Information Support for Groundwater Management in the Wisconsin Central Sands, 2011-2013

A Report to the Wisconsin Department of Natural Resources

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Supplemental Document 1: Excel file; “Q for Central WI Rivers thru June 2014”

Supplemental Document 2: Excel file; “Lake Level Data Updated thru 2013”

1. INTRODUCTION

This report summarizes data and information gathering for 2011 through 2013 that supports groundwater management activities in the Wisconsin central sands. The report supplements the previous and more in-depth work of Clancy et al. (2009) in the Little Plover River area and that of Kraft et al. (2010, 2012a, 2012b) in the broader central sands region. Previous works summarized important hydrologic literature on the central sands, created groundwater flow models, and statistically analyzed records for signs of pumping diversions and drawdowns. They concluded 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, 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 1-2).

The central sands contains Wisconsin's greatest density of high capacity wells, about 2199 in the seven counties that this study area overlaps (Figure 1-3). High capacity well pumping in the region amounted to 27-34% of Wisconsin's total, 86-90% being used for agricultural irrigation (2011 and 2012 statistics, WDNR 2013). Other uses (municipal, industrial) are small and limited geographically, but can be locally significant (Clancy et al. 2009). Growth in high capacity irrigation well numbers and groundwater pumping has been rapid, minimally managed, and mainly without regard for impacts on lake, stream, and wetland resources. This growth mirrors increases in irrigated farmland (USDA NASS 2008 and predecessors).

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 provoked apparent 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 most of the last 10 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) 70% of the time in 2013.

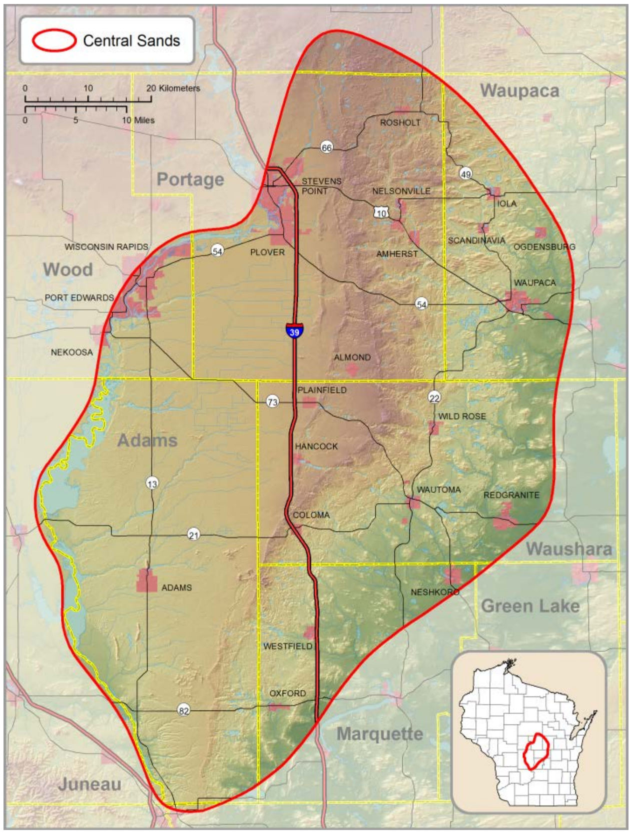


Figure 1-1. The Wisconsin central sands region with selected municipalities and roads.

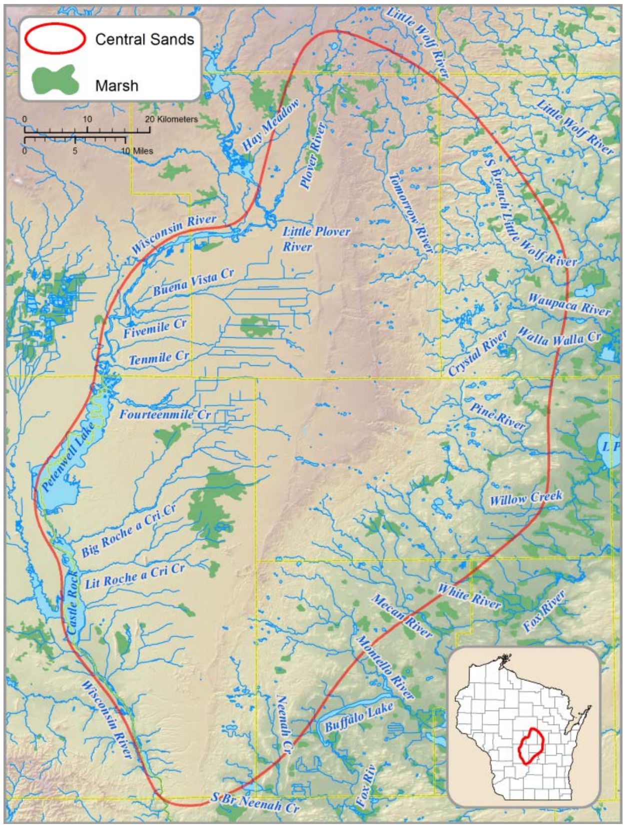


Figure 1-2. Hydrography of the Wisconsin central sands region.

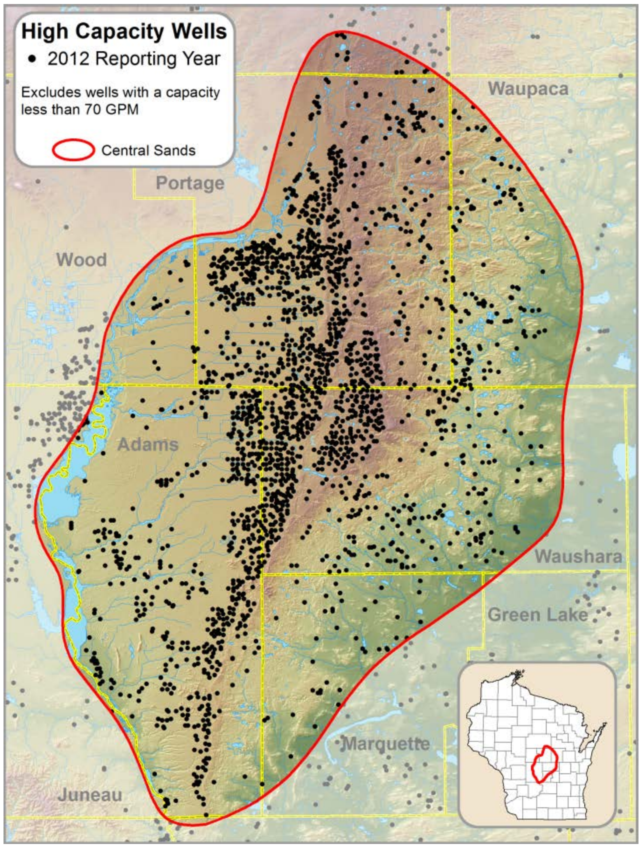


Figure 1-3. Locations of high capacity wells.

Objectives of this effort and brief description of how objectives were addressed

The goal of this proposed project was to continue information support for management activities concerning groundwater pumping and its impacts on surface waters in the Wisconsin central sands. Specific objectives were to:

1. ***Measure baseflow discharges on select streams and groundwater levels in select wells, upload measurements to USGS for archiving.***

Baseflow discharge measurements continued at 31 of 42 stream locations previously measured by Kraft et al. (2010). Discharges were usually measured monthly. Complete data are included with this report as electronic media in a spreadsheet entitled "Q for Central WI Rivers thru June 2014.xlsx". Data collected through June 2014 were sent to USGS to be archived in their database.

2. ***Estimate irrigation rates for crops grown in central Wisconsin for years 2011 and 2012.***

Irrigation rates were estimated for 52 well / field combinations and are reported in Chapter 8.

3. ***Compile precipitation, stream discharge, groundwater, and lake level data from NOAA, WDNR, County, and USGS data sources for years 2012 and 2013, merge with previously compiled data. Use precipitation and reference location data to contextualize the relative wetness or dryness of the study period and for estimating drawdowns and diversions in pumping affected areas.***

These data are compiled and interpreted in Chapter 2.

4. ***Estimate pumping drawdowns for select lakes and monitoring wells and pumping diversions for the Little Plover River for 2009-2012.***

Pumping drawdowns estimations are in Chapter 5. Little Plover pumping diversions are in Chapter 7.

5. Run existing groundwater flow models to meet agency and process information needs; run "numerical experiments" with the central sands groundwater flow model to advance scientific conceptions about pumping and managing pumping impacts.

The existing groundwater flow model was run to support Little Plover River diversion estimations; assist the Town of Hull, Portage County, in exploring causes of well drying; explore how future pumping development may further impact the region's water resources (Appendix B); and in assisting WDNR in evaluating the following high capacity well proposals: Mortenson Hi-Cap property 70-01-0048, Mortenson Hi-Cap property 70-01-0092, Kaminski proposed and alternate well, Pratt proposed and alternate well, Bacon Farms proposed and alternate well, and Hamerski Hi-Cap property.

2. WEATHER AND HYDROLOGIC CONDITIONS FOR 2012-2013

Summary

Years 2012 and 2013 followed two years of larger than average precipitation amounts that raised streamflows and groundwater levels from previous low levels. 2012 precipitation was less than average at Stevens Point, Hancock, and Wautoma by 1.6 to 4 inches, while 2013 precipitation was average at Stevens Point and Hancock but 4 inches above average at Wautoma. Summers were dry, however. Summer 2012 was the driest or among the driest on record, depending on station, and summer 2013 had 20% less than average precipitation.

Indicator streamflows at locales unaffected by groundwater pumping were typical for the record, at about 23 to 61 percentile in 2012 and 2013 respectively. Reference monitoring wells (those only slightly impacted by groundwater pumping) were above long-term medians, 62 to 83 percentile.

In brief, year 2012 had below average precipitation with a dry summer, while 2013 was average to above average with a dry summer. Hydrologic conditions as judged by long term streamflows and water levels at sites unaffected or only slightly affected by pumping were average to above average.

Precipitation

Precipitation presentations from Kraft et al. (2010, 2012a) were updated and are displayed in Figures 2-1 and 2-2 for Stevens Point, Hancock, and Wautoma. The Stevens Point and Hancock records are virtually complete for the period, but the record for Wautoma needed to be inferred through 2008 using the methods of Serbin and Kucharik (2009).

Trends over past decades

Central sands precipitation has generally increased in recent decades (Figures 2-2 and 2-3, WICCI 2011), possibly masking some of the influence of irrigation pumping on ground and surface waters (Kraft et al. 2012a). The precipitation increase is consistent with wetter conditions that have prevailed over much of the eastern US since 1970 (Juckem et al. 2008), including over much of Wisconsin (WICCI 2011). Compared with 1940-1970, post-1970 precipitation is greater by 0.7 in at Stevens Point, 2.2 in at Hancock, and 2.8 in at Wautoma.

Conditions 2000-2011

Precipitation from 2000 through 2004 was mostly average to above average for Stevens Point, Hancock, and Wautoma. Conditions in 2005-2008 were slightly below average for Stevens Point, and average to slightly above average for Hancock and Wautoma, and in 2009 were about average for all stations. Substantially wet conditions prevailed in 2010, 6.5 to 10.6 in greater than average depending on station, when Stevens Point experienced its third wettest year in an 80 year record. Wet conditions continued in 2011 for Stevens Point and Wautoma, by 2.2 and 5.1 in, though Hancock was average.

2012 and 2013 precipitation

Year 2012 as a whole was drier than average though not unusually dry. However, the summer months were the driest on record for Stevens Point and the 3rd driest for Hancock. Summer (June, July, and August) precipitation totals were 6.3 and 5.4 inches for Stevens Point and Hancock respectively, compared with averages of 11.6 and 11.5. Year 2013 precipitation was about average in Stevens Point and Hancock, but above average at Wautoma. Summer 2013 was slightly dry in Stevens Point and Hancock, with 9.3 and 9.1 inches of precipitation.

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 an indicator of wet and dry conditions, as it contains an algorithm that uses temperature as a surrogate for evapotranspiration. Previously, we concluded that the Palmer Drought Index indicated that central Wisconsin was moderately droughty to very moist from 2000 through 2008, and near normal to very moist in 2009-2011. Years 2012-2013 ranged moderately droughty to moderately moist, with droughty conditions in both summers.

Discharges on Reference Streams

Long term annual discharges for several area streams provide context for current 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 (1914-2014), the Embarrass River at Embarrass (1920-2014 with nine missing years), the Waupaca River at Waupaca (1917-1984 with 20 missing years, plus 2009-2014), and the Wisconsin River between Wisconsin Dells and Wisconsin Rapids (1935 to 2014 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. The Wisconsin River – Central replaced the Wisconsin at Wisconsin Dells and at Wisconsin Rapids from our previous reports, which we found to be heavily affected by drought in northern Wisconsin. We also left out Ten Mile Creek at Nekoosa, as it has apparently become irrigation pumping affected.

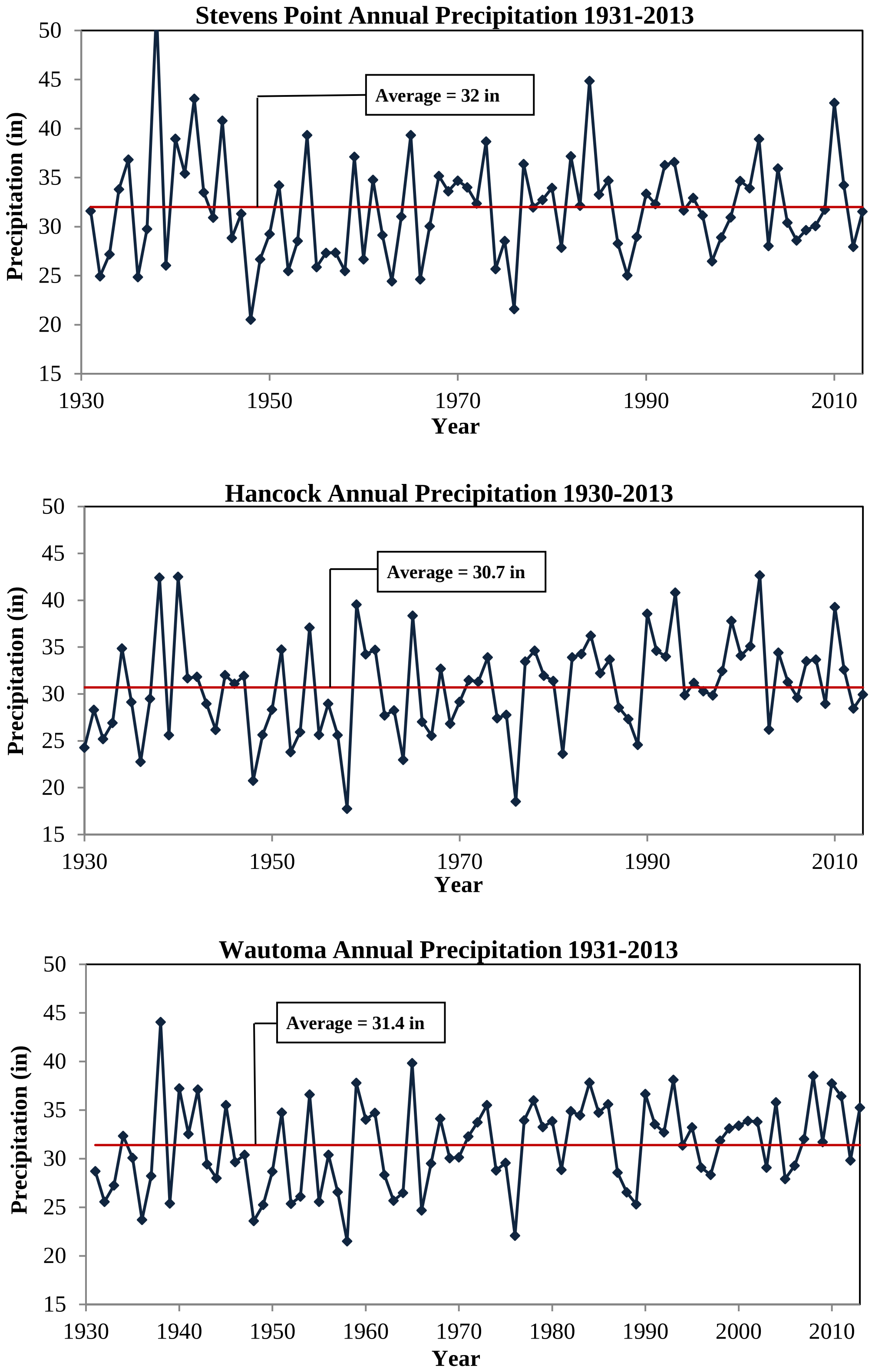
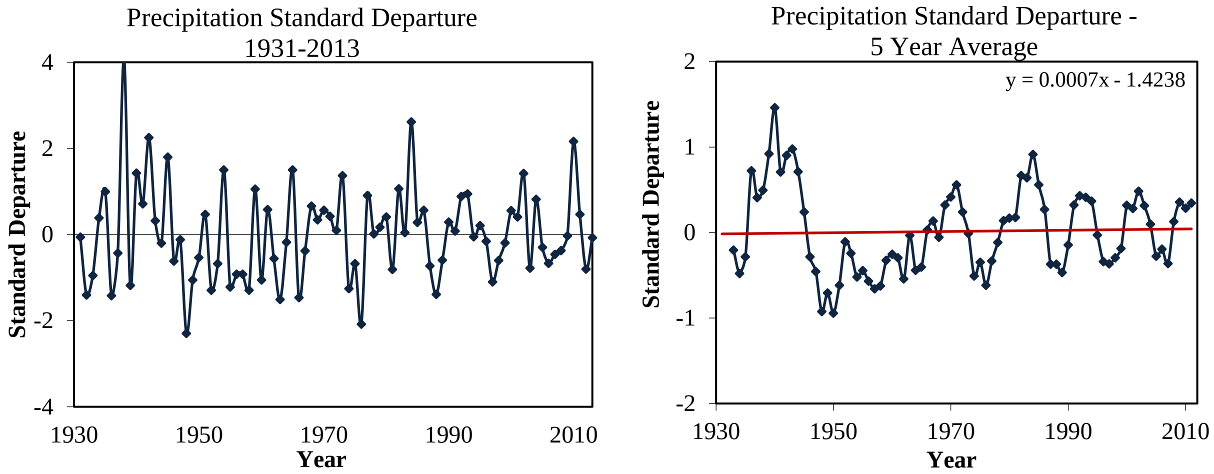
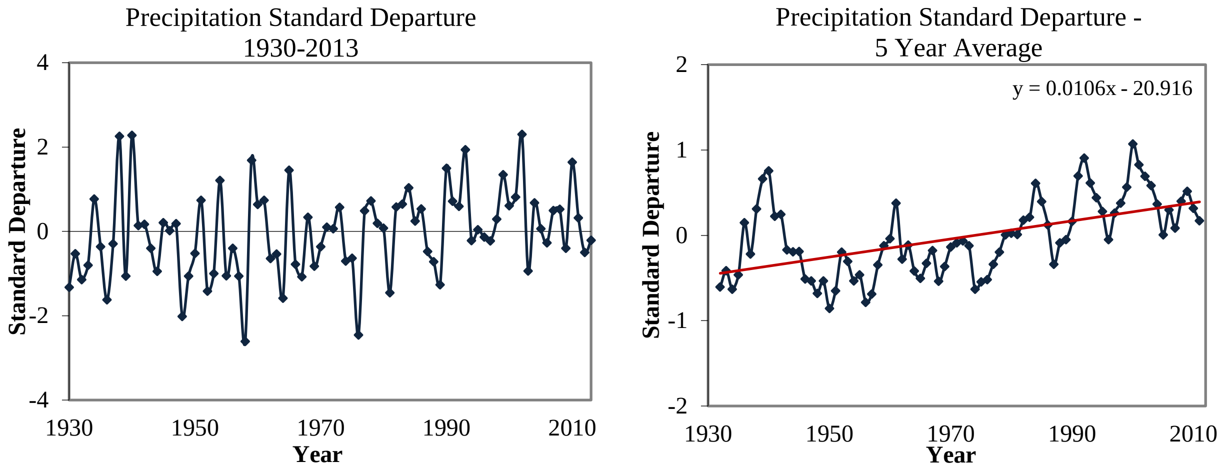


Figure 2-1. Precipitation at Stevens Point, Hancock, and Wautoma. Stevens Point and Hancock data are from historical records with a few inferred values. Wautoma's data from 1931-2007 are inferred using methods of Serbin and Kucharik (2009) and data from 2008-2013 are from historical records.

Stevens Point



Hancock



Wautoma

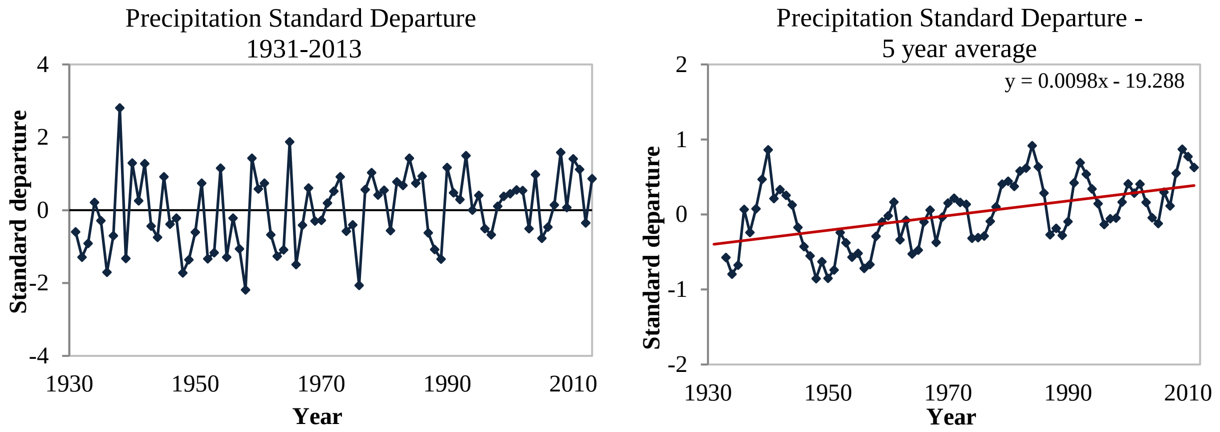


Figure 2-2. Standard departure of annual precipitation and five year average of the standard departure for Stevens Point, Hancock, and Wautoma.

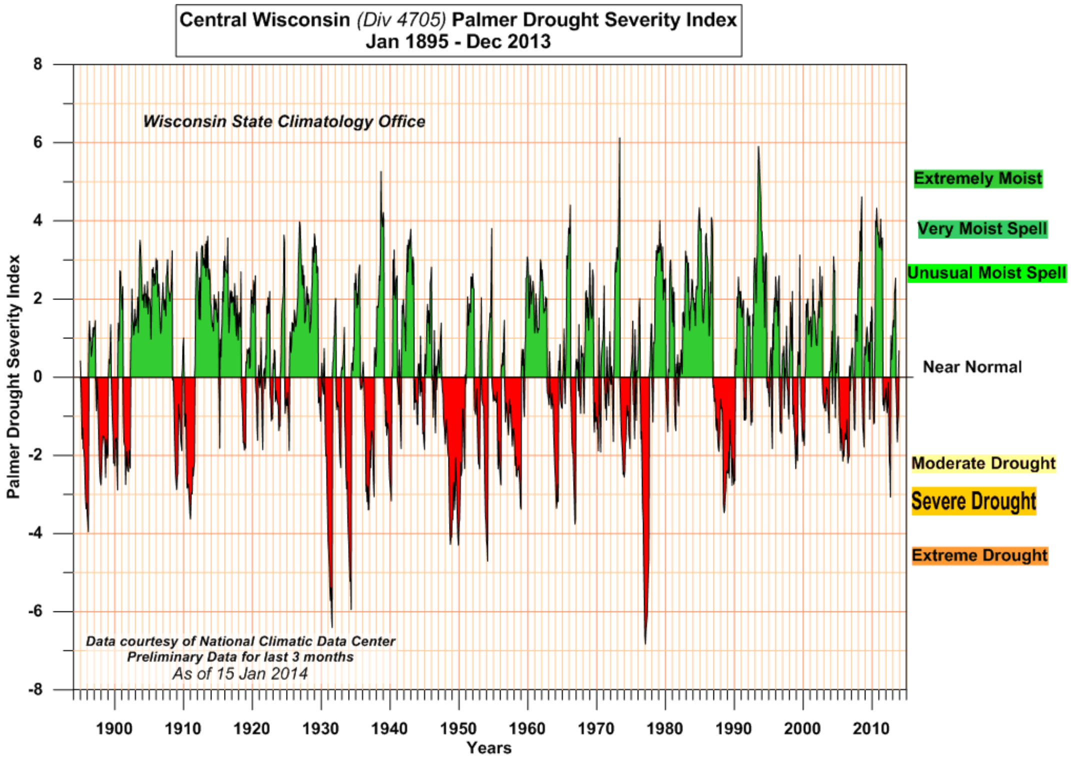


Figure 2-3. Palmer Drought Index graph for central Wisconsin ending December 2013, produced by the Wisconsin State Climatology Office (2013). Note that the post-2000 period is not substantially droughty compared to the historical record.

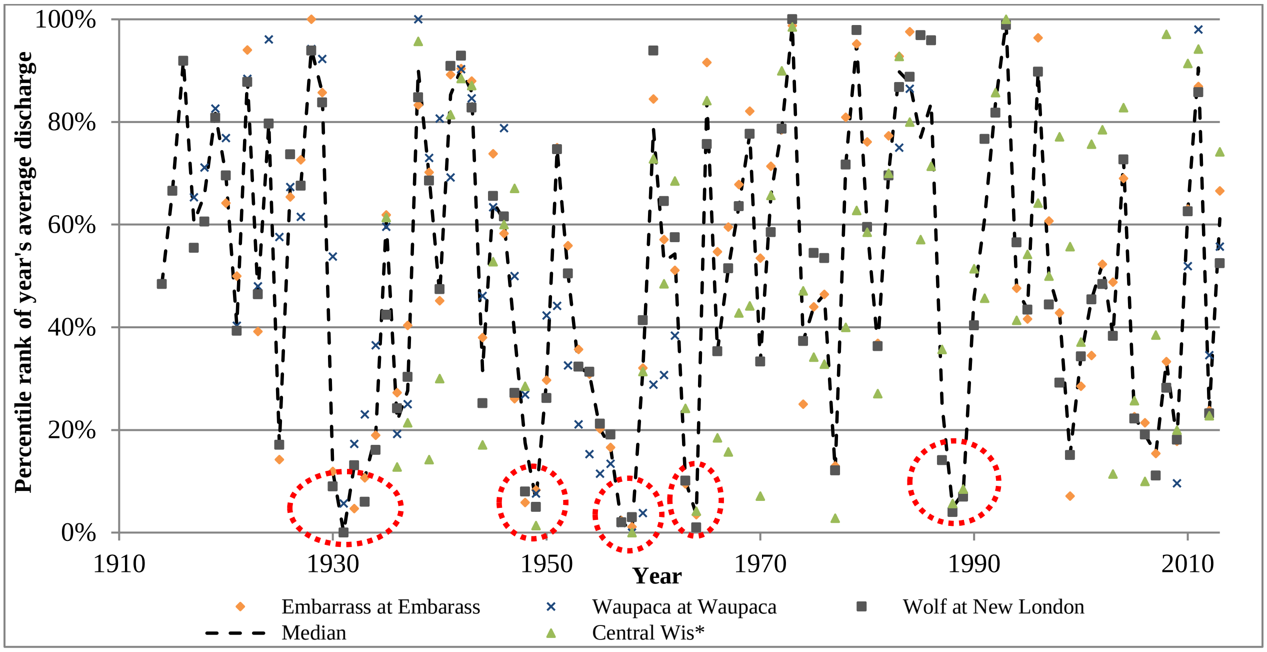


Figure 2-4. Percentile rank of streamflows by year ending 2013. Connecting line is for the median percentile rank. Significant dry periods (median of percentile rank <10%) are highlighted by red circles. "Central Wis" is the difference in Wisconsin River discharges between Wisconsin Rapids and Wisconsin Dells.

