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#186

Center for Watershed Science and Education

A Survey of Baseflow Discharges in the Western Fox-Wolf Watershed

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EXECUTIVE SUMMARY

Wisconsin's 2003 Act 310 expanded the State's authority to manage the environmental impacts of high capacity wells. Implementation of Act 310 represents a formidable challenge for WDNR staff, both in terms of the complexity of making a "no significant adverse environmental impact" determination and in having a sufficient decision-making knowledge base. WDNR staff identified among other knowledge needs a priority for baseflow information in the GPAs (Groundwater Protection Areas) of the western Fox-Wolf watershed. GPAs in the western Fox-Wolf contain about 1800 km of high quality streams and 10 lakes. With respect for increasing the baseflow knowledge base, the scope of this project included the following: compiling and interpreting USGS daily and interpreting miscellaneous ("spot") stream discharge measurements; measuring stream discharges during baseflow periods at 304 sites during 2005-6; regressing project baseflows against potentially explanatory variables suitable for use by WDNR review staff;, and comparing project baseflows against those previously measured.

Precipitation during the project period was near normal to moderately dry , though summers tended to be drier than the years as a whole. USGS daily discharge gauges in 2005 and 2006 averaged the 21st and 9th percentiles annual average flow, respectively. Thus baseflow discharge measurements made for this project reflect somewhat drier weather conditions. Large-scale USGS daily discharge gauges further suggest a baseflow of 11.2" per unit of watershed.

Baseflow measurements made for this project as well as summary statistics of USGS daily discharge sites and miscellaneous discharge sites have been forwarded with this report as ArcGIS map document and geodatabase files. We found that stream baseflows correlated well with the cumulative amount of stream channel occurring upstream from a measurement point. In a watershed-by-watershed analysis, streams gained baseflow by an average 1.5 cfs per cumulative stream mile (range of 0.26 to 10.6 cfs per mile). Further, an average 17.1 cumulative stream miles (range of 0.98 to 38.13) are required to generate 10 cfs of baseflow.

Comparisons of baseflows measured in this study agreed well with low flow measurements at 35 collocated points previous measurement sites used by the USGS from the 1930s until 2006, bolstering confidence in both data sets. Repetitive measurements made at select sites indicated that baseflow variability is small near headwaters streams, but increases greatly in the lower reaches of a system. This suggests that efforts to quantify baseflow variability are better spent in larger stream reaches.

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I. INTRODUCTION

Wisconsin's 2003 Act 310 expanded the State's authority to manage the environmental impacts of high capacity wells. Among other considerations, the Act requires an environmental review for wells located in "groundwater protection areas" (GPAs), which are areas within 1,200 feet of an outstanding resource water, exceptional resource water, or any class I, II, or III trout stream. The review must find (subject to certain exemptions) that an approval for a new high capacity well will not result in a significant adverse environmental impact. Implementation of Act 310 represents a formidable challenge for WDNR staff, both in terms of the complexity of making a "no significant adverse environmental impact" decision, and having a sufficient decision-making resource base. WDNR requested proposals under the 2004 Joint Solicitation for assisting with Act 310 implementation. Among other needs, staff put a priority on gathering baseflow information in the GPAs of the western Fox-Wolf watershed. GPAs are common in the region, and often occur near existing or anticipated high capacity wells (Figure 1). These GPAs contain about 1800 km of streams and 10 lakes.

