Knowledge Development for Groundwater Withdrawal Management around the Little Plover River, Portage County Wisconsin

A Report to the Wisconsin Department of Natural Resources
in Completion of
Project: NMG00000253

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January 14, 2009

EXECUTIVE SUMMARY

The Little Plover River is a 5-mile long, baseflow-dominated, cold-water stream located in Portage County on the Wisconsin Central Sand Plain. The Little Plover begins at the foot of the Arnott moraine, and flows westward where it discharges to the Wisconsin River. It supports a naturally reproducing brook trout population and highly diverse wetlands in its riparian corridor. In earlier times, the fishery was highly prized but its quality has deteriorated for reasons that include diminished streamflow. Average annual discharge (Hoover Rd. station) was 10.6 cfs during 1959-1987, a historical period of continuous flow monitoring. The groundwater basin in the vicinity of the Little Plover has been greatly developed for agricultural, municipal, and industrial groundwater pumping.

Acutely small discharges were noted in the Little Plover beginning in 2003. In summer 2005 discharge dropped to 1.6 cfs at Hoover Rd., and a 1.3 mile stream reach centered near Eisenhower Rd. dried completely. (Notably, a public rights stage of 4 cfs has been calculated at Eisenhower Rd. by the Wisconsin Department of Natural Resources, which amounts to about a Q_{14} for the 1959 through 1987 historical period). Comparisons to nearby streams suggest that the discharge at Hoover, without an artificial stress, should have been about 7 cfs. Similar low flows and dried stretches occurred in summer 2006, summer 2007, and winter 2008.

Drought and groundwater pumping were postulated to be the causes of low flow conditions. However, precipitation, drought index, and discharges in reference streams indicate near average conditions from 2000 through 2004, and moderately dry conditions (about a 10 year return period) in 2005-7. Much drier conditions prevailed during parts of the 1959-1986 historical record without the extreme low flows that have been observed in 2005-7. Thus recent climate alone does not adequately explain the record low flow conditions in the Little Plover River.

Groundwater pumping in the vicinity of the Little Plover developed rapidly from around 1960 through the mid 1980s, due to the growth of crop irrigation. Initially crop irrigation occurred every third year but this rotation schedule quickly progressed to biannual and annual crop irrigation. Additional high capacity wells were installed over the decades for municipal water supplies (1964 – Whiting, 1989-Plover), vegetable processing (1965 – Del Monte), and paper production (1960 and increasing greatly in the late 1980s). Some 97 high capacity wells lie within 2 miles of the stream. Presently, Del Monte pumping follows an annual cycle that begins on July 1 and continues for 90 days at a rate of about 2 million gallons per day, then declines to 0.75 million gallons per day for 45 days, and then ceases for the year. About 77% of pumped water is returned to the landscape as wastewater discharge. Village of Plover pumpage is split between two wellfields, one containing wells 1 and 2, the other containing well 3. Plover pumpage grew from an average 310,000 gallons per day (gpd) in 1990 and was about 1.3 million

gallons per day in 2006 and 2007. The Whiting-area wellfield, tapped for municipal and industrial use, contains two wells serving municipal needs, and five that serve two paper producers. Total wellfield pumping amounts to 4.1 million gallons per day (mgd) or about 6.3 cubic feet per second (cfs). Agricultural irrigation is somewhat enigmatic as until 2007 growers were not required to report pumpage nor were grower recollections and records of past irrigation complete. The irrigated crop rotation, with some variation, in the vicinity of the Little Plover is typically a 3 year rotation of potato, sweet corn, and snap beans. Grower recollections of irrigation for 2006 – a year with a dry growing season - averaged 4.4 to 6.1 inches depending on crop. More reliable data are available for 2007, which is the first year that growers were required to report pumpage under Wisconsin's new groundwater management law. Thus, in 2007 irrigation amounts could be quantified more accurately, and averaged 12.5 in. Notably 2007 had a much drier than average growing season.

Statistical and flow modeling approaches were employed to help understand how much streamflow diversion might be attributable to groundwater pumping. Double mass curve analysis discerns pumping diversions were beginning in about 1973. (Pumping diversions were likely occurring earlier, but they were not be discernable as the Little Plover flow record did not encompass a period where groundwater pumping was totally absent in the vicinity). By 1986, about 2.2 cfs of missing discharge was apparent. Statistical methods also indicate missing discharges at Hoover Rd. were 3.9 - 5.0 cfs in May-August 2005 and 3.4 cfs in 2006.

Groundwater flow modeling approaches agreed well with statistical ones, indicating on average 3.2-5.4 cfs of discharge at Hoover Rd. is diverted by current groundwater pumping amounts (the range is due to uncertainties in average irrigation amounts). Groundwater flow modeling is also able to apportion pumping diversions to individual sectors and individual wells. Village of Plover pumping prompted the single largest diversion, about 1.2 cfs for 2004 to 2006 pumping. Diversions amount to about ¾ of pumped water from wells 1 and 2, and about 1/3 of pumped water from well 3. Del Monte annual diversions peak at about 0.38 cfs at Hoover Rd. every year and then diminish. Annually, this diversion averages only about 0.2 cfs. Whiting municipal and industrial pumping divert about 0.57 cfs at Hoover. Irrigation diversions are only roughly known due to grower uncertainty regarding average irrigation amounts. Assuming a range of 2 to 6 in of consumptive use on irrigated lands, irrigation diversions would average 1.1 to 3.3 cfs at Hoover, but peak annually at 1.7 to 5 cfs. About 40% of irrigation diversions originate from within 0.5 miles of the Little Plover, 58% from within 1.0 miles, and 82% from within 2.0 miles. About 18% or irrigation diversions originate from beyond 2 miles.

We conclude that Little Plover flows would be robust in the absence of groundwater pumping, with minimums in recent years of about 6.5 cfs at Hoover Rd. Diversions by groundwater pumping capture roughly 3-5.4 cfs of potential Little Plover discharges.

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I. INTRODUCTION

The Little Plover is a 5-mile long, baseflow-dominated, cold-water stream located in Portage County, Wisconsin on the Wisconsin Central Sand Plain (Figure 1). Average annual discharges in 1959 through 1987 (Hoover Rd. station, Figure 2) were 10.6 cfs. The stream supports a coldwater fishery containing a naturally reproducing brook trout population and highly diverse wetlands in its riparian corridor. In earlier times, the fishery was highly prized but the fishery quality seems to have deteriorated substantially for reasons not completely understood (Hunt, 1985 and 1988), but possibly related to flow or water quality deterioration. In more recent times, the fishery has been definitively impacted by diminished stream discharges (T. Meronek, Wisconsin Department of Natural Resources, pers. comm.)

The groundwater basin in the vicinity of the Little Plover has been greatly developed for agricultural, municipal, and industrial groundwater extraction purposes. Some 97 high capacity wells lie within 2 miles of the stream (Figure 3). Acutely small discharges were noted in the Little Plover beginning in 2003. Discharge diminished further in subsequent years and on August 8, 2005 discharge dropped to 1.6 cfs at Hoover Rd., near zero at Kennedy, and a 1.3 mile stream reach centered near Eisenhower Rd. (County R) dried completely, resulting in a fish kill (Figure 4). Comparisons to nearby streams suggest that the discharge at Hoover, without an artificial stress, should have been about 7 cfs (Chapter V). Similar low flows and dried stretches occurred in summer 2006, summer of 2007, and winter 2008. Emergency stream flow augmentation precluded a prolonged dry-up during summer 2007 when 900 gallons per minute (2 cfs) from a nearby well were pumped into the river from the beginning of July through mid-September. Notably, a public rights stage of 4 cfs has been calculated at Eisenhower Rd. by the Wisconsin Department of Natural Resources (WDNR) , which amounts to about a Q_{14} (flow would be greater than 4 cfs 86% of the time) for the 1959 through 1987 record.

In response to concerns about the health of the Little Plover River and the impacts of groundwater pumping on streamflow, WDNR initiated a stakeholder-driven, collaborative watershed management process (Born and Genskow, 2001). This report summarizes the results of a project providing knowledge to the stakeholders and assisting the WDNR to understand the causes of the streamflow impairments.

Goal and scope of investigation

The **goal** of the project described herein was to gain an understanding of the role of high capacity well pumping on Little Plover River discharges, and to develop knowledge and tools for advancing a groundwater withdrawal management strategy in the vicinity of the Little Plover River (LPR). The work tasks that were accomplished in support of this goal included:

1. Estimating the amount of high capacity well pumping in the vicinity of the Little Plover River from the Village of Plover, Village of Whiting, paper production at the New Page (formerly Stora Enso and Consolidated Papers) and the Neenah Papers mills, the Del Monte vegetable processing facility, and agricultural irrigation.

2. Compile the record of Little Plover River discharges.

3. Monitor present Little Plover discharges.

4. Acquire improved spatial information on the position of the Little Plover River stream channel and elevation of the Little Plover River streambed for improving groundwater flow models.

5. Estimate the amount of pumping-induced baseflow diversions in the historical (1959-1987) and modern (post 1987) periods, with particular attention to 2003-5.

6. Use a pre-existing calibrated groundwater flow model to address immediate needs of the agency and stakeholders.

7. Build an improved groundwater flow model for the area using new spatial data and improved calibration techniques.

8. Use the improved flow model as a check on projections made with the pre-existing flow model, and to generate new projections.

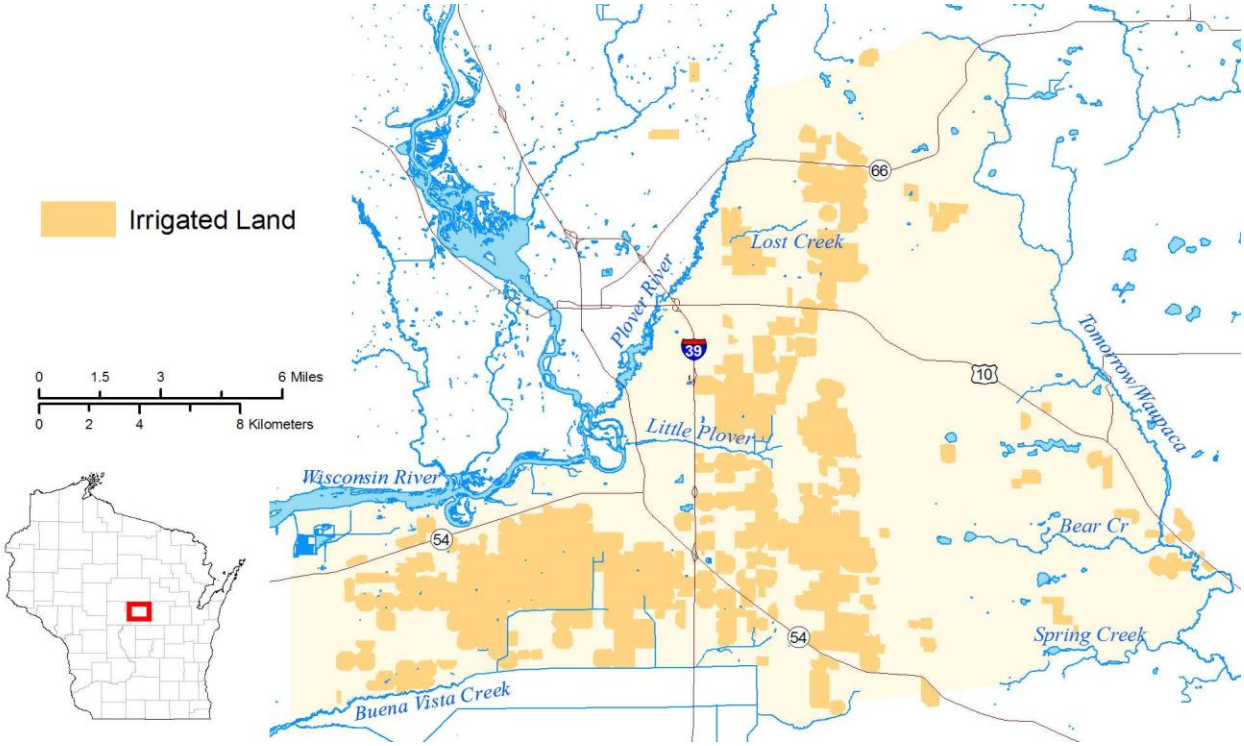


Figure 1. Location of the Little Plover River and general project area with irrigated land cover indicated.

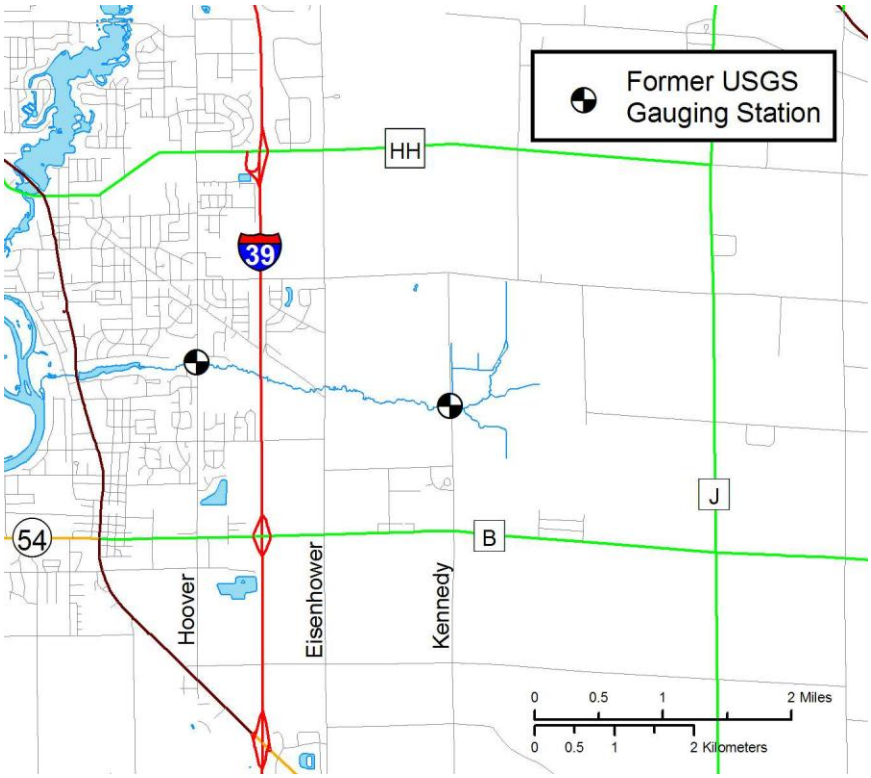


Figure 2. Roads and other features in the vicinity of the Little Plover River.

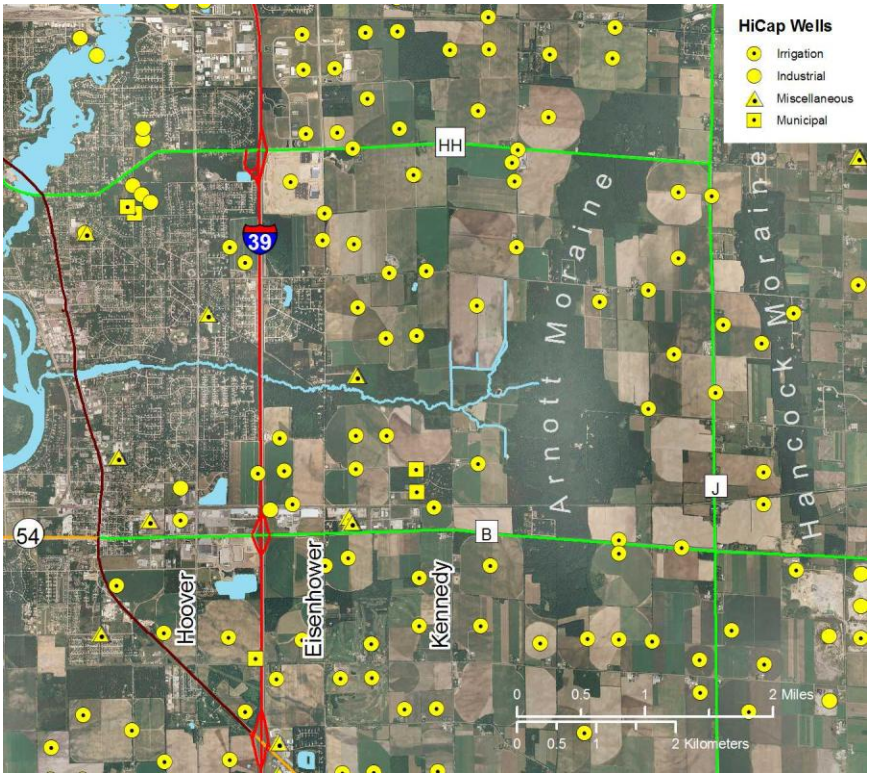


Figure 3. High capacity wells and landscape features in the vicinity of the Little Plover.

Background

The Little Plover begins at the foot of the Arnott moraine (Figure 3), flowing westward across a glaciofluvial sand plain, and discharges into the Wisconsin River. Eastward lies an extension of the sand plain, and then surficial deposits of Horicon Formation till, including the Hancock and Almond moraines and other associated ice-contact features (Holt, 1965; Weeks et al., 1965; Mechenich and Kraft, 1997). The region's aquifer is contained in coarse sediments that blanket low permeability bedrock to thicknesses typically 75 to 130 ft. The area of interest effectively is bounded to the east by the Tomorrow River system and to the west by the (Big) Plover and Wisconsin Rivers (Figure 1). Dominant land uses are irrigated agriculture, non-irrigated agriculture, urban, and forests.

Weeks et al. (1965) estimated that 90 to 95% of Little Plover discharge is derived from groundwater, and that the Little Plover River had a pre-development groundwater basin of approximately 12 mi^2. Weeks et al. further suggested a pre-development average annual water budget for the landscape that consisted of 31 to 32 in of precipitation, 1 in of direct runoff, 20 to 22 in of evapotranspiration, and perhaps 9 to 10 in of groundwater recharge that eventually discharges to the Little Plover. Groundwater for irrigation was thought to increase evapotranspiration by an average 4 in, depending on crop, resulting in a reduction of net groundwater recharge on irrigated lands by the same amount (Weeks et al., 1965; Weeks and Stangland, 1971). Other estimates of recharge amounts are discussed in Mechenich and Kraft (1997).

