Information support for groundwater management in the Wisconsin central sands. [DNR-208] 2012

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Stevens Point, Wisconsin: College of Natural Resources, University of Wisconsin - Stevens Point, 2012

Information Support for Groundwater Management in the Wisconsin Central Sands, 2009-2011

A Report to the Wisconsin Department of Natural Resources
In Completion of Project NMA00000253

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October 1, 2012

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1. INTRODUCTION

This report summarizes 2009-2011 efforts to gather data and continue information support for groundwater management in the Wisconsin central sands. These efforts supplement the previous more in-depth work of Clancy et al. (2009) in the Little Plover River area and that of Kraft et al. (2010) and Kraft et al. (2012) 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 having a substantial impact on the region's water levels and streamflows.

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 work particularly addresses the region between the headwater streams of the Fox-Wolf Basin and those of the Central Wisconsin Basin, which contain some 83 lakes (> 12 ha) 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, with about 2310 in the five counties that this study area overlaps (Figure 1-3). Twenty percent of Wisconsin's groundwater pumping occurs within the three central sands counties of Portage, Waushara, and Adams. Most (about 86%, Buchwald 2009) is for irrigation. 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 controlled, and mainly without regard for impacts on lake and stream resources. This growth mirrors increases in irrigated farmland (USDA NASS 2008 and others).

Lake levels, groundwater levels, and streamflows in the Wisconsin Central Sands have been depressed in many recent years, greatly so in areas with large densities of high capacity wells. 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 winter fish kills on Pickerel Lake 2006-2009. Wolf Lake County Park in Portage County has had its swimming beach closed due to low water levels for most of the last 8-10 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), flowed mostly at less than the former minimum and dried in stretches between 2005 and 2009.

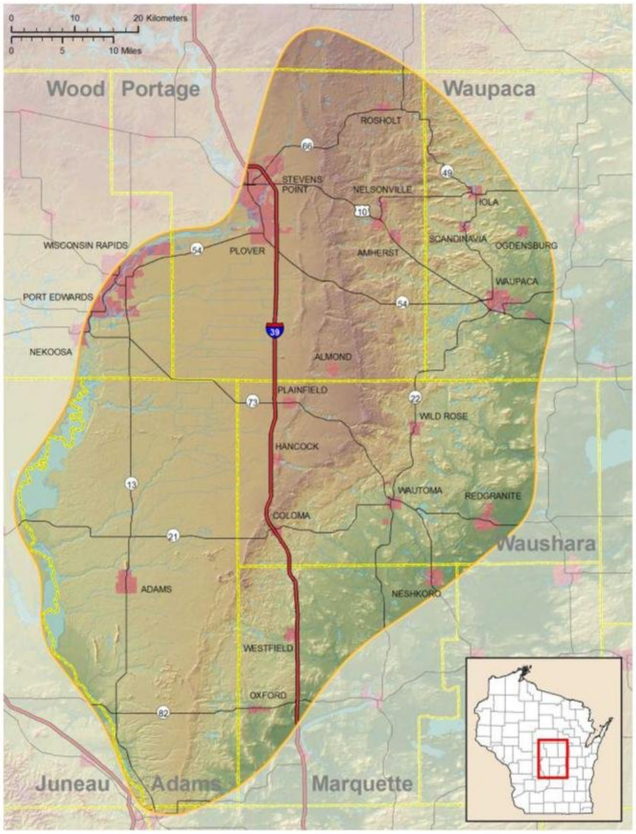

Figure 1-1. The Wisconsin central sands region with selected municipalities and roads.

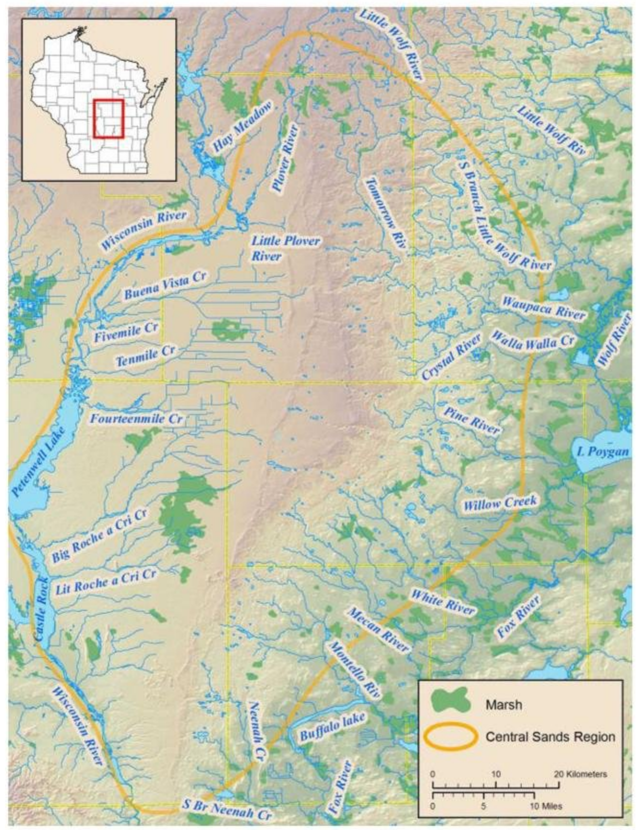

Figure 1-2. Hydrography of the Wisconsin central sands region.

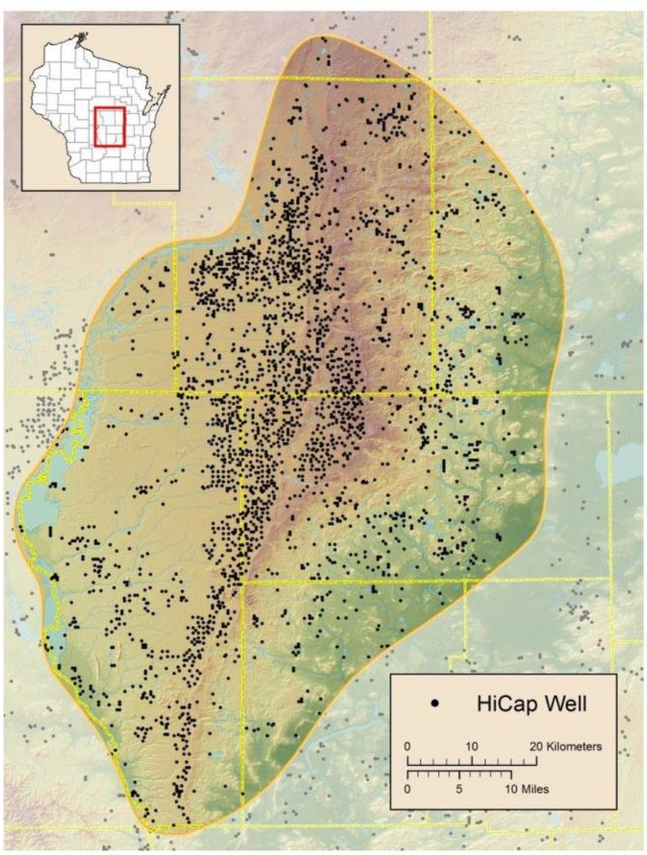

Figure 1-3. Locations of high capacity wells.

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. *Resume periodic (monthly to bimonthly) measurements of baseflow discharges on select streams.*

Discharge measurements resumed at 31 stations, at monthly to bimonthly frequencies. These are appended as electronic media in a spreadsheet entitled "Q from Central WI. Rivers thru Sept. 2012.xlsx" and have also been uploaded to the USGS for archiving. Data are summarized in chapter 3. Additionally, groundwater elevation measurements were made at 3 sites; USGS Belmont (44195808918360), USGS Belmont Cty Rd D (441900089164501), and UWSP Nelsonville (443126089174201) and uploaded to USGS.

2. *Compile newly generated groundwater and lake level data into databases along with previously gathered data; examine for potential trends.*

Compiled lake level data are appended as electronic media with this report in a spreadsheet entitled "Lake Level Data Updated to 2011.xlsx". Trends in USGS monitoring well and in lake data are examined in Chapters 4 and 5.

3. *Estimate irrigation rates for crops grown in central Wisconsin for 2008, 2009, and 2010.*

Rate estimation is discussed in Chapter 7.

4. *Revamp and monitor a historic groundwater level monitoring well (USGS site no. 443127089174101) at Nelsonville; upload measurements to USGS.*

A replacement well was constructed, as documented in Appendix A. The new well is USGS 443126089174201, PT-24/10E/28-1487. (http://waterdata.usgs.gov/nwis/inventory?agency_code= USGS&site_no=443126089174201) It was constructed to give almost identical groundwater elevation data as the well it replaced.

5. *Run existing groundwater flow models to meet WDNR staff and stakeholder information needs; modify models as needed.*

Flow models were run to support a publication in Ground Water Journal (Kraft et al. 2012), the Little Plover Workgroup, the University of Wisconsin-Madison WISA Central Sands Collaboration, and the efforts of local governments.

6. *Extend the existing central sands flow model to adjacent areas where large densities of high capacity wells have proliferated; and use it to assess potential impacts on surface waters.*

The extended model was completed and is documented in Appendix B.

7. *Assemble and provide interpretation, as needed, of precipitation, stream discharge data, and groundwater elevation.*

These data are discussed in chapters 2, 3, and 4.

2. WEATHER AND HYDROLOGIC CONDITIONS FOR 2009-2011

Summary

Year 2009 precipitation was about average for Stevens Point, Hancock, and Wautoma, but 2010 was notably wet, by 6.5 to 10.6 in above average, depending on station. Year 2011 was also wetter than average by 2.2 in at Stevens Point and 5.1 in at Wautoma, but average at Hancock. The greater precipitation amounts in 2010 and 2011 are important drivers that raised water levels and streamflows through the region.

Hancock and Wautoma precipitation has been increasing continuously since the late 1940s, but a similar increase stagnated in the 1980s in the Stevens Point vicinity. As a result, the southern central sands as exemplified by Hancock and Wautoma have been receiving 0.9 in more annual precipitation than has the Stevens Point vicinity. The drought index for 2009-2011 was near normal to very moist. Discharges in reference streams, which were below average in 2005-2009, began increasing in 2008, and exceeded the 90 percentile in 2011. Similarly, groundwater levels that were somewhat low at Amherst Junction and average at Wautoma rose to 72 percentile and 91 percentiles of record.

Precipitation

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

Precipitation summary, 2000 through 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, and Stevens Point experienced its third wettest year in its 80 year record. Wet conditions continued in 2011 for Stevens Point and Wautoma, by 2.2 and 5.1 in, though Hancock was average. Precipitation excesses during 2009-2011 were mostly comparable at surrounding stations (Necedah, Mauston, Friendship, and Wisconsin Dells).

Trends

Precipitation has been increasing in the central sands over recent decades (Figures 2-2 and 2-3, WICCI 2011) possibly masking for a time the influence of irrigation on ground and surface waters (Kraft et al. 2012). The precipitation increase is consistent with wetter conditions that prevailed over much of the eastern US, including much of Wisconsin. Juckem et al. (2008) describe the increase as a step change that occurred in about 1970. Compared with 1940-1970, precipitation is greater by 0.7 in at Stevens Point, 2.2 in at Hancock, and 2.8 in at Wautoma.

Figure 2-2 suggests that the increasing precipitation signal is more nuanced than a simple step change. Precipitation has apparently been increasing continuously at Hancock and Wautoma since the late 1940s, but the increase apparently stalls during the 1980s at Stevens Point. As a result of the continuing increase at Hancock and Wautoma, these stations in the southern central sands have been averaging 0.9 in yr^{-1} more precipitation since than Stevens Point.

Drought Index

The Palmer Drought Index is an indicator of climatic dryness based on precipitation and temperature. Hence, it is an improvement on precipitation alone as an indicator of drought 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. Years 2009-2011 ranged near normal to very moist (Figure 2-4).

Discharges on Reference Streams

Long term annual discharges for several area streams provide context for current hydrologic conditions. Displayed in Figure 2-5 are the percentile rank of annual streamflows for four streams that surround the central sands: Wolf River at New London (1914-2011), the Embarrass River at Embarrass (1920-2011 with nine missing years), Waupaca River at Waupaca (1917-1984 with 20 missing years, plus 2009-2011), and the Wisconsin River between Wisconsin Dells and Wisconsin Rapids (1935 to 2011 with eight missing years). We term the Wisconsin River between Wisconsin Dells and Wisconsin Rapids as the "Central Wisconsin River," obtaining discharge values as the difference between Wisconsin Rapids and Wisconsin Dells discharges. The Central Wisconsin River is new in this report, and replaces 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.

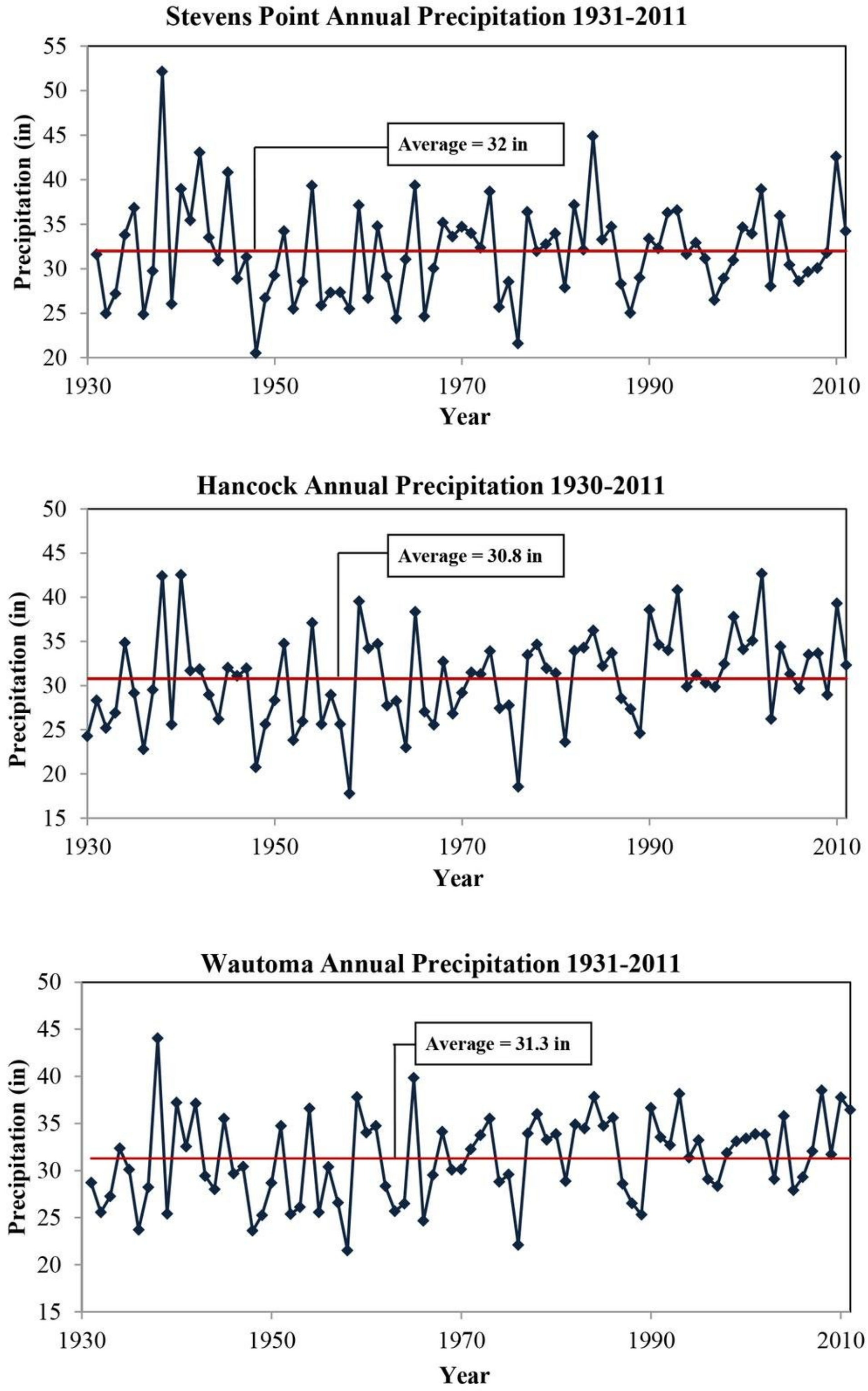

Figure 2-1. Precipitation at Stevens Point, Hancock, and Wautoma. Stevens Point and Hancock data are from historical records with a few inferred values. Wautoma's data from 1931-2007 are inferred using methods of Serbin and Kucharik (2009) and data from 2008-2011 are from historical records.

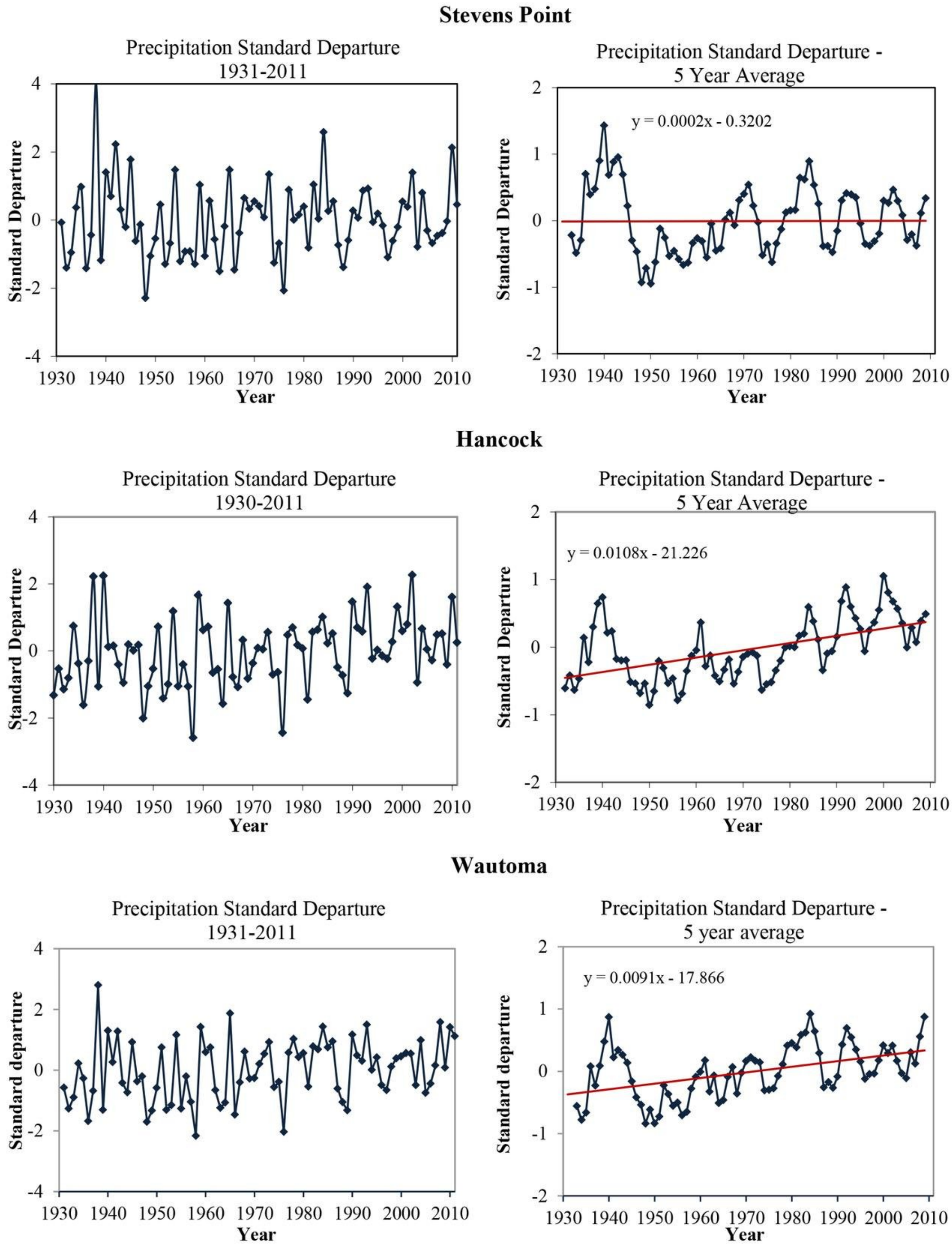

Figure 2-2. Standard departure of annual precipitation and five year average of the standard departure for Stevens Point, Hancock, and Wautoma.

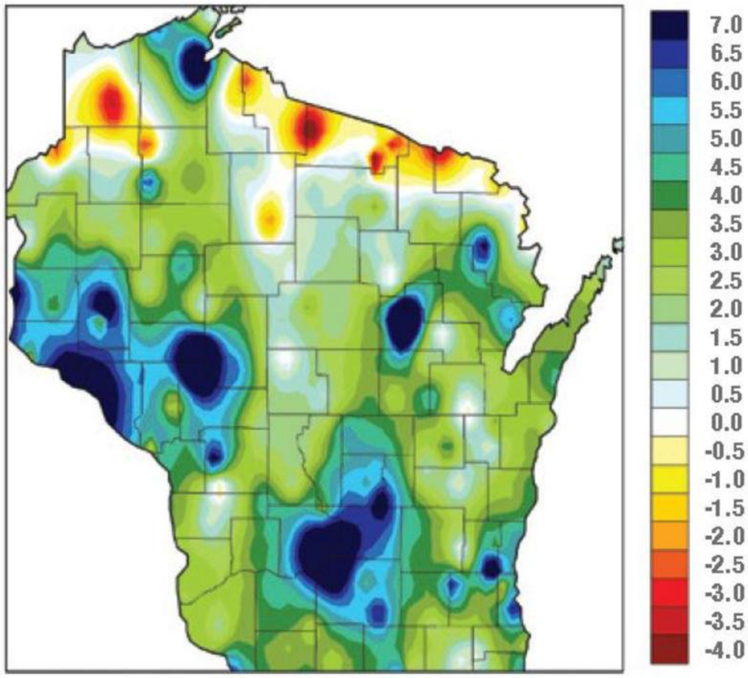

Figure 2-3. Change in average annual Wisconsin precipitation, 1950-2006. WICCI 2011.

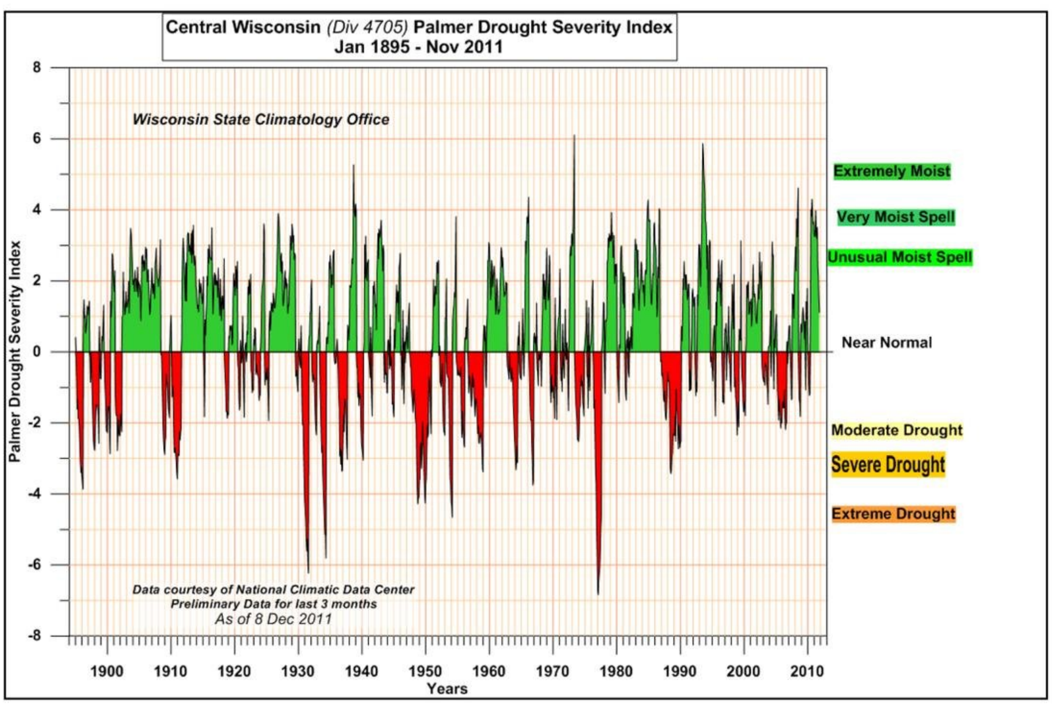

Figure 2-4. Palmer Drought Index graph for central Wisconsin ending November 2011, produced by the Wisconsin State Climatology Office (2011). Note that the post-2000 period is not substantially droughty compared to the historical record.

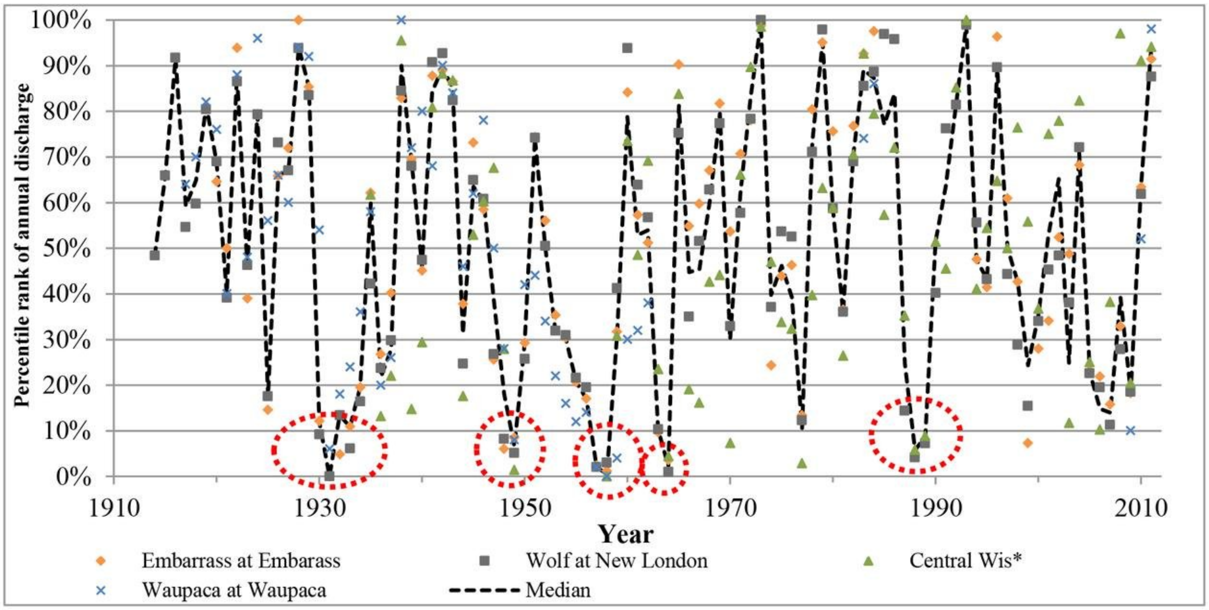

Figure 2-5. Percentile rank of streamflows by year, ending 2010. Connecting line is for the median percentile rank. Significant dry periods (median of percentile ranks <10%) are highlighted by red circles. "Central Wis" is the difference in Wisconsin River discharges between Wisconsin Rapids and Wisconsin Dells.

Each station has problems when used to infer the central sands water stressed area. The Wolf River at New London drains a large basin somewhat removed to the northeast of the central sands, and is likely to be affected by the ongoing drought there. The Embarrass River at Embarrass is nearer, and drains a smaller basin (384 sq mi), but also is also likely recently drought affected. The Waupaca River at Waupaca is near the water stressed area of the central sands, 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 Central Wisconsin 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, and 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. The recent lower flows and rebounds to higher flows generally follow the precipitation record.

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, 2012). These are Amherst Junction (1958 to 2011 record), Nelsonville (1950 to 1998, 2010 and 2011), Wild Rose (1956 to 1998), and Wautoma (1956 to 2011) (Figure 2-6).

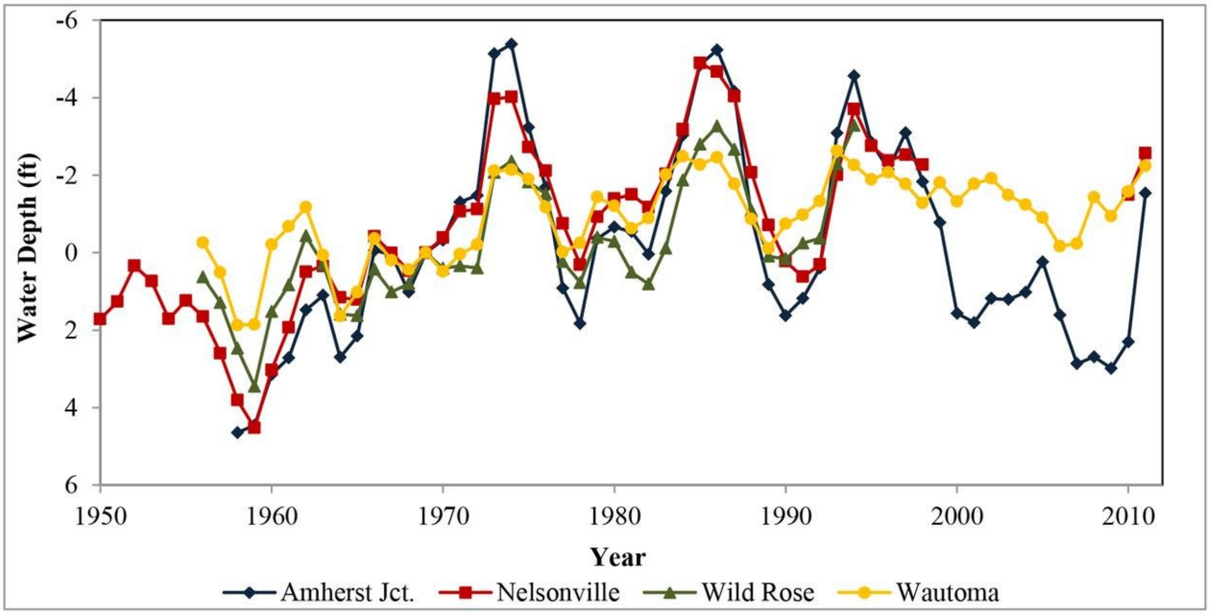

Figure 2-6. Annual average depth to water in four long term USGS monitoring wells located in areas with fewer high capacity wells. Water levels were adjusted so that 1969 values were zero for display purposes.

