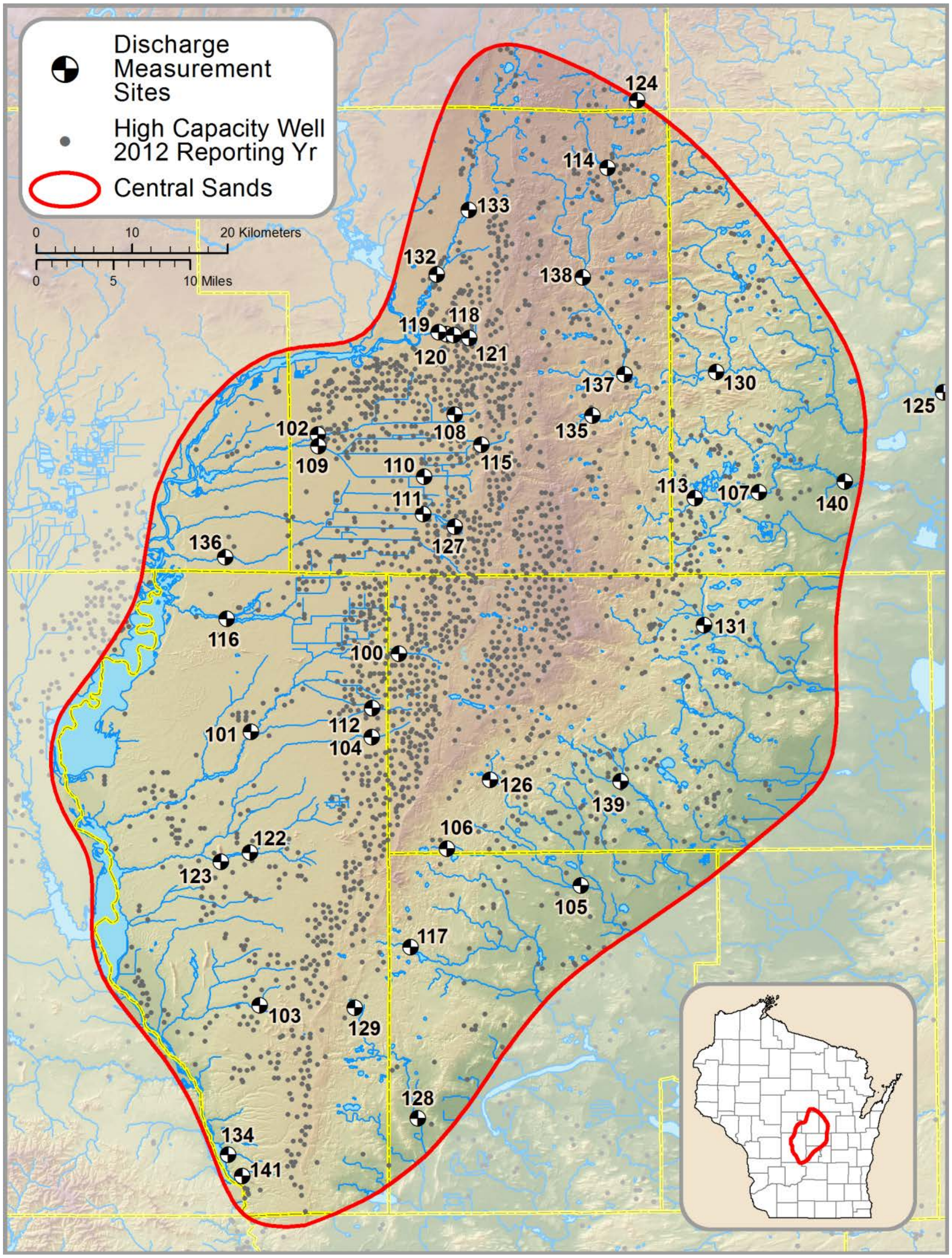


Figure 4-1. Discharge measurement sites from Kraft et al. 2010, most of which were continued for this study.

Table 4-1. Discharge measurement sites from Kraft et al. 2010. Sites not included in the present study are shaded. Also indicated is whether the site had measurements in the USGS Daily or Spot record or in the Fox-Wolf project (Kraft et al. 2008), and whether the location is dam affected.

Map Location	Project Site Name	USGS Site Type[1]	USGS Years	Fox-Wolf Site?	Comments
100	Big Roche-A-Cri @ 1st Ave	Near Daily	1963 - 1967		Moved 0.8 Miles Downstream
101	Big Roche-A-Cri @ Brown Deer Ave	At Daily	1963 - 1978		
102	Buena Vista Creek @ 100th Rd	Near Daily	1964 - 1967		Moved 0.4 Miles Upstream
103	Campbell Creek @ A	At Spot	1971		
104	Carter Creek @ G				
105	Chaffee Creek @ 14th	At Spot	1962 - 1988	Y	
106	Chaffee Creek @ CH			Y	
107[2]	Crystal River @ K			Y	
108	Ditch #2 N Fork @ Isherwood	At Spot	1966		
109	Ditch #4 @ 100th Rd	Near Daily	1964 - 1967		Moved 0.9 Miles Upstream
110	Ditch # 4 @ Taft				
111	Ditch #5 @ Taft	At Daily	1964 -1973		
112	Dry Creek @ G				
113	Emmons Creek @ Rustic Road 23	At Daily	1968 - 1974	Y	
114	Flume Creek in Rosholt @ 66	At Spot	1972 - 1976	Y	
115	Four Mile Creek @ JJ&BB				
116[2]	Fourteen Mile Creek @ 13	At Daily	1964 - 1979		
117	Lawrence Creek @ Eagle	Near Daily	1967 - 1973	Y	Moved 0.5 Miles Downstream
118	Little Plover @ Eisenhower	At Spot	1961 - 1963		
119	Little Plover @ Hoover	At Daily	1959 - 1987		
120	Little Plover @ I-39	At Spot	1961 - 1963		
121	Little Plover @ Kennedy	At Daily	1959 - 1976		
122	Little Roche-A-Cri @ 10th Ave.				
123[2]	Little Roche-A-Cri @ Friendship Park	At Spot	1972 - 1976		
124	Little Wolf @ 49	At Daily	1973 - 1979		
125	Little Wolf @ 54	At Daily	1914 -1985		
126	Mecan @ GG	At Spot	1956 - 1988	Y	
127	NB Ten Mile @ Isherwood/Harding				
128	Neenah @ A			Y	
129	Neenah @ G			Y	
130	Peterson Creek @ Q	At Spot	1962 - 1988	Y	
131	Pine River @ Apache			Y	Moved 0.5 Miles Downstream
132	Plover River @ I-39	At Daily	2010-2015		Moved 0.5 Miles Upstream

Table 4-1. Discharge measurement sites from Kraft et al. 2010 (continued).

Map Location	Project Site Name	USGS Site Type[1]	USGS Years	Fox-Wolf Site?	Comments
133	Plover River @ Y	At Daily	1914 - 1951		
134	Shadduck Creek @ 13				
135	Spring Creek @ Q			Y	
136	Tenmile Creek @ Nekoosa	At Daily	1963 - 2009		
137	Tomorrow @ A			Y	
138	Tomorrow @ River Rd (Clementson)	At Daily	1995	Y	
139	W Branch White River @ 22	At Daily	1963 - 1965	Y	
140	Waupaca River @ Harrington Rd	At Daily	1916 - 1985		
141	Witches Gulch @ 13	Near Spot	1972 - 1973		Moved 0.1 Miles Downstream

1. "At" is at the exact USGS site. "Near" is at the specified distance up or down stream.
2. Measurements are potentially affected by a nearby dam.

Table 4-2. Comparison of archived USGS and recent UWSP discharge data (cfs) through 2015.

Project Site Name	USGS						UWSP				
	Years	Data Type	N	Mean	Min	Max	Years	N	Mean	Min	Max
Big Roche-A-Cri @ 1st Ave	1963-1967	Daily	1,461	9.3	4.1	50.0	2007-2015	74	9.4	2.4	27.6
Big Roche-A-Cri @ Brown Deer Ave	1963-1978	Daily	5,496	60.6	28.0	460.0	2007-2015	62	46.4	26.2	83.1
Buena Vista Creek @ 100th Rd	1964-1967	Daily	1,309	44.6	14.0	187.0	2007-2015	68	33.0	8.7	66.5
Campbell Creek @ A	1971	Spot	1	2.6	2.6	2.6	2007-2015	74	2.4	1.0	4.3
Chaffee Creek @ 14th	1962-1988	Spot	18	34.7	25.9	47.5	2007-2015	76	37.8	24.0	62.6
Ditch #2 N Fork @ Isherwood	1966	Spot	1	5.7	5.7	5.7	2007-2015	95	6.2	3.1	11.6
Ditch #4 @ 100th Rd	1964-1967	Daily	1,309	39.6	4.0	256.0	2007-2015	14	39.2	13.9	71.8
Ditch #5 @ Taft	1964-1973	Daily	3,383	8.0	2.2	166.0	2007-2015	59	5.2	0.4	15.0
Emmons Creek @ Rustic Road 23	1968-1974	Daily	2,330	26.7	21.0	203.0	2007-2015	87	23.0	15.1	39.7
Flume Creek in Rosholt @ 66	1972-1976	Spot	5	6.3	3.6	8.7	2007-2015	66	8.9	2.6	34.3
Lawrence Creek @ Eagle	1967-1973	Daily	2,161	16.9	12.0	39.0	2007-2015	76	19.8	14.7	22.7
Little Plover @ Eisenhower	1968	Spot	6	4.1	2.6	5.1	2007-2015	109	3.1	0.0	8.9
Little Plover @ Hoover	1959-1987	Daily	1,0319	10.6	3.9	81.0	2007-2015	230	5.8	1.7	17.4
Little Plover @ Kennedy	1959-1976	Daily	6,218	4.0	0.8	50.0	2007-2015	221	1.8	0.0	6.8
Little Roche-A-Cri @ Friendship Park	1972-1976	Spot	8	35.7	18.2	68.8	2007-2015	62	37.2	2.6	93.4
Little Wolf @ 49	1973-1979	Daily	2,199	17.1	3.1	220.0	2007-2015	45	13.7	4.3	56.6
Mecan @ GG	1956-1988	Spot	22	12.8	10.3	17.9	2007-2015	76	13.1	9.4	15.3
Peterson Creek @ Q	1962-1988	Spot	15	18.0	12.9	28.8	2007-2015	81	22.3	10.2	36.2
Plover River @ I-39	2010-2015	Daily	1,894	176.0	61.0	730.0	2005-2015	101	113.6	36.6	208.3
Plover River @ Y	1914-1951	Daily	5,113	146.9	37.0	1450.0	2007-2015	114	108.8	39.2	263.0
Tomorrow @ River Rd (Clementson)	1993-1995	Daily	905	33.6	16.0	212.0	2007-2015	107	23.0	12.5	88.8
W Branch White River @ 22	1963-1965	Daily	731	22.1	16.0	61.0	2007-2015	75	25.2	20.0	50.2

5. LONG TERM MONITORING WELL WATER LEVELS AND TRENDS – UPDATE

Summary

The long-term records of eight central sands monitoring wells have proved useful for exploring groundwater level trends over the last 60 years and for separating the influences of pumping from the influences of weather. Four of the eight monitoring wells, three of which are still active, are located in areas with few high capacity wells and are only modestly affected by high capacity well pumping. Their levels are thus representative of groundwater controlled mostly by weather. Levels in few high capacity well areas demonstrated record lows during the 1950s and early 1960s, concurrent with the acute drought that prevailed at the time. Water levels rose from these lows through 1974 and have since fluctuated cyclically. Levels were somewhat low during 2005-2010 (at the 5th to 23rd percentile of record, depending on locale), but rebounded sharply following the wet 2010-2011 years and in 2014-2015 were at the 47th to 91st percentiles of record.

The four monitoring wells located in areas with many high capacity wells are substantially pumping affected. Their water levels initially paralleled those of few high capacity well areas, but began an incongruent decline during 1973-1990, depending on locale. Water levels plummeted in 2005-2010 to lows deeper than the 1950s drought. Recent levels in many high capacity well areas were still at or near the record lows of the pre-pumping era. Drawdowns in 2013-2014 were estimated at about 4.5 feet at Plover and Hancock, 0.5 feet at Bancroft, and 2.3 feet at Coloma.

Monitoring Wells

The records of eight monitoring wells in the USGS archives have proved useful (Kraft et al. 2010, 2012a, 2014) for exploring central sands groundwater level trends over the last half-century (Table 5-1, Figure 5-1). Four of the eight monitoring wells (Amherst Junction, Nelsonville, Wild Rose, and Wautoma) are in areas with relatively few high capacity wells, and four (Plover[1], Hancock, Bancroft, and Coloma NW) are in areas with many high capacity wells. Here we update the analysis of these records for 2014-2015.

Water level records suffer several deficiencies. The Wild Rose record terminated in 1994, and the Nelsonville record lacks observations for 1998-2010. Records are sparse at some locations during some periods, particularly at Coloma NW. With the reconstruction of the Nelsonville monitoring well (Kraft et al. 2012a), seven of the eight wells are currently generating data.

[1] Three wells have been located at the Plover site with water levels recorded under two different well numbers in the USGS database. Data explored in this study use combined information from these three wells referenced to a common datum, discussed further in Kraft et al. 2010.

Table 5-1. Useful USGS water level monitoring wells with long term records.

USGS Station Name	Locale or Quadrangle	Well Depth (ft)	First Observation	Last Observation	Number of Observations
PT-24/10E/28-0015*	Nelsonville	52.0	8/24/1950	2015+	1,372+
PT-23/10E/18-0276	Amherst Jct.	17.4	7/2/1958	2015+	1,740+
PT-23/08E/25-0376**	Plover	19.0	12/1/1959	2015+	1,214+
WS-18/10E/01-0105	Wautoma	14.0	4/18/1956	2015+	18,974+
WS-19/08E/15-0008	Hancock	18.0	5/1/1951	2015+	20,479+
PT-21/08E/10-0036	Bancroft	12.0	9/7/1950	2015+	1,684+
PT-21/07E/31-0059***	Coloma NW	15.3	8/8/1951	2015+	787+
WS-20/11E/02-0053	Wild Rose	177.0	2/6/1956	5/20/1994	442

* Replaced by 443126089174201 on November 17, 2010.

** Three different monitoring wells have been located at this site, see text.

***Replaced by 441452089433001 in 1995

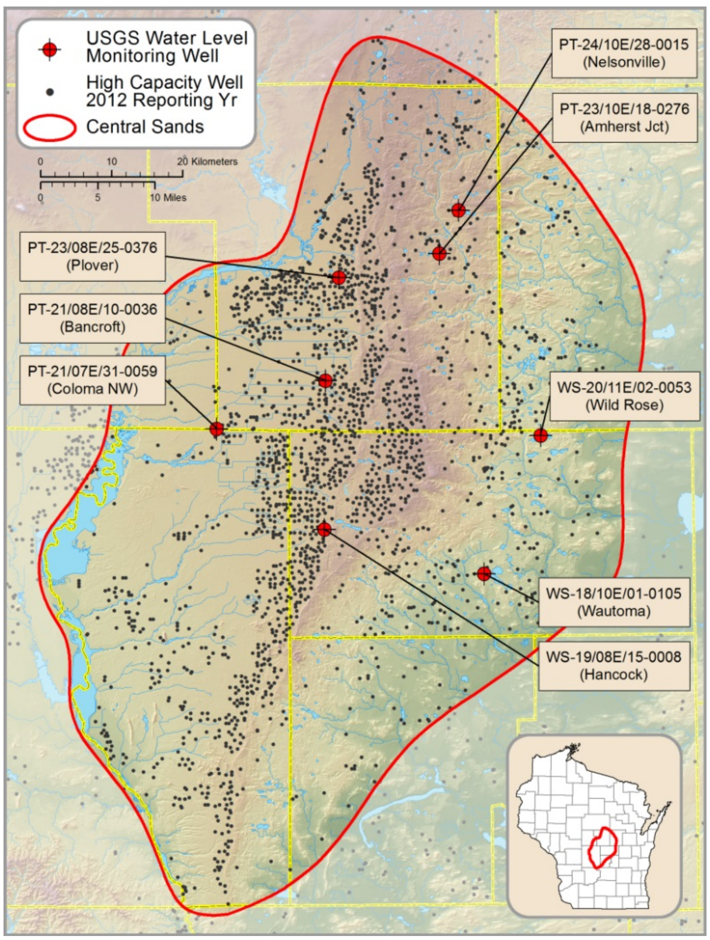


Figure 5-1. Location of eight USGS monitoring wells with records sufficient for exploring long term water level trends.