Groundwater pumping developed rapidly from around 1960 through the mid 1980s, due to the growth of irrigated crop production and a progression to growing irrigated crops annually instead of only bi- or triennially (Weeks et al., 1965; Albertson, 1998). In addition to wells installed for irrigation, high capacity wells were also developed beginning in about 1989 for the Village of Plover, 1964 for Village of Whiting, 1965 for industrial vegetable processing (Del Monte), and 1960 for paper production (Figure 3).

High capacity well development in the Wisconsin Central Sand Plain has long provoked concern that unmanaged withdrawals would deleteriously affect streams, wetlands, and groundwater levels (e.g., Weeks et al., 1965; WDNR, 1970; Weeks and Stangland, 1971; Hindall, S.M. 1978; Butler, 1978). Such concerns led to a well-known USGS study (Weeks et al., 1965) that sought to quantify the impacts of irrigation pumping on streamflow, and the production of a classic film featuring a pumping test adjacent to the Little Plover. Weeks et al. concluded that the net effect of irrigation development on irrigated land is an average 20% increase in evapotranspiration and 40-50% decrease in groundwater recharge. The effect of irrigation on streamflow is a loss of 0.0004-0.0005 cfs per irrigated acre. Given that 500 acres of irrigated land use prevailed during the period of the Weeks study, average baseflow depletion was estimated at about 2.5%. Weeks et al. cautioned strongly that averages are not an adequate indicator of streamflow depletion and stream biota impact, but rather peak depletions needed to be considered, i.e.,

those occurring during low-flow months (July, August) and drought years. With respect to municipal pumping, groundwater flow modeling (Mechenich and Kraft, 1997) indicated that the Plover wells could cause a greater than 40% Little Plover average flow reduction when they reach their 2005 design average pumping rate of 2.7 cfs. (In reality, this design capacity was reached by the late 1990s, and during June and July 2005 monthly averaged pumpage exceeded 3.0 cfs).

Figure 4. Location and photos of dry stretch in 2005. Upper right - dry river bottom near Eisenhower. Middle - dry streambed upstream of Eisenhower about 1 km. Bottom - pool of dead trout; note cracked riverbed indicating drying had been more severe. (Photos Courtesy of Bryant Browne and Jeremy Wisz)

II. DROUGHT INDEX, PRECIPITATION AND DISCHARGES IN REFERENCE STREAMS

In this chapter we examine records of precipitation, drought index, and stream discharges to gain clues as to whether climate alone is likely to account for the recent extreme low-flows observed for the Little Plover. Historically low precipitation, severe to extreme drought indices, and greatly diminished flows on reference streams unaffected by diversions would argue that climate is the major factor affecting the Little Plover. The absence of the same would argue that other factors are responsible.

Precipitation

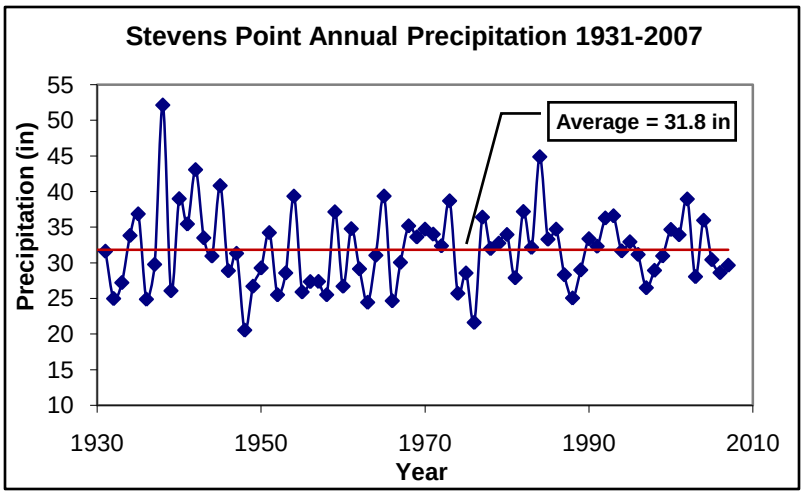
Annual precipitation at Stevens Point (Figure 5, top) from 1931 to 2007 averaged 31.8 in. The standard departure of annual precipitation (a year's precipitation minus the average divided by the standard deviation; Figure 5, middle) shows that 2000-2007 precipitation was about typical, and that years 2005 -7 were slightly dry but not substantially so.

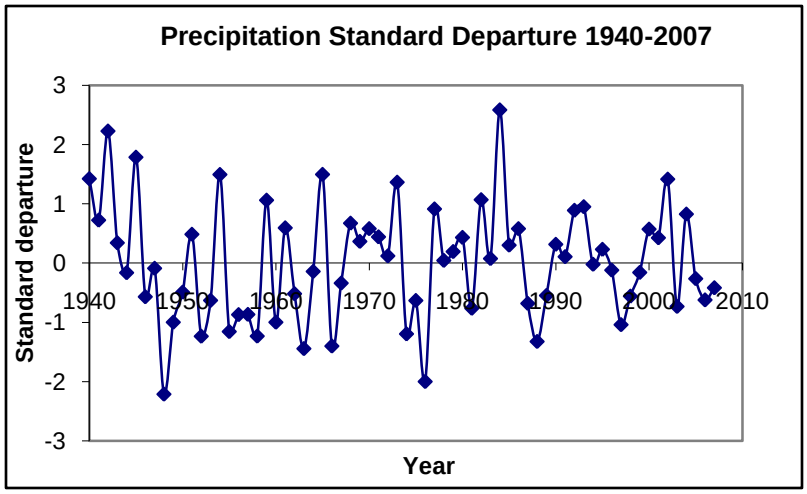
Other workers have concluded that baseflows increased beginning at about 1970 for many streams in the eastern US (McCabe and Wollock, 2002), including the Coon Creek Watershed of Wisconsin. Juckem et al. (2008) attributed much of the baseflow increase in the Coon Creek Watershed to a step increase in the precipitation there. We note a similar step increase in precipitation for the Stevens Point station, from 31.4 in yr^{-1} in 1940 -1970 to 32.1 in yr^{-1} in 1971-2007. Following Juckem et al. (2008) we plot the 5-yr moving average of the standard departure of precipitation from 1942 through 2005 (fore- and hind-casting 2 years on each side of a given year). The result (Figure 5, bottom) reinforces that present times are, on the whole, wetter than earlier ones.

Unusually low precipitation alone thus cannot be invoked to explain low flow conditions in the Little Plover. However, other factors besides precipitation affect groundwater recharge and surface runoff. Ongoing work by Lowery and Bland (in progress) seeks to estimate evapotranspiration for the study area, thus allowing groundwater recharge over time to be estimated.

Drought Index

The Palmer Drought Index is used as 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. The Palmer Drought Index indicates that central Wisconsin has been mostly near normal to moderately droughty since about 2000. Recent conditions are not particularly dry compared with much of the historical record. Thus, in 2003 the degree of dryness was historically not great compared with the 1930's, late 1940's through 1960, 1977, and the late 1980's (Figure 6).





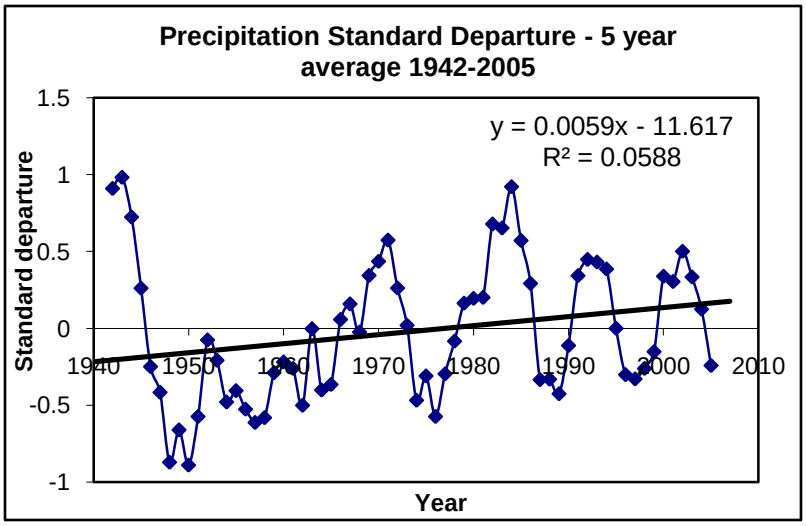


Figure 5. Precipitation at Stevens Point, Wisconsin. Top: 1931 to 2007 precipitation. Middle: Standard departure of precipitation, 1940 to 2000. Bottom: 5-year average standard departure, 1942 to 2005.

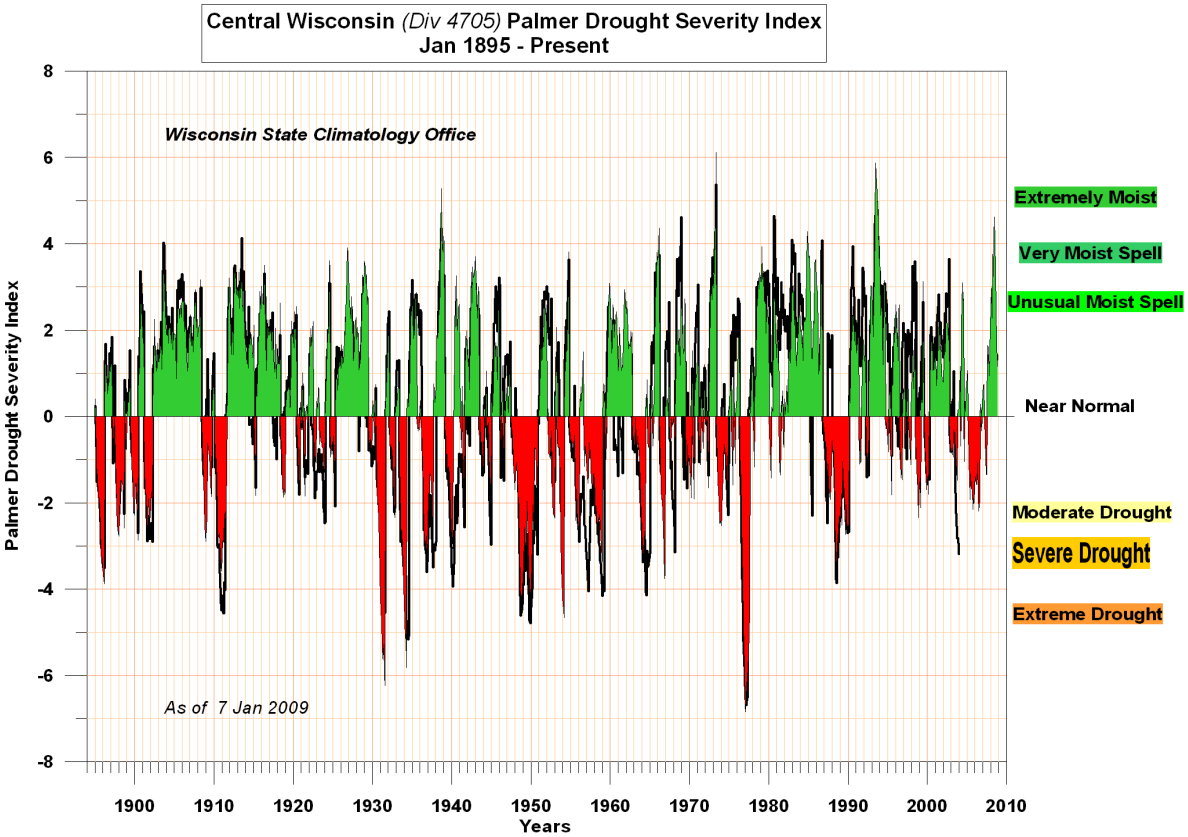


Figure 6. Palmer drought index for central Wisconsin. (Wisconsin State Climatology Office, 2008). Note that the post-2000 period is not substantially droughty compared to the historical record.

Discharges on reference streams

We examined the long term annual discharge records of several area streams to draw inferences as to how large or small recent (post-2000) discharges have been at other locales. If extreme low flows were ubiquitous, climate would be supported as a likely cause of the extreme low flows in the Little Plover; the lack of the same implies something else is likely responsible. Percentile ranks of annual discharge were used as the statistic for exploring streamflow trends.

Sites with long and mainly complete flow records were initially used as indicators of long term flow conditions: Fox at Berlin (1899 to 2007), Wolf at New London (1914 to 2007), Wisconsin at Wisconsin Rapids (1914 to 2007 with seven missing years), Wisconsin at Wisconsin Dells (1935 to 2007), and the Embarrass at Embarrass (1920 to 2007 with 9 missing years). The first four have the disadvantage that they represent large watersheds not necessarily representative of the study area as a whole or of the behavior of small watersheds within the study area. However, more representative sites with extensive flow histories and without pumping impacts are lacking, so data from large watersheds needed to be used.

As a check, we compared discharge statistics from the large watersheds against each other and against two smaller watersheds with highly incomplete records and only slightly affected by pumping.

The smaller watersheds are the Waupaca at Waupaca (1917 to 1985 with 18 missing years) and Tenmile Creek at Nekoosa (1964 to 2007 with 12 missing years).

The percentile ranks were correlated across the seven sites (Table 1). Percentile ranks correlated well, with the exception of the Fox at Berlin, for which correlations were sometimes mediocre. The Wolf at New London correlated the best among remaining sites (correlation = 0.81 to 0.95). Hence, we reject the Fox at Berlin as being representative of long term patterns in the region's streams, and accept the Wolf at New London as being most representative. Correlations of annual flows among sites closely followed correlations of ranks. Figure 7 displays percentile ranks of streamflows by year. Significant periods of low flows (defined as percentile ranks of 10% or less, or a 10 year return frequency) during the past ~ 90 years, include 1931 to 1934, 1948-9, 1957-9, 1964, 1977, and 1988. The period from 1948 to 1964 marked a long period when low flows were unusually common (6 of 17 years). Note that streamflows in 2005-7 were somewhat low, 8-18% percentile rank at most stations, but not unusually so compared with the historical record. An anomaly is the Wisconsin River at Wisconsin Rapids, which was at a record low in water year 2007. This is likely due to the station representing discharge mainly from northern Wisconsin, which unlike central Wisconsin was in a more severe drought in 2007. Note that the Wisconsin River at the Wisconsin Dells station, which is more representative of more of central Wisconsin, was not nearly so dry.

Though recent discharges in reference streams were somewhat low in 2005-7, they were not close to all-time lows, and thus are unable to account for the extreme low flows observed for the Little Plover.

Summary

Precipitation, drought indices, and discharges in reference streams indicate near average conditions in 2000 through 2004, and slightly dry conditions in 2005-7. The absences of extremely dry conditions in 2005-7 suggest that recent climate alone does not explain the record low flow conditions in the Little Plover River. Ongoing work by Lowery and Bland (in progress) on evapotranspiration from the central sands landscape may provide additional insight as to questions of climate, groundwater recharge, and reduced streamflows in the Little Plover.

Table 1. Correlation of annual streamflow percentile ranks among sites.

	Fox at Berlin	Wolf at New London	Wis at Wis Rapids	Wis at Wis Dells	Embarrass at Embarrass	Tenmile at Nekoosa	Waupaca at Waupaca
Fox at Berlin	1.00						
Wolf at New London	0.78	1.00					
Wis at Wis Rapids	0.59	0.88	1.00				
Wis at Wis Dells	0.68	0.91	0.98	1.00			
Embarrass at Embarrass	0.72	0.95	0.89	0.91	1.00		
Tenmile at Nekoosa	0.80	0.87	0.76	0.82	0.77	1.00	
Waupaca at Waupaca	0.75	0.81	0.73	0.76	0.79	****	1.00

*** Insufficient overlap between sites.

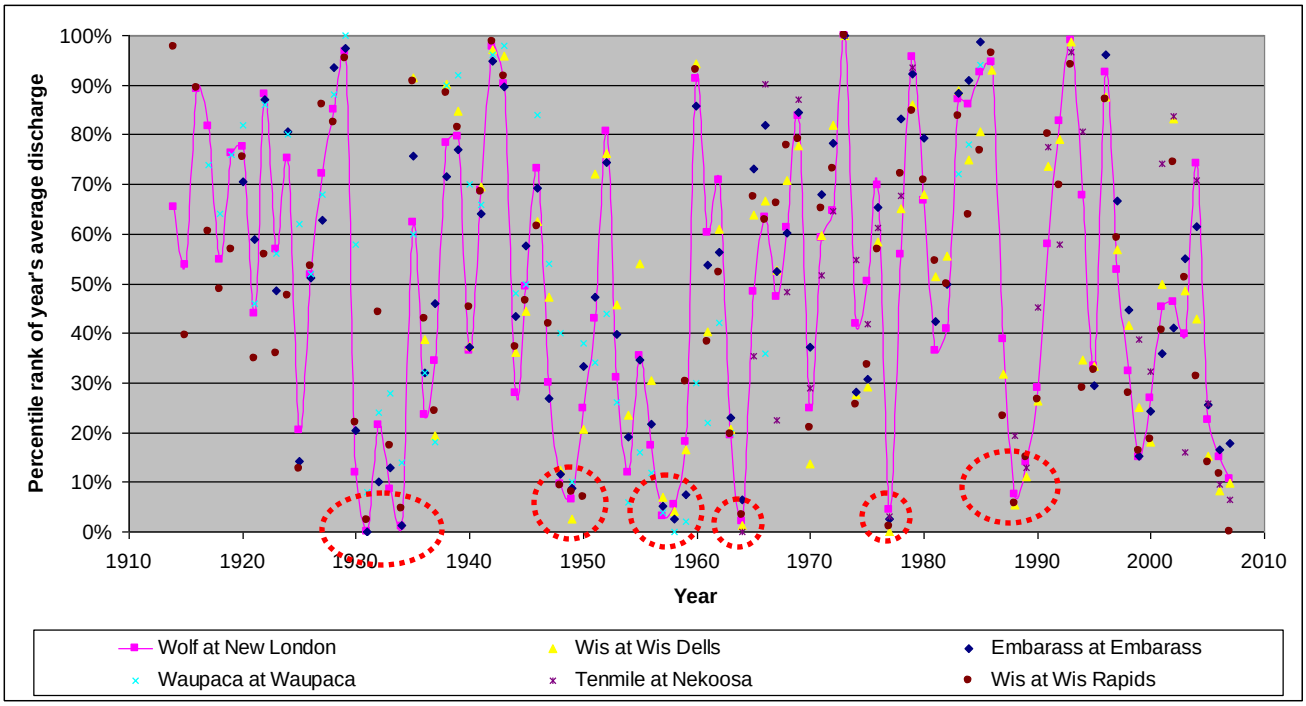


Figure 7. Percentile rank of streamflows by year. Connecting line is for Wolf at New London only. Significant dry periods (percentile rank <10%) are highlighted by red circles. Note that while streamflows in 2005-7 were dry, the degree of dryness was not uncommon.