Each station has problems when used as reference sites for the central sands. The Wolf River at New London drains a large basin to the northeast of and somewhat removed 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 sq mi), 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 after 1962 and few recent observations until 2009. The Wisconsin River – Central may 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 of the record, and years 1948 to 1964 mark a long period when low flows were unusually common (6 of 17 years). Years 2000-2004 were about average, while 2005-2007 were somewhat low. Discharges began increasing in 2008, and exceeded 90 percentile in 2011. In 2012 and 2013 the median percentile was 23 and 61 respectively.

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). These are Amherst Junction (1958 to 2013 record), Nelsonville (1950 to 1998, 2010 to

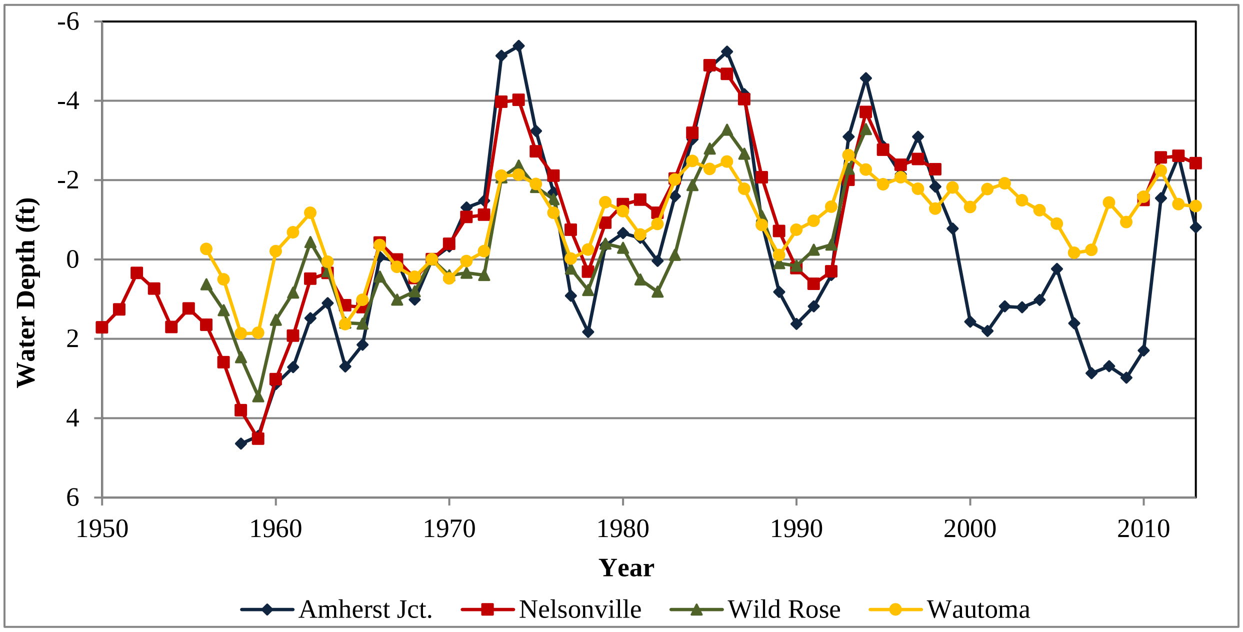


Figure 2-5. Annual average depth to water in four long term USGS monitoring wells located in areas with fewer high capacity wells. Water levels were adjusted so that 1969 values were zero for display purposes.

2013), Wild Rose (1956 to 1998), and Wautoma (1956 to 2013) (Figure 2-5).

The monitoring well record indicates central sands groundwater levels were at long term lows in 1958-9, mostly rose through about 1974, and have since mostly fluctuated cyclically (Kraft et al. 2010, 2012b). During 2000-2010, water levels at Amherst Junction were somewhat low, 6 to 46 percentile, but were typical for Wautoma, 24 to 82 percentile. Levels rose in 2011 for both Amherst Junction and Wautoma, to 72 percentile and 91 percentiles, presumably connected to increased precipitation in the latter half of 2010 and through 2011. Levels for 2012 and 2013 ranged 62 to 83 percentile for the three stations with data.

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 2011 AND 2012

Summary

The central sands region contains 30% of all Wisconsin's high capacity wells. Most are used for irrigation, and their rate of increase has accelerated since 2005. Central sands high capacity well pumping amounted to 54 and 95 billion gallons in 2011 and 2012, 27-34% of Wisconsin's total. Irrigation usage was 86-90% of the total.

High Capacity Well Numbers, Uses, and Growth

Recently implemented statutory requirements and data collection infrastructure provide an improved basis for understanding the geographical distribution and expansion of high capacity wells and groundwater pumping. Reliable, systematic, and highly inclusive pumping data sets are now available for 2011 and 2012.

As of June 2013, some 2199 high capacity wells were listed as active in the central sands, according to the WDNR (2013) data base, mostly in Portage, Waushara, and Adams Counties (Figure 3-1). The region contains 30% of all Wisconsin high capacity wells. Most (90%) are for irrigation (Table 3-1). High capacity well numbers have grown rapidly in the last decade or so, increasing from 1772 in 2000, to 2067 in 2010, and to 2199 by mid- 2013 (Figure 3-2).

2011 and 2012 High Capacity Well Pumping

High capacity well pumping in the central sands amounted to 54 billion gallons in 2011 and 95 billion gallons in 2012 (Table 3-2, Figure 3-3). The disparity between years is likely due to summer 2011 being somewhat wet, while summer 2012 was very dry. Wet conditions in 2011 suppressed the need for irrigation, while dry conditions in 2012 encouraged substantial irrigation application.

Portage, Adams, and Waushara Counties were the top three groundwater pumping counties in Wisconsin in 2012, accounting for almost a third of all Wisconsin groundwater pumping. The same counties ranked first, third, and fourth in 2011 and accounted for a quarter of all Wisconsin groundwater pumping.

Central sands high capacity well groundwater pumping was dominated by irrigation, amounting to 86-90% of the total in 2011 and 2012 (Table 3-1).

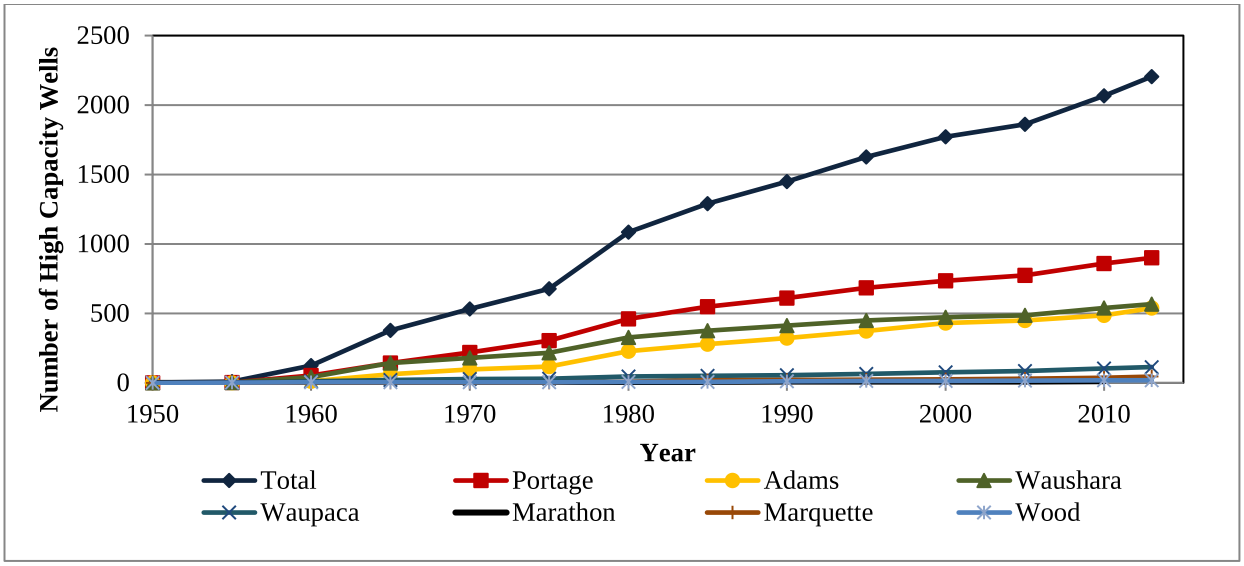


Figure 3-1. Growth of high capacity wells in the central sands, total and by county.

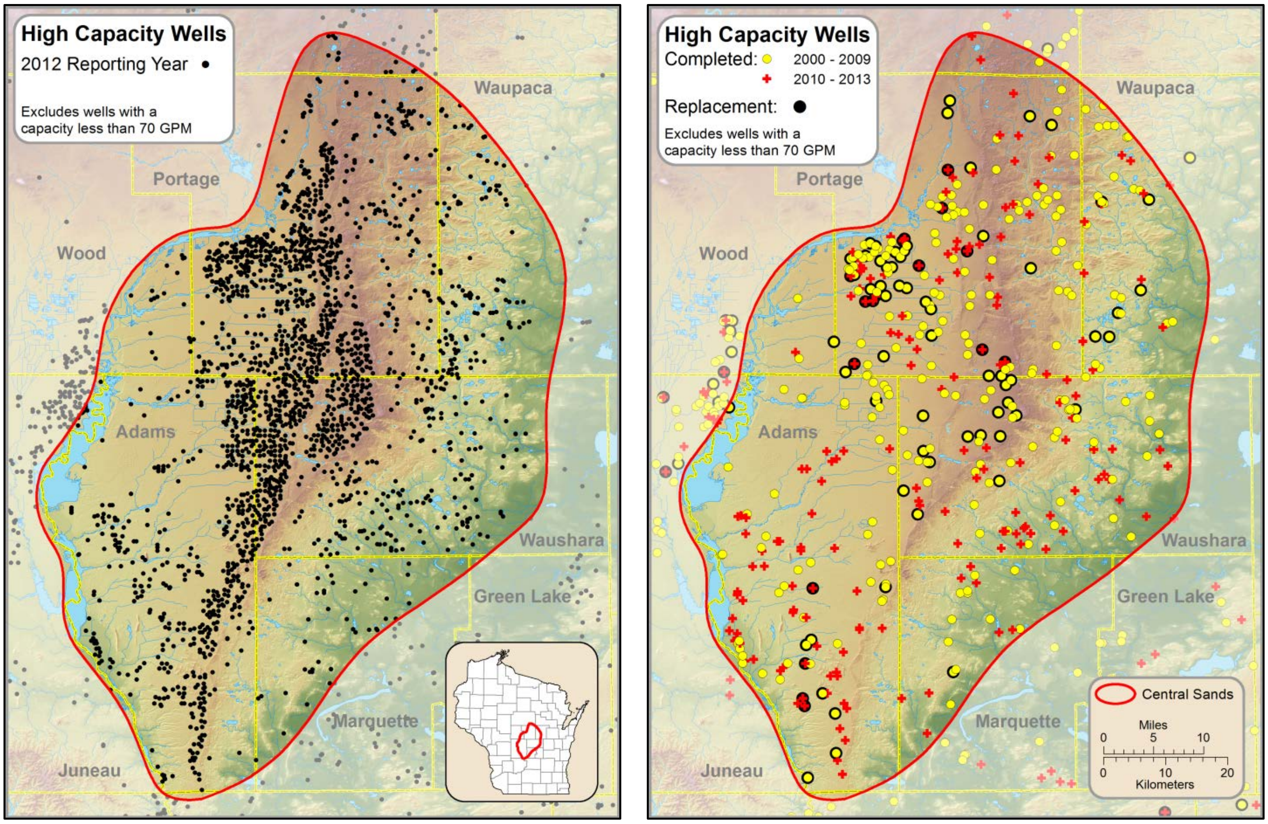


Figure 3-2. High capacity wells in the central sands (left), and their growth since 2000 (right).

Table 3-1. Central sands high capacity wells, total and by use.

	Total	Irrigation	Industrial	Public	Other Ag	Other / Unknown
All Central Sands	2199	1984	52	60	23	80
	------------- Central Sands Portion of Each County ------------					
Adams	538	490	4	11	4	29
Marathon	13	12	-	-	-	1
Marquette	45	26	2	-	7	10
Portage	900	821	39	18	4	18
Waupaca	114	95	3	12	-	4
Waushara	570	529	3	13	8	17
Wood	19	11	1	6	-	1

Table 3-2. Central sands high capacity well pumping, total and by county, for 2011 and 2012, billions of gallons.

2011	Total	Irrigation	Industrial	Public	Other Ag	Other/ Unknown
All Central Sands	54.24	46.95	2.21	2.85	2.13	0.10
	-------------- Central Sands Portion of Each County -------------					
Adams	15.89	15.61	0.02	0.21	0.02	0.03
Marathon	0.14	0.14	0.00	0.00	0.00	0.00
Marquette	1.34	0.54	0.10	0.00	0.65	0.05
Portage	19.05	16.19	2.09	0.71	0.06	0.00
Waupaca	1.86	1.04	0.00	0.82	0.00	0.00
Waushara	14.96	13.34	0.00	0.21	1.40	0.02
Wood	1.00	0.10	0.00	0.90	0.00	0.00

2012	Total	Irrigation	Industrial	Public	Other Ag	Other/ Unknown
All Central Sands	94.69	85.56	2.32	4.44	2.28	0.08
	-------------- Central Sands Portion of Each County -------------					
Adams	28.59	28.01	0.03	0.31	0.23	0.00
Marathon	0.14	0.14	0.00	0.00	0.00	0.00
Marquette	1.88	1.15	0.10	0.00	0.63	0.00
Portage	33.96	29.47	2.17	2.27	0.04	0.00
Waupaca	3.32	2.56	0.01	0.76	0.00	0.00
Waushara	25.27	23.63	0.00	0.21	1.39	0.04
Wood	1.13	0.23	0.00	0.89	0.00	0.00

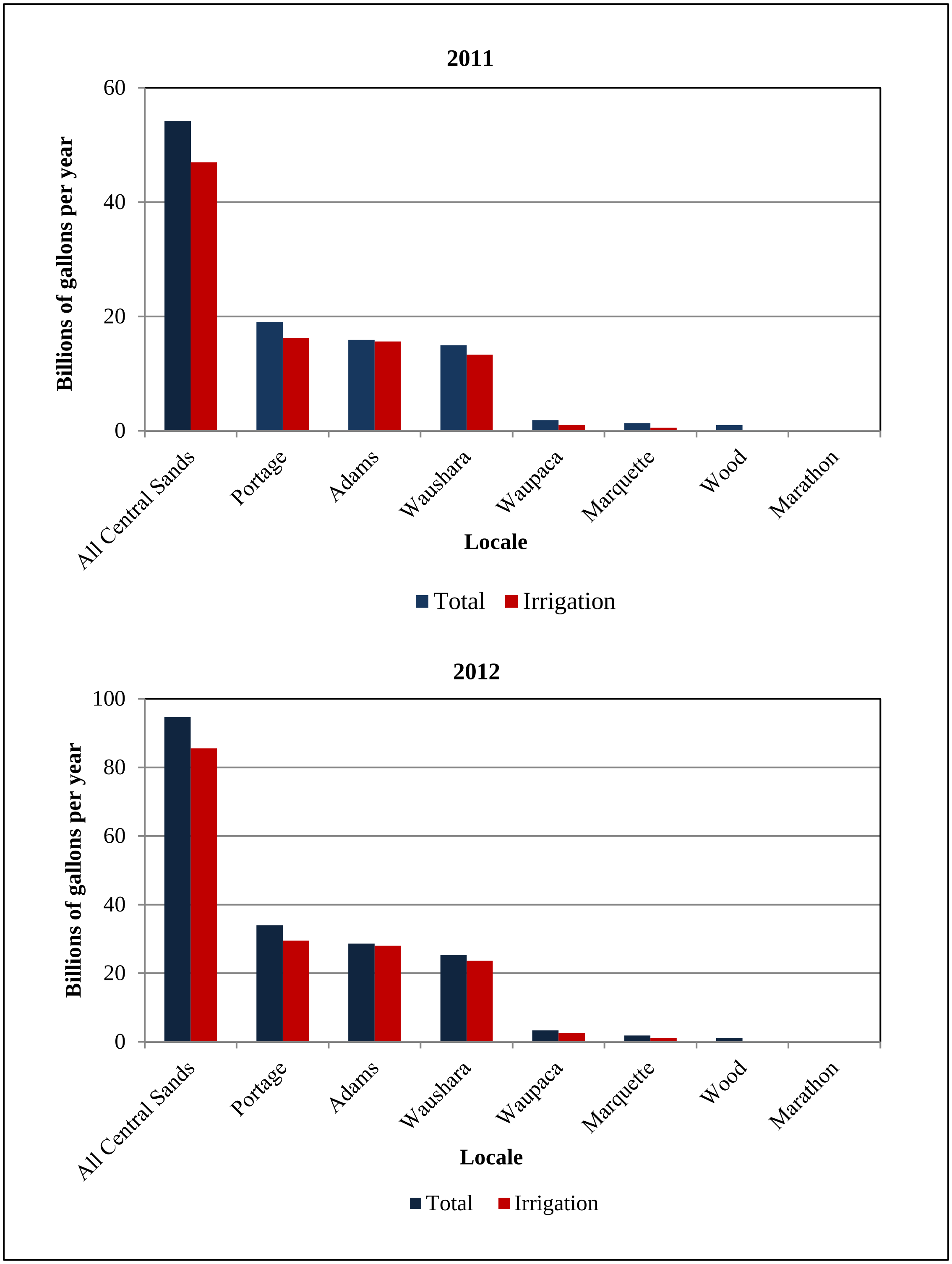


Figure 3-3. Total and irrigation high capacity well pumping in the central sands, total and by county, 2011 and 2012.

4. BASEFLOW DISCHARGES ON SELECT STREAMS – UPDATE

Baseflow discharge measurements continued at 31 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 31 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 2014.xlsx". Data collected through June 2014 were sent to USGS to be archived in their database.

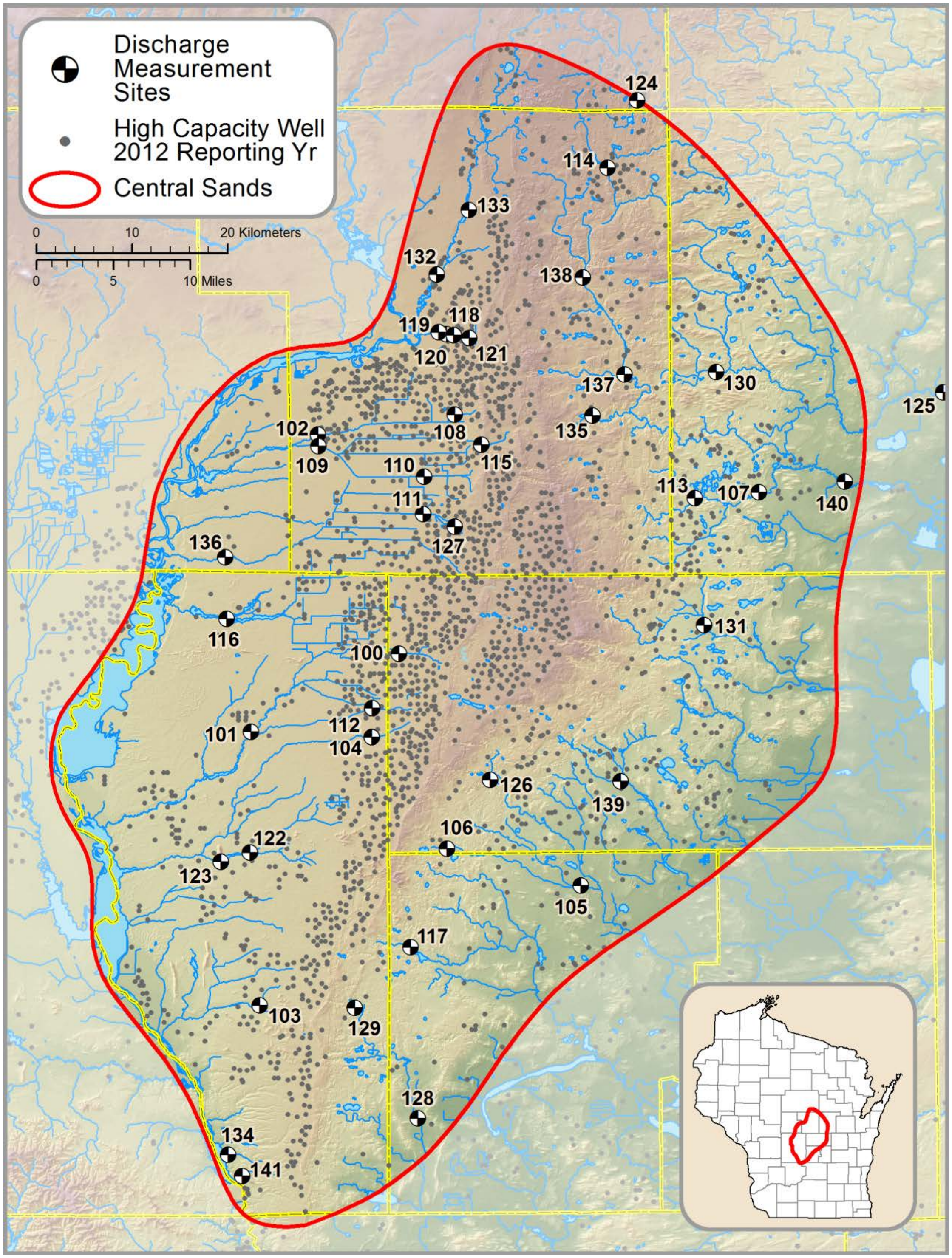


Figure 4-1. Discharge measurement sites from Kraft et al. 2010, most of which were continued for this study.

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				

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 2013.

Project Site Name	USGS					UWSP				
	Years	N	Mean	Min	Max	Years	N	Mean	Min	Max
Big Roche-A-Cri @ 1st Ave	1963-1967	1461	9.3	4.1	50.0	2007-2013	51	9.3	2.4	27.6
Big Roche-A-Cri @ Brown Deer Ave	1963-1978	5496	60.6	28.0	460.0	2007-2013	44	46.5	26.2	83.1
Buena Vista Creek @ 100th Rd	1964-1967	1309	44.6	14.0	187.0	2007-2013	48	31.3	8.7	66.5
Campbell Creek @ A	1971	1	2.6	2.6	2.6	2007-2013	51	2.3	1.0	4.3
Chaffee Creek @ 14th	1962-1988	18	34.7	25.9	47.5	2005-2013	58	37.6	24.0	62.6
Ditch #2 N Fork @ Isherwood	1966	1	5.7	5.7	5.7	2007-2013	71	6.1	3.1	11.6
Ditch #4 @ 100th Rd	1964-1967	1309	39.6	4.0	256.0	2007-2013	37	41.7	7.7	114.1
Ditch #5 @ Taft	1964-1973	3383	8.0	2.2	166.0	2007-2013	35	5.0	0.4	15.0
Emmons Creek @ Rustic Road 23	1968-1974	2330	26.7	21.0	203.0	2005-2013	64	22.3	15.1	39.7
Flume Creek in Rosholt @ 66	1972-1976	5	6.3	3.6	8.7	2005-2013	45	8.0	2.6	34.3
Lawrence Creek @ Eagle	1967-1973	2161	16.9	12.0	39.0	2005-2013	53	19.8	14.7	22.7
Little Plover @ Eisenhower	1968	6	4.1	2.6	5.1	2007-2013	88	2.8	0.0	8.9
Little Plover @ Hoover	1959-1987	10319	10.6	3.9	81.0	2005-2013	204	5.4	1.7	17.4
Little Plover @ Kennedy	1959-1976	6218	4.0	0.8	50.0	2005-2013	194	1.6	0.0	6.8
Little Roche-A-Cri @ Friendship Park	1972-1976	8	35.7	18.2	68.8	2007-2013	39	35.7	2.6	76.3
Little Wolf @ 49	1973-1979	2199	17.1	3.1	220.0	2007-2013	26	10.4	4.3	37.9
Mecan @ GG	1956-1988	22	12.8	10.3	17.9	2005-2013	53	13.3	9.4	15.3
Peterson Creek @ Q	1962-1988	15	18.0	12.9	28.8	2005-2013	60	21.2	10.2	36.2
Plover River @ Y	1914-1951	5113	146.9	37.0	1450.0	2005-2013	101	105.0	39.2	263.0
Tomorrow @ River Rd (Clementson)	1993-1995	905	33.6	16.0	212.0	2005-2013	84	22.1	12.5	88.8
W Branch White River @ 22	1963-1965	731	22.1	16.0	61.0	2005-2013	52	26.1	20.0	50.2

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

Summary

The long-term groundwater level records of eight central sands monitoring wells have proved useful for exploring trends during the last half century and separating the effects of pumping from the influences of weather. Four of the eight, three of which are still active, are located in areas with few high capacity wells and are relatively slightly affected by high capacity well pumping. The four others are located in areas with many high capacity wells and are substantially pumping affected. Groundwater level records in areas with few high capacity wells thus provide a useful reference for groundwater mainly under the influence of weather. Water levels in the areas with few high capacity wells were at a record low during the dry extreme of 1958-1959, rose through 1974, and fluctuated cyclically through the late 1990s. During 2007-2009, water levels were somewhat low (6 to 24 percentile of the reference record), but rebounded sharply (72 to 91 percentile) during the wet 2010-2011 years, and in 2012-13 were at 62 to 78 percentiles. Water levels in the areas with many high capacity wells were initially similar, but then incongruent declines became observable beginning in 1973-1990, depending on locale. Water levels plummeted in the late 2000s, increased briefly in 2010-2011, and then declined again in 2012-2013. Water levels in the areas with many high capacity wells in 2012-2013 were below 1958-1959 lows at two locations and were at 4 to 12 percentile at two others. Pumping declines for 2012-2013 were estimated at about 4 feet at Hancock and Plover and 1 foot at Bancroft.

Monitoring Wells

The records of eight monitoring wells in the USGS archives have previously proved useful (Kraft et al. 2010, 2012a) 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 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 2012 – 2013.

Water level records suffer several deficiencies. The Wild Rose record terminated in 1994, and the Nelsonville record (PT-24/10E/28-0015) lacks observations from 1998 until it was replaced in 2010 (PT-24/10E/28-1487). 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

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[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.

wells are currently generating data.

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	2013+	1353+
PT-23/10E/18-0276	Amherst Jct.	17.4	7/2/1958	2013+	1723+
PT-23/08E/25-0376**	Plover	19.0	12/1/1959	2013+	1199+
WS-18/10E/01-0105	Wautoma	14.0	4/18/1956	2013+	18206+
WS-19/08E/15-0008	Hancock	18.0	5/1/1951	2013+	19722+
PT-21/08E/10-0036	Bancroft	12.0	9/7/1950	2013+	1672+
PT-21/07E/31-0059***	Coloma NW	15.3	8/8/1951	2013+	776+
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.