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, 2012). In more recent times, only the records of Amherst Junction and Wautoma are available. 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.

Though Amherst Junction 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. 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. BASEFLOW DISCHARGES ON SELECT STREAMS - UPDATE

Baseflow discharge measurements continued at 31of 42 stream locations (Figure 3-1, Table 3-1) previously measured by Kraft et al. (2010). Discharges were measured monthly through the study period except in February. 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 3-1). Data for locations with both UWSP and USGS histories are summarized and compared in Table 3-2. Complete data are included with this report as electronic media in a spreadsheet entitled "Q from Central WI. Rivers thru Sept. 2012.xlsx". Data collected through December 2011 by UWSP were sent to USGS to be archived in their database.

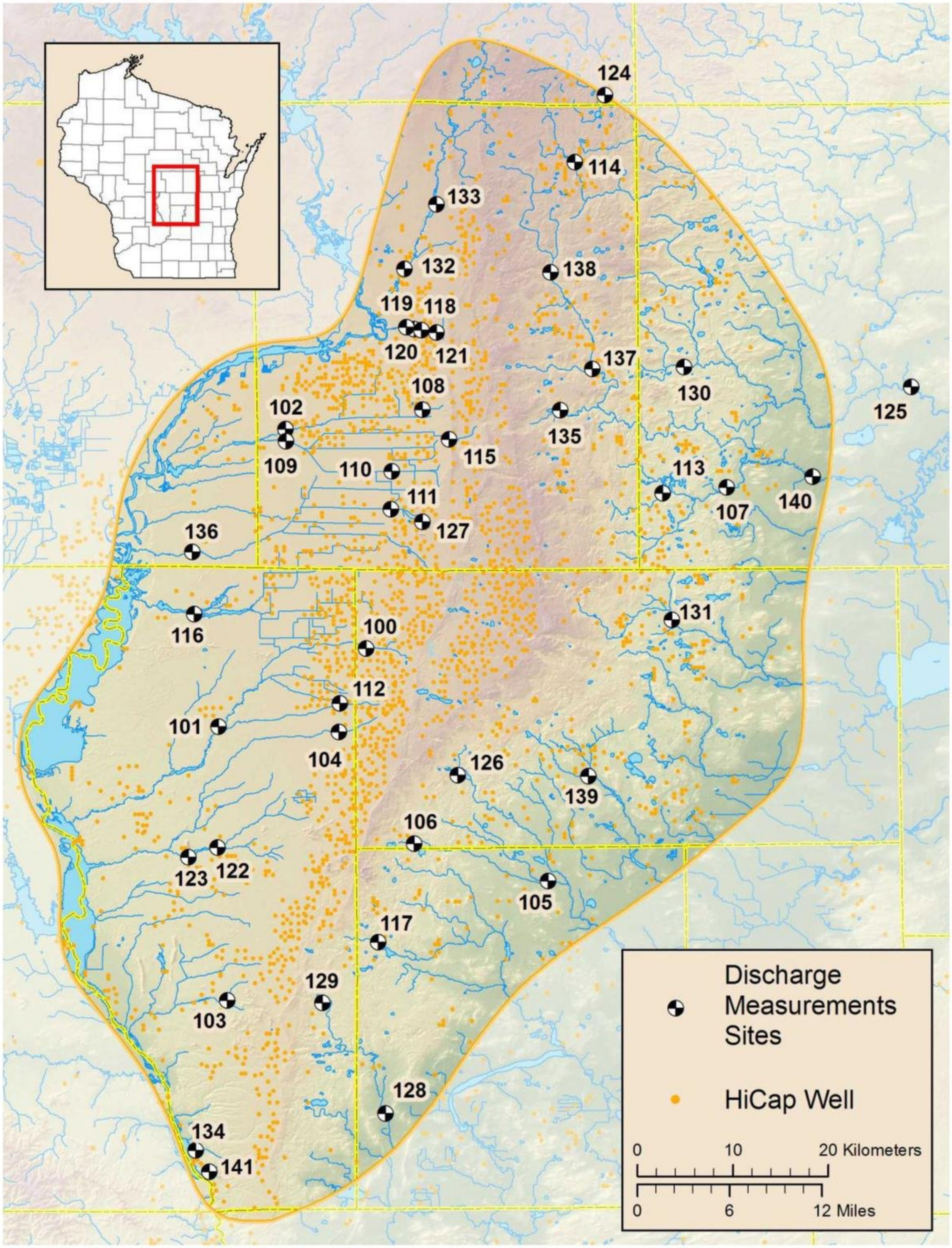

Figure 3-1. Discharge measurement sites from Kraft et al. 2010, most of which were continued for this study.

Table 3-1. 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 3-1. Continued

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 3-2. Comparison of archived USGS and recent UWSP discharge data through 2011.

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	2007-2011	30	9.6	2.4	27.6
Big Roche-A-Cri @ Brown Deer Ave	1963-1978	5496	60.6	28.0	460.0	2007-2011	27	50.3	28.1	83.1
Buena Vista Creek @ 100th Rd	1964-1967	1309	44.6	14.0	187.0	2007-2011	28	31.0	8.7	52.1
Campbell Creek @ A	1971	1	2.6	2.6	2.6	2007-2011	30	2.4	1.0	4.3
Chaffee Creek @ 14th	1962-1988	18	34.7	25.9	47.5	2005-2011	40	37.3	24.0	62.6
Ditch #2 N Fork @ Isherwood	1966	1	5.7	5.7	5.7	2007-2011	48	5.9	3.1	11.6
Ditch #4 @ 100th Rd	1964-1967	1309	39.6	4.0	256.0	2007-2011	20	45.6	7.7	114.1
Ditch #5 @ Taft	1964-1973	3383	8.0	2.2	166.0	2007-2011	14	5.9	0.4	15.0
Emmons Creek @ Rustic Road 23	1968-1974	2330	26.7	21.0	203.0	2005-2011	43	21.7	15.1	33.0
Flume Creek in Rosholt @ 66	1972-1976	5	6.3	3.6	8.7	2005-2011	28	8.4	2.6	34.3
Lawrence Creek @ Eagle	1967-1973	2161	16.9	12.0	39.0	2005-2011	32	19.6	14.7	22.7
Little Plover @ Eisenhower	1968	6	4.1	2.6	5.1	2007-2011	71	2.7	0.0	8.9
Little Plover @ Hoover	1959-1987	10319	10.6	3.9	81.0	2005-2011	182	5.3	1.7	17.4
Little Plover @ Kennedy	1959-1976	6218	4.0	0.8	50.0	2005-2011	172	1.5	0.0	6.8
Little Roche-A-Cri @ Friendship Park	1972-1976	8	35.7	18.2	68.8	2007-2011	19	35.6	2.6	76.3
Little Wolf @ 49	1973-1979	2199	17.1	3.1	220.0	2007-2008	11	7.9	4.5	10.7
Mecan @ GG	1956-1988	22	12.8	10.3	17.9	2005-2011	32	13.5	10.7	15.2
Peterson Creek @ Q	1962-1988	15	18.0	12.9	28.8	2005-2011	42	20.9	10.2	36.2
Plover River @ Y	1914-1951	5113	146.9	37.0	1450.0	2005-2011	89	104.2	39.2	263.0
Tomorrow @ River Rd (Clementson)	1993-1995	905	33.6	16.0	212.0	2005-2011	63	21.8	12.5	88.8
W Branch White River @ 22	1963-1965	731	22.1	16.0	61.0	2005-2011	31	27.8	20.5	50.2

4. LONG TERM MONITORING WELL WATER LEVELS AND TRENDS - UPDATE

Summary

Eight Central Sands monitoring wells with long records have proved useful for exploring groundwater trends during the last half century. The records indicate that water levels in the central sands experienced record lows during the dry extreme of 1958-1959, rose through 1974, and then fluctuated cyclically until the late 1990s. In areas with relatively few high capacity wells, water levels were somewhat low (6 to 24 percentile) during 2007-2009, but rebounded sharply (72 to 91 percentile) during the wet 2010-2011 period. In contrast, areas with many high capacity wells reached record lows in the late 2000s, during a period of average to modestly dry weather, a signal consistent with a pumping impact. Pumping declines reached 4 to 5 feet at Hancock and Plover, and smaller amounts at Bancroft and Coloma SW. The wet conditions of 2010-2011 eased pumping declines somewhat in many high capacity well areas.

Groundwater Level Record

Eight monitoring well sites in the USGS archives have previously proved useful (Kraft et al. 2010, 2012) for exploring groundwater level trends over the last half-century (Table 4-1, Figure 4-1). Four of the eight (Amherst Junction, Nelsonville, Wild Rose, and Wautoma) are in areas with few high capacity wells, and four are in areas with many high capacity wells (Plover[1], Hancock, Bancroft, and Coloma NW). With the reconstruction of the Nelsonville monitoring well as part of this study (Appendix A), seven of the eight sites (the Wild Rose monitoring well is apparently defunct) are currently generating data. Here we update monitoring well levels and trends.

The monitoring well record suffers several deficiencies. In addition to the terminated record of Wild Rose in 1994, 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.

Updated annual average hydrographs of the eight sites are displayed in Figure 4-2, grouped according to location in an area of few or many high capacity wells. For display purposes, water levels were zeroed to the measured level of each well in 1969, with positive values indicating a greater depth to water (water level decline) compared to 1969, and negative values a shallower depth (water level rise). All hydrographs demonstrate common peaks (evident around 1974, 1985, and 1993) and valleys (1959, 1978, 1990, and perhaps 2007) that coincide with indicators of wet and dry condition (Chapter 2).

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

Table 4-1. 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	2011+	1331+
PT-23/10E/18-0276	Amherst Jct.	17.4	7/2/1958	2011+	1714+
PT-23/08E/25-0376**	Plover	19.0	12/1/1959	2011+	1161+
WS-18/10E/01-0105	Wautoma	14.0	4/18/1956	2011+	17466+
WS-19/08E/15-0008	Hancock	18.0	5/1/1951	2011+	18958+
PT-21/08E/10-0036	Bancroft	12.0	9/7/1950	2011+	1639+
PT-21/07E/31-0059	Coloma NW	15.3	8/8/1951	2011+	748+
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.

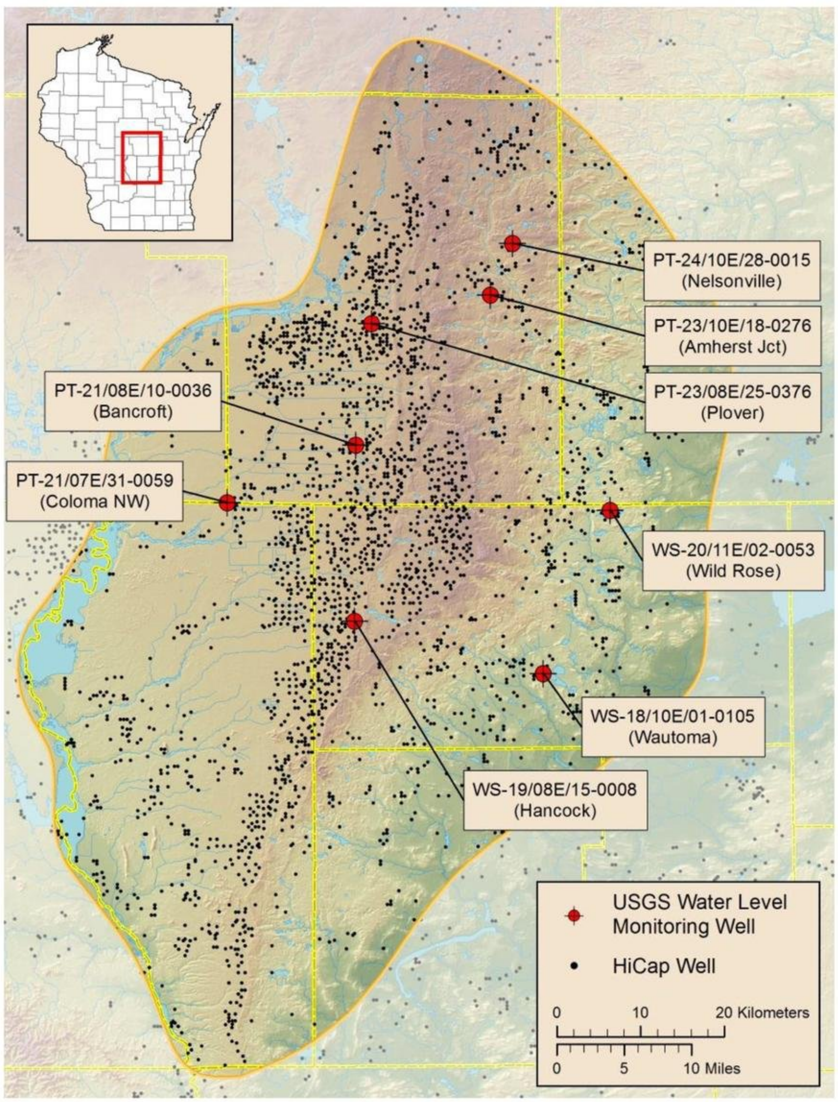
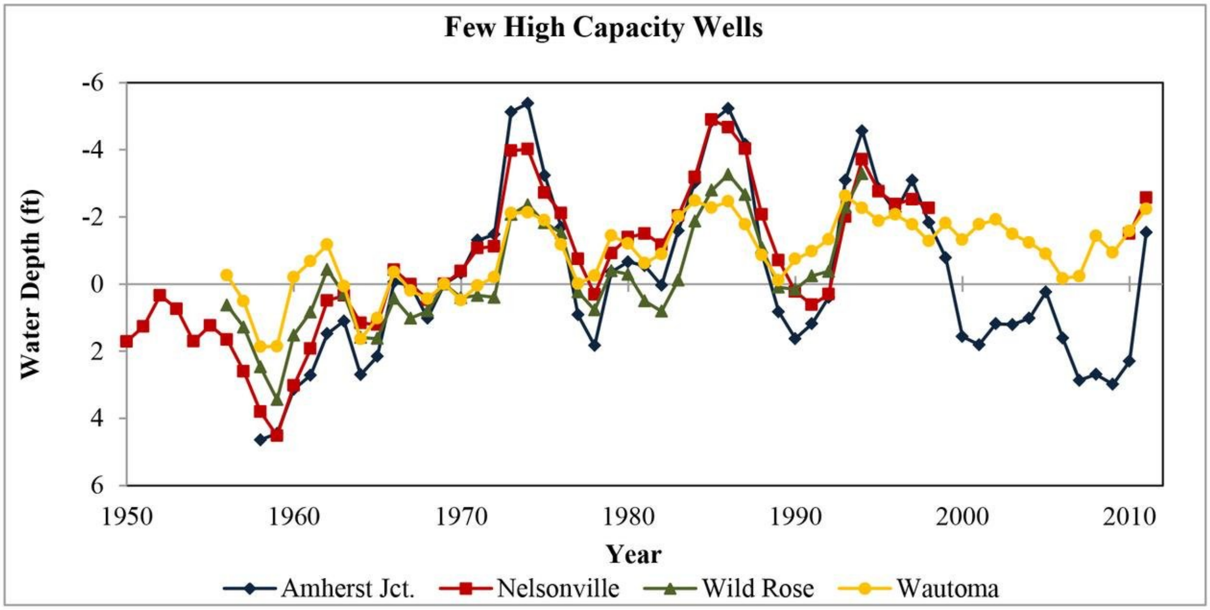


Figure 4-1. Location of eight USGS monitoring wells with records sufficient for exploring long term water level trends.



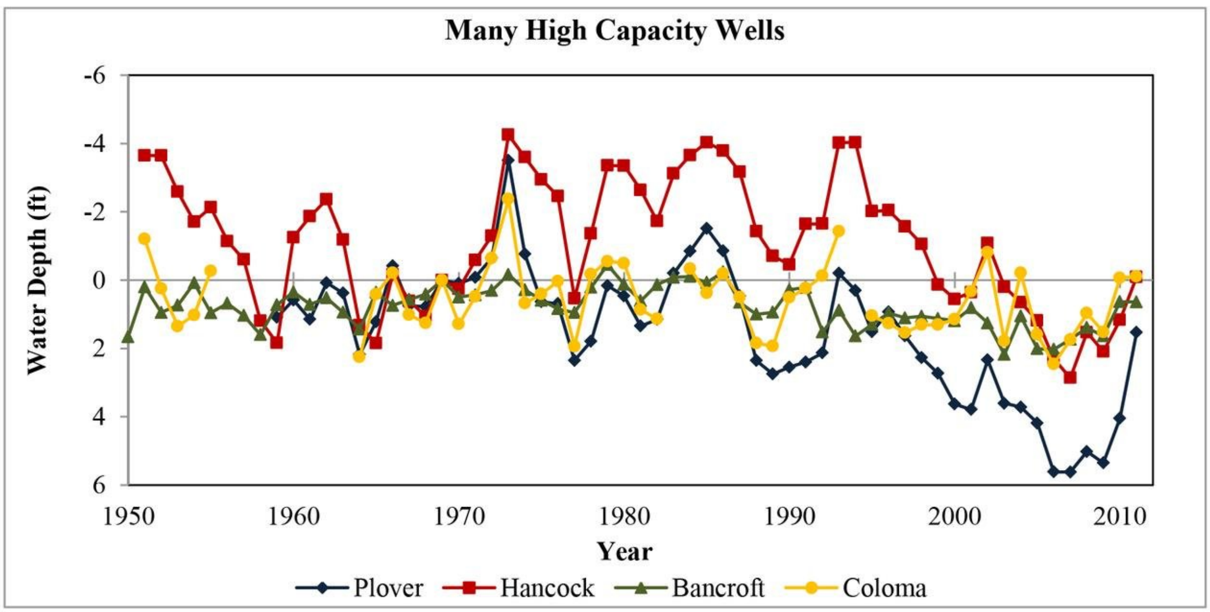


Figure 4-2. Annual average water levels in areas of few (top) and many (bottom) high capacity wells. Water levels are zeroed to 1969 water depths for display purposes.

Though water level peaks and valleys coincide, amplitudes and trends differ among wells. Amplitude differences are expected and are predictable 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.

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). Levels rose in these locations from 1959 through about 1974, and then displayed a cyclical fluctuation around an average through the late 1990s. Levels declined through 2007-2009, particularly at Amherst Junction, before rebounding in 2010-2011. 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. These declines, beyond what is explainable by weather variability alone, are attributed to a pumping effect, and were estimated previously for the period ending in 2008 (Table 4-2, Kraft et al. 2010, 2012).

Table 4-2. 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. 2012).

Station	Decline (ft)	Decline rate (ft y^{-1})	Decline start
Plover	2.1 (3.4)[1,*]	0.12	1973
Hancock	3.2*	0.21	1990
Bancroft-Am Jct[2]	0.82*	0.062	1984
Bancroft-Waut[3]	1.2*	0.062	1984
Coloma NW-Am Jct[2]	0.0	--	--
Coloma NW-Waut[3]	2.2*	--	1978

* Decline is significant at 0.05 level.
1. Total decline = 3.4 ft; irrigation decline = 2.1 ft
2. Comparison against Amherst Junction
3. Comparison against Wautoma

Estimated Declines due to Pumping, Update for 2009-2011

Year-by-year estimated pumping declines in many high capacity well areas are updated here. The declines 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 many high capacity well areas to water levels in few high capacity well ("reference") areas during an early baseline period when pumping effects were presumed small. Annual average water levels (Figure 4-2) were used as the statistic for comparison. Linear regressions were used to describe the water level relationships between high density pumping sites and reference sites. The Plover record was compared against its nearest reference location at Amherst Junction (8 miles), and Hancock against its nearest reference at Wautoma (11 miles). These comparisons are consistent with precipitation patterns (Serbin and Kucharik 2009, Haucke 2010). Coloma NW and Bancroft were compared against both reference locations as they are not particularly nearer to either. More detail on methodology is documented in Kraft et al. (2010) and Kraft et al. (2012).

Plover

Water levels at the Plover monitoring well have been decreasing since the 1980s (Figure 4-3, top), and reached a record low in 2007-2008. Water levels rose in 2010-2011 by about four feet, presumably in response to the large rains that prevailed during that period.

Pumping began affecting Plover water levels around 1973 (Figure 4-3, bottom), causing declines that averaged 0.12 ft yr^{-1} through 2009. Pumping lowered water levels an estimated average 3.4 feet beyond the effects of normal weather induced variability (Kraft et al. 2010, 2012), 2.1 feet of which is due to irrigation pumping and 1.3 feet to municipal and industrial pumping. A maximum pumping effect of a 4.9 foot decline was estimated for 2007. Pumping effects in 2010 and 2011 diminished somewhat, likely because large rains depressed irrigation pumpage and boosted groundwater recharge rates.

Hancock

Measured water levels at Hancock began a systematic decrease in the early 1990s, and were at record lows through much of 2006-2009 (Figure 4-4, top). Water levels rebounded several feet in 2010-2011 (again presumably in response to large rains) to about the 1960-1990 period average. Estimated pumping declines at Hancock averaged 3.2 feet for 1999-2008 (Kraft et al. 2010, 2012) and reached a maximum of 4.0 feet in 2008 (Figure 4-4, bottom). Pumping declines diminished somewhat in 2010 and 2011, to about 3.5 feet.

Bancroft

Bancroft water levels have been declining since the mid 1980s, and were at record lows in much of 2003-2007 (Figure 4-5, top). Water levels rebounded in 2010 and 2011 to about historical averages.

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 in about 1984, and in 1999-2008 averaged 1.2 feet, Wautoma reference (Figure 4-5, bottom), or 0.82 feet Amherst Junction reference. Pumping declines almost entirely abated during the wet period of 2010-2011.

Coloma NW

Coloma NW water levels exhibit an oddness compared with other sites, and hence pumping impacts based on its record should be used judiciously. Potential reasons for eccentricity include the sparseness of the record and its location near groundwater discharges. Levels were at a record low in 2006, and rebounded to about the long term average in 2010 and 2011 (Figure 4-6, top).

Estimated pumping declines at Coloma NW have been calculated against both Wautoma and Amherst Junction since Coloma NW is not particularly near either. No statistically significant declines were found when the Amherst Junction reference was used. Compared with Wautoma, levels at Coloma NW began their decline in the mid 1970s, and during the 2002-2011 averaged 2.2 feet (Figure 4-6, bottom). A maximum decline of 3.3 feet was estimated for 2003.

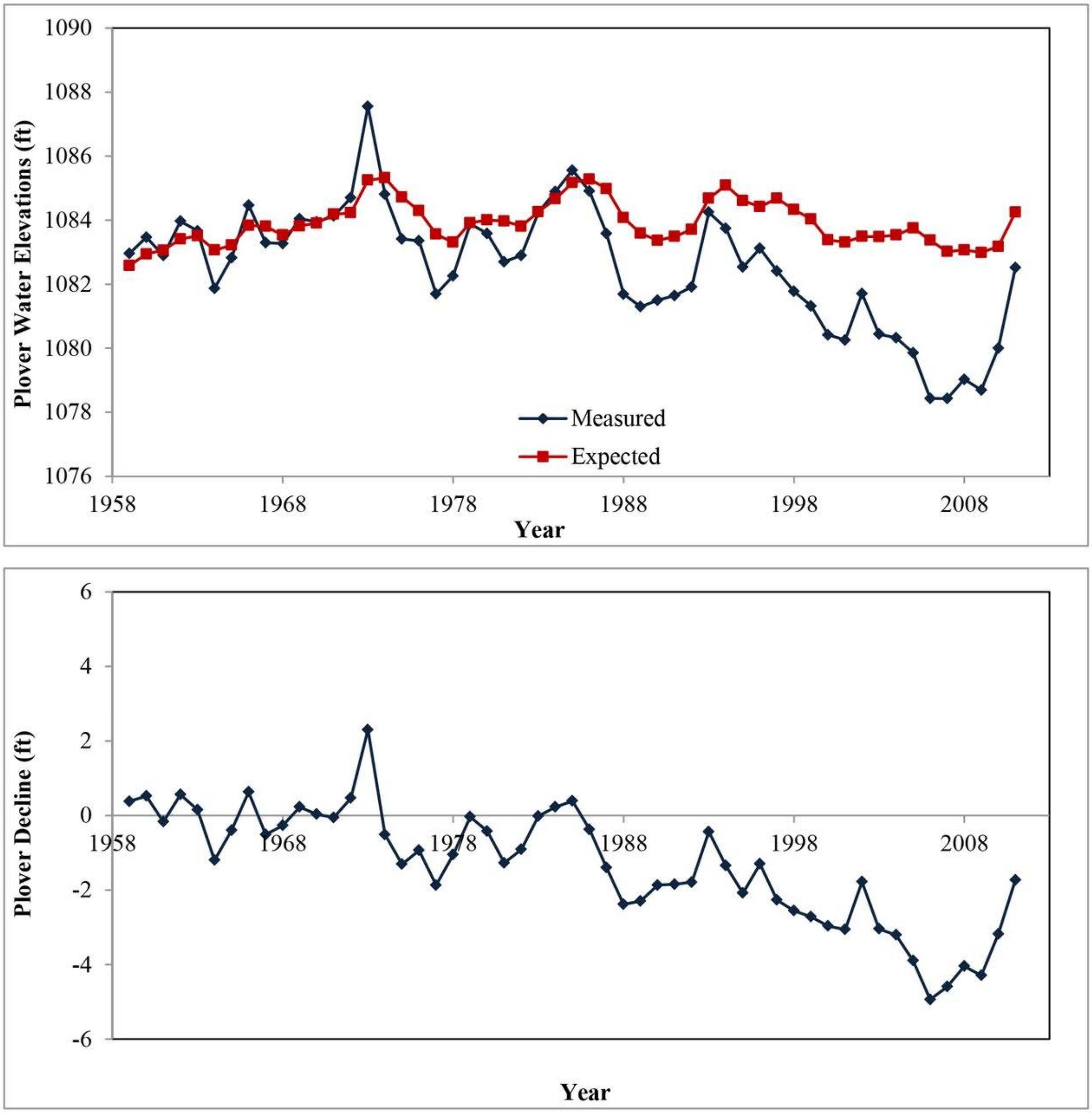


Figure 4-3. Top: Measured and expected average annual groundwater elevations at Plover. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels.

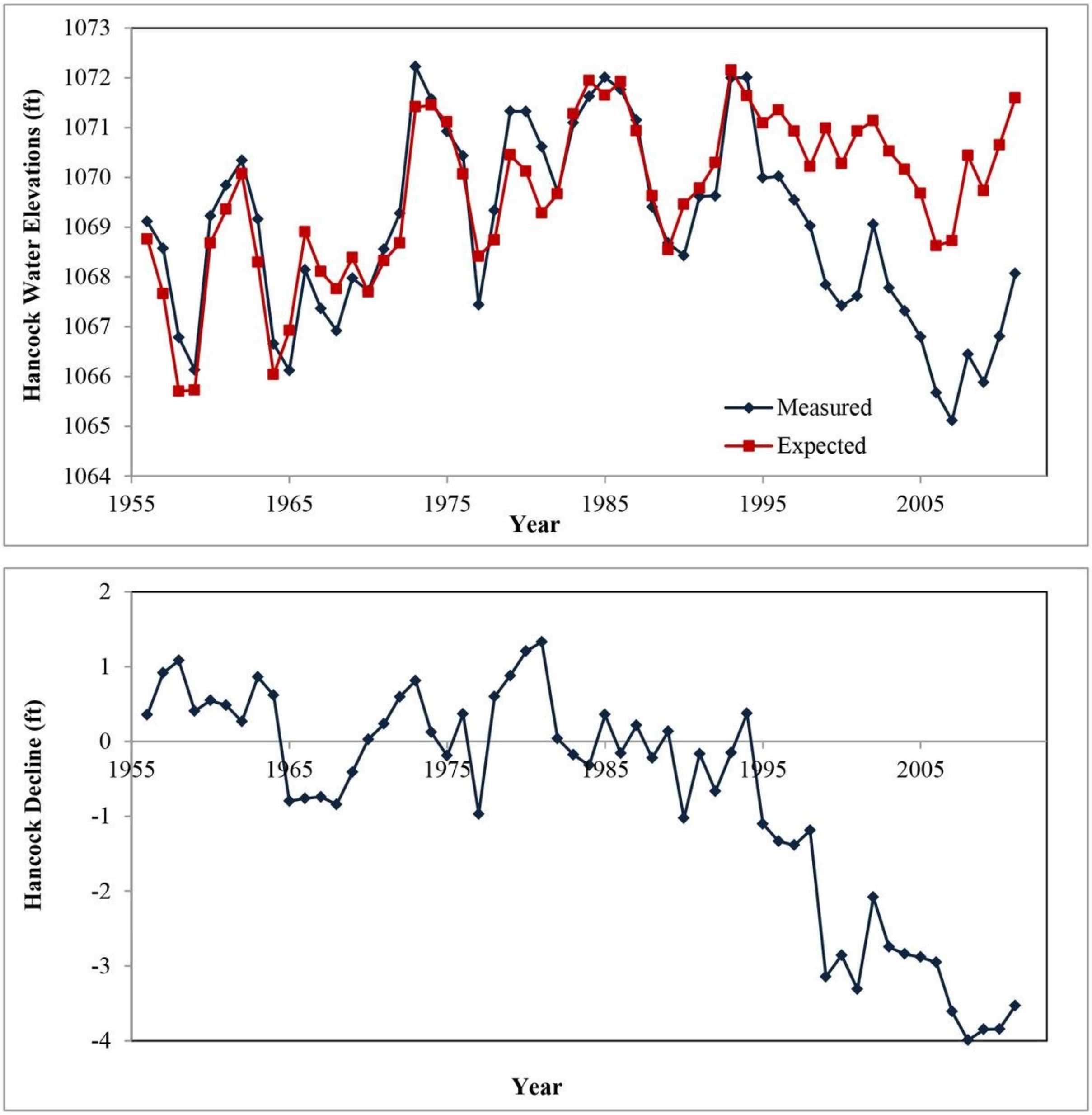
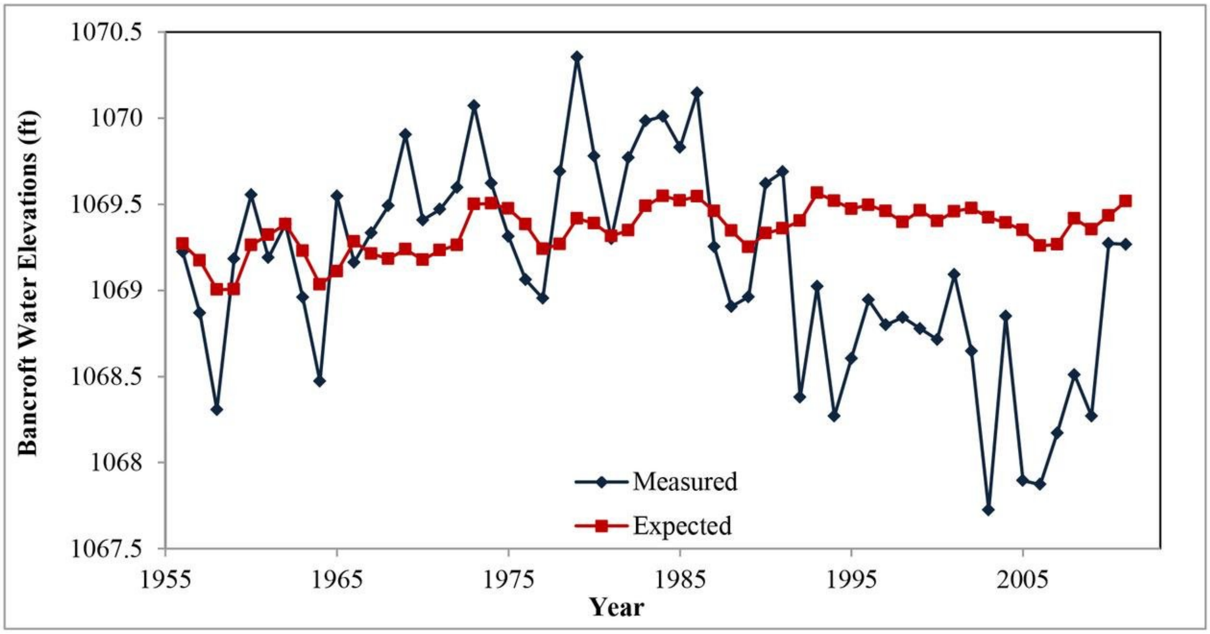


Figure 4-4. Top: Measured and expected average annual groundwater elevations at Hancock. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels.