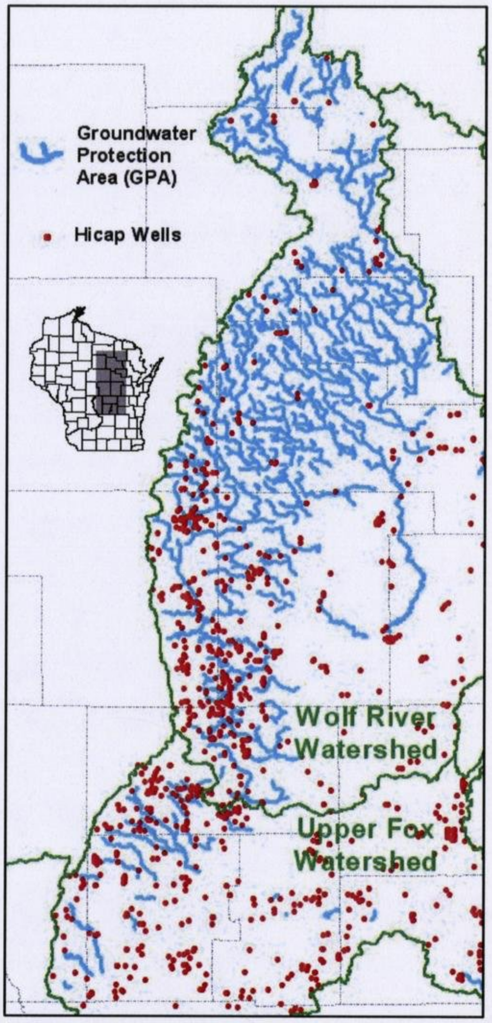


Figure 1. Groundwater protection areas and high-capacity wells in the western Fox-Wolf watershed.

Limited information on streamflows in the western Fox-Wolf watershed is available from USGS archives (http://waterdata.usgs.gov/wi/nwis/sw) and published reports (e.g., Hindall, 1978; Summers, 1965; Weeks et al., 1965, and Weeks and Stangland, 1971). Gebert and Holmstrom (1977) measured low flow characteristics of streams in the Fox and Wolf watersheds, and developed regression relationships between low streamflows ($Q_{7,10}$), watershed size, and landscape characteristics. These regressions were developed for stream segments with substantially more discharge than the headwater segments of interest in this study.

As this project was beginning in the summer of 2005, a related concern developed, that being the partial dry-up of the Little Plover River. Though the Little Plover lies outside the Fox-Wolf Basins, we included flow measurements there as part of this project. These flow measurements have been forwarded to WDNR under separate cover.

Objectives & Scope

The objective of this study was to survey baseflows for the headwaters streams lying within GPAs in the western Fox-Wolf watershed (Figure 2). The scope of work included the following:

1. Compiling and interpreting USGS daily discharge information. We examined the daily discharge record for the Upper Fox and Wolf basins, determined which stations might be useful, inferred baseflows, and compared water years 2005 and 2006 against the long term record at each station.

2. Compiling USGS miscellaneous ("spot") stream discharge measurements from the Upper Fox and Wolf basins and comparing to those measured in this study.

3. Measuring stream discharges during baseflow periods at 304 sites on headwaters streams.

4. Regressing baseflows against potentially explanatory variables suitable for use by WDNR review staff.

5. Comparing measured baseflows against previously measured USGS baseflows and low flow statistical relationships.

Study area

The Upper Fox River and Wolf River Basins drain 2090 and 3690 square miles, respectively (Figure 2 and 3). The study area is the western part of the basins, and contains 2400 miles of streams that drain the flanks of terminal moraines and areas of pitted outwash and outwash deposited during the Pleistocene. Approximately 1680 miles of area streams are listed as trout streams. The geology usually comprises 50 to 100 feet or more of glacial drift covering Cambrian sandstone or Precambrian crystalline rock. Soils are generally coarse textured, but grade into finer textures where ice-contact and fluvial deposits give way to lower lying areas containing glacial lacustrine deposits. Dominant land uses are agriculture and forestry. The area has a baseflow index of over 0.8, which is one of the highest found in Great Lakes watersheds. This indicates that over 80% of stream discharge at any given time would be expected to originate from groundwater discharge. This accounts for the basin's high-quality water resources (Neff et al, 2005).

Figure 2. The Fox-Wolf basin with the eastern extent of study area shown and groundwater protection areas highlighted. County boundaries and some cities and villages also shown.

Figure 3 Hydrography and watersheds of the western Fox-Wolf basin.