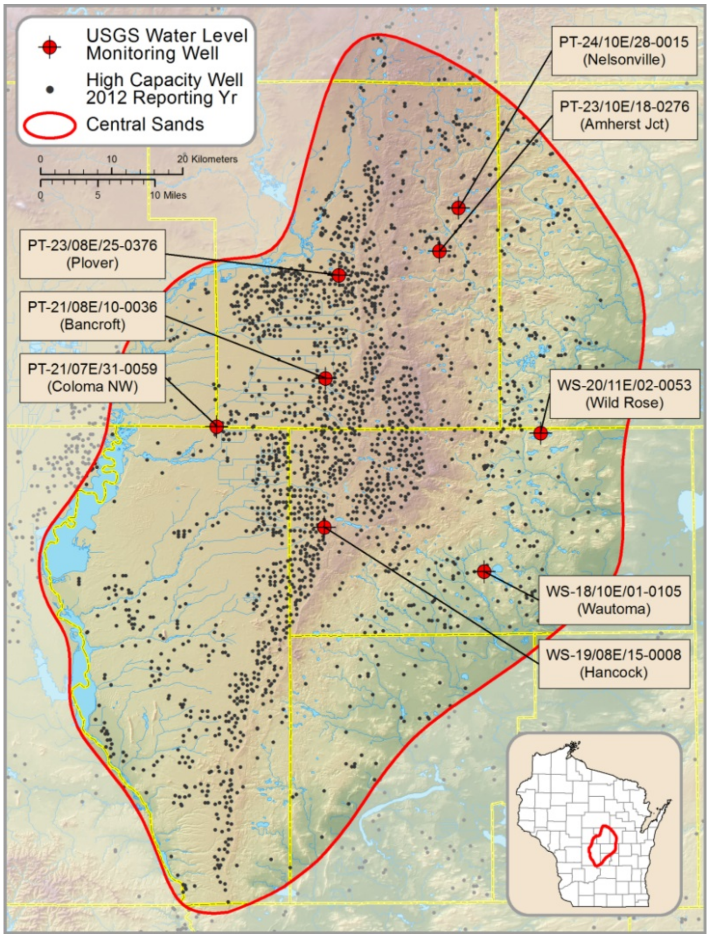

Figure 5-1. Location of eight USGS monitoring wells with records sufficient for exploring long term water level trends.

Groundwater Hydrographs

Updated annual average hydrographs are displayed in Figure 5-2, grouped according to location in an area 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 indicators of wet and dry condition (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 in the groundwater flow system, water level trends conform to whether the monitoring well is 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, 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 at their lowest in the late 2000s, even when compared with the extremely dry 1950s. 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). Average pumping declines were estimated previously for the period 1999-2008 (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

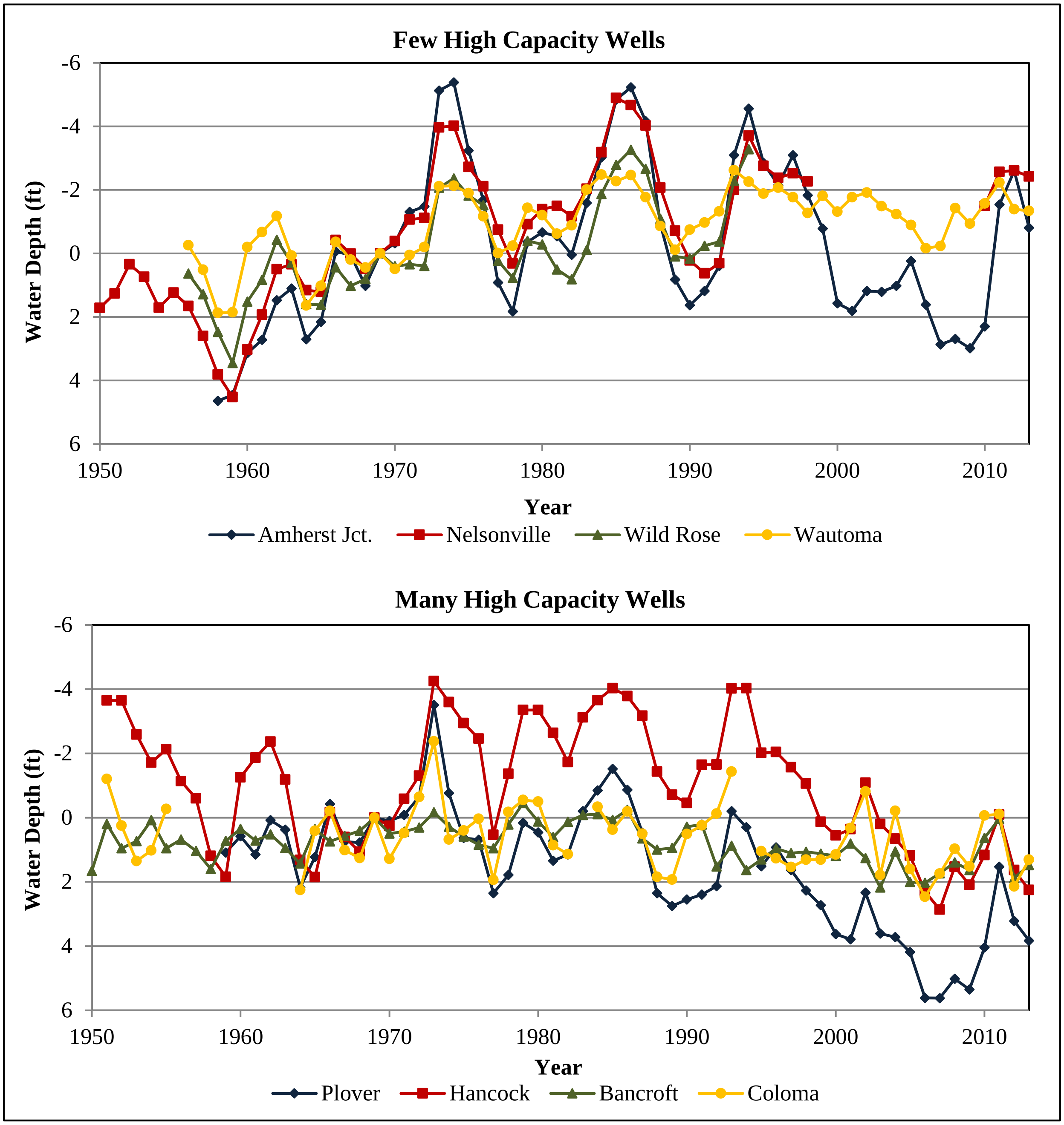

Figure 5-2. Annual average water levels in areas of few (top) and many (bottom) high capacity wells. Water levels are zeroed to 1969 water depths for display purposes.

2012-2013 Groundwater Levels and Pumping Declines

Water levels in 2012-2013 generally declined compared to 2010-2011. Levels in areas of fewer high capacity wells remained above average, 62 to 78 percentile of the 1959-1990 reference record, while those in areas with many high capacity wells were below their 1959-1990 minimum at Plover and Bancroft, and 4 to 12 percentile at Hancock and Coloma.[1]

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. Water levels rose in 2010-2011 by about 4 feet, presumably in response to the large rains that prevailed during that period, but fell by about 2 feet in 2012-2013. Estimated pumping declines averaged 3.8 feet in 2012-2013 (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 2012-2013 were about 4.3 feet (Figure 5-4, bottom).

Bancroft

Bancroft water levels have been declining since the mid 1980s and were at record lows in much of 2003-2007 (Figure 5-5, top). Water levels rebounded in 2010 and 2011 to about historical averages, and fell in 2012-2013 by about 0.7 feet. 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 began about 1984, and in 1999-2008 averaged 1.2 feet, Wautoma reference (Figure 5-5,

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[1] The 1959 to 1990 period was chosen as a reference period because it starts in a year when most stations were operational and ends about when all stations in areas of many high capacity wells become pumping affected. Note that the Coloma NW site had insufficient data to generate representative annual estimates.

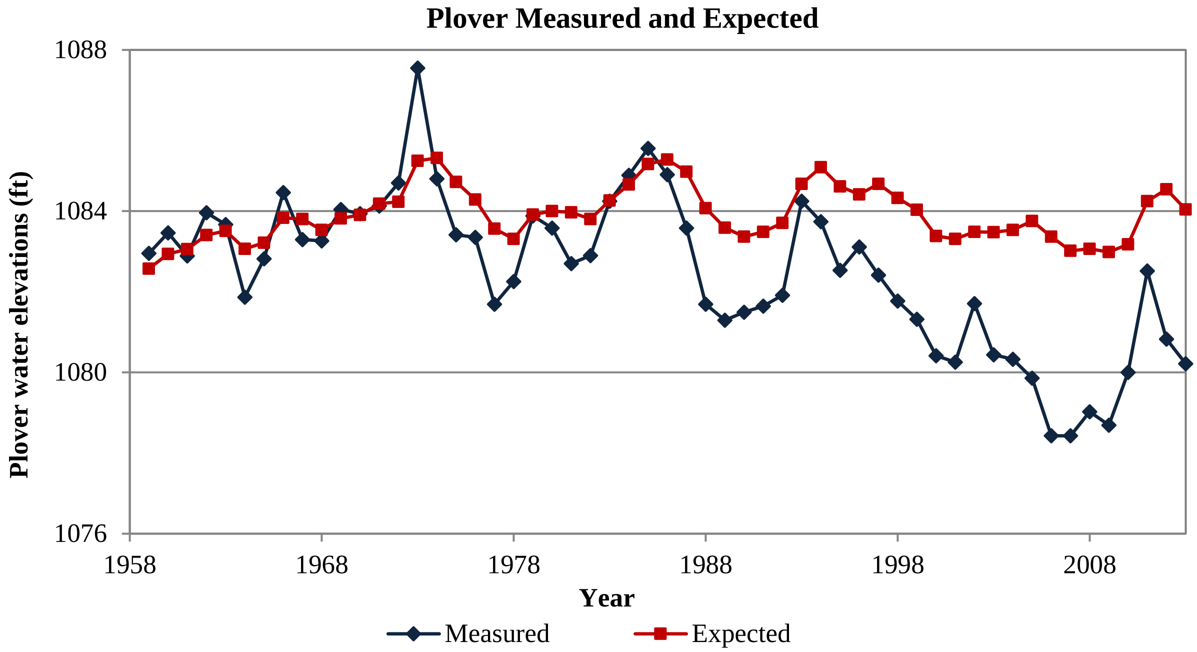
bottom), or 0.82 feet, Amherst Junction reference. Estimated pumping declines almost entirely abated during the wet period of 2010-2011, but increased to 1.0 foot in 2012-2013.

Coloma NW

Groundwater levels at Coloma NW have been generally declining since the early 1990s. Levels were at a low for the 1964-2013 record in 2006, but rebounded to about the long term average in 2010 and 2011 (Figure 5-6, top). Post-2011 levels dropped by about 1.8 feet in 2012-2013.

Coloma NW water levels exhibit an oddness compared with other sites, possibly due to its location near groundwater discharges. In addition, the Coloma NW locale is 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 conflicting 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. These indicate a maximum pumping decline of 3.6 feet occurred in 2012. However, comparisons using the Amherst Junction reference site do not indicate such a pumping decline. Another approach (Haucke 2010) using a statistical method based on precipitation, has estimated a pumping drawdown averaging 0.7 feet at Coloma NW.

In summary, Coloma NW water levels have shown a general decline to levels only previously seen during the very dry year of 1964. The reference well methodology used here gives conflicting estimates of pumping in drawing down water levels. Other approaches do indicate a significant pumping effect.



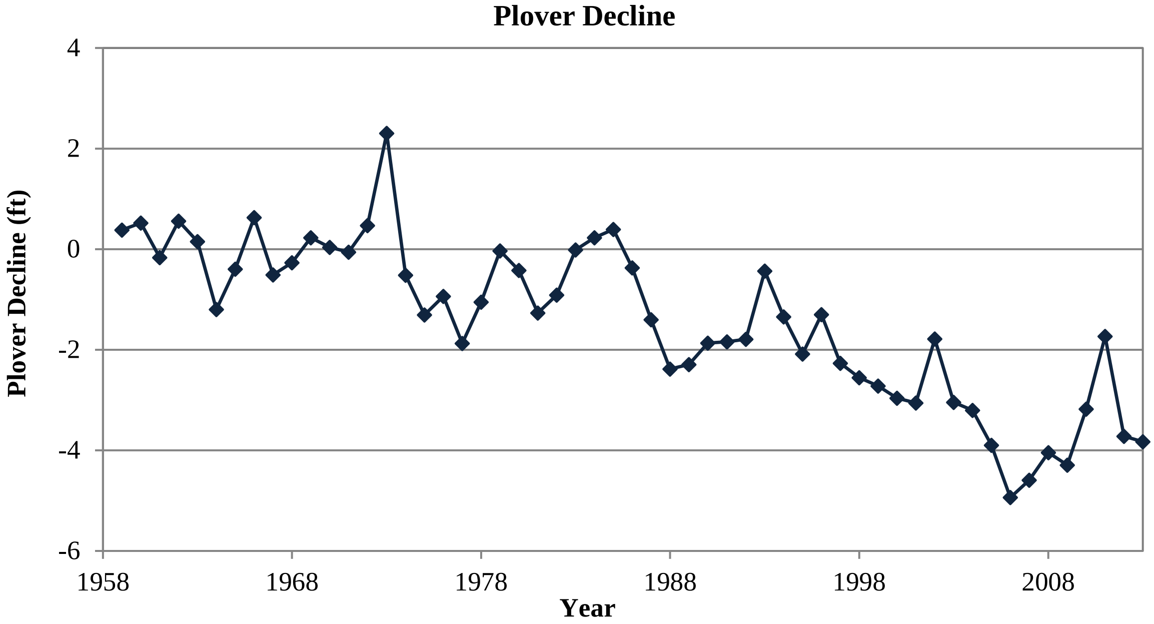
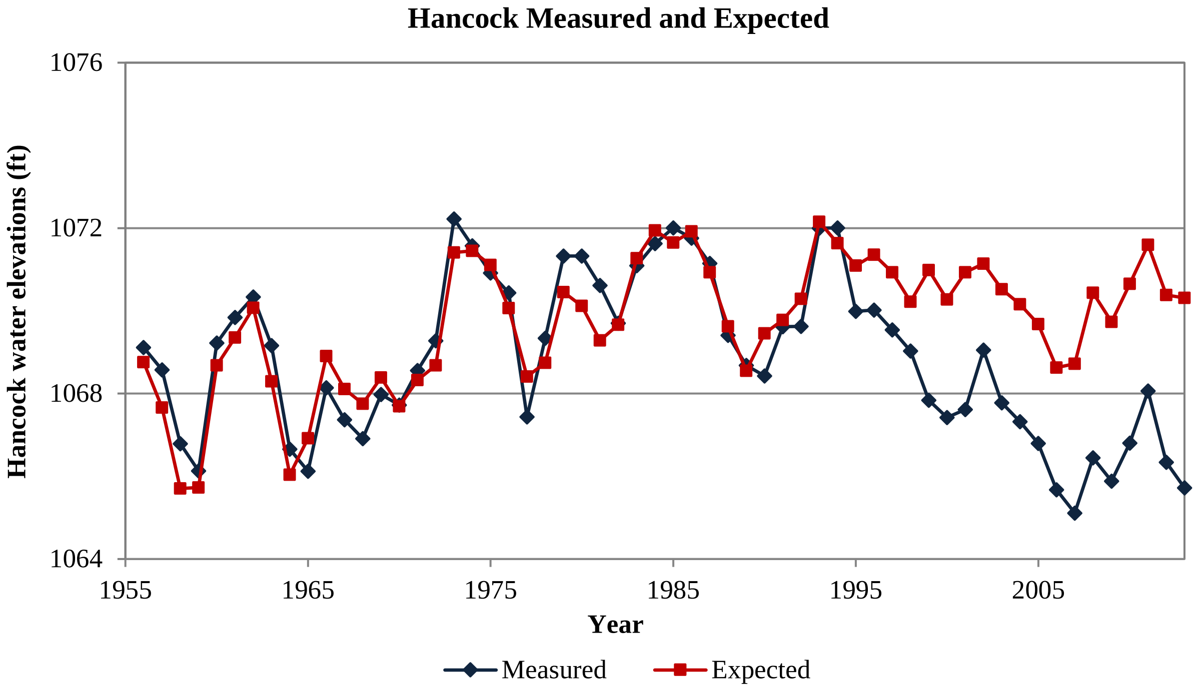


Figure 5-3. Top: Measured and expected average annual groundwater elevations at Plover. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels.



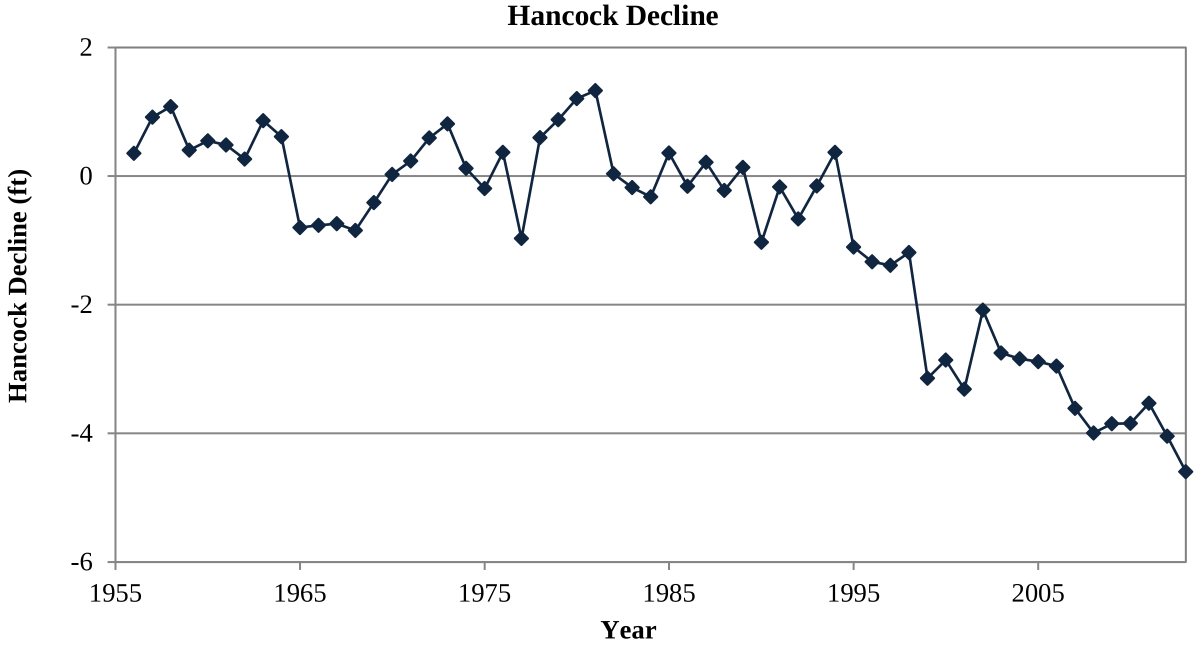
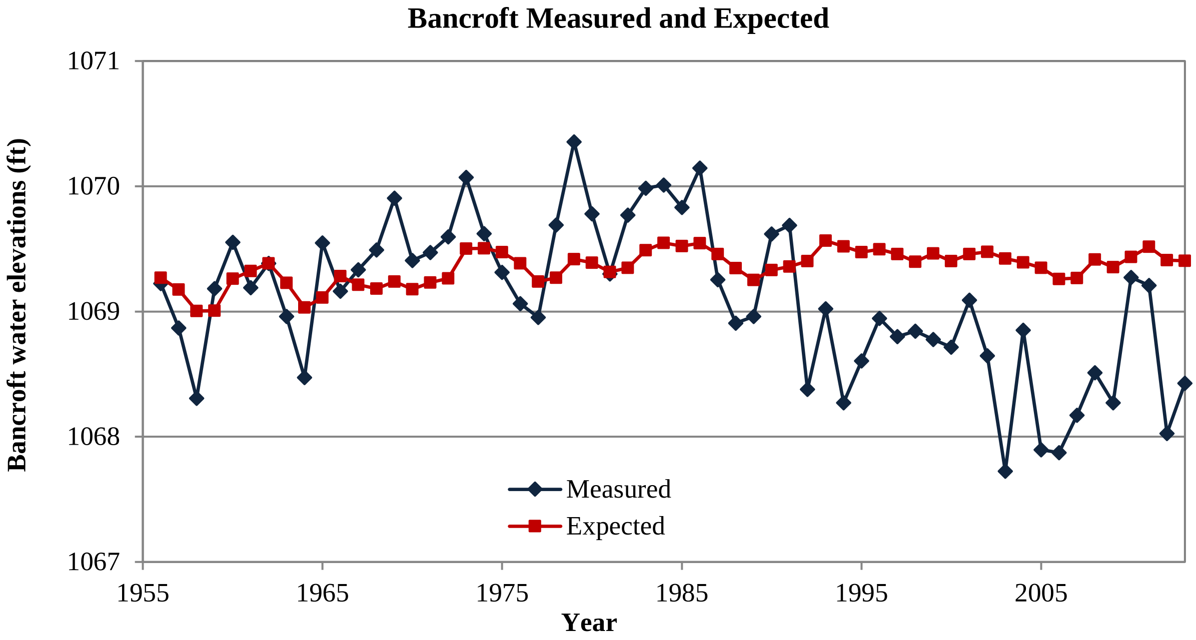


Figure 5-4. Top: Measured and expected average annual groundwater elevations at Hancock. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels.



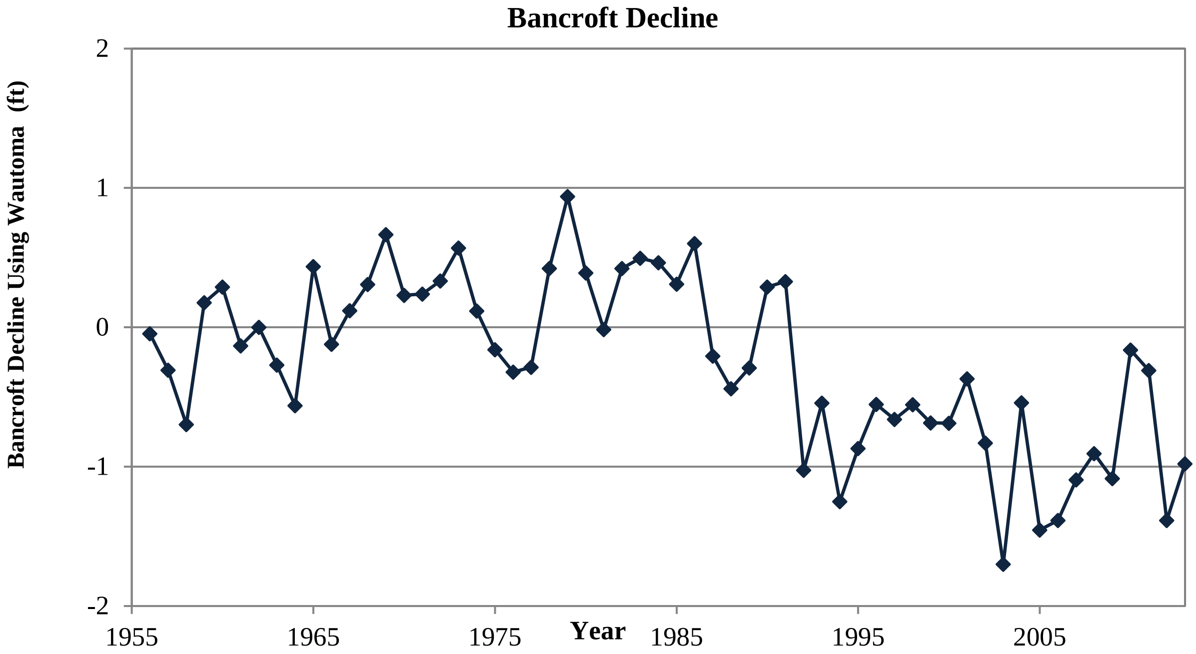


Figure 5-5. Top: Measured and expected average annual groundwater elevations at Bancroft. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels. Wautoma reference shown, Amherst Junction is similar.

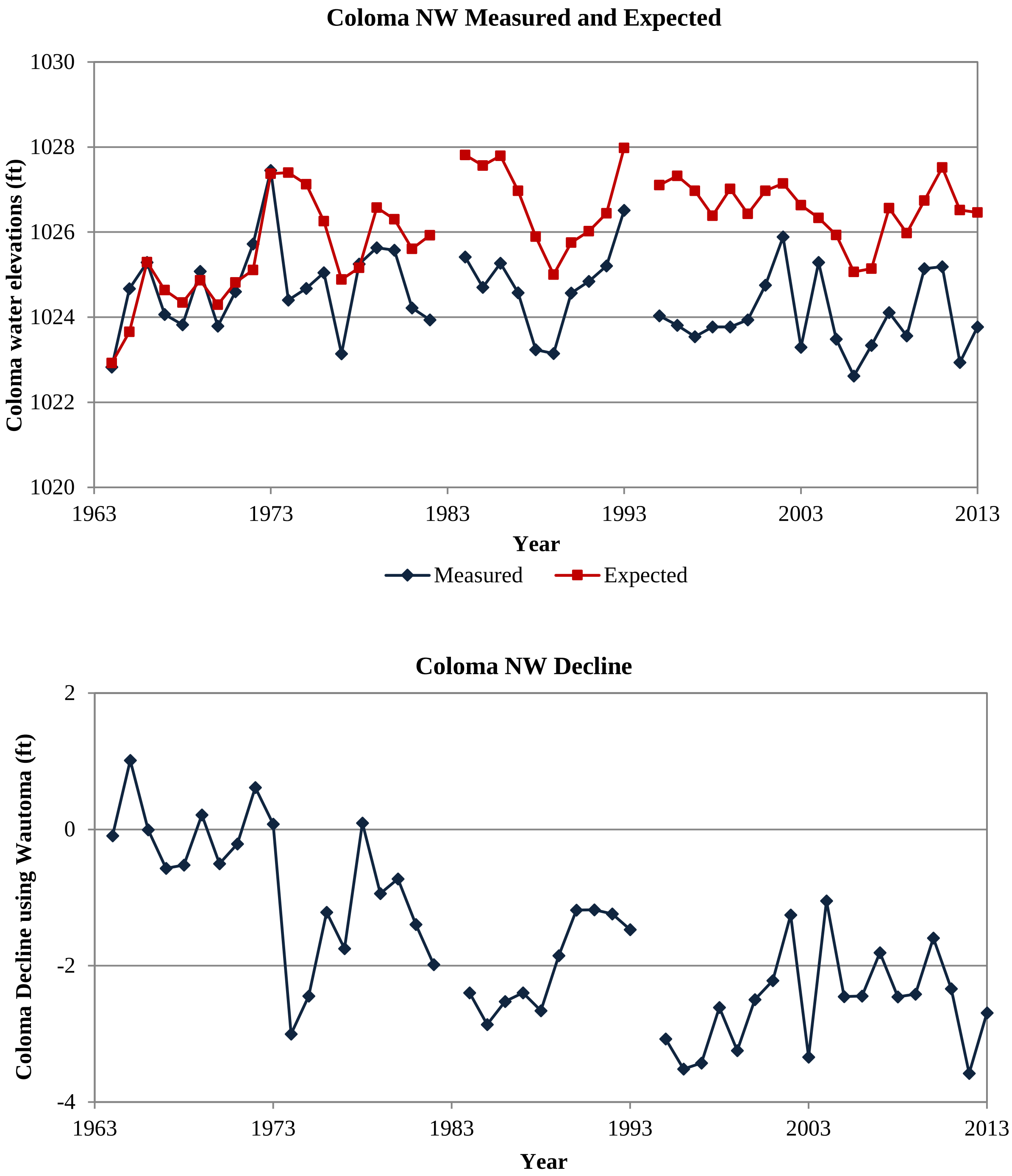


Figure 5-6. Top: Measured and expected average annual groundwater elevations at Coloma NW. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels. Wautoma is used as the reference gauge. Use of the Amherst Junction gauge does not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

6. LAKE LEVEL RECORD AND TRENDS – UPDATE

Summary

Levels for previously inventoried lakes were downloaded and added to the project's database. For the 31 lakes with data, lake levels mostly increased from 2007 lows through 2011, by an average 2.6 feet, presumably due to the large rains of 2010-2011, and then declined by an average 0.7 feet by 2013. The levels of four lakes previously found to have large and significant apparent pumping declines were revisited. Estimated pumping declines, which reached 3.3 to 8 feet in 2007-2010, were 1.6 to 6.3 feet for 2012-2013.