III. LITTLE PLOVER DISCHARGE RECORD

USGS Records at Hoover (1959-1987) and Kennedy (1959-1976)

The Little Plover has a continuous flow record for 1959 to 1987 (the “historical period”) at the "Hoover Rd." (same as “Plover”) gauge (Figure 8) and from 1959 to 1976 at the “Kennedy Ave." (same as “Arnott”) gauge (Figure 9). These measurements are available at http://waterdata.usgs.gov/wi/nwis/sw. The longer record at Hoover Rd. indicates an average, minimum, and maximum daily discharges of 10.6, 3.9 and 81 cfs, respectively, for the period and a Q_{10} and Q_{50} of 6.6 and 9.4 cfs (Figure 10). The minimum discharge occurred in 1977, when an exceptional drought (Figure 5 and 6) contributed to what is known locally as the "Dewey Marsh Fires". Gauges on other streams (Figure 7) indicate discharges were at about 30 year lows at that time. Discharges at Kennedy correlated closely with those at Hoover (Figure 11). The average, minimum, and maximum discharges at Kennedy (1959-1976) were 4.1, 0.8, and 50 cfs, respectively. The Q_{10} and Q_{50} were 1.9 cfs and 3.5 cfs.

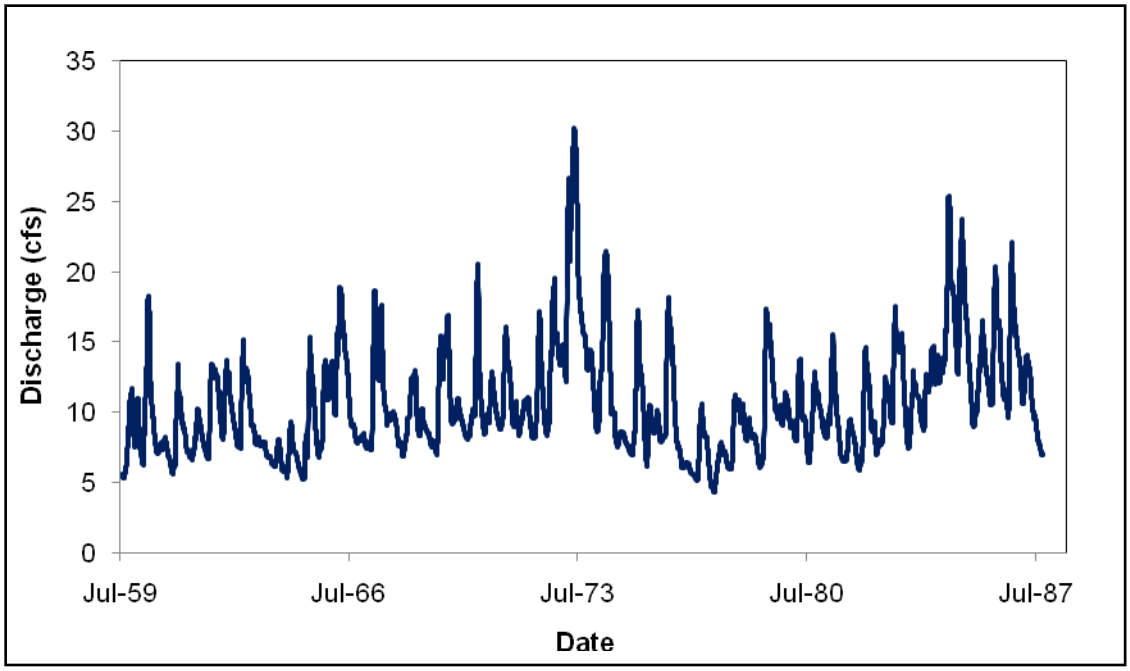


Figure 8. Discharge of the Little Plover at Hoover Rd. 1959-1989. A 30 day moving average was used to smooth the curve.

1988 through 2004 Record

We were unable to locate any discharge records for years 1988 through 1994. We located 153 discharge measurements at 14 locations that were taken between 1995 and 2004; three from 2003 were made by the USGS; the remainder were made by various entities at UW-Stevens Point,

mainly the predecessors to the Watershed Center and the student Fisheries Society group. Most information (Table 2) was for the Kennedy Ave. and Hoover Rd. locations. Some locations were vague or unknown. These data are supplied electronically as a supplement to this report.

Flow measurements were checked for consistency against staff gauges and flows at other locations on the same date. Measurements were given a reliability rating using a 1 - 4 convention. A rating of "1" means that the flow measurement was verified through a cross-check with a staff gauge measurement or streamflow information at another station. A rating of "2" means that cross-checking revealed that a reported streamflow or staff gauge value needed to be modified. A rating of "3" indicates that no independent flow data from another location, nor staff gauge reading was available for a cross-check. A rating of "4" indicates a value deemed unreliable and without a basis for fixing (Table 3). Plots of flows (Reliability 1, 2, 3 only) at Hoover and Kennedy are shown in Figure 12 and 13.

Note that the discharge data in 1995 and 2003 show Little Plover discharges beneath the 1959-1987 record daily minimum flow, despite that the years were not particularly droughty and that other streams were not close to low discharges (Figures 12 and 13). This indicates the stream likely had flow difficulties during this period.

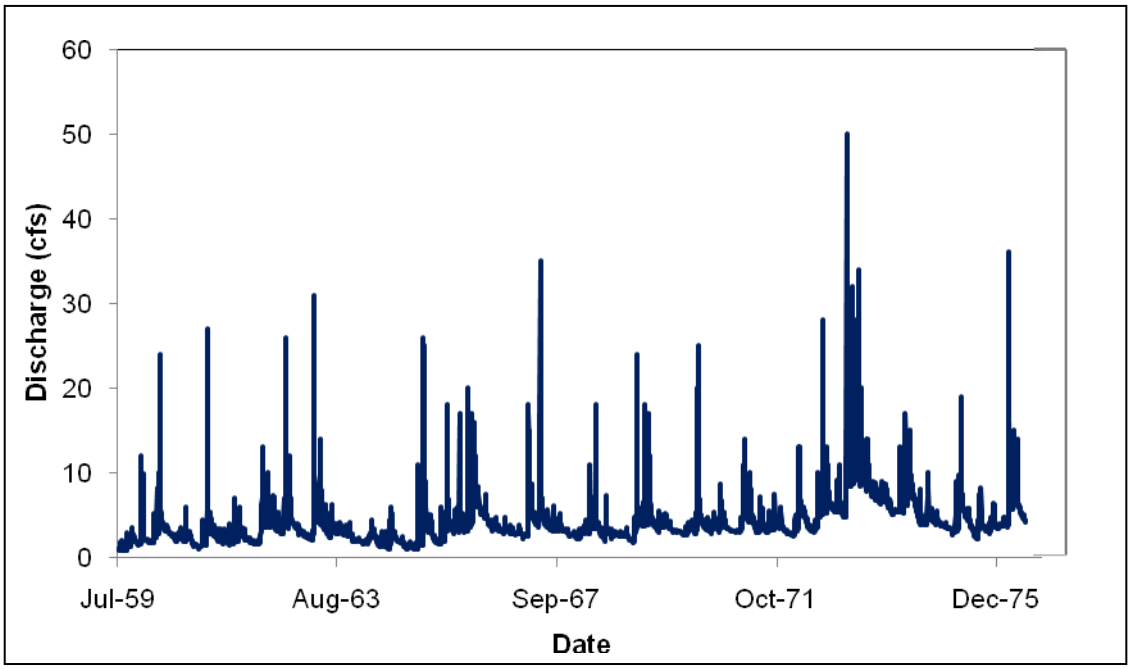


Figure 9. Discharge of Little Plover at Arnott (Kennedy Ave.) 1969-1977.

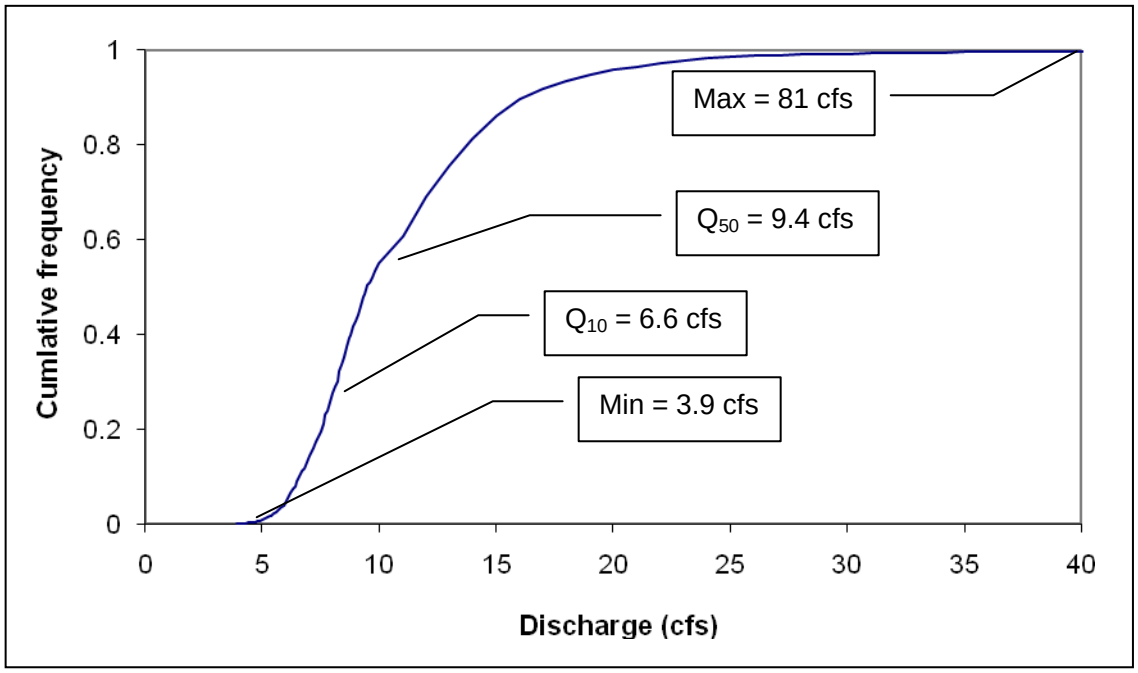


Figure 10. Cumulative frequency of Little Plover at Hoover daily discharge, 1959-1987.

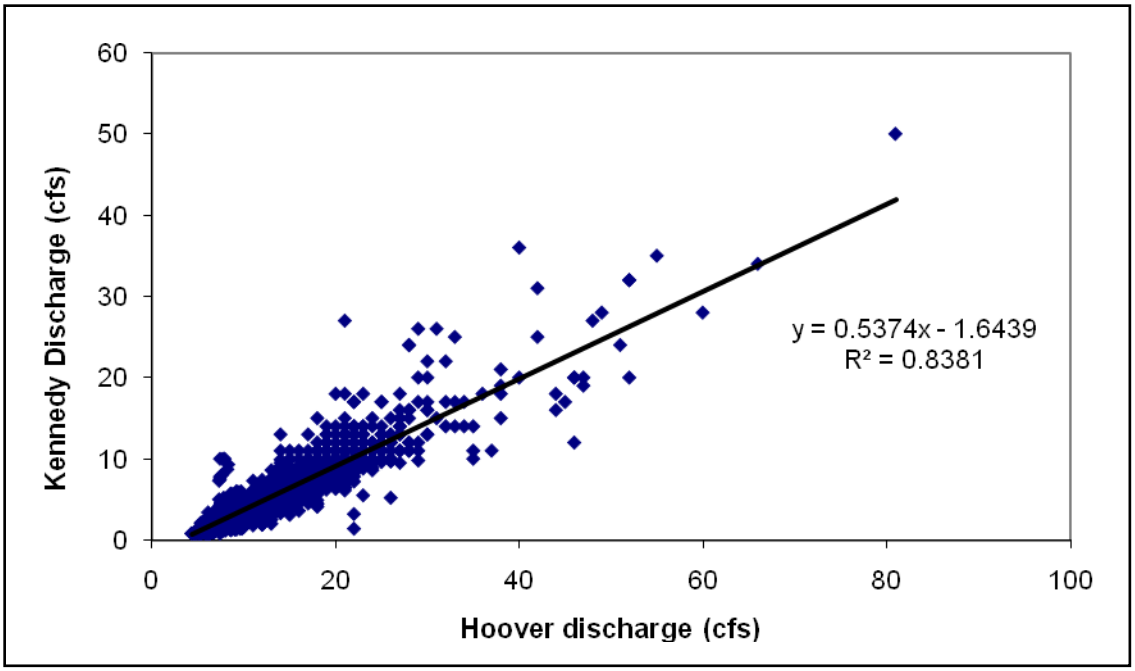


Figure 11. Comparison of daily discharge at Kennedy (Arnott) and Hoover.

Table 2. Little Plover River discharges, 1995-2004. Locations are listed as they appeared in the record.

Location	Count
Kennedy	62
Hoover	60
Eisenhower	7
Wetlands lab	7
Unknown	3
Airline	2
Bluebird	2
W of hwy 51	1
1/4 mile W of Eisenhower	1
Hwy 51 bridge	1
Site 1	1
Site 2	1
Springville outflow	1
E of hwy 51	1

Table 3. Reliability rating count of 1995-2004 discharge records.

Reliability rank	Count
1	100
2	15
3	20
4	15

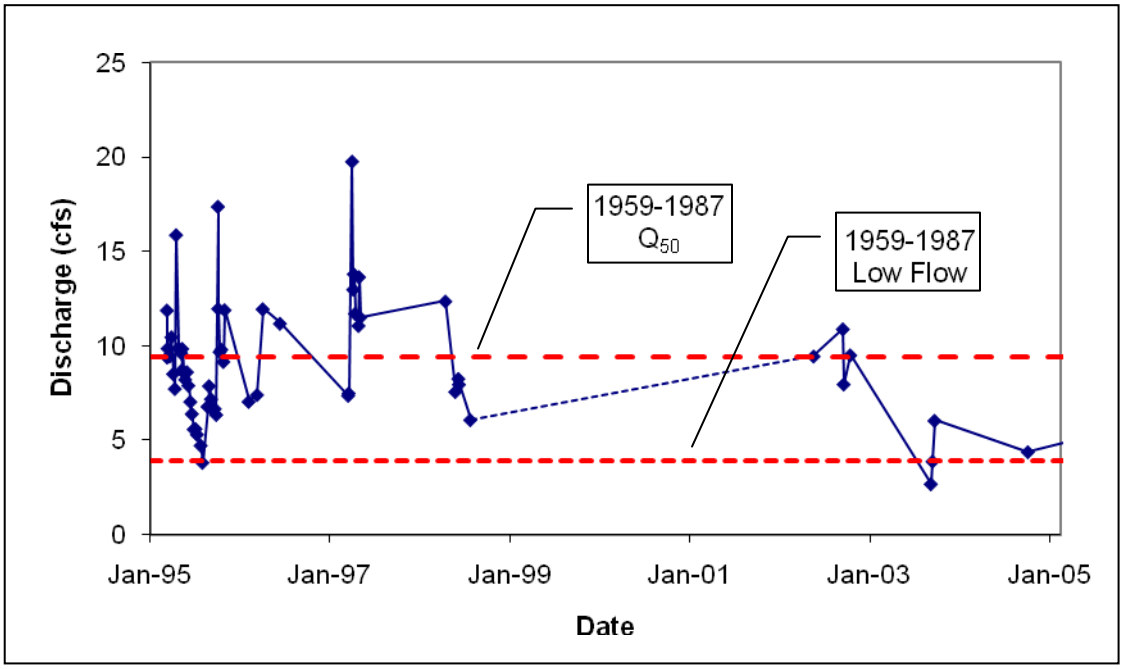


Figure 12. Little Plover at Hoover discharge (cfs) for 1995 through 2004 period.