Groundwater Hydrographs

Updated annual average hydrographs are displayed in Figure 5-2, grouped by location in areas of few or many high capacity wells. For display purposes, average annual water levels in each well were zeroed to the well's 1969 level, with positive values indicating a greater depth to water (water level decline) compared with 1969, and negative values a shallower depth (water level rise).

The hydrographs demonstrate some common peaks (evident around 1974, 1985, and 1993) and valleys (1959, 1978, 1990, and 2007) that coincide with wet and dry weather periods (Chapter 2). Though peaks and valleys coincide, amplitudes and trends differ. Amplitude differences are expected and are explainable by groundwater hydraulics: groundwater levels near discharge zones are constrained by the water level of the discharge zone, while groundwater levels far from discharge zones are less constrained. Thus, groundwater levels at the Coloma NW and Bancroft locations, which are near groundwater discharge zones, have small amplitudes.

Though water level amplitudes are explainable by the location within the groundwater flow system, water level trends conform as to whether monitoring wells are in an area of fewer or many high capacity wells. Levels in areas with fewer high capacity wells were at their record lows during the late 1950s - early 1960s, coincident with a decade that witnessed some years of the smallest precipitation amounts and stream discharges of the twentieth century (Chapter 2). In contrast, water levels in areas with many high capacity wells were lower during the modestly dry period of 2005-2010 than the historic record lows. The declines in areas of many high capacity wells are beyond what is explainable by weather variability alone and are attributed to a pumping effect (Kraft et al. 2010, 2012a). Water level decline start date, rate, and average 1999-2008 amount were previously estimated (Table 5-2, Kraft et al. 2010, 2012a, 2012b).

Table 5-2. Pumping induced water level decline 1999-2008, decline rate, and approximate start of decline for monitoring wells in high density irrigated areas (Kraft et al. 2012a, 2012b).

Station	Comparison Station(s)	Decline (ft)	Decline rate (ft y^{-1})	Decline start
Plover	Amherst Junction	2.1 (3.4)[1,*]	0.12	1973
Hancock	Wautoma	3.2*	0.21	1990
Bancroft	Amherst Junction	0.82*	0.062	1984
Bancroft	Wautoma	1.2*	0.062	1984
Coloma NW	Amherst Junction	0.0	--	--
Coloma NW	Wautoma	2.2*	--	1978

* Decline is significant at 0.05 level.

[1] Total decline = 3.4 ft; irrigation decline = 2.1 ft

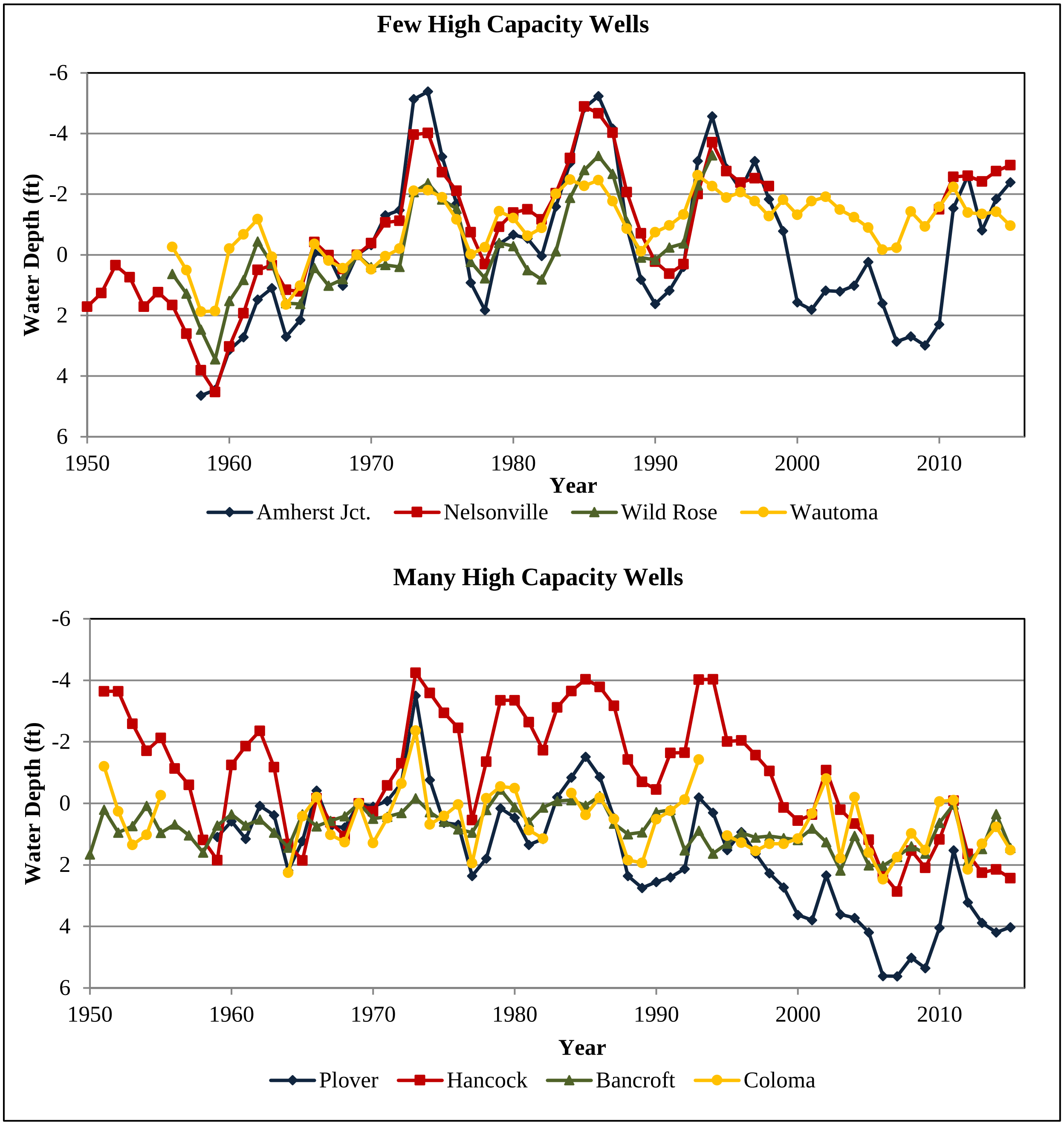


Figure 5-2. Annual average water levels in areas of few (top) and many (bottom) high capacity wells. Water levels are zeroed to 1969 water depths for display purposes.

Recent Groundwater Levels and Pumping Drawdowns

Groundwater levels since 2011 have been mostly steady. Levels in areas of fewer high capacity well were generally above average, at the 47th to 91st percentile, while those in areas with many high capacity wells were near or below their historic drought minimums.

Year-by-year pumping declines in pumping affected areas were estimated by subtracting the actual measured water level from the water level expected in the absence of pumping. Expected water levels in the absence of pumping were generated using the relationship of water levels in the areas with many high capacity wells to water levels in one or more wells in areas with few high capacity wells ("reference" areas) during an early baseline period when pumping effects were assumed small. More detail on methodology is documented in Kraft et al. (2010, 2012a).

Plover

Water levels at the Plover monitoring well have been decreasing since the 1980s (Figure 5-3, top), and reached a record low in 2007-2008. Pumping drawdowns at Plover were estimated at 4.5 feet for 2014-2015 (Figure 5-3, bottom).

Hancock

Water levels at Hancock began a systematic decrease around 1990, and were at record lows through much of 2006-2009 (Figure 5-4, top). Water levels rebounded several feet in 2010-2011 (again, presumably in response to large rains), but fell by about 2 feet in 2012-2013. Estimated pumping declines in 2014-2015 were about 4.4 feet (Figure 5-4 bottom).

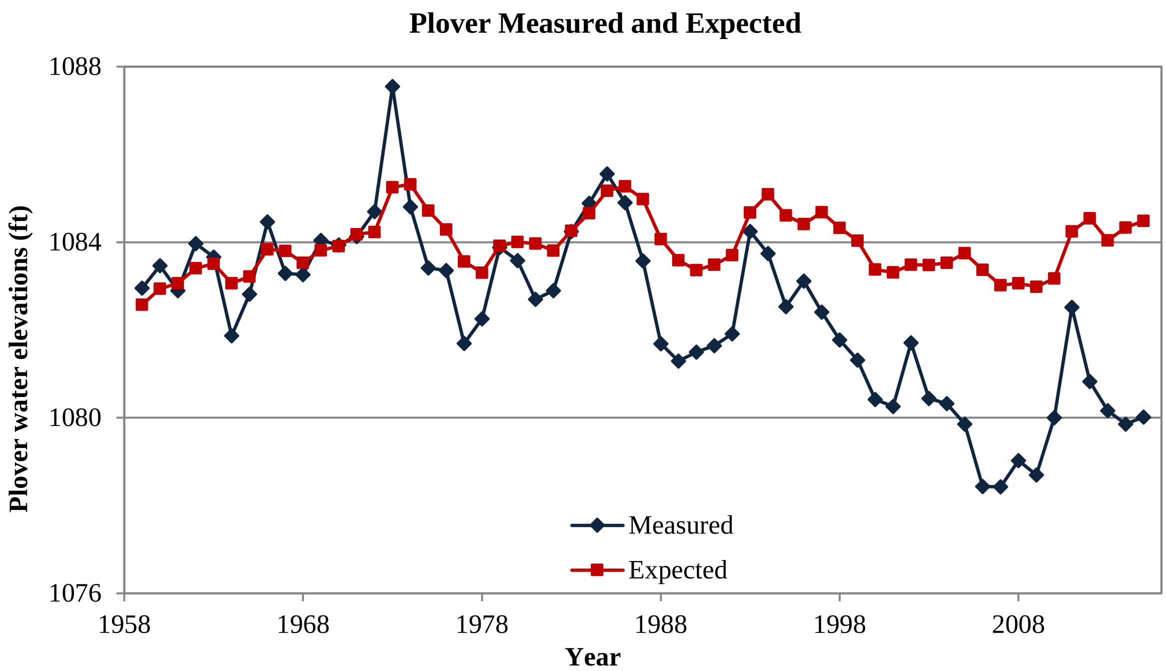
Bancroft

Bancroft water levels have been in decline since the mid-1980s and were at record lows during much of 2003-2007 (Figure 5-5, top). Estimated pumping declines at Bancroft were calculated against both Wautoma and Amherst Junction, since Bancroft is not particularly nearer to either. The comparison against Wautoma is likely more appropriate, as the Bancroft early water level record correlates more closely with Wautoma, and precipitation increase patterns are more similar. Pumping induced declines at Bancroft have an apparent beginning around 1984, and in 1999-2008 averaged 1.2 feet, Wautoma reference (Figure 5-5, bottom), or 0.82 feet, Amherst Junction reference. Estimated average pumping declines in 2014-2015 were 0.34 feet (Wautoma) and 0.55 feet (Amherst Junction).

Coloma NW

Groundwater levels at Coloma NW have generally been declining since the early 1990s. Levels were at a low for the 1964-2015 record in 2006, rebounded to near the long term average in 2010-2011, and in 2012-2015 were near the low of the long term record (Figure 5-6, top).

Coloma NW water levels are odd compared with other sites, possibly because of complications due to its location near a groundwater discharge. The Coloma locale is also distant from both the Amherst Junction and Wautoma reference wells and not well correlated with either. For this reason, the methodology used here to estimate the influence of groundwater pumping gives differing estimates depending on the reference well. The expected water level in absence of pumping and estimated pumping decline are shown relative to the Wautoma reference well in Figure 5-6 (bottom), which indicates a maximum pumping decline of 3.6 feet in 2012 and a decline in 2014-2015 of 2.4 feet. Comparisons using the Amherst Junction reference site indicates a maximum pumping decline of 3.0 feet in 2012 and a decline in 2014-2015 of 1.7 feet. Haucke (2010), using a statistical method based on precipitation, estimated a pumping drawdown averaging 0.7 feet at Coloma NW.



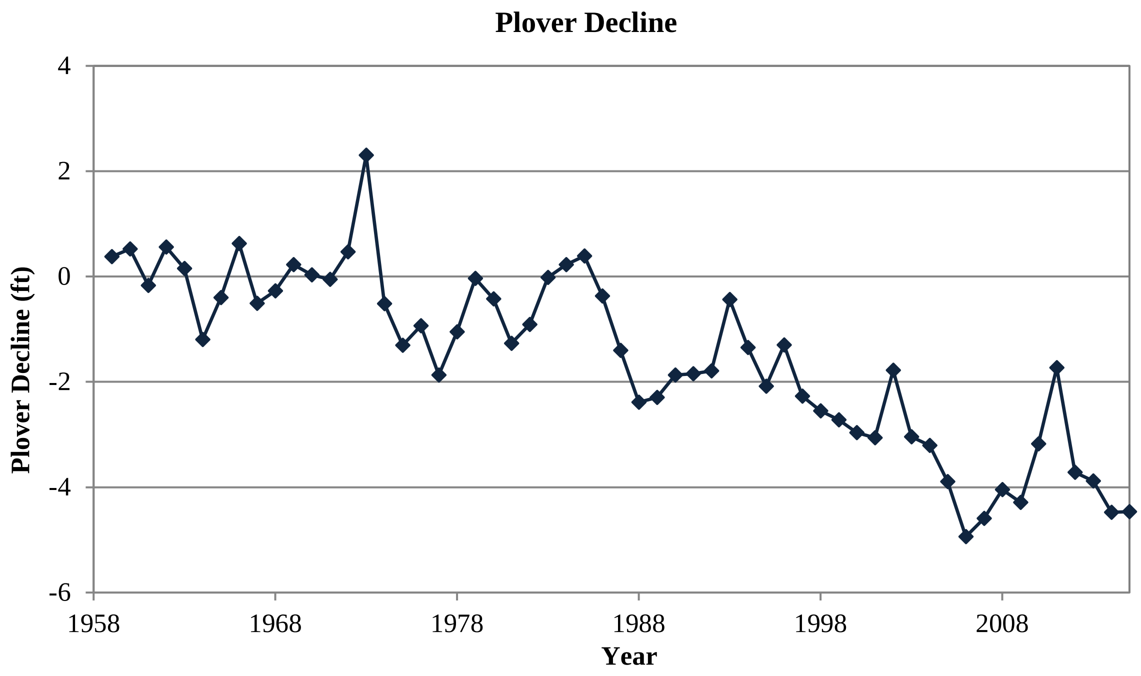
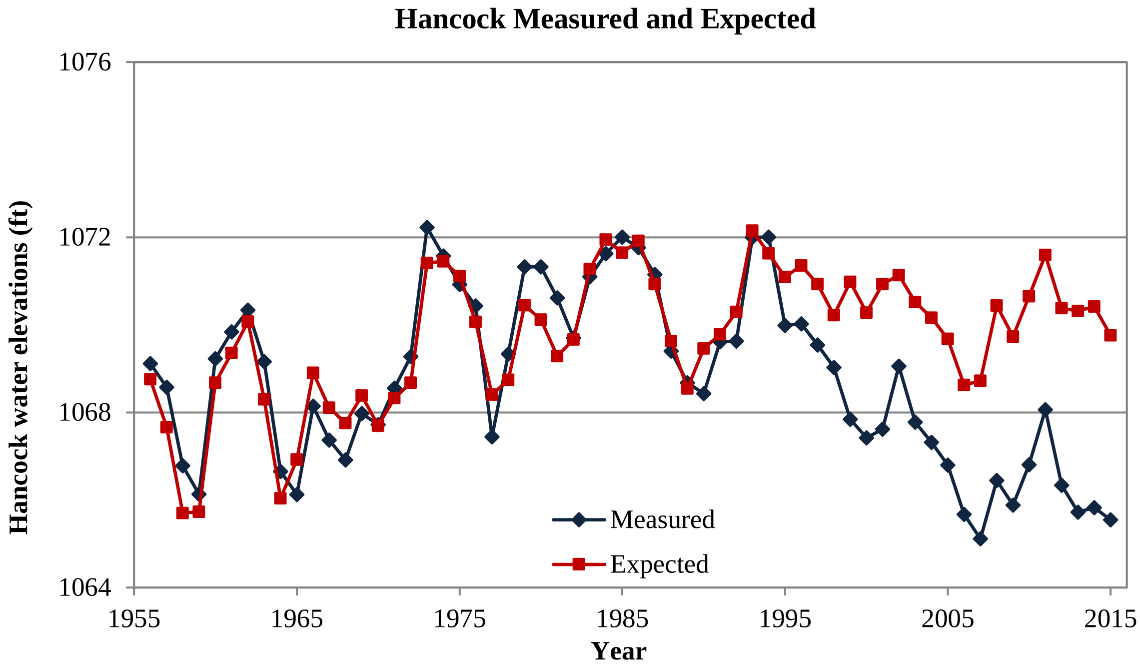


Figure 5-3. Measured and expected average annual groundwater elevations at Plover (top). Estimated pumping induced water level declines calculated as the difference between measured and expected water levels (bottom).