Lake Level Data

Kraft et al. (2010) previously identified 39 lakes with potentially useful level records (Figure 6-1). The lake data inventory (Table 6-1) and level data base (Lake Level Data Updated to 2013.xlsx,

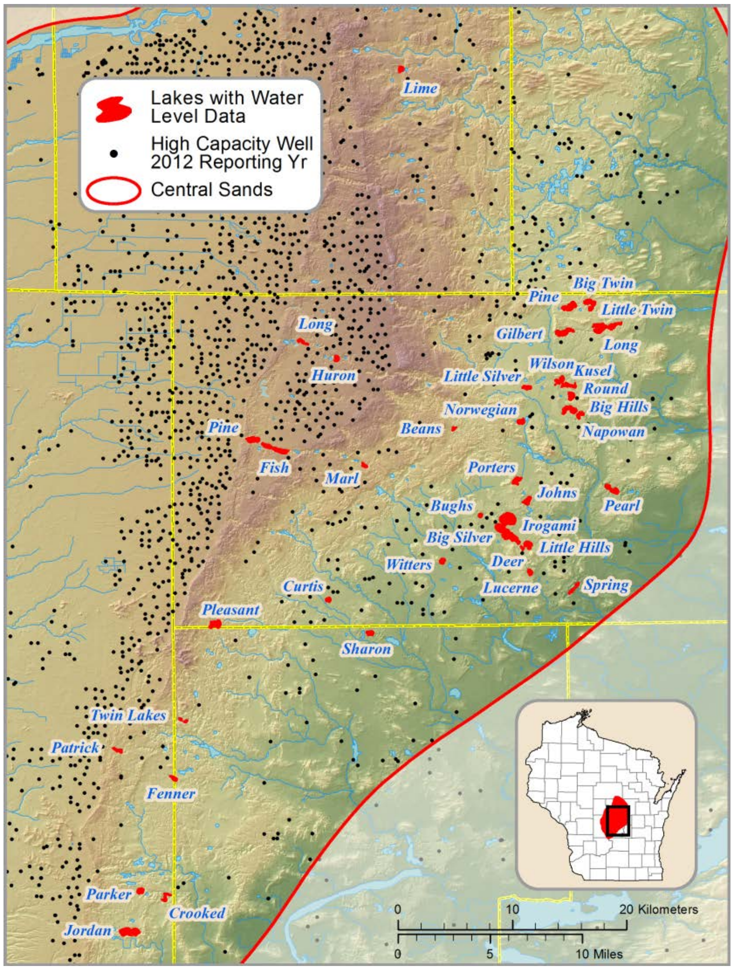


Figure 6-1. Location of lakes with water level data in the project database.

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

Lake Name	County	Number of Levels	First Lake Level	Last Lake Level	Avg. Yrs. Between Levels
Bean's Lake	Waushara	17	7/10/73	7/25/13	2.36
Big Hills Lake (Hills)	Waushara	16	9/7/95	8/1/13	1.12
Big Silver Lake	Waushara	29	5/14/66	8/8/13	1.63
Big Twin Lake	Waushara	19	6/18/75	8/6/13	2.01
Burghs Lake	Waushara	24	9/7/73	7/25/13	1.66
Crooked Lake	Adams	12	6/14/73	6/20/89	1.34
Curtis Lake	Waushara	16	9/12/95	8/15/13	1.12
Deer Lake	Waushara	17	7/28/93	8/13/13	1.18
Fenner Lake	Adams	8	4/25/74	6/13/85	1.39
Fish Lake	Waushara	17	7/10/73	7/25/13	2.36
Gilbert Lake	Waushara	34	5/10/62	8/6/13	1.51
Huron Lake	Waushara	19	7/3/73	7/25/13	2.11
Irogami Lake	Waushara	30	1/1/31	8/13/13	2.76
John's Lake	Waushara	17	7/28/93	7/25/13	1.18
Jordan	Adams	20	9/8/67	9/6/90	1.15
Kusel Lake	Waushara	32	9/30/63	8/1/13	1.56
Lake Lucerne	Waushara	28	9/30/63	8/13/13	1.78
Lake Napowan	Waushara	20	5/21/85	8/1/13	1.41
Lime	Portage	6	10/2/40	11/7/94	9.02
Little Hills Lake	Waushara	13	8/3/01	8/13/13	0.93
Little Silver Lake	Waushara	17	7/20/93	8/1/13	1.18
Little Twin	Waushara	17	5/21/85	7/30/12	1.60
Long Lake	Waushara	29	8/16/61	7/25/13	1.79
Long Lake Saxeville[1]	Waushara	20	11/3/87	8/6/13	1.29
Long Lake Saxeville[2]	Waushara	84	6/1/47	7/1/09	0.74
Marl Lake	Waushara	16	4/1/98	7/25/13	0.96
Norwegian	Waushara	18	6/23/75	8/1/13	2.12
Parker	Adams	13	5/26/83	9/6/90	0.56
Patrick	Adams	9	5/6/77	6/16/86	1.01
Pearl	Waushara	17	6/17/75	8/2/13	2.24
Pine Lake Hancock	Waushara	21	7/10/73	7/25/13	1.91
Pine L (Springwater)	Waushara	33	2/8/61	8/6/13	1.59
Pleasant Lake	Waushara	27	7/9/64	8/15/13	1.82
Porter's Lake	Waushara	12	7/26/02	7/25/13	0.92
Round Lake	Waushara	15	4/1/98	8/1/13	1.02
Sharon	Marquette	72	11/17/84	5/31/94	0.13
Spring Lake	Waushara	24	10/1/63	8/16/13	2.08
Twin Lakes Westfield	Marquette	11	6/6/02	8/23/04	0.20
Wilson Lake	Waushara	19	6/18/75	8/1/13	2.01
Witter's Lake	Waushara	26	10/6/63	7/25/13	1.92

[1] Record provided by Waushara County and WDNR

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

appended as electronic media) have been updated through 2013.

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 levels average 0.6 lakes per year in the 1950s, 5 per year from 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 and a 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. The 2011-2013 trend was downward, by an average of 0.7 feet and a maximum of 2.3 feet.

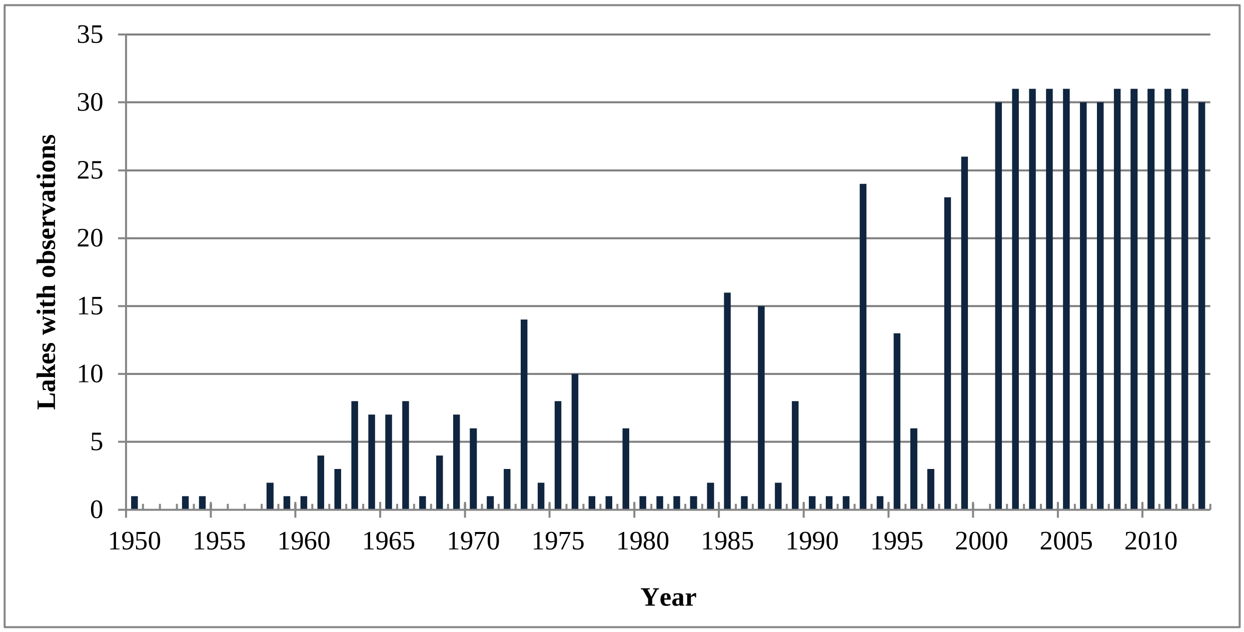


Figure 6-2. Number of lakes with water level elevations by year (two lakes combined had five total observations prior to 1950).

Long Lake Saxeville Levels

Long Lake - Saxeville (not to be confused with Long Lake – Oasis near Plainfield, which dried in 2006), unlike most lakes in the region, has a detailed record that includes multiple observations in the 1940s and 1950s, and even a single observation in 1927. The record has three 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 data types were reconciled by P. Juckem of the USGS (pers. comm.) and stages were inferred from citizen beach width measurements by regression. For the most part, Long Lake data sources are mutually corroborative, with the possible exception of 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 in 2012-2013.

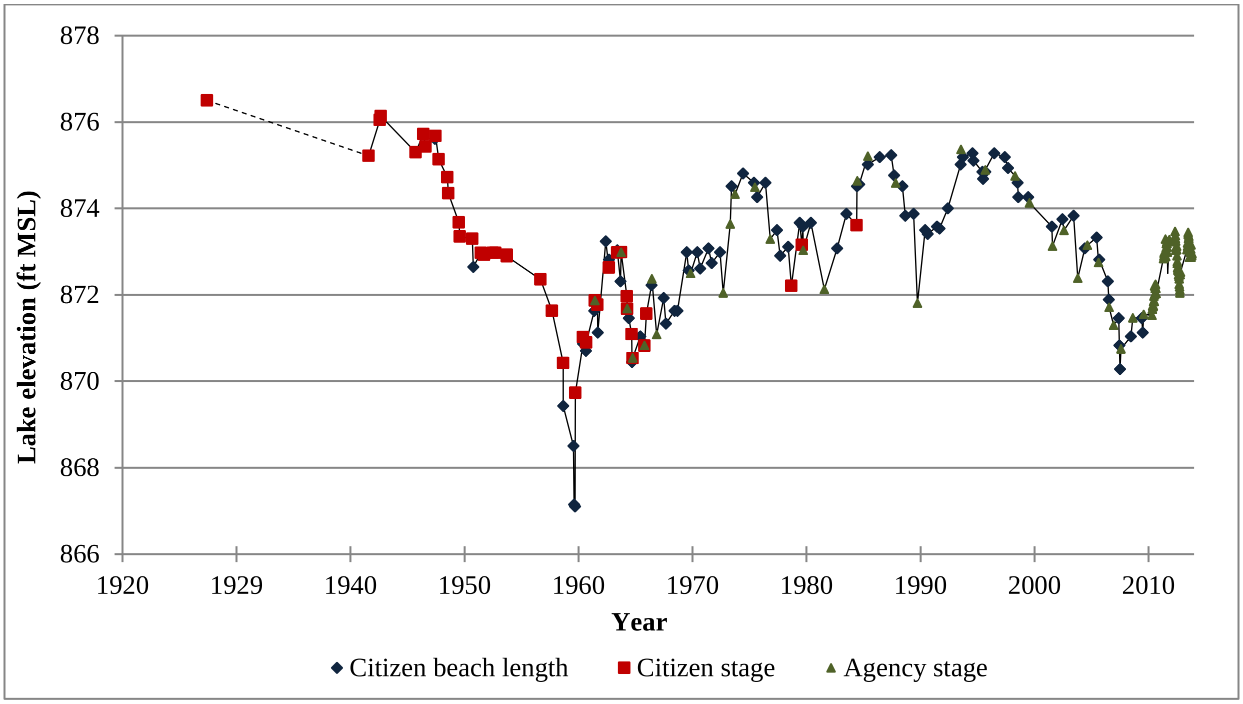


Figure 6-3. Hydrograph of Long Lake - Saxeville 1950-2013 (not to be confused with Long Lake - Oasis, which dried in 2006).

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 pumping declines 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 2013, 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. In 2013, estimated pumping declines ranged from 1.6 feet (Pleasant Lake) to 6.3 feet (Huron Lake).

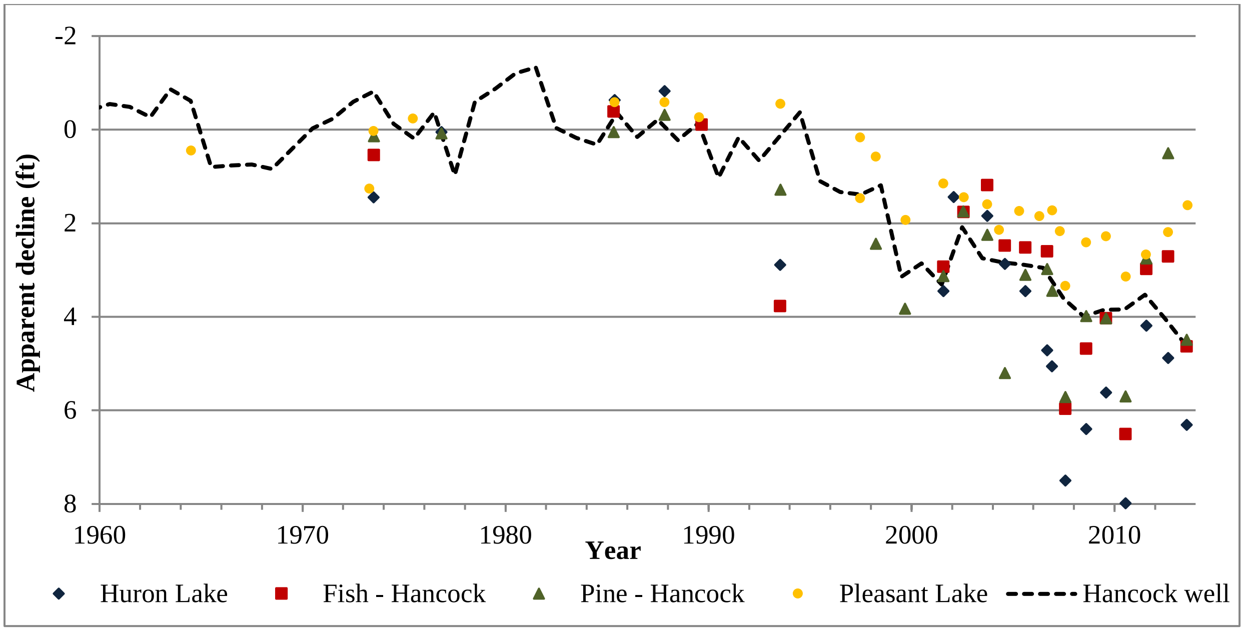


Figure 6-4. Declines in water levels at four lakes and the Hancock monitoring well.

7. LITTLE PLOVER RIVER 2011-2013 UPDATE

Summary

Little Plover baseflows returned to a less-than public rights flow (PRF) regime in August 2012 that continued beyond December 2013. The return marked the end of almost two years of "healthy flows" (greater than PRF) brought about by large amounts of precipitation in 2010 and 2011. Baseflow discharges were less than the public rights flow at Hoover Rd. 49% of the time in 2012, 69% of the time during 2013, and 70% of the entire 2005 through 2013 period of recent observations.

High capacity well pumping was substantial in 2011-2012. Municipal pumping, industrial pumping, and the pumping of 69 irrigation wells located within two miles of the Little Plover totaled 2.9 and 4.1 billion gallons in 2011 and 2012. Summer 2012 pumping was particularly notable, 32.7 Mgd (50.6 cfs), or the equivalent of five Little Plover Rivers at average flows before pumping began excessively affecting the river (Hoover Rd. gauge). Irrigation pumping within two miles of the Little Plover was 1.39 and 2.58 billion gallons in 2011 and 2012, respectively. Village of Plover pumping was 1.26 Mgd in 2011, consistent with the previous 6 years, but increased to 1.49 Mgd in 2012. Plover pumping from well 3, its well with the least impact on the Little Plover, declined to 56% of total Village pumpage from the stated goal of 80%. Del Monte pumping remained a relatively constant 203 million gallons per year, and Whiting wellfield pumping decreased from about 4.2 Mgd to 1.9 Mgd due to closure of the New Page paper mill. Diversions from municipal and industrial pumping were 1.51 and 1.37 cfs in 2011 and 2012. Total diversions, including irrigation, were previously estimated at about 4.5 cfs on average.

Five diversion reduction measures have been implemented or proposed over the past 9 years. A reassessment of those measures indicates diversion reductions were smaller than anticipated, mainly due to (1) increased total Plover pumping and increased reliance on well 3, and (2) smaller than anticipated decreases in Whiting wellfield pumping. Current and proposed diversion reduction measures might reduce the PRF failure rate from a 2005-2007 baseline of 77% of the time to 72-74% of the time, assuming average diversions of 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 has flowed below the public rights levels 70% of the time during 2005-2013. Here we briefly update the more detailed work of Clancy et al. (2009) and Kraft et al. (2012a, 2012b).

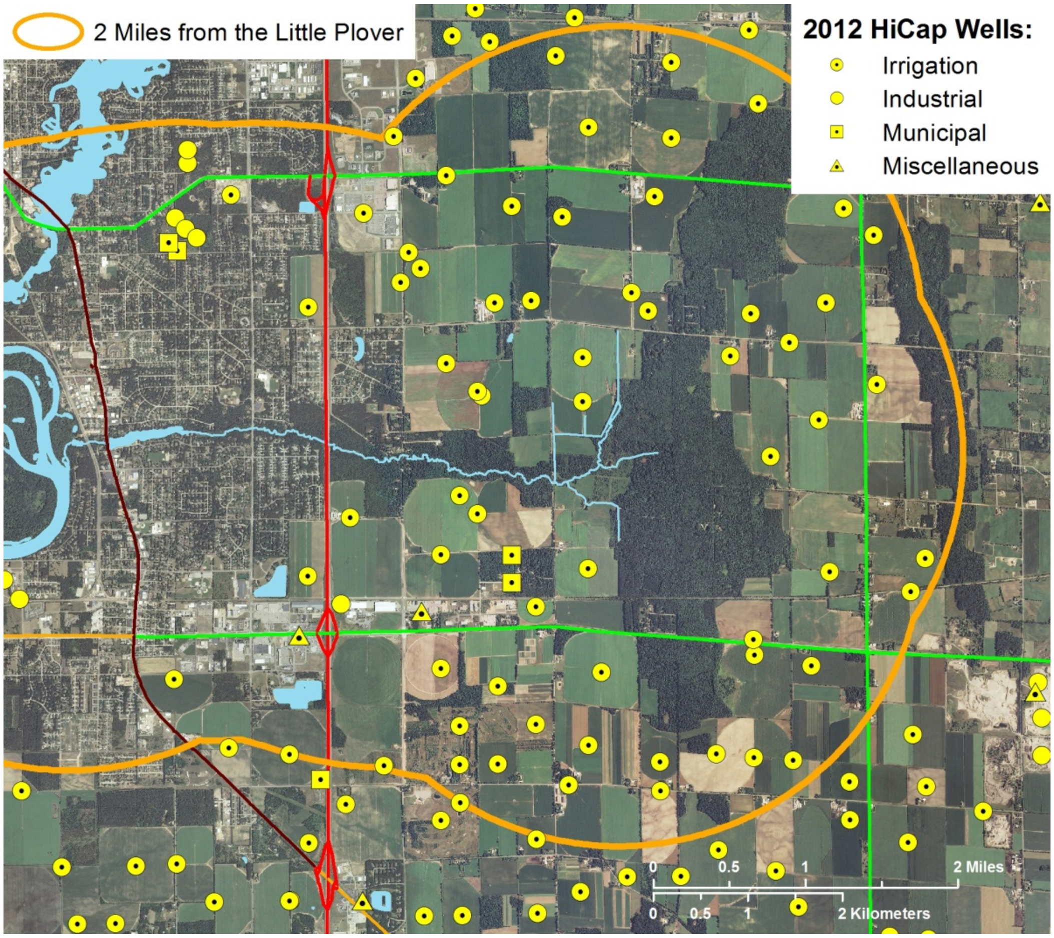


Figure 7-1. Little Plover River, its surroundings, and high capacity wells in its vicinity.

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

Statistic	Kennedy Ave. (1959-1976)		Hoover Rd. (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%	

Historic discharges

The historic record for Little Plover discharges (Table 7-1) affords a basis for comparison to current conditions. The record comprises daily measurements during 1959-1987 at the "Little Plover at Plover" station (USGS # 05400650, also known as "Hoover Rd.") and during 1959-1976 at the "Little Plover near Arnott" station (USGS #05400600, also known as "Kennedy Ave."). Baseflows at Hoover and Kennedy during the historic period averaged 9.9 and 3.6 cfs. Historic one-day baseflow minima were 3.9 and 0.88 cfs, measured at a time when the Little Plover was already pumping affected.

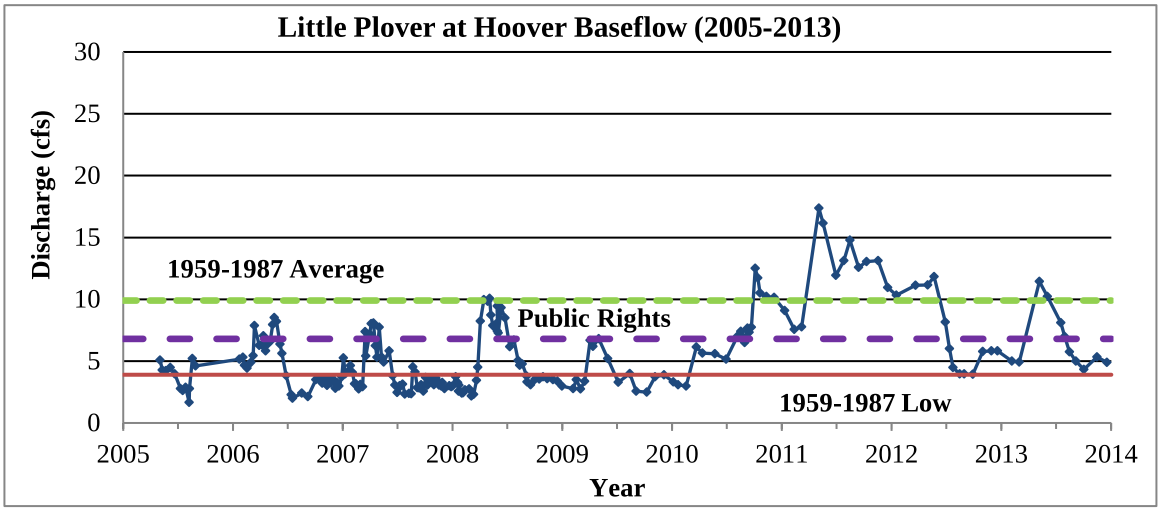
2011-2013 Baseflow Discharges

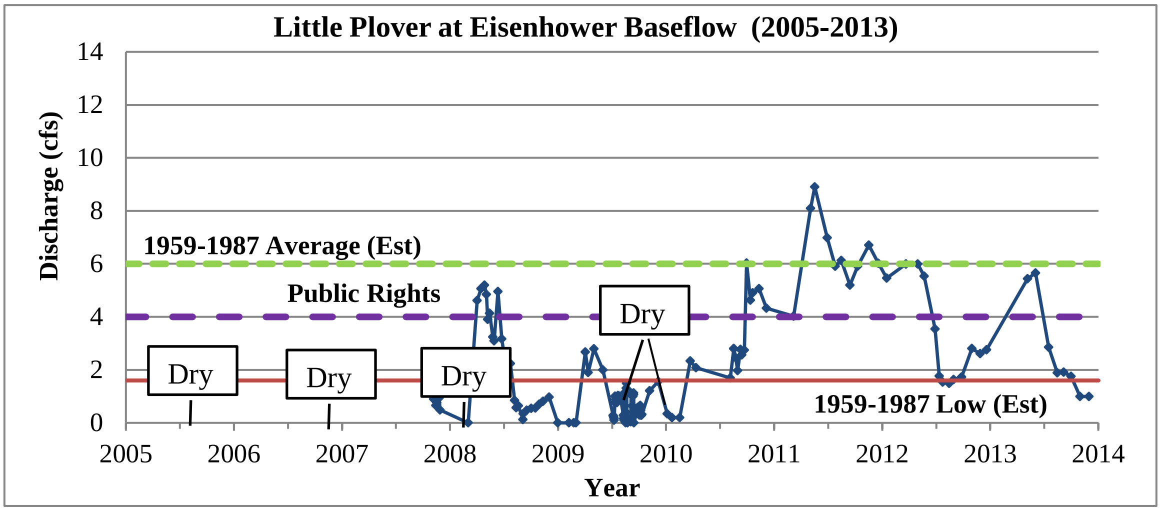
Baseflows in 2011 through mid-2012 continued the period of "healthy" flows (discharges exceeding the PRF) that began in mid-2010 (Figures 7-2 and 7-3). These healthy flows were the result of extraordinary precipitation during 2010 and 2011.

Summer 2012 brought an end to the healthy flow period, when dry weather triggered a likely unparalleled amount of irrigation pumping in the Little Plover vicinity (see next section). Baseflows during this time declined 7.8 cfs over 75 days (Figure 7-3), from a robust 12 cfs to near the historic one day low flow. The magnitude of this flow decline is unprecedented in the historic record. Baseflows rebounded briefly in spring 2013 above public rights levels, but again declined steeply during the irrigation season, by 5.8 cfs over 109 days. Baseflows remained less than the PRF from July 2013 through the end of the reporting period (December 31, 2013).

Public Rights Flow Failure Rate

Baseflows failed to reach the PRF 49% of the time in 2012 and 69% in 2013. For the May 2005 through December 2013, the failure rate was 70% (Figures 7-2 and 7-3).





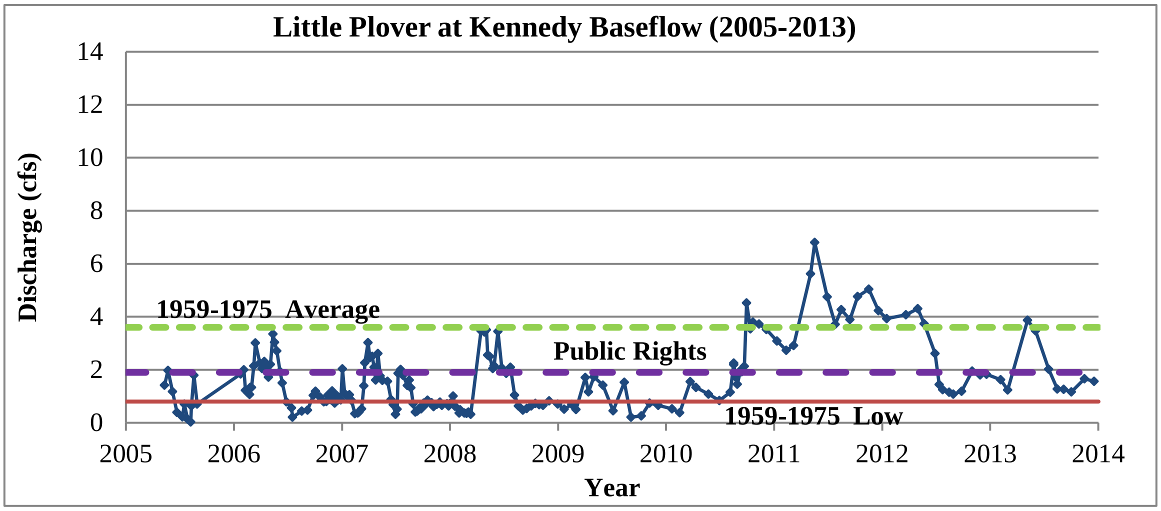


Figure 7-2. Baseflow discharges for the Little Plover River at Hoover, Eisenhower and Kennedy, 2005-2013.