Precipitation in 2005-6

The National Climate Data Center characterizes the Fox-Wolf Basins as experiencing near normal to moderately dry weather (Figures 4 and 5) in 2005 and 2006. Summers tended to be drier than the years as a whole (Figures 6 and 7). Four precipitation measurement stations representing the area (Oshkosh, Shawano, Stevens Point and Waupaca) also indicate that conditions were drier than average (Tables 1 and 2). For 2005 the average precipitation deficit among stations was 4.9 inches, which is approximately 15 percent less than the norm. For 2006 the deficit was 3.4 inches, which is approximately 11 percent less than the norm. Note that precipitation deficit estimates could be biased somewhat due to incomplete records at some stations. Eliminating stations with incomplete records yields deficit estimates of 4.2 and 1.9 inches respectively for 2005 and 2006. Precipitation deficits in 2005 and 2006 explain the smaller than average stream discharges for USGS daily gauge sites in the study area (see section II). Thus baseflow discharge measurements made for this project reflect somewhat drier weather conditions.

Table 1: 2005 Precipitation for stations in or near the Fox-Wolf Basin. The average departure from the norm was -4.9 inches (data obtained from the National Climate Data Center at http//www5.ncdc.noaa.gov/ancsum/ACS).

2005 precipitation (inches)														
Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Depart
Oshkosh	1.68	1.4	0.99	1.31	2.52	1.77	4.42	2.3	3.63	1.16	3.28	1.04	25.5	-6.07
Shawano	1.22	1.1	1.19	1.87	2.72	4.93	1.31	4.55	3.38	2.99	2.63	1.25	29.14	-2.33
Stevens Point	1.45	1.1	1.05	1.91	2.55	5.04	2.52	4.54	5.7	1.18	2.64	0.74	30.42	-3.53*
Waupaca	1.37	1.37	1.18	1.98	1.96	2.34	2.24	4.82	3.16	1.59	3.15	0.92	26.08	-7.53*

Table 2: 2006 Precipitation for stations in or near the Fox-Wolf Basin. The average departure from the norm was -3.4 inches (data obtained from the National Climate Data Center at http//www5.ncdc.noaa.gov/ancsum/ACS).

2006 precipitation (inches)														
Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Depart
Oshkosh	1.89	0.94	1.29	2.16	6.19	1.33	3.03	1.24	2.12	4.07	1.93	2.32	28.51	-3.06*
Shawano	1.43	0.89	1.52	1.73	6.06	3.04	2.48	4.42	3.74	3.21	1.46	1.84	31.82	0.34
Stevens Point	1.07	0.99	1.08	2.27	5.51	2.18	3.16	3.5	3.01	1.87	1.35	2.61	28.6	-3.53
Waupaca	1.46	0.84	0.87	2.44	4.98	1.67	1.75	2.38	4.61	1.85	1.5	2.34	26.69	-6.92*

* Indicates incomplete time series where 1-9 days precipitation data are missing for one or more months from the annual totals; therefore, the departure from the norm may be overestimated.

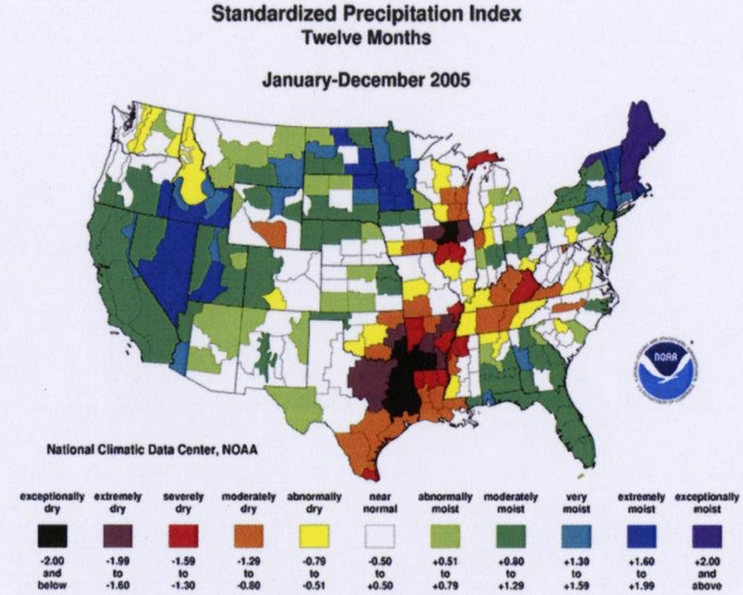


Figure 4. The precipitation index for the 2005 shows that the study area was moderately dry, using the Palmer drought index (National Climate Data Center, Climate of 2005).