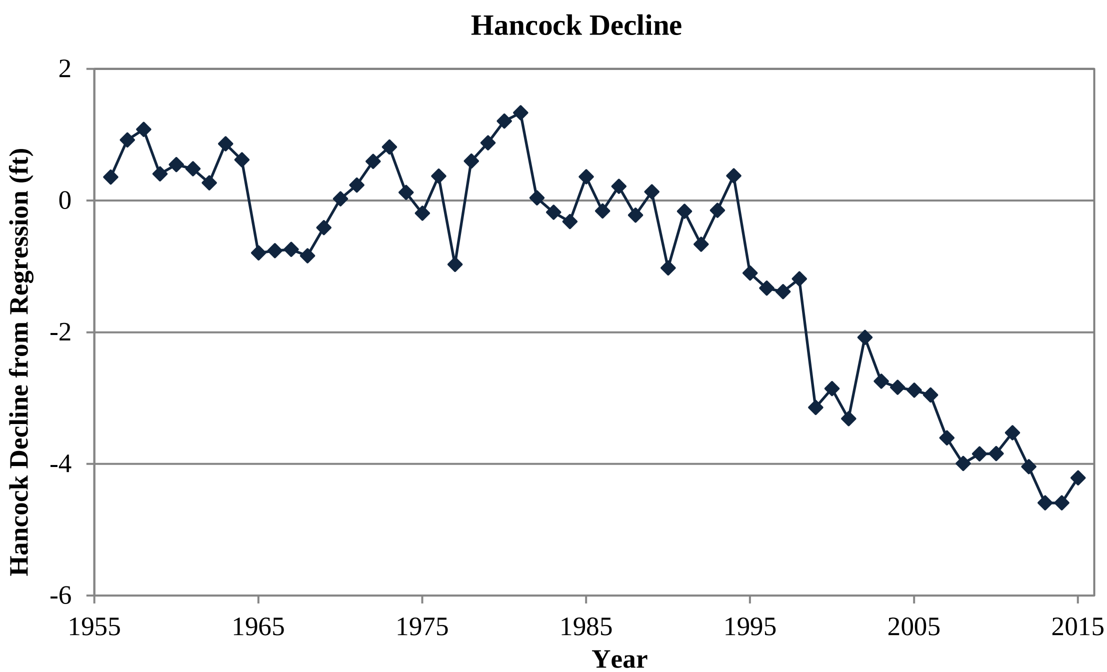
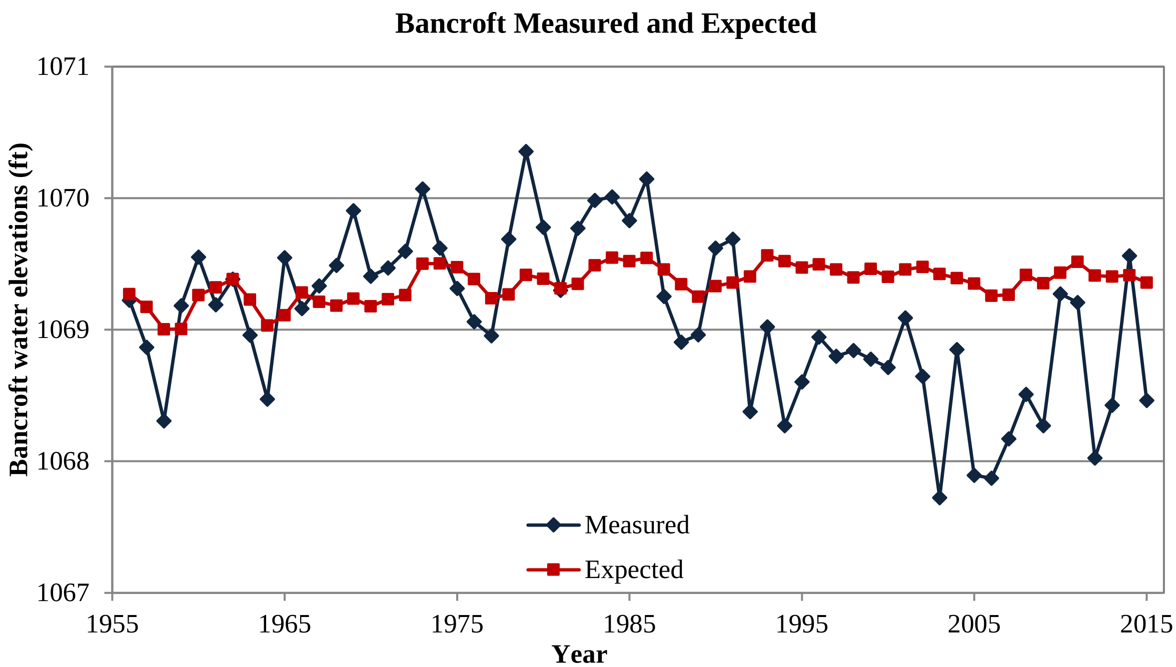


Figure 5-4. Measured and expected average annual groundwater elevations at Hancock (top). Estimated pumping induced water level declines calculated as the difference between measured and expected water levels (bottom).



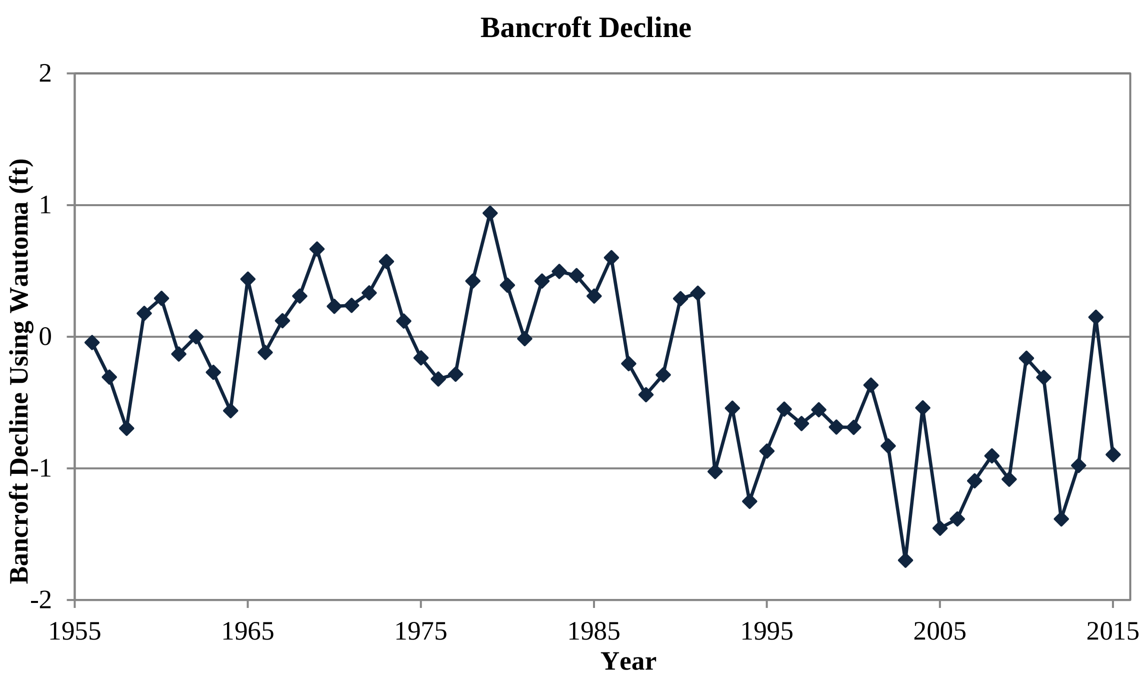
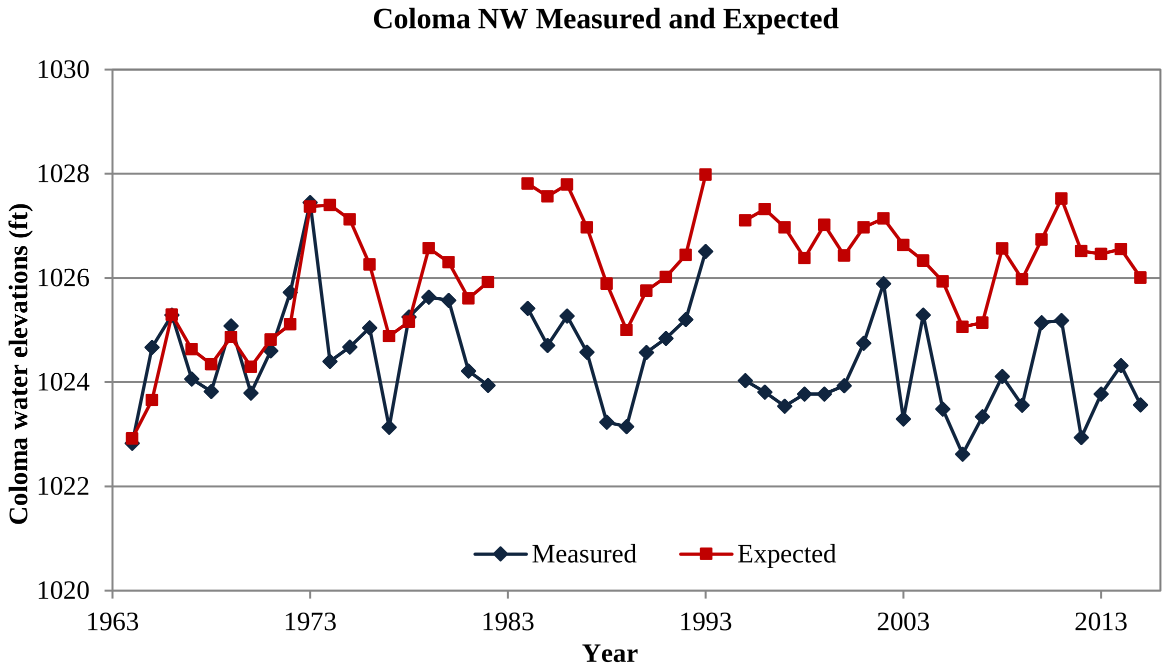


Figure 5-5. Measured and expected average annual groundwater elevations at Bancroft (top). Estimated pumping induced water level declines calculated as the difference between measured and expected water levels (bottom). Wautoma reference shown, Amherst Junction is similar.



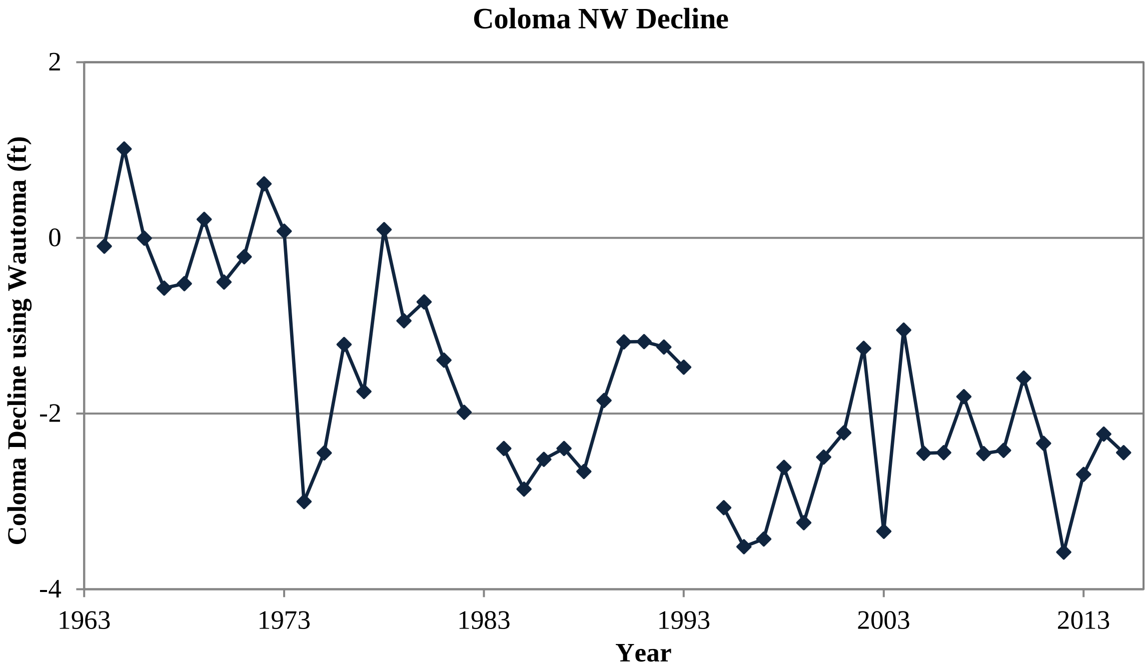


Figure 5-6. Measured and expected average annual groundwater elevations at Coloma NW (top). Estimated pumping induced water level declines calculated as the difference between measured and expected water levels (bottom). Wautoma is used as the reference gauge. Use of the Amherst Junction gauge does not show a pumping decline (see text).

6. LAKE LEVEL RECORD AND TRENDS – UPDATE

Summary

Lake levels for previously inventoried lakes were downloaded and added to the project's database. For the 31 lakes with data, levels were at long-term lows in 2007. Levels increased by an average 2.6 feet in 2011, presumably due to large rains in 2010-2011. Levels have since declined, by an average 1.4 feet through 2015. The drawdowns of four lakes previously found to have large and significant pumping declines were revisited. Estimated drawdowns in the four, which reached 3.3 to 8 feet in 2007-2010, were 1.8 to 5.5 feet in 2015.