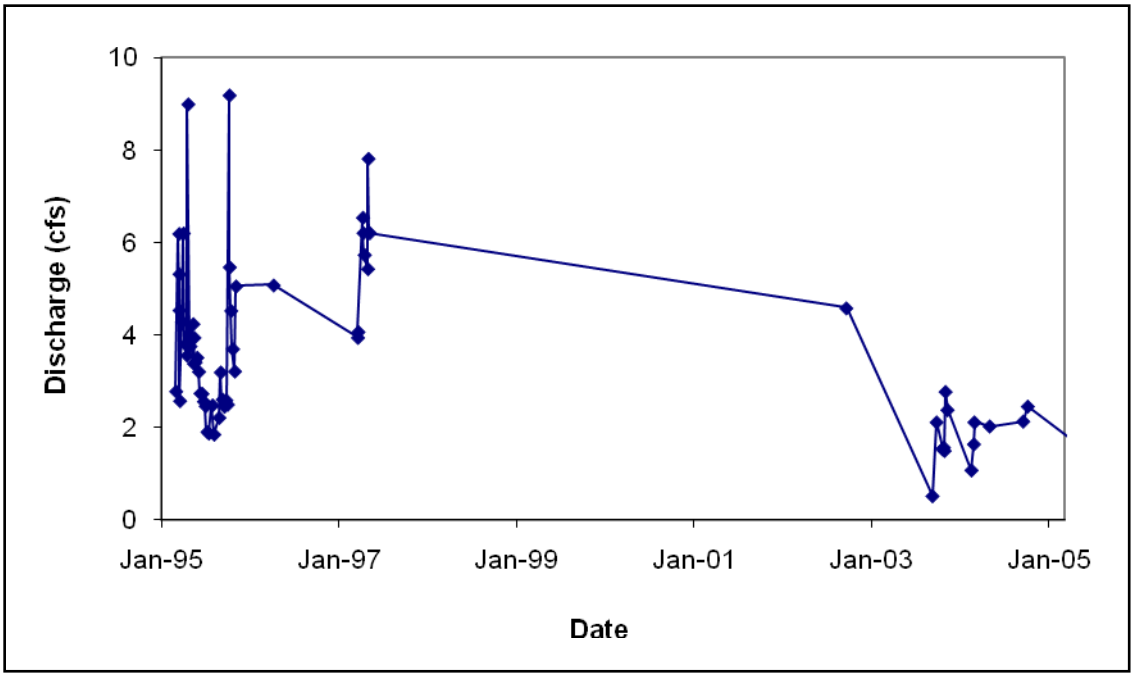


Figure 13. Little Plover discharge (cfs) at Kennedy for 1995 through 2004 period.

2005 through 2008 Record

Discharges were taken weekly to monthly through much of 2005 to 2008, mainly at the Kennedy Ave., I-39, and Hoover Rd. crossings as part of this current project. Some discharges were also taken at Eisenhower Rd. (County Rd. R) in response to WDNR needs there. Discharges for this period are shown (Hoover and Kennedy) in Figures 14 and 15, with detail and annotation for Hoover Rd. shown in Figure 16 (discharge measurements continued at the time of this writing, but are not included in this report).

The 2005 water year started with the Little Plover flows nearing the historic period low, which reached a new low of 1.6 cfs at Hoover on August 8, 2005, 60% less than the historic period low. The entire stream was flow-stressed at that time, discharges were near zero at Kennedy Ave. (0.03 cfs), and the 2.1 km (1.3 miles) stretch centered near Eisenhower Rd. (County R) dried (Figure 4). Flow was likely lower prior to August 7, as indicated by desiccation cracks in the submerged streambed (B. Browne, 2005 personal communication with photo documentation). The same stretch was observed dry on July 18, 2006 when discharges at Hoover were at 2.0 cfs (0.22 at Kennedy), and remained dry or nearly dry through September 7 of that year, when a discharge at Hoover of 2.1 was recorded. Apparently, the stretch near Eisenhower dries completely when discharge at Hoover is less than about 2.2 to 2.4 cfs. At the end of June 2007, the stretch at Eisenhower practically dried (some wetness and perhaps a trickle were observed), but flow augmentation precluded a larger and prolonged drying. The augmentation involved pumping approximately 900 gallons per minute (about 2 cfs) from a nearby irrigation well into the headwaters of the Little Plover. This augmentation continued until the end of September 2007. The stream was once again observed dry at Eisenhower on March 11, 2008, when a discharge of 2.2 cfs was observed at Hoover.

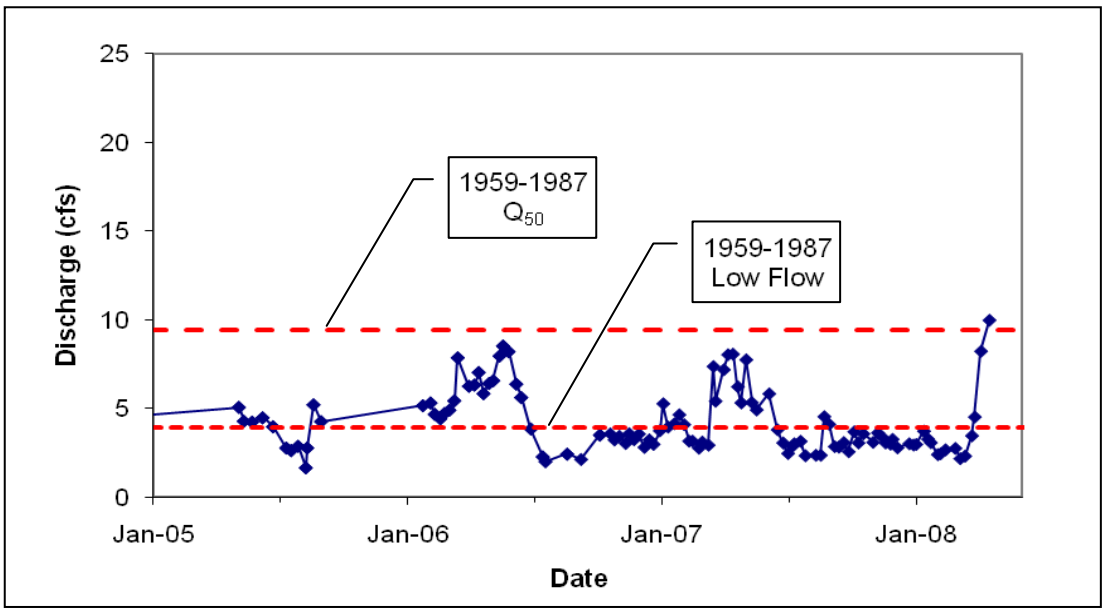


Figure 14. Little Plover discharge at Hoover, 2005-2008.

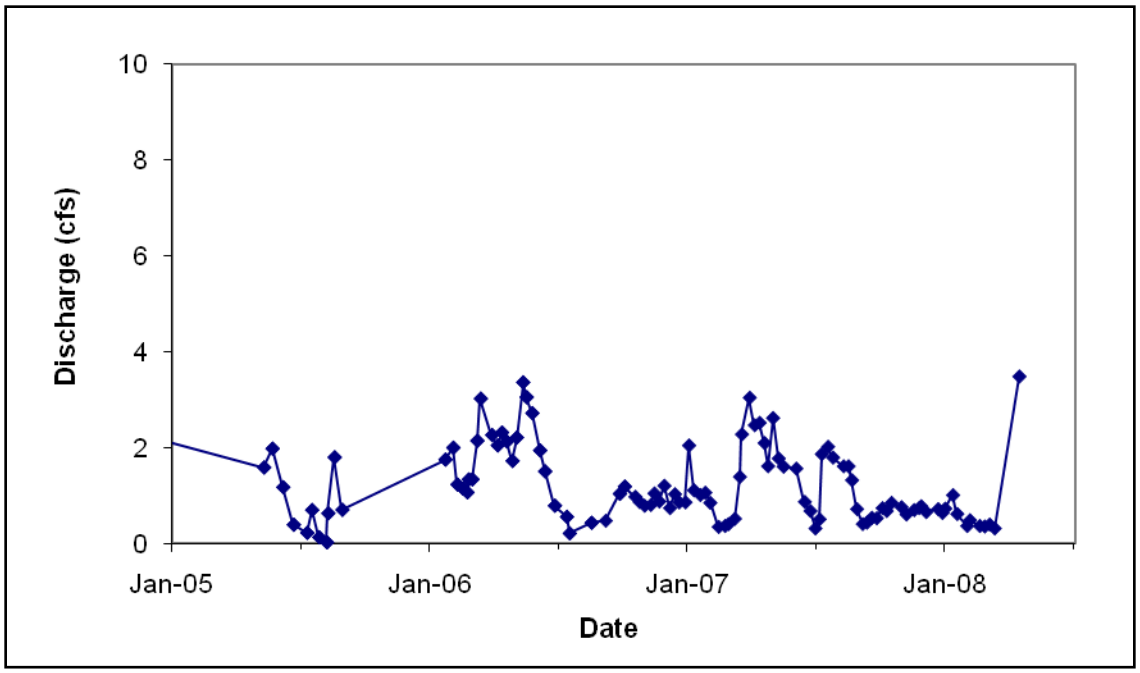


Figure 15. Little Plover discharge at Kennedy, 2005-2008

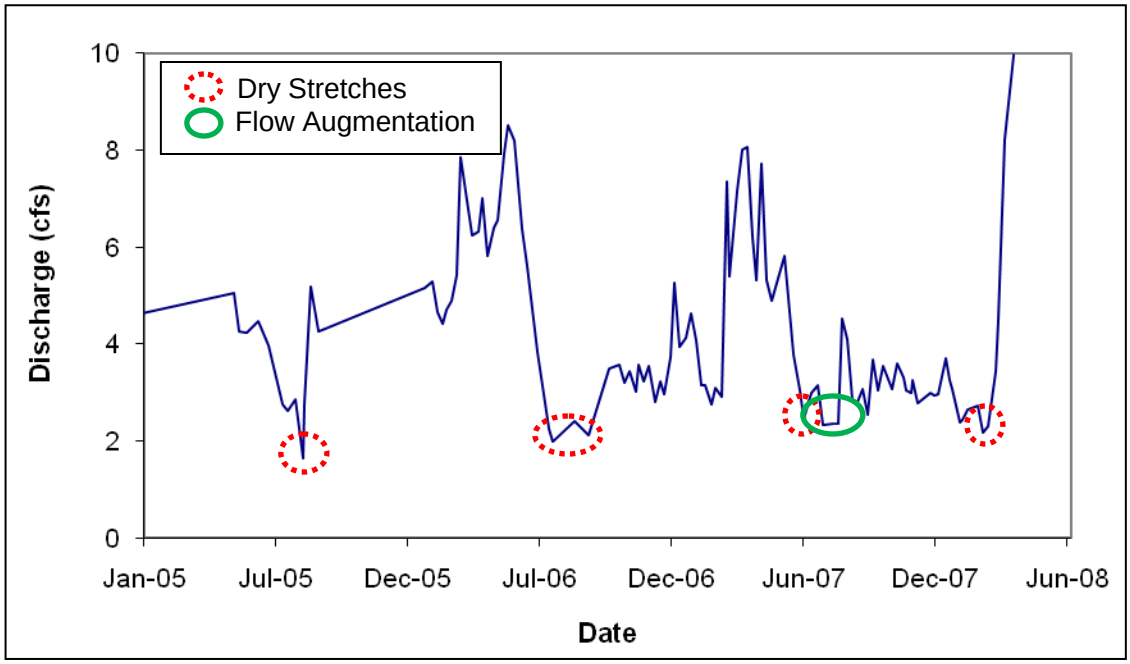


Figure 16. Detail of Little Plover at Hoover discharges 2005 to April, 2008.

IV. HIGH CAPACITY WELL PUMPING IN THE VICINITY OF THE LITTLE PLOVER

In describing high capacity well pumping in the vicinity of the Little Plover, we group pumping into four sectors: Del Monte industrial for vegetable processing, Village of Plover municipal, Whiting wellfield for municipal needs and the industrial needs of New Page (formerly Stora Enso and Consolidated Papers) and Neenah Papers, and agricultural irrigation.

Del Monte

The Del Monte plant pumps groundwater for processing and cooling (Figure 17). Pumping follows an annual cycle that begins on July 1 and continues for 90 days at a rate of about 2 million gallons per day. Thereafter, pumping declines to 0.75 million gallons per day for 45 days, after which pumping ceases. About 77% of pumped water is returned to the landscape as wastewater discharge on lawns, 120 acres across Hwy B directly south of the plant and 49 acres south of that field.

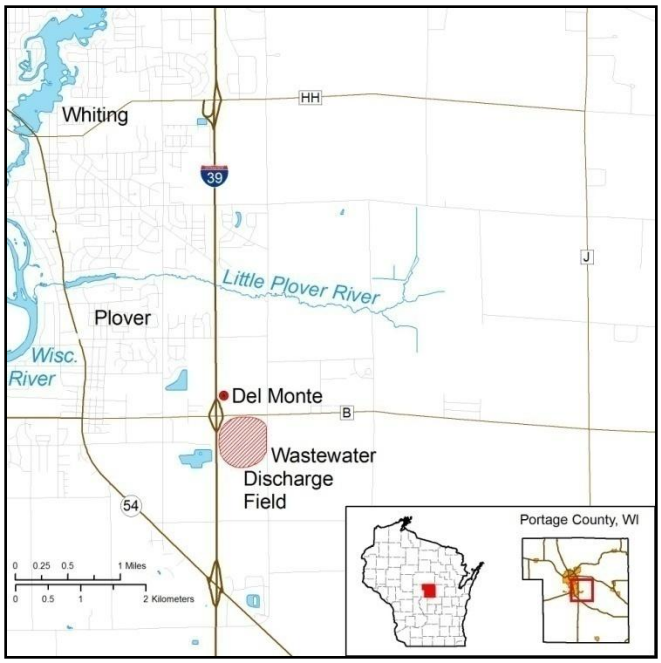


Figure 17. Location of Del Monte high capacity well and main wastewater discharge field in relation to the Little Plover River.

Plover

Pumping for Village of Plover (Figure 4) municipal supply began in 1989 at the wellfield containing wells 1 and 2 (the "1+2 wellfield"). In December 2001, well 3, about 2 miles to the southwest, began service. Statistics referred to here are from "Plover Water System Pumpage Reports" sent to WDNR. Additional documentation can be found in Technical Memorandum 8, included as supplemental materials.

Total Plover groundwater pumpage grew from an average 310,000 gallons per day (gpd) in 1990 to 1.25 million gpd in 1997 (Figure 18). (For reference, 1 million gpd is 1.5 cfs, or about half the flow of the Little Plover in 2007). After dropping slightly for several years, average pumpage reached 1.3 million gpd in 2005 where it remained relatively steady in 2006 and 2007. Groundwater demand for the Plover system, like most municipal systems, is lowest in winter and highest in summer (Figure 19). In recent years, winter demand has increased from an average 1 million gpd to 1.2 million gpd and peak monthly summer demand from about 1.5 to 1.8 million gallons per day.

Wellfield 1+2 was the sole source of groundwater until well 3 went online in December 2001. Records indicate that groundwater demand was about equally split between wells 1 and 2 from 1989 until December 1993, when well 2 became the principally pumped well, supplying 97% of pumpage. When well 3 came on line in January 2002, it briefly supplied up to 75% of the village's water, but its pumpage shrank rapidly to less than a fourth of demand by July 2002, and less than 10% of demand by January 2005 (Figure 19). Pumping from wellfield 1+2 continued to provide up to 91% of demand through July 2005, with most water (up to 88%) coming from well 2. Pumping from wellfield 1+2 diminished in August 2005 to October 2006 from supplying ~90% of Plover water to an average of 60%, with the difference being made up by well 3. Pumping from well 3 increased afterwards, as a way of diminishing the Village's pumping impacts on the Little Plover, supplying an average 80% of the Village's water in the latter half of 2007 and into February 2008. Plover presently manages its pumping split between the two wellfields based on qualitative assessments of streamflow (D. Mahoney, Village of Plover, pers. comm.).

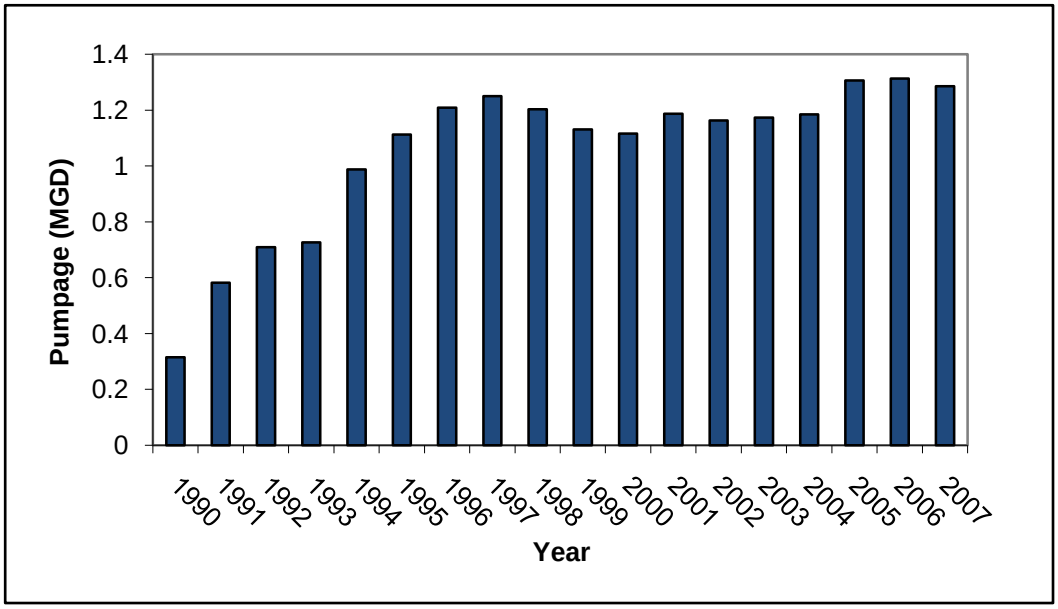


Figure 18. Village of Plover total pumpage, by year.