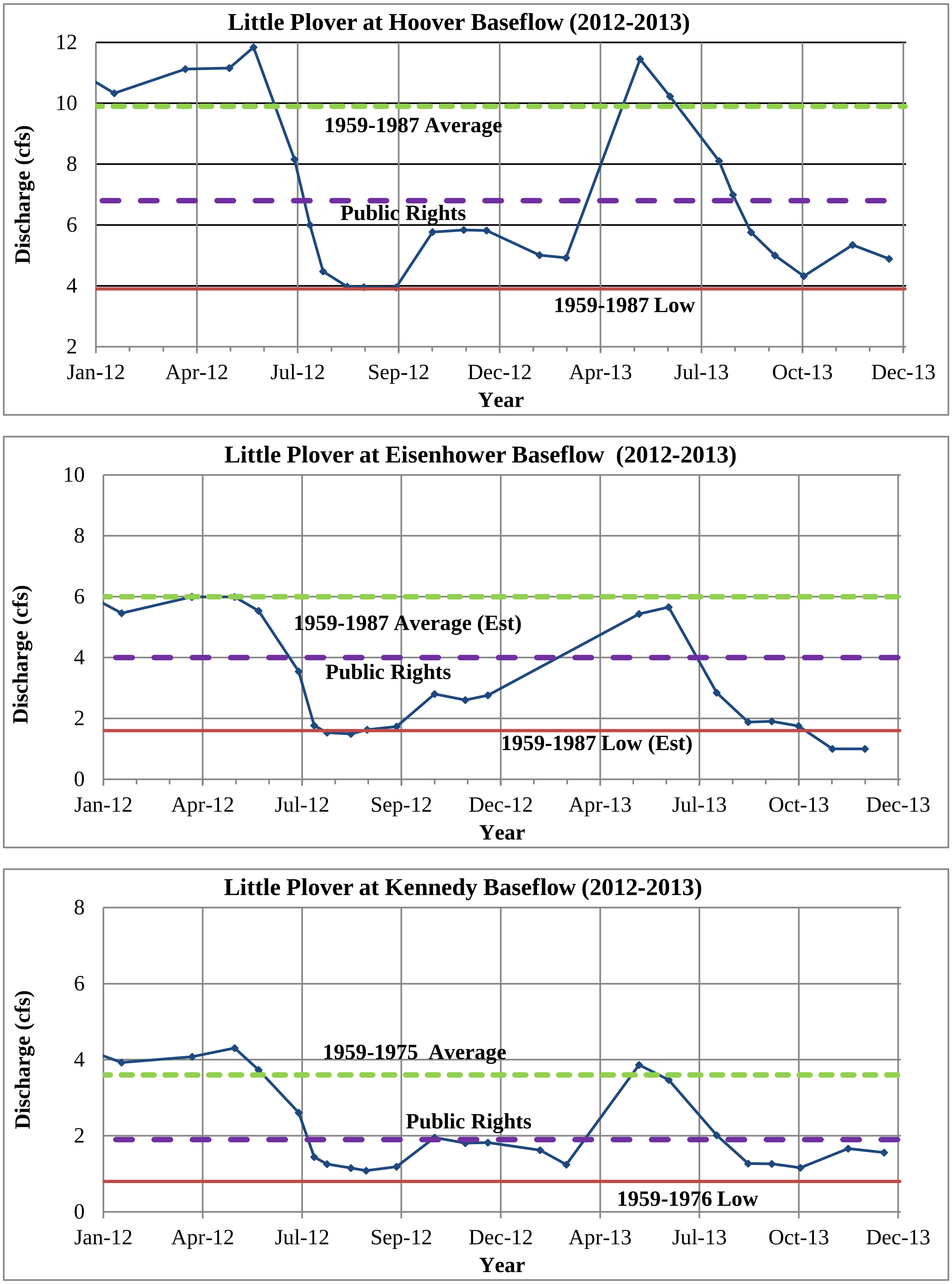


Figure 7-3. Detailed Little Plover baseflows for January 2012 through December 2013.

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 2.9 billion gallons in 2011 and 4.1 billion gallons in 2012 (WDNR 2013). Pumping is greatest during summers, chiefly due to irrigation. Summer 2012 pumping amounted to 32.7 Mgd (50.6 cfs), or the average flow of more than five Little Plover Rivers at Hoover Rd. during pre-pumping impact times. Other pumping, such as rural residential or urban lawn watering from small wells, has been dismissed as insignificant because it is either nonconsumptive (rural domestic water discharging to onsite wastewater disposal systems), too far removed from the Little Plover to be important, or small compared to the major pumping sectors.

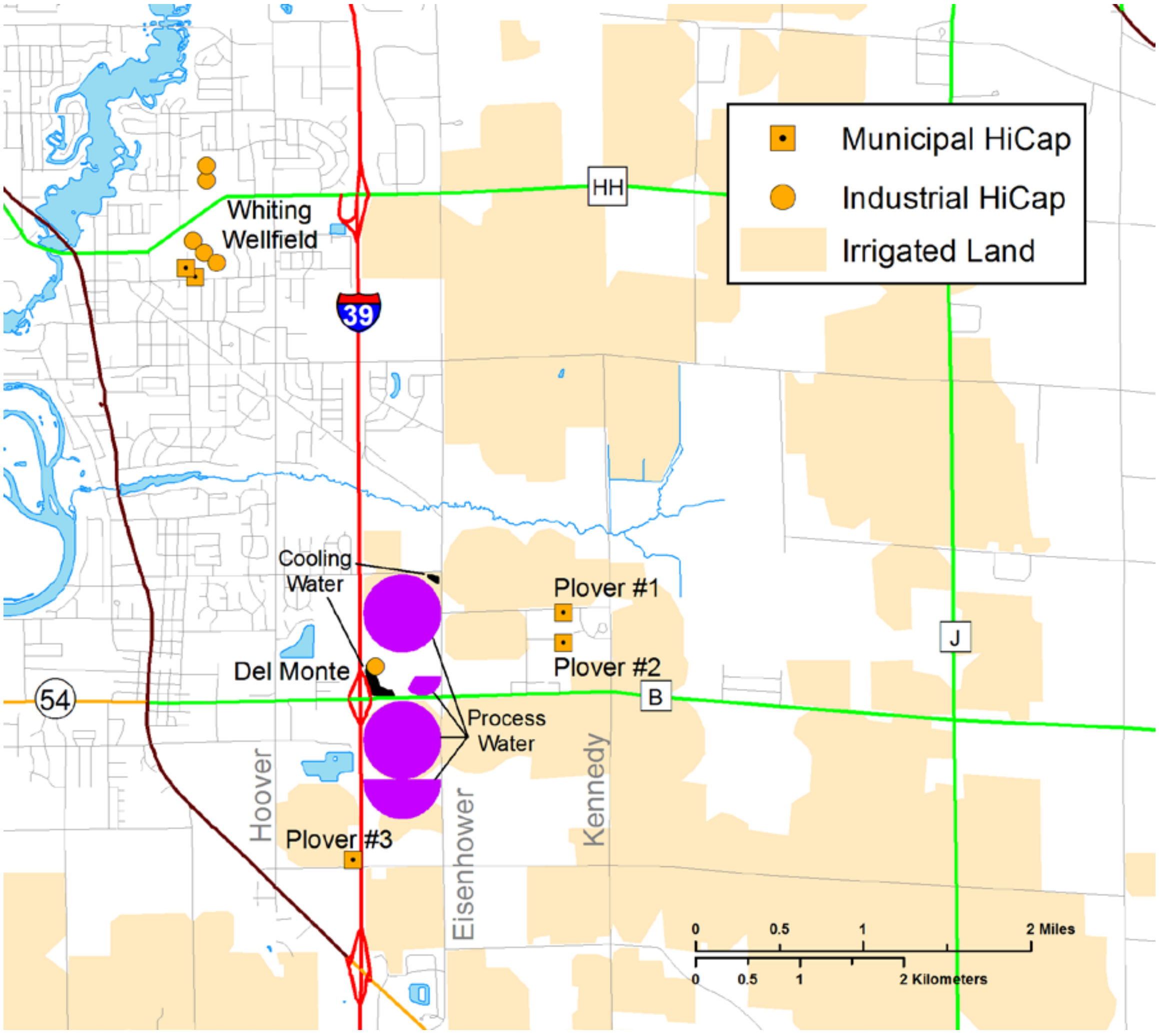


Figure 7-4. Municipal and industrial high capacity wells in the vicinity of the Little Plover, and Del Monte wastewater disposal fields for process and cooling water.

Plover pumping

Village of Plover pumping averaged 1.26 Mgd in 2011, about the same as in recent years, but increased to 1.49 Mgd in 2012 (Figure 7-5). Pumping is from three wells, numbers 1 and 2 which divert about 75% of their pumpage from the Little Plover, and number 3 that diverts 30% of its water

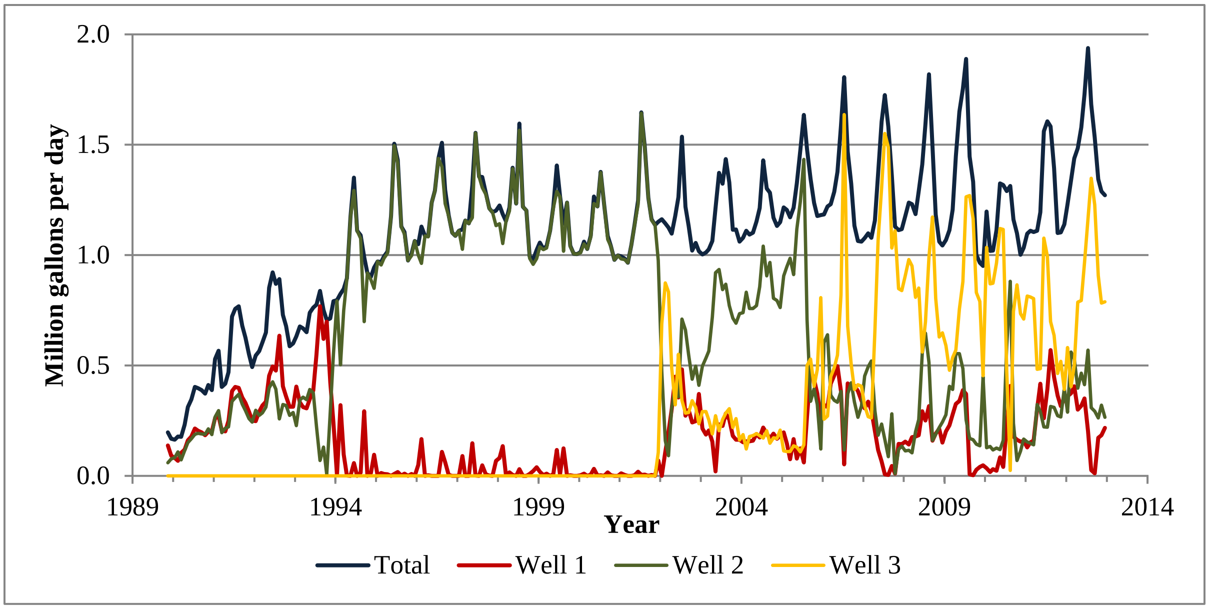


Figure 7-5. Village of Plover total and well-by-well pumping through 2012.

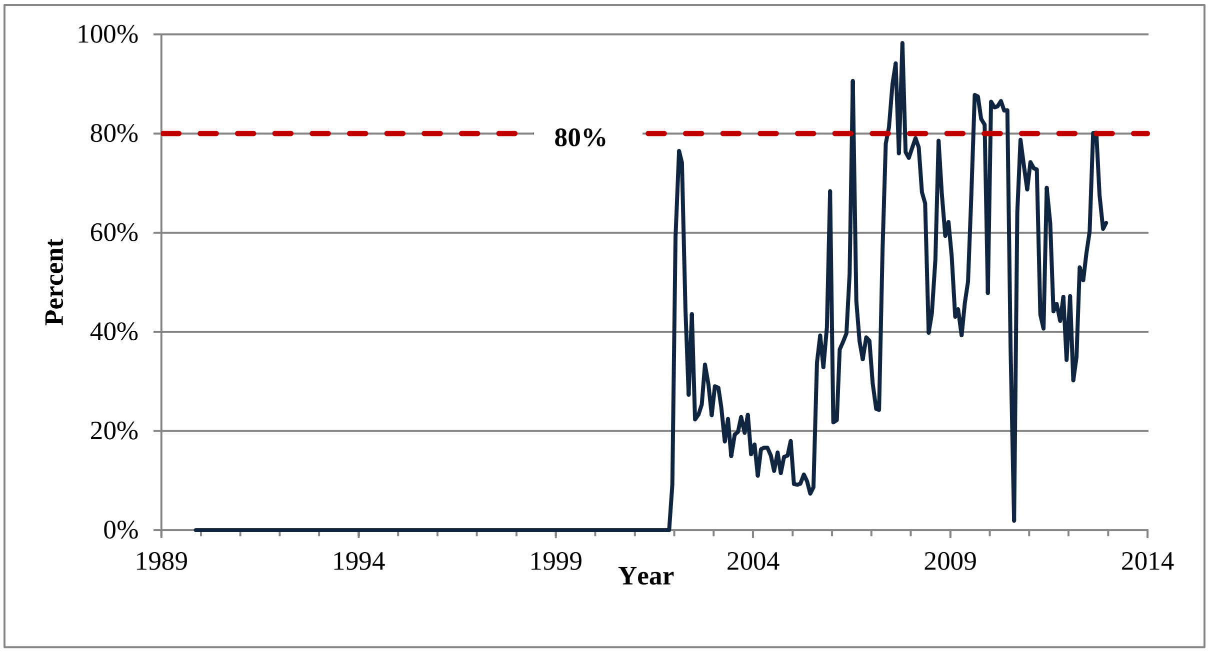


Figure 7-6. Percentage of Plover pumping from well 3. The 80% pumping level is indicated.

from the Little Plover (Clancy et al. 2009). Plover extracted 56% of its water from well 3 and 44% from wells 1 and 2 during 2011-2012 (Figure 7-6). The well 3 fraction was substantially less than the previously articulated goal of 80%. As previous calculations of streamflow diversion reductions were predicated on the 80% pumping from well 3 and no increase in Village pumping, previous diversion reduction estimates for Plover (Kraft et al. 2012b) need to be revised.

Del Monte pumping and wastewater disposal

Del Monte pumping averages 203 million gallons annually that occurs in June through December. Three-fourths of pumped water is reportedly discharged to 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 supplied the Village of Whiting and two paper mills, Neenah Papers (formerly Kimberly Clark) and New Page (formerly Consolidated Papers). Pumpage from this wellfield was 2.2 Mgd (3.4 cfs) in 2011 and 1.9 Mgd (2.9 cfs) for 2012. These mark a large decline from the 4.2 Mgd (6.5 cfs) that prevailed for the previous 10 year period (Figure 7-7), due to the closure of the New Page paper mill. However, the 2012 pumping rate is about double the anticipated 0.78 Mgd (Kraft et al. 2012a), so previous estimates of diversion reductions from New Page closure need to be revised downward.

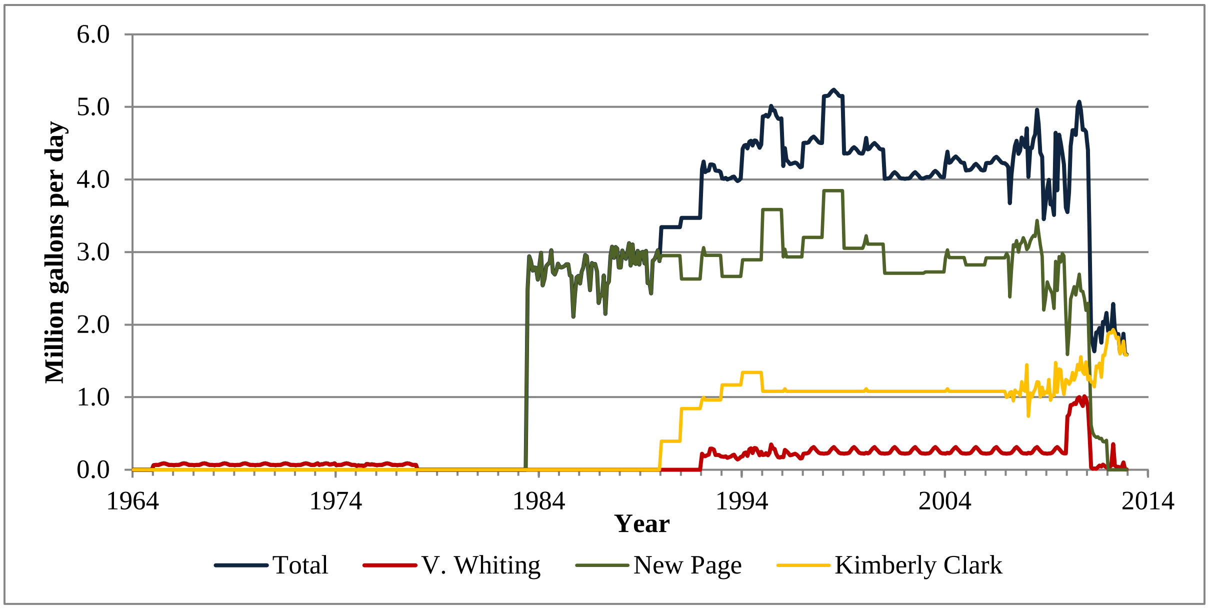


Figure 7-7. Pumping from the Whiting wellfield through December 2012.

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 69 high capacity irrigation wells are located within two miles of the Little Plover (Figure 7-1), and these wells pumped 1.39 and 2.58 billion gallons in 2011 and 2012, 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 2017. For the post-2012 period, 2012 pump rates and wastewater disposal conditions were used. For Del Monte, average pumpage and wastewater disposal (Roger Jacob email 3/3/2011) was used in the model; 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 Rd. for 1965-2013 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.

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[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.

Total municipal/industrial diversions were 1.51 and 1.37 cfs in 2011 and 2012, a modest decrease from the 2005-2007 baseline of 1.77 cfs (Table 7-2). Diversions (2011/2012) by pumping entity were Plover - 0.83/0.94 cfs, Whiting - 0.61/0.36 cfs, and Del Monte - 0.07/0.07 cfs. If 2012 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 increase slightly for Plover to 0.98 cfs, decrease for Whiting to 0.22 cfs, and remain about the same for Del Monte. Total diversions from the municipal and industrial sector would be 1.27 cfs, a decline of 0.5 cfs compared to the 2005-2007 baseline, due mainly to the New Page closure.

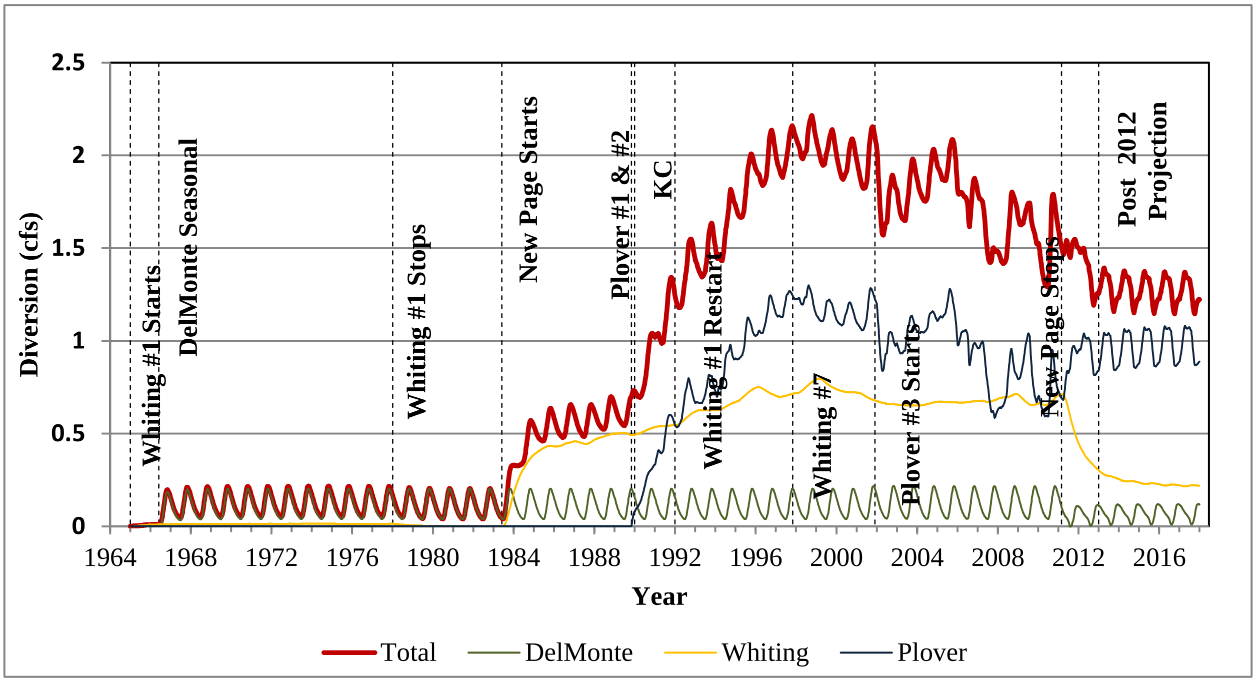

Figure 7-8. Municipal and industrial groundwater pumping diversions from the Little Plover River.

Table 7-2. Average annual municipal and industrial diversions for the 2005-2007 reference period, 2011, 2012, and projected for 2017. 2017 projections assume 2012 pumping patterns hold constant.

	---------------- Municipal / Industrial Diversion (cfs) ---------------			
	--Year --			
Sector	2005-2007	2011	2012	2017*
Plover	0.98	0.83	0.94	0.98
Whiting	0.67	0.61	0.36	0.22
Del Monte	0.12	0.07	0.07	0.07
Total	1.77	1.51	1.37	1.27

* Projection assumes 2012 pumping conditions prevail into the future.

Reassessing Potential Diversion Reduction Measures

Over the 9 years or so that the Little Plover Workgroup has been meeting, five measures with some potential to reduce pumping diversions (estimated to be 4.5 cfs, Kraft et al. 2012a) have been proposed. Three of the measures have been implemented or partially implemented, and two may be implemented in the future. (The five do not include several measures whose potential to reduce pumping diversions was tenuous or could not be demonstrated; e.g., a road culvert was removed, a slope regraded, a crop rotation was altered).

Some sort of yardstick is needed to judge the efficacy of proposed diversion reduction measures in achieving the goal of restoring "healthy flows" (the equivalent of flows to equal or exceed the PRF) to the Little Plover. This efficacy was previously judged as the decrease in long-term failure rates of baseflows to achieve the PRF (Kraft et al. 2012a) relative to a reference failure rate calculated for 2005-2007 diversions. Long-term failure rates were calculated for two sets of assumptions; that (1) total diversions average 4.5 cfs, implying a net irrigation consumption of 5.6 inches and (2) net irrigation consumption is only 2 inches, implying total diversions average 2.8 cfs. The failure rate for 2005-2007 diversions (prior to implementation of any diversion reduction measures) was estimated at 77% (4.5 cfs diversion assumption) and at 57% (2.8 cfs diversion assumption), compared with a failure rate without diversions of 6.1%.

We previously estimated that eventual (perhaps in decades) full implementation of the five measures as proposed would reduce Little Plover diversions by 1.1 cfs (4.5 cfs diversion assumption) or by 0.95 cfs (2.8 cfs diversion assumption), thus decreasing the PRF failure rate from the reference 77% to 66% or from the reference 57% to 35%. Since measures 1 and 3 thusfar are not being implemented as proposed, a reassessment of diversion and failure rate reductions is performed here.

Pumping Diversion Reduction Measures – as Proposed and as Implemented

The five diversion reduction measures (Table 7-3), as proposed and as thusfar implemented, are:

1. <u>Plover pumpage.</u> *Proposed:* Move 80% of Plover pumpage to well 3 while keeping total pumpage constant. Well 3 diverts only 30% of its pumpage from the Little Plover compared with 75% from wells 1 and 2. The potential diversion reduction equals 0.29 cfs. *As implemented:* Only 56% of Plover pumpage was coming from well 3 in 2011 and 2012, and total Plover pumping has increased. Characterizing Plover diversions by 2011 and 2017 values (Table 7-2) leads to a revised Plover diversion reduction of 0 to 0.15 cfs.

2. <u>Del Monte.</u> *Proposed:* Moving Del Monte wastewater disposal closer to the Little Plover. Estimated Del Monte diversion reduction is 0.04 cfs. *As implemented:* Same as proposed.

3. New Page closure. *Proposed:* The unfortunate closure of the New Page paper mill was estimated to reduce total Whiting wellfield pumping from 4.1 Mgd to 0.78 Mgd and diversions by 0.51 cfs. *As implemented:* Pumping was reduced to only 1.9 Mgd. Characterizing Whiting diversion reductions by 2017 near steady-state values decreases the diversion reduction estimate to 0.45 cfs.

4. Plover/Portage County park Acquisition. *Proposed, to be implemented in 2015(?):* The acquisition of 140 acres south of the Little Plover between Kennedy and Eisenhower Avenues would result in retirement of 100 acres of irrigated land and an estimated diversion reduction of 0.08 cfs.

5. Plover urban area expansion. *Proposed, to be implemented 2020-2030 (?):* Develop 620 acres of irrigated land (1137 total acres) for residential, commercial, and industrial use in the Little Plover vicinity. (This acreage includes some of that in (4), above). Estimated potential diversion reduction beyond (4), 0.22 cfs.

Reassessing Little Plover Diversion Reductions and PRF Failure Rates

Here we reassess potential diversion reductions and PRF failure rates based on 2011-2012 actual implementation of measures 1-3, and full future implementation of measures 4 and 5 (Table 7-3).

Previous PRF failure rate estimation efforts are described in Kraft et al. (2012b) and summarized briefly here. These concluded that full implementation of all measures as originally proposed would reduce PRF failure rates from a baseline 77% (assumes a 2005-2007 average diversion of 4.5 cfs) to 66%, or from a baseline 57% (assumes a 2005-2007 average diversion of 2.8 cfs) to 35%. PRF failure rate estimation begins by constructing a synthetic baseflow hydrograph in the absence of pumping for the Little Plover at Hoover Rd. for 1960-2009. This hydrograph was assumed to be representative of future baseflow discharges in the absence of pumping. The synthetic hydrograph used actual Little Plover discharge record for the period when the Little Plover was not overly pumping affected, and otherwise inferred Little Plover baseflows using reference streams. PRF failure rates in the absence of pumping for 1960-2009 were then calculated as the fraction of days less than the public rights flow with the result of 6.1%. PRF failure rates for 2005-2007 baseline diversions were then estimated by subtracting estimated average diversions (two scenarios, 4.5 and 2.8 cfs) from the nonpumping hydrograph and retallying days less than the public rights flow. These revealed PRF failure rates of 77% (4.5 cfs diversion) and 57% (2.8 cfs diversion). Finally, diversion reductions due to measures as proposed (0.95 to 1.1 cfs) were added back into the diversion hydrograph, leading to PRF failure rate estimates of 66% and 35% for baseline 4.5 cfs and 2.8 cfs diversion, respectively.

Updated diversion reductions for the measures as implemented are shown in Table 7-3, which are smaller than for the measures as originally proposed. PRF failure with diversion reductions as implemented are 67-70% (4.5 cfs assumption) and 40-44% (2.8 cfs diversion assumption).

Table 7-3. An update of baseflow reduction measures as currently implemented, estimated diversion reductions, and estimated failure rate to attain public rights discharges.