Lake Level Data

Kraft et al. (2010) previously identified 39 lakes with potentially useful level records in agency archives (Figure 6-1). The lake data inventory (Table 6-1) and level data base (Lake Level Data Updated

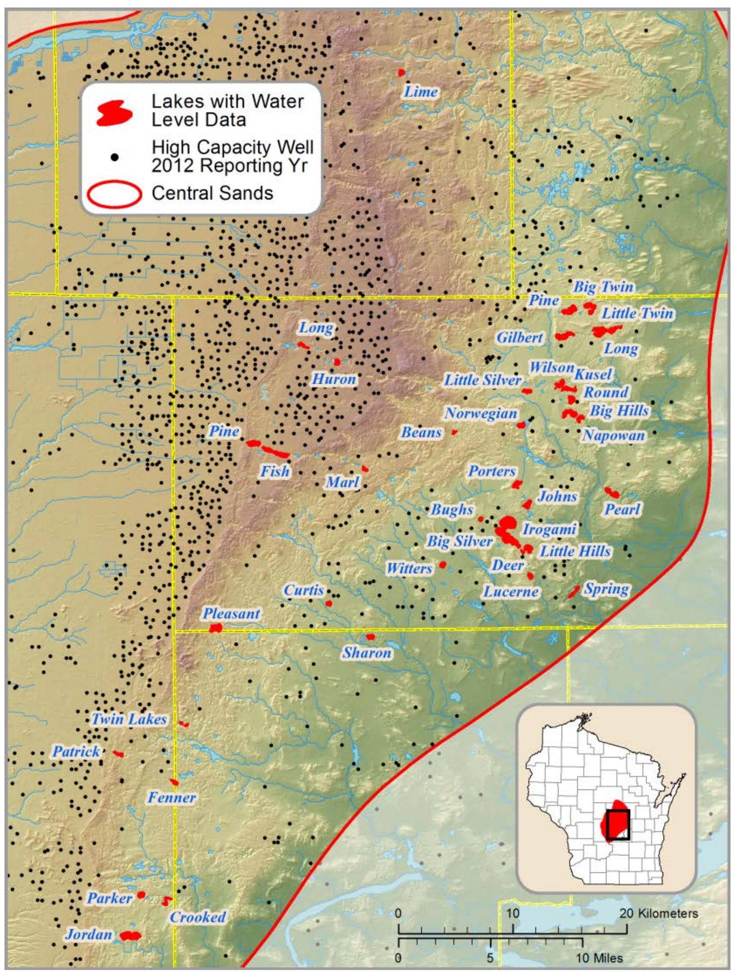


Figure 6-1. Location of lakes with water level data in the project database.

Table 6-1. Lakes with potentially useful water level information.

Lake Name	County	Number of Levels	First Lake Level	Last Lake Level	Avg. Years Between Levels
Bean's Lake	Waushara	19	7/10/73	8/26/15	2.22
Big Hills Lake (Hills)	Waushara	18	9/7/95	8/28/15	1.11
Big Silver Lake	Waushara	31	5/14/66	8/26/15	1.59
Big Twin Lake	Waushara	21	6/18/75	8/27/15	1.92
Burghs Lake	Waushara	26	9/7/73	8/26/15	1.62
Crooked Lake	Adams	12	6/14/73	6/20/89	1.34
Curtis Lake	Waushara	18	9/12/95	8/24/15	1.11
Deer Lake	Waushara	19	7/28/93	8/26/15	1.16
Fenner Lake	Adams	8	4/25/74	6/13/85	1.39
Fish Lake	Waushara	19	7/10/73	8/24/15	2.22
Gilbert Lake	Waushara	36	5/10/62	8/27/15	1.48
Huron Lake	Waushara	21	7/3/73	8/24/15	2.01
Irogami Lake	Waushara	32	1/1/31	8/26/15	2.65
John's Lake	Waushara	19	7/28/93	8/28/15	1.16
Jordan Lake	Adams	20	9/8/67	9/6/90	1.15
Kusel Lake	Waushara	34	9/30/63	8/28/15	1.53
Lake Lucerne	Waushara	30	9/30/63	8/26/15	1.73
Lake Napowan	Waushara	22	5/21/85	8/28/15	1.38
Lake Sharon	Marquette	72	11/17/84	5/31/94	0.13
Lime Lake	Portage	6	10/2/40	11/7/94	9.02
Little Hills Lake	Waushara	15	8/3/01	8/26/15	0.94
Little Silver Lake	Waushara	19	7/20/93	8/28/15	1.16
Little Twin Lake	Waushara	20	5/21/85	8/27/15	1.51
Long Lake	Waushara	31	8/16/61	8/24/15	1.74
Long Lake Saxeville[1]	Waushara	22	11/3/87	8/27/15	1.27
Long Lake Saxeville[2]	Waushara	84	6/1/47	7/1/09	0.74
Marl Lake	Waushara	18	4/1/98	8/24/15	0.97
Norwegian Lake	Waushara	20	6/23/75	8/28/15	2.01
Parker Lake	Adams	13	5/26/83	9/6/90	0.56
Patrick Lake	Adams	9	5/6/77	6/16/86	1.01
Pearl Lake	Waushara	19	6/17/75	8/26/15	2.12
Pine Lake Hancock	Waushara	23	7/10/73	8/24/15	1.83
Pine Lake (Springwater)	Waushara	35	2/8/61	8/27/15	1.56
Pleasant Lake	Waushara	29	7/9/64	8/24/15	1.76
Porter's Lake	Waushara	14	7/26/02	8/28/15	0.94
Round Lake	Waushara	17	4/1/98	8/28/15	1.02
Spring Lake	Waushara	26	10/1/63	8/26/15	2.00
Twin Lakes Westfield	Marquette	11	6/6/02	8/23/04	0.20
Wilson Lake	Waushara	21	6/18/75	8/28/15	1.92
Witter's Lake	Waushara	28	10/6/63	8/24/15	1.85

[1] Record provided by Waushara County and WDNR

[2] Distance of benchmark to water (“beach width”) provided by Long Lake resident.

to 2015.xlsx, appended as electronic media) have been updated through 2015.

Thirty-one of the 39 lakes have some post-2000 water level data, but data for the more distant past are scarce (Figure 6-2). Only five measurements from two lakes pre-date 1950. Lake level records averaged 0.6 per year in the 1950s, 5 per year in 1960-1989, 10 per year in the 1990s, and almost 31 per year after 2000.

For the 31 lakes with recent water level information, 2007 marked a long term low, rivalled only by lows during 1958-1964. Levels increased from 2007 through 2011, by an average of 2.6 feet (maximum 4.8 feet), though for a few “headwater” lakes (lakes with outlets that control water levels), increases were a few tenths of a foot. We attribute the water level increases mainly to the large precipitation amounts of 2010-2011. Lake level trends since 2011 have been downward. Declines between 2011 and 2015 averaged 1.4 feet and had a maximum of 3.5 feet (Huron Lake).

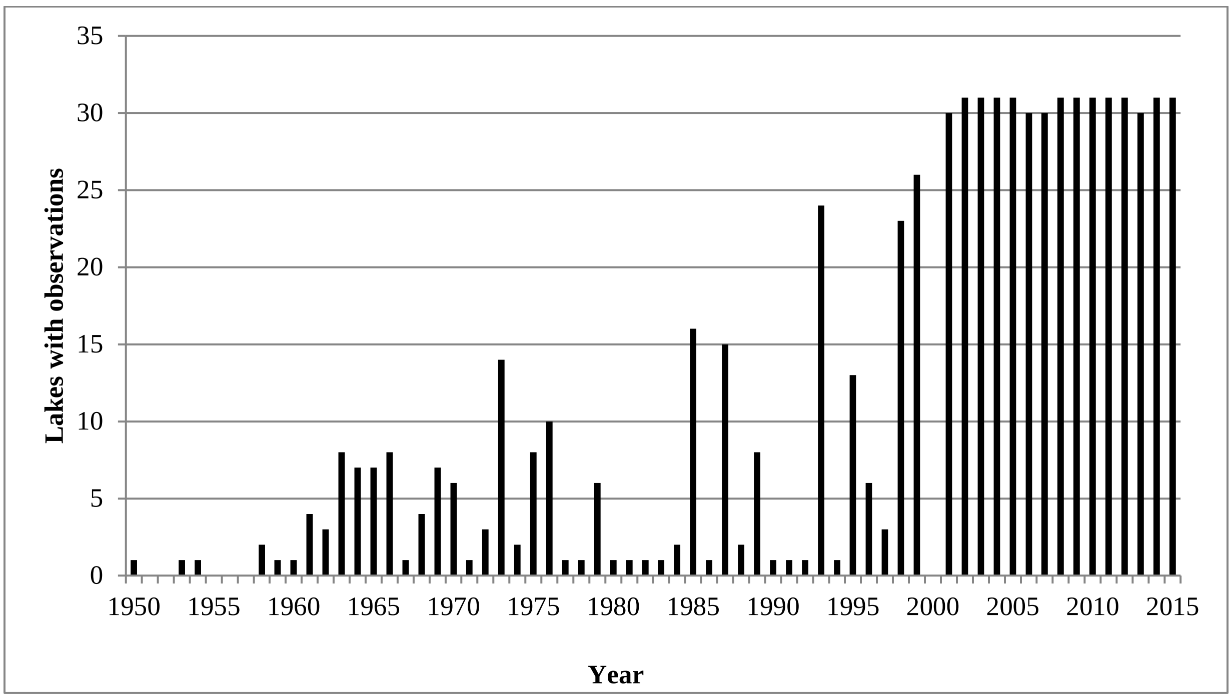


Figure 6-2. Number of lakes with water level elevations by year (two lakes combined had five total observations prior to 1950).

Long Lake – Saxeville Levels

Long Lake – Saxeville (not to be confused with Long Lake – Oasis near Plainfield, which dried in 2006), has an uncommonly detailed record that includes multiple observations in the 1940s and 1950s, and even a single observation in 1927. The record has four data sources (Kraft et al. 2010): citizen stage data, agency (WDNR, Wisconsin Conservation Department, Waushara County) stage data, USGS staff gauge data, and stages inferred from a citizen’s beach width record (Figure 6-3). The first three sources were reconciled by P. Juckem of the USGS (pers. comm.), and stages were inferred from citizen beach width measurements by Kraft et al. (2010) regression. For the most part, Long Lake data sources are mutually corroborative, with the possible exception of the 1958-1959 period, when beach width derived levels might be lower than directly observed ones. The Long Lake – Saxeville record shows an extended period of water level decline from 1940s highs through 1959. In common with monitoring wells in areas with few high capacity wells (Figure 5-2), water levels generally rose from 1964 through 1974, and thereafter have fluctuated cyclically. The 2000-2006 lake levels remained above their long term average, but in 2007 dropped to levels unseen since 1964. Levels rebounded through 2011 before declining somewhat through 2015.

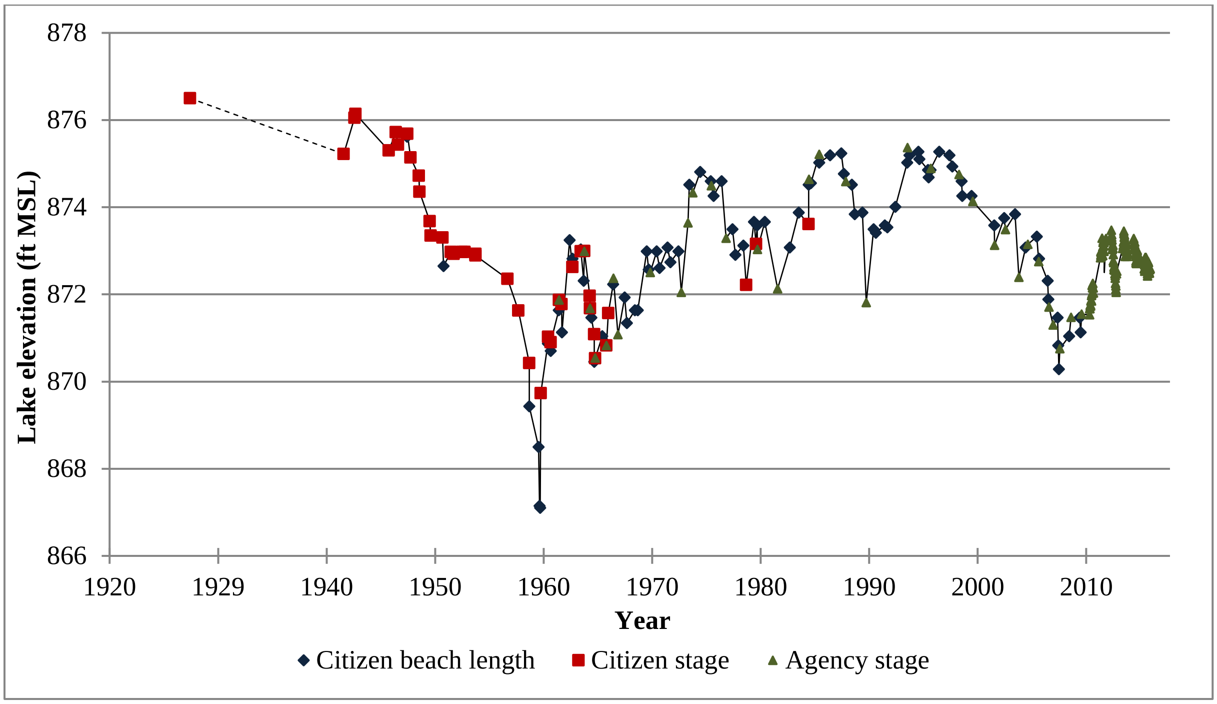


Figure 6-3. Hydrograph of Long Lake - Saxeville 1950-2015 (not to be confused with Long Lake - Oasis, which dried in 2006).

Pumping Effects Update for Four Lakes

Previously, the records of 13 lakes with sufficient data were evaluated to determine if their water levels had declined beyond what could be expected from weather influences alone (Kraft et al. 2010). The evaluation was similar to that used for monitoring wells (Chapter 5), and compared lake water levels to Wautoma monitoring well levels during a period when pumping was less developed and during the present period. A difference in the relation between the periods is a signal of a nonweather influence, presumed to be pumping. Four lakes in the Plainfield – Hancock – Coloma vicinity (Huron, Fish, Pine – Hancock, and Pleasant) demonstrated large and statistically significant declines. Estimated drawdowns averaged 1.5 to 3.6 feet, depending on lake, for 1993 through 2007.

Estimated pumping induced declines are revisited here for the four lakes through 2015, with a look toward year-by-year declines rather than longer term averages (Figure 6-4). Pumping declines have rebounded somewhat since their maximum in 2007-2010, and in 2015, estimated pumping declines ranged from 1.8 feet (Pleasant Lake) to 5.5 feet (Huron Lake).

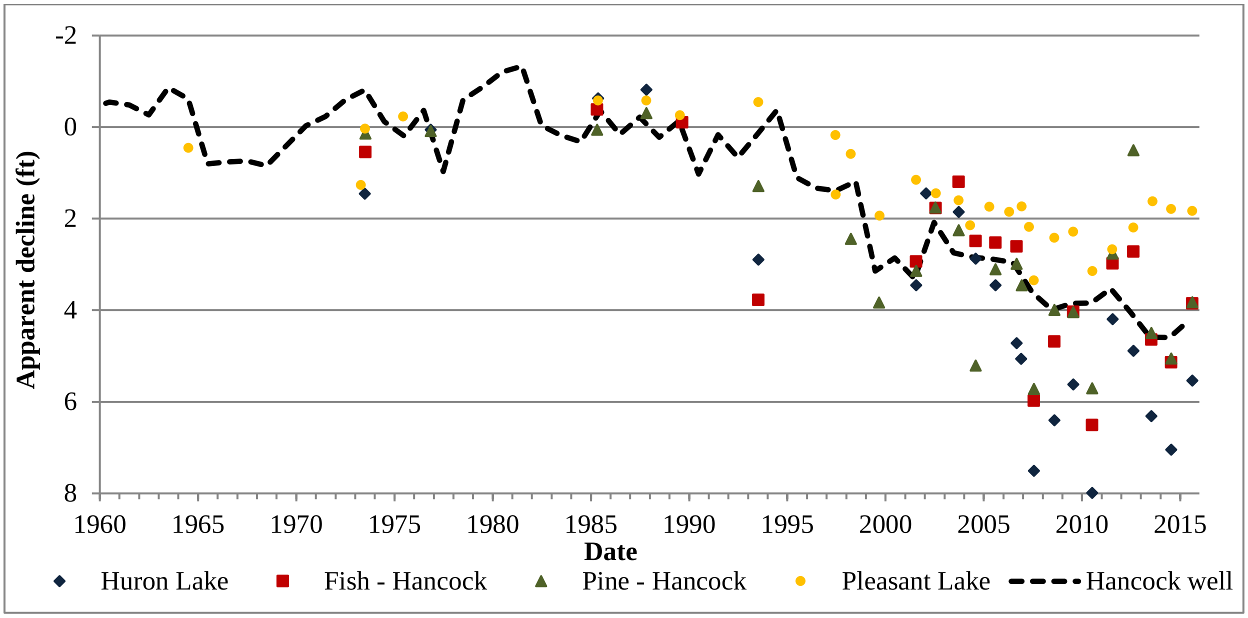


Figure 6-4. Declines in water levels at four lakes and the Hancock monitoring well.