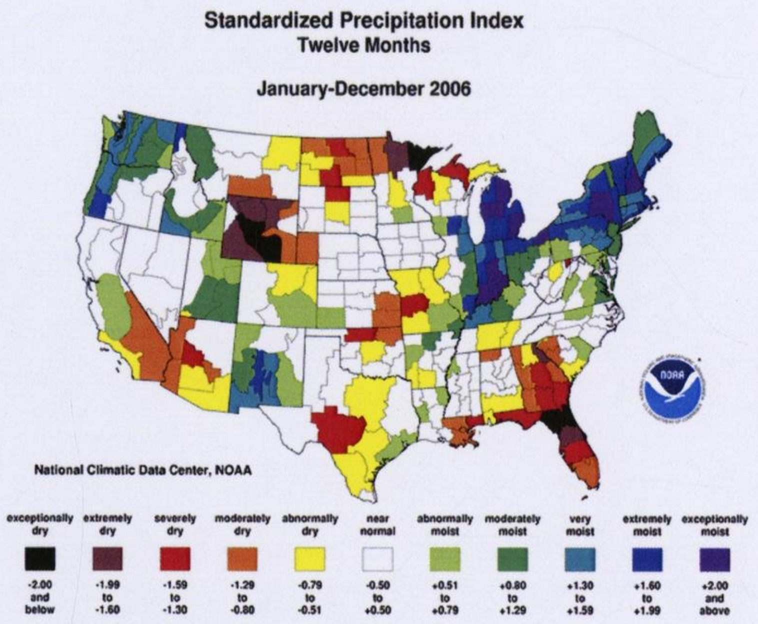


Figure 5. The precipitation index for the 2006 shows that the study region area was near normal, using the Palmer drought index (National Climate Data Center, Climate of 2006).

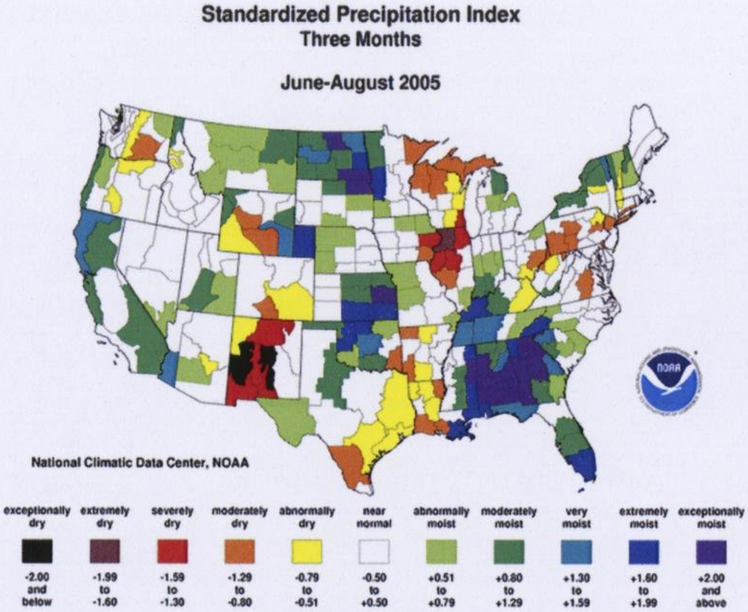


Figure 6. The precipitation index for the summer of 2005 shows that the study region was abnormally dry, using the Palmer drought index (National Climate Data Center, Climate of 2005).