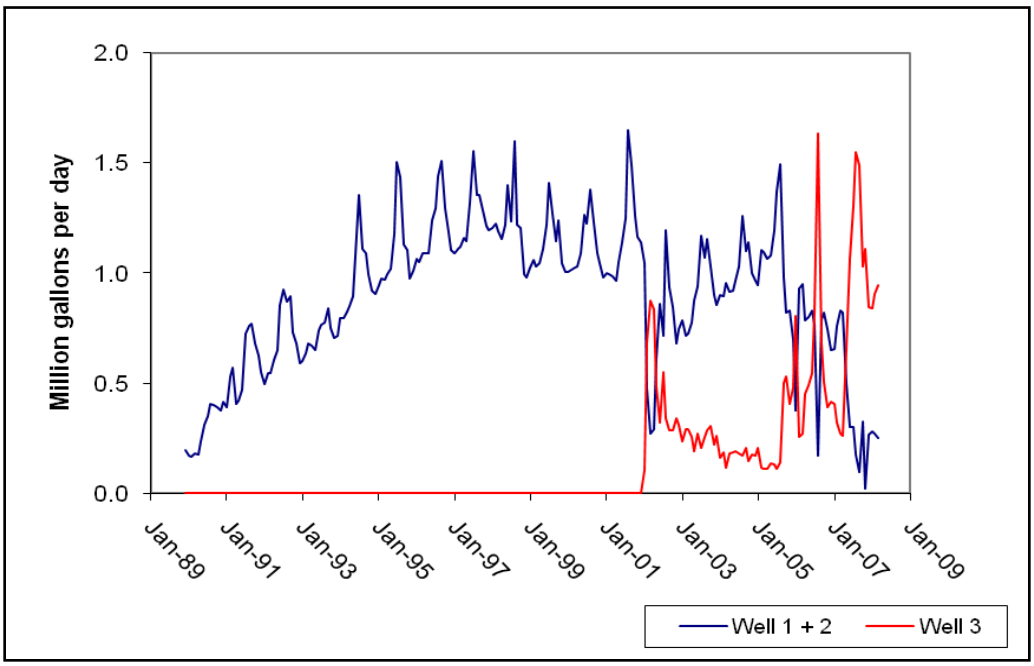


Figure 19. Pumping from 1 + 2 wellfield and well 3.

Whiting and Mills

The Whiting-area wellfield is tapped for municipal and industrial use. The wellfield is operated by the Village of Whiting, and contains seven high capacity wells. Two wells serve Village municipal needs, two serve the Neenah Papers mill, and three serve the New Page mill (Figure 4). Additional detail is presented in Technical Memorandum 9.

Based on 2003 through 2006 averages supplied by the Village, total wellfield pumping amounted to 4.1 million gallons per day (mgd) or about 6.34 cubic feet per second (cfs). Pumping for municipal water supply (Table 4) averaged 0.27 mgd (range 0.19 to 0.44 mgd) for the period. Most municipal water is pumped from well 7, according to WDNR records. Pumping for the Neenah Papers mill averaged 0.94 mgd (1.45 cfs). Pumping for the Whiting New Page mill averages 2.9 mgd (4.6 cfs) equally divided among three wells. The three wells are pumped sequentially (i.e., not simultaneously).

Table 4. Estimated pumping from the wells in the Whiting-area wellfield.

Well owner/Operator	Local Well No/ WUWN	Estimated Avg. Pumping Rate (mgd/cfs)
Whiting	1 - BG715	0.00097 / 0.001
Whiting / New Page	2 - BE822	0.96 / 1.5
Whiting / New Page	3 - BE823	0.96 / 1.5
Whiting / New Page	4- BE824	0.96 / 1.5
Whiting / Neenah Papers	5 - AR318	0.47 /0.73
Whiting / Neenah Papers	6 - AR317	0.47 /0.73
Whiting	7 - MD170	0.27 / 0.42
Total		4.1 / 6.4

Agricultural Irrigation

Pumping for irrigation is somewhat enigmatic as until 2007 growers were not required to report pumpage nor were grower recollections and records of past irrigation complete (Technical Memorandum 10, supplemental materials). According to area growers, the irrigated crop rotation in the vicinity of the Little Plover is typically 3 years, with a year in potato, a second year in sweet corn, and third year of snap bean. Variations include replacing snap bean with peas, field corn, soybean, and on occasion rye for combining. The potato year can be full-season russet burbanks, or shorter season burbank, white, or red potato. Full season potatoes are 120 days, while short season potatoes run 90-100 days. Perhaps about a fourth of the potato crop is full season.

2006 Growing Season

Grower recollections of irrigation for 2006 are presented in Table 5 and further documented in Technical Memorandum 10. Accordingly, irrigation estimates ranged from about 3.2 in for snap bean to 8 in for full season potato. Growers cautioned that the 2006 growing season was dry, and reported amounts should not be generalized to other growing years.

Assuming a 3-yr rotation of potato, sweet corn, and snapbean; and that a fourth of the potato crop is full-season and three-fourths is short season, water use based on grower estimates averaged 4.4 to 6.1 inches on the irrigated fields in 2006. The growers further reported that peas and soy beans typically receive only 2-3 in of irrigation water.

Table 5. Grower reported water use by crop in 2006.

Crop	Plant Date	Season Length (days)	Irrigation Use	
			Range (inches)	Mid-Range (inches)
Russet Burbanks	April 1-20	120	7 - 9	8
Shorter season potato	April 1-20	90-100	5 – 6.8	6
Sweet Corn	5/1 - 7/1	75	5 – 7.5	6.2
Snap Bean	5/1 – 7/1	67	2.5 - 4	3.2

2007 Growing Season

The 2007 growing season was the first that growers were required to report pumpage under the terms of Wisconsin's new groundwater management law. Thus, better estimates of irrigation amounts should now be achievable. Technical Memorandum 17 (supplementary materials) presents the methodology for estimating irrigation pumpage amounts for a subset of fields within about 2 miles of the Little Plover. Twenty-seven irrigation wells in this vicinity had reported pumping amounts for 2007.

Wells and their pumping amounts were matched to respective fields, and the fields were matched to Farm Services Administration crop census data to determine what crops were grown in each. Fields averaged 12.5 in of irrigation (after five estimates were eliminated from consideration, due to being excessively large, small, or uncertain). By individual crop (Table 6), fields with potato alone averaged 12.4 in (five fields, range = 8.8 to 15 in), fields with potato in combination with beans, yellow corn, or sweet corn averaged 13.6 in (8 fields, range = 8.5 to 20.3 in), and sweet corn alone averaged 9.9 in. These amounts are about the same as groundwater recharge in an average year (Weeks et al., 1965; Chapter VI of this report).

Table 6. Average irrigation by crop or crop combination. (Outliers and high uncertainty values removed).

Crop type, subtype	n	Avg Irrigation (in)
Beans, ?	1	13.2
Beans, g & Corn, y	1	16.0
Corn, ?	1	12.7
Corn, s	3	9.9
Corn, y	1	10.4
Corn, y & Alfalfa	1	10.9
Corn, y & Beans, soy	1	11.5
Potato, ru	3	12.7
Potato, ru & Corn, s	1	12.2
Potato, ru & Corn, y	5	15.1
Potato, w	2	12.0
Potato, w & Beans, g	1	8.5
Potato, w & Corn, y	1	12.3

Key: g = green
y = yellow
s = sweet
ru = russet
w = white
? = subtype unknown

V. ASSESSING MISSING STREAMFLOW USING HISTORICAL DISCHARGE DATA

Missing Little Plover discharge due to groundwater pumping diversions was estimated by comparing historical Little Plover discharges (1959-1987; Chapter III) against reference stream discharges of the same period, before and after the large growth in groundwater pumping. (In reality, the Little Plover was already being somewhat impacted by groundwater pumping during the entire historical period, and so this analysis is likely underestimating Little Plover flow diversions.) Discharge relationships were also extended to more recent years in order to provide estimates of more recent streamflow diversions.

Reference streams were chosen due to the completeness of their discharge record, their proximity to the Little Plover, and small amounts of physical alteration in their watersheds that would be likely to produce substantial changes in their discharges. The Little Plover Hoover Rd. station was used for comparison, as it has the longest and most complete record.

Inferences from Double Mass Curve Analysis

A double mass curve is a plot of cumulative discharge over time of one stream against the cumulative discharge of another stream during the same period (Searcy and Hardison, 1960). If no changes occur in the hydrology of the streams being compared, the double mass curve plots as a straight line. A change in the slope of the plot indicates a change in hydrology brought about by forces such as construction, urbanization, or groundwater pumping (Searcy and Hardison, 1960). Double mass curve techniques were used here as an indicator of when Little Plover discharge began to go missing, how missing discharge accrued during the historical period, and what average annual discharges would be expected during 2005-7 without the influences of groundwater pumping.

For this analysis we used the calendar years with complete Little Plover discharge records (1960 to 1986) and the five reference stations listed in Table 7. Double mass curves were plotted for each reference station. A sample double mass curve, for the Wolf at New London, is shown in Figure 20; others are similar.

All double mass curves contained a slope break in about 1973, indicating this was about the time at which noticeable diversions from the Little Plover began to accrue. Though the stations agreed well when diversions began, they differ somewhat for the magnitude of diversions. Table 7 shows that the average estimated diversion for 1973 through 1986 was 0.4 to 4 cfs, depending on the reference stream.

The Wolf at New London was the station most highly correlated with the region's other streams (Chapter II), and hence we selected it to further illustrate missing Little Plover River discharges (Table 8). Estimates of annual missing discharge using this station ranged from 1.0 to 2.8 cfs during 1973 through 1986, with diversions generally increasing, before leveling at 2.2 cfs in 1984-1986.

The double mass relationship can also be extended farther into the future to provide estimates of Little Plover discharges in the absence of pumping. For years 2005, 2006, and 2007, these estimated discharges were 8.1, 7.7, and 6.7 cfs respectively. These discharges are comparable to those in the 1960-1986 historical record, and indicate that recent discharges would have been relatively healthy in the absence of pumping.

The Little Plover flow record is too spotty from 1987 to 2005 (Chapter III) to estimate actual average annual discharges, but sufficient data are available to do so for 2006 and 2007; (Average annual Little Plover discharge was estimated by using the weekly to monthly discharges measured during this study and then extrapolating to the entire year). From estimated average annual Little Plover discharge and the double mass relationships, an amount of missing water can be estimated. The 2006 actual average annual discharge was 4.4 cfs, and the expected average annual discharge in the absence of pumping (based on the Wolf at New London double mass curve analysis, Table 8) was 7.7 cfs, which implies a diversion of 3.3 cfs. For 2007 the actual annual discharge was 4.4 cfs and the expected discharge in the absence of pumping was 6.7 cfs, which amounts to a diversion of 2.3 cfs.

Table 7. Results of double mass curve analysis between the Little Plover and five reference streams.

Station	Double Mass Curve	R^2	Average missing flow (cfs) 1973-1986
Fox River at Berlin	y = 0.0093x + 88	0.99	4.0
Embarrass River at Embarrass*	y = 0.0359x - 2620	0.99	1.9
Wolf River at New London	y = 0.0061x - 3100	0.99	1.7
Wisconsin River at Wisconsin Dells	y = 0.0016x - 2050	0.99	0.9
Eau Claire at Kelly	y = 0.0412x - 2960	0.99	0.4

*Embarrass River at Embarrass did not have data for 1986 so the DMC dates run from 1960- 1986

Inferences from Daily Baseflow

Estimates of Little Plover discharges in the absence of pumping diversions and the magnitude of those diversions at timescales finer than annual are not possible using the double mass method alone. Thus, we used comparisons of Little Plover and reference stream daily discharges to make these inferences, separating daily discharges into their baseflow and overland flow components so as to better estimate groundwater contributions to stream discharge. The reference streams that were used are those in Table 7 plus Tenmile Creek at Nekoosa.

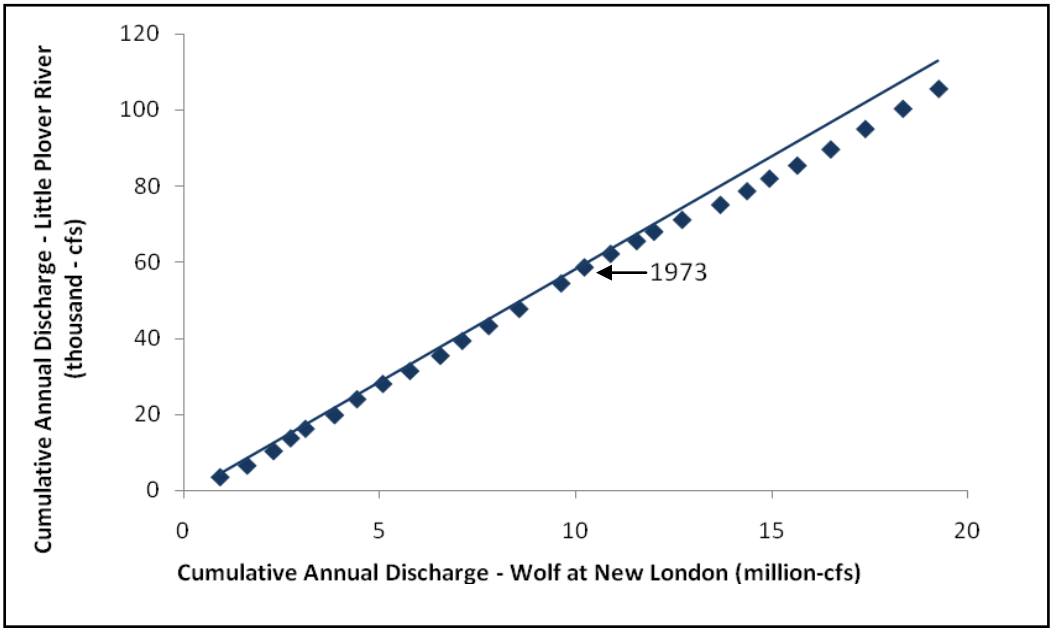


Figure 20. Double mass Curve comparing the cumulative annual discharge of the Wolf River at New London to that of the Little Plover, 1960-1986.

Table 8. Little Plover actual, expected, and missing average daily flows from double mass curve analysis using Wolf River at New London, 1960 to 1986.

Year	Actual (cfs)	Expected (cfs)	Missing (cfs)
1973	18.4	21.2	2.8
1974	11.6	13.3	1.8
1975	9.7	11.2	1.5
1976	9.2	10.6	1.4
1977	6.8	7.8	1.0
1978	8.6	9.9	1.3
1979	10.8	12.4	1.6
1980	9.8	11.4	1.5
1981	9.0	10.4	1.4
1982	9.4	10.8	1.4
1983	11.7	13.5	1.8
1984	14.7	16.9	2.2
1985	14.5	16.8	2.2
1986	14.3	16.5	2.2
Average missing flow for 1973-1986			**1.7 cfs**

The flow record from 1959 to 1968 was used as the baseline period of little groundwater extraction for the Little Plover. All reference stream stations had complete data for this period, except for Tenmile Creek, whose data extended from 1963.

Baseflow separation was performed using the Web-Based Hydrograph Analysis Tool (WHAT), (Lim et al., 2005) which downloads daily flow daily directly from the USGS gauging station website. The local minimum separation method was used, as implemented in the USGS FORTRAN-based program HYSEP (Sloto and Crouse, 1996).

The regression of Little Plover against Tenmile Creek baseflow for 1963 to 1968 was done directly (Figure 21) with the result:

Little Plover baseflow (cfs) = 0.0845 * (Tenmile Creek baseflow) + 5.4 $R^2 = 0.70$

Note that the regression implies that even if Tenmile Creek baseflow were to drop to zero, the expected Little Plover baseflow would still be 5.4 cfs. Further, note that actual baseflows (Figure 21) of the Little Plover were never smaller than about 4.8 cfs, no matter how small Tenmile Creek baseflows became.

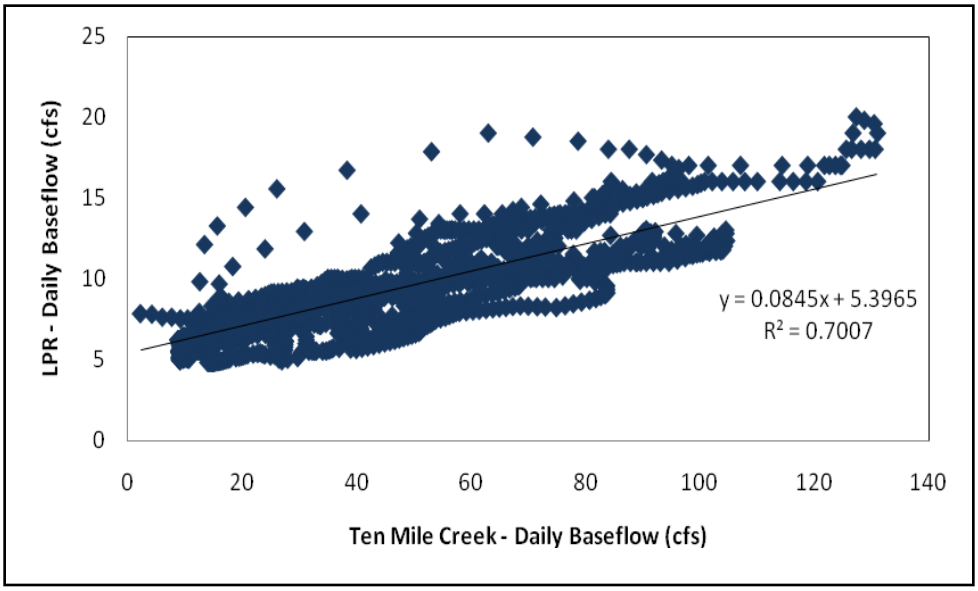


Figure 21. Regression of Little Plover daily baseflow to Ten Mile Creek baseflow.

Other reference streams did not present as neat a regression, as illustrated in Figure 22 for the Embarrass River at Embarrass, i.e., substantial variability of Little Plover baseflow values exists for any given Embarrass River value. This scatter results in a low R^2 value (and hence a wide confidence interval) and masks the clear trend that Little Plover baseflow increases as the Embarrass River baseflow increases, and despite how small Embarrass baseflows become, Little Plover baseflows remained robust, above 4.9 cfs.

To more clearly define Little Plover baseflow trends, we binned Little Plover baseflow data in 1cfs increments along with the corresponding daily value for the reference streams, and then regressed the average of each Little Plover baseflow bin against the average of each reference stream baseflow bin. The result of such binning is shown in Figure 23 for the Embarrass. Table 9 displays the mean value and number of values of each Little Plover bin. So, for the Little Plover baseflow bin of 5 cfs or smaller, 46 values existed for the 1959-1968 period with an average baseflow of 4.8 cfs. Note the majority of the Little Plover daily values fell within 7-10 cfs.