7. LITTLE PLOVER RIVER 2013-2015 UPDATE

Summary

Little Plover River discharges were mostly between the public rights and historic average in 2014-2015. The public rights flow failure rate was estimated at 37% in 2014 and 53% in 2015 (Eisenhower Road continuous gauge), despite the years being quite wet.

Municipal, industrial, and the 68 irrigation wells located within two miles of the Little Plover pumped 3.3 and 2.9 billion gallons in 2013 and 2014. Pumping for years 2013 and 2014, respectively, was irrigation, 1.93 and 1.52 billion gallons; the Village of Plover, 521 and 540 million; Del Monte, 190 and 180 million; and the Whiting wellfield, 693 and 693 million. Plover pumping from Well 3, its well with the least impact on the Little Plover, amounted to 59% and 71% of total Village pumping in 2013 and 2014, smaller than the goal of 80% articulated by Plover to help Little Plover discharges. Whiting wellfield pumping remained smaller than historic amounts due to the closure of the New Page paper mill.

Little Plover diversions from municipal and industrial pumping were 1.27 cfs in 2013 and 1.15 cfs in 2014 at Hoover Road. Total diversions, including irrigation pumping (Hoover Road gauge), were previously estimated to average 4.5 cfs.

Introduction

The Little Plover River (Figure 7-1) is among the more prominent of pumping-affected central sands streams and one of the few with a lengthy continuous discharge record. Formerly renowned as a productive trout stream (Hunt 1988) that flowed robustly even during the severest droughts (Clancy et al. 2009), the Little Plover dried in stretches during 2005-2009 when precipitation was about average to only modestly low, and flowed below the public rights levels about half the time since 2005. Here we briefly update the more detailed work of Clancy et al. (2009) and Kraft et al. (2012a, 2012b, 2014).

Historic discharges

The historic record of Little Plover discharges includes both USGS daily monitoring and numerous “spot” measurements, as described in Clancy et al. (2009). The historic USGS daily record is particularly useful and affords a basis for comparison to current conditions (Table 7-1). It comprises measurements taken 1959-1987 at the “Little Plover at Plover” gauge (USGS # 05400650, also known as “Hoover Road,” and 1959-1976 at the “Little Plover near Arnott” gauge (USGS #05400600, also known as “Kennedy Avenue.” Total discharges at Hoover and Kennedy averaged 10.7 and 4.0 cfs, respectively, baseflow discharges averaged 9.9 and 3.6 cfs, and one-day minima were 3.9 and 0.88 cfs. Minima were measured at a time when the Little Plover was apparently already pumping affected (Clancy 2009).

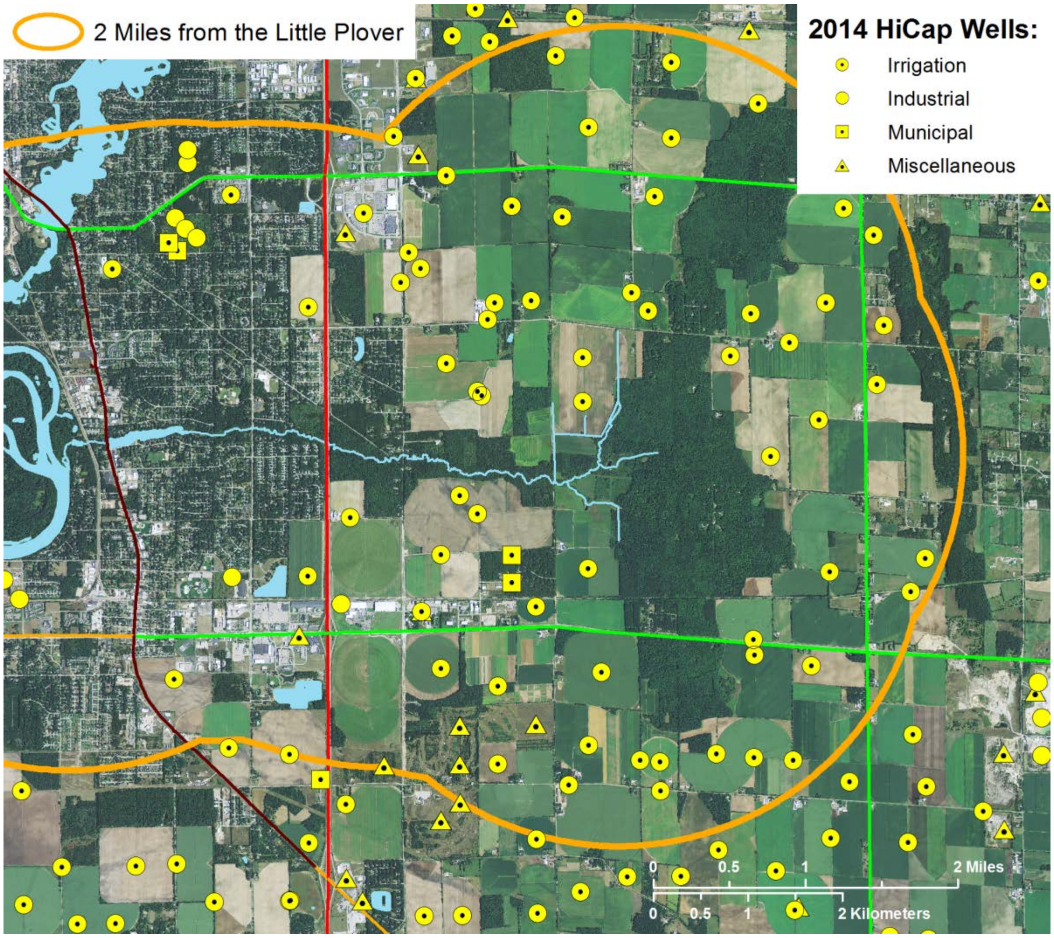


Figure 7-1. Little Plover River, its surroundings, and high capacity wells in its vicinity.

Table 7-1. Little Plover discharge statistics for the historical record.

Statistic	Kennedy Avenue (1959-1976)		Hoover Road (1959-1987)	
	Total (cfs)	Baseflow (cfs)	Total (cfs)	Baseflow (cfs)
Minimum	0.88	0.88	3.9	3.9
Q10	1.8	1.8	6.6	6.4
Q50	3.4	3.2	9.5	9.0
Q90	6.8	5.8	16.0	14.1
Maximum	50.0	17.0	81.0	33.0
Average	4.0	3.6	10.7	9.9
Public Rights Discharge	1.9 cfs		6.8 cfs	
% Days < Public Rights Discharge	10%		11%	

Post 2005 Discharges

Post-2005 discharges have been measured by UWSP staff during baseflow periods at roughly monthly intervals at Hoover Road, Eisenhower Road, Kennedy Avenue (Figure 7-2 and Figure 7-3) and occasionally other sites. A USGS gauge (# 05400625) at Eisenhower Road has also been gathering continuous flow data since October 2013.

The baseflow record shows that 2005 to mid-2010 was a period of extremely-low flow in the Little Plover, with discharges commonly smaller than the historic one-day low as well as the public rights flow. Precipitation amounts then were modestly low to about average (Figure 2-1) and alone cannot explain the small discharges. An unusual wet period spanning 2010-2011 (2010 was the third wettest year on record, 10 inches above average) brought Little Plover flows out of extreme lows and into a regime more representative of historic conditions. Little Plover flows once again crashed during the summer 2012 drought, coinciding with an extreme amount of pumping. Discharges improved during 2013-2015, likely due to the wet conditions. Flows in 2014-2015 have ranged from slightly above former one-day low flow to about average.

Public Rights Flow Failure Rate

Public rights flow failure rates (fraction of time that discharges were smaller than the established public rights flow) were estimated from USGS continuous gaging data at Eisenhower Road and from monthly baseflow measurements at Kennedy, Eisenhower, and Hoover. Failure rate estimation from continuous data is straightforward and involves a simple tally of daily discharges less than the public rights flow. Estimates derived from baseflows are somewhat more complicated as the data are spotty and periods when runoff contributes to discharges is not represented. Spotty data issues were reconciled using a linear interpolation to assign baseflow discharges to days between measurement dates. The missing of runoff events is an inherent shortcoming in the procedure that likely biases failure rates upward.

Eisenhower public rights flow failure rates (Table 7-2) estimated from continuous data were 37% and 53% for 2014 and 2015, respectively, while the same estimated from baseflow were 51% and 67%, 14 percentage points greater. The comparison may provide a basis for assessing bias at Eisenhower, at least for wet years.

The 2014 failure rates estimated from baseflow data were 31% and 29% at Kennedy and Hoover, respectively, and in 2015, 4% and 2%. Since 2005, the public rights flow failure rate based on baseflow discharges averaged 53%.

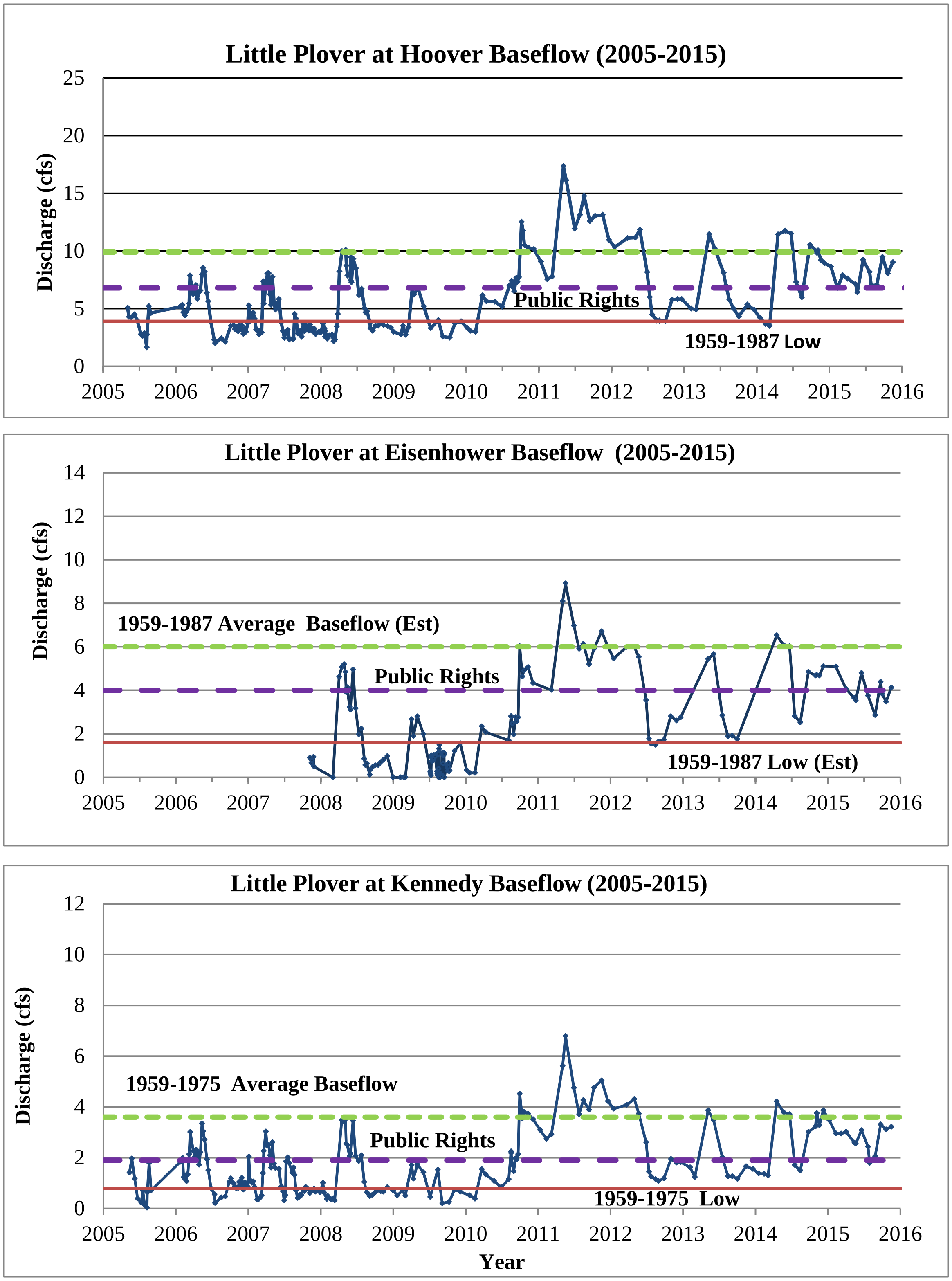


Figure 7-2. Baseflow discharges for the Little Plover River at Hoover, Eisenhower and Kennedy, 2005-2013.

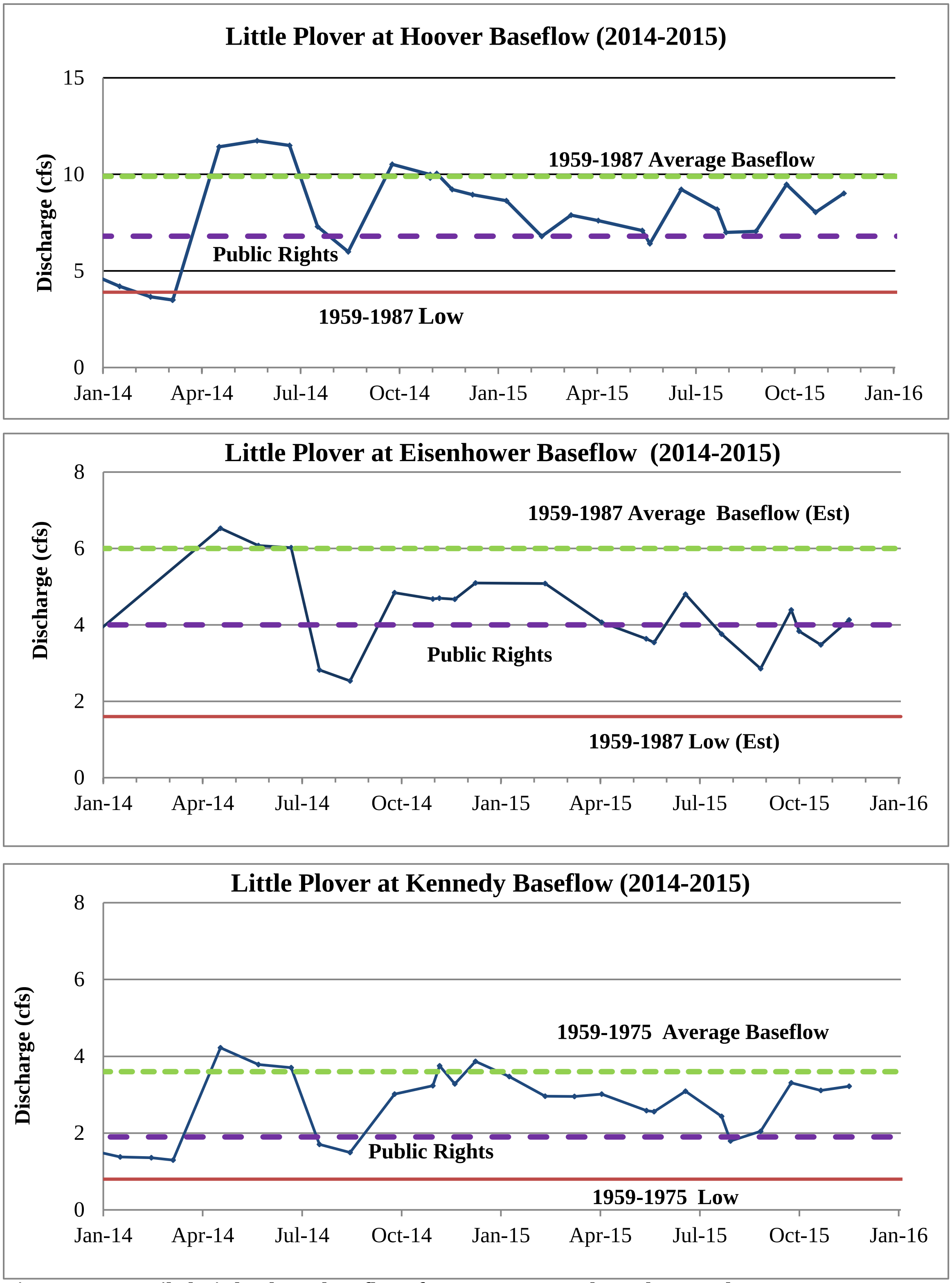


Figure 7-3. Detailed Little Plover baseflows for January 2014 through December 2015.