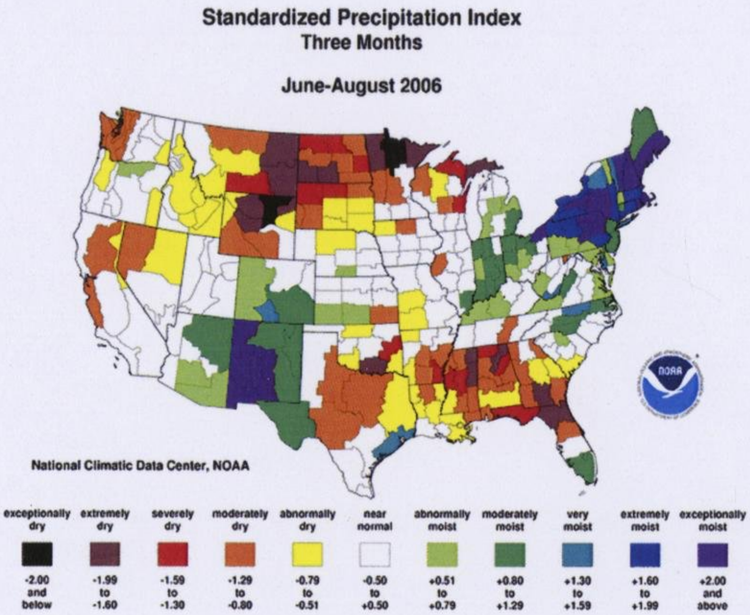


Figure 7.The precipitation index for the summer of 2006 shows that the study area was moderately to severely dry, using the Palmer drought index (National Climate Data Center, Climate of 2006).

II. DAILY AND MISCELLEANOUS USGS DISCHARGE RECORDS – INVENTORY AND INFERENCES

The USGS stream discharge record for the western Fox Wolf comprises miscellaneous sites (those where one to a few measurements are available) and daily discharge sites (those where daily measurements are available for varying lengths of time). These data were compiled, used to infer baseflow conditions at various scales, and provide a context for 2005 and 2006 flow conditions.

Miscellaneous discharge measurements

Two hundred seventy three USGS miscellaneous spot discharge measurements are available for the Upper Fox – Wolf Basins, of which 180 lie in the western Fox-Wolf basin (Figure 8). Sites had 1 to 40 discharge observations (average = 4.6) made during 1931 to 2006. These data are included as GIS map document and geodatabase files forwarded as part of this report, and compared against measurements gathered in this study at collocated stations.

Daily discharge measurements

Thirty-eight USGS daily gauging sites exist within the Upper Fox and Wolf River basins. Twelve are not useful due to distance from the study area or because they represent very small drainage features, such as a storm sewer. The utility of the remaining 26 (Figure 9, Appendix I and II) varies because of length of discharge record (2 to 108 years; median = 9) and size of drainage area (5.6 to 5310 mi^2, median = 114). Short discharge records provide a poor basis for providing robust descriptive statistics about discharges. Small drainage basins may not integrate a sufficient portion of a landscape to be representative, and cause error because the groundwater basin and surface watershed areas may be substantially different. Only 10 of the gauges were operating in USGS water years 2005-6. Available daily stream gauges were used to make inferences about average baseflows as well as flow conditions in water years 2005 and 2006 relative to the long term record. Location and discharge information from daily measurement sites are included in a GIS map document and geodatabase files.

Water years 2005 and 2006 in the Western Fox-Wolf Watershed

The water years 2005-6 hydrographs for eight of 10 gauges with available data are presented in Figure 10. The available discharge record indicates that water years 2005 and 2006 were dry (Appendix I). Judging by active stations with a record of 14 years or more, 2005 discharges averaged the 21st percentile (i.e., 79% of years had greater discharges), and 2006 discharges averaged the 9th percentile. Discharges in 2006 were particularly low in the northern part of the Wolf watershed, where the station at Langlade (4074950, Figure 9) was at a

Figure 8. USGS miscellaneous spot discharge measurement sites.