Original Diversion Reduction Measure	Measure Implementation Update	Updated diversion reduction estimate	
		4.5 cfs assumption	2.8 cfs assumption
	----------- Measures Partially or Fully Implemented -----------		
Plover pumpage. Total pumping remains constant, 80% from well 3	Plover pumping potentially is increasing (1.26 Mgd in 2011, 1.49 Mgd in 2012); only 56% of pumpage is from well 3.	0 – 0.15 cfs	0 – 0.15 cfs
Del Monte wastewater management	No change.	0.04	0.04
New Page closure	Pumping in Whiting well field declined from 4.2 Mgd to 1.9 Mgd instead of to anticipated 0.78 Mgd.	0.45	0.45
	SUBTOTAL :	0.49 – 0.64 cfs	0.49 – 0.64 cfs
	----------- Measures Proposed and Not Yet Implemented -----------		
Plover / Portage County Land Acquisition	Acquisition of 140 acres south of the Little Plover between Kennedy and Eisenhower Avenues. Retires 100 acres of irrigated land.	0.08 cfs	0.03
Plover urban area expansion	Repurpose 620 acres of irrigated land (1137 total acres) for residential, commercial, and industrial use in the Little Plover vicinity. Includes previously described acquisition of 140 total acres/100 irrigated acres previously described. An additional 0.22 cfs diversion reduction (4.9% of the 4.5 cfs total diversion) could accrue.	0.22	0.08
	SUBTOTAL:	0.30 cfs	0.11
	UPDATED TOTAL DIVERSION REDUCTION:	0.79 – 0.94 cfs	0.60 – 0.75 cfs
	UPDATED PRF FAILURE RATE:	67-70%	40-44%

8. IRRIGATION RATES FOR THE CENTRAL SANDS, 2011-2012

Summary

Irrigation rates were estimated for 2011 and 2012 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 7.5 inches in 2011 and 14.9 inches in 2012. Irrigation rates were greatest for potato followed by field corn, sweet corn, and snap bean. For the 2008 through 2012 period, the annual irrigation rate across all crops was 8.7 inches, with a range of 4 to 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. In addition to the 52 previously selected fields, we deliberately selected six additional fields planted to potato as a check on the reasonableness of calculated potato irrigation rates.

Methods

Irrigation rates were estimated by dividing the reported pumping amount for a high capacity irrigation well by the field acreage served by that well. We calculated rates for 52 previously selected wells / fields, 43 of which were randomly chosen in 2008 and nine that were specifically selected for 2011 and 2012 (Figure 8-1). Rates for the cadre of 43 were previously reported for 2008-2010 (Kraft et al. 2012a). The nine specifically selected wells / fields were chosen to constrain irrigation rate estimates on some primary central sands crops. They were chosen using as criteria the field size (160 acres), a center-field irrigation well location, availability of pumping records, and single crop type.

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 2012). 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.

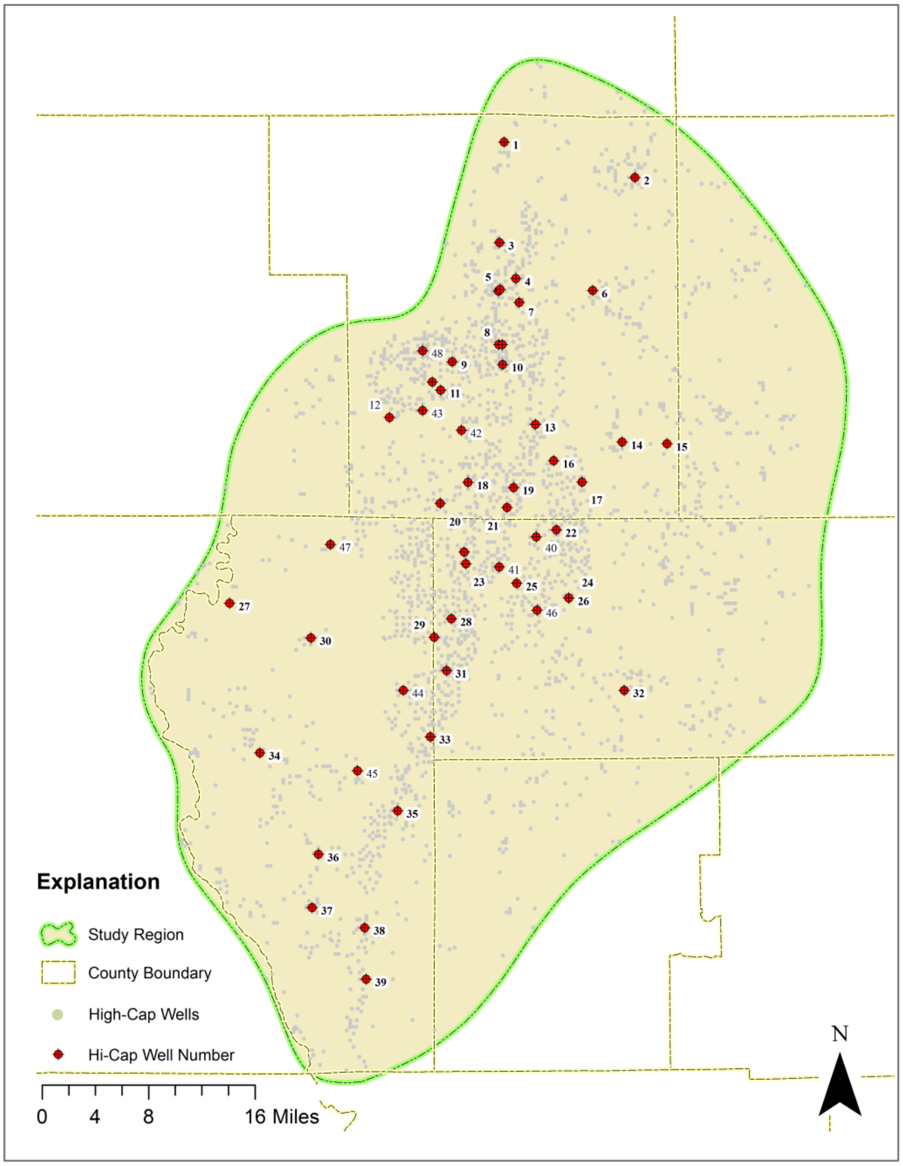

Figure 8-1. Well and field locations used to estimate irrigation rates for 2008-2012. Field ID and Hi-Cap well numbers are listed in Appendix A.

Results

2011 and 2012 irrigation rates

Median irrigation rate estimates across all fields were 7.5 inches in 2011 and 14.9 inches in 2012. Fields containing single plantings of sweet corn, field corn, potato, and snap bean had 2011 median irrigation rates of 7.1, 10.2, 12.2, and 3.3 inches, respectively, and 2012 rates of 15.4, 17.2, 22.3, and 8.5 inches (Table 8-1). Because potato irrigation rate estimates were so large in 2012, we purposely (nonrandomly) sought out six well-defined single-crop potato fields belonging to large operators as a check. Our rationale was that these fields had highly constrained acreages, and because they belonged to large operators, might have more consistent pumping reporting protocols than small operators. These data revealed a median irrigation rate of 19.3 inches, somewhat smaller than our 22.3 inch estimate, with a range of 13.6 to 22.1 inches. We did not feel that the nonrandom check of six fields from large operations warranted negating the results from surveys of the 52 fields.

Irrigation rates for 2011 and 2012 were also estimated using a large scale GIS approach by Smail (pers. comm.) of WDNR. His results showed and an 8.5 inch average across all irrigated land for 2011, and 14.3 inch average for 2012. The 2011 irrigation rates for sweet corn, field corn, potato, and snap bean were 7.6, 7.9, 11.6, and 7.2 inches. 2012 rates for the same crops were 13.4, 13.6, 18.1 and 11.1 inches.

At this time, a clear-cut superior methodology for estimating irrigation rates has not been demonstrated. This may be the focus of a future collaboration between our group and WDNR staff.

Comparisons for 2008-2012

Median estimated irrigation rates across central Wisconsin's crops for 2008-2012 are given in Figure 8-2. Over the five years, potato had the greatest irrigation amount (10.8 inches) followed by field corn (8.7 inches), sweet corn (7.5 inches), and snap bean (4.7 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.

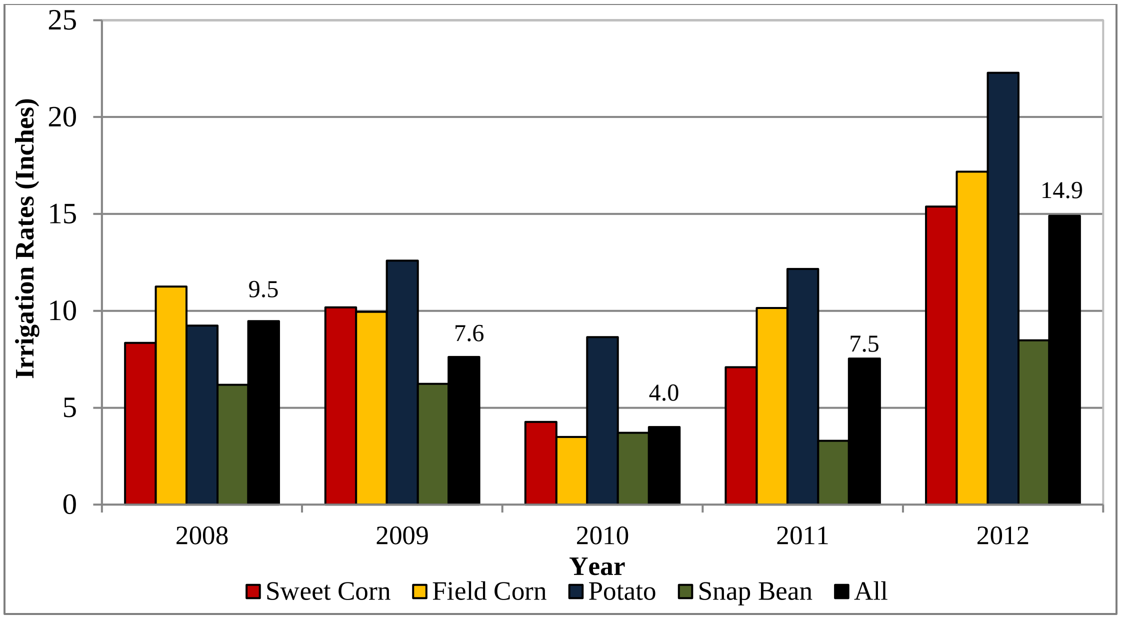

Figure 8-2. Median rates for all fields and for four specific crops in central Wisconsin for 2008-2012. The irrigation rates shown in black on the chart are for all crops and all fields.

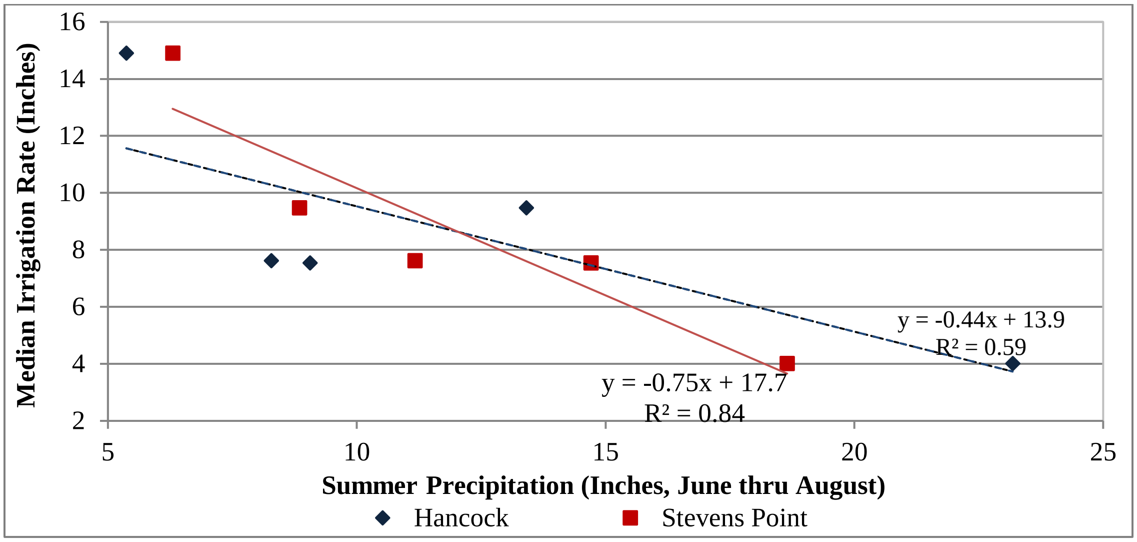

Figure 8-3. 2008-2012 median annual irrigation rates compared with Hancock and Stevens Point summer precipitation.

Concluding remarks

Annual irrigation rate estimates for 2008-2012 ranged 4.0 to 14.9 inches and correspond with summer precipitation amounts (Figure 8-3). Over the five years, potato had the greatest irrigation amount (10.8 inches) followed by field corn (8.7 inches), sweet corn (7.5 inches), and snap bean (4.7 inches). Additional work could be done to improve irrigation estimation, which has as potential error estimation and reporting by operators, field size and crop data, and assigning wells to fields.

Table 8-1. 2011 and 2012 irrigation rates for single and mixed crop fields in central Wisconsin.

Crop	n	Min	Max	Average	Median
		----2011----			
Sweet corn	7	1.7	12.5	7.4	7.1
Field corn	10	0.0	13.6	8.4	10.2
Potato	7	5.0	21.2	12.0	12.2
Snap bean	7	0.7	11.8	4.4	3.3
Pea	1	9.9	9.9	9.9	9.9
Soybean	1	8.7	8.7	8.7	8.7
Sweet corn/field corn	4	2.9	7.4	5.0	4.9
Sweet corn/potato	1	11.7	11.7	11.7	11.7
Sweet corn/soybean	1	10.0	10.0	10.0	10.0
Sweet corn/field corn/soybean	1	12.4	12.4	12.4	12.4
Sweet corn/potato/carrot	1	5.3	5.3	5.3	5.3
Field corn/potato	4	5.4	14.0	9.3	8.9
Field corn/snap bean	1	1.3	1.3	1.3	1.3
Field corn/soybean	1	10.4	10.4	10.4	10.4
Field corn/potato/snap bean	1	11.4	11.4	11.4	11.4
Field corn/potato/soybean	1	8.6	8.6	8.6	8.6
Potato/snap bean	1	13.0	13.0	13.0	13.0
Potato/soybean	1	13.5	13.5	13.5	13.5
Winter wheat/rye	1	3.8	3.8	3.8	3.8
		----2012----			
Sweet corn	9	7.6	20.7	13.7	15.4
Field corn	9	3.2	25.9	15.5	17.2
Potato	9	14.4	30.0	22.1	22.3
Snap bean	2	7.1	9.9	8.5	8.5
Sweet corn/field corn	1	16.9	16.9	16.9	16.9
Sweet corn/potato	2	13.1	17.6	15.4	15.4
Sweet corn/snap bean	1	11.1	11.1	11.1	11.1
Sweet corn/field corn/potato	2	3.8	6.9	5.4	5.4
Sweet corn/potato/snap bean	1	13.7	13.7	13.7	13.7
Field corn/potato	3	11.9	20.8	17.8	20.7
Field corn/snap bean	4	8.9	14.1	11.3	11.0
Potato/snap bean	1	14.4	14.4	14.4	14.4
Potato/pea	1	6.1	6.1	6.1	6.1
Potato/soybean	2	9.7	21.3	15.5	15.5
Winter wheat/pepper	1	21.2	21.2	21.2	21.2
Winter wheat/oat	1	16.3	16.3	16.3	16.3

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Appendix A
Irrigation Rate Estimation by field for 2011-2012

Table A-1. Irrigation rate estimates by field and crop for 2011.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2011 NASS Crop[1]	Irrigated Crop Inches in 2011
1	23619	130.7	130.7	Sweet Corn/Potato	11.67
2a	23906	16.5		Field Corn	
2b	23906	18.5	35	Alfalfa	0.00
3b	23858	73		Potato	
3c	23858	14.6		Field Corn	
3a	23858	55	142.6	Potato/Soybean	8.62
4	23847	55	55	Potato	6.37
5b	24203, 68697	52.1		Field Corn	
5a	24203, 68696	93.2	145.3	Snap Bean	1.25
6a	68917	31.3		Alfalfa	
6b	68917	33		Alfalfa	
6c	68917	53.3		Field Corn	
6d	68917	19.3		Field Corn	
6f	68917	32.5		Field Corn	
6e	68917	20.2	189.6	Field Corn	2.77
7b	1584	14.7		Potato	
7d	1584	18		Potato	
7c	1584	18.2		Field Corn	
7a	1584	14.8	65.7	Field Corn	5.35
8d	24049	19.6		Alfalfa	
8a	24049	50.1		Snap Bean	
8c	24049	16.9	86.6	Alfalfa	11.75
8b	24293	17.3		Sweet Corn	
8e	24293	34.5	51.8	Field Corn	2.94
9c	422	37.7		Potato	
9a	422	33.7		Potato	
9b	422	36.9	108.3	Field Corn	7.23
10	24091	41.7	41.7	Pea	9.92
11a	581	41.6		Soybean	
11b	581	42	83.6	Sweet Corn	9.96
11c	813	148.4	148.4	Sweet Corn	6.94
12a	24098	65.1		Field Corn/Snap Bean	
12b	24098	60.4	125.5	Potato	11.36
13a	23792	38.1		Snap Bean	

Table A-1, cont'd.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2011 NASS Crop[1]	Irrigated Crop Inches in 2011
13b	23792	37.5		Snap Bean	
13c	23792	38.1		Snap Bean	
13d	23792	37.5	151.2	Snap Bean	1.66
14	23839	135	135	Snap Bean	2.77
15	24173	87.3	87.3	Field Corn	5.42
16a	23602	62.3		Field Corn	
16b	23602	63.1	125.4	Sweet Corn	4.45
17a	24014	34.8		Sweet Corn	
17b	24014	56.2		Sweet Corn/Field Corn	
17c	24014	64	155	Sweet Corn	5.38
18	23666	148	148	Sweet Corn/Potato/Carrot	5.28
19	23711	119	119	Snap Bean	3.29
20b	411	30.9		Sweet Corn	
20a	411	51		Field Corn	
20c	411	50.7	132.6	Soybean	12.38
21a	911	32.8		Potato	
21b	911	35.2		Soybean	
21c	911	72.3	140.3	Potato	13.53
22	36394	146.4	146.4	Field Corn	11.30
23b	36666	30.6		Field Corn/Potato/pea	
23a	36666	29.1		Potato/Pea	
23c	36666	33.8	93.5	Field Corn/Pea	10.59
23d	1650	144.8	144.8	Potato	7.54
24	36550	154.2	154.2	Field Corn	8.71
25a	36728	28.6		Field Corn	
25b	36728	37		Field Corn	
25c	36728	39.7		Field Corn	
25e	36728	34		Field Corn	
25f	36728	75.7		Field Corn	
25d	36728	37.3	252.3	Field Corn	10.58
26b	67319	69.4		Sweet Corn/Field Corn	
26a	67319	68.9	138.3	Field Corn/Oat	7.39
27	64	124.2	124.2	Snap Bean	4.56
28b	36454	75.8		Field Corn	
28a	36454	110.3	186.1	Soybean	10.35
29b	36720	113		Hay/Pasture	
29a	36720	150	263	Field Corn	9.72
30b	258	37.4		Snap Bean	
30c	258	35.4		Snap Bean	

Table A-1, cont'd.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2011 NASS Crop[1]	Irrigated Crop Inches in 2011
30a	258	72.9	145.7	Potato	12.99
31b	36508	74.2		Field Corn	
31a	36508	114	188.2	Potato	14.01
32	36529	149.2	149.2	Soybean	8.70
33	146	145.4	145.4	Potato	21.20
34a	1616	85		Field Corn	
34b	1616	76.5	161.5	Field Corn	10.90
35	339	136.7	136.7	Sweet Corn	7.53
36	311	149.1	149.1	Sweet Corn	10.83
37	55	148.9	148.9	Field Corn	13.58
38	24	151.2	151.2	Potato	18.38
39	42	102.7	102.7	Winter Wheat/Rye	3.82
40	36457	134.5	134.5	Snap Bean	0.73
41	36732	140	140	Snap Bean	5.88
42	24148	135	135	Potato	12.16
43	23946	147	147	Potato	5.00
44	297	135	135	Potato	12.98
45	116	152	152	Sweet Corn	1.73
46	36470	147	147	Sweet Corn	12.51
47	115	132	132	Sweet Corn	7.09
48	23855	150	150	Sweet Corn	4.78
				Median	**7.54**
				Average	**8.15**

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

Table A-2. Irrigation rates for crops in 2012.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2012 Crop[1]	Irrigated Crop Inches in 2012
1	23619	130.7	130.7	Sweet Corn	20.69
2a	23906	16.5		Field Corn	
2b	23906	18.5	35	Alfalfa	3.21
3b	23858	73		Potato	
3c	23858	14.6		Potato	
3a	23858	55	142.6	Potato	0.00
4	23847	55	55	Sweet Corn	7.55
5b	24203, 68697	52.1		Field Corn	
5a	24203, 68696	93.2	145.3	Field Corn	17.45
6a	68917	31.3		Alfalfa	
6b	68917	33		Alfalfa	
6c	68917	53.3		Field Corn	
6d	68917	19.3		Field Corn	
6f	68917	32.5		Field Corn	
6e	68917	20.2	189.6	Field Corn	10.58
7b	1584	14.7		Rye	
7d	1584	18		Field Corn	
7c	1584	18.2		Potato	
7a	1584	14.8	65.7	Potato	20.69
8d	24049	19.6		Alfalfa	
8a	24049	50.1		Snap Bean	
8c	24049	16.9	86.6	Field Corn	8.94
8b	24293	17.3		Potato	
8e	24293	34.5	51.8	Field Corn	11.92
9c	422	37.7		Field Corn	
9a	422	33.7		Sweet Corn	
9b	422	36.9	108.3	Potato	3.76
10	24091	41.7	41.7	Sweet Corn	9.16
11a	581	41.6		Potato	
11b	581	42	83.6	Soybean	21.27
11c	813	148.4	148.4	Sweet Corn	10.06
12a	24098	65.1		Sweet Corn	
12b	24098	60.4	125.5	Snap Bean	0.00
13a	23792	38.1		Sweet Corn	
13b	23792	37.5		Sweet Corn	
13c	23792	38.1		Sweet Corn	
13d	23792	37.5	151.2	Sweet Corn	9.39
14	23839	135	135	Potato	19.20
15	24173	87.3	87.3	Snap Bean	9.85

Table A-2, cont'd.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2012 Crop[1]	Irrigated Crop Inches in 2012
16a	23602	62.3		Field Corn	
16b	23602	63.1	125.4	Field Corn	11.10
17a	24014	34.8		Sweet Corn	
17b	24014	56.2		Field Corn/Potato	
17c	24014	64	155	Sweet Corn	6.93
18	23666	148	148	Potato	22.29
19	23711	119	119	Potato	14.39
20b	411	30.9		Sweet Corn	
20a	411	51		Snap Bean	
20c	411	50.7	132.6	Potato	13.66
21a	911	32.8		Sweet Corn	
21b	911	35.2		Field Corn	
21c	911	72.3	140.3	Sweet Corn	16.88
22	36394	146.4	146.4	Field Corn/Snap Bean	11.25
23b	36666	30.6		Sweet Corn	
23a	36666	29.1		Sweet Corn	
23c	36666	33.8	93.5	Potato	17.64
23d	1650	144.8	144.8	Potato/Pea	6.14
24	36550	154.2	154.2	Field Corn/Snap Bean/Alfalfa	10.76
25a	36728	28.6		Soybean	
25b	36728	37		Soybean	
25c	36728	39.7		Soybean	
25e	36728	34		Soybean	
25f	36728	75.7		Soybean	
25d	36728	37.3	252.3	Potato	9.71
26b	67319	69.4		Potato	
26a	67319	68.9	138.3	Sweet Corn	13.05
27	64	124.2	124.2	Field Corn	25.89
28b	36454	75.8		Snap Bean	
28a	36454	110.3	186.1	Potato	14.37
29b	36720	113		Field Corn	
29a	36720	150	263	Potato	20.81
30b	258	37.4		Sweet Corn	
30c	258	35.4		Sweet Corn	
30a	258	72.9	145.7	Sweet Corn	18.78
31b	36508	74.2		Field Corn	
31a	36508	114	188.2	Field Corn	18.09
32	36529	149.2	149.2	Field Corn	17.18

Table A-2, cont'd.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2012 Crop[1]	Irrigated Crop Inches in 2012
33	146	145.4	145.4	Pepper/Winter Wheat/Alfalfa	21.16
34a	1616	85		Snap Bean	
34b	1616	76.5	161.5	Field Corn	14.10
35	339	136.7	136.7	Potato	25.26
36	311	149.1	149.1	Potato	25.52
37	55	148.9	148.9	Oat/Winter Wheat/Alfalfa	16.31
38	24	151.2	151.2	Field Corn	20.92
39	42	102.7	102.7	Field Corn	15.36
40	36457	134.5	134.5	Snap Bean	7.11
41	36732	140	140	Sweet Corn	16.39
42	24148	135	135	Sweet Corn	15.39
43	23946	147	147	Sweet Corn/Snap Bean	11.12
44	297	135	135	Sweet Corn	15.50
45	116	152	152	Potato	27.03
46	36470	147	147	Potato	30.04
47	115	132	132	Potato	19.85
48	23855	150	150	Potato	14.90
				Median	**14.90**
				Average	**14.68**

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

Appendix B

Assessing the Impacts of Future Irrigation Development – A Demonstration in the Tomorrow-Waupaca River Headwaters Area

Assessing the Impacts of Future Irrigation Development – A Demonstration in the Tomorrow-Waupaca River Headwaters Area

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October 1, 2014

SUMMARY

High capacity well pumping mainly for irrigation purposes is impacting the levels of groundwater, lakes, and wetlands and the discharges of streams in the Wisconsin Central Sands. Pumping impacts continue to increase as new irrigation wells are installed and as new irrigated lands are developed. A need exists for methodologies capable of assessing the impacts of anticipated irrigation development in the region. Here we explore a procedure for assessing these impacts in the Tomorrow-Waupaca River Headwaters area of the Wisconsin Central Sands. The procedure had two components; evaluating the suitability of land parcels for irrigation development, and then assessing the drawdown and streamflow impacts of converting these lands to irrigation using groundwater flow modeling. Suitability evaluation placed land parcels into four tiers, from "little apparent limitation" for irrigation conversion (Tier 1) through "not convertible" to irrigation (Tier 4). To assess the impacts of converting lands to irrigation, four scenarios were created encompassing two levels of irrigation development and two of irrigation consumption. Irrigation development scenarios were the current level (9.2% of the demonstration area) and a moderate increase level (38% of the demonstration area, amounting to 76% of Tier 1 lands). Irrigation consumption scenarios were 2 and 4 inches of water. Under moderate increase levels, irrigation development causes substantial drawdowns (2-8 ft) in the vicinity of many lakes, nearly dries numerous stream headwaters, and diverts 9.2 to 28% of main stream Tomorrow-Waupaca River baseflow.

INTRODUCTION

High capacity well pumping mainly for irrigation purposes is impacting the levels of groundwater, lakes, and wetlands and the discharges of streams in the Wisconsin Central Sands (Kraft et al. 2012a, Clancy et al. 2009, Kniffin et al. In press). The greatest impacts are in the heavily pumped upland between the Wisconsin and Fox/Wolf river basins in south central Portage County and western Waushara County (Figure 1), and in the adjacent area of headwater streams. Water level drawdowns amount to 6 ft or more in places, and streamflow diversions have seasonally or permanently dried some headwater streams (Kraft et al. 2012b).

Pumping impacts on water levels and streamflows continue to increase as new irrigation wells are installed and as new irrigated lands are developed. Some physical factors formerly thought to be limiting to irrigation, such as land slope, minimal field size, forest cover, and soil stoniness, are more frequently being overcome (Figure 2). New lands being brought into irrigation sometimes have C slopes (6-12%) and are as small as a few acres. Forest cover and a moderate amount of stones have not been shown to be an impediment.

While a picture of current irrigation pumping has been painted in earlier work, an awareness gap exists of how irrigation will expand across the landscape and how this expansion will further affect the region's water resources. The purpose of this work is to investigate an approach to fill this gap through a demonstration in the Tomorrow-Waupaca River Headwaters Area (TWHA) (Figure 1).