Table 7-2. Public rights flow failure rates estimated for Kennedy, Eisenhower, and Hoover from continuous and baseflow spot measurements.

Station	Period	Baseflow/ Continuous	Time < PRF (%)
Kennedy	5/11/2005-12/31/2015	Baseflow	51
	2014	Baseflow	31
	2015	Baseflow	4
Eisenhower	11/7/2007-12/31/2015	Baseflow	56
	2014	Baseflow	51
	2015	Baseflow	67
	11/14/2013-12/31/2015	Continuous	48
	2014	Continuous	37
	2015	Continuous	53
Hoover	5/4/2005-12/31/2015	Baseflow	53
	2014	Baseflow	29
	2015	Baseflow	2

Pumping in the Little Plover River Vicinity

Pumping in the Little Plover vicinity occurs mainly in four sectors: Village of Plover (municipal), Del Monte (industrial), Whiting (municipal and industrial), and agricultural (irrigation) (Figure 7-4) (Clancy et al. 2009). Pumping from these (counting only irrigation pumping within 2 miles) totaled 3.3 billion gallons in 2013 and 2.9 billion gallons in 2014 (WDNR 2015). Pumping is greatest during summers, chiefly due to irrigation. Non-high capacity well pumping, such as rural residential or urban lawn watering from small wells, has been dismissed as insignificant because it is mostly nonconsumptive (rural domestic water discharging to onsite wastewater disposal systems), often too far removed from the Little Plover to be important, or small compared to the major pumping sectors.

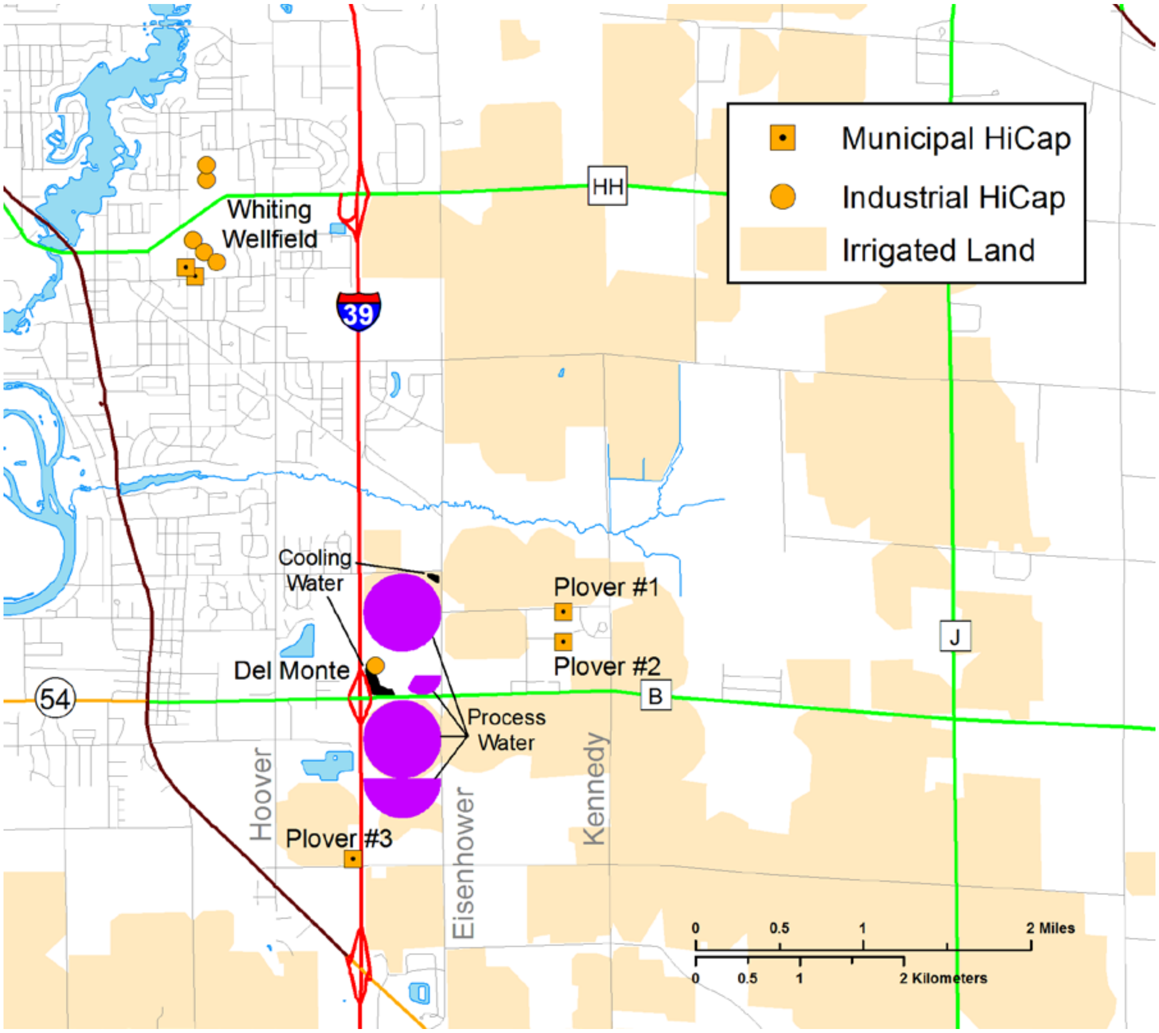


Figure 7-4. Irrigated land, municipal and industrial high capacity wells, and Del Monte wastewater disposal areas.

Plover pumping

Village of Plover pumping was 521 million gallons in 2013 and 540 million gallons in 2014 (Figure 7-5). Pumping is from three wells; Wells 1 and 2 which divert about 75% of their pumpage from the Little Plover, and Well 3 that diverts 30% of its water from the Little Plover (Clancy et al. 2009). Plover extracted 59% and 71% of its water from Well 3 in 2013-2014, with the remainder from Wells 1 and 2 (Figure 7-6). The Well 3 fraction is below the articulated goal of 80% to help restore some Little Plover baseflow.

Del Monte pumping and wastewater disposal

Del Monte pumping was 190 and 180 million gallons in 2013 and 2014. Most of that pumping occurs in June through December. Three-fourths of pumped water is reportedly discharged to

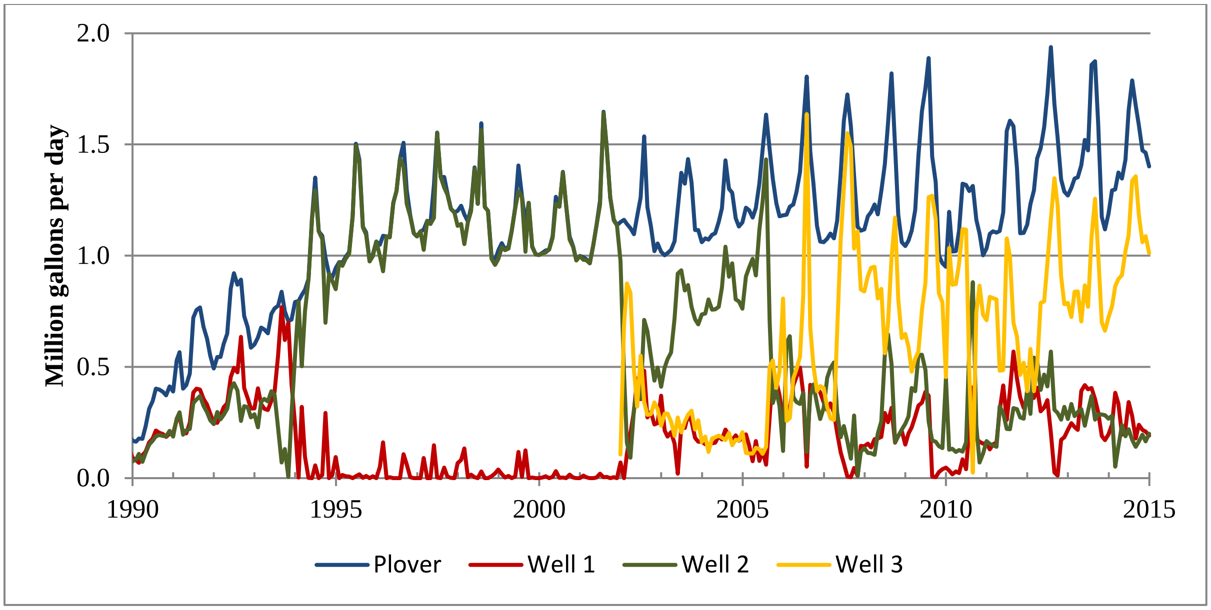


Figure 7-5. Village of Plover total and well-by-well pumping through 2014.

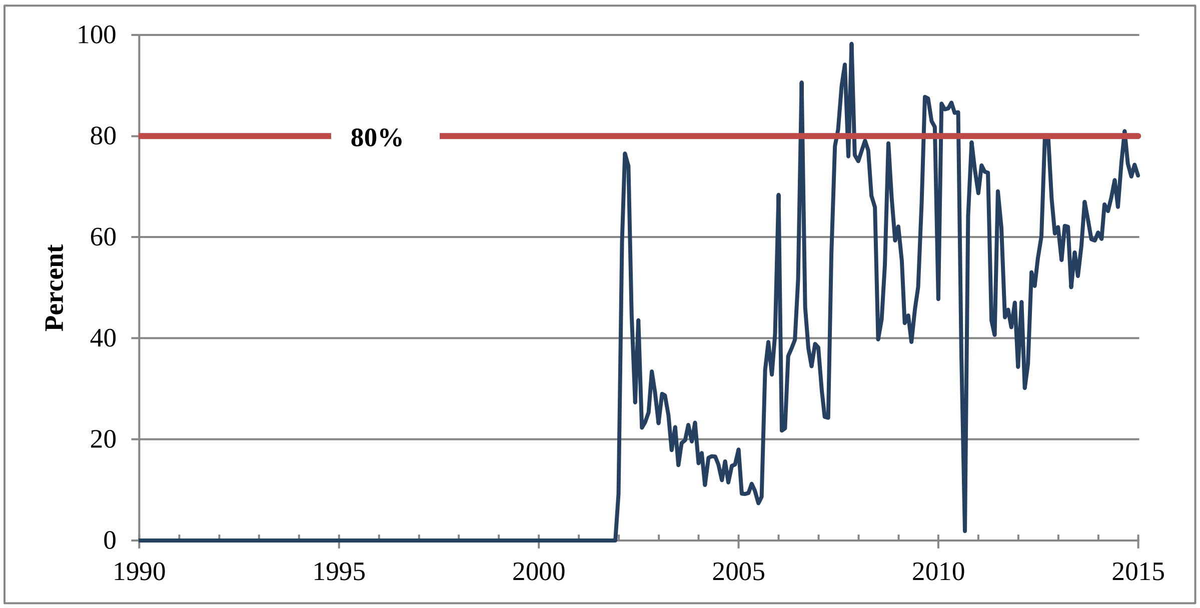


Figure 7-6. Percentage of Plover pumping from Well 3. The 80% pumping level is indicated.

nearby spray fields that recharge groundwater, reducing Del Monte's potential pumping diversions from the Little Plover. In 2010, Del Monte moved some of its wastewater discharge closer to the Little Plover, which further reduced its pumping impacts.

Whiting wellfield

Municipal / industrial pumping from the large Whiting wellfield once supplied the Village of Whiting and two paper mills; Neenah Papers (formerly Kimberly Clark) and New Page (formerly Consolidated Papers), before closure of the latter. Pumpage from this wellfield was 693 million gallons in both 2013 and 2014, a marked decline from the 1.5 billion gallons annually pumped in the previous 10 years (Figure 7-7).

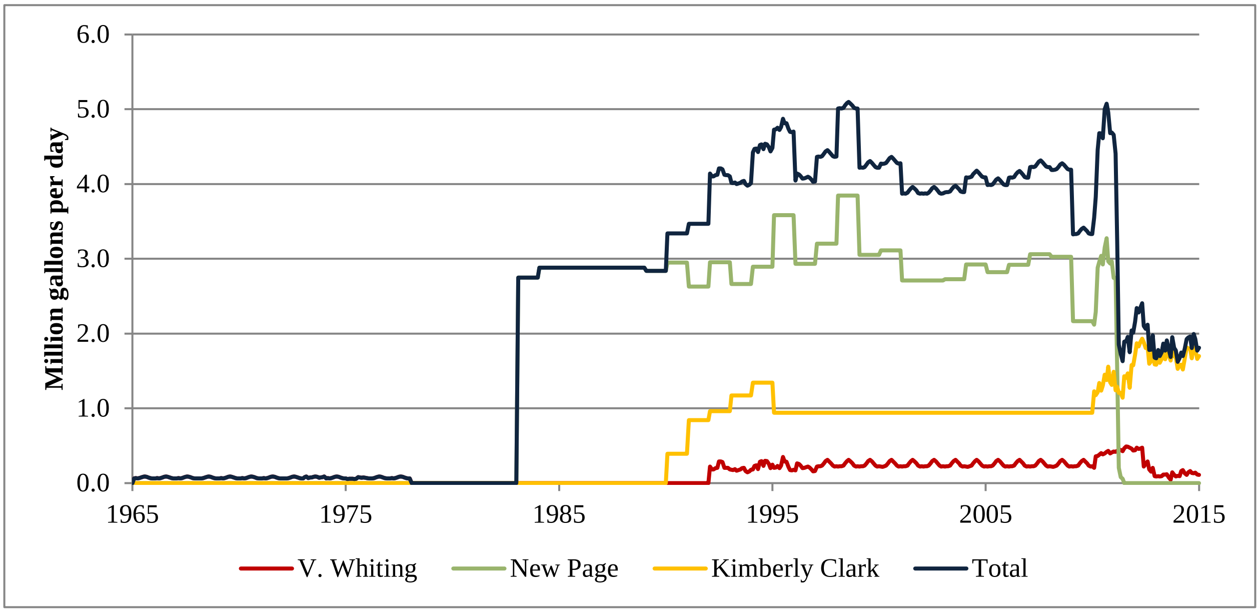


Figure 7-7. Pumping from the Whiting wellfield through December 2014.

Irrigation pumping

Irrigation pumping extends over a broad area with an impact that diminishes slowly with distance from the Little Plover and in amounts that vary by crop and year. Some 68 high capacity irrigation wells are located within two miles of the Little Plover (Figure 7-1), and these wells pumped 1.93 and 1.52 billion gallons in 2013 and 2014, respectively. Numerous high capacity irrigation wells lie beyond two miles of the Little Plover, and these cause an estimated 18% of the Little Plover irrigation diversion (Clancy et al. 2009).