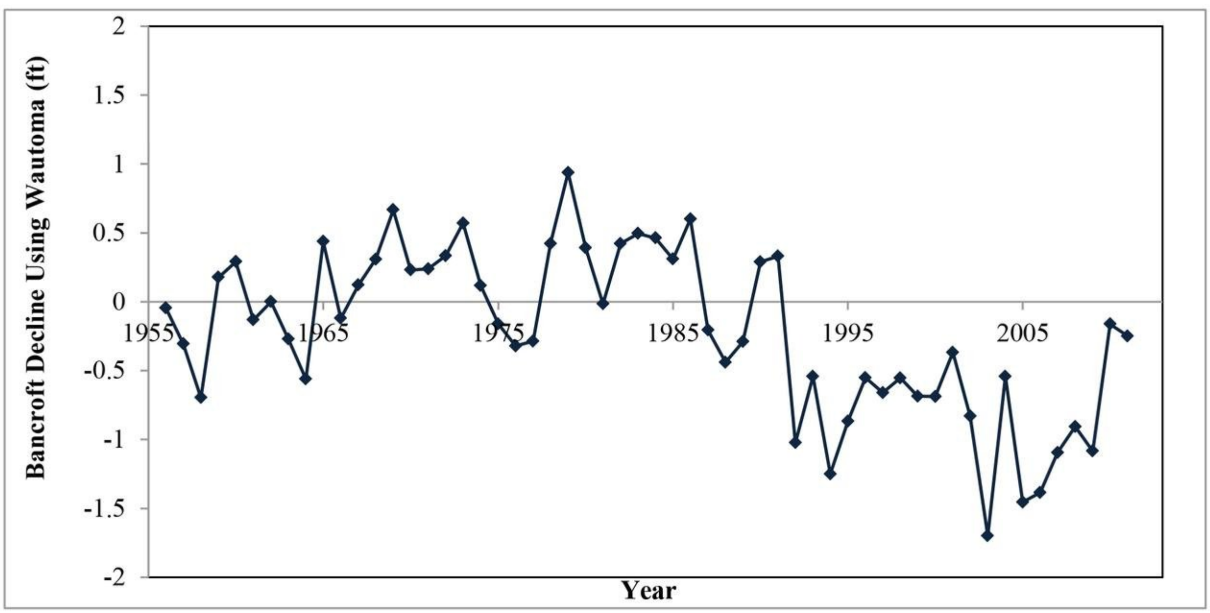


Figure 4-5. Top: Measured and expected average annual groundwater elevations at Bancroft. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels. Wautoma reference shown, Amherst Junction is similar.

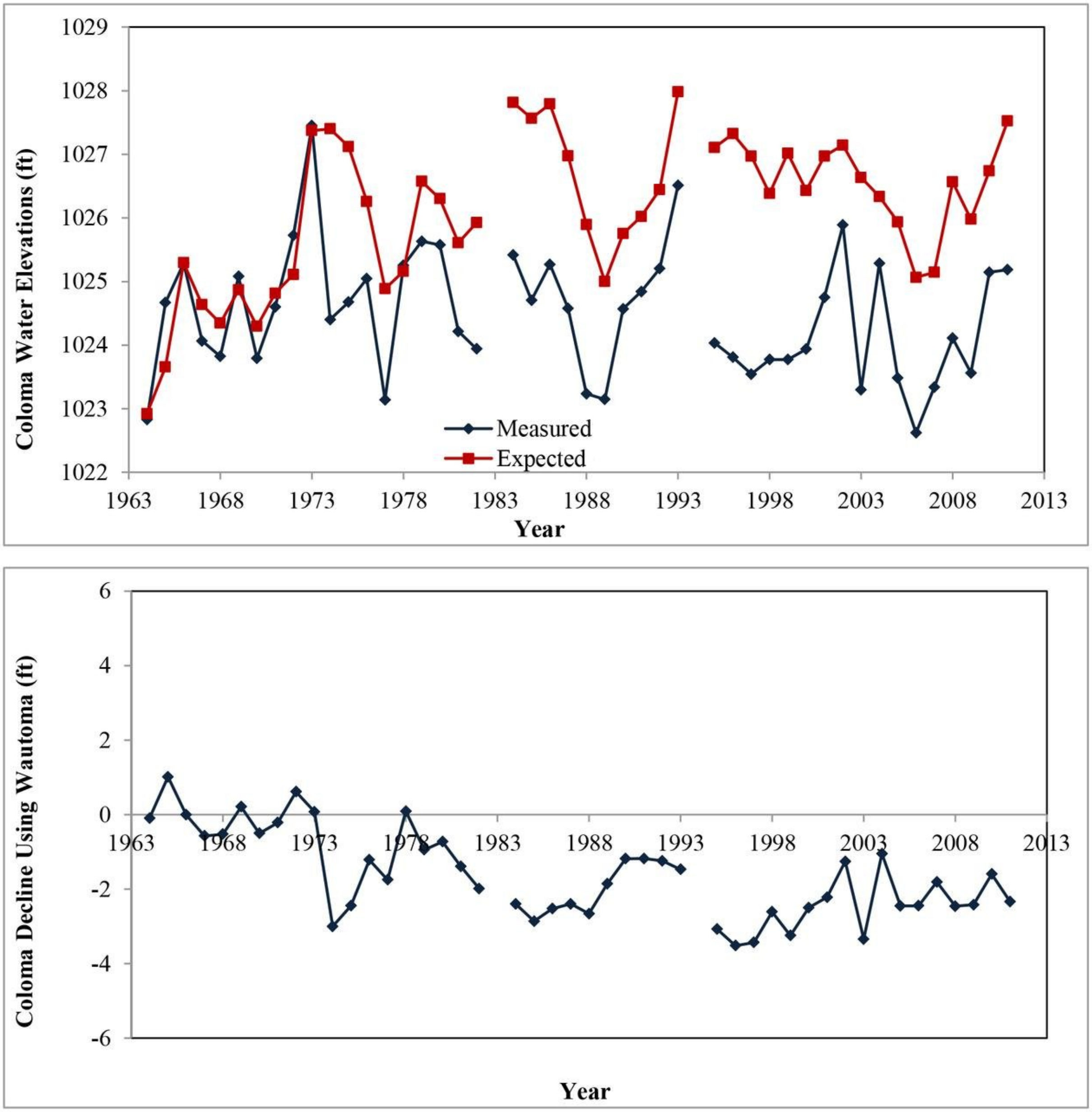


Figure 4-6. Top: Measured and expected average annual groundwater elevations at Coloma NW. Bottom: Estimated pumping induced water level declines calculated as the difference between measured and expected water levels. Wautoma reference gauge shown, Amherst Junction does not exhibit a significant decline.

5. LAKE LEVEL RECORD AND TRENDS - UPDATE

Summary

Levels for previously inventoried lakes were downloaded and added to the project's database. Lake levels mostly increased in 2011 from 2007 lows, by an average 2.6 feet, presumably due to the large rains of 2010-2011. The levels of four lakes previously found to have large and significant apparent pumping declines were revisited. Maximum pumping declines in these reached 3.3 to 8 feet in 2007-2010, depending on lake.

Lake Level Database

Kraft et al. 2010 previously identified 39 lakes with potentially useful level records (Figure 5-1). The data inventory for these lakes (Table 5-1) and data base ("Lake Level Data Updated to 2011.xlsx", appended as electronic media) of lake levels (Kraft et al. 2010) have been updated.

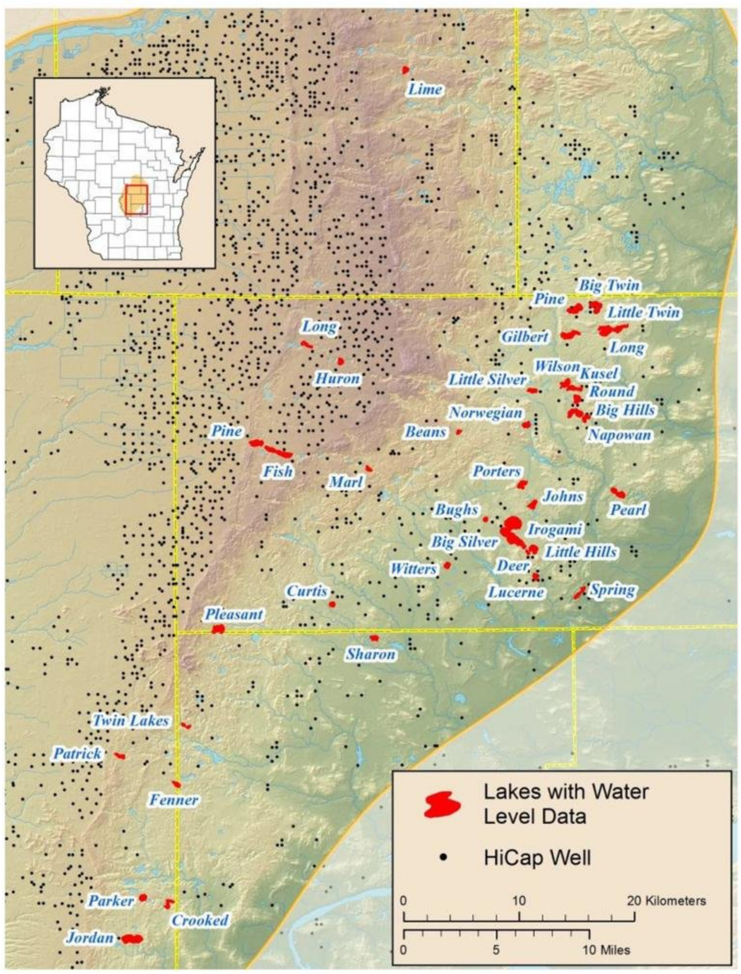


Figure 5-1. Location of Lakes with water level data in the project database.

Table 5-1. 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	15	7/10/73	8/10/11	2.54
Big Hills Lake (Hills)	Waushara	14	9/7/95	8/10/11	1.14
Big Silver Lake	Waushara	27	5/14/66	7/25/11	1.68
Big Twin Lake	Waushara	17	6/18/75	8/3/11	2.13
Burghs Lake	Waushara	22	9/7/73	7/25/11	1.72
Crooked Lake	Adams	12	6/14/73	6/20/89	1.34
Curtis Lake	Waushara	14	9/12/95	7/26/11	1.13
Deer Lake	Waushara	15	7/28/93	7/25/11	1.20
Fenner Lake	Adams	8	4/25/74	6/13/85	1.39
Fish Lake	Waushara	15	7/10/73	8/4/11	2.54
Gilbert Lake	Waushara	32	5/10/62	8/3/11	1.54
Huron Lake	Waushara	17	7/3/73	8/4/11	2.24
Irogami Lake	Waushara	28	1/1/31	7/25/11	2.88
John's Lake	Waushara	15	7/28/93	8/11/11	1.20
Jordan	Adams	20	9/8/67	9/6/90	1.15
Kusel Lake	Waushara	30	9/30/63	8/10/11	1.60
Lake Lucerne	Waushara	26	9/30/63	7/26/11	1.84
Lake Napowan	Waushara	18	5/21/85	8/10/11	1.46
Lime	Portage	6	10/2/40	11/7/94	9.02
Little Hills Lake	Waushara	11	8/3/01	7/25/11	0.91
Little Silver Lake	Waushara	15	7/20/93	8/10/11	1.20
Little Twin	Waushara	16	5/21/85	8/03/11	1.64
Long Lake	Waushara	27	8/16/61	8/4/11	1.85
Long Lake Saxeville[1]	Waushara	18	11/3/87	8/3/11	1.32
Long Lake Saxeville[2]	Waushara	84	6/1/47	7/1/09	0.74
Marl Lake	Waushara	14	4/1/98	8/4/11	0.95
Norwegian	Waushara	16	6/23/75	8/10/11	2.26
Parker	Adams	13	5/26/83	9/6/90	0.56
Patrick	Adams	9	5/6/77	6/16/86	1.01
Pearl	Waushara	15	6/17/75	8/5/11	2.41
Pine Lake Hancock	Waushara	19	7/10/73	8/4/11	2.00
Pine L (Springwater)	Waushara	31	2/8/61	8/3/11	1.63
Pleasant Lake	Waushara	25	7/9/64	7/28/11	1.88
Porter's Lake	Waushara	10	7/26/02	8/11/11	0.90
Round Lake	Waushara	13	4/1/98	8/10/11	1.03
Sharon	Marquette	72	11/17/84	5/31/94	0.13
Spring Lake	Waushara	22	10/1/63	7/26/11	2.17
Twin Lakes Westfield	Marquette	11	6/6/02	8/23/04	0.20
Wilson Lake	Waushara	17	6/18/75	8/10/11	2.13
Witter's Lake	Waushara	24	10/6/63	7/26/11	1.99

[1] Record provided by Waushara County and WDNR

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

For the 30 lakes with recent level information, levels increased from 2007 (the year many lakes were at a recent minimum) through 2011, by an average 2.6 feet. Some lake levels increased over four feet. A few others, usually "headwater" lakes (having an outlet but no inlet), increased only a few tenths of a foot. We attribute the increases mainly to the large precipitation amounts of 2010-2011.

Long Lake Saxeville Levels

Few area lakes have detailed long-term water level records. An exception is Long-Lake Saxeville (not to be confused with Long Lake – Oasis near Plainfield, which dried in 2006), which has multiple observations in the 1940s and 1950s, and even a single observation in 1927. The record has three source types: 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 5-2). The first two data types were reconciled by P. Juckem of the USGS (pers. comm.) and stages inferenced from citizen beach width measurements were derived by regression (Kraft et al. 2010):

Long Lake elevation (ft MSL) = -0.081 (Beach width) + 875.63 ft

At least some of these data will be archived by USGS at this location: http://waterdata.usgs.gov/wi/nwis/dv/?site_no=441257089071500&agency_cd=USGS&referred_module=sw 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

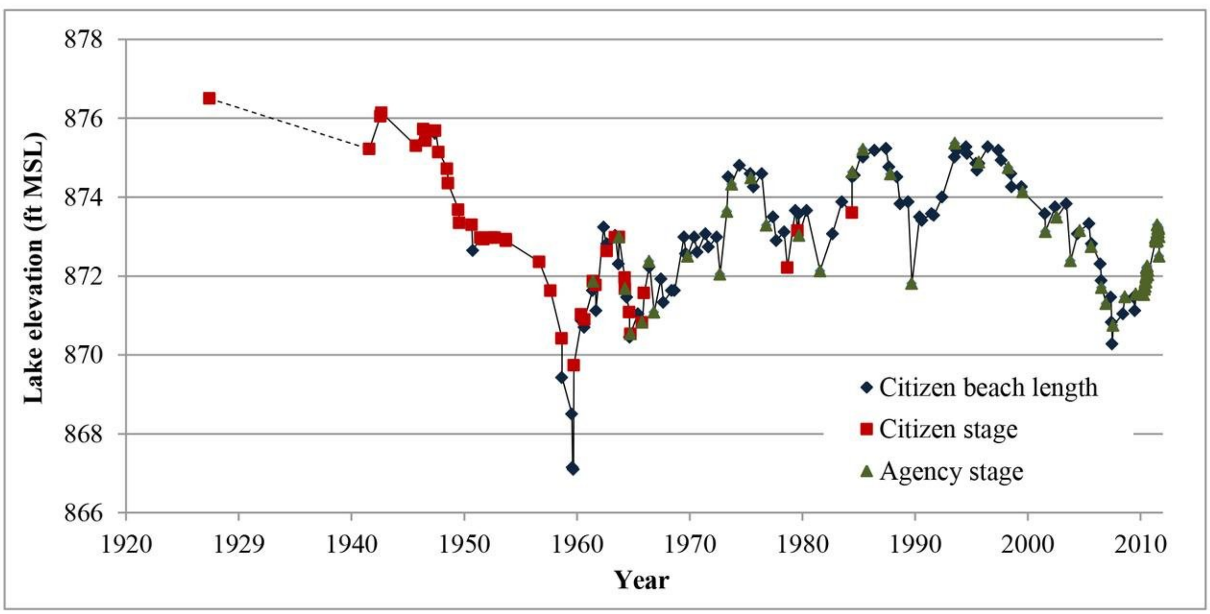


Figure 5-2. Hydrograph of Long Lake - Saxeville 1950-2011 (not to be confused with Long Lake - Oasis, which dried in 2006).

through 1959. In common with monitoring wells in areas with few high capacity wells (Figure 4-2), 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 to levels typical of post 1970 conditions.

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 4), 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 would be 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.

Here we revisit water level declines on the four lakes through 2011, with a view toward year-by-year declines rather than longer term averages (Figure 5-3). Pumping declines were at their greatest in 2007-2010. Maximum estimated pumping declines ranged 3.3 feet (Pleasant Lake in 2007) to 8 feet (Huron Lake in 2010).

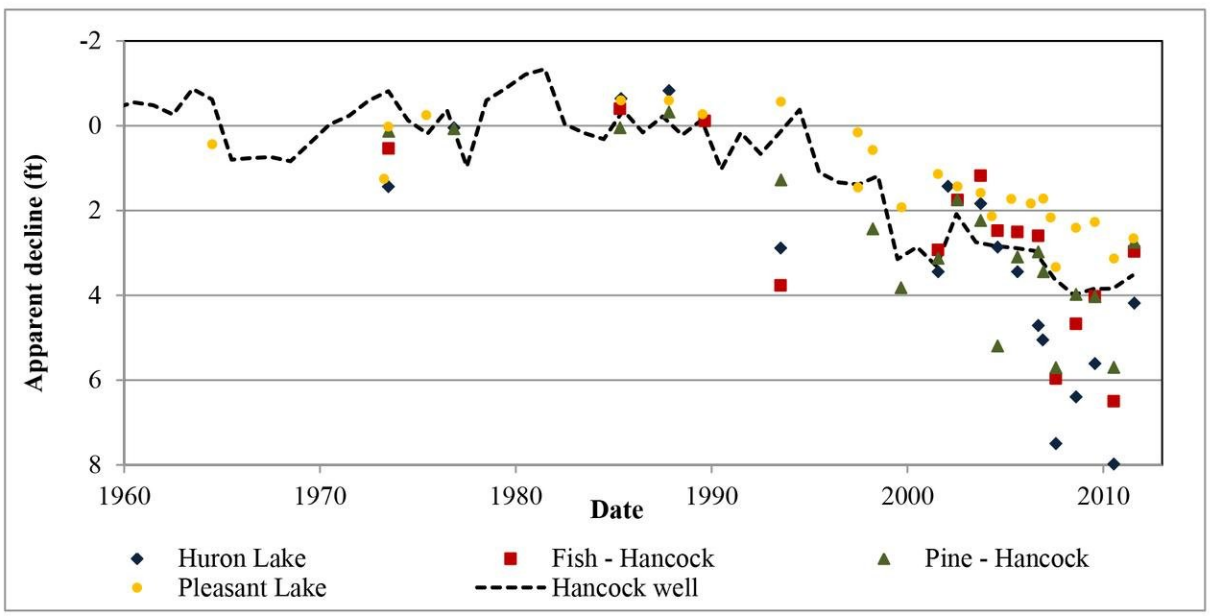


Figure 5-3. Declines in water levels at four lakes and Hancock well.

6. LITTLE PLOVER RIVER - UPDATE

Summary

Little Plover discharges during 2005-2011 were mainly less than the one-day low of the entire historic period, and the stream experienced dry-ups in stretches during 2005-2009. The extreme wet period that began in mid 2010 increased discharges above the historic one-day low and even the historic average for much of 2010 and 2011.

Groundwater pumping diversions (using 2005-2007 as a reference period) were an estimated 4.5 cfs. Implemented and planned diversion reduction strategies, and the unplanned closure of the New Page paper mill, may in a decade or two reduce diversions by 25%, assuming no increases in Plover pumping or repurposing of New Page pumpage. However, these may only reduce the percentage of unhealthy flow days eventually from 77% of the time to 66%, or under a best case scenario from 57% to 35%. (Without a pumping influence, the stream would experience unhealthy flows only 6.1% of the time.)

Introduction

The Little Plover River is among the more prominent of pumping-affected central sands streams and one of the few with some continuous discharge record. Formerly renown as a productive trout stream (Hunt 1988) that flowed robustly even during the most severe droughts (Clancy et al. 2009), the Little Plover in 2005-2009 dried in stretches when precipitation conditions were average to only modestly dry. Here we briefly update the more detailed work of Clancy et al. (2009) and Kraft et al. (2012).

Recap of Historic Discharges, 1959-1987

The historical record for Little Plover discharges (Table 6-1, Figure 6-1) 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 "Kennedy Ave."). Discharges were occasionally measured at other stations (Clancy et al. 2009). Little Plover baseflows at Hoover and Kennedy (respectively) averaged 9.9 and 3.6 cfs. Baseflow minima were 3.9 and 0.88 cfs, measured at a time when the Little Plover was already pumping affected.

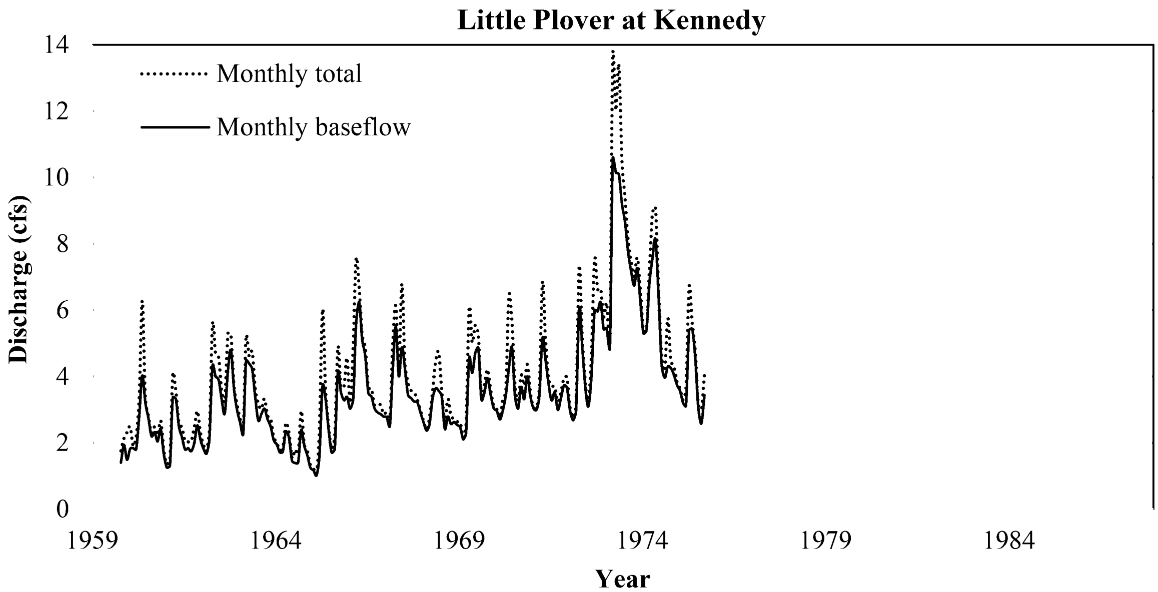
Baseflow Discharges 2005-2011

Baseflow discharges have been measured routinely at four locations since 2005 (data are included as electronic supplements to this report), and are presented for three locations in Figure 6-2. Little Plover discharges during 2005-2011 were mainly less than the one-day low of the entire historic period, and the stream experienced dry-ups in stretches during 2005-2009. These dry-ups were sometimes averted or shortened through flow augmentation (water being pumped from nearby irrigation wells). In mid 2010, streamflows increased above the historic one-day low and even the historic average for much of 2010 and

2011. We attribute this to the extreme wet period that began in mid 2010 and continued through 2011. Wet conditions depress the need for irrigation pumping and increase groundwater recharge rates.

Table 6-1. Total and baseflow daily discharge statistics for the Little Plover at Kennedy and Hoover during continuous discharge measurement periods.

Statistic	Kennedy (1959-1976)		Hoover (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 less than Public Rights Discharge	10%		11%	



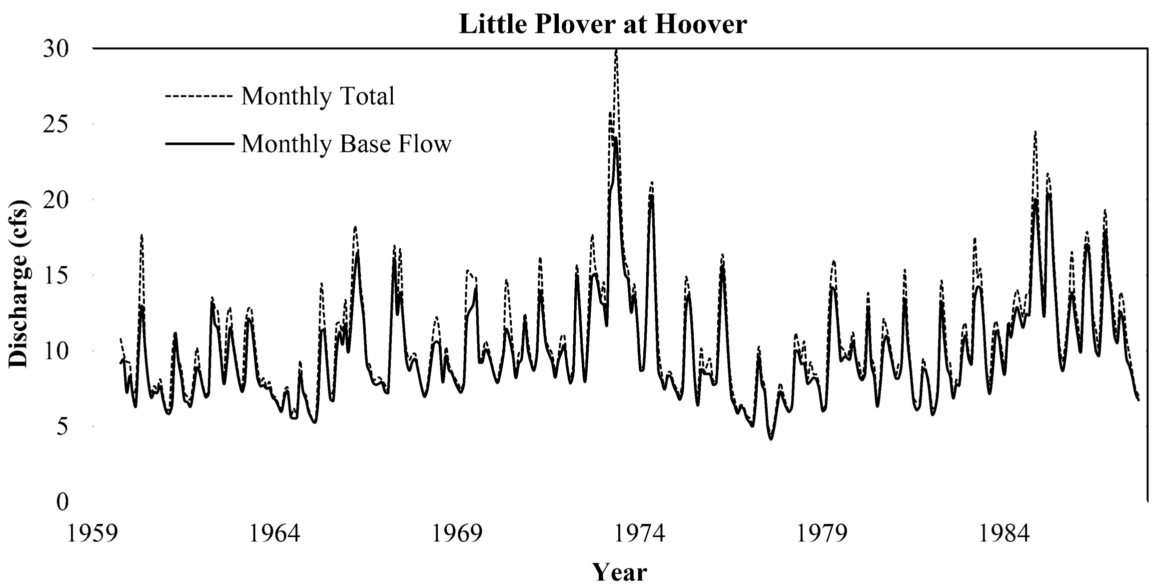


Figure 6-1. Little Plover baseflow and total discharges measured at Hoover Rd. and Kennedy Ave. by USGS, 1959-1987 (monthly averages).

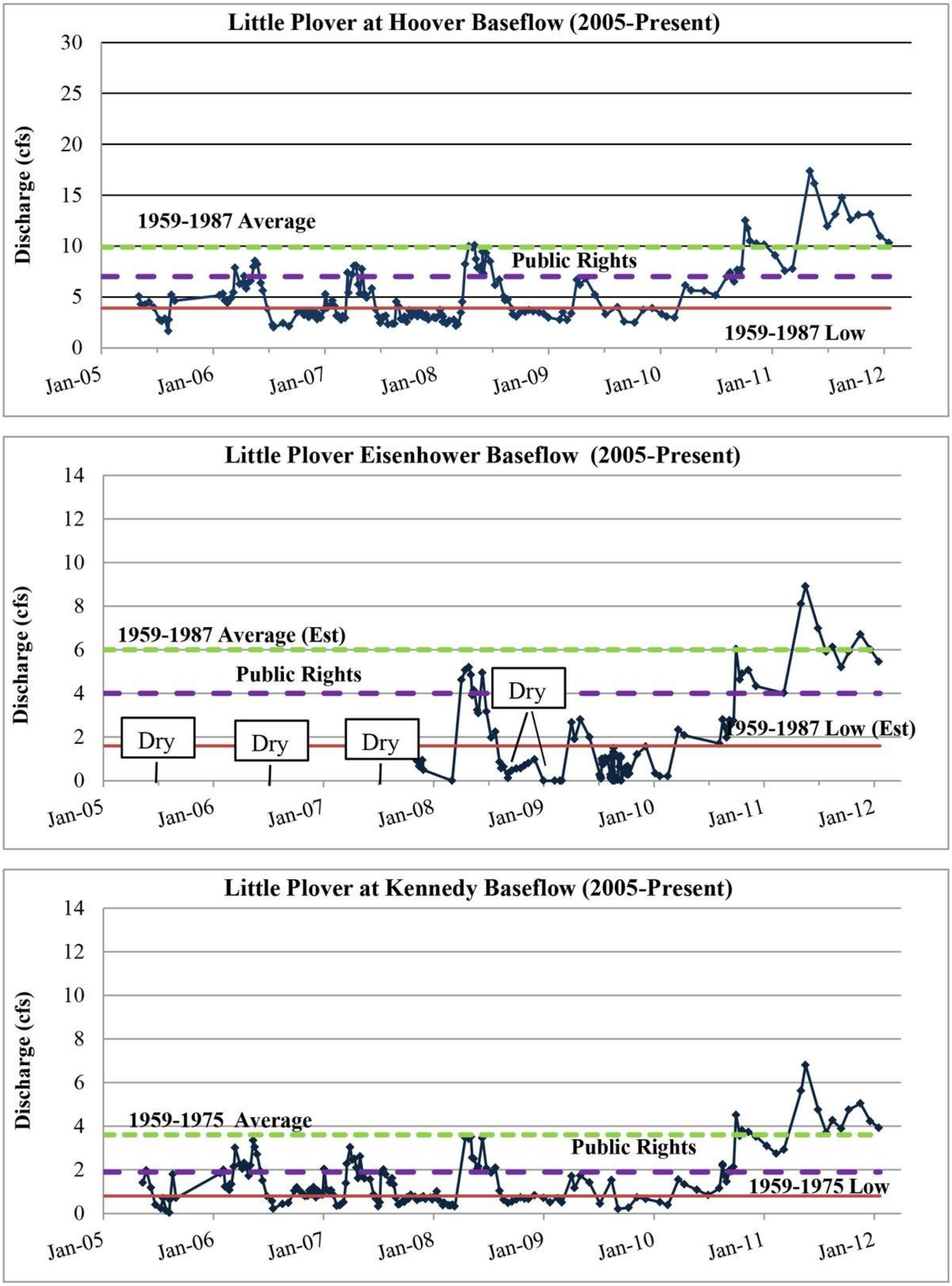


Figure 6-2. Baseflow and total discharges for the Little Plover River at Hoover, Eisenhower and Kennedy, 2005-2011.