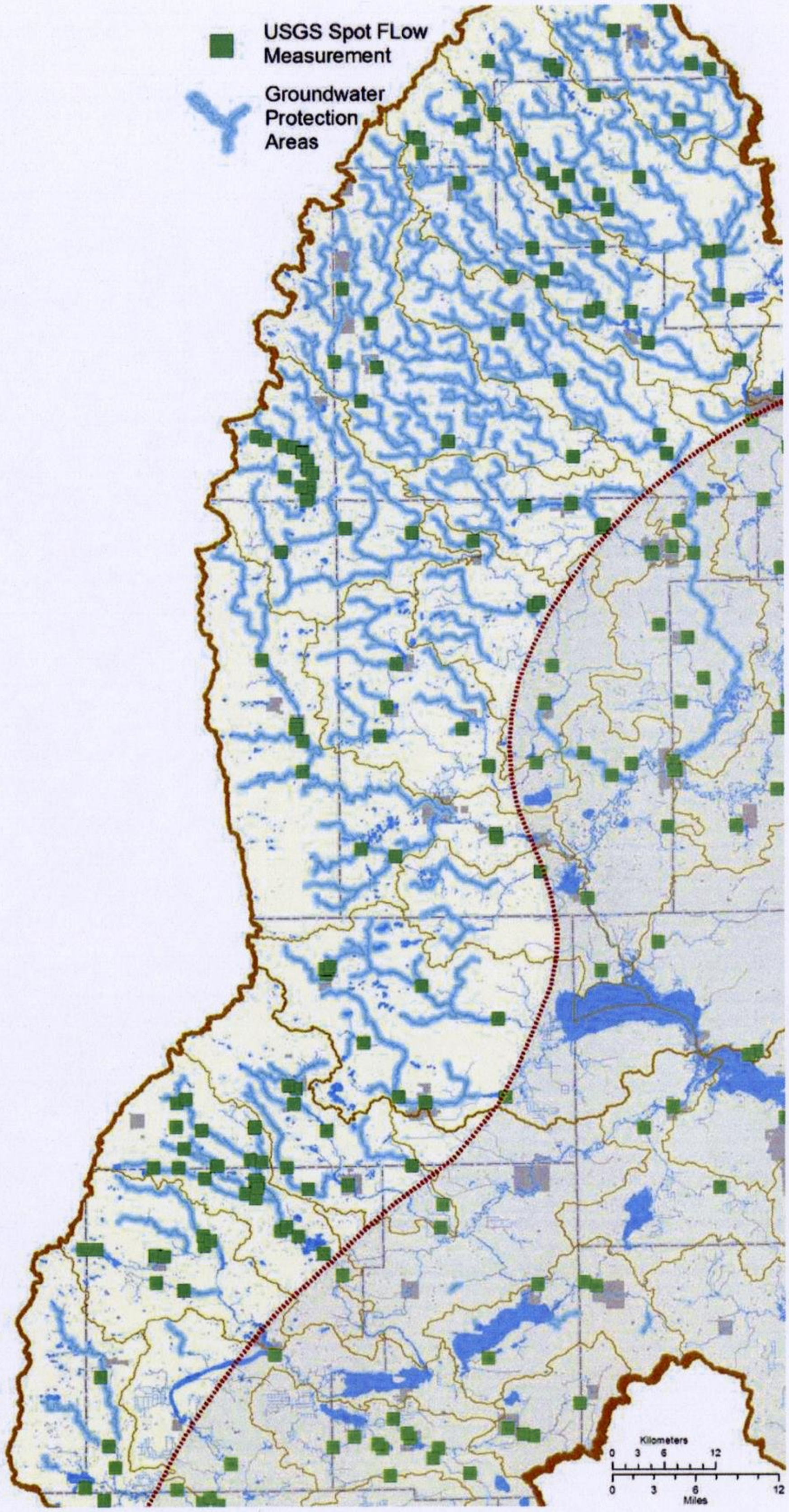
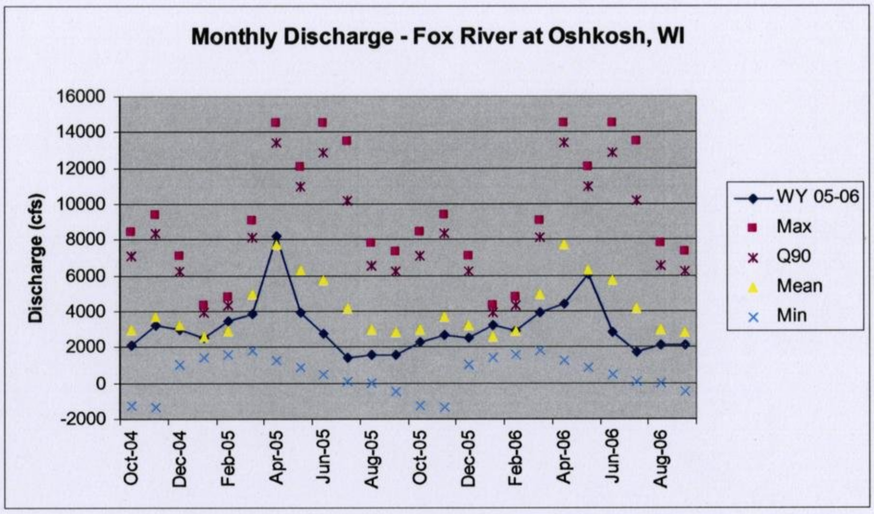