Diversions by Municipal and Industrial Pumping

Because municipal and industrial pumping (and in the case of Del Monte, wastewater discharge) histories are well known, their diversions from the Little Plover are directly amenable to calculation using numerical models. These diversions were calculated using "Model 4" (Technical Memorandum #16, Clancy et al. 2009) in transient mode with monthly stress periods beginning in 1965 and ending through 2018. For the post-2014 period, 2014 pump rates and wastewater disposal conditions were projected into the future. Del Monte simulation used average pumpage and wastewater disposal (Roger Jacob email 3/3/2011); 203 million gallons distributed as 10, 48, 57, 51, 18, 12, and 7 million gallons for the months June through December. The 79% of the Del Monte pumpage returned via spray fields as process or cooling wastewater was modeled as an addition to the base recharge, and the monthly rate was calculated proportional to the monthly pumpage.[1]

Calculated municipal and industrial diversions at Hoover Road for 1965-2014 are shown in Figure 7-8, along with important pumping events, such as the start and stop of pumping for individual members of the pumping sector. Total diversions were minor through 1984, about 0.12 cfs, when only the Del Monte facility and Whiting municipal well were extracting groundwater. As groundwater extraction increased to service other purposes (paper manufacturing by New Page / Consolidated and Kimberly Clark / Nekoosa, Village of Plover), diversions steadily increased to about 2.2 cfs by the late 1990s. Since then, municipal and industrial diversions have experienced a decline.

Total municipal / industrial diversions were 1.27 and 1.15 cfs in 2013 and 2014, a modest decrease from the 2005-2007 baseline of 1.77 cfs (Table 7-3). Diversions (2013/2014) by pumping entity were Plover, 0.92/0.84 cfs; Whiting, 0.28/0.24 cfs; and Del Monte, 0.07/0.07 cfs. If 2014 pumping patterns persist into the future (i.e., no increase in pumping rates or how pumping is apportioned among wells), 2017 diversions (near steady-state) would be almost steady for Plover at 0.85 cfs, decrease for Whiting to 0.22 cfs, and remain the same for Del Monte. Total diversions from the municipal and industrial sector would be 1.14 cfs, a decline of 0.63 cfs compared to the 2005-2007 baseline, due mainly to the New Page closure.

[1] The current spray field areas (Figure 7-4) were simulated from 2010 forward. Del Monte estimated return flows of 10 million gallons cooling water to the northeast basin, 49.6 million gallons cooling water to the plant lawn fields, 37.2 million gallons wastewater to the 113 acre spray field north of the plant, 5.6 million gallons wastewater to the 17 acre spray field immediately southeast of the plant, 41.2 million gallons wastewater to the 125 acre spray field immediately south of CTH B, and 16.2 million gallons wastewater to the 49 acre spray field farthest to the south. Prior to 2011, all cooling water was returned to the plant lawn fields. The wastewater return areas have also changed over time and been modeled accordingly. Originally, all wastewater was returned to the 17 and 125 acre fields south of the plant; the 49 acre southernmost field was added later, and the northern 113 acre field was brought fully online in 2011.

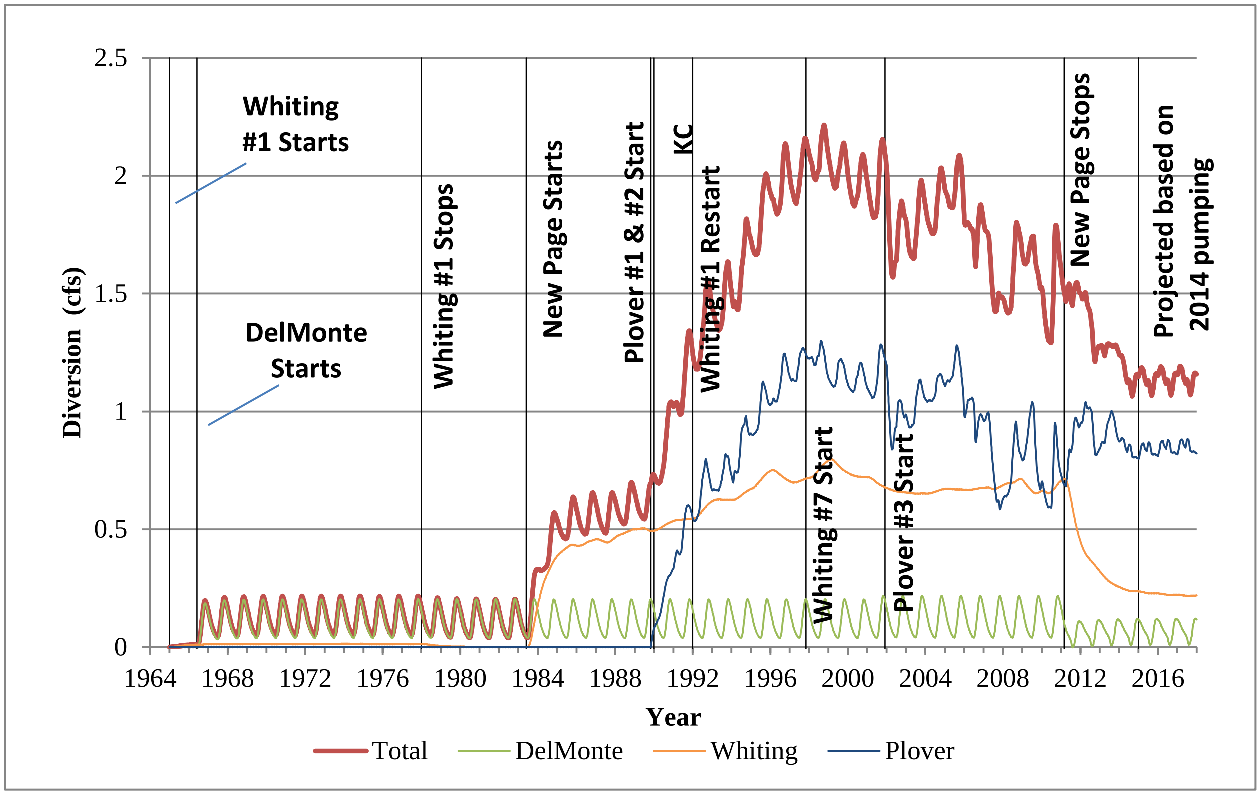


Figure 7-8. Municipal and industrial groundwater pumping diversions from the Little Plover River.

Table 7-3. Average annual municipal and industrial diversions for the 2005-2007 reference period, 2013, 2014, and projected for 2017. 2017 projections assume 2014 pumping patterns hold constant.

	--------------- Municipal / Industrial Diversion (cfs) ---------------			
	--Year --			
Sector	2005-2007	2013	2014	2017*
Plover	0.98	0.92	0.84	0.85
Whiting	0.67	0.28	0.24	0.22
Del Monte	0.12	0.07	0.07	0.07
Total	1.77	1.27	1.15	1.14

* Projection assumes 2014 pumping conditions prevail into the future.

8. IRRIGATION RATES FOR THE CENTRAL SANDS, 2013-2014

Summary

Irrigation rates were estimated for 2013 and 2014 by sampling the pumpage, crop type, and crop area associated with 52 irrigation wells in Portage, Waushara, and Adams Counties. Median rates among all irrigated acreages were 9.3 inches in 2013 and 7.8 inches in 2014. Irrigation rates were greatest for potato followed by field corn, sweet corn, and snap bean. For the 2008 through 2014 period, the annual irrigation rate across all crops was 8.7 inches, with a range of 4.0-14.9 inches. Annual irrigation rates correspond to the dryness of summers.

Introduction

Irrigation rates - the depth of irrigation water applied on a field - were estimated for 52 previously selected well / field combinations and their associated crops from across the central sands (Figure 8-1). Details of irrigation rate calculation are presented in Appendix A.

Methods

The 52 previously selected well / field combinations comprised 43 that were randomly chosen in 2008 and nine that were specifically selected in 2011 to constrain irrigation rate estimates for certain crops at that time (Figure 8-1; Kraft et al. 2010, 2012, 2014). Irrigation rates were estimated by dividing the reported pumping amount for high capacity irrigation wells by the field area served by that well.

Wells and fields were matched using ArcMap GIS 2008 aerial coverage with limited field verification. Assigning fields to wells was occasionally subjective, as sometimes well to field matches were not obvious. Crop data were gathered from GIS grid files called “Crop Data Layers” (CDL) from the National Agricultural Statistics Services (NASS) (USDA 2014). Fields irrigated by a single well could be planted to a single or to multiple crops during any given year. When more than one crop existed in a particular field, a mixed crop was reported. The NASS CDL has the idiosyncrasy of reporting substantial acreages of “dry bean” in addition to soybean, but no snap bean. Our field checks showed so-called “dry bean” acres to be snap bean. Hence we report NASS CDL “dry bean” as snap bean.

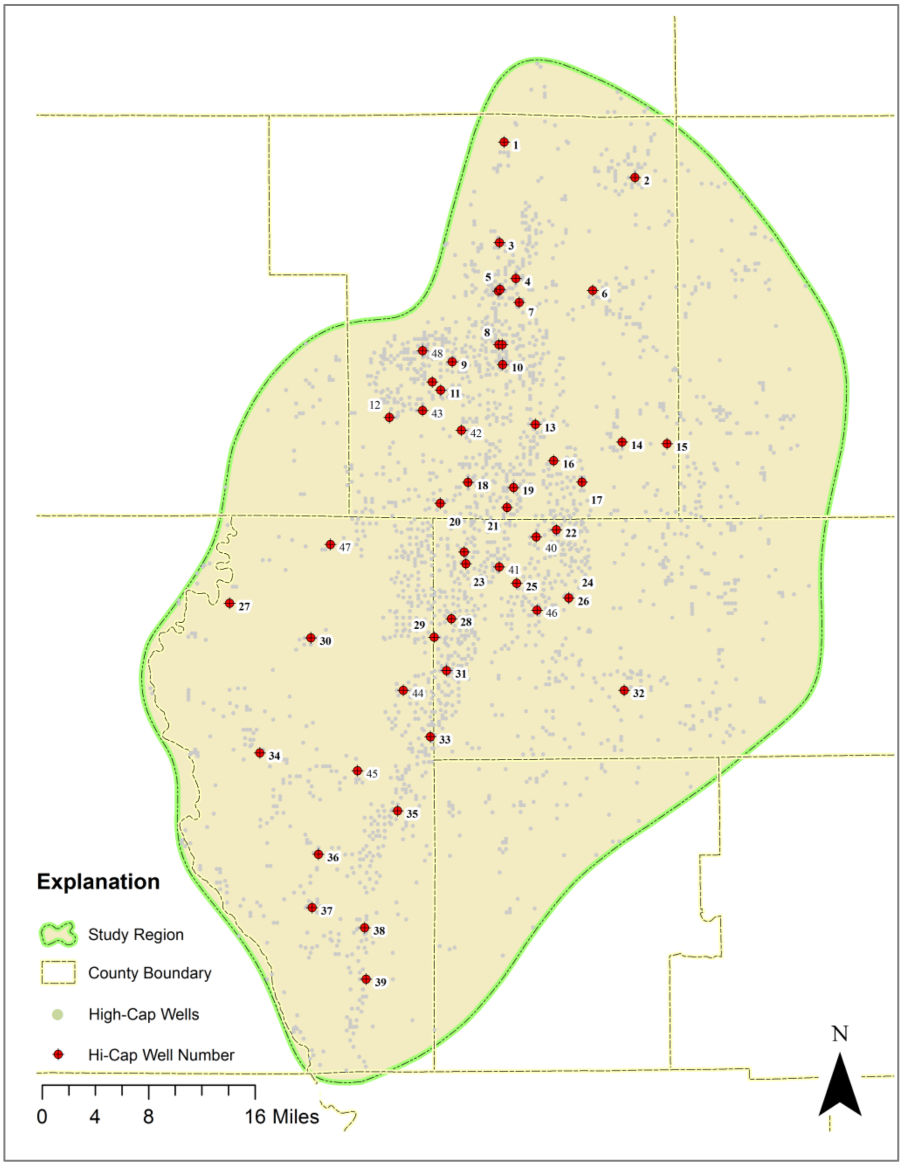


Figure 8-1. Well and field locations used to estimate irrigation rates for 2008-2014. Field ID and Hi-Cap well numbers are listed in Appendix A.

Results

2013 and 2014 irrigation rates

Median irrigation rate estimates across all fields were 9.3 inches in 2013 and 7.8 inches in 2014. Fields containing single plantings of sweet corn, field corn, potato, and snap bean had 2013 median irrigation rates of 4.9, 12.3, 16.9, and 5.6 inches, respectively, and 2014 rates of 8.1, 8.4, 11.5, and 4.8 inches (Table 8-1).

Irrigation rates for 2013 and 2014 were also estimated at the Wisconsin-scale using GIS approach by R. Smail of WDNR (pers. comm.). His results indicated a 9.3 inch average across all irrigated land for 2013, and a 7.0 inch average for 2014. The 2013 irrigation rates for sweet corn, field corn, potato, and snap bean were 10.6, 8.7, 13.3 and 8.3 inches. 2014 rates for the same crops were 7.8, 6.1, 11.2 and 6.7 inches.

Comparisons for 2008-2014

Median estimated irrigation rates across central Wisconsin's crops for 2008-2014 are given in Figure 8-2. Over the seven years, potato had the greatest irrigation amount (11.7 inches) followed by field corn (10.1 inches), sweet corn (8.4 inches), and snap bean (5.9 inches).

Annual irrigation rates across all fields during the period ranged 4.0 to 14.9 inches, corresponding closely with summer precipitation amounts (Figure 8-3). For instance, the 2012 median rate of 14.9 inches occurred during a summer with only 5.4 inches of precipitation, while the 2010 rate of 4.0 inches occurred in a summer of 23.2 inches of precipitation.

Conclusions

Annual irrigation rate estimates for 2008-2014 ranged 4.0 to 14.9 inches and correspond with summer precipitation amounts (Figure 8-3). Over the seven years, potato had the greatest irrigation amount (11.7 inches) followed by field corn (10.1 inches), sweet corn (8.4 inches), and snap bean (5.9 inches). Additional work could refine irrigation estimation, which has several potential errors: estimation and reporting by operators, field size and crop data, and assigning wells to fields.

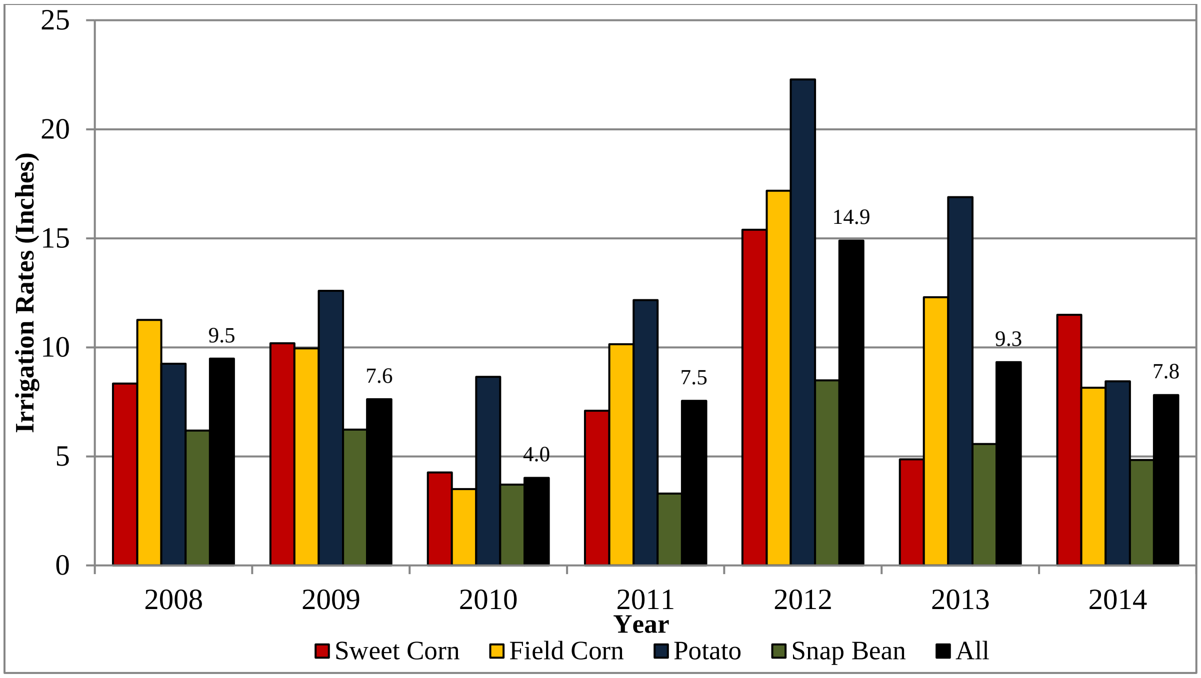


Figure 8-2. Median rates for all fields and for four specific crops in central Wisconsin for 2008-2014. The irrigation rates shown in black on the chart are for all crops and all fields.