Pumping in the Little Plover River vicinity

The major portion of groundwater pumping in the Little Plover vicinity occurs in four sectors (Clancy et al. 2009): Village of Plover (municipal), Del Monte (industrial), Whiting (municipal and industrial), and agricultural (irrigation). Other pumping, such as rural residential use or urban lawn watering from shallow wells, has been dismissed as insignificant because these uses are 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.

Village of Plover pumping has averaged about 1.3 Mgd (2.0 cfs), an amount that may grow as the Village expands. Pumpage is from three wells, numbers 1 and 2 located near the headwaters of the Little Plover, and number 3 located about two miles away. Wells 1 and 2 divert about 75% of their pumpage from the Little Plover, and well 3 about 30% (Clancy et al. 2009). For much of 2005 through 2007, Plover obtained about 65% of its water from wells 1 and 2. The Village has since shifted pumpage toward well 3 in an effort to reduce Little Plover diversions. Reportedly, 80% of Plover pumpage has been coming from well 3 since 2010.

Del Monte has revised previous estimates of its pumping to an annual average 203 million gallons pumped June through December. Three-fourths of pumped water is reportedly discharged to nearby spray fields that recharge groundwater, which reduce Del Monte's pumping impacts on the Little Plover. In 2010, Del Monte moved some of its wastewater discharge closer to the Little Plover, further reducing its pumping impacts.

Whiting municipal / industrial pumping from the large wellfield there supplied the Village of Whiting and two paper mills, Neenah Papers (formerly Kimberly Clark) and New Page (formerly Consolidated) with pumpage that averaged 4.1 Mgd (6.38 cfs). The closure of New Page has, for now, reduced this pumpage to 0.78 Mgd (1.2 cfs). The future of this pumpage reduction is uncertain as Whiting may repurpose this pumping capacity for other uses.

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. Irrigation amounts in the vicinity of the Little Plover averaged 12.5 in during 2007, and 10.9-12.4 in during 2008. These are likely larger than average. Irrigation amounts have also been estimated for 2008-2010 for the broader central sands region: 9.5 in in 2008, 7.6 in in 2009, and 4.2 in in 2010 (Chapter 7).

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 direct calculation using groundwater flow modeling (Kraft et al. 2012). Figure 6-3 displays these diversions as well as important pumping events, such as the start of pumping for each sector and the temporary stop in Whiting municipal pumping. The annual diversion oscillation is due to the annual pumping cycle of the Del Monte facility.

Through 1984, municipal and industrial pumping and diversions were small, but then ramped up rapidly due to new pumpage being added for New Page / Consolidated, Plover, and Kimberly Clark / Neenah Papers. Municipal and industrial diversions peaked in 1997 at about 2.2 cfs and averaged 1.8 cfs in 2005-2009 when the Little Plover began drying. Using years 2005-2007 as a baseline, estimated diversions by municipal and industrial pumping were Plover - 0.97 cfs, Whiting - 0.67 cfs, and Del Monte - 0.12 cfs.

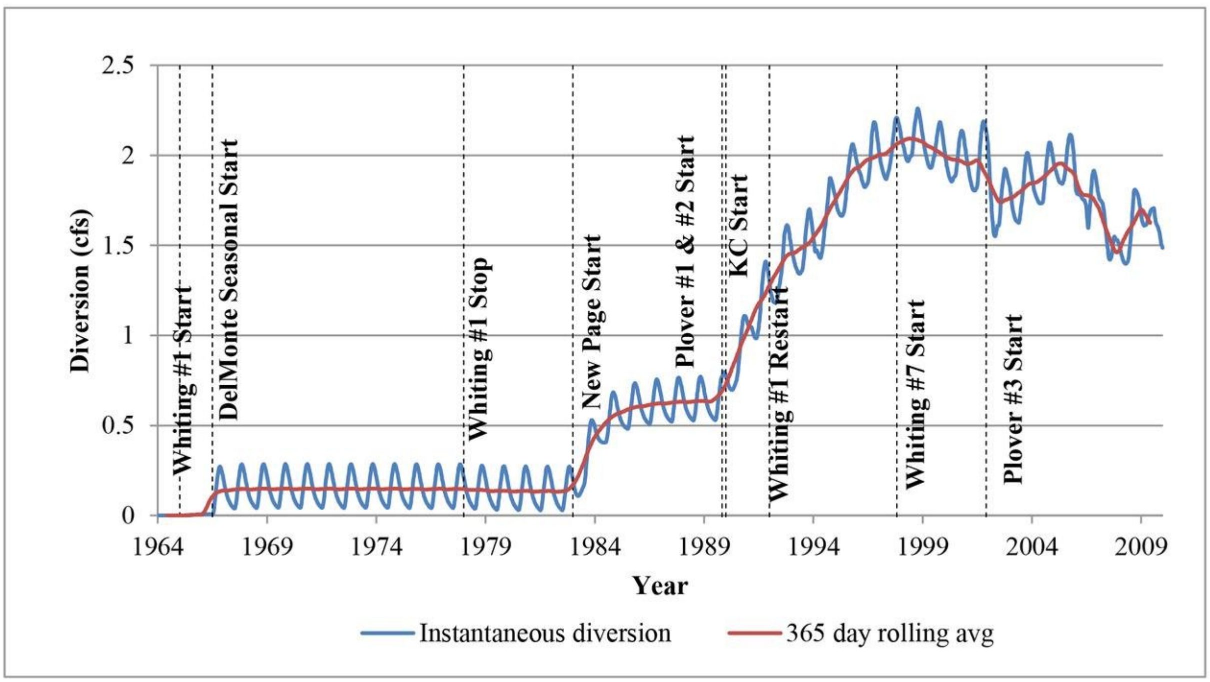


Figure 6-3. Municipal and industrial groundwater pumping diversions from the Little Plover River.

Baseflow Diversions - Total and Irrigation

Total baseflow diversions were estimated statistically by subtracting measured baseflows from baseflows expected in the absence of pumping diversions (Figure 6-4, top). Details are presented in Kraft et al. (2012) and summarized here. Briefly, expected baseflows were generated using reference location baseflows and the regression relationships of Little Plover to reference location baseflows before 1977 when diversions were small. Annual diversion amounts were calculated for the pre-1987 continuous record, and instantaneous amounts were calculated for the post-1987 occasional record. Irrigation diversions were calculated as the difference between total and municipal/industrial diversions.

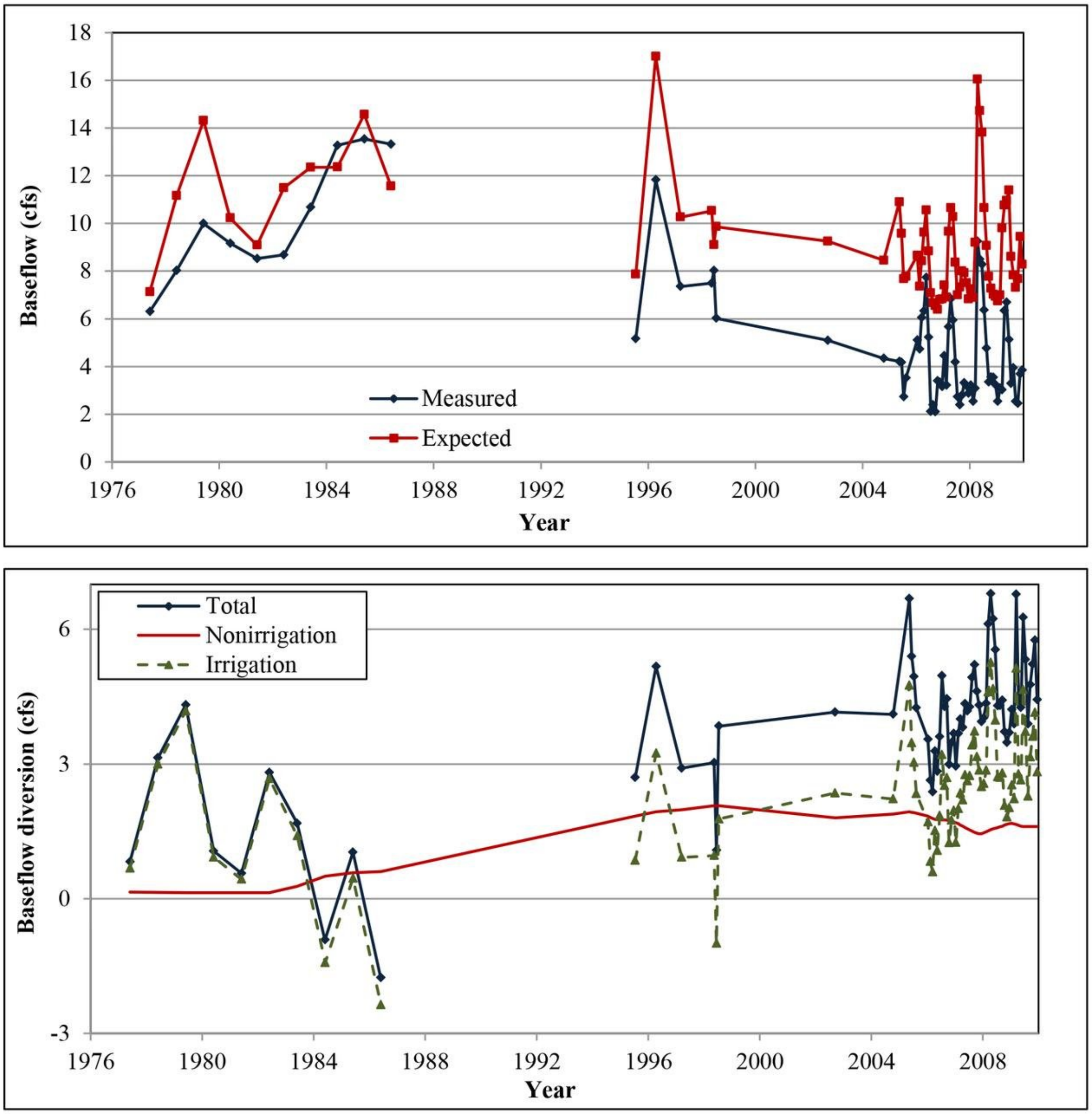


Figure 6-4. Top: Measured and expected baseflow for the Little Plover River. Bottom: Little Plover River baseflow diversions from irrigation and nonirrigation.

The Little Plover began demonstrating pumping diversions by 1977. Average annual total baseflow diversions for 1977-1986 were 0.99 cfs with substantial differences between 1977-1983 and 1984-1986 (Figure 6-4, bottom). An abrupt leveling of diversions is apparent in 1984, coinciding with an extraordinarily wet year (second wettest in 80 years) that provided 13 in (41%) greater than average precipitation. Years 1985 and 1986 were also above average, by 5 and 11%. Precipitation excesses in the basins of reference gauges were not as large. We hypothesize that the apparent leveling was produced by (1) anomalously large precipitation and recharge in the Little Plover vicinity in 1984, (2) smaller precipitation and recharge amounts in reference basins the same year, and (3) a depressed need for irrigation in 1984 and possibly 1985 and 1986. Presumably, had continuous flow monitoring persisted after 1986, the 1977-1983 trend would have resumed along a similar slope.

Total baseflow diversions for 1995-2009 (Figure 6-4, bottom) ranged 1.1 to 6.7 cfs, displaying a "peakiness" that is likely part real and due to, for example, transient cycles of aquifer depletion during irrigation seasons and recharge in the springs and falls, but also likely part due to the inability of regression relationships to account for short-term variability between the Little Plover vicinity and reference watersheds. For this reason a better picture of baseflow diversions is probably painted by averaging individual estimates over months to years.

Irrigation diversions (Figure 6-4 bottom, Table 6-2) amounted to almost all of the average 0.99 cfs diversions during the continuous monitoring years of 1977 to 1986, and generally increased to 2.77 cfs in 2005-2009. Groundwater flow modeling indicates that this amount of diversion is consistent with 5.6 in of consumed irrigation or "net recharge reduction" relative to the pre-irrigation landscape (Kraft et al. 2012). The 2005-2009 irrigation diversions amounts were about a third of the expected baseflow at the Plover gauge, and 63% of the total baseflow diversion.

Table 6-2. Estimated irrigation baseflow diversions from the Little Plover for various periods. Years 1977-1986 are averages of annual estimates, all others are average of monthly estimates.

Period	n	Average (cfs)	Stan Dev	% of Expected
1977-1983	7	1.9	1.4	16
1984-1986	3	-1.1	1.4	-9.6
1977-1986	10	0.99	1.9	8.5
1995-1998	6	1.1	1.4	18
2002-2004	2	2.3	0.92	26
2005-2009	55	2.8	1.1	32

Improvements and Potential Diversion Reductions

Several actualized and possible improvements in the vicinity of the Little Plover potentially reduce Little Plover baseflow diversions. Here we explore the amount of water that may be "undiverted" by such improvements and in the following section, estimate how these changes might contribute to the goal of restoring the stream to a "healthy flow." "Healthy flow" was evaluated by DNR staff as the flow and coincident stage that fish habitat dries. Healthy flow was codified as "Public Rights Stages" (PRS) at four locations (Table 6-1 presents two).

For present purposes, we consider only the effects of improvements at the Hoover gauge. We chose to evaluate improvements against 2005-2007 diversions, which averaged 4.5 cfs; 2.77 cfs from irrigation and 1.76 cfs from municipal and industrial pumping (previous section). We also consider diversion reductions under an optimistically low irrigation diversion scenario at the end of this section.

The following improvements were considered and the resulting potential baseflow diversion reductions were evaluated using groundwater flow modeling (Figure 6-5):

2009 - Plover moving 80% of pumpage to well #3. This improvement, made in 2010, undiverts 0.29 cfs (6.4% of the 4.5 cfs total diversion), assuming total Village pumpage does not increase.

2010 - Del Monte changes in wastewater management. Del Monte has moved significant amounts of wastewater discharge north of its plant and nearer the Little Plover. This change reduces Del Monte's 0.12 cfs diversion by 0.04 cfs (0.9% of the 4.5 cfs diversion).

2011 - New Page closure. The unfortunate closure of New Page, which pumped water from the Whiting wellfield, caused the greatest reduction of Little Plover diversions, 0.51 cfs (11% of 4.5 cfs total diversion). Whether the pumping capacity will remain unused is presently unknown, as the capacity may be repurposed for paper production or other uses.

2013(?) Plover / Portage County Land Acquisition and Irrigated Land Retirement. This acquisition of 140 acres just south of the Little Plover between Kennedy and Eisenhower Avenues will result in the retirement of 100 acres of irrigated land. At 5.6 in of consumed irrigation or "net recharge reduction," this improvement might reduce the diversions by 0.08 cfs (1.8% of the 4.5 cfs diversion).

2020-2030 (?) Expansion of the Plover Urban Area. The Village of Plover has suggested repurposing 620 acres of irrigated land (1137 acres total acres) for residential, commercial, and industrial use in the Little Plover vicinity. This includes the 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.

The total potential improvement under the 4.5 cfs total diversion scenario, given previous assumptions, amounted to 0.84 cfs by the end of 2011, or 18.7% of the total diversion (Figure 6-5). If the planned irrigated land retirement occurs in 2013, a potential exists to decrease the diversion an additional 1.8%, and the urban expansion in a decade or two may decrease it by another 4.9% for a total diversion reduction of 25%.

We consider now an optimistically low irrigation diversion scenario, predicated by an assumption that irrigation net recharge reductions are only 2 in (instead of 5.6 in), which leads to an estimate of irrigation diversion of only 1.1 cfs and total diversion of 2.8 cfs (adding 1.1 cfs irrigation diversion plus 1.7 cfs municipal and industrial diversion) (Figure 6-6). In this scenario the total diversion reduction of

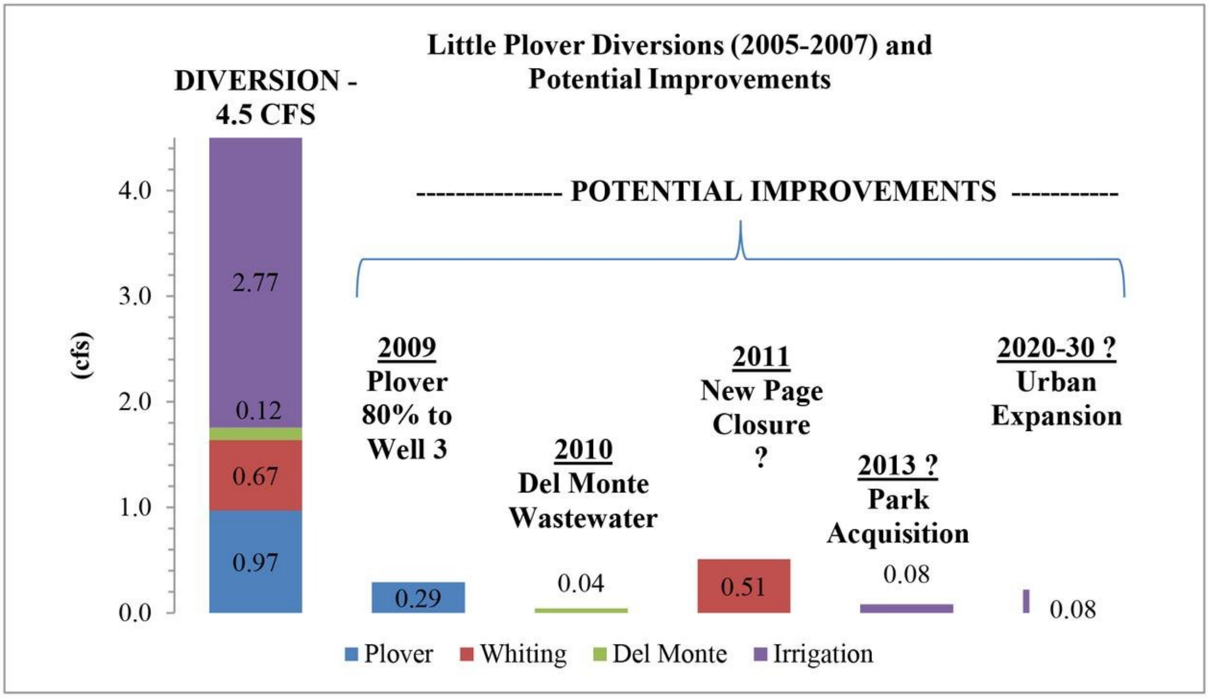


Figure 6-5. Potential improvement to Little Plover River baseflow under a diversion scenario of 4.5 cfs.

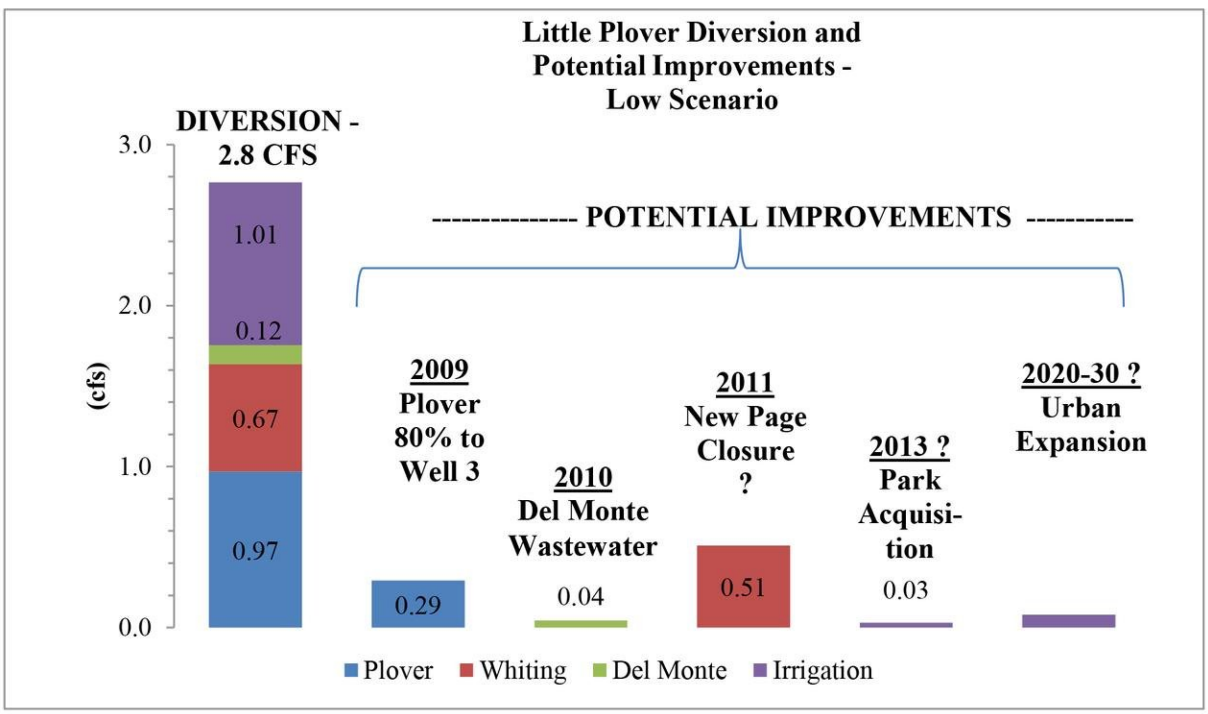


Figure 6-6. Potential improvement to Little Plover River baseflow under a diversion scenario of 2.8 cfs which is consistent with an assumed low 2 inch net recharge reduction on irrigated lands.

0.84 cfs due to Plover, Del Monte, and New Page improvements made by 2011 would be 30%. If the planned improvements of 2013 occur, diversions may decrease by 1.1%, and the urban expansion in a decade or two may decrease it by another 2.9% for a total diversion reduction of 34%.

Progress toward the "Healthy Flow" Goal

As a metric for evaluating progress toward a healthy flow goal, we used the estimated frequency of days that the Little Plover would experience "unhealthy" discharges with improvements compared to without improvements. For this evaluation, we first constructed a "no-pumping" Little Plover baseflow hydrograph for 1960 through 2009 conditions. For years 1960 to 1976, actual Little Plover baseflows were used as the stream was not yet substantially impacted by pumping. The 1977 through 2009 portion of the hydrograph was constructed using regression relationships of the Little Plover to reference streams during 1960 through 1976 (Kraft et al. 2012). The nonpumping hydrograph reveals that unhealthy flows would occur only 6.1% of the time (Figure 6-7). Subtracting the estimated 4.5 cfs diversion from the expected hydrograph in the absence of pumping (Figure 6-7) reveals unhealthy flows would occur 77% of the time. If all the potential improvements discussed above come to pass, the number of unhealthy flow days is diminished from 77% of days to 66%.

Under the optimistically low diversion scenario, diverting only 2.8 cfs would result in unhealthy flows 57% of the time. All improvements, including those that will not accrue for 1-2 decades would decrease diversions by 34%, potentially reducing unhealthy flows to 35% of the time.

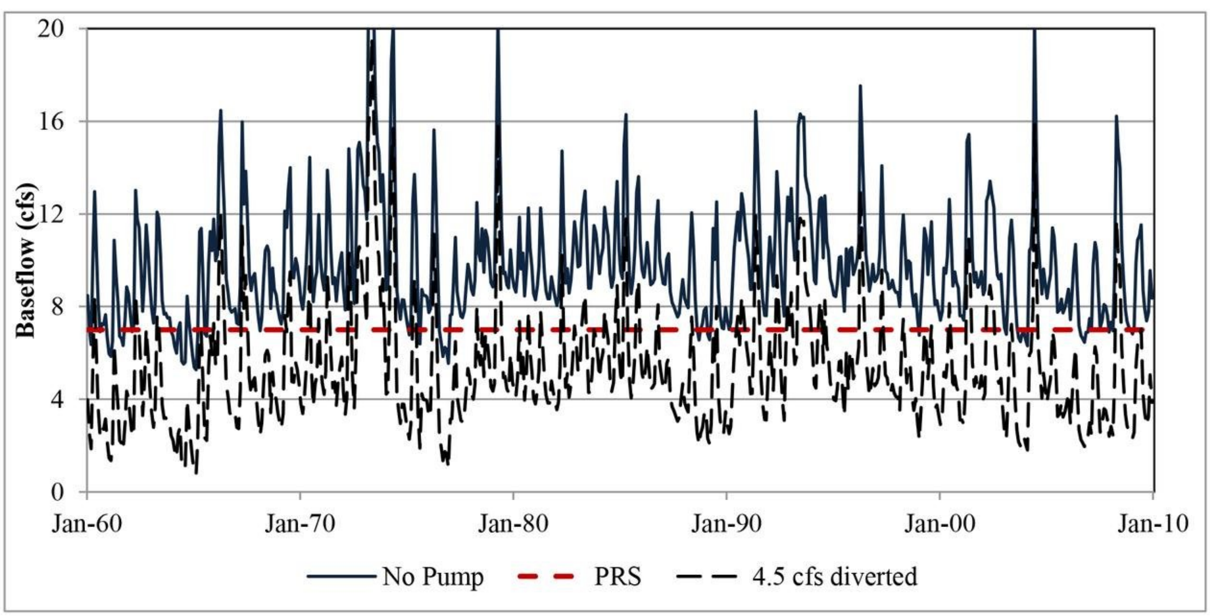


Figure 6-7. Constructed baseflow record for the Little Plover River, 1960-2010, under nonpumping conditions, and influence of a 4.5 cfs diversion on baseflows.

7. IRRIGATION RATES FOR THE CENTRAL SANDS, 2008-2010

Summary

Irrigation rates were estimated for the central sands counties of Portage, Waushara and Adams counties during 2008-2010. Median rates among irrigated acreages were 9.5 in in 2008, 7.6 in in 2009, and 4.2 in in 2010. Yellow field corn, potato, and sweet corn received the greatest amounts of irrigation with 2009 potato receiving the most (12.6 in).

Full details of irrigation rate analysis are presented in Appendix 3.

Methods

Irrigation amounts were estimated by matching 43 randomly selected irrigation wells to the fields they service, and then dividing the reported well pumping by the serviced field acreage, yielding a result in depth of water. Wells (Figure 7-1) were randomly selected from a narrowed group originally consisting of all WDNR approved high capacity wells in Portage, Waushara, and Adams counties. The narrowed group was chosen using the following criteria: 1) the well was active and used for irrigation, 2) screen diameter was 12 in or greater, 3) the approved pumping rate was greater than 1000 gallons per minute, and 4) pumping records existed for 2008-2010. Irrigated acreages were assigned to each irrigation well using aerial coverages, each acreage comprising one or more Farm Services Agency fields, and each field potentially comprising one or more crops. Crop data were gathered from Farm Services Agency (FSA) files or from a GIS grid file from the National Agricultural Statistics Services (NASS) called "CDL" (USDA, 2010). Results by crop and by year are reported as median values to help account for extreme values likely due to pumpage reporting or method error. When more than one crop existed in a particular acreage, a mixed crop was reported.

Results

Estimated irrigation rates across all fields and crops ranged 0.51 to 19.2 in during 2008-2010. Median rates were 9.5 in in 2008, 7.6 in in 2009 and 4.2 in in 2010. The 2010 irrigation rates were expectedly lower because of near record precipitation that year.

For crops or crop mixes that occurred on at least three fields in a given year, median irrigation (Tables 7-1) ranged 3.5 in for yellow field corn in 2010 to 12.6 in for potato in 2009, with potato/yellow field corn in 2008 being a very similar 12.2 in.

Potato, yellow field corn, and sweet corn were most consistently grown at the greatest number of acreages (Table 7-2). Over the three years, yellow field corn had the greatest irrigation amount (9.8 in) followed by potato (8.9 in) and then sweet corn (8.3 in).

Irrigation rates varied greatly among years (For 2008, 2009, and 2010, 9.5, 7.6, and 4.2 in). The 2010 irrigation rates were expectedly lower because of near record precipitation that year.

Rate estimation is confounded by potential errors in pumping reports and by assigning fields to individual irrigation wells. The latter sometimes involves subjectivity, and perhaps argues for using different methodology, for example, utilizing fields that clearly can be assigned to only one well. However, this precludes the use of random sample approaches.