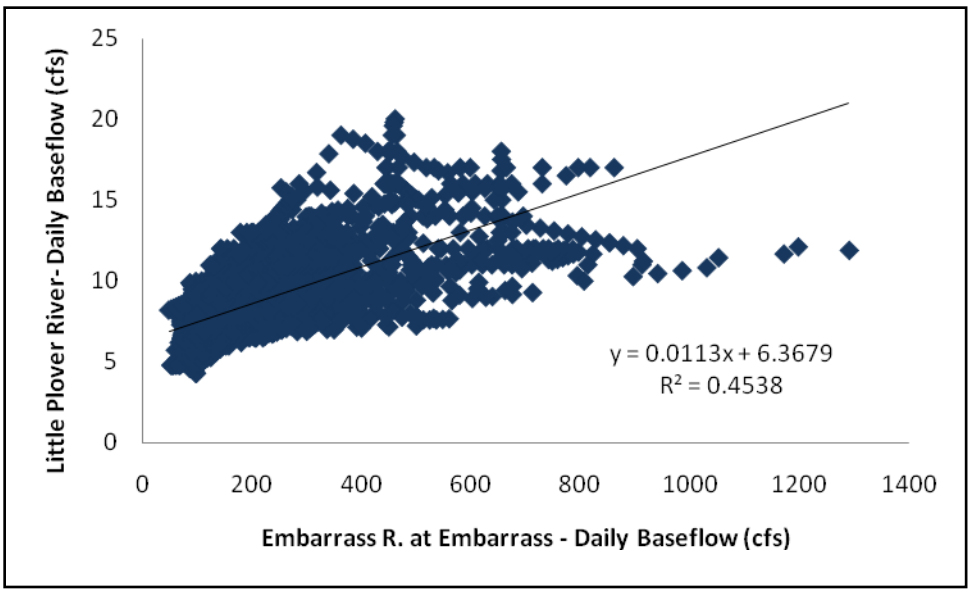


Figure 22. Little Plover daily baseflow compared to Embarrass River daily baseflow record.

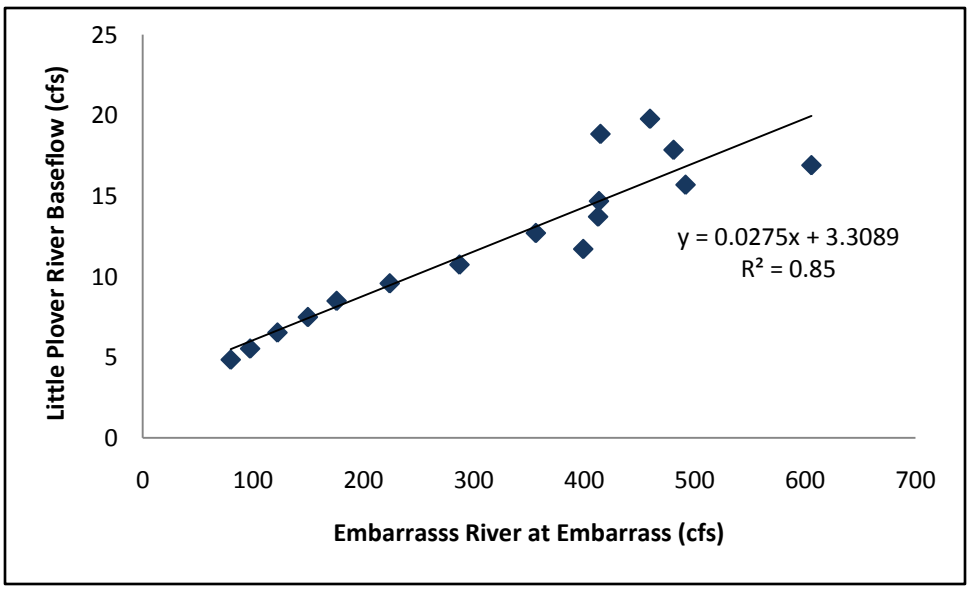


Figure 23. Data from Figure 21 collapsed into 1-cfs bins. Note that the regression equation in Figure 22 is driven less by the static intercept and more by the slope.

Table 9. Binned Little Plover daily baseflow from 1959-1968 with corresponding frequency of occurrence.

Bin for LPR (cfs)	Avg of Bins –Daily Baseflow (cfs)	Count
≤ 5	4.8	46
5.1-6	5.5	244
6.1-7	6.5	559
7.1-8	7.5	815
8.1-9	8.5	438
9.1-10	9.6	406
10.1-11	10.7	256
11.1-12	11.7	220
12.1-13	12.7	127
13.1-14	13.7	65
14.1-15	14.7	30
15.1-16	15.7	45
16.1-17	16.9	17
17.1-18	17.9	12
18.1-19	18.9	5
19.1-20	19.8	3

Table 10. Average of Little Plover binned baseflow data and corresponding mean reference river baseflow values for 1959-1968.

LPR	Embarrass	Eau Claire	Fox	Wolf	WI Dell
4.8	79.8	63.6	419	682	2870
5.5	97.4	82.6	502	809	3630
6.5	122	93.6	625	915	4140
7.5	150	116	682	1010	4060
8.5	176	138	784	1220	4540
9.6	224	188	915	1540	5940
10.7	287	232	1230	1960	7230
11.7	399	362	1440	2440	10300
12.7	356	322	1360	2310	8920
13.7	412	332	1630	3070	9540
14.7	413	350	1300	2760	10220
15.7	492	515	1750	3090	12810
16.9	606	689	2530	4050	13930
17.9	481	826	2650	3590	15990
18.9	415	913	2240	2870	14630
19.8	460	342	2100	3500	12070

In Table 10, the mean reference stream bin value is matched to each corresponding Little Plover bin value. In all cases, a trend holds between Little Plover and reference stream baseflows up to a Little Plover baseflows of about 17 cfs. The trend breaks down at greater values probably due to the small number of data points within those bin sizes (20 values total) along with anomalous conditions that affected the Little Plover and not the reference streams. Regardless, smaller baseflow bin values (11 cfs and less) are of greater interest in this analysis.

The values from Table 10 were used to develop regression equations which estimate Little Plover discharges in the absence of pumping (Table 11). All regressions indicate that Little Plover baseflows should not fall below 2.9 cfs, even if all the reference streams were to become dry. Estimated average monthly and annual baseflows for the Little Plover in the absence of pumping were calculated using the regression equations in Table 11 for and 2005 and 2006 in Table 12 (binned data) and Table 13 (unbinned data for Tenmile Creek near Nekoosa).

Table 11. Regression equations to predict Little Plover baseflow (cfs) developed from binned data as shown in Table 10.

Station	Regression	R^2
WI Dell	y = 0.0010x + 2.93	R^2 = 0.95
Fox R. at Berlin	y = 0.0064x + 3.37	R^2 = 0.89
Eau Claire R. @Kelly	y = 0.0156x + 6.76	R^2 = 0.72
Wolf at New London	y = 0.0042x + 2.86	R^2 = 0.89
Embarrass at Embarrass	y = 0.0275x + 3.31	R^2 = 0.85
Tenmile Ck nr Nekoosa*	y = 0.0845x + 5.40	R^2 = 0.70

*Tenmile Creek uses unbinned data

As shown in Tables 12 and 13, on average for 2005 and 2006 more than 3.3 cfs of streamflow were missing. The highest deficiencies occured in May 2005 and September 2006 with over 4 cfs missing. Measured flows remained below predicted values by over 3 cfs after June 2006, and missing discharge exceeded measured discharge from July on.

Summary

Double mass methods indicate that diversions from the Little Plover were discernable beginning in 1973. Pumping diversions were likely occurring earlier, but were not detectable as the Little Plover flow record did not encompass a period where groundwater pumping was totally absent in the vicinity. By 1986, about 2.2 cfs of missing discharge was apparent. Double mass methods further indicate missing discharges were 3.4 cfs in 2006 and 2.2 cfs in 2007. By comparison, daily baseflow discharge regressions against reference streams indicate missing baseflows of 3.9 - 5.0 cfs in May-August 2005, 3.4 cfs in 2006.

Table 12. Actual Little Plover baseflow and missing baseflow calculated using the average from the six stations shown in Table 11.

Month	LPR 2005 Measured Avg. Baseflow (cfs)	2005 Estimated Missing Baseflow (cfs)	LPR 2006 Measured Avg Baseflow (cfs)	2006 Estimated Missing Baseflow (cfs)
January	n/a	n/a	5.2	2.4
February	n/a	n/a	4.8	2.5
March	n/a	n/a	6.1	2.9
April	n/a	n/a	6.4	3.6
May	4.3	4.3	7.8	3.1
June	4.2	3.9	5.3	3.1
July	2.8	4.0	2.1	3.8
August	3.6	3.0	2.4	3.3
September	n/a	n/a	2.1	4.3
October	n/a	n/a	3.4	3.6
November	n/a	n/a	3.4	3.5
December	n/a	n/a	3.2	4.0
Average		**3.8**		**3.3**

Table 13. Actual Little Plover baseflow and missing baseflow calculated using Tenmile Creek (unbinned) baseflow data.

Month	LPR 2005 Measured Avg. Baseflow (cfs)	2005 Estimated Missing Baseflow (cfs)	LPR 2006 Measured Avg. Baseflow (cfs)	2006 Estimated Missing Baseflow (cfs)
January	n/a	n/a	5.2	3.2
February	n/a	n/a	4.8	2.9
March	n/a	n/a	6.1	2.1
April	n/a	n/a	6.4	2.7
May	4.3	5.8	7.8	2.0
June	4.2	5.1	5.3	3.6
July	2.8	5.1	2.1	5.2
August	3.6	4.1	2.4	4.5
September	n/a	n/a	2.1	4.7
October	n/a	n/a	3.4	3.2
November	n/a	n/a	3.4	3.5
December	n/a	n/a	3.2	3.7
Average		**5.1**		**3.4**

VI. ASSESSING HIGH CAPACITY WELL DIVERSIONS WITH GROUNDWATER FLOW MODELS

Overview of modeling efforts and outcomes

Groundwater flow modeling efforts took three paths. Due to needs by the Little Plover stakeholders group and WDNR for immediate results, we used a pre-existing calibrated flow model ("Model I", for "initial") for diversion estimation during most of the life of this project. Concurrently, the pre-existing model was improved by incorporating new field data and recalibrating using new head and flux targets and advanced calibration techniques. Improved models ("Models 1-4") were run as checks on the outcomes of Model I, and to serve as a platform for future groundwater and streamflow management efforts. Model I and its successors are described briefly here and in more detail in Technical Memoranda 7 and 16 (included as supplementary materials). Model outcomes summarized in this chapter are described in greater detail in Technical Memoranda 1, 2, 8, 11, and 12.

Modeling efforts indicate that groundwater pumping diverts on average 1.2-2.3 cfs of Little Plover discharge at Kennedy Ave. and 3.2-5.4 cfs of cumulative discharges at Hoover Rd. Hence, the recent low flows would have been relatively robust in the absence of pumping. Village of Plover pumping prompted the largest single entity diversion, about 1.2 cfs with 2004 to 2006 pumping, though the irrigation sector as a whole was greater. Plover, for a time, changed its pumping regime after 2006, relying more on well 3 and less on wells 1 and 2, perhaps halving its diversion from the Little Plover. Del Monte annual diversions peak at about 0.38 cfs at Hoover Rd. every year and then diminish. Annually, this diversion averages only about 0.2 cfs. Whiting municipal and industrial pumping divert about 0.57 cfs at Hoover. Irrigation diversions are only roughly known due to grower uncertainty regarding average irrigation amounts. Assuming a range of 2 to 6 in of consumptive use on irrigated lands, irrigation diversions would average 1.1 to 3.3 cfs at Hoover, but peak annually at 1.7 to 5 cfs. About 40% of irrigation diversions originate from within 0.5 miles of the Little Plover, 58% from within 1.0 miles, and 82% from within 2.0 miles. About 18% or irrigation diversions originate from beyond 2 miles.

Description of models

Model I was implemented in the MODFLOW2000 code (Harbaugh et al., 2000) using the GMS pre-/post-processing environment. The model was initially developed by Mechenich and Kraft (1996) for wellhead protection planning in the Stevens Point - Whiting - Plover area.

Later, it was extended farther to the east and south for delineating source water protection areas of other communities, calibrated for an area around the Little Plover (2000-2002), and modified for evaluating the success of a wetland restoration project east of Stevens Point for WDOT (2006-7). Model I and its newly created successors focused on the area shown in Figure 24.

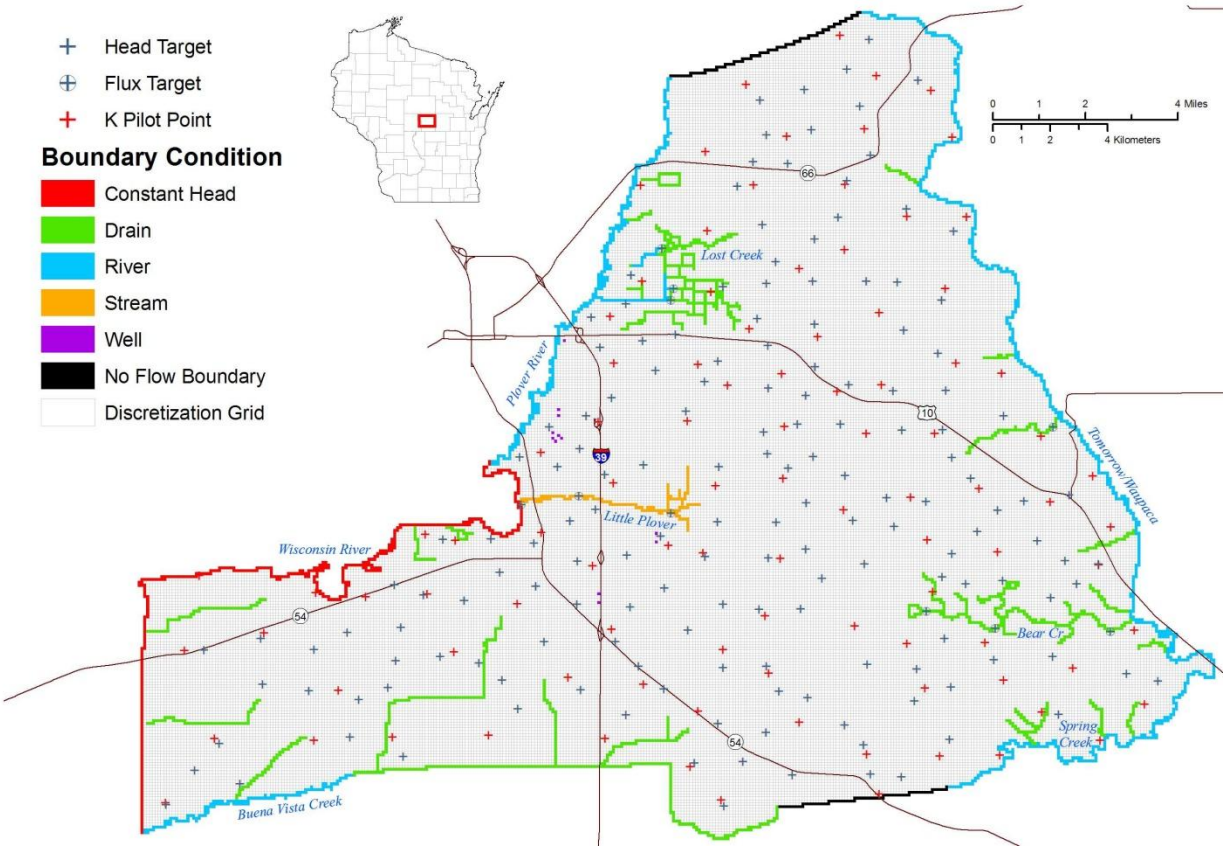


Figure 24. Extent, boundaries, head and flux targets, and hydraulic conductivity pilot points for the Little Plover area model.

Four improved models (Models 1-4) were derived from Model I. These were implemented in the Groundwater Vistas pre-/post-processor environment (Rumbaugh and Rumbaugh, 2005), allowing the model to be more easily shared with other collaborators (WGNHS, USGS), as well as allowing more sophisticated versions of PEST parameter estimation software to be more easily used. In addition, improved physical environment information was included to provide a better representation of a series of drainage ditches north of the Little Plover, and to incorporate more accurate Little Plover River streambed elevations. We also built in the MODFLOW stream routing package for the Little Plover. A bulk of development was directed at a re-calibration, using both manual and formal inverse techniques as implemented in the code PEST (Dougherty, 2003). Calibration targets involved fluxes on the Little Plover and some nearby streams as well as 163 heads.

Models 1-4 represent an evolution from a zoned calibration approach used in Model I to approaches less dependent on manual smoothing of parameters and more dependent on statistical parameter fitting to calibration targets. Both Models 1 and 2 had head and flux target weights adjusted so that they had roughly the same importance in the PEST calculations. Model 1 used a hybrid of PEST pilot point parameter estimation calibration plus manual adjustments in an area of anomalous hydraulic conductivities. Model 2 started with uniform recharge assumption, but PEST produced two questionably high K values at two pilot points. These points were manually smoothed and the recharge adjusted slightly in a final calibration Model 3 avoided the need for K adjustment at any pilot points by reducing the weighting by 50% of 28 central head targets up-gradient of K trouble spots. Model 4 achieved the same results by reducing the weighting by 25% for all head targets. All four models give a reasonable solution. While the K distribution (Figure 25) and recharges (10.5 to 13.7 in/yr) differ somewhat amongst Models 1-4, all values are "reasonable" and within the expected range. Though the K distribution varies with the model, the general configuration is quite similar.

Estimated pumping diversions from pumping

High capacity well pumping in the vicinity of the Little Plover can be broken into four sectors (Chapter IV): that from the Del Monte processing plant, Whiting area municipal and industrial wellfield, Village of Plover wells, and agricultural irrigation wells. Each sector is unique in the way it stresses the aquifer, thus determining whether pumping can be adequately modeled in the steady-state, or that transient effects need to be taken into account. Again, Model I was used as the tool for producing these diversion estimates, with checks for veracity using Models 1-4; usually model 4.