The TWHA

The TWHA is located mostly east and northeast of the presently most developed irrigated area (Figures 1 and 3). The area contains 33 lakes greater than 10 acres (126 total) and about 72 miles of headwaters streams, many of which are trout streams and designated outstanding and exceptional resource waters (Figure 3). All are sustained by groundwater. Active high capacity irrigation wells numbered 113 in 2012 (WDNR 2013), and these are already impacting water levels and streamflows. Kraft et al. (2010, 2012a) estimated current water level drawdowns for the TWHA are greatest, about 2 ft, in the southwest. They also estimated that 32.5% of the area has existing drawdowns exceeding one foot, and 14.5% has drawdowns of 0.5 to 1.0 feet.

Description of investigation

This investigation has two components; mapping potentially irrigable lands and then estimating how converting these lands to irrigation could impact water levels and streamflows. Groundwater flow modeling was used as the tool to estimate water level and streamflow impacts. Four irrigation impact scenarios were explored, encompassing two levels of irrigation extent (the amount of area converted to irrigation) and two of irrigation consumption. Irrigation extent scenarios were the present level of irrigation, where 9.2% of the demonstration area is irrigated, and a moderate increase level, where 38% of the demonstration area would become irrigated. Irrigation consumption scenarios were 2 inches and 4 inches of water. Two inches is an amount that previous modeling (Kraft et al. 2010, 2012a) suggested could explain the current drawdowns in a dynamic system still not at equilibrium, and that might underestimate irrigation impacts. Larger net irrigation consumption, up to 5.6 inches, was supported by Kraft et al. (2012a) in the Little Plover vicinity, and by Weeks et al. (1965) and Weeks and Stangland (1971). Hence the 2 to 4 inch recharge reduction provides a reasonable, though possibly low, bracketing of a true value.

METHODS

Delineating potentially irrigable land

Potentially irrigable land was delineated in a Geographic Information System (GIS) environment with limited field checking. A GIS layer of irrigated land suitability was constructed starting with a Portage County parcel layer clipped to the project area. Irrigated land suitability was then estimated for each parcel or subparcel, classifying each polygon into one of four tiers:

> Tier 1 – little apparent limitation for conversion to irrigated land; land slopes are small (usually 0-5%); existing land covers are at least half agricultural, soils not wet.
>
> Tier 2 – some limitations for conversion to irrigated land; land may be more sloping (up to about 10%), half or more forested, soils not wet.

Tier 3 – highly limited for conversion to irrigated land; parcels may contain steep slopes (up to 20%), forested landcover, wet soils, near proximity to streams or lakes, or are highly fragmented.

Tier 4 - Not convertible to irrigated agriculture; limitations include existing land uses (homes, farmsteads, businesses, gravel pits, roads), wetlands, slopes that exceed 20%, public wildlife and fishery areas, and parks.

Delineation of potentially irrigable land

Nearly half (49.8%) of the total project area fell into tier 1, 19.1% into tier 2, 6.8% into tier 3, and 24.3% in Tier 4 (Figure 4, Table 1). Present irrigation development comprises an estimated 11707 irrigated acres (9.2% of the area, 18% of all tier 1 acreage, and 0.4% of all tier 2 acreage) serviced by 113 irrigation wells. The moderate growth level comprises 48174 irrigated acres, including existing irrigated acres and wells. The increase in irrigated acres from the current level was applied exclusively to tier 1 lands, the easiest to convert to irrigation. Irrigated lands in the moderate growth level comprise 38% of total project area, 76% of tier 1 lands and 0.4% of tier 2 lands.

Groundwater flow modeling

Groundwater flow modeling to assess potential future irrigation impacts is described briefly here, and in more detail in Attachment 1.

Potential irrigation impacts were explored using a slightly modified version of a previously developed MODFLOW 2005 model for the Wisconsin Central Sands (Figure 5, Kraft et al. 2012b). The effect of irrigation was conceptualized and simulated as a reduction in groundwater recharge relative to a native or pre-irrigated land reference condition (Weeks et al. 1965, Weeks and Stangland 1971, Kraft et al. 2010, 2012a), though implemented differently than in previous work. Net recharge reduction was simulated as withdrawals from MODFLOW wells, with each well representing the net recharge reduction on 103.6 acres of nearby Tier 1 lands, an average for the region. Thus the moderate growth scenario of 48174 irrigated acres, including the existing 11707 acres, was simulated by using 465 wells, including the 113 existing wells. Wells representing potentially irrigated lands were randomly placed amongst tier 1 lands.

The modeling for this project calculates aquifer drawdown at lakes, but does not simulate lake stage explicitly. This approach is valid for the steady-state type modeling that we are performing here, and comparisons with an explicit lake simulation for a Central Sands lake (S.S. Papadopulos & Associates 2012) have agreed well.

RESULTS AND DISCUSSION

Projected water level drawdowns

Scenario 1 – 2013 irrigation development level (9.2% of region), 2 inches net irrigation consumption

This scenario approximates past drawdown estimations (1999-2008 average drawdowns at 17 locations, Kraft et al. 2010, 2012a) but likely underestimates the ultimate impacts of current levels of irrigation development, as the hydrologic system is not yet at an equilibrium with current development.

As previously discussed, projected drawdowns in this scenario are greatest to the southwest of the TWHA (Figure 6a), about 2 ft, and smallest within 2-3 miles of the Tomorrow River and in the New Hope area lakes of Sunset, Onland, Rinehart and others northeast of the river (Figure 7), due to relatively small amounts of irrigation development and the effect of the river constraining drawdowns. Drawdowns are one foot or more in 25.8% of the region and 0.5-1.0 ft in 19.4% (Figure 6).[4] Lakes Emily and Adams area drawdowns are 0.5-1.0 ft. Modest drawdowns (1.1-2 ft) are calculated for Lakes Thomas, Bear, and the Boelter-Riley Lake area (Figure 7).

Scenario 2 – 2013 irrigation development level (9.2% of region), 4 inches of net irrigation consumption

This scenario likely brackets a higher end of impacts that may accrue as the aquifer comes to an equilibrium with 2013 levels of irrigation development. Drawdowns are greatest, almost 4 ft, in the southwest of the TWHA, with 7.1% of the region exceeding a 3 ft drawdown, 20.1% ranging 2-3 ft, and 18.4% ranging 1-2 ft (Figure 6b). Drawdowns are estimated as 0.5-1.0 ft in the New Hope lakes (Sunset, Onland, Rinehart and others) area, 1.1-2.0 ft for Lake Emily and Adams Lake, 2.0 to 3.0 at Thomas and Bear Lakes, and 3.0 to 4.0 in the Riley-Boelter Lakes area (Figure 7). While not in the demonstration area, the Wolf and Pickerel Lakes area in the south have drawdowns of 4-5 ft.

Scenario 3 – Moderate increase in irrigated land (38% **of region),** *2 inches of net irrigation consumption*

This scenario produces a large northward expansion of the heavily pumping-impacted region presently centered in northern Waushara County, and the development of a large drawdown region in the New Hope lakes area. Drawdowns are greatest, almost 4 ft, in the west central TWHA, with 11.2% of the area having drawdowns exceeding 3 ft, and 27.9% having 2-3 ft, and 24.4% having 1-2 ft. Drawdowns in the New Hope lakes are large for Sunset (> 2 ft) and Onland and Rinehart (about 3 ft). Lake Emily, Bear Lake, and Adams Lake area drawdowns are 2-3 ft, as is the Boelter-Riley Lake area. Drawdown at Lake Thomas is 3.8 ft (Figure 7).

Scenario 4 - Moderate increase in irrigated land (38% of region), 4 inches of net irrigation consumption.

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[4] Note these fractions differ somewhat from that which was reported by Kraft et al. (2012a), due to the somewhat different way of handling irrigation stresses. See Attachment 1.

Two large drawdown centers form in this scenario in the vicinities of Thomas Lake (8 ft drawdown) and Onland – Rinehart Lakes (about 6 ft drawdown). Over half the region has drawdowns exceeding 3 ft, 12.8% has drawdowns of 2-3 ft, and 16.8% has a drawdown of 1-2 ft. Other drawdowns are, Sunset Lake, 4.2 ft; Lake Emily and Adams Lake, 4-5 ft; Bear, > 6 ft; Riley and Boelter Lakes, 5-6 ft; and Pickerel and Wolf Lakes, 6 ft.

Projected streamflow diversions

Streamflow diversions at select Tomorrow-Waupaca River locations

Diversions from the Tomorrow-Waupaca River were evaluated at Merryland, Nelsonville, and County Rd. A (Figure 8, Table 2). Under scenario 1 (current irrigation levels, 2 inches of net irrigation consumption), diversions are 2.5 to 6.7% of estimated baseflow. These double with the scenario 2 assumption of 4 inches of irrigation consumption. With moderate growth and 2 inches of net irrigation consumption diversions are 9.2 to 14%, and these roughly double with 4 inches of irrigation consumption to 18-28% of Tomorrow-Waupaca discharges.

Streamflow diversions at select headwaters locations

Streamflow diversions at headwaters locations were evaluated for 19 streams at stream locations approximately one mile below where the stream “wets up” in the groundwater flow model (Figure 9, Table 3). This is the most sensitive part of a stream system, and where a small diminishment of stream flows makes the difference between a flowing or dry stream. Modeled baseflows in these headwaters locations ranged 0.074 to almost 3 cfs.

Headwater streamflows under scenario 1 are already diminished by 1.3 to 51%. Of note are the calculated diversions on Stoltenberg Creek (13.5%) which has already experienced dry-ups in its headwaters, and Allen Creek (40%, near Hartman Creek State Park) which anecdotally has been mostly dry in its headwaters. An assumption of four inches of net irrigation consumption roughly doubles the estimated current irrigation impact.

Under a moderate increase in irrigated land, most headwater streams lose a substantial part of their baseflow. The median baseflow loss is 28.2% under the 2-inch scenario, and 57.4% under the 4-inch scenario. Some headwaters streams dry.

CONCLUSIONS

We demonstrated an approach leading to estimates of surface water impacts from future irrigation development. The approach evaluated land parcels for irrigation suitability and then assessed the impacts of increased irrigation using an assumption of moderate irrigation development and a bracketing of estimated irrigation consumption amounts. The procedure for irrigation suitability evaluation was labor intensive and required human assessment on a parcel by parcel basis. The procedure could be partly streamlined and automated. Our experience leads us to believe that an automated approach might work well for at least distinguishing the best of Tier 1 lands and Tier 3 and 4 lands, but automation distinguishing some Tier 1 from Tier 2 lands could be difficult.

The modelling procedure of attributing pumping from a certain land area to MODFLOW wells seems an efficient and valid way of assessing conversion of irrigated land. Additional field data leading to more accurate model representations of stream headwaters would likely improve predictions of streamflow impacts. Finer model discretization might also benefit impact predictions.

Current irrigation development in the TWHA is already impacting its surface waters. Under the most optimistic scenario (current irrigation development, 2 inches of net irrigation consumption), drawdowns are small (< 0.5 ft) around the New Hope Lakes (Sunset, Onland, Rinehart and others); 0.6- 1.0 ft in the Lake Emily and Adams Lake areas; and larger (1.1-2 ft) for Thomas, Bear, and the Boelter-Riley Lake area. Streamflow diversions from the main stem of the Tomorrow-Waupaca River are 2.5-6.7% of estimated baseflow, but are 1.3-51% at headwaters streams. An assumption of the current level of irrigation development with 4 inches of net irrigation consumption substantially increases drawdowns and streamflow diversions. Drawdowns are almost 4 ft in the southwest of the TWHA, with 7.1% of the area exceeding 3 ft, 20.1% ranging 2-3 ft, and 18.4% ranging 1-2 ft. Estimated drawdowns are 0.6-1 ft in the New Hope lakes (Sunset, Onland, Rinehart and others) area, 1.1-2.0 ft for Lake Emily and Adams Lake, 2.1 to 3.0 at Thomas and Bear Lakes, and 3.0 to 4.0 in the Riley-Boelter Lakes area.

A moderate increase in irrigated land to 38% of the region with 2 inches of net irrigation consumption produces a large northward expansion of the heavily pumping-impacted region presently centered in northern Waushara County, and the development of a large drawdown region in the New Hope lakes area. Drawdowns become greatest, almost 4 ft, in the west central TWHA, with 11.2% of the area having drawdowns exceeding 3 ft, and 27.9% having 2-3 ft, and 24.4% having 1-2 ft. Drawdowns in the New Hope lakes increase to 2 ft for Sunset and 3 ft for Onland and Rinehart. Lake Emily and Bear and Adams Lake area drawdowns are 2-3 ft, as is the Boelter-Riley Lake area. Drawdown at Lake Thomas is 3.8 ft. Diversions from the Tomorrow-Waupaca River increase to 9.2-14%, and most headwater stream segments lose a substantial part of their baseflow, with a median of 28.2%.

A moderate increase in irrigated land (38% of the region) with 4 inches of net irrigation consumption produces two large drawdown centers in the vicinities of Thomas Lake (8 ft) and Onland – Rinehart Lakes (about 6 ft). Drawdown at Sunset Lake is 4.2 ft; Lake Emily and Adams Lake, 4-5 ft; Bear, 5-6 ft; Riley and Boelter Lakes, 5-6 ft; and Pickerel and Wolf Lakes, 6 ft. Diversions increase to 18-28% from Tomorrow-Waupaca discharges, and the median baseflow loss for headwater streams is 57.4% under the 4-inch scenario.

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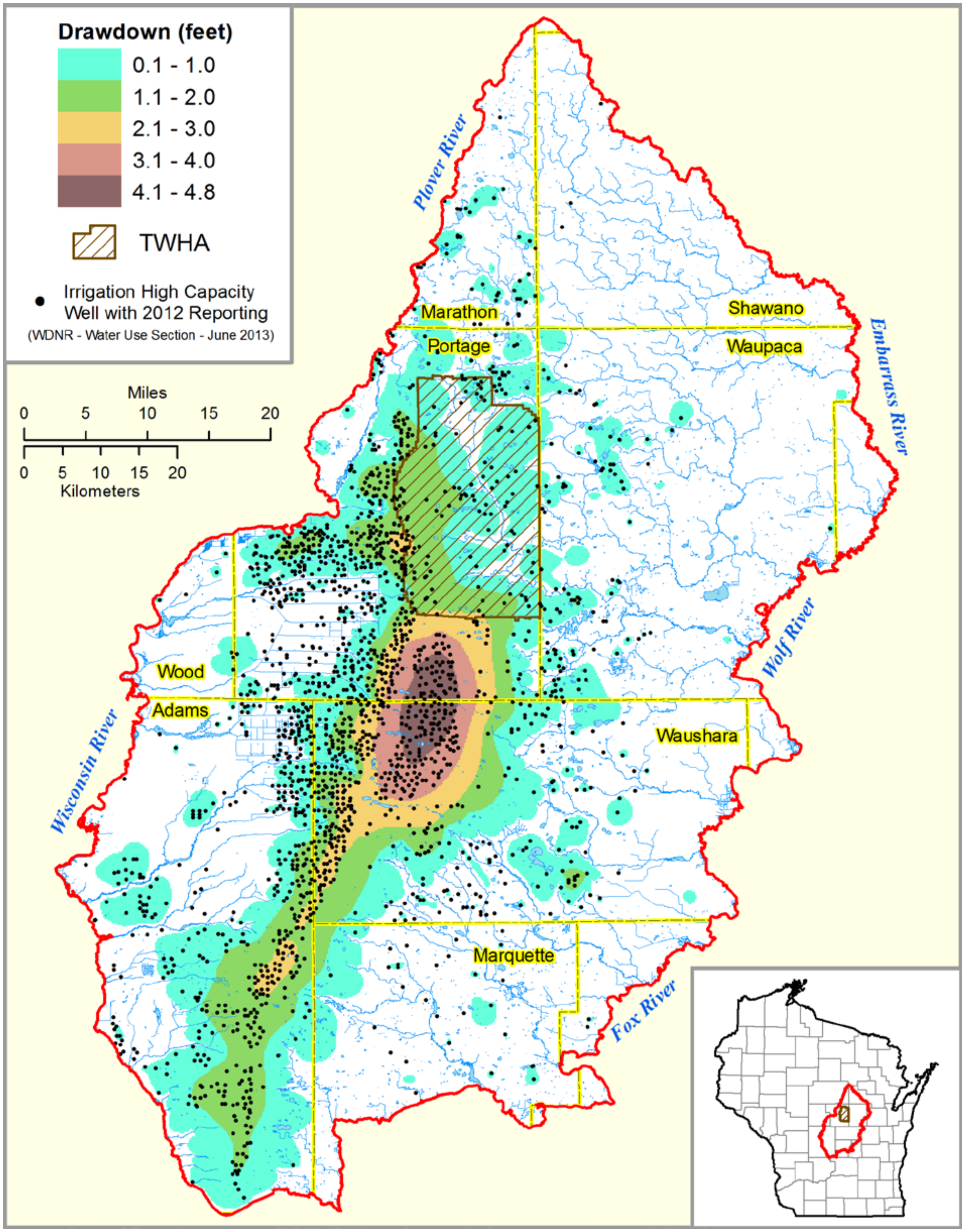

Figure 1. The Wisconsin Central Sands groundwater flow model domain with the TWHA indicated. Also shown are existing irrigation wells (through 2012) and groundwater drawdowns. Drawdowns shown here were computed on a steady-state, 2 inches of irrigation consumption basis in Kraft et al. (2012b) using a slightly different methodology than used in this report.

Figure 2. Expansion of irrigation into nontraditional settings. Top: Hilly land in east central Portage County. Middle: Small field (11.5 acres) in eastern Portage County. Bottom: Pine plantation being logged for conversion to irrigated land in the Emmons Creek watershed.

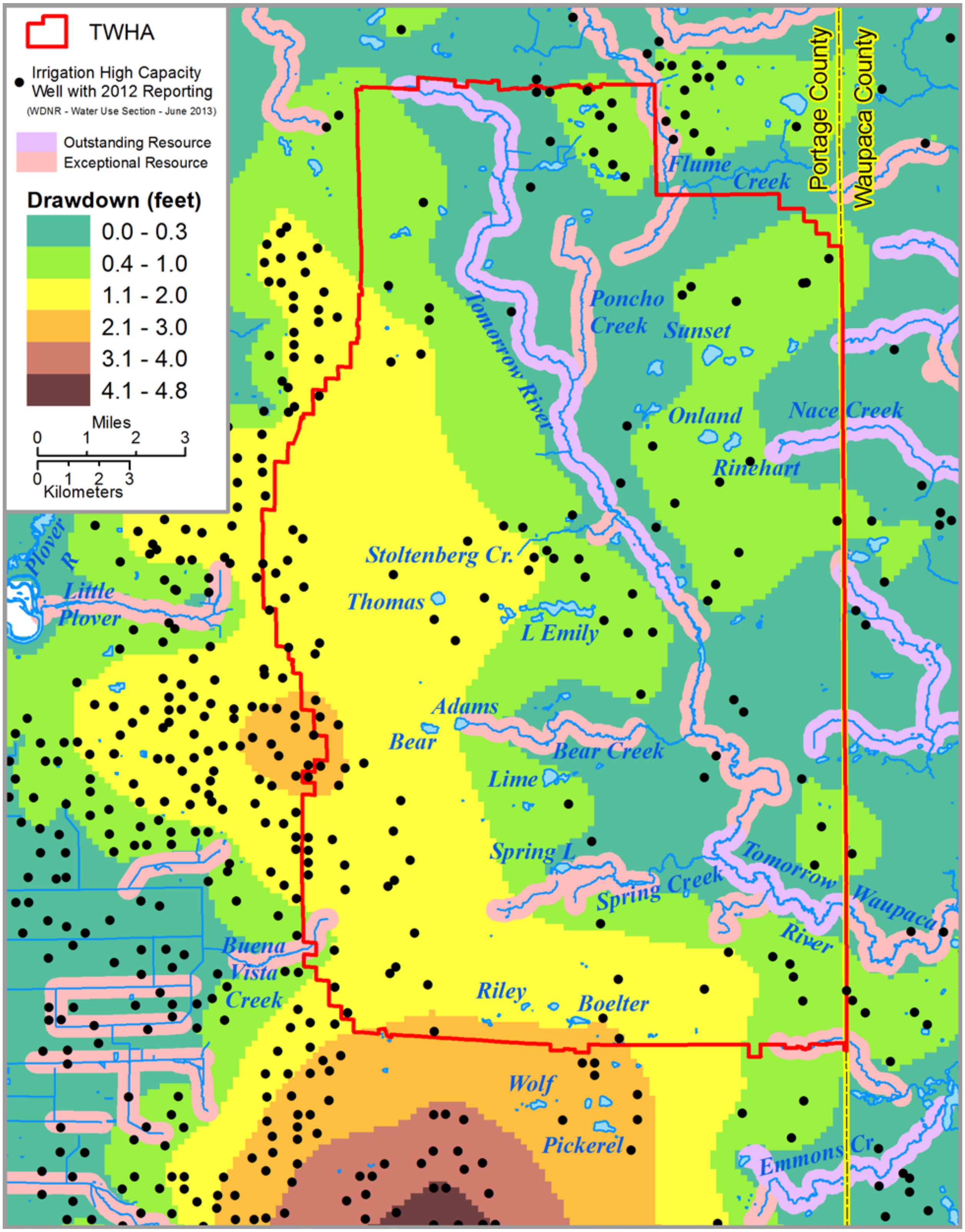

Figure 3. The TWHA with key water bodies, irrigation wells, and estimated current drawdowns shown.

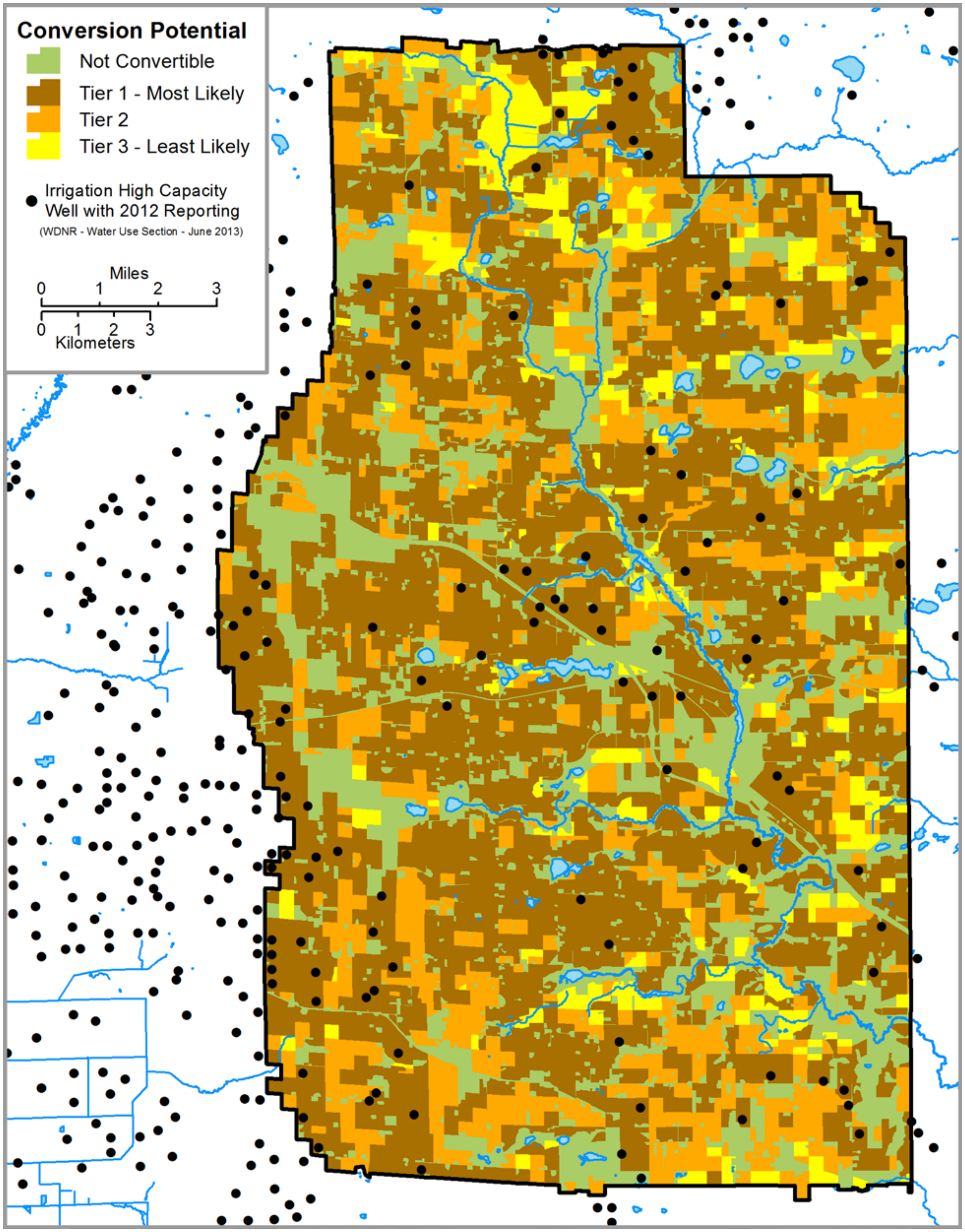

Figure 4. Potential for irrigated agriculture in the TWHA.

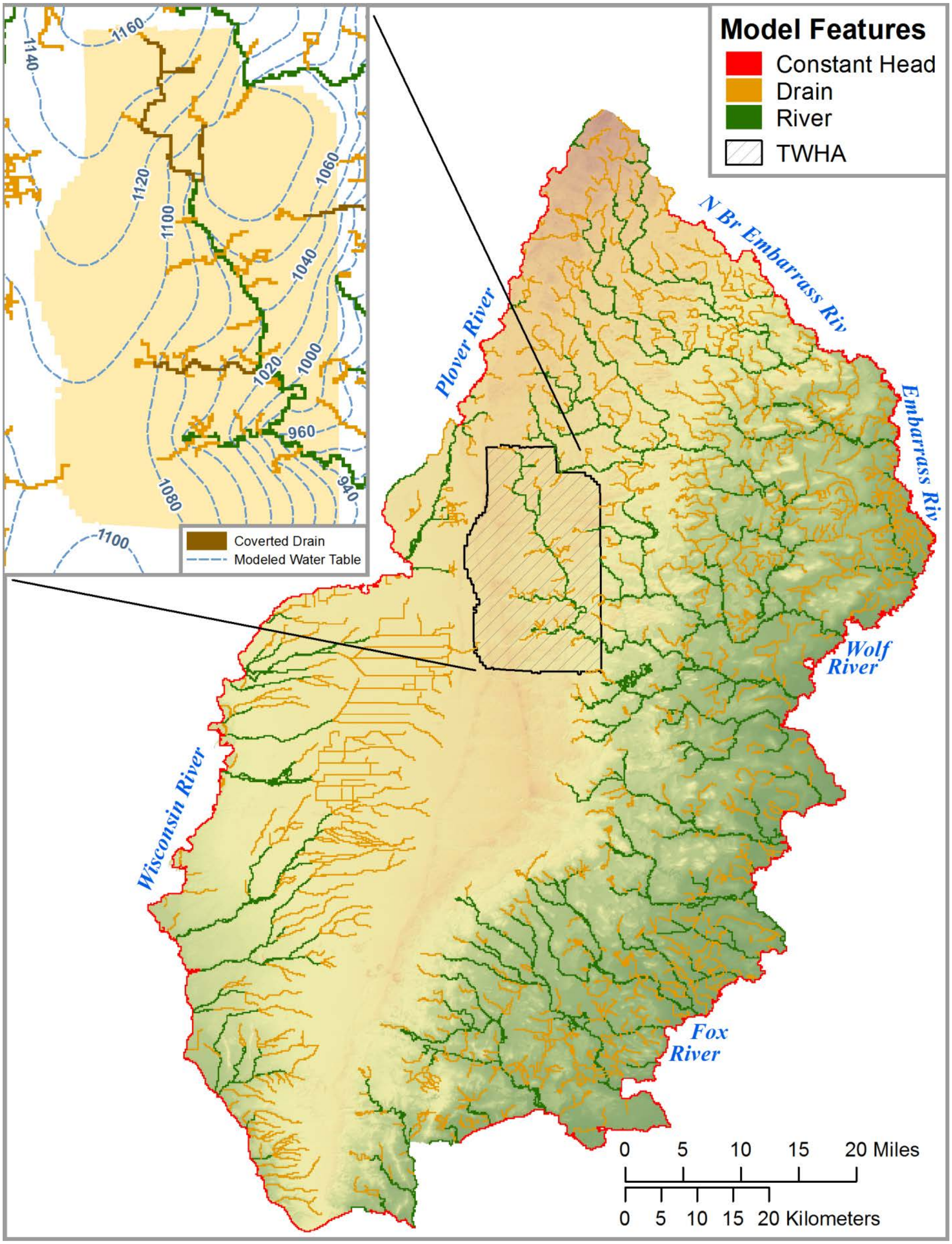

Figure 5. Domain and features of the Central Sands groundwater flow model.