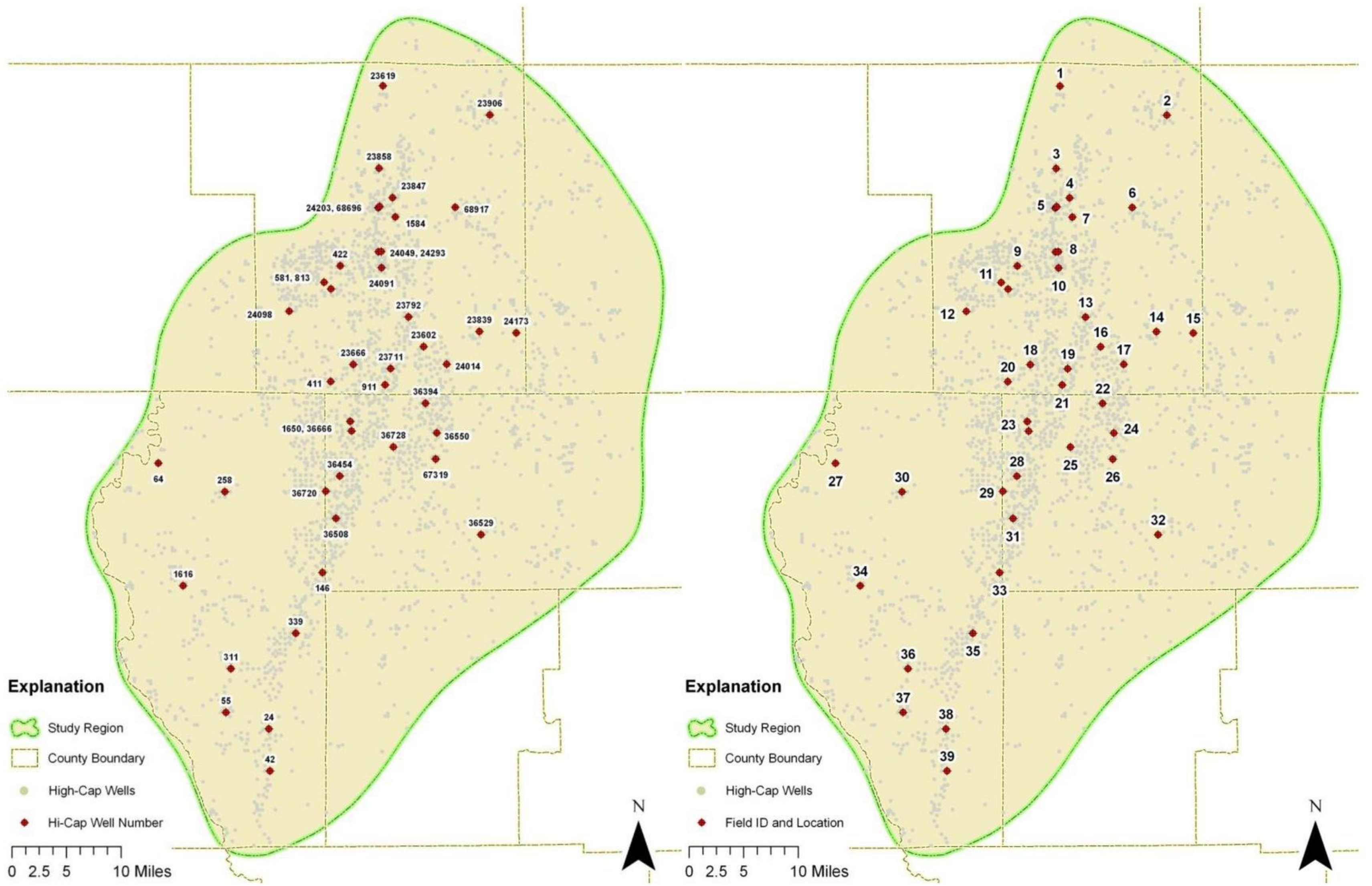


Figure 7-1. Hi-Cap well numbers (left) and field ID numbers (right) of locations used to estimate irrigation rates for 2008-2010.

Table 7-1. Yearly median irrigation rates for crops or mixed crops on three or more acreages.

Crop	Acreages 2008	Median (in) 2008	Acreages 2009	Median (in) 2009	Acreages 2010	Median (in) 2010
Potato	4	9.2	3	12.6	7	8.3
Potato/Y.Corn	3	12.2	3	7.0		
S. (Sweet) Corn	5	8.3	6	10.2	4	4.3
Y. (Yellow, Grain) Corn	12	11.3	7	10.0	5	3.5
Y.Corn/G.Beans			4	6.4		
Y.Corn/Soybean	3	9.9				
G. (Green) Bean	3	6.2	6	6.2		

Table 7-2. Irrigation rates for the three most common crops at multiple field locations.

Crop and Irrigation rate (in)		
	------2008------	
Potato	**Sweet Corn**	**Yellow Corn**
9.16	5.51	5.42
10.79	6.66	7.52
9.32	8.60	11.07
4.72	8.34	11.45
	8.86	12.33
		13.11
		12.49
		9.20
		9.92
		13.46
		12.52
		9.64
	------2009------	
Potato	**Sweet Corn**	**Yellow Corn**
12.59	11.36	5.98
8.50	9.25	7.59
16.17	11.11	12.60
	7.12	9.95
	5.92	13.78
	15.61	11.21
		1.87
	------2010------	
Potato	**Sweet Corn**	**Yellow Corn**
2.07	3.94	1.21
3.60	12.38	3.84
8.64	4.58	3.18
4.07	3.65	3.50
11.20		6.83
8.27		
9.55		
	------- Median ------	
Potato	**Sweet Corn**	**Yellow Corn**
8.90	8.34	9.78

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APPENDICIES

Appendix A

Documentation for Nelsonville Monitoring Well

Nelsonville Monitoring Well
Technical Memorandum CS 2010 - 1
Replacement of Monitoring Well; USGS Site Number 443127089174101

Jessica Haucke and George Kraft
Center for Watershed Science and Education
November 22, 2010

Date: 17-November-2010

Background: Here we describe construction of a replacement monitoring well for USGS monitoring well number 443127089174101, location PT-24/10E/28-0015. The USGS well has a record extending 1950-1998 and is particularly valuable since it is a long term record for a location likely unaffected by groundwater pumping. The rehabilitation or replacement of this well was proposed as a potential alternative to the Amherst Junction monitoring well (site no. 44281008919501) which may be becoming increasingly influenced by irrigation in the vicinity.

The new well was constructed with a top elevation within 0.1 ft of the top of the old well. Concurrent water depths in the two wells were within 0.05 ft. Thus the new well gives virtually the same information as the old one.

The location is in Portage County north of Nelsonville on county road A, north of Highway 161 and ½ mile south of Hotvedt Rd. The property is owned by Bernice Krogwald and managed by her son James. The home there is a rented out. Bernice and James live approximately a mile up the road at a larger farmstead.

On 26-October-2010 the owners were approached about the possibility of continuing water level measurements, and we received permission to do so.

On 9-November-2010, we observed that the well responded very slowly to water level changes. A clogged or collapsed screen was suspected. We attempted to rehabilitate by surging and blowing out water with compressed nitrogen, but to no avail. A decision was made to construct a replacement monitoring well.

Permission was given on 16-November-2010 by James Krogwald to drill a new monitoring well on the property with the warning that the property could be sold at some point in the near future and permission to continue measurements may not be given by the new owners. James and Jessica Haucke determined the location of the new well to be approximately 60 feet to the west of the old well on the right side of the shed/garage outbuilding (Figure A-1).

Data Storage Location: G:\usr\projects\Nelsonville_2010

Construction of New Monitoring Well: The replacement well was constructed on 17-November-2010 by Jessica Haucke, George Kraft, and Dick Stephens from UW-Stevens Point. Coordinates for the old monitoring well installed by USGS are Latitude 44° 31' 27", Longitude 89° 31' 41", those for the new well are shown below. The replacement well was installed with a 3-1/4 inch hollow stem auger and a

Giddings drill rig. The formation is sand and gravel. A steel protective cap was placed over the monitoring well. Pictures in Figure A-2 show the location of the replacement monitoring well and its proximity to the shed/garage and the old monitoring well.

Coordinates: Latitude, 44° 31' 26"; Longitude, 89° 31' 42"
Well diameter: 2 in
Total well length: 51.5 ft
Screen Length: 5 ft.
Stick-up: 2.9 ft
Water depth on 17 November 2010: 35.45 ft
(Water depth at USGS well 443127089174101, same date, 35.40 ft)

Figure A-1. Approximate location of the USGS monitoring well near Nelsonville and the newly constructed replacement monitoring well.

Figure A-2. Location of the newly constructed monitoring well and its proximity to the driveway, shed, and the old monitoring well.

Appendix B

Model Documentation

EXTENDING THE WISCONSIN CENTRAL SANDS GROUNDWATER FLOW MODEL

David J. Mechenich, Center for Watershed Science and Education,
University of Wisconsin – Stevens Point

July 16, 2012

Summary

A Wisconsin Central Sands groundwater flow model was extended to the northeast to include an important headwater stream area with significant current and potential high capacity well development. In addition to expanding the extent, the recharge was changed from a single fixed amount over the entire model to a continuously variable distribution based on a soil water balance model. Calibration and sensitivity results are presented. The impacts of irrigation pumping were explored as for the previous model, with very similar results.

A Note About Units

This documentation generally uses SI units, except the more common “inches” are used for measures that express water depth, such as recharge or precipitation, and “cubic feet per second” is used for discharges.

Introduction

An existing groundwater flow model of the Wisconsin Central Sands was extended to the northeast to include much of the headwaters area for the Embarrass, Little Wolf, and Pigeon River watersheds (Figures 1 and 2) in portions of Marathon, Shawano, Waupaca, and Outagamie Counties. Significant numbers of high capacity wells exist there, and more will likely be developed. Some indicators show that stream baseflows reductions are already occurring in this area.

This new version of the Central Sands model is hereafter referred to as the Extended Model. Groundwater flow models were developed in 2009 for the Wisconsin Central Sands (Mechenich et al. 2009) in order to investigate the impact on groundwater withdrawals on surface waters. Four model versions were developed based on somewhat differing conceptual model, specifically in the number of layers and the spatial distribution of recharge. All four versions gave similar quality calibrations and produce similar responses to modeled stresses. Of the four, we chose “Model C” as the basis for the Extended Model. Model C is two layer, representing the glacial drift and sandstone aquifers, and used a single recharge rate.

Conceptual Model

Groundwater originates as diffuse precipitation recharge that is transmitted through a coarse textured glacial drift aquifer and an underlying sandstone aquifer to the area’s streams where it discharges. A north-south trending groundwater divide roughly follows the topographic high; flow is west and southwest from the divide to the Wisconsin River system, and east and southeast to the Wolf/Fox systems. No significant flow is attributed to the basement Precambrian crystalline bedrock underlying the entire model area. Seepage lakes are assumed to be too small and sparse to affect groundwater flow patterns at the scale of the Extended Model.

Model Design

The following discussion concentrates on the extended area; refer to Mechenich et al. (2009) for additional design details for the Model C portion of the Extended Model.

MODFLOW

The USGS MODFLOW computer code (Harbaugh et al. 2000) was used to implement the model. Groundwater Vistas (ESI 2005) was used as the main pre/post processing environment for MODFLOW. The Groundwater Modeling System (Aquaveo 2005) was used to calculate the initial source/sink properties of surface waters which were then imported into Groundwater Vistas. The model area was discretized into square 200 meter cells, 790 rows by 560 columns (WTM coordinates of the origin are 517,000, 351,000). This cell size is consistent with Model C, balancing sufficient detail with data management and computational overhead. The active area of the model (see Boundaries below) includes 231,614 cells per layer. Spatial data management for the MODFLOW model, especially construction of bedrock surfaces from well data, was accomplished using ArcGIS software (ESRI 2010).

Boundaries

Exterior boundaries were chosen using major streams where available, and then minor streams to fill gaps. In the extended area, the model boundaries are coincident with the Plover River in the northwest, Elmhurst Creek of the Middle Branch of the Embarrass River is the far north, and the North Branch and main stem Embarrass River to the Wolf River in the northeast (Figure 2). Two small no flow boundaries following local topographic highs were utilized to connect the stream boundary systems. The north-south groundwater divide between the Wisconsin and Wolf systems is very close to the Plover River. A small extension was also made to the southeast exterior boundary to better follow the Fox River major stream boundary in the Lake Puckaway area (Figure 1).

A 1:24000 hydrography layer (WDNR 2007) was used as the basis for defining surface water boundaries and internal features. Water elevations for these features were taken from DRGs (Digital Raster Graphic) of 7.5 minute USGS topographic maps or field studies when available. External boundaries were usually input as MODFLOW constant head cells (major streams/rivers), although some river, drain, and no flow boundaries were also used. Internal streams and ditches were modeled as MODFLOW rivers and drains; drains being used in headwater areas were flow would be uncertain (Figure 3). The conductance of the river and drain cells reflect the length and general size of a stream in a cell, ranging from 10 m/d per unit length for small headwaters to 40 for large rivers, River cell bottom elevations were also scaled by river size, generally from 0.6 to 1.5 feet below the water elevation.

Aquifer Units

The extended model was implemented in two layers, an upper representing unconsolidated surficial deposits and a lower representing the underlying sandstone. The lower boundary of the active model is therefore the top of the Precambrian crystalline rock. Three elevation surfaces were developed for the model: the land surface (top layer 1), the sandstone surface (bottom layer 1, top layer 2), and the crystalline rock surface (bottom layer 2) (Figure 4). The land surface was developed from a 30m DEM (Digital Elevation Model) for Wisconsin (USGS 1998). Surface elevations range from 453.8 meters (1489 feet) in the extreme north to 228.0 m (748 ft) in the southeast of the extended area at the Wolf River to 240.7 m (790 ft) at the southeastern extreme of the entire model. Well construction reports and logs from the WDNR HiCap (197 wells) and Well Construction Report (WCR) (7268 wells) databases (WDNR 2010) and the wiscLITH database (155 wells, WGNHS 2009) were used to construct the sandstone and crystalline surfaces in the extended areas. The surfaces were contoured using recorded rock contacts and other well points that might represent the surface (well bottom below the surface calculated only from recorded contacts). While significant areas of sandstone are present in the southern portions of the model area, it is largely absent from the extended area except for sparse deposits up to 40 meters thick in east central Waupaca County and the small portion of the model in Outagamie County (Figures 5 and 6). For modeling purposes, a minimum sandstone thickness of one meter was assumed, which could be considered a weathered crystalline rock transition zone. The unconsolidated thickness also tends to decrease to the north. While the thickness of this layer approaches 100 meters in eastern Waupaca County, similar to other thick deposits towards the south, the northern area in Marathon, Shawano, and north central Waupaca Counties trends from 0 to 73 meters thick, averaging only 16 meters (Figures 5 and 6). This presents some modeling difficulty in that the sand/gravel/till/sandstone aquifer pinches out entirely in small isolated areas related to crystalline bedrock highs and stream cuts. To enhance model stability and to model a continuous water surface on a regional scale, the crystalline rock surface was lowered just as needed to maintain a thin saturated thickness in the unconsolidated layer and to place all surface water source/sinks in layer one.

Recharge

Model C calibrated to a single recharge value of 8.85 inches. Attempts to calibrate to a single recharge value over the entire Extended Model were disappointing; recharge variability presumably due to physiographic variability is apparently too diverse. Hence we took a two-step approach for recharge, first determining areal recharge rates and variability using a soil water balance model (the SWB, Westenbrook et al. 2010) and second scaling SWB recharge rates during PEST calibration (see below) to values consistent with flux targets.

Weather inputs into the SWB model used three average precipitation years taken from each of three weather stations with long records. The stations used were Hancock, Stevens Point, and Waupaca. The Hancock weather years were 1903, 1941, and 1947; Stevens Point were 1972, 1983, and 1991; and Waupaca were 1967, 1985, and 1996. The average annual recharge for the nine weather records varied considerably from about 10 inches to 16.5 inches (Figure 7); the recharge-precipitation relationship apparently complicated by the timing of the precipitation and ET/temperature variability. The recharge distribution input into MODFLOW for calibration was the cell by cell average of the nine annual weather records smoothed over a seven cell moving window. The smoothing was necessary to eliminate very small scale and unrealistic large recharge rates calculated by SWB. The final MODFLOW recharge distribution ranged 4 to 19 inches and averaged 14.9 inches.

Calibration Targets

Targets for the Extended Model include the 499 head and 84 flux targets from Model C, an additional 222 new head and 65 flux targets in the extended area, and 66 hydraulic conductivity pilot points (Figure 8). As for Model C, the new head targets are sub-grouped as clustered spot observations (203 targets), USGS monitoring wells (14 targets), and topographic map elevations of seepage lakes (5 targets). Each cluster observation is the average of 2 to 22 wells in close proximity, representing a total of 930 wells from the WDNR HiCap and WCR databases (WDNR 2010) and USGS single observations (USGS 2011a). The USGS monitoring wells (USGS 2011a) have from 4 to 481 observations. Unfortunately, the dates for the head observations span a long period; the HiCaps and WCR's are mostly from 1988 to 2008 and the USGS observations are from 1953 to 2011. Observation weighting factors included number of observations, elevation range, and date relative to "typical" precipitation years, although a minimum weight of 0.5 was used. New flux targets for the extended area include 4 USGS daily sites with 852 to 22,748 observations (USGS 2011b), 21 USGS spot flow measurements with 1 to16 observations, and 40 sites from ongoing UWSP monitoring with 1 to 15 observations (Kraft et al. 2008; Kraft and Haucke 2012). Flux target calculation and weighting followed the methods used for the Model C targets (Mechenich et al. 2009). The 66 pilot points were located across the active model area in a relatively uniform grid so that each pilot point impacted approximately an equivalent area. There are no known abrupt changes in hydraulic conductivity or other geologic factors that would suggest some other arrangement.

Model Calibration, Sensitivity, and Results

Calibration

PEST parameter estimation software (Doherty 2007) was used to calibrate hydraulic conductivity (K) and recharge. A spatially variable layer one K was calibrated by estimating its value at 66 layer one pilot points and interpolating these values to the entire MODFLOW cell grid. K was calibrated for layer two as a single parameter over the entire model domain. Recharge was calibrated by PEST as a single multiplier of the spatially variable recharge grid from the SWB model. In addition to the head and flux targets, a regularization or smoothing constraint was also applied to the pilot point K values. Many runs were made exploring the impact of changing the relative weighting of head, flux, and regularization observation groups. The best PEST calibration occurred with a flux group weighting of x3, and a regularization group weighting of x1000. Probably because of issues with pilot point sensitivity and uneven target reliability and weighting, the PEST calibration was then adjusted slightly by professional judgment with minor impact on calibration stats. Hydraulic conductivity for layer one pilot points varied from 4 to 64 m/day, and the MODFLOW cell average is 20.6 across the model domain (Figure 9). The average cell K in the Extended Model for the previous Model C area is 20.8 compared to 23.0 for Model C.   Layer two K is 3.5 m/d compared with 2.1 for Model C. Vertical K was assumed to be 0.1 that of the horizontal K. Recharge varies from 2.2 to 10.3 inches (Figure 10), averages 8.1 inches, and represents approximately 54% of the SWB model. The average recharge for the Model C area is 8.36 inches, compared to the uniform recharge of 8.85 for Model C. The modeled water table contours (Figure 11) nicely reflect the conceptual flow model. The north-south trending divide is clear, very close to the Plover River in the north and broad through the central sand plain. Regional flow in the extended area is primarily to the southeast and is largely controlled by a relatively well defined surface water network. Final calibration statistics (Table 1, Figure 12) are reasonable and compare well to previous models. The absolute residual mean (ARM) for all heads increased slightly from 1.13 meters for Model C to 1.31 for the Model C area of the Extended Model and 1.89 for the entire Extended Model. This may be due to the slightly higher weighting given to the flux targets for the Extended Model; the ARM for the Extended Model flux targets is essentially the same as for Model C, and improved slightly from 4.12 cfs to 3.86 cfs when limited to the original Model C area. The ARM for the head target subgroups ranges from 1.19 m for seepage lakes to 1.52 for USGS monitoring wells to 2.01 for the observation clusters. Residuals trend noticeably higher in the extended area (Figure 13). The all heads ARM for the extended area is 3.18 m compared to 1.31 for the original Model C area, and the flux ARM is 5.16 cfs compared to 3.86. This may reflect target noise from the wide time frame encompassed by the targets as well as elevation datum error for head target calculation referenced from the variable surface topography noted in the extended area. The very low head residual mean (RM) of -0.02 m for the extended area suggests the model did an adequate job of balancing the pluses and minuses. There appears to be a flux calibration conflict between the original Model C area and the extended area. The flux RM is a plus 3.41 cfs in the extended area compared to a minus 1.69 for the Model C area. It may be that the flux targets for the extended area trend low because of inadequate record to accurately define a representative or non-impacted base flow condition for the steady state. Forty of the 66 flux targets in the extended area are new observations in the 2005 to 2011 period.

Sensitivity

Relative to possible K and recharge driven error, the location and elevation of the external and interior boundaries, as well as the layer elevations, are based on substantial data and are therefore considered adequate and fixed for the model. As noted above, the Kz/Kx ratio is fixed at 0.1. Varying this ratio from 0.01 to 10 has no substantial impact on the calibration. The river/drain cell conductance is fixed based on the feature size and length, and the model also has very low sensitivity to this parameter (Figure 14a and 14b). Heads are equally sensitive to K and recharge, but flux is strongly driven by recharge (Figure 14a and 14b). While this difference suggests a good “unique” solution for the model, it also points to the need for representative baseflow flux targets. While individual targets follow this same pattern, the response, or slope of the curve, is variable (Figure 14c and 14d).

Assessing Impacts of Irrigation Pumping

Water Table Drawdowns

As with previous studies, irrigation impacts were explored with a steady state approach; simulating irrigation losses as reductions in net recharge on irrigated lands. The irrigated lands cover used for Model C was expanded to cover the extended areas, following the same procedure as described in

Mechenich et al. (2009). The irrigable lands cover was intersected with the MODFLOW grid and recharge reductions calculated based on the extent of irrigation within the cell. By running the model with 0 to 10 inches of recharge reduction in 1 inch increments, a plot of the drawdown potential per inch of recharge reduction was constructed (Figure 15). While the relationship is not exactly linear for every model cell, the plot does identify vulnerability. For example, the drawdown for 2 inches of recharge reduction is largely as would be expected (Figure 16). The critical area is the central extensively irrigated agriculture area along the groundwater divide where streams are absent. The extent and magnitude is almost identical to that derived from Model C.

Stream Flow Depletions

The relationship between recharge reduction and stream flow at flux target locations was also explored for 2 inches of net recharge reduction on irrigated lands (Table 2 and Figure 17). The percent reduction is most evident in headwater areas near irrigated agriculture. Care is needed when interpreting percent changes for very small flows. Again, the modeled reductions as a percent of baseflow are very similar to Model C, the biggest percent change differences noted with smaller base flows.

Conclusions

The Extended Model is a reasonable representation of the extended Central Sands area. Its ability to model regional to sub-watershed level stressors, such as irrigation pumping, is demonstrated. While the accuracy of the model is adequate, the precision of before/after analyses is robust for predictive modeling, as shown by very similar results from previous models and the Extended Model. As the model grows in areal size, the need for solid targets and spatial recharge rates is apparent to minimize compromises across an increasingly varied domain. Because of the sensitivity of the model to recharge, refining the SWB recharge model may be the best way to improve model accuracy. Further consideration needs to be given to the base model condition and related targets; does the steady state model reflect a true "before" condition or is it some combination of natural and stressed recharge and targets. The higher variability of the extended area head targets and the low trending flux targets should be addressed with additional research.

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Table 1. MODFLOW calibration statistics.

	Model:	Extended	Extended	Extended	Model C
	Scope:	Entire Model	Extension Only	Ori Model C	Entire Model
All Heads (m):	Number:	721	222	499	499
	Residual Mean:	0.24	0.61	0.08	-0.17
	Std Dev:	2.72	4.11	1.76	1.55
	Sum of Squares:	5357.12	3810.29	1546.83	1214.99
	Abs Residual Mean:	**1.89**	**3.18**	**1.31**	**1.13**
	Min Residual:	-11.74	-11.74	-6.66	-6.90
	Max Residual:	13.78	13.78	8.62	8.89
	Range in Obs Head:	196.31	193.35	141.52	141.52
	Residual Std Dev/Rng:	0.01	0.02	0.01	0.01
Head1 Subgroup:	Residual Mean:	0.16	0.50	-0.02	-0.27
Clusters	Std Dev:	2.85	4.19	1.73	1.52
	Sum of Squares:	4734.52	3599.64	1134.88	906.78
	Abs Residual Mean:	**2.01**	**3.28**	**1.33**	**1.19**
	Min Residual:	-11.74	-11.74	-6.66	-6.90
	Max Residual:	13.78	13.78	5.98	5.47
	Range in Obs Head:	195.29	193.35	140.49	140.49
	Residual Std Dev/Rng:	0.01	0.02	0.01	0.01
Head2 Subgroup:	Residual Mean:	0.56	2.40	0.18	0.24
USGS Monitoring	Std Dev:	2.41	3.05	2.08	1.90
	Sum of Squares:	488.82	201.44	287.38	245.79
	Abs Residual Mean:	**1.52**	**2.56**	**1.30**	**1.13**
	Min Residual:	-5.26	-0.55	-5.26	-4.45
	Max Residual:	9.24	9.24	8.62	8.89
	Range in Obs Head:	139.04	131.34	111.87	111.87
	Residual Std Dev/Rng:	0.02	0.02	0.02	0.02
Head3 Subgroup:	Residual Mean:	0.57	0.11	0.61	0.05
Seepage Lakes	Std Dev:	1.42	1.51	1.42	1.09
	Sum of Squares:	133.78	9.21	124.57	62.42
	Abs Residual Mean:	**1.19**	**1.11**	**1.20**	**0.77**
	Min Residual:	-3.63	-2.51	-3.63	-3.20
	Max Residual:	4.26	1.25	4.26	3.15
	Range in Obs Head:	158.20	26.82	114.31	114.31
	Residual Std Dev/Rng:	0.01	0.06	0.01	0.01

Table 1. MODFLOW calibration statistics (continued).

	Model:	Extended	Extended	Extended	Model C
	Scope:	Entire Model	Extension Only	Ori Model C	Entire Model
Flux (m/d):	Number:	149	65	84	84
	Residual Mean:	1315.10	8348.04	-4127.05	-2793.63
	Std Dev:	19616.03	13471.96	21851.15	20744.97
	Sum of Squares:	57206397373.53	16145420812.85	41060976560.68	36374923928.60
	Abs Residual Mean:	**10134.59**	**12626.11**	**9445.68**	**10076.54**
	Min Residual:	-151471.51	-28468.46	-151471.51	-127080.80
	Max Residual:	52195.40	52195.40	49057.27	69140.11
	Range in Obs Flux:	679902.00	679743.00	547787.00	547787.64
	Residual Std Dev/Rng:	0.03	0.02	0.04	0.04
Flux (cfs):	Residual Mean:	0.54	3.41	-1.69	-1.14
	Std Dev:	8.02	5.51	8.93	8.48
	Sum of Squares:	23382256.83	6599198.58	16783058.25	14867704.53
	Abs Residual Mean:	**4.14**	**5.16**	**3.86**	**4.12**
	Min Residual:	-61.91	-11.64	-61.91	-51.94
	Max Residual:	21.33	21.33	20.05	28.26
	Range in Obs Flux:	277.90	277.83	223.90	223.90
	Residual Std Dev/Rng:	0.03	0.02	0.04	0.04

Table 2. Comparison of stream discharges (measured, modeled, and with 2 inches net recharge reduction) for the Extended Model and Model C.

Station Name	Observed	Extended Base	Model 2" Irr	% Depletion	Base	Model C 2" Irr	% Depletion
Dry_Creek_@_G	0.92	0.12	0.02	82.51	0.38	0.24	37.43
Bird_Creek_@_CTH_C	2.86	-0.08	-0.13	54.64	-0.46	-0.51	10.82
Pine_R._@_Apache_Dr	0.79	1.41	0.70	49.94	7.57	6.64	12.21
NB_Ten_Mile_@_Ish/Hrd	0.10	1.12	0.63	43.78	1.19	0.71	40.18
Chaffee_Creek_@_CH	1.66	0.12	0.07	41.62	0.00	0.00	
Schmudlack_@_Cottonv	1.18	1.15	0.70	39.31	1.10	0.65	40.62
Carter_Creek_@_G	2.28	2.62	1.74	33.30	3.43	2.58	24.79
Ditch_#2_N_Fork_@_Ish	3.65	2.00	1.35	32.56	2.12	1.47	30.41
DOT_Wetland_-_S_Out	1.50	1.64	1.21	26.10	0.95	0.61	36.13
L_Plover_nr_Arnott	3.00	3.03	2.24	25.90	2.41	1.67	30.71
Four_Mile_Cr_@_JJ&BB	0.23	3.67	2.74	25.26	3.98	3.01	24.17
B_Roche_A_Cri_Hancock	7.80	7.44	5.59	24.82	7.56	5.66	25.11
Tenmile_Creek_Ditch_5	6.50	5.16	4.10	20.53	5.11	4.10	19.85
Tommorrow_@_Merryland	0.72	0.95	0.76	19.21	3.50	3.34	4.57
L_Plover_at_Plover	9.00	8.91	7.48	16.06	8.06	6.64	17.64
Campbell_Creek_@_A	2.50	0.65	0.55	15.13	0.22	0.15	30.23
Lost_Creek	1.16	1.70	1.45	14.51	1.22	0.98	19.66
Trib_to_Tommorrow	1.48	1.12	0.96	14.27	1.47	1.30	11.43
L_Wolf_Riv_@_Benvent	0.90	0.02	0.01	13.33			
Buena_Vista_Kellner	33.00	29.63	26.10	11.92	28.81	25.38	11.91
Tagtaz_Creek_@_CTH_CH	2.57	1.90	1.68	11.41	1.36	1.10	18.77
Fourteenmile_New_Rome	30.00	29.54	26.26	11.11	28.11	25.01	11.03
Fourmile_Cr_Kellner	26.00	33.60	30.00	10.74	34.71	31.12	10.33
Emmons_Creek_@_3rd	0.36	0.21	0.19	10.34	0.00	0.00	
Neenah_@_G	0.60	1.67	1.50	10.19	2.62	2.46	5.86
Sucker_Creek_@_CTH_Z	3.03	1.83	1.68	8.62	1.52	1.39	9.12
Tenmile_Creek_Nekoosa	53.00	49.66	45.82	7.73	47.34	43.38	8.35
B_Roche_A_Cri_Adams	52.00	52.02	48.36	7.03	51.58	47.89	7.15
SB_Wedde_nr_Richford	7.13	2.17	2.02	6.89	1.20	1.05	12.00
Radley_Creek_@_Hwy_22	13.12	13.26	12.47	5.96	15.29	14.41	5.80
WB_Lunch_Cr_@_11th	1.65	0.24	0.23	5.58	0.21	0.20	6.53
LRoche-A-Cri_@_10th	33.09	32.69	30.88	5.55	30.93	29.21	5.54
Bear_Creek_near_mouth	12.05	9.84	9.34	5.12	13.01	12.53	3.72
L_Roche_A_Cri_Adams	64.20	69.51	66.02	5.02	69.16	65.88	4.73
Big_Roche_A_Cri_Creek	80.10	92.84	88.46	4.72	89.64	85.21	4.94
Willow_Creek_@_CTH_G	4.53	2.58	2.47	4.47	2.76	2.68	3.21
Holt_Cr_nr_Galloway	4.55	1.52	1.46	4.45	3.01	2.94	2.26
Pine_River_@_Apache	37.47	36.80	35.23	4.25	37.35	35.78	4.21
Holt_Cr_nr_Galloway	11.49	5.66	5.42	4.19	7.66	7.43	3.04
Tomorrow_@_A	47.68	43.83	42.15	3.83	53.17	51.55	3.04
Lunch_Creek_@_Y	10.18	4.42	4.26	3.70	3.80	3.64	4.23
WB_White_nr_Wautoma	21.00	21.01	20.25	3.63	20.63	19.96	3.23
Flume_Cr_@_T	13.86	17.35	16.73	3.59	19.37	18.76	3.16
Pine_Riv_@_Saxeville	47.30	49.86	48.15	3.42	49.48	47.77	3.46
Shadduck_Creek_@_13	0.95	0.78	0.76	3.41	1.20	1.16	2.86
Crystal_River_@_K	64.45	53.08	51.28	3.38	57.09	55.17	3.36
Lunch_Cr_@_Deerborn	13.60	8.45	8.16	3.36	8.79	8.51	3.18
Tomorrow_nr_Nelsonvil	28.00	18.07	17.50	3.18	20.90	20.38	2.47
Flume_Cr_Rosholt_66	4.16	6.98	6.75	3.17	9.55	9.32	2.39
Emmons_Cr_near_Rural	26.00	15.88	15.39	3.06	17.02	16.52	2.92

Table 2. Comparison of stream discharges (measured, modeled, and with 2 inches net recharge reduction) for the Extended Model and Model C (continued).