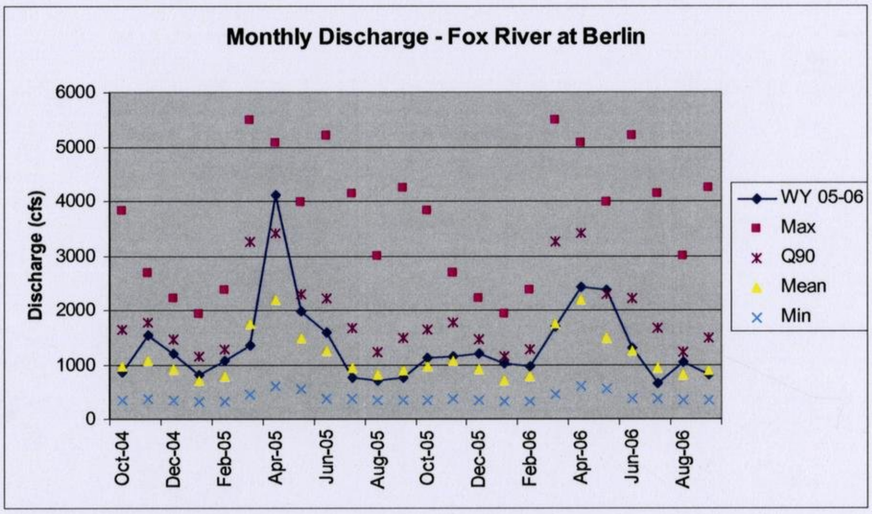
Figure 9. USGS daily flow discharge sites useful for this study.

record low over a fairly long history (31 years), and in agreement with the two stations with short histories at Swamp Creek (4074548 and 4074538). The Fox River at Oshkosh also was at a record low in 2006, but the brevity of the record (15 years) there needs to be taken into account.

Large scale baseflow estimates from USGS daily sites

The Q_{50} (discharge which is exceeded 50% of the time) is sometimes used as a surrogate for estimating baseflow (U.S. Fish and Wildlife Service, 1981; Caissie and El-Jabi, 1995). For each station, we calculated an average and standard deviation of daily Q_{50} (Appendix I) and a Q_{50} normalized for drainage area (i.e., Q_{50}/drainage area, Figure 11). The Q_{50} (and hence estimated baseflow) ranged 0.56 to 1.35 cfs/mi^2, equivalent to 7.6 to 18.3 inches per year. Substantial scatter exists in the data for small watersheds. We attribute the scatter for small watersheds to the effect of surface watersheds and groundwater basins matching poorly at small scales. Hence, we believe it is more sound to only use the Q_{50} of larger watersheds as an estimator of baseflow per area for the region. Using data only from watersheds of 100 mi^2 produces a baseflow estimate of 0.83 cfs/mi^2, (equivalent to a groundwater recharge rate of 11.2 in).