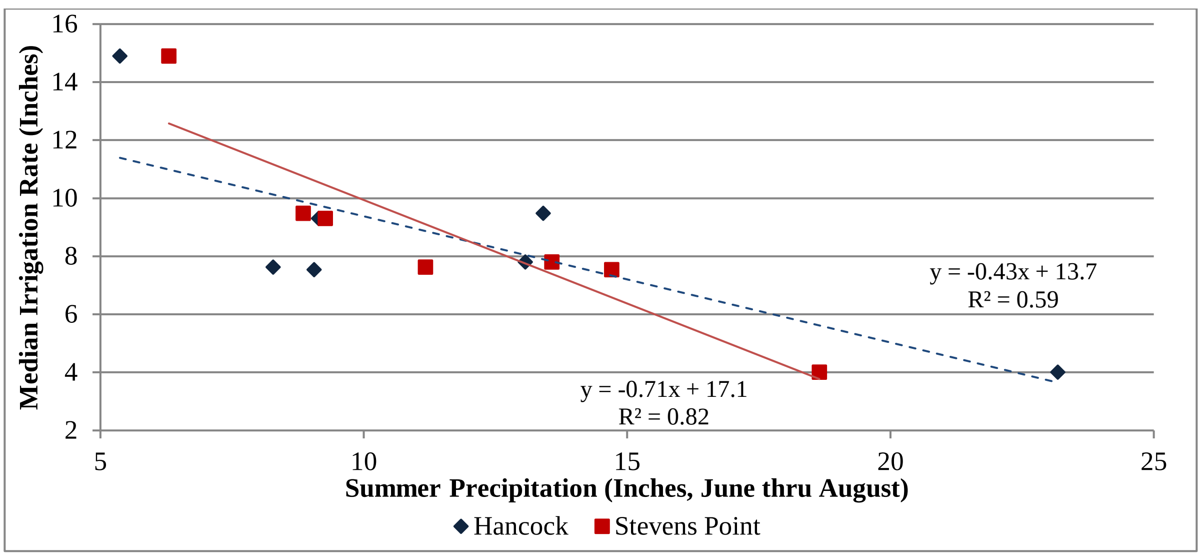


Figure 8-3. 2008-2014 median annual irrigation rates compared with Hancock and Stevens Point summer precipitation.

Table 8-1. 2013 and 2014 irrigation rates for single and mixed crop fields in central Wisconsin.

Crop	n	Min	Max	Average	Median
		----2013----			
Sweet Corn	4	0.7	20.3	7.7	4.9
Field Corn	9	2.7	21.1	11.7	12.3
Potato	6	9.3	21.6	15.7	16.9
Snap Bean	6	4.1	10.6	6.7	5.6
Soybean	2	5.9	8.5	7.2	7.2
Sweet Corn/Potato	7	6.3	14.9	10.2	10.0
Sweet Corn/Field Corn	3	4.9	9.7	7.0	6.3
Sweet Corn/Field Corn/Alfalfa	1	5.0	5.0	5.0	5.0
Sweet Corn/Snap Bean	1	7.2	7.2	7.2	7.2
Field Corn/Potato	5	7.1	15.6	11.0	11.3
Field Corn/Soybean	2	9.9	10.3	10.1	10.1
Field Corn/Potato/Rye	1	5.5	5.5	5.5	5.5
Field Corn/Pea	1	8.1	8.1	8.1	8.1
Potato/Soybean	1	9.2	9.2	9.2	9.2
Potato/Pea	1	4.1	4.1	4.1	4.1
Carrot	2	4.5	11.7	8.1	8.1
Winter Wheat/Rye	1	3.6	3.6	3.6	3.6
		----2014----			
Sweet Corn	6	3.9	12.2	8.1	8.1
Field Corn	8	3.7	10.2	7.3	8.4
Potato	6	5.3	20.1	12.5	11.5
Snap Bean	4	1.9	8.4	5.0	4.8
Sweet Corn/Grass	3	5.8	7.3	6.6	6.7
Sweet Corn/Snap Bean	2	5.1	5.7	5.4	5.4
Sweet Corn/Potato	1	6.3	6.3	6.3	6.3
Sweet Corn/Field Corn	1	8.1	8.1	8.1	8.1
Sweet Corn/Field Corn/Snap Bean	1	13.8	13.8	13.8	13.8
Sweet Corn/Potato/Soybean	1	15.8	15.8	15.8	15.8
Field Corn/Potato	1	10.3	10.3	10.3	10.3
Field Corn/Snap Bean	1	7.4	7.4	7.4	7.4
Field Corn/Soybean	1	5.3	5.3	5.3	5.3
Field Corn/Alfalfa	1	6.9	6.9	6.9	6.9
Potato/Snap Bean	2	0.0	11.3	5.6	5.6
Potato/Grass	1	17.4	17.4	17.4	17.4
Potato/Snap Bean/Pea	1	11.4	11.4	11.4	11.4
Snap Bean/Pea	2	4.6	6.0	5.3	5.3
Snap Bean/Soybean	1	8.3	8.3	8.3	8.3
Soybean/Pea	1	5.5	5.5	5.5	5.5
Alfalfa	2	0.3	13.0	6.6	6.6
Pea	1	5.1	5.1	5.1	5.1
Barley	1	2.7	2.7	2.7	2.7
Grass	1	13.2	13.2	13.2	13.2

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APPENDIX A. Irrigation Rate Estimation by Field for 2013-2014

Table A-1. Irrigation rate estimates by field and crop for 2013.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2013 NASS Crop[1]	Irrigated Crop Inches in 2013
1	23619	130.7	130.7	Sweet Corn/Potato	9.74
2	23906	54	54	Alfalfa	0.00
3b	23858	73		Sweet Corn	
3c	23858	14.6		Potato	
3a	23858	55	142.6	Potato	6.28
4	23847	55	55	Potato	9.32
5b	24203	52.1		Field Corn	
5a	24203	93.2	145.3	Field Corn	21.15
6a	68917	31.3		Sweet Corn	
6b	68917	33		Alfalfa	
6c	68917	53.3		Field Corn	
6d	68917	19.3		Alfalfa	
6f	68917	32.5		Field Corn	
6e	68917	20.2	189.6	Alfalfa	5.04
7b	1584	14.7		Potato	
7d	1584	18		Potato	
7c	1584	18.2		Field Corn	
7a	1584	14.8	65.7	Rye	5.53
8a	24049	70		Sweet Corn	
8b	24049	50	120	Potato	8.79
8c	24293	36	36	Soybean	5.89
9c	422	37.7		Sweet Corn	
9a	422	33.7		Sweet Corn	
9b	422	36.9	108.3	Sweet Corn	3.58
10	24091	41.7	41.7	Snap Bean	4.96
11a	581	41.6		Sweet Corn	
11b	581	42	83.6	Potato	10.04
11c	813	148.4	148.4	Potato/Field Corn	7.10
12a	24098	65.1		Potato	
12b	24098	60.4	125.5	Sweet Corn	11.36
13a	23792	38.1		Sweet Corn	
13b	23792	37.5		Potato	
13c	23792	38.1		Sweet Corn	
13d	23792	37.5	151.2	Potato	10.40
14	23839	135	135	Field Corn/Soybean	10.31
15	24173	87.3	87.3	Potato/Field Corn/Grass	7.72

Table A-1. Irrigation rate estimates by field and crop for 2013, continued

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2013 NASS Crop[1]	Irrigated Crop Inches in 2013
16a	23602	62.3		Pea	
16b	23602	63.1	125.4	Field Corn	8.13
17a	24014	34.8		Sweet Corn	
17b	24014	56.2		Sweet Corn	
17c	24014	64	155	Snap Bean	7.23
18	23666	148	148	Carrot	11.70
19	23711/23607	36		Field Corn	
19	23711/23607	119	155	Field Corn	2.70
20b	411	30.9		Potato	
20a	411	51		Potato	
20c	411	50.7	132.6	Soybean	9.16
21a	911	32.8		Field Corn	
21b	911	35.2		Field Corn	
21c	911	72.3	140.3	Field Corn	11.15
22	36394	146.4	146.4	Snap Bean	4.10
23b	36666	30.6		Potato	
23a	36666	29.1		Potato	
23c	36666	33.8	93.5	Sweet Corn	14.93
23d	1650	144.8	144.8	Sweet Corn	6.14
24	36550	154.2	154.2	Potato	14.95
25a	36728	28.6		Potato	
25b	36728	37		Potato	
25c	36728	39.7		Potato	
25e	36728	34		Potato	
25f	36728	75.7		Potato	
25d	36728	37.3	252.3	Field Corn	11.35
26b	67319	69.4		Potato	
26a	67319	68.9	138.3	Potato	10.43
27	64	124.2	124.2	Snap Bean	9.74
28b	36454	75.8		Field Corn	
28a	36454	110.3	186.1	Field Corn	8.86
29b	36720	113		Field Corn	
29a	36720	150	263	Potato	13.19
30b	258	37.4		Potato	
30c	258	35.4		Potato	
30a	258	72.9	145.7	Field Corn	15.61
31b	36508	74.2		Soybean	
31a	36508	114	188.2	Soybean	8.48
32	36529	149.2	149.2	Field Corn/Soybean	9.87

Table A-1. Irrigation rate estimates by field and crop for 2013, continued

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2013 NASS Crop[1]	Irrigated Crop Inches in 2013
33	146	145.4	145.4	Potato	21.58
34a	1616	85		Field Corn	
34b	1616	76.5	161.5	Field Corn	12.30
35	339	136.7	136.7	Field Corn	13.60
36	311	149.1	149.1	Snap Bean	10.61
37	55	148.9	148.9	Potato	18.83
38	24	151.2	151.2	Field Corn	14.11
39	42	102.7	102.7	Field Corn	9.06
40	36457	134.5	134.5	Winter Wheat/Rye	3.60
41	36732	140	140	Potato/Pea	4.07
42	24148	135	135	Carrot	4.47
43	23946	147	147	Sweet Corn	0.65
44	297	135	135	Potato	19.02
45	116	152	152	Field Corn	12.76
46	36470	147	147	Sweet Corn	20.32
47	115	132	132	Snap Bean	6.19
48	23855	150	150	Snap Bean	4.59
				Median	**9.32**
				Average	**9.62**

1. NASS "dry beans" is designated here-in as "snap bean."

Table A-2. Irrigation rate estimates by field and crop for 2014.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2014 NASS Crop[1]	Irrigated Crop Inches in 2014
1	23619	130.7	130.7	Sweet Corn/Potato	6.33
2	23906	54	54	Alfalfa	0.29
3b	23858	73			
3c	23858	14.6			
3a	23858	55	142.6	Sweet Corn/Snap Bean	5.72
4	23847	55	55	Pea	5.07
5b	24203	52.1			
5a	24203	93.2	145.3	Potato/Snap Bean	11.30
6a	68917	31.3			
6b	68917	33			
6c	68917	53.3			
6d	68917	19.3			
6f	68917	32.5			
6e	68917	20.2	189.6	Field Corn/Alfalfa	6.92
7b	1584	14.7			
7d	1584	18			
7c	1584	18.2			
7a	1584	14.8	65.7	Field Corn/Potato	10.29
8a	24049	70			
8b	24049	50	120	Sweet Corn/Field Corn	8.11
8c	24293	36	36	Sweet Corn	3.90
9c	422	37.7			
9a	422	33.7			
9b	422	36.9	108.3	Sweet Corn/Potato/Soybean	15.81
10	24091	41.7	41.7	Sweet Corn	8.39
11a	581	41.6			
11b	581	42	83.6	Soybean/Pea	5.54
11c	813	148.4	148.4	Grass	13.19
12a	24098	65.1			
12b	24098	60.4	125.5	Potato/Snap Bean	0.00
13a	23792	38.1			
13b	23792	37.5			
13c	23792	38.1			
13d	23792	37.5	151.2	Sweet Corn	6.85
14	23839	135	135	Snap Bean/Pea	4.61
15	24173	87.3	87.3	Field Corn	3.66
16a	23602	62.3			
16b	23602	63.1	125.4	Sweet Corn	7.91

Table A-2. Irrigation rate estimates by field and crop for 2014, continued.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2014 NASS Crop[1]	Irrigated Crop Inches in 2014
17a	24014	34.8			
17b	24014	56.2			
17c	24014	64	155	Field Corn	4.67
18	23666	148	148	Sweet Corn/Snap Bean	5.09
19	23711/23607	36			
19	23711/23607	119	155	Snap Bean	3.00
20b	411	30.9			
20a	411	51			
20c	411	50.7	132.6	Sweet Corn/Field Corn/Snap Bean	13.83
21a	911	32.8			
21b	911	35.2			
21c	911	72.3	140.3	Snap Bean/Soybean	8.25
22	36394	146.4	146.4	Sweet Corn	9.27
23b	36666	30.6			
23a	36666	29.1			
23c	36666	33.8	93.5	Snap Bean	6.66
23d	1650	144.8	144.8	Potato	5.27
24	36550	154.2	154.2	Sweet Corn/Grass	6.73
25a	36728	28.6			
25b	36728	37			
25c	36728	39.7			
25e	36728	34			
25f	36728	75.7			
25d	36728	37.3	252.3	Field Corn	7.82
26b	67319	69.4			
26a	67319	68.9	138.3	Barley	2.71
27	64	124.2	124.2	Potato	20.11
28b	36454	75.8			
28a	36454	110.3	186.1	Field Corn	9.81
29b	36720	113			
29a	36720	150	263	Field Corn	4.07
30b	258	37.4			
30c	258	35.4			
30a	258	72.9	145.7	Potato/Grass	17.37
31b	36508	74.2			
31a	36508	114	188.2	Snap Bean/Pea	6.00
32	36529	149.2	149.2	Potato	12.68
33	146	145.4	145.4	Field Corn	9.13
34a	1616	85			

Table A-2. Irrigation rate estimates by field and crop for 2014, continued.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2014 NASS Crop[1]	Irrigated Crop Inches in 2014
34b	1616	76.5	161.5	Field Corn/Snap Bean	7.38
35	339	136.7	136.7	Snap Bean	8.42
36	311	149.1	149.1	Alfalfa	13.00
37	55	148.9	148.9	Field Corn	10.21
38	24	151.2	151.2	Potato	16.76
39	42	102.7	102.7	Field Corn/Soybean	5.28
40	36457	134.5	134.5	Snap Bean	1.87
41	36732	140	140	Potato/Snap Bean/Pea	11.37
42	24148	135	135	Potato	10.07
43	23946	147	147	Potato	10.31
44	297	135	135	Sweet Corn/Grass	5.84
45	116	152	152	Field Corn	9.06
46	36470	147	147	Potato/Dry Bean/Soybean/Grass	14.57
47	115	132	132	Sweet Corn	12.24
48	23855	150	150	Sweet Corn/Grass	7.30
				Median	**7.82**
				Average	**8.24**

1. NASS "dry beans" is designated here-in as "snap bean."