Station Name	Observed	Extended Base	Model 2" Irr	% Depletion	Base	Model C 2" Irr	% Depletion
Waupaca_R_nr_Waupaca	224.00	162.09	157.40	2.90	172.06	166.96	2.96
Spring_Creek_@_Q	10.92	11.69	11.36	2.86	6.28	5.54	11.84
Sucker_Cr_nr_Berlin	6.39	9.21	8.97	2.59	10.55	10.33	2.10
Quinnell_Creek_WiRap	1.37	1.31	1.28	2.53	1.19	1.16	2.82
Pine_Riv_@_Poy_Sippi	66.62	72.86	71.04	2.50	71.93	70.11	2.54
Lawrence_nr_Westfld	16.00	16.98	16.56	2.50	15.77	15.38	2.50
Bird_Creek_@_Hwy_21	10.35	8.90	8.68	2.46	8.84	8.59	2.86
Neenah_Cr_nr_Oxford	30.88	27.30	26.64	2.44	27.96	27.42	1.92
L_WOLF_@_NORSKE	26.53	30.23	29.51	2.37			
Mecan_@_GG	13.44	14.27	13.94	2.31	12.91	12.59	2.49
Mecan_River_@_14th	57.06	58.55	57.24	2.23	55.53	54.21	2.38
Trout_Cr_@_Trout_Cr	6.00	6.99	6.83	2.21	7.70	7.52	2.31
Poncho_Creek_@_CTH_Z	0.90	0.50	0.49	2.21	0.57	0.56	1.63
Tagatz_Cr_Harrisville	10.20	12.89	12.62	2.10	12.42	12.11	2.52
Sarines_Creek_@_CTH_T	0.37	0.42	0.41	1.96	0.52	0.51	2.14
L_Wolf_@_Ness_Rd	34.00	39.90	39.13	1.93			
Caves_Creek_@_CTH_CH	6.14	5.45	5.34	1.87	6.57	6.45	1.89
Plainville_Creek	2.55	2.47	2.43	1.84	2.61	2.56	1.80
Chaffee_Creek_@_14th	34.01	33.14	32.54	1.82	33.89	33.29	1.78
L_WOLF_NR_GALLOWAY	10.00	11.75	11.54	1.79			
Rattlesnake_MtMorris	13.18	9.42	9.25	1.76	8.78	8.63	1.72
Little_Wolf_River_@_J	75.00	96.33	94.69	1.71			
White_R_nr_Princeton	279.74	91.53	89.97	1.70	93.49	91.98	1.61
Chaffee_Creek_@_JJ	14.25	14.98	14.73	1.65	15.49	15.23	1.69
Willow_C_@_Redgranite	60.28	44.42	43.69	1.65	41.66	40.97	1.68
NF_Blake_Cr_@_E	0.69	3.55	3.50	1.61			
White_R_@_Cottonville	29.79	25.49	25.10	1.55	25.57	25.12	1.74
L_WOLF_@_GALLOWAY	7.56	10.57	10.41	1.46			
Westfield_nr_Harrisv	50.87	45.72	45.06	1.45	46.00	45.36	1.39
L_WOLF_NR_SYMCO	113.63	126.91	125.17	1.37			
O'_Keefe_Cr_@_CTH_A	8.06	12.16	12.01	1.26	13.99	13.79	1.40
Willow_@_Auroraville	66.37	59.22	58.48	1.26	59.68	58.97	1.19
NB_L_Wolf_Cozy_Pine	1.57	3.67	3.63	1.21			
Comet_Cr_@_Cleveland	2.22	3.76	3.71	1.20			
L_Wolf_Riv_@_River	3.10	4.74	4.68	1.19			
Flume_Creek_@_Hemlock	1.43	2.22	2.19	1.12	3.80	3.78	0.60
L_WOLF_@_MANAWA	156.70	167.61	165.76	1.10			
SB_L_Wolf_Elm_Valley	59.00	56.69	56.12	1.00			
Spranger_Cr_@_Oriole	5.39	9.44	9.35	0.93			
Blake_Creek_@_HWY_161	3.16	11.58	11.47	0.93			
L_WOLF_AT_ROYALTON	278.00	279.71	277.18	0.91			
SF_Blake_Cr_@_E	3.38	5.85	5.80	0.87			
Walla_Walla_Cr_@_Pope	4.73	6.36	6.31	0.85	6.26	6.21	0.85
Peterson_Creek_@_Q	17.80	17.41	17.27	0.82	17.55	17.42	0.74
Comet_Cr_@_BlueGoose	6.82	13.13	13.04	0.66			
BLAKE_CREEK_@_SYMCO	7.75	19.81	19.70	0.57			
Austin_@_Pine_Hill_Rd	8.27	7.63	7.59	0.55	7.98	7.93	0.57
Comet_Creek_@_Comet_R	6.88	16.41	16.32	0.55			
WHITCOMB_CR_BIG_FALLS	12.76	15.41	15.34	0.51			
Klawitter_nr_Westfld	5.42	8.32	8.28	0.41	10.51	10.47	0.32

Table 2. Comparison of stream discharges (measured, modeled, and with 2 inches net recharge reduction) for the Extended Model and Model C (continued).

Station Name	Observed	Extended Base	Model 2" Irr	% Depletion	Base	Model C 2" Irr	% Depletion
SB_EMBARRASS_WITTENB	22.65	25.23	25.13	0.41			
COMET_CR_NR_BIG_FALLS	16.19	22.12	22.04	0.41			
Norrie_Br_Birnamwood	1.00	0.30	0.30	0.36			
Walla_Walla_nr_Weyau	19.66	39.72	39.60	0.28	47.92	47.81	0.24
McDanz_@_Pine_Hill_Rd	3.18	2.19	2.19	0.28	2.50	2.50	0.25
SB_Embarrass_Tigerton	29.00	39.10	39.00	0.27			
NB_L_Wolf_Shambeau	3.06	7.64	7.62	0.24			
SB_EMBARRASS_Tigerton	43.70	46.08	45.97	0.23			
Whitcomb_Cr_@_CTH_C	3.64	9.79	9.77	0.19			
Alder_Cr_nr_Fremont	1.11	3.22	3.21	0.15	4.89	4.89	0.11
MAPLE_CR_NR_SUGAR_BSH	0.60	7.61	7.60	0.10			
EMBARRASS_@_CAROLINE	95.60	109.38	109.28	0.10			
Unnamed_Trib_@_Norrie	3.50	4.95	4.94	0.09			
Tiger_Cr._@_Bluebird	1.33	2.78	2.78	0.07			
Tiger_Creek_@_Alder_R	2.05	3.68	3.68	0.05			
SB_EMBARRASS_WITTENB	9.74	11.27	11.26	0.05			
TIGER_CR_@_WITTENBERG	0.60	0.18	0.18	0.02			
MB_Embarrass_@_N	5.63	9.75	9.75	0.01			
PIGEON_N_CLINTONVILLE	68.20	62.69	62.69	0.01			
BEAR_CREEK_NR_BEAR_CR	0.21	3.96	3.96	0.01			
Packard_Cr_@_Trout_L	1.09	3.63	3.63	0.00			
BEAR_CREEK_@_BEAR_CR	0.79	7.15	7.15	0.00			
RAILROAD_CR_BIRNAMWD	1.25	1.18	1.18	0.00			
Beetle_Cr_@_Beetle_Cr	0.19	0.27	0.27	0.00			
Trib_SB_Emb_Spiegel	0.17	1.81	1.81	0.00			
MB_EMBARRASS_Wittenbg	28.14	20.26	20.26	0.00			
Packard_Cr_@_Bluebird	10.08	7.61	7.61	0.00			
BEAR_CREEK	1.04	13.15	13.15	0.00			
Wilson_Cr._@_Maple_Rd	2.88	1.65	1.65	0.00			
SB_Pigeon_R_@_EE	0.46	3.26	3.26	0.00			
Simpson_Cr_@_Church	0.82	1.67	1.67	0.00			
SPAULDING_C_BIG_FALL	3.00	2.95	2.95	0.00			
Trib_to_Tiger_@_Apple	0.37	0.42	0.42	0.00			
Hydes_Cr_@_Magolski	1.33	5.28	5.28	0.00			
Dent_Cr._@_Fink_Rd	13.38	1.74	1.74	0.00			
PIGEON_@_CLINTONVILLE	38.58	58.14	58.14	0.00			
Loggemanns_Cr._Weasel	0.22	1.08	1.08	0.00			
Trib_SB_Pigeon_@_EE	1.00	4.98	4.98	0.00			
Pony_Creek_@_Maple_Ln	0.33	4.15	4.15	0.00			
Trib_Emb_nr_Embarrass	0.20	0.01	0.01	0.00			
SB_Pigeon_R_@_Brewer	1.33	11.06	11.06	0.00			
Unnamed_@_Pine_Tree_L	0.34	0.57	0.57	0.00			
NB_PIGEON_NR_MARION	3.65	8.59	8.59	0.00			
Strassburg_Cr_Regina	2.97	1.69	1.69	0.00			
Unnamed_@_Sugarbush	0.39	2.06	2.06	0.00			
Trib_SB_Emb_Hasse_Rd	0.35	0.82	0.82	0.00			
Witches Gulch @ 13	1.57	0.00	0.00		0.00	0.00	
Bear_Creek_headwaters	0.73	0.00	0.00		0.00	0.00	
Unnamed @ Schoolhouse	0.95	0.00	0.00				

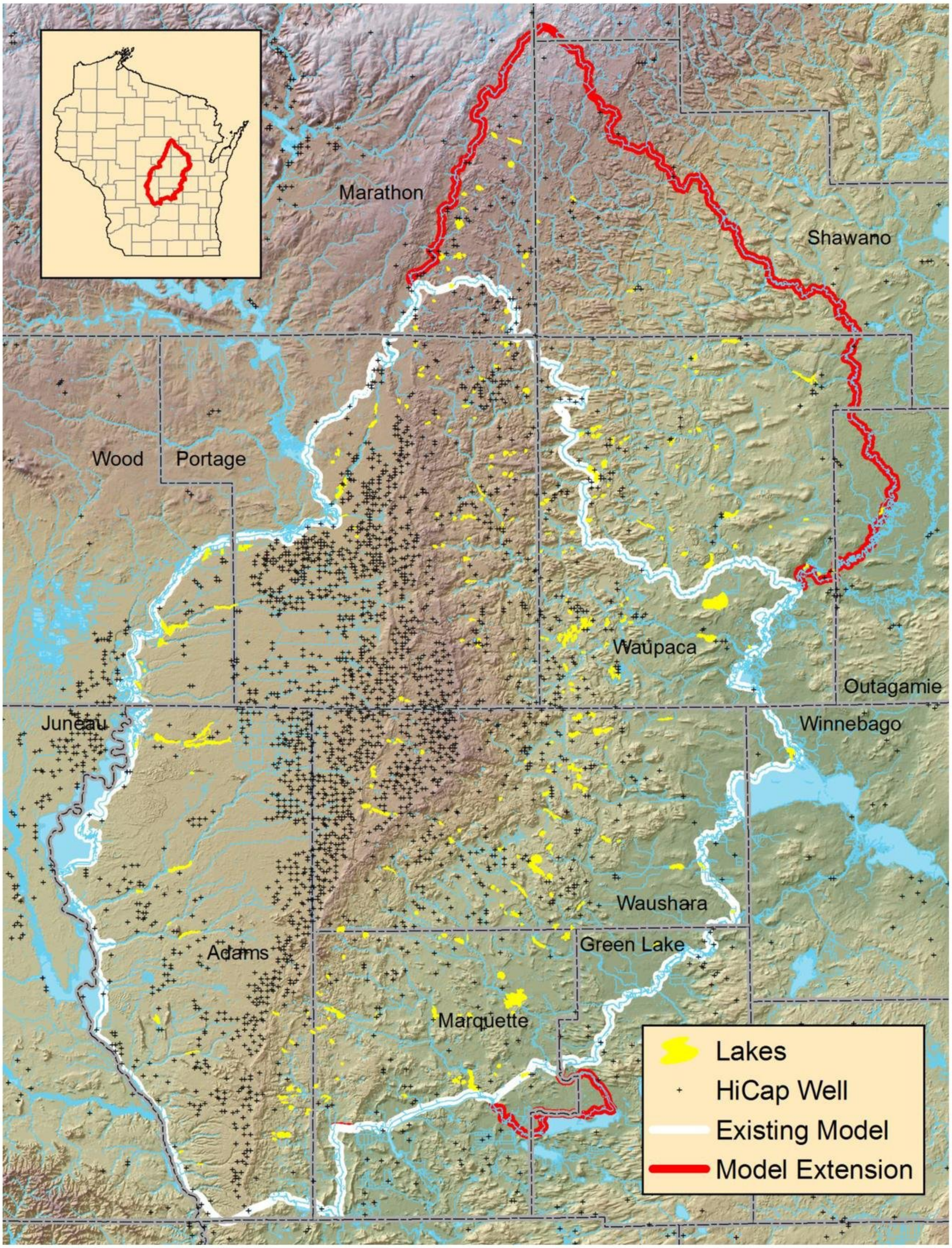


Figure 1. The Central Wisconsin groundwater modeling area of interest.

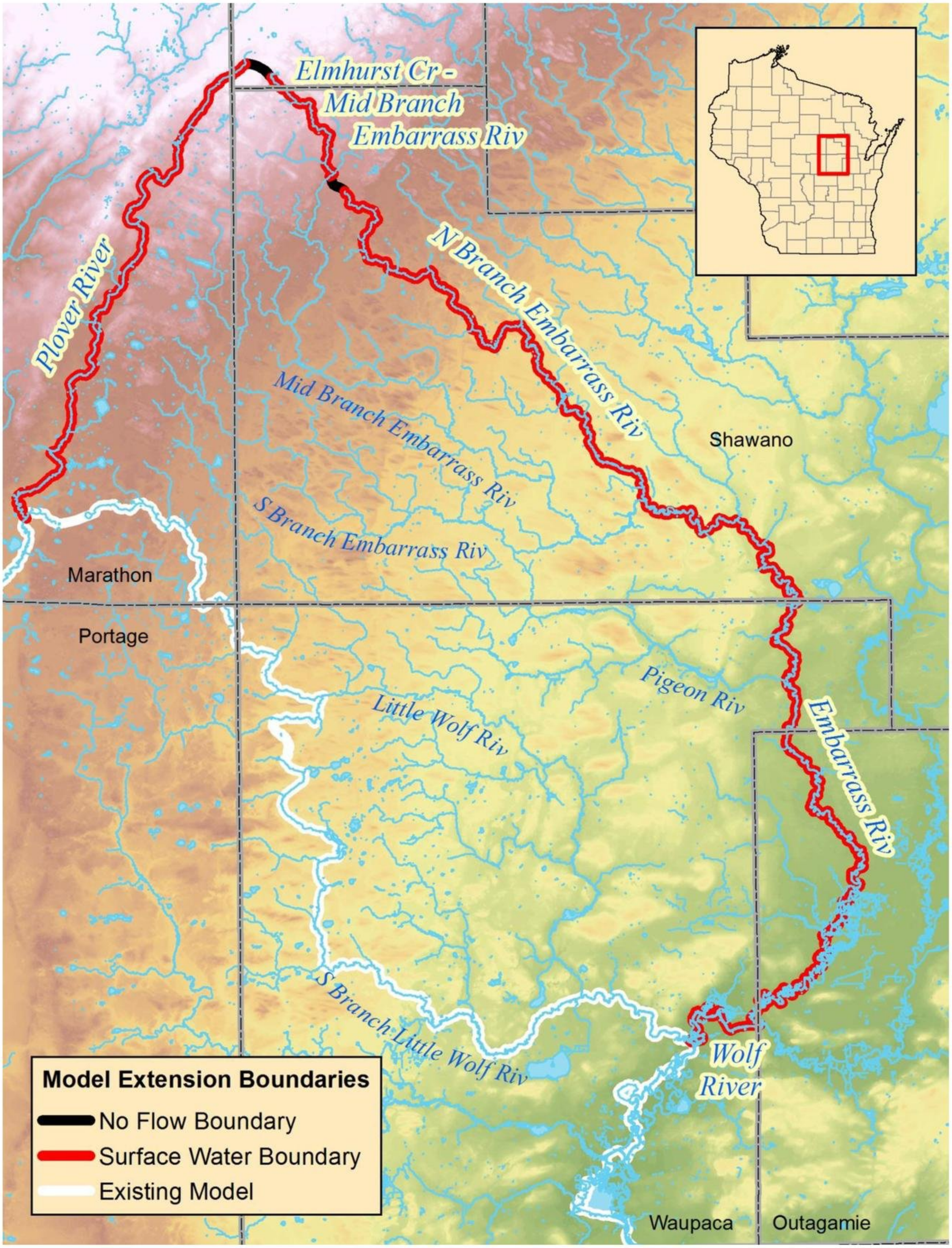


Figure 2. Conceptual model for groundwater flow in the northern extension to the Wisconsin Central Sands model.

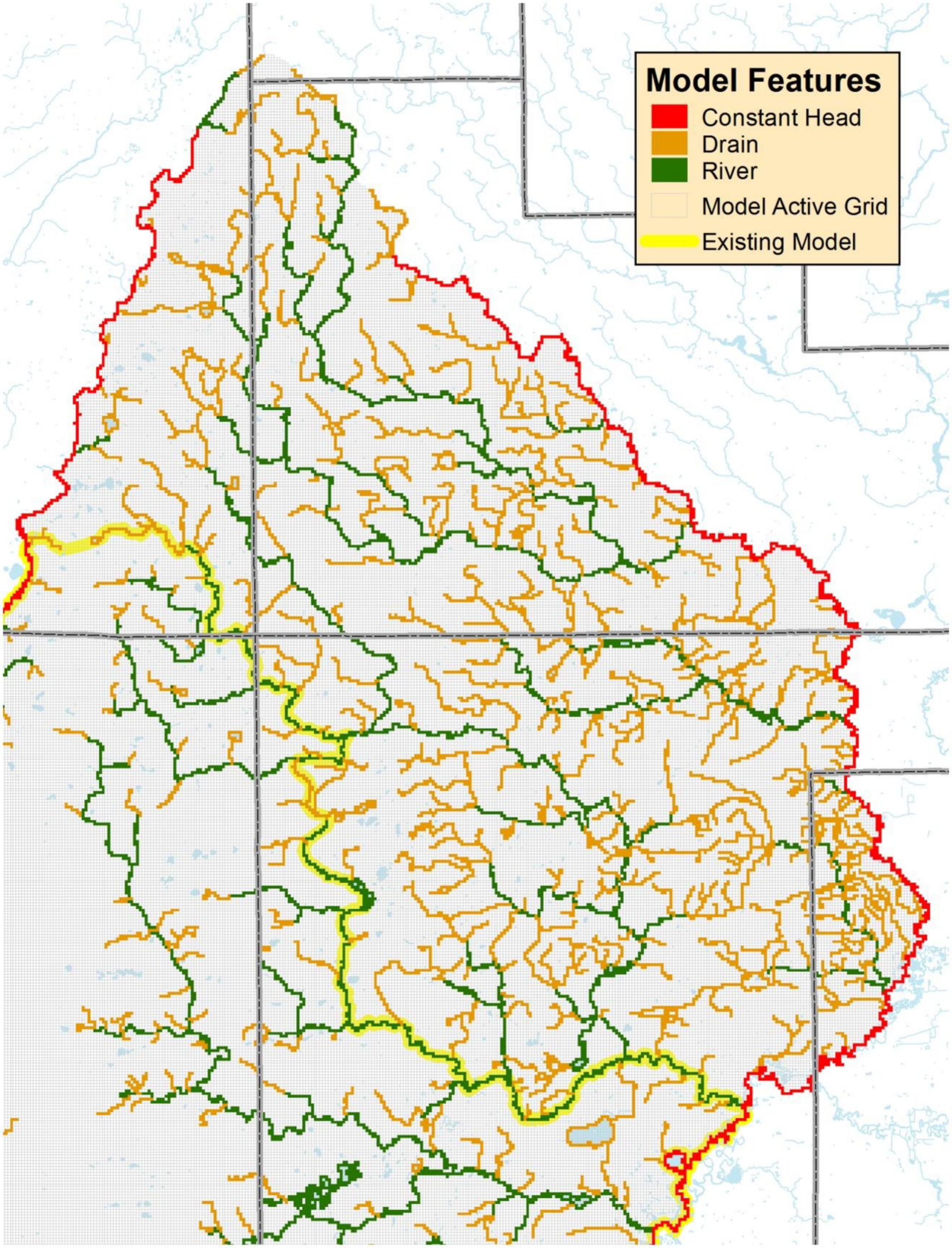


Figure 3. MODFLOW source/sinks for the northern portion of the Extended Model.

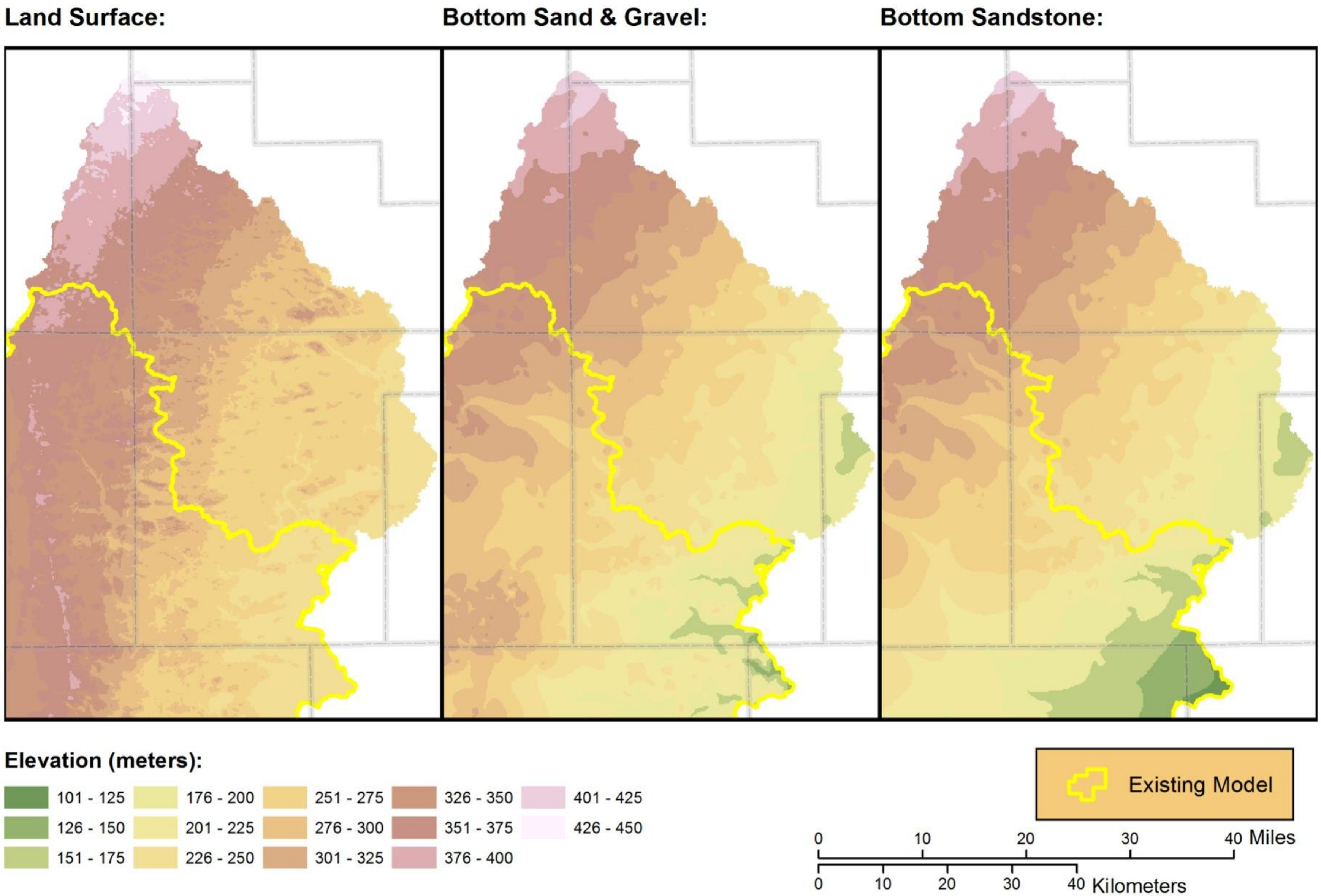


Figure 4. MODFLOW layer top and bottom elevations for the northern portion of the Extended Model.

Surface Unconsolidated Sand & Gravel:

Sandstone:

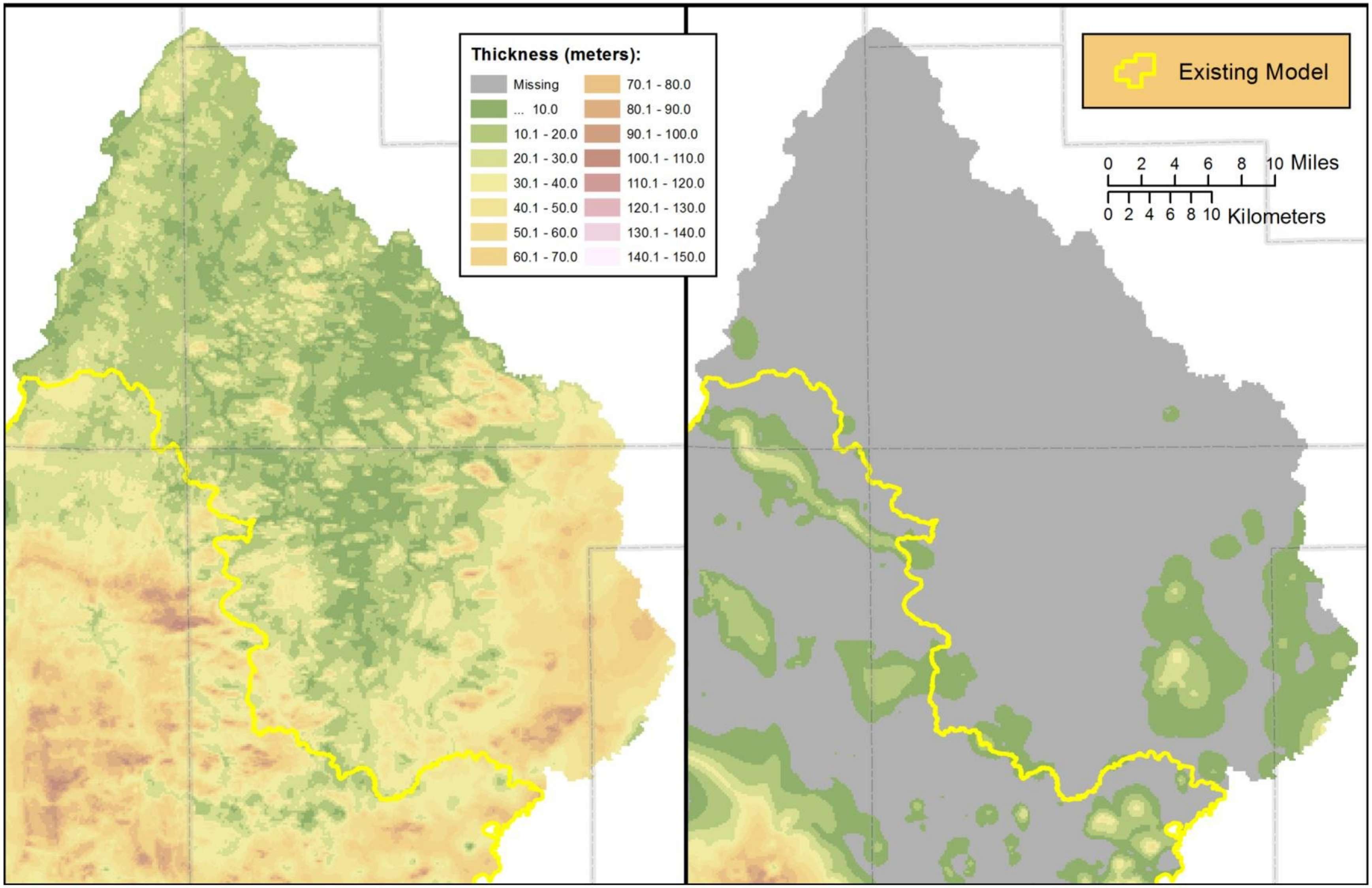


Figure 5. Thickness of the unconsolidated and sandstone layers for the northern portion of the Extended Model.