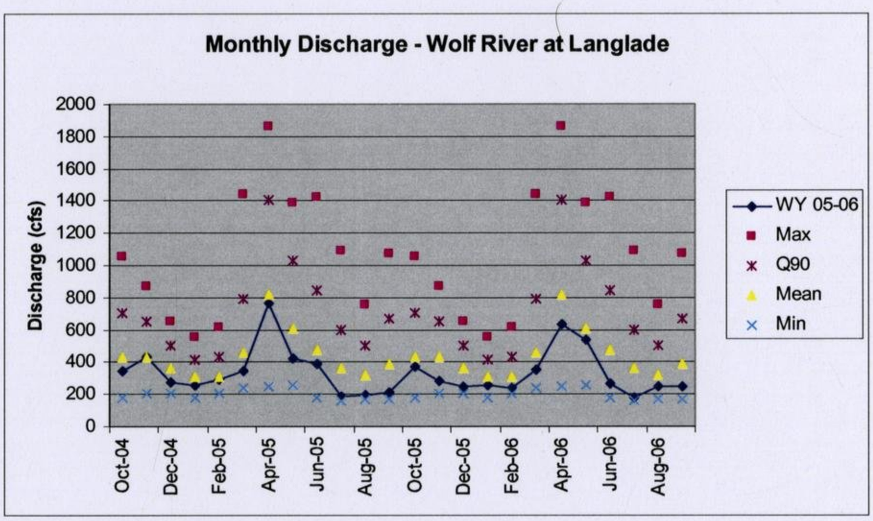


Figure 10. Monthly discharge during water year 2005-6 compared to gauge statistics for select Fox-Wolf streams

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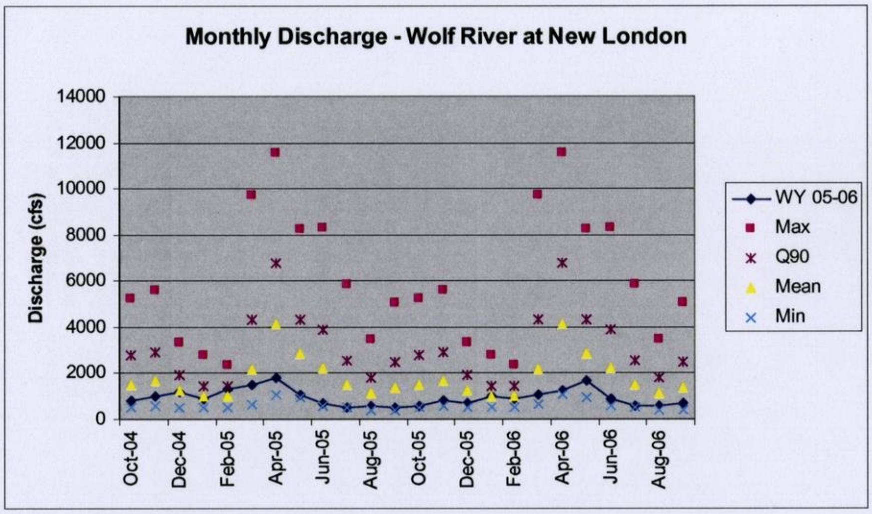

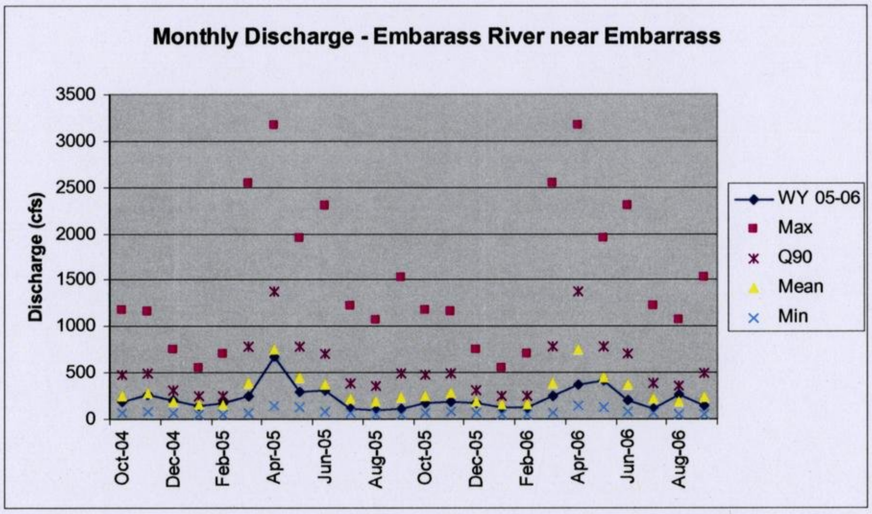