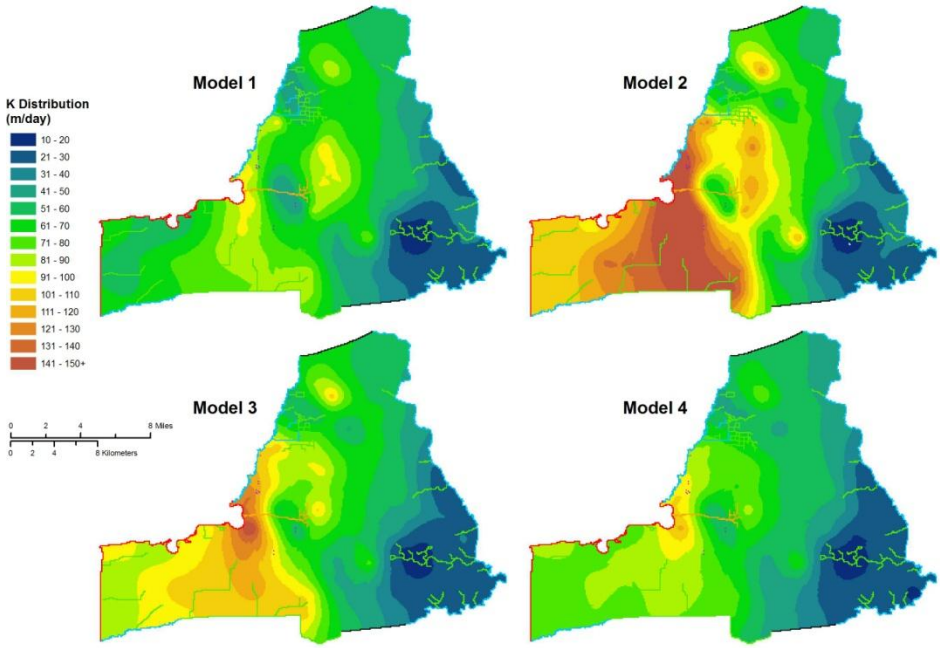


Figure 25. Hydraulic conductivity distributions for Models 1-4.

Del Monte Pumping Diversions

Pumping effects on Little Plover discharges were evaluated using transient simulations and the reported annual pumping schedule of 2 million gallons per day (mgd) for 90 days and then 0.75 mgd for 45 days, with a 77% return of pumped water as field-applied wastewater discharge (Chapter IV). Simulations showed that pumping causes a maximum diversion of 0.38 cfs at Hoover Rd. 100 days after the start of pumping, about October 8th every year (Figure 26). The simulation further showed that diversion drops off rapidly after the cessation of pumping, and reaches a minimum of about 0.02 cfs by the time pumping resumes the following year. Almost none of the stream diversion accrues above Kennedy Ave. The same simulation conducted with Model 4 agreed well with Model I, indicating a 0.27 cfs diversion (as opposed to 0.38 cfs) at Hoover Rd.

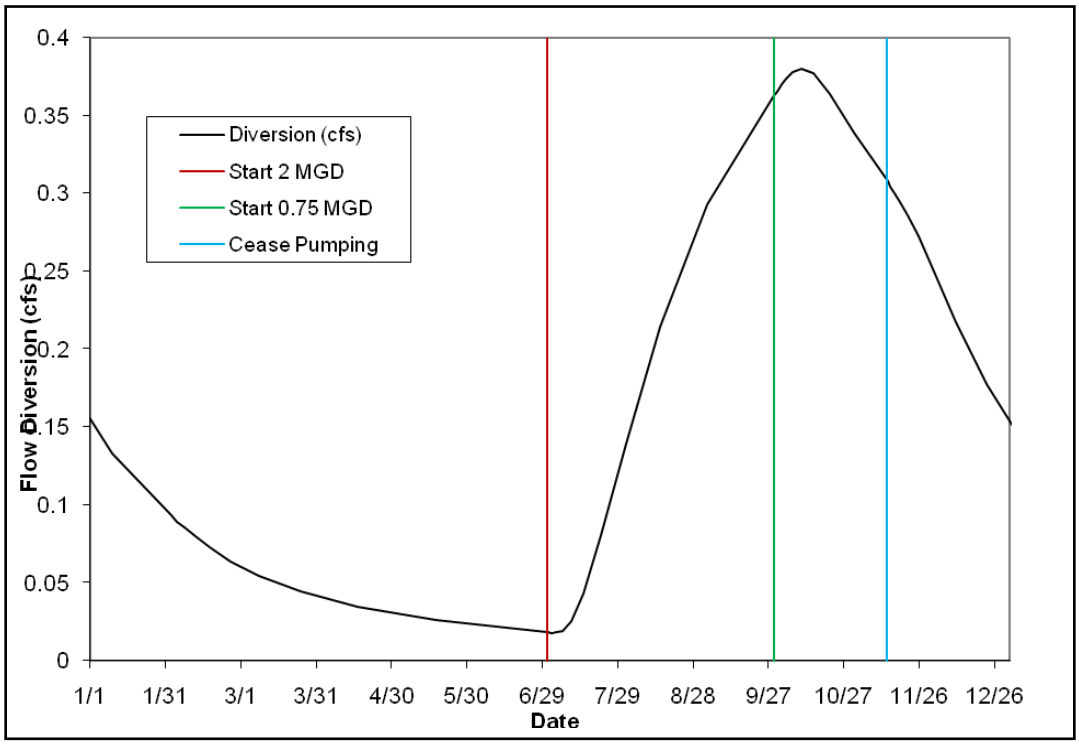


Figure 26. Annual cycle of diversion from the Little Plover River from Del Monte pumping. Vertical lines indicate pumping events.

Whiting Wellfield Diversions (including paper mills)

The Whiting-area wellfield contains two wells that serve Village municipal needs, two that serve the Neenah Papers mill and three that serve the New Page mill. Total wellfield pumping amounts to 4.1 million gallons per day (mgd) or about 6.34 cubic feet per second (cfs). Table 14 apportions the pumping diversion due to Whiting pumping among area surface waters using Model I. Model I revealed that 15.5% of the pumpage from this wellfield is groundwater diverted from the Little Plover.

Remaining water is diverted from the Plover (71%), the Wisconsin (12.8%), with small (0.7%) amounts to other water bodies. Little Plover diversions total 0.98 cfs: 0.12 cfs in the headwaters above Kennedy Ave., 0.45 from Kennedy to Hoover Rd., and 0.41 from Hoover to the Wisconsin. The diversion at Hoover amounts to 0.57 cfs, or about 5.7% of average flow in the 1959 to 1987 period. A check using Models 1-4 produced similar results (Table 15).

Table 14. Apportioning Whiting wellfield pumpage to stream diversions from the Tomorrow/Waupaca (TW) system, Buena Vista Creek (BV Cr) and nearby ditches, the Plover River, Wisconsin River (Wis R) and Little Plover River.

Diversions (cfs)

TW Riv Sys	BV Cr & ditches	Plover R	Wis R
0.03	0.01	4.49	0.81

Little Plover River by Reach (cfs)

Above Kennedy	Kennedy to Hoover	Hoover to Mouth	Total
0.12	0.45	0.41	0.98

Little Plover Cumulative (cfs)

Kennedy	Kennedy to Hoover	Hoover to Mouth	Total
0.12	0.57	0.98	0.98

Diversion as % of Pumpage

TW Riv Sys	BV Cr & ditches	Plover R	Wis R
0.5%	0.2%	71.0%	12.8%

Little Plover River by Reach

Above Kennedy	Kennedy to Hoover	Hoover to Mouth	Total
1.9%	7.1%	6.5%	15.5%

Table 15. Comparison of diversion for Whiting 2003-2006 pumping, comparing Model I and Models 1-4.

	Little Plover River by Reach			Cumulative		
Model	Above Kennedy	Kennedy to Hoover	Hoover to Mouth	Above Kennedy	Kennedy to Hoover	Hoover to Mouth
I	0.12	0.45	0.41	0.12	0.57	0.98
1	0.16	0.46	0.39	0.16	0.62	1.01
2	0.13	0.43	0.34	0.13	0.56	0.91
3	0.15	0.47	0.35	0.15	0.62	0.96
4	0.16	0.50	0.39	0.16	0.66	1.05

Village of Plover Diversions

Technical Memorandum 8 documents five modeling experiments produced with Model I that are summarized here.

Apportioning Plover pumping to surface water diversions

Simulations indicate that stream diversions, as a percentage of pumping by individual Plover wells, were fairly independent of pumping rate and the interplay among other pumping wells in the area (Table 16). Wells 1 and 2 divert about 75% of their pumpage from the Little Plover, about 25% from above Kennedy Ave. and 50% from between Kennedy and Hoover. Well 3 diverts about 30% of its pumpage from the Little Plover. Remaining diversions are from the Buena Vista Creek system, the Wisconsin, the Plover, and the Tomorrow-Waupaca system.

Table 16. Fraction of Little Plover River pumpage by well diverted from nearby streams at two pumping rates.

			% of Pumpage							
Well	**Pumping Rates**		**TW Riv Sys**	**BV Cr & ditches**	**Plover R**	**Wis R**	**Little Plover River by Reach**			
	gpm	**cfs**					**Above Kennedy**	**Kennedy to Hoover**	**Hoover to Mouth**	**Total**
1	300	0.67	3.9	13.9	1.3	2.7	26.1	50.2	1.8	78.1
	1330	2.96	4.0	14.5	1.5	2.9	26.0	49.1	1.9	77.0
2	300	0.67	5.0	18.4	1.5	3.5	25.4	44.1	2.2	71.7
	1330	2.96	5.1	18.9	1.6	3.6	25.1	43.3	2.3	70.8
3	300	0.67	4.2	53.1	1.0	10.6	7.7	19.2	4.4	31.3
	1330	2.96	4.3	53.0	0.9	10.6	7.7	19.2	4.4	31.3

Diversions from the Little Plover under different municipal pumping schemes

Given a fixed water demand, what percentage of pumpage would be diverted from the Little Plover depending on the proportion of water withdrawn from well 1, 2, or 3? To explore this in the groundwater flow model, we fixed pumpage demand at 918 gpm (2.0 cfs), about the average for the Plover municipal system. We then investigated scenarios of water being a) equally split among all three wells, b) equally split between wells 1 and 2 only, c) equally split between wells 2 and 3 only (this is about the same as well 1 and 3 only), d) a 2:1 split between wells 2 and 3, and e) all pumpage is from well 3. Detail is presented in Table 17. Most water, about 75%, is diverted from the Little Plover River when wells 1 and 2 only are used. The least amount of water, about a third of pumpage, is diverted from the Little Plover when only well 3 was used.

When all wells are pumped equally, 61% of pumpage is diverted from the river. Diversion is 58% of pumpage when the ratio of well 2 to well 3 pumping is 2:1, and 52% when the ratio is 1:1.

Table 17. Pumpage diverted from groundwater discharging to the Little Plover River under different pumping scenarios.

Pumpage (gpm)			Little Plover Diversions by reach (cfs)				% Pumpage Diversion by reach			
Well #1	Well #2	Well #3	Above Kennedy	Kennedy to Hoover	Hoover to Mouth	**Total**	Above Kennedy	Kennedy to Hoover	Hoover to Mouth	**Total**
306	306	306	0.41	0.77	0.06	**1.24**	20.1%	37.7%	2.9%	**60.8%**
	612	306	0.41	0.73	0.06	**1.20**	19.8%	35.8%	3.1%	**58.6%**
	459	459	0.34	0.65	0.07	**1.06**	16.8%	31.8%	3.4%	**52.0%**
		917	0.16	0.39	0.09	**0.65**	7.9%	19.3%	4.4%	**31.6%**
459	459		0.54	0.95	0.04	**1.53**	26.2%	46.7%	2.2%	**75.1%**

Diversions from the Little Plover under 2004-6 pumping

How much groundwater was diverted from the Little Plover under the actual average daily pumping conditions in 2004 through 2006? We ran the model using the average pumping rate from wells 1, 2, and 3 for year 2004, 2005, and from October 2005 through October 2006. These indicate that Village of Plover pumping diverted about 1.2 cfs from the Little Plover (Table 18). For 2004 through 2006, average discharges at Hoover were about 5 cfs and minimum flow was about 2 cfs. Plover diversions at Hoover amounted to one fourth of the average and over 50% of the minimum flows during the 2004-6 period. Compared to historical river flows at Hoover (1959 through 1987 continuous monitoring period) Village of Plover pumping diversions amount to about 12% of average flow and about a third of the record minimum flow.

Table 18. Apportioning actual average Plover pumpage to the Little Plover River.

Scenario	Pumpage (gpm)			Little Plover Reach Diversion (cfs)			
	Well#1	Well#2	Well#3	Above Kennedy	Kennedy to Hoover	Hoover to Mouth	**Total**
2004	122	576	122	0.42	0.75	0.05	**1.21**
10/'05 to 10/'06	252	252	415	0.36	0.70	0.06	**1.12**
2005	154	545	208	0.43	0.79	0.05	**1.28**

Diversions since inception of Plover pumping

The amount of groundwater diverted from the Little Plover grew rapidly from 1990 through 1996 and then leveled (Figure 27). Total stream diversion from 1996 through 2006 averaged 1.24 cfs.

About 0.43 cfs of this diversion occurred in the headwaters above Kennedy, 0.76 cfs in the mid-reach between Kennedy and Hoover, and only a small amount (0.045 cfs) below Hoover.

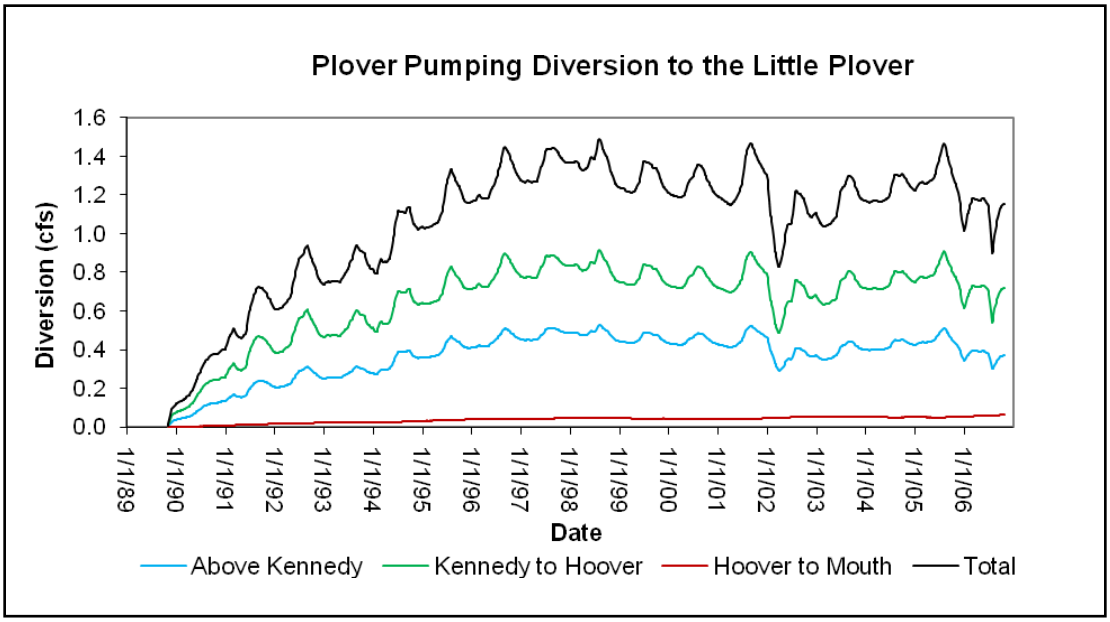


Figure 27. Plover pumping diversions from the Little Plover River 1989 through 2006.

Decline of depletion with time after cessation of pumping

After pumping ceases, how quickly would river diversions decline? To help understand the time lag between a cessation of pumping and the decline of streamflow diversion, we modeled a scenario where Village wells were pumped at their 2004 average until a steady-state diversion was reached. These pumping rates for wells 1, 2, and 3 were 122, 576, and 122 gallons per minute, respectively, which at steady-state would result in a streamflow diversion of 1.21 cfs. About 0.42 cfs of this would be in the headwaters above Kennedy, 0.75 cfs in the mid-reach between Kennedy and Hoover, and only 0.05 cfs below Hoover. Figure 28 shows that if Plover pumping were discontinued, the decline in groundwater diversion from the Little Plover would be slow: about 80 days are needed for diversions to decline by half, and about one year for diversions to decline by 85%.

Comparison to Model 4

We tested Model I veracity through comparison with Model 4, using both to simulate Village of Plover actual October 2005-2006 pumping (Table 19). The predicted diversion amounts were within 0.1 cfs.