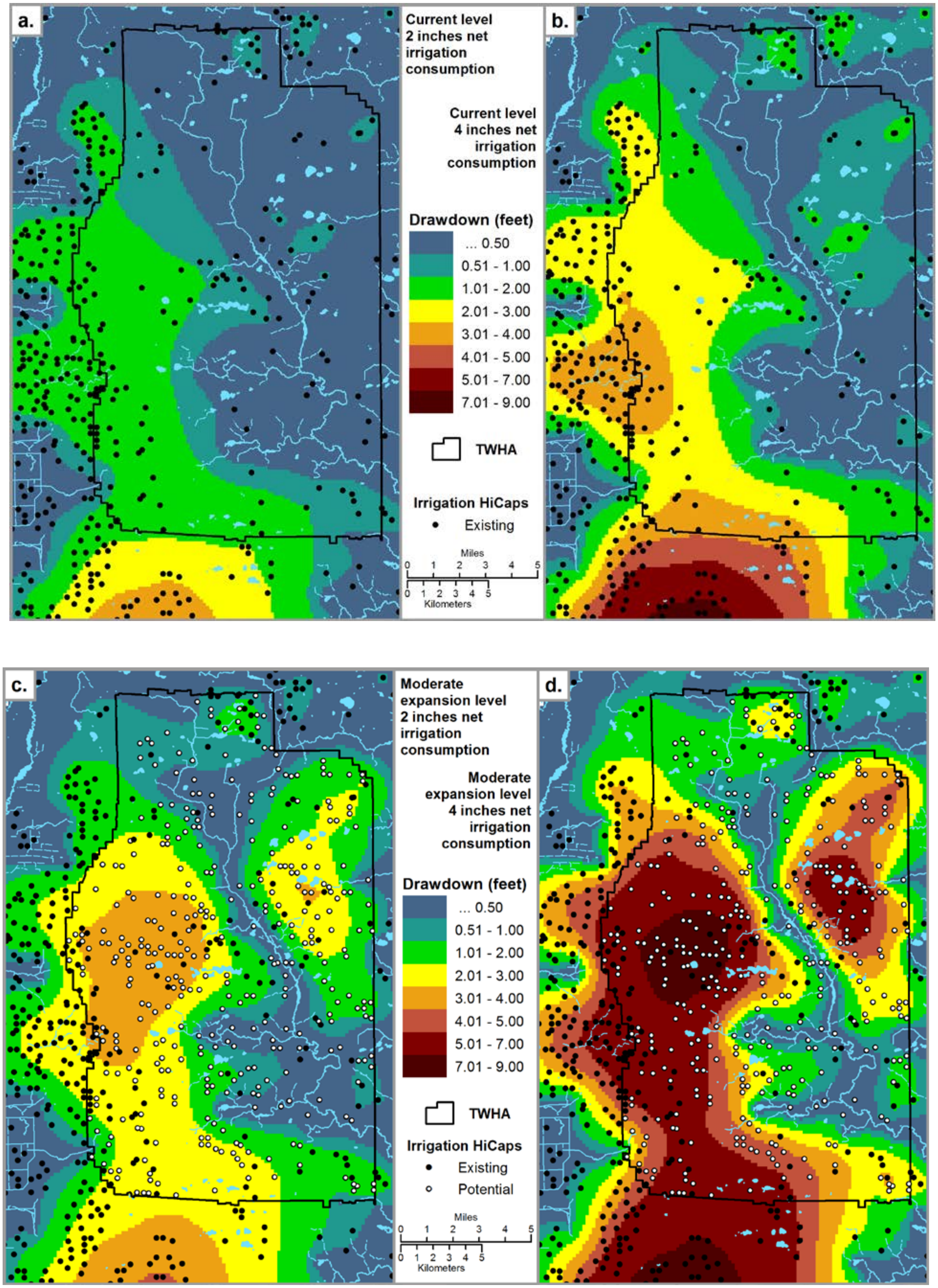

Figure 6. Drawdowns for four irrigation scenarios with two levels of irrigation development and two of irrigation consumption.

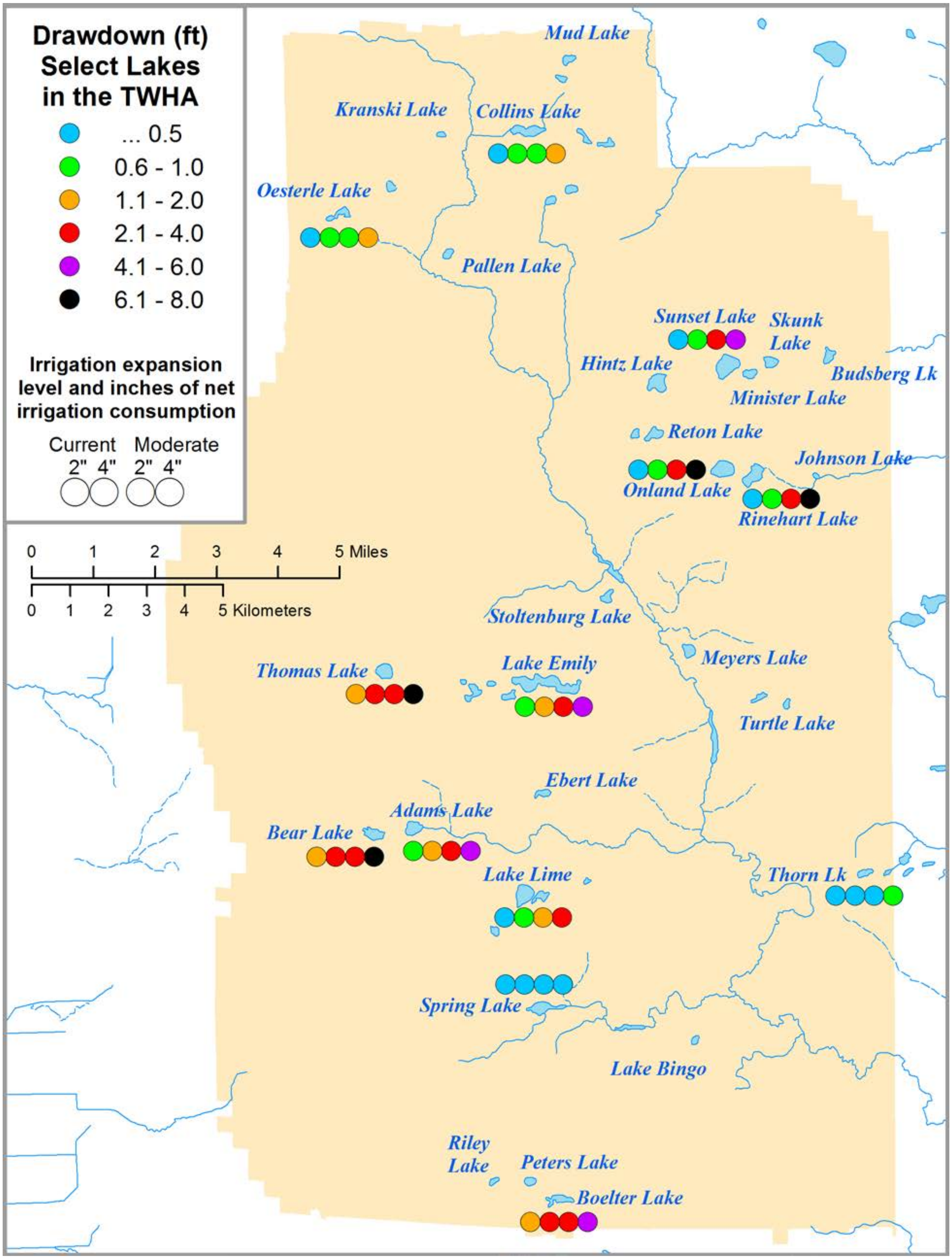

Figure 7. Drawdowns at select lakes for four irrigation scenarios with two levels of irrigation development and two of irrigation consumption.

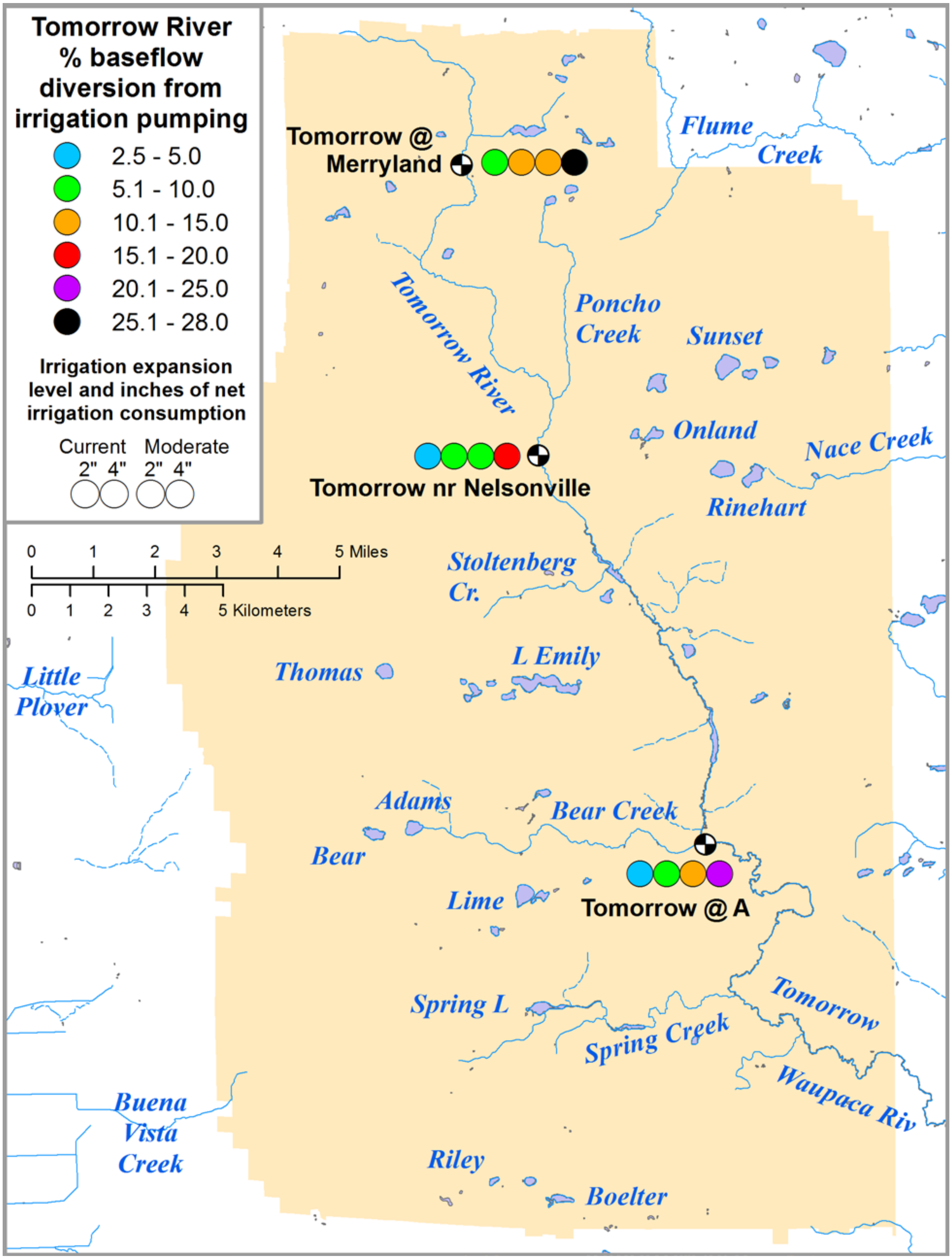

Figure 8. Fraction of Tomorrow River baseflow diverted under four scenarios with two levels of irrigation development and two of irrigation consumption.

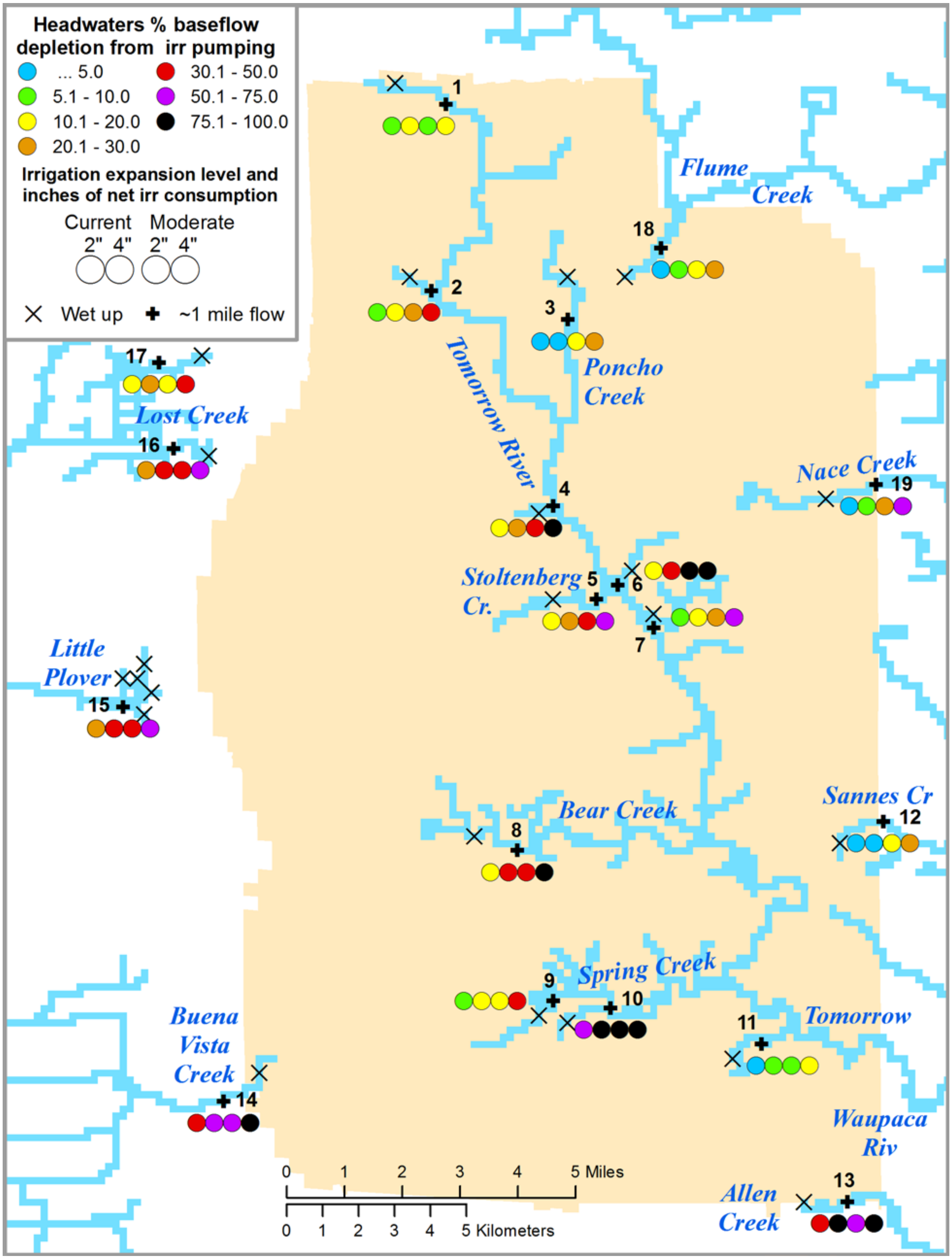

Figure 9. Fraction of baseflow diversion on select tributary headwaters under four irrigation scenarios with two levels of irrigation development and two of irrigation consumption.

Table 1. Some summary characteristics of tiered irrigated land suitability.

Characteristic	Tier			
	1	**2**	**3**	**4**
Number of parcels	2565	1027	395	6593
Acres	63376	24299	8693	30965
% of TWHA	49.8	19.1	6.8	24.3
	----------- % of Parcels -----------			
Dominant land cover				
Agriculture	83	4	2	7
Forest	5	84	87	35
Developed	< 1	< 1	< 1	40
Water	0	0	< 1	2
Other	12	11	10	16
Parcel wetness				
< 25% wet	96.6	79	33.6	44.8
≥ 25 to <50% wet	2.3	7.2	20.4	21.4
≥ 50% wet	1.1	13.8	46	33.8
Dominant slope				
≤ 5%	97.3	87.6	59.2	83.4
>5 to 10%	2.7	12.3	40.5	14.5
> 10%	< 1	< 1	< 1	2.1

Table 2. Tomorrow-Waupaca River baseflow diversions at three locations under four scenarios of two levels of irrigation development and two of irrigation consumption.

	Irrigation development level:	Current		Moderate increase	
	Consumptive irrigation level:	2 Inches	4 Inches	2 Inches	4 Inches
Location	Baseflow (cfs)	--------% Baseflow Diversion ------			
Merryland	1.4	6.7%	13.6%	14.0%	27.7%
Nelsonville	18.6	2.5%	5.1%	9.2%	18.4%
County Highway A	44.3	3.1%	6.3%	11.4%	22.7%

Table 3. Irrigation diversions from headwater streams under four scenarios of two levels of irrigation development and two of irrigation consumption.

		Irrigation development level:	Current		Moderate increase	
		Consumptive irrigation level:	2 in	4 in	2 in	4 in
Map Location	Location Name	Baseflow (cfs)	---------- % Baseflow Diversion -------			
1	Tomorrow River Headwaters	0.96	5.1	10.3	9.5	19.9
2	Unnamed Trib to Tomorrow River - near Polonia	0.86	9.6	19.3	22.5	44.6
3	Poncho Creek	1.60	2.0	4.2	10.4	21.0
4	Unnamed Trib to Tomorrow River - Rolling Hills Rd	0.23	10.1	20.9	44.1	89.8
5	Stoltenberg Creek	1.06	13.5	25.8	33.0	58.8
6	Unnamed Trib to Tomorrow River - Nelsonville Pond	0.09	18.3	36.6	84.6	99.1
7	Unnamed Trib to Tomorrow River - below Nelsonville	0.23	8.2	15.8	28.2	57.4
8	Bear Creek Headwaters	1.01	16.1	31.3	48.4	91.5
9	Mack Creek - trib to Spring Lake	1.41	6.1	12.3	14.5	30.9
10	Upper Spring Creek - trib to Spring Creek	0.07	51.1	99.4	99.5	99.6
11	Stedman Creek	2.19	3.2	6.4	6.3	12.9
12	Sannes Creek	1.14	1.3	2.6	11.2	22.5
13	Allen Creek	0.21	39.9	80.3	66.6	100.0
14	Buena Vista Creek	1.54	33.5	65.0	51.4	93.6
15	Little Plover River at Kennedy	2.99	23.4	46.8	34.4	67.5
16	WDOT Lost Creek Wetland	1.14	23.5	45.3	36.1	68.0
17	Lost Creek	1.26	13.8	26.7	17.5	34.6
18	Rainy Creek	1.64	2.7	5.4	14.2	28.9
19	Nace Creek	0.96	3.8	7.7	27.2	53.3
	Minimum	0.07	1.3	2.6	6.3	12.9
	Maximum	2.99	51.1	99.4	99.5	100.0
	Average	1.08	15.0	29.6	34.7	57.6
	Median	1.06	10.1	20.9	28.2	57.4

ATTACHMENT 1

Groundwater Flow Modeling Detail

Model description

Irrigation impact scenarios were explored using a previously developed MODFLOW model of the Wisconsin Central Sands area (Kraft et al. 2012a). This model, identified as the Extended Model, is a 4 hectare square cell, two layer model encompassing the groundwater flow system in the project area (Figure Attachment 1-1). Far-field model boundaries utilize the main stem and large tributaries of the Wisconsin, Plover, Embarrass, Wolf, and Fox Rivers. Within the project area, groundwater flow is mainly toward the Tomorrow-Waupaca River and its tributaries (modeled as internal river and drain source/sinks). Some drains westward toward Wisconsin River tributaries, and some eastward toward those of the Little Wolf. Calibrated recharge rates range 6.1 to 9.9 inches across the project area. The upper model layer represents the surficial sand and gravel aquifer, which conducts most groundwater recharge to the area's lakes and streams, and is the aquifer usually used as an irrigation water source. The saturated thickness of this layer averages 41 m and ranges 5.5 to 65 m within the demonstration area. The lower model layer represents the sandstone aquifer. It averages 6.1 m thick in the demonstration area, ranges 1 to 70 m, and occurs mostly in the south central portion of the project area. Crystalline Precambrian bedrock bounds the model's bottom boundary. The model is implemented with MODFLOW 2005 with the Upstream Weighting Package (UPW) and the Newton Solver (NWT). The existing model was modified slightly in the project area. Exploratory modeling revealed that several stream reaches modeled as river cells lost unrealistic amounts of water to the aquifer under large pumping stresses. These river cells were therefore converted to drains for all model runs (Figure Attachment 1-1).

The modeling for this project calculates aquifer drawdown at lakes, but does not simulate lake stage explicitly. This is valid for the steady-state type modeling that we are performing here, and comparisons of this approach with explicit lake simulations for a Central Sands lake (S.S. Papadopulos & Associates 2012) have been close.

Simulating irrigated land hydrologic stresses

Previous studies have conceptualized and simulated the hydrology of irrigated land (combined pumping, increased evapotranspiration, and recharge processes) as a reduction in groundwater recharge relative to a native or pre-irrigated land reference condition (Weeks et al. 1965, Weeks and Stangland 1971, Kraft et al. 2012a, 2012b) for steady-state and long time period computations. This reduced recharge is termed "net groundwater recharge," defined as the difference between the recharge of the pre-existing condition and the irrigated conditions. This difference is sometimes termed "net recharge reduction" or "net irrigation consumption." The net recharge reduction is usually less than the depth of groundwater pumped and applied to an irrigated field. The disparity between actual irrigation depth and net recharge reduction has been attributed to "enhanced recharge" compared with nonirrigated land covers that occur during noncropped periods on irrigated fields, such as spring and fall. The net recharge reduction approach was adopted in recent modeling studies in the Central Sands (e.g., Kraft et al. 2010, 2012a, 2012b) where reduced recharge rates were applied to irrigated model cells. Ongoing work (Bradbury and Fienen in progress, Kucharik et al. in progress) seeks to simulate irrigation impacts more explicitly, directly considering pumping and recharge processes on irrigated land as they change through the year. These explicit approaches are not yet ready for broader adoption and incorporation into flow models, and for steady-state analysis, explicit approaches will likely not improve drawdown and stream depletion estimates.

Though irrigation stresses in principle were simulated as a net reduction in recharge rates, we did so differently than in our earlier work to facilitate more efficient simulations. Instead of reducing the recharge rate in irrigated MODFLOW cells, we simulated the net recharge reduction for an irrigated field as a withdrawal from a single MODFLOW well. This brought about three issues: (1) what field size should be simulated by a single irrigation well, (2) how should several neighboring small parcels be aggregated so as to be simulated efficiently by a single irrigation well, and (3) when neighboring parcels lie in different tiers, how will their tier be represented?

For field size, we used 103.6 acres per irrigation well, the apparent average for the region. Drawdowns calculated using the former method and attributing the same net irrigation reduction to a well representing 103.6 acres produced similar results at the large scale.

In order to address parcel fragmentation and provide a reasonable base area to site a new well, tier 1, 2, and 3 parcels were aggregated to approximately a quarter-quarter section level and assigned an area-weighted tier value. Aggregated tier values less than 1.5 were assigned to tier 1, tier values 1.5 to < 2.5 were assigned to tier 2, and tier values 2.5 to 3 were assigned to tier 3.

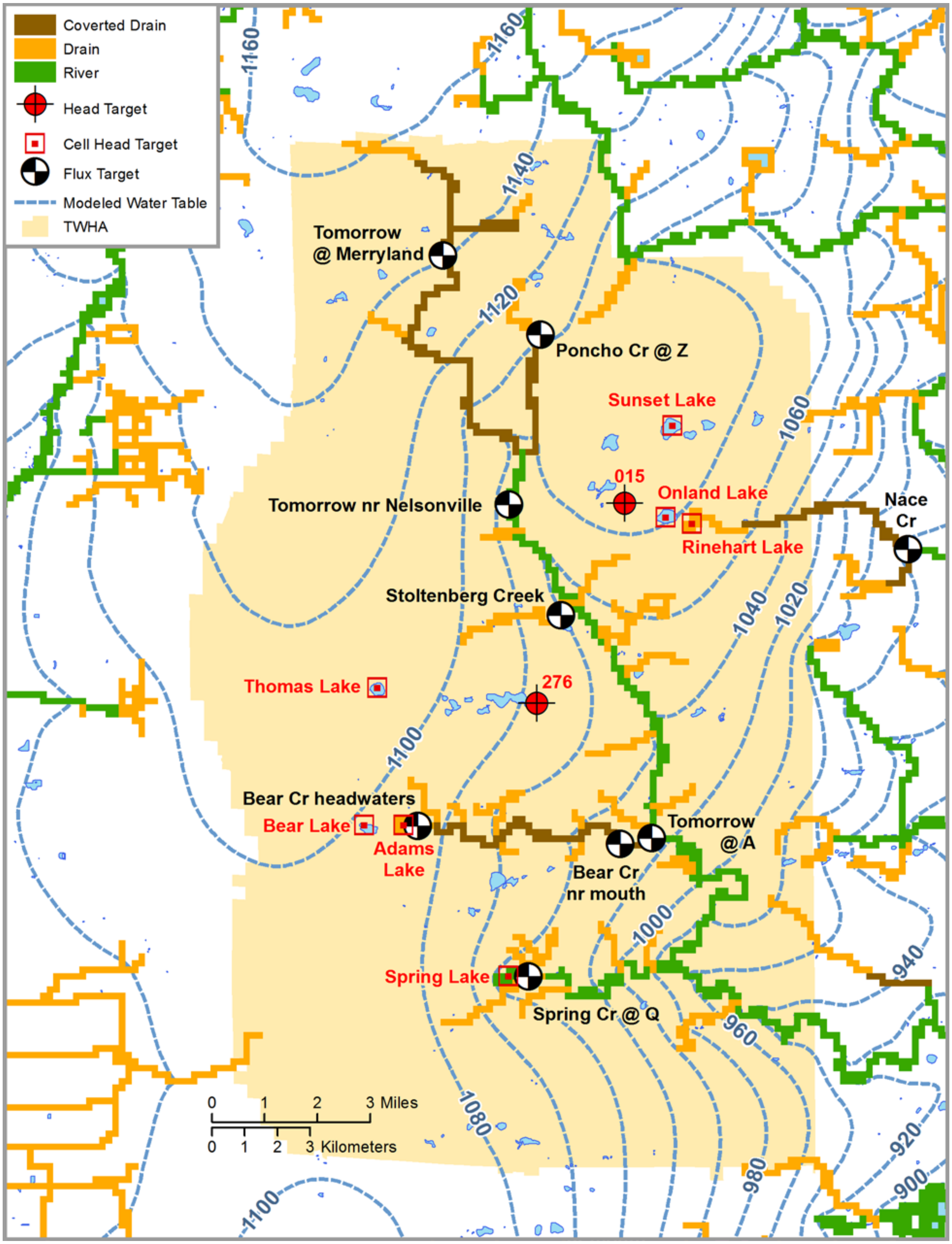

Figure Attachment 1-1. Groundwater flow model features for the vicinity of the TWHA.