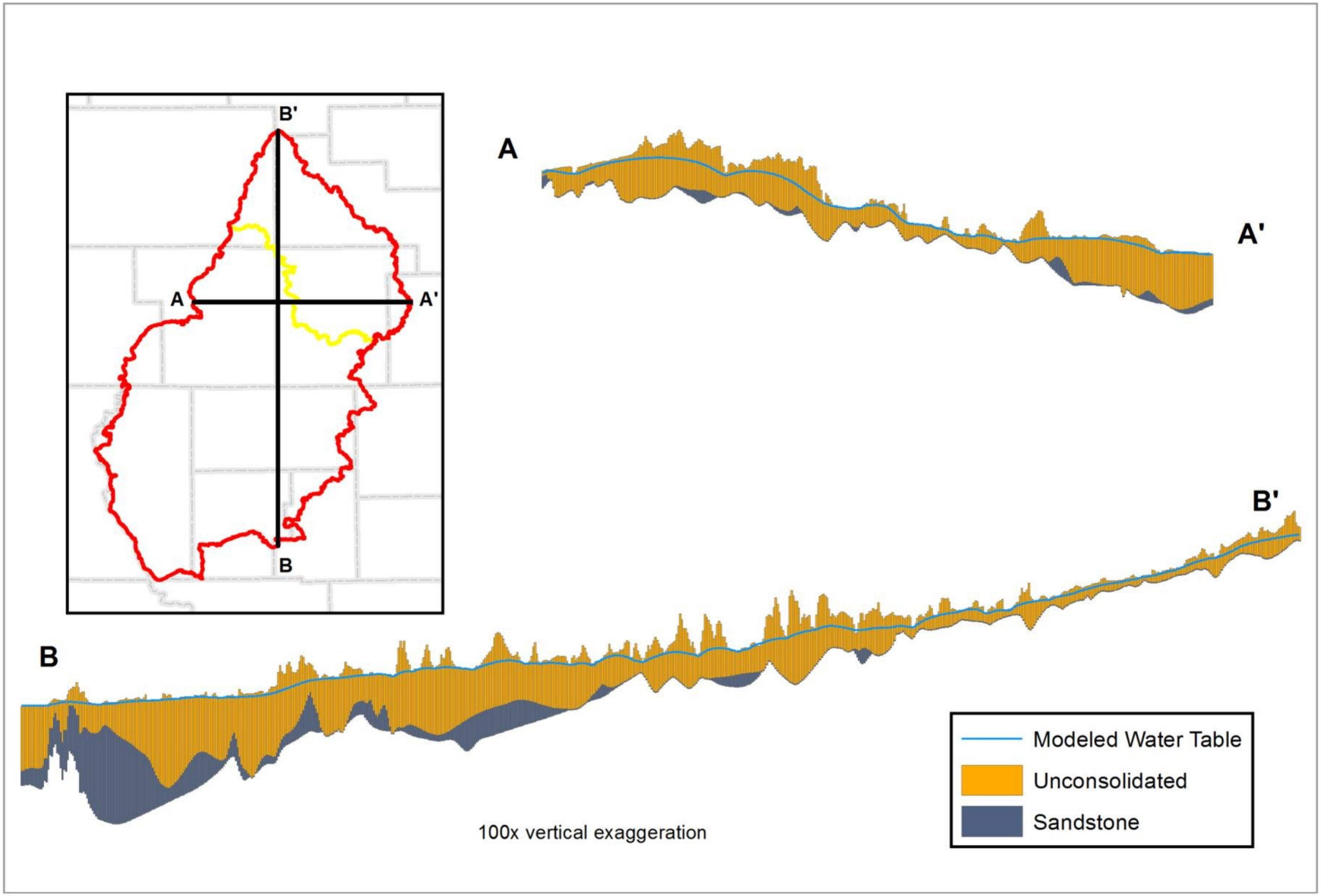


Figure 6. Cross-sections of the MODFLOW unconsolidated and sandstone layers.

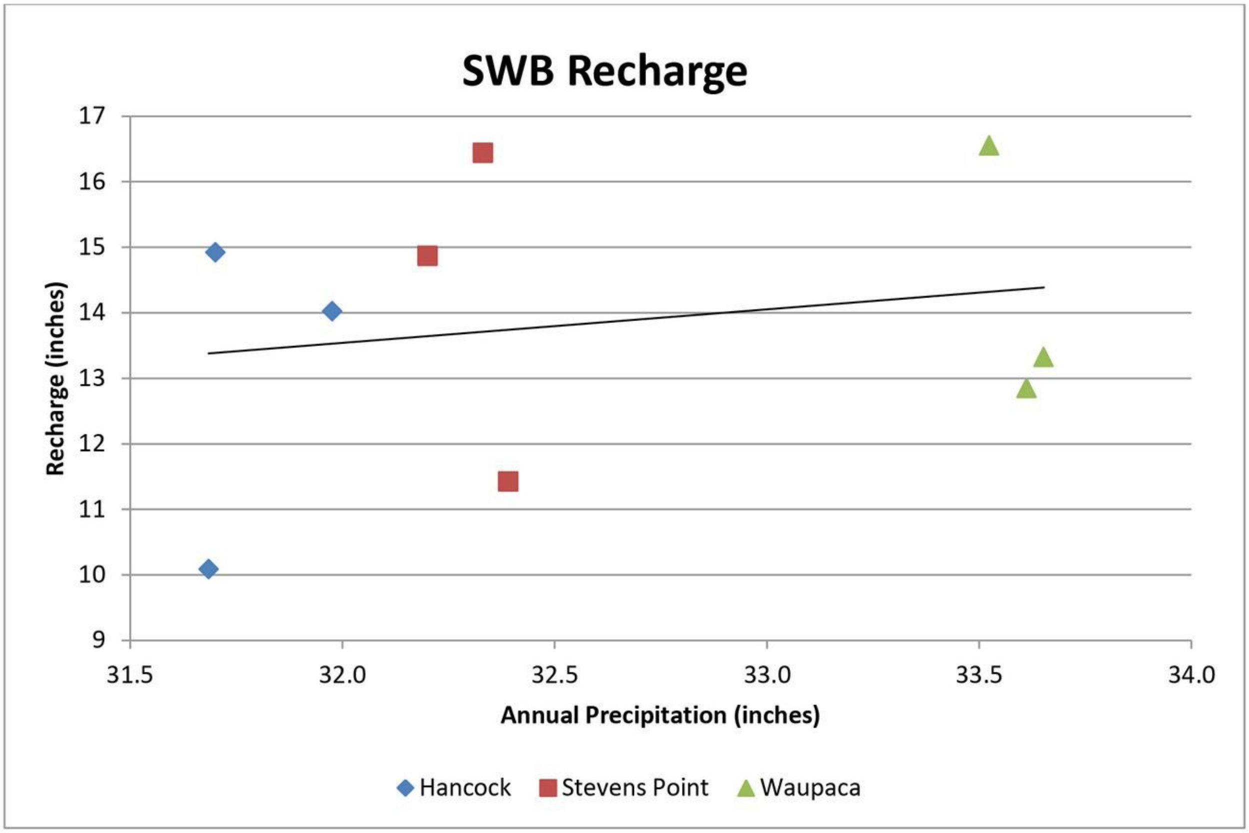


Figure 7. Relationship of domain-averaged SWB modeled recharge to precipitation typical for the three years of weather record each at Hancock, Stevens Point, and Waupaca, Wisconsin.

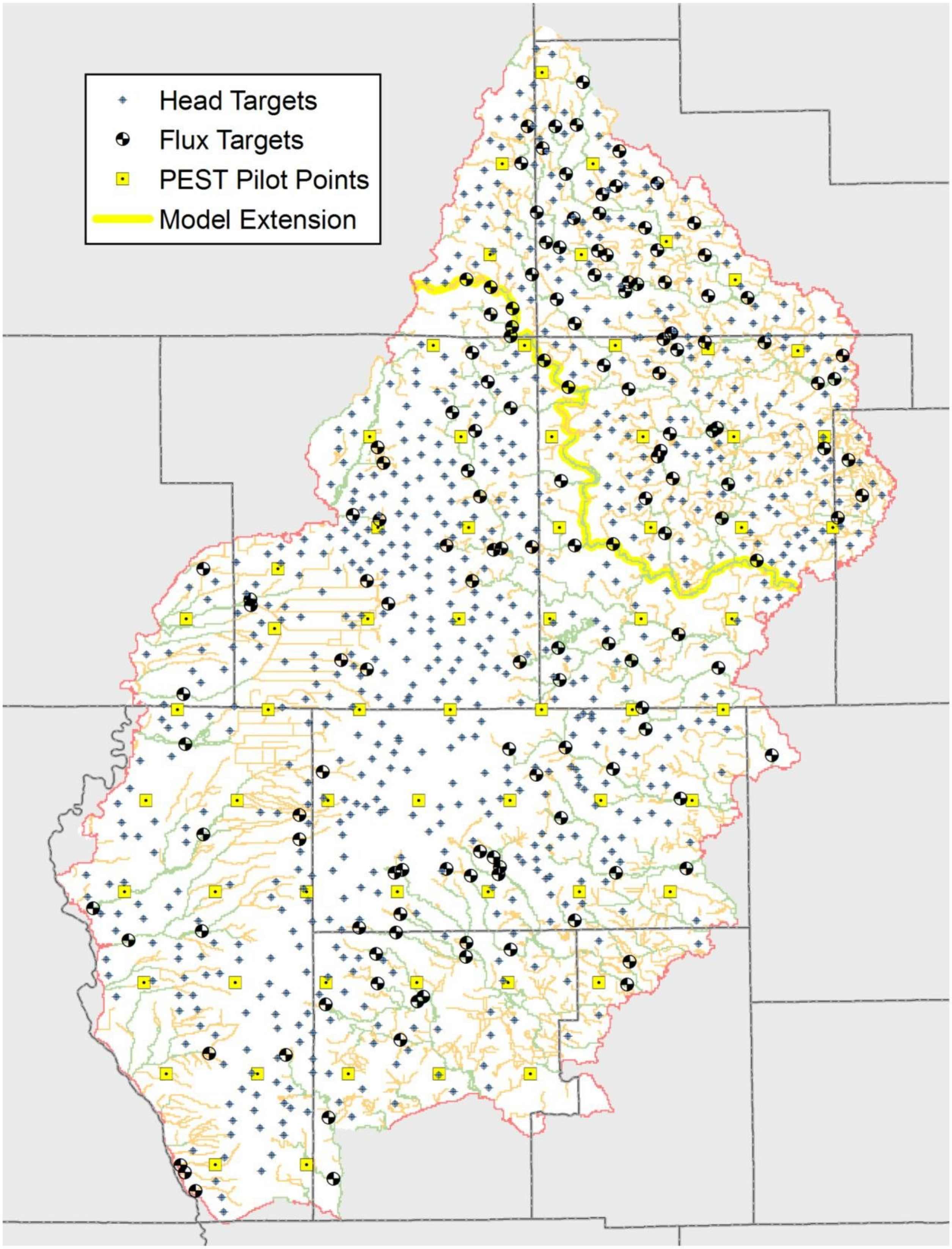


Figure 8. MODFLOW head and flux targets and PEST pilot points.

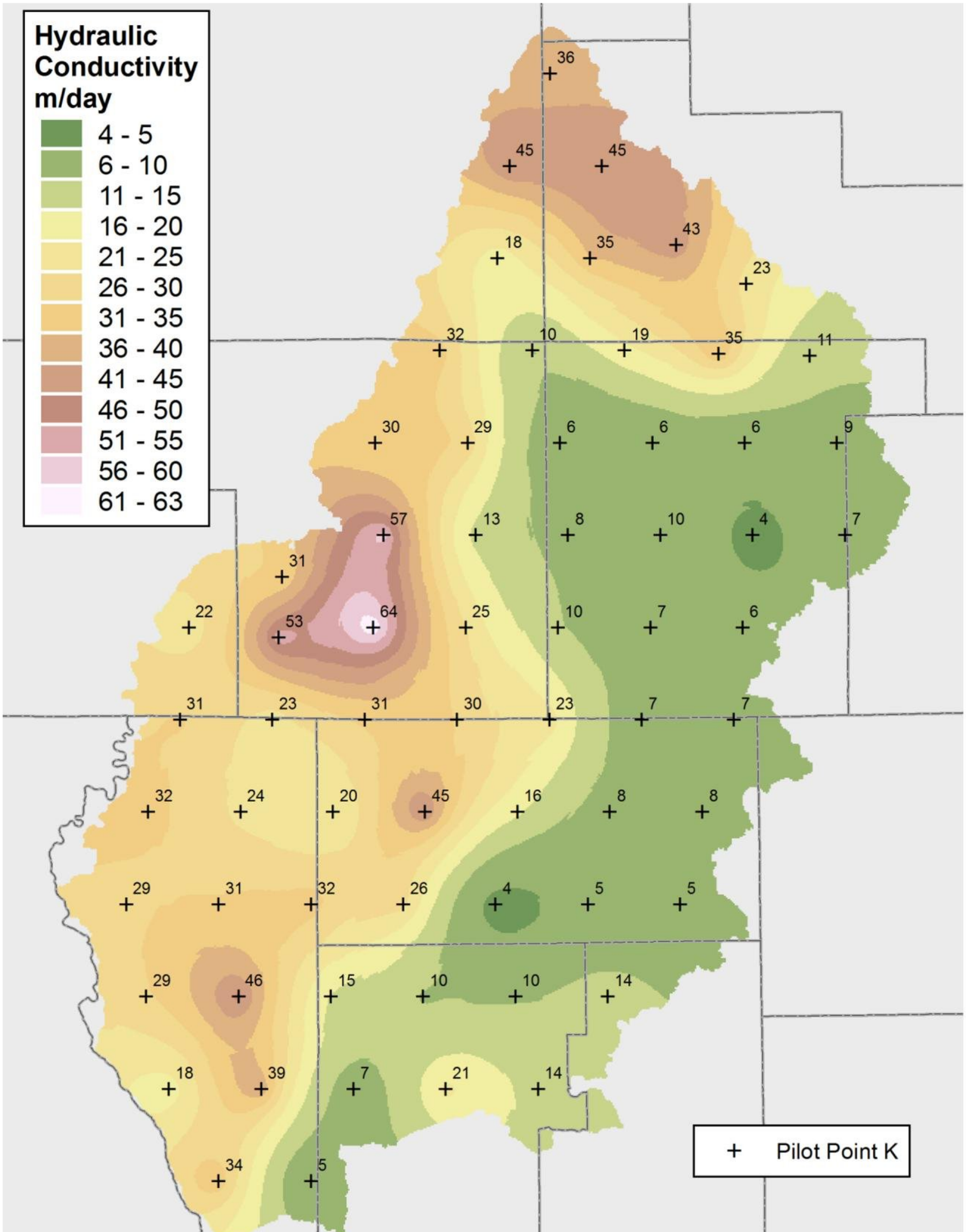


Figure 9. Hydraulic Conductivity distribution for layer one for the calibrated MODFLOW model.

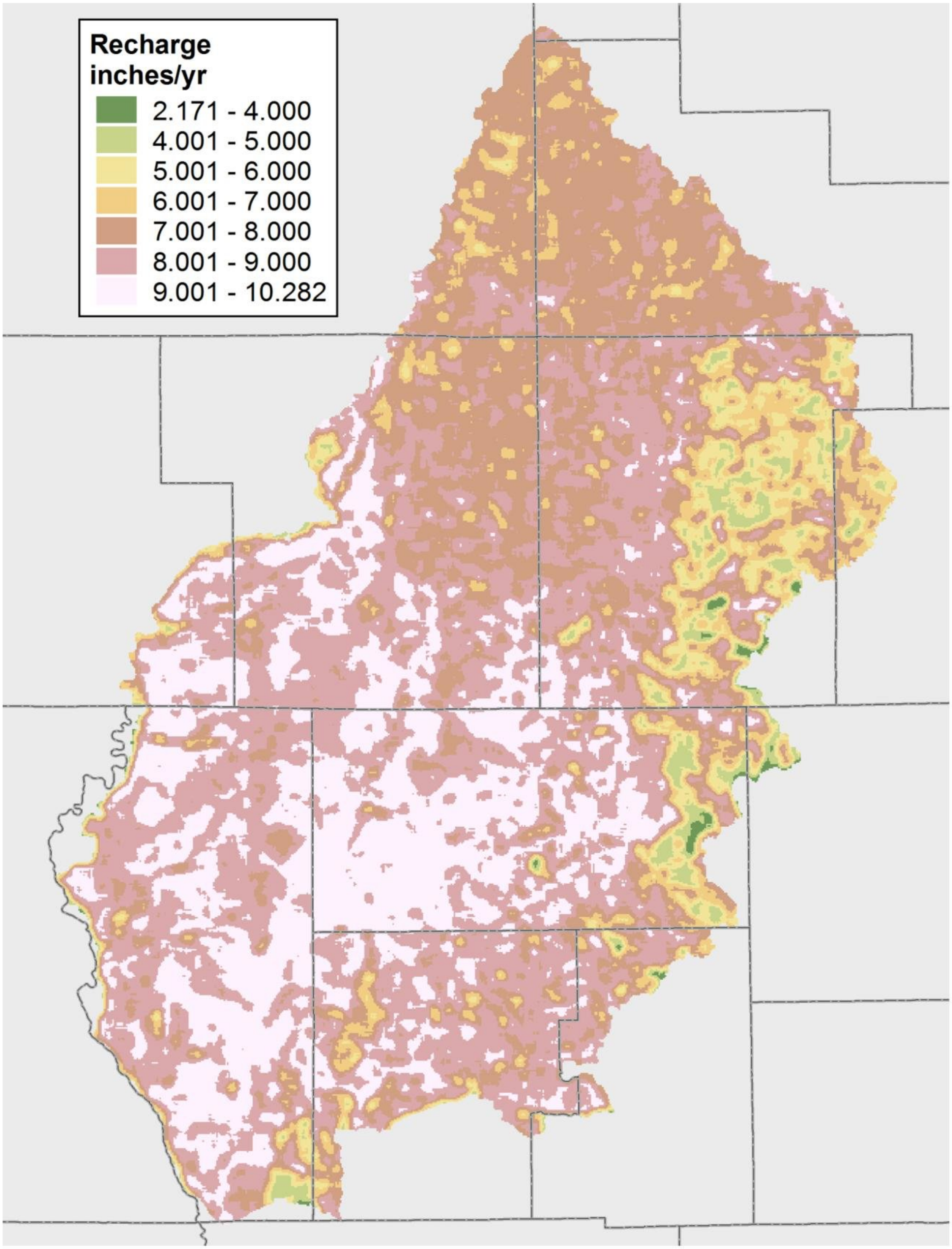


Figure 10. Recharge distribution for the calibrated MODFLOW model.

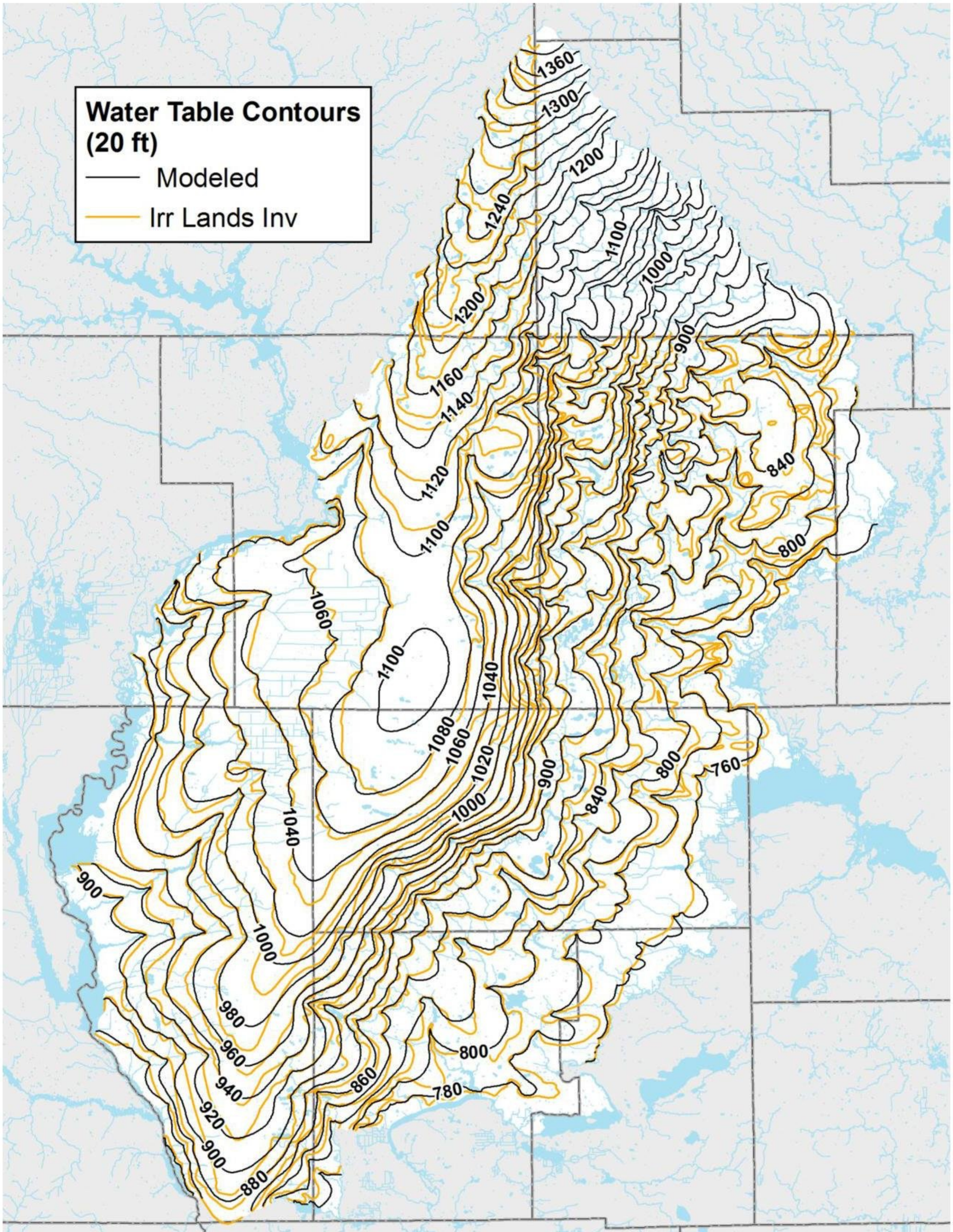
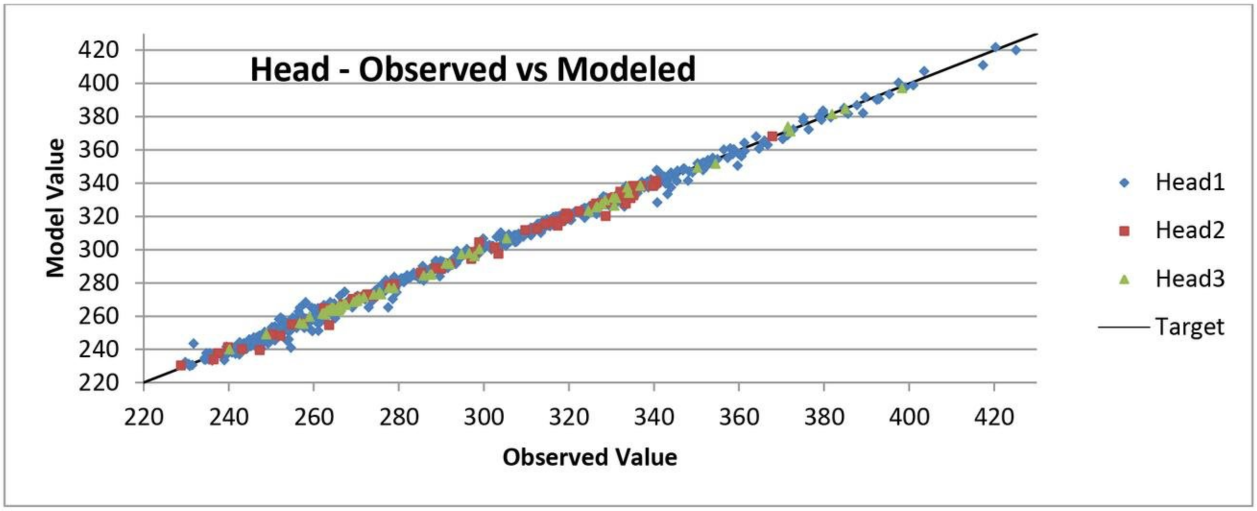


Figure 11. Modeled water table elevations compared to those mapped by Lippelt and Hennings (1981).



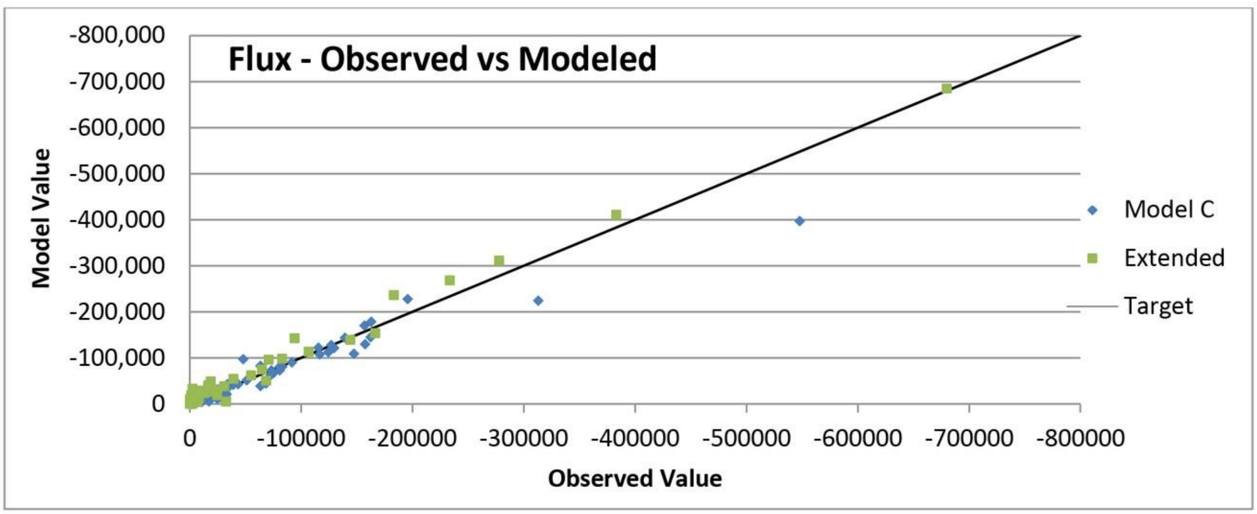


Figure 12. Observed versus modeled head and flux targets for the calibrated MODFLOW model.

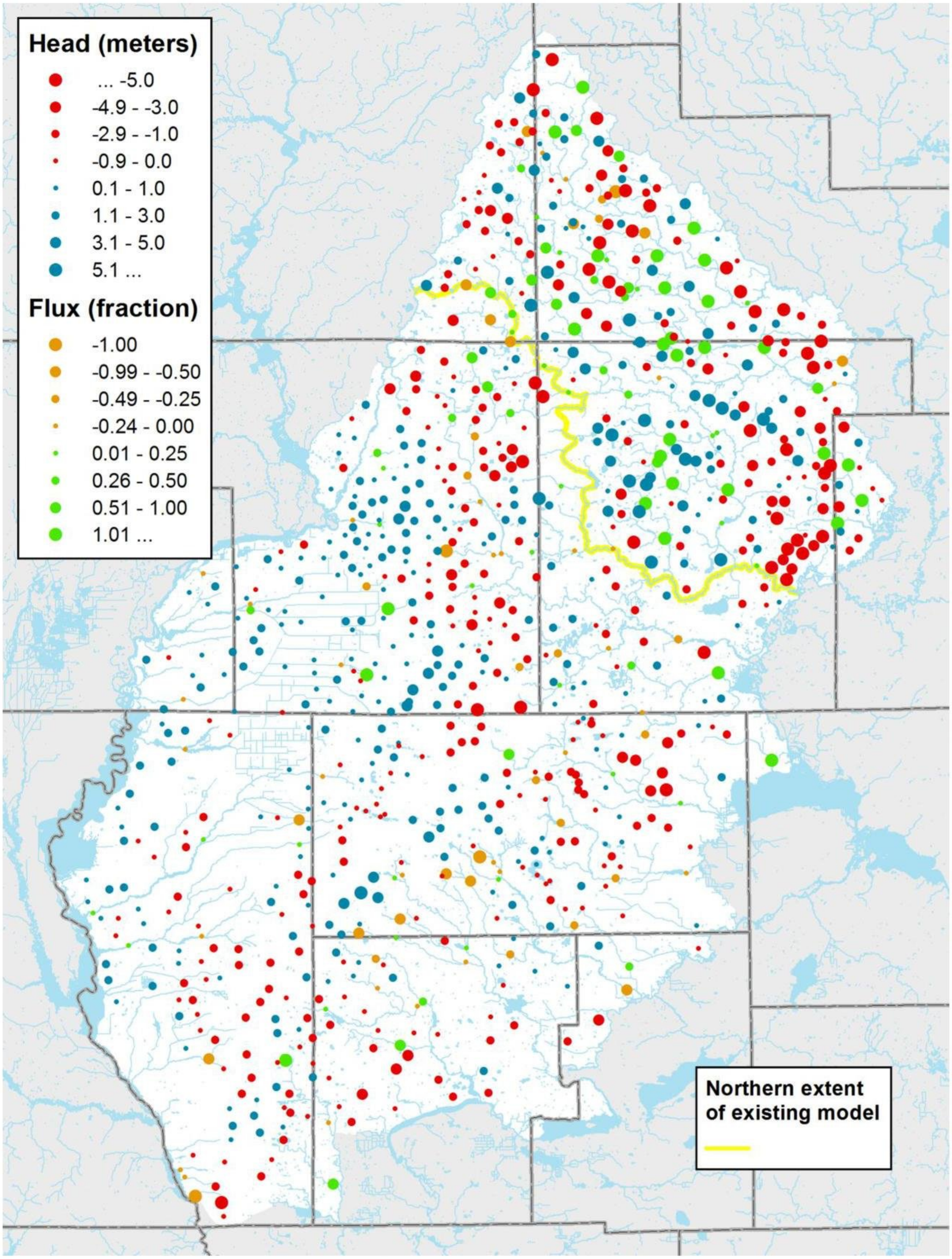


Figure 13. Head and flux target residuals for the calibrated MODFLOW model.