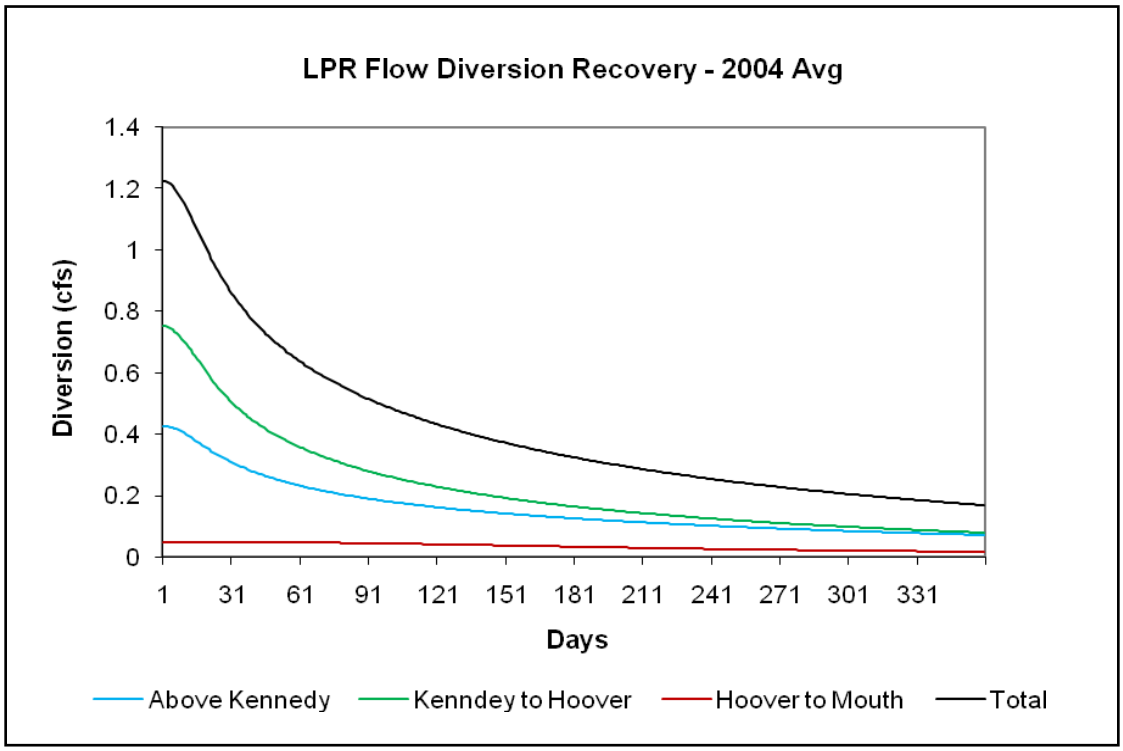


Figure 28. Little Plover River recovery from Plover pumping if pumping were ceased (using 2004 average pumping).

Table 19. Comparison of Model I results with Models 1-4 for Village of Plover October 2005-6 pumping.

	Stream Reach Diversion			Cumulative Diversion		
	Above Kennedy	Kennedy to Hoover	Hoover to Mouth	Kennedy	Hoover	Mouth
Model I	0.36	0.70	0.06	0.36	1.06	1.12
Model 1	0.43	0.55	0.01	0.43	0.98	0.99
Model 2	0.38	0.53	0.03	0.38	0.91	0.94
Model 3	0.41	0.56	0.02	0.41	0.96	0.99
Model 4	0.42	0.58	0.01	0.42	1.00	1.01

Diversions from the Little Plover by Irrigation Pumping

Irrigation amounts vary by crop and by weather (Chapter IV), however this variability is not presently well understood. Due to uncertainties in average irrigation amounts, we explored diversions from the Little Plover under scenarios of irrigation water averages of 2, 4, or 6 inches per year. For these simulations, we assumed a 61 day annual irrigation season. (Assumptions of longer or shorter irrigation seasons change predictions only slightly.) Groundwater pumping for irrigation was represented as a reduction in groundwater recharge on irrigated acres rather than withdrawal from a particular well. For instance, 2 in of irrigation was simulated as a 0.0328 inches per day reduction in groundwater recharge for 61 days annually.

Irrigation-reduced recharge rates were mapped into the groundwater flow model using the irrigated land GIS coverages, and then the model was run for a number of annual cycles until the modeled depletions from the river stayed constant between years. About 8-10 cycles were needed before modeled depletions remained constant between years. [Note: We acknowledge growers concerns that the available Portage County GIS coverage of irrigated lands might sometimes include non-irrigated field corners and other acreage, and thus irrigated acreage would be overestimated. Given the likely greater uncertainty in irrigation amounts, this potential overestimate is likely to have a relatively small effect, and for these exploratory purposes can be neglected.]

Irrigated lands for the entire modeled region are shown in Figure 29, and a close-up of the vicinity of the Little Plover is shown in Figure 30.

Diversion estimates and timing

Figure 31 shows depletion cycles for 2, 4, and 6 inch annual average irrigations. Diversions are smallest at the start of the annual irrigation season, and peak on the last day of the season. The decline from the peak is slow, and does not reach zero before the start of the next irrigation season. Annual maximum, minimum, and average diversion amounts are summarized in Table 20. Maximum total stream diversions were 1.8, 3.5, and 5.2 cfs for scenarios of average annual irrigation amounts of 2, 4, and 6 inches. Modeled diversions were highly sensitive to assumptions regarding irrigation amounts.

Table 20. Maximum, minimum, and average Little Plover River diversion from irrigation pumping under three scenarios of annual irrigation rates.

Irrigation Amount (in)	Annual cumulative diversion from irrigation pumping (cfs)								
	Maximum			Minimum			Average		
	Kennedy	Hoover	Mouth	Kennedy	Hoover	Mouth	Kennedy	Hoover	Mouth
2.0	0.83	1.74	1.79	0.39	0.70	0.75	0.57	1.08	1.14
4.0	1.63	3.42	3.52	0.80	1.44	1.54	1.15	2.19	2.31
6.0	2.29	4.99	5.15	1.23	2.22	2.38	1.71	3.29	3.47

From how far out do irrigation diversions result?

Questions have emerged regarding how far out from the Little Plover irrigation impacts affect stream diversion. To address this question, we evaluated under a 4 in of irrigation water per year scenario how the Little Plover is affected by irrigation pumping from within 0.5, 1.0, 2, miles and beyond (Figure 30). Model results indicate that substantial amounts of streamflow depletions can accrue from distances beyond 2 miles. About 40% of irrigation diversions originate from within 0.5 miles of the Little Plover,

58% from within 1.0 miles, and 82% from within 2.0 miles. About 18% or irrigation diversions originate from beyond 2 miles (Table 21).

Table 21. Diversion arising from various distances from the Little Plover River under the 4 in annual irrigation scenario.

Distance (mi)	Maximum Diversion (cfs)		
	Kennedy	Hoover	Total
Within 0.5	0.58	1.37	1.38
Within 1.0	0.88	2.04	2.06
Within 2.0	1.31	2.80	2.86
All	1.63	3.42	3.52

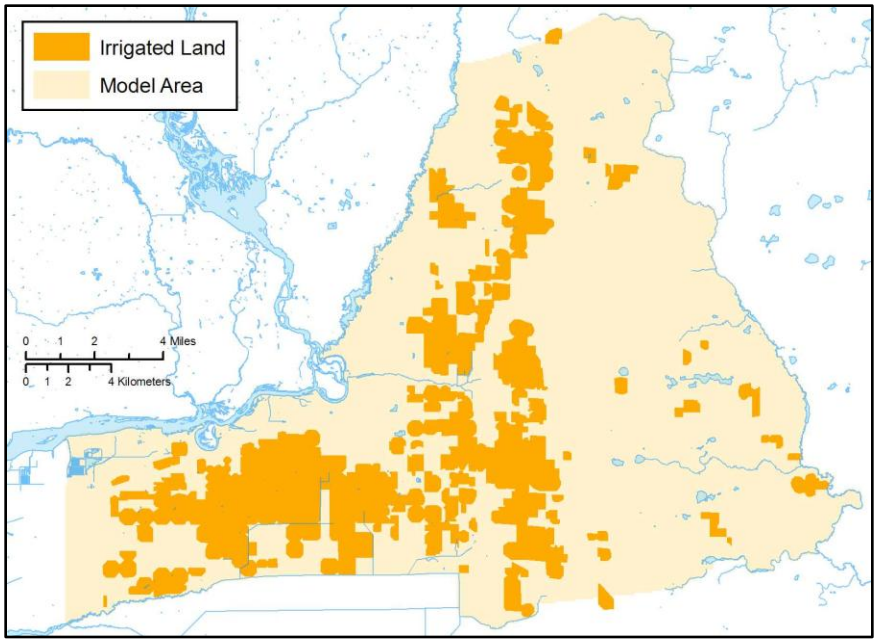


Figure 29. Irrigated land in the modeled area.

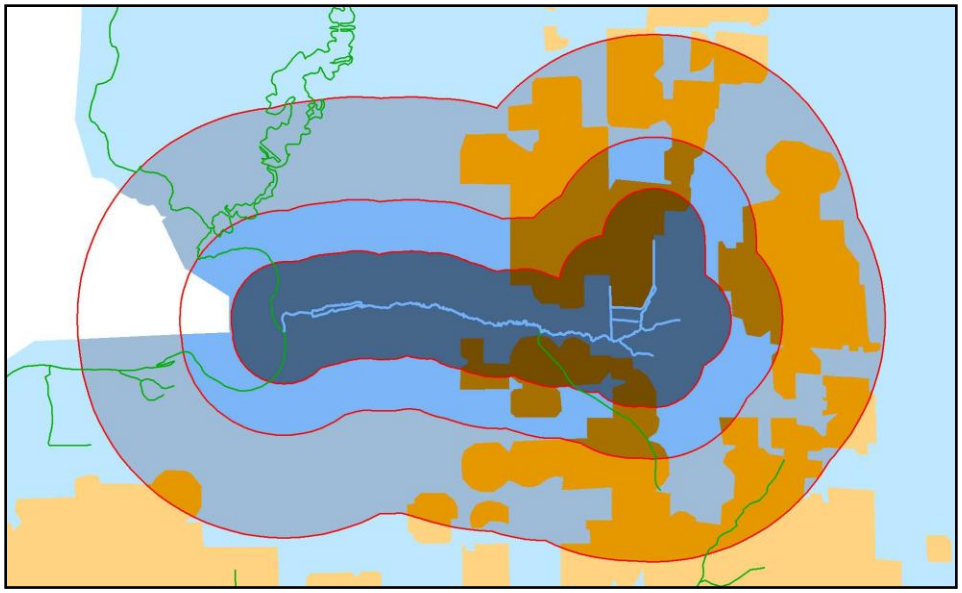
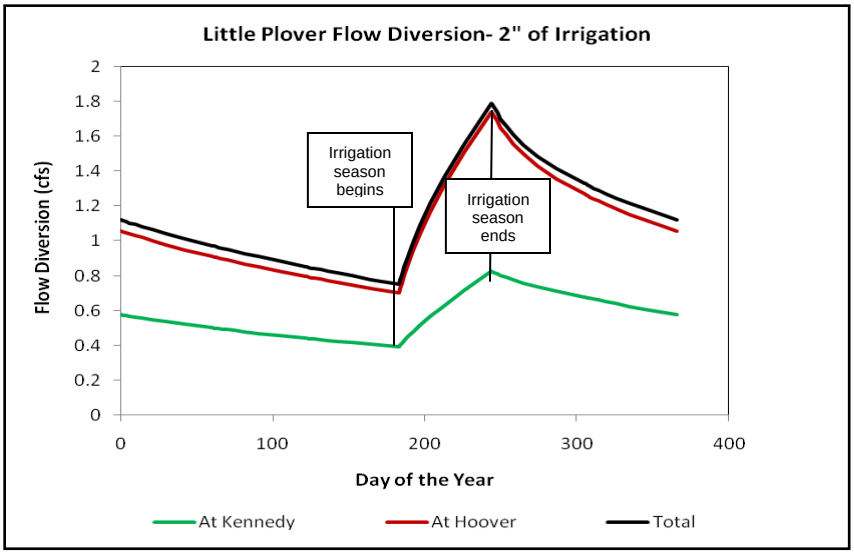
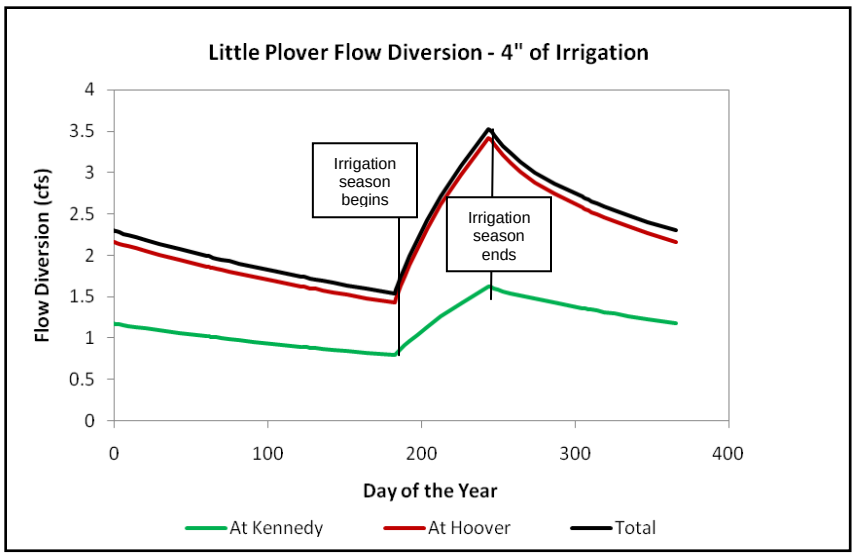


Figure 30. Irrigated land within 0.5, 1.0, 2.0, and great than 2 miles from the Little Plover





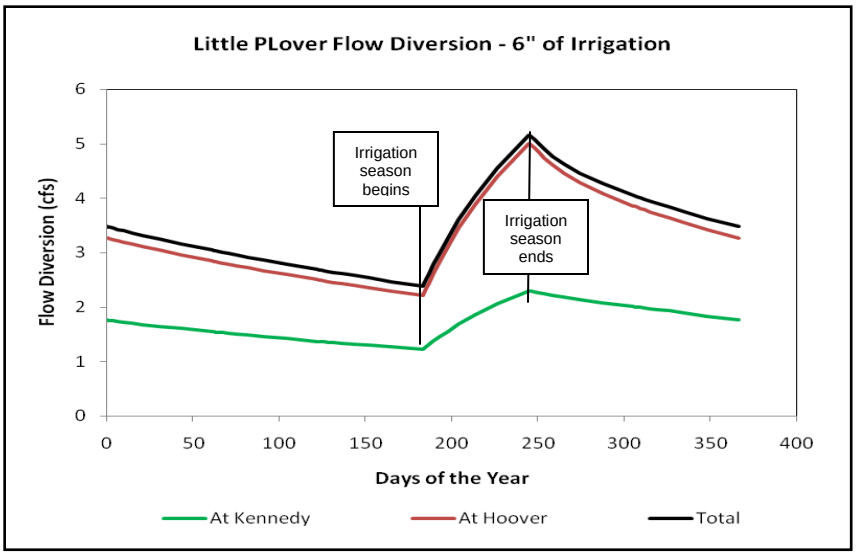


Figure 31. Little Plover depletion: at Kennedy, Hoover, and total stream for scenarios of 2, 4, and 6 inches of average annual irrigation.

CONCLUSION

In support of the goal to "... gain an understanding of the role of high capacity well pumping on Little Plover River discharges and develop knowledge and tools for advancing a groundwater withdrawal management strategy in the vicinity of the Little Plover River," this project:

- estimated high capacity well pumping amounts (Chapter IV),
- compiled past records of stream discharges and acquired new ones (Chapter III),
- improved spatial information on Little Plover stream configuration,
- estimated pumping-induced streamflow diversion (Chapters V and VI),
- made dozens of groundwater flow model runs to meet the needs of agencies and stakeholders (Supplemental Materials), and
- built an improved groundwater flow model for further groundwater management activities (Chapter VI).

Specifically answering the question, "Is it drought or groundwater pumping causing the recent extreme Little Plover low flow conditions?" all indicators show that pumping is the far larger cause. Certainly drier conditions would contribute to a smaller than average streamflow (drier conditions always do) in the absence of pumping, but would not produce the catastrophic low flows that were observed during the last few years.

A context and intuitive view of recent climatic conditions and what Little Plover discharges might be without pumping is provided by records of precipitation, drought index, and discharges in reference streams. These indicate that 2000 through 2004 climate was near average, and that moderately dry conditions (about a 10 year return period) prevailed in 2005-7. Much drier conditions existed during parts of 1959-1986 (when Little Plover discharge was continuously recorded), yet Little Plover discharges remained robust when compared to 2005-7. Thus, recent climate alone does not adequately explain the record low flow conditions in the Little Plover River.

Little Plover discharges in the absence of pumping and amounts of "missing" discharge can be estimated quantitatively through statistical methods and groundwater flow modeling. Statistical analyses employing double mass methods for the 1960 through 1986 record at Hoover Rd. discerns missing discharge beginning in about 1973. (Pumping diversions were likely occurring earlier, but were not discernable as the Little Plover flow record did not encompass a period where groundwater pumping was totally absent.) By 1986, about 2.2 cfs of discharge was apparently missing. Other statistical approaches indicate missing discharges at Hoover Rd. were 3.9 - 5.0 cfs in May-August 2005 and 3.4 cfs in 2006. For comparison, the actual discharge of the Little Plover at Hoover was frequently below 4 cfs during this time. Groundwater flow modeling approaches agree well with statistical ones, indicating on average 3.2-

5.4 cfs of discharge is diverted by groundwater pumping at Hoover Rd. (the range is due to uncertainties in average irrigation amounts).

Groundwater flow modeling is also able to apportion pumping diversions to individual sectors and individual wells. Village of Plover pumping prompts the single largest diversion from the Little Plover, about 1.2 cfs for 2004 to 2006 pumping. Diversions amount to about ¾ of pumped water from wells 1 and 2, and about 1/3 of pumped water from well 3. Del Monte annual diversions peak at about 0.38 cfs at Hoover Rd. every year and then diminish. Annually, this diversion averages only about 0.2 cfs. Whiting municipal and industrial pumping divert about 0.57 cfs at Hoover. Irrigation diversions are only roughly known due to grower uncertainty regarding average irrigation amounts. Assuming a range of 2 to 6 in of consumptive use on irrigated lands, irrigation diversions would average 1.1 to 3.3 cfs at Hoover, but peak annually at 1.7 to 5 cfs. About 40% of irrigation diversions originate from within 0.5 miles of the Little Plover, 58% from within 1.0 miles, and 82% from within 2.0 miles. An additional 18% originates from beyond 2 miles.

We conclude that recent Little Plover flows would be robust (though a little below average) in the absence of groundwater pumping, with a minimum discharge of about 6.5 cfs at Hoover Rd. Diversions by groundwater pumping however captured roughly 3-5.4 cfs of this amount, causing the extreme low flow conditions and the dry stretches. No evidence exists suggesting that Little Plover discharges will return to some sort of "normal" without groundwater pumping management.

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