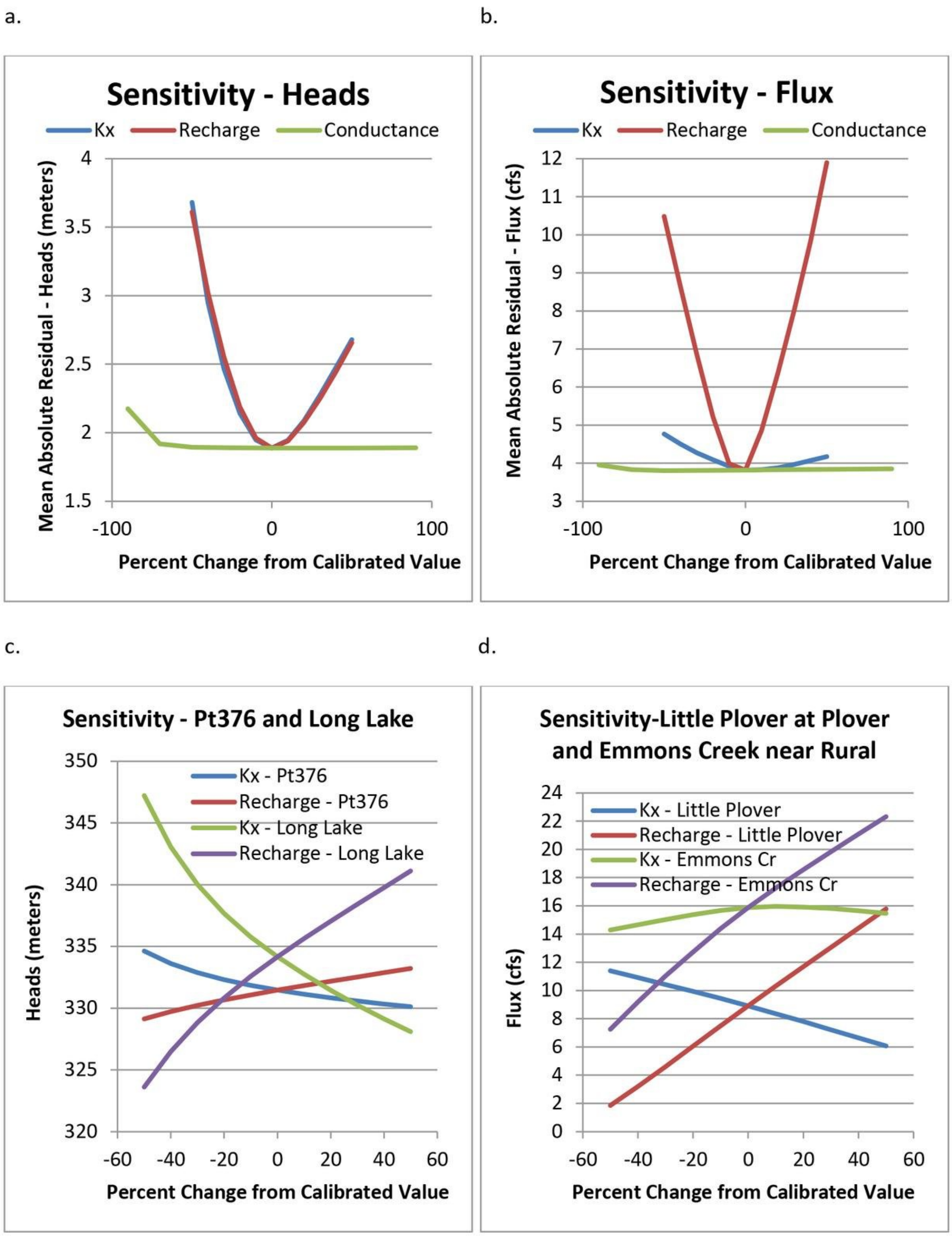


Figure 14. Model sensitivity to hydraulic conductivity, recharge, and river/drain conductance for all head targets (a) and flux targets (b). Model sensitivity to hydraulic conductivity and recharge at two head observation points, Pt376 in Portage County and Long Lake in west central Waushara County (c), and two flux targets, Little Plover River at Plover and Emmons Creek near Rural (d).

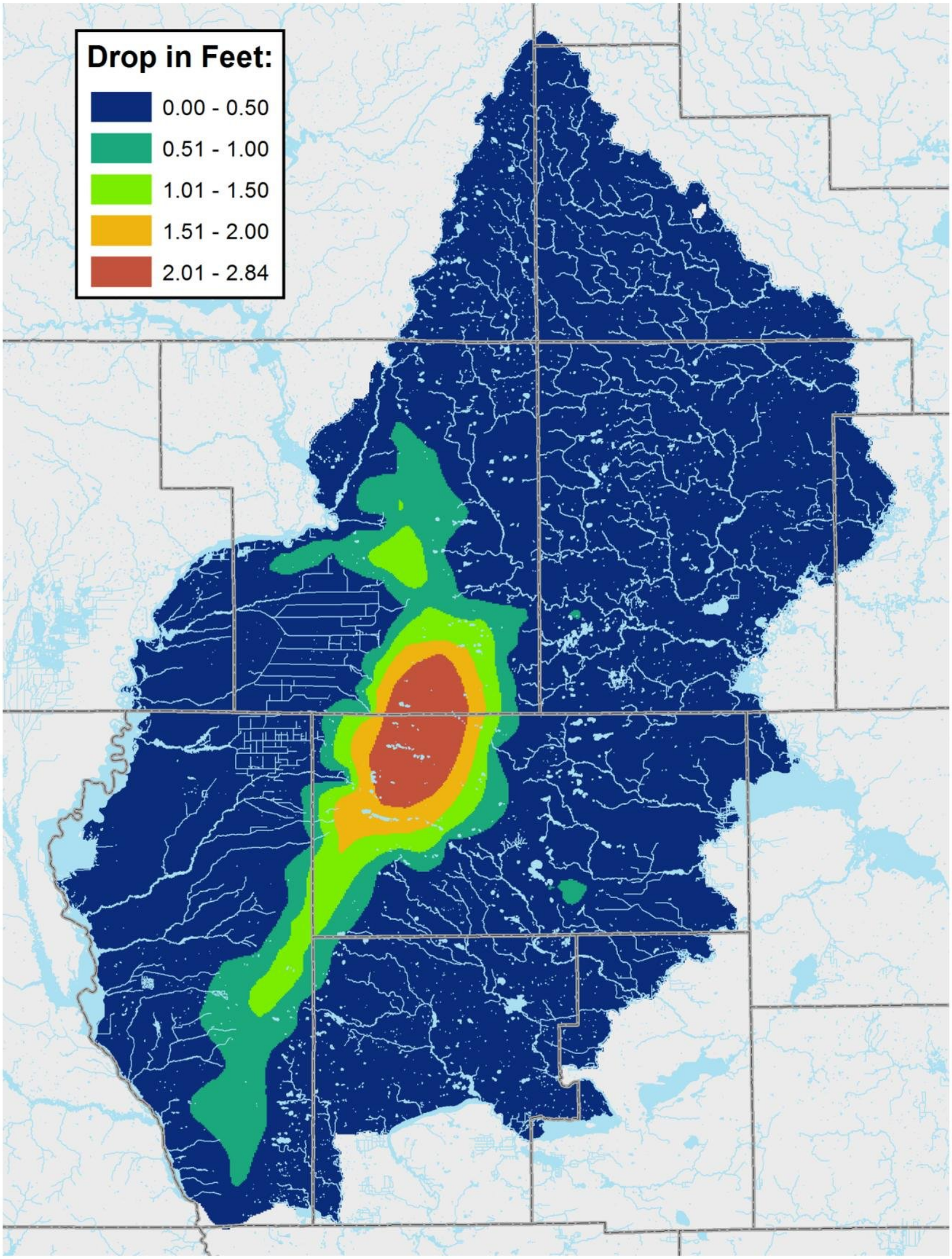


Figure 15. Drop in water table per inch reduction in net recharge on irrigated lands.

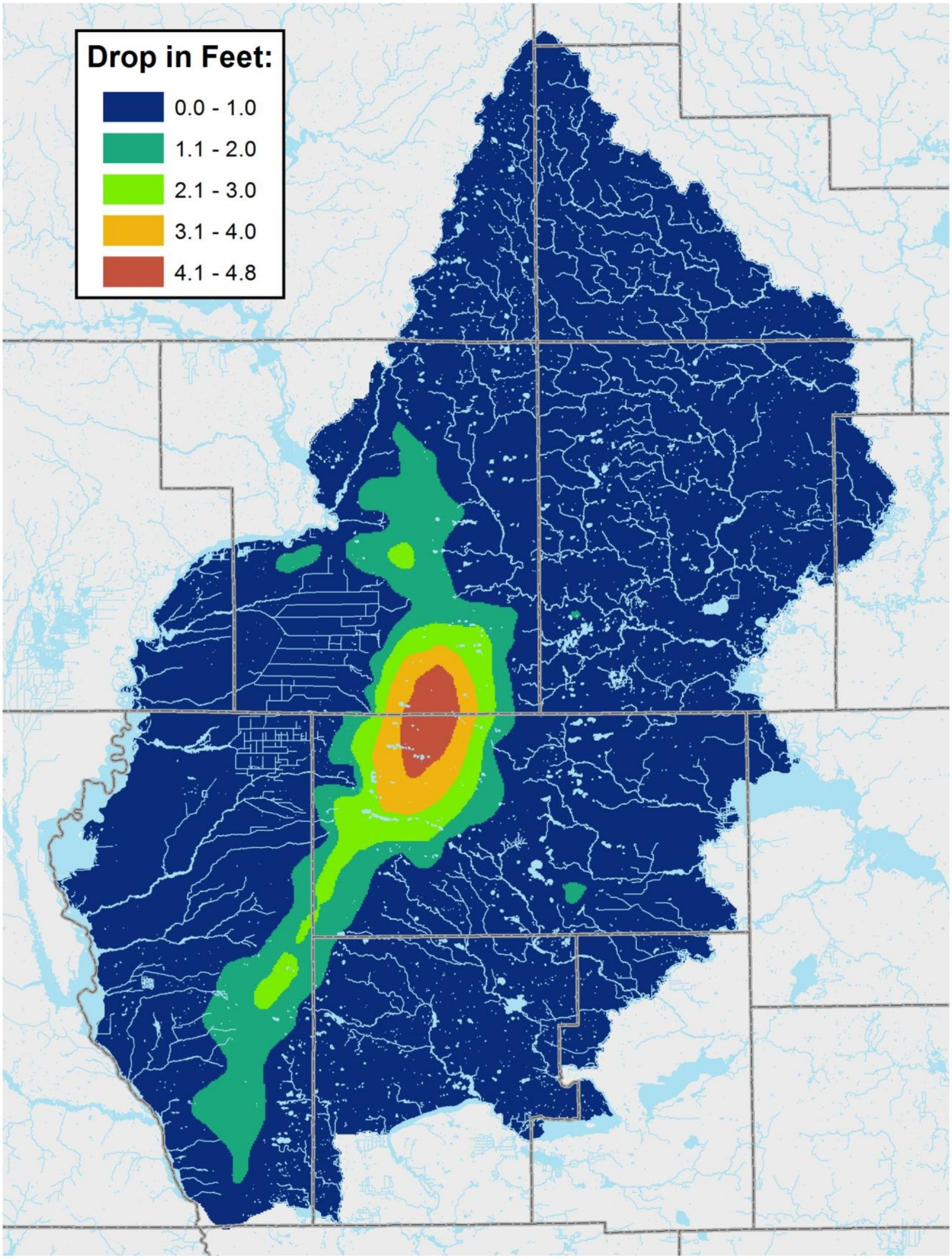


Figure 16. Drop in water table with 2 inches reduction in net recharge on irrigated lands.

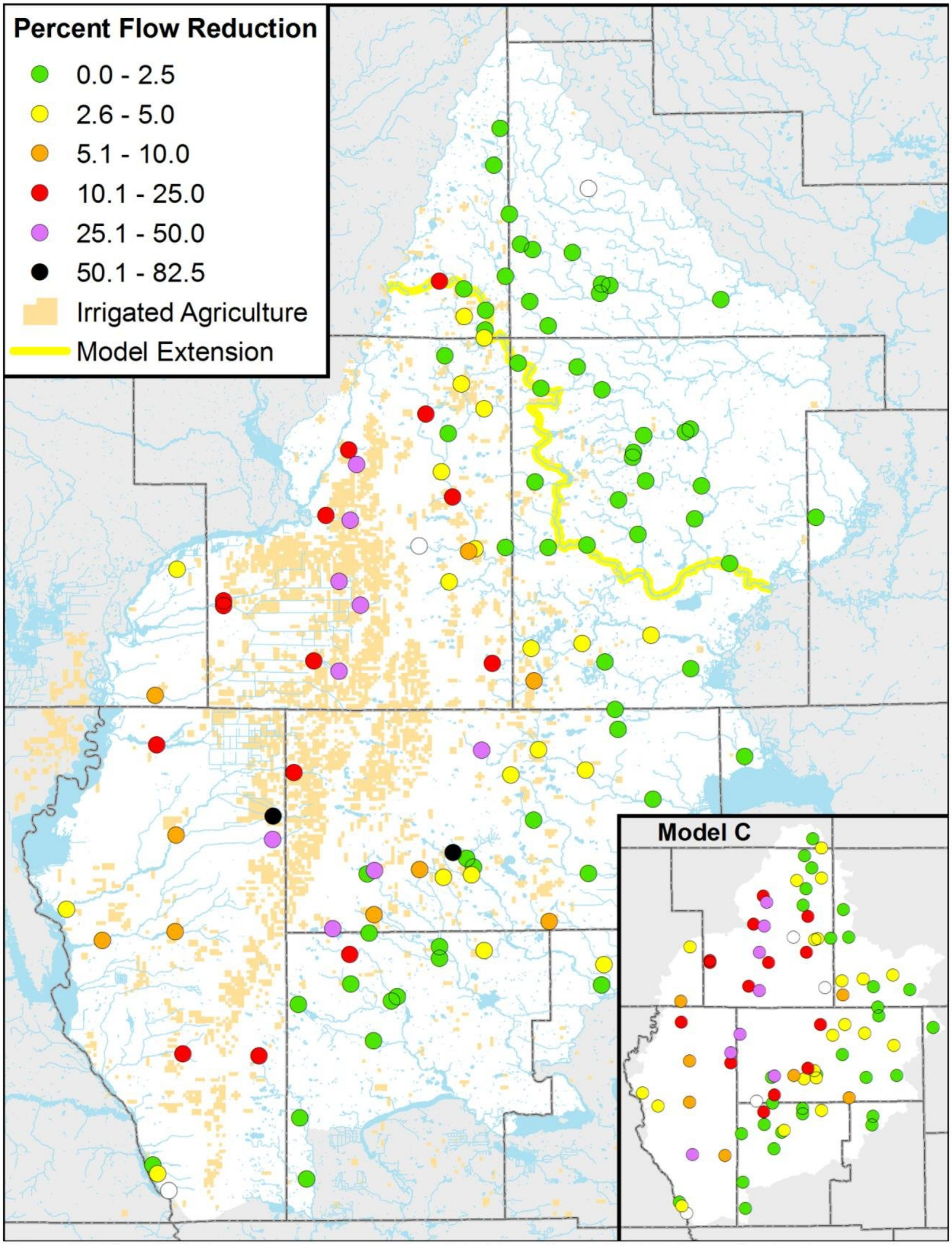


Figure 17. Flow depletion as a percentage of modeled base flow with 2 inches reduction in net recharge on irrigated lands.

Appendix C

Irrigation Rate Estimation for 2008 – 2010

Table C-1. Irrigation rates for crops in 2008.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2008 Crop	Irrigated Crop Inches in 2008
1	23619	130.7	130.7	Potatoes (Russet)	9.16
2a	23906	16.5		Corn (Yellow, Grain)	
2b	23906	18.5	35	Alfalfa/Hay	5.42
3a	23858	55		Potatoes (Russet)	
3b	23858	73		Corn (Sweet)	
3c	23858	14.6	142.6	Corn (Yellow, Grain)	12.08
4	23847	55	55	Peas	5.43
5a	24203, 68696	93.2		Corn (Yellow, Grain)	
5b	24203, 68697	52.1	145.3	Soybeans	5.54
6a	68917	31.3		Corn (Yellow, Grain)	
6b	68917	33		Corn (Yellow, Grain)	
6c	68917	53.3		Corn (Yellow, Grain)	
6d	68917	19.3		Alfalfa/Hay	
6e	68917	20.2		Alfalfa/Hay	
6f	68917	32.5	189.6	Alfalfa/Hay	7.52
7a	1584	14.8		Potatoes (Russet)	
7c	1584	18.2		Potatoes (Russet)	
7d	1584	18		Corn (Yellow, Grain)	
7b	1584	14.7	65.7	Alfalfa/Hay	12.22
8a	24049	50.1		Corn (Sweet)	
8d	24049	19.6		Soybeans	
8c	24049	16.9	86.6	Alfalfa/Hay	9.90
8b	24293	17.3		Corn (Yellow, Grain)	
8e	24293	34.5	51.8	Corn (Yellow, Grain)	11.07
9b	422	36.9		Potatoes (Russet)	
9c	422	37.7		Corn (Yellow, Grain)	
9a	422	33.7	108.3	Alfalfa/Hay	9.28
10	24091	41.7	41.7	Corn (Yellow, Grain)	11.45
11b	581	42		Corn (Sweet)	
11a	581	41.6	83.6	Soybeans	14.04
11c	813	148.4	148.4	Soybeans	6.94
12b	24098	60.4		Potatoes (Uncategorized)	
12a	24098	65.1	125.5	Corn (Yellow, Grain)	13.66

13a	23792	38.1		Red Beets	
13c	23792	38.1		Red Beets	
13b	23792	37.5		Wax Beans	
13d	23792	37.5	151.2	Wax Beans	4.17
14	23839	135	135	Green Beans	6.19
15	24173	87.3	87.3	Green Beans	5.21
16a	23602	62.3		Corn (Sweet)	
16b	23602	63.1	125.4	Corn (Sweet)	5.51
17a	24014	34.8		Corn (Sweet)	
17b	24014	56.2		Corn (Sweet)	
17c	24014	64	155	Corn (Sweet)	6.66
18	23666	148	148	Green Beans	12.84
19	23711	119	119	Potatoes (Russet)	10.79
20c	411	50.7		Potatoes or Peas	
20a	411	51		Green Beans	
20b	411	30.9	132.6	Green Beans	9.32
21b	911	35.2		Potatoes (Russet)	
21c	911	72.3		Potatoes (Russet)	
21a	911	32.8	140.3	Green Beans	19.17
22	36394	146.4	146.4	Corn (Yellow, Grain)	12.33
23c	36666	33.8		Potatoes (Yukon Gold)	
23b	36666	30.6		Misc. Vegetables	
23a	36666	29.1	93.5	Alfalfa/Hay	13.18
23d	1650	144.8	144.8	Potatoes (Russet)	4.72
24	36550	154.2	154.2	Corn (Sweet)(Including edges)	8.60
25a	36728	28.6		Green Beans	
25b	36728	37		Green Beans	
25c	36728	39.7		Green Beans	
25e	36728	34		Green Beans	
25d	36728	37.3		Peas	
25f	36728	75.7	252.3	Peas	10.38
26a	67319	68.9		Corn (Sweet)(Including edges)	
26b	67319	69.4	138.3	Green Beans (include edges)	5.38
27	64	124.2	124.2	Peas	6.72
28a	36454	110.3		Corn (Yellow, Grain)	
28b	36454	75.8	186.1	Soybeans	9.85
29b	36720	113		Corn (Yellow, Grain)	
29a	36720	150	263	Alfalfa/Hay	13.11
30a	258	72.9		Potatoes (Uncategorized)	
30b	258	37.4		Green Beans	
30c	258	35.4	145.7	Green Beans	13.12
31a	36508	114		Corn (Yellow, Grain)	
31b	36508	74.2	188.2	Corn (Yellow, Grain)	12.49

32	36529	149.2	149.2	Corn (Yellow, Grain)	9.20
33	146	145.4	145.4	Corn (Yellow, Grain)	9.92
34b	1616	76.5		Corn (Yellow, Grain)	
34a	1616	85	161.5	Green Beans	2.08
35	339	136.7	136.7	Corn (Sweet)	8.34
36	311	149.1	149.1	Corn (Sweet)	8.86
37	55	148.9	148.9	Corn (Yellow, Grain)	13.46
38	24	151.2	151.2	Corn (Yellow, Grain)	12.52
39	42	102.7	102.7	Corn (Yellow, Grain)	9.64
				Median	9.48
				Average	9.46

Table C-2. Irrigation rates for crops in 2009.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2009 Crop	Irrigated Crop Inches in 2009
1	23619	130.7	130.7	Corn (Sweet)	11.36
2a	23906	16.5		Corn (Yellow, Grain)	
2b	23906	18.5	35	Alfalfa/Hay	1.87
3b	23858	73		Potatoes (Russet)	
3c	23858	14.6		Corn (Yellow, Grain)	
3a	23858	55	142.6	Green Beans	7.64
4	23847	55	55	Potatoes (Russet)	8.50
5b	24203, 68697	52.1		Corn (Yellow, Grain)	
5a	24203, 68696	93.2	145.3	Green Beans	2.43
6a	68917	31.3		Corn (Yellow, Grain)	
6b	68917	33		Corn (Yellow, Grain)	
6c	68917	53.3		Corn (Yellow, Grain)	
6d	68917	19.3		Corn (Yellow, Grain)	
6f	68917	32.5		Corn (Yellow, Grain)	
6e	68917	20.2	189.6	Alfalfa/Hay	5.98
7b	1584	14.7		Potatoes (Russet)	
7d	1584	18		Potatoes (Russet)	
7c	1584	18.2		Corn (Yellow, Grain)	
7a	1584	14.8	65.7	Rye	9.18
8d	24049	19.6		Corn (Yellow, Grain)	
8a	24049	50.1		Green Beans	
8c	24049	16.9	86.6	Alfalfa/Hay	7.02
8b	24293	17.3		Potatoes (Uncategorized)	
8e	24293	34.5	51.8	Corn (Yellow, Grain)	4.99
9c	422	37.7		Potatoes (Uncategorized)	
9a	422	33.7		Corn (Yellow, Grain)	
9b	422	36.9	108.3	Corn (Yellow, Grain)	9.40
10	24091	41.7	41.7	Green Beans	6.49
11a	581	41.6		Potatoes (Uncategorized)	
11b	581	42	83.6	Soybeans	6.91
11c	813	148.4	148.4	Corn (Sweet)	9.25
12a	24098	65.1		Corn (Sweet)	
12b	24098	60.4	125.5	Corn (Sweet)	11.11
13a	23792	38.1		Cucumbers	
13b	23792	37.5		Cucumbers	
13c	23792	38.1		Cucumbers	
13d	23792	37.5	151.2	Cucumbers	2.78
14	23839	135	135	Corn (Sweet)	7.12
15	24173	87.3	87.3	Corn (Yellow, Grain)	7.59

16a	23602	62.3		Corn (Yellow, Grain)	
16b	23602	63.1	125.4	Green Beans	6.83
17a	24014	34.8		Corn (Yellow, Grain)	
17b	24014	56.2		Corn (Yellow, Grain)	
17c	24014	64	155	Green Beans	5.23
18	23666	148	148	Potatoes (White)	12.59
19	23711	119	119	Green Beans	3.59
20b	411	30.9		Potatoes (Uncategorized)	
20a	411	51		Corn (Yellow, Grain)	
20c	411	50.7	132.6	Corn (Yellow, Grain)	7.04
21a	911	32.8		Corn (Yellow, Grain)	
21b	911	35.2		Corn (Yellow, Grain)	
21c	911	72.3	140.3	Corn (Yellow, Grain)	12.60
22	36394	146.4	146.4	Green Beans	6.83
23b	36666	30.6		Potatoes (Uncategorized)	
23a	36666	29.1		Green Beans	
23c	36666	33.8	93.5	Green Beans	8.76
23d	1650	144.8	144.8	Corn (Sweet)	5.92
24	36550	154.2	154.2	Green Beans	5.98
25a	36728	28.6		Potatoes (Uncategorized)	
25b	36728	37		Potatoes (Uncategorized)	
25c	36728	39.7		Potatoes (Uncategorized)	
25e	36728	34		Potatoes (Uncategorized)	
25f	36728	75.7		Potatoes (Uncategorized)	
25d	36728	37.3	252.3	Soybeans	14.85
26b	67319	69.4		Potatoes (White)	
26a	67319	68.9	138.3	Green Beans	7.54
27	64	124.2	124.2	Corn (Sweet)	15.61
28b	36454	75.8		Corn (Yellow, Grain)	
28a	36454	110.3	186.1	Green Beans	5.93
29b	36720	113		Potatoes (Russet)	
29a	36720	150	263	Corn (Sweet)	7.41
30b	258	37.4		Corn (Sweet)	
30c	258	35.4		Corn (Sweet)	
30a	258	72.9	145.7	Green Beans	9.02
31b	36508	74.2		Corn (Yellow, Grain) and Soybeans	
31a	36508	114	188.2	Green Beans	6.92
32	36529	149.2	149.2	Peas	9.62
33	146	145.4	145.4	Corn (Yellow, Grain)	9.95
34a	1616	85		Corn (Yellow, Grain)	
34b	1616	76.5	161.5	Soybeans	7.67
35	339	136.7	136.7	Green Beans or Peas	19.13
36	311	149.1	149.1	Potatoes (Uncategorized)	16.17

37	55	148.9	148.9	Corn (Yellow, Grain)	13.78
38	24	151.2	151.2	Corn (Yellow, Grain)	11.21
39	42	102.7	102.7	Soybeans	7.75
				Median	**7.62**
				Average	**8.51**

Table C-3. Irrigation rates for crops in 2010.

Field ID #	Hi-Cap Well #	Crop Acres	Total Acres	2010 Crop	Irrigated Crop Inches in 2010
1	23619	130.7	130.7	Sweet Corn	3.94
2a	23906	16.5		Corn Silage	
2b	23906	18.5	35	Alfalfa	No pump data
3b	23858	73		Sweet Corn	
3c	23858	14.6		Corn (Yellow, Grain)	
3a	23858	55	142.6	Potatoes (White)	3.36
4	23847	55	55	Green Beans/Soybeans	0.83
5b	24203, 68697	52.1		Potatoes (Russet)	
5a	24203, 68696	93.2	145.3	Potatoes (Russet)	2.07
6a	68917	31.3		Oats	
6b	68917	33		Corn (Yellow, Grain)	
6c	68917	53.3		Corn (Yellow, Grain)	
6d	68917	19.3		Corn (Yellow, Grain)	
6f	68917	32.5		Corn (Yellow, Grain)	
6e	68917	20.2	189.6	Corn (Yellow, Grain)	1.21
7b	1584	14.7		Rye	
7d	1584	18		Corn (Yellow, Grain)	
7c	1584	18.2		Potatoes (Russet)	
7a	1584	14.8	65.7	Potatoes (Russet)	4.39
8d	24049	19.6		Alfalfa	
8a	24049	50.1		Sweet Corn	
8c	24049	16.9	86.6	Alfalfa	12.38
8b	24293	17.3		Sweet Corn	
8e	24293	34.5	51.8	Corn (Yellow, Grain)	0.51
9c	422	37.7		Corn (Yellow, Grain)	
9a	422	33.7		Soybeans	
9b	422	36.9	108.3	Potatoes (Russet)	No pump data
10	24091	41.7	41.7	Sweet Corn	4.58
11a	581	41.6		Sweet Corn	
11b	581	42	83.6	Corn (Yellow, Grain)/Potatoes (Russet)	6.97
11c	813	148.4	148.4	Potatoes (Russet)/Potatoes (Red)	3.60
12a	24098	65.1		Potatoes	
12b	24098	60.4	125.5	Sweet Corn	7.98
13a	23792	38.1		Sweet Corn	
13b	23792	37.5		Red Beets	
13c	23792	38.1		Sweet Corn	
13d	23792	37.5	151.2	Red Beets	2.63
14	23839	135	135	Cucumbers	No pump data

15	24173	87.3	87.3	Potatoes (Russet)/Corn (Yellow, Grain)	7.73
16a	23602	62.3		Green beans	
16b	23602	63.1	125.4	Corn (Yellow, Grain)	2.39
17a	24014	34.8		Sweet Corn	
17b	24014	56.2		Sweet Corn	
17c	24014	64	155	Corn (Yellow, Grain)	0.98
18	23666	148	148	Green Beans	No pump data
19	23711	119	119	Corn (Yellow, Grain)	3.84
20b	411	30.9		Green Beans	
20a	411	51		Potatoes (Russet)	
20c	411	50.7	132.6	Corn (Yellow, Grain)	5.64
21a	911	32.8		Green Beans	
21b	911	35.2		Green Beans	
21c	911	72.3	140.3	Green Beans	3.71
22	36394	146.4	146.4	Potatoes (Russet)	No pump data
23b	36666	30.6		Soybeans	
23a	36666	29.1		Potatoes (Russet)	
23c	36666	33.8	93.5	Potatoes (Russet)	6.87
23d	1650	144.8	144.8	Sweet Corn	3.65
24	36550	154.2	154.2	Potatoes (White)	8.64
25a	36728	28.6		Sweet Corn/Carrots	
25b	36728	37		Sweet Corn/Carrots	
25c	36728	39.7		Green Beans	
25e	36728	34		Peas	
25f	36728	75.7		Green Beans	
25d	36728	37.3	252.3	Green Beans	3.73
26b	67319	69.4		Millet	
26a	67319	68.9	138.3	Potatoes (White)	4.07
27	64	124.2	124.2	Potatoes	11.20
28b	36454	75.8		Potatoes	
28a	36454	110.3	186.1	Potatoes	8.27
29b	36720	113		Corn (Yellow, Grain)	
29a	36720	150	263	Potatoes	No pump data
30b	258	37.4		Potatoes	
30c	258	35.4		Alfalfa	
30a	258	72.9	145.7	Green Beans	11.70
31b	36508	74.2		Potatoes	
31a	36508	114	188.2	Winter Wheat	9.55
32	36529	149.2	149.2	Peas	10.44
33	146	145.4	145.4	Corn (Yellow, Grain)	3.18
34a	1616	85		Green Beans	
34b	1616	76.5	161.5	Corn (Yellow, Grain)	No pump data
35	339	136.7	136.7	Soybeans	10.20

36	311	149.1	149.1	Green Beans	8.07
37	55	148.9	148.9	Potatoes	No pump data
38	24	151.2	151.2	Corn (Yellow, Grain)	3.50
39	42	102.7	102.7	Corn (Yellow, Grain)	6.83
				Median	**4.23**
				Average	**5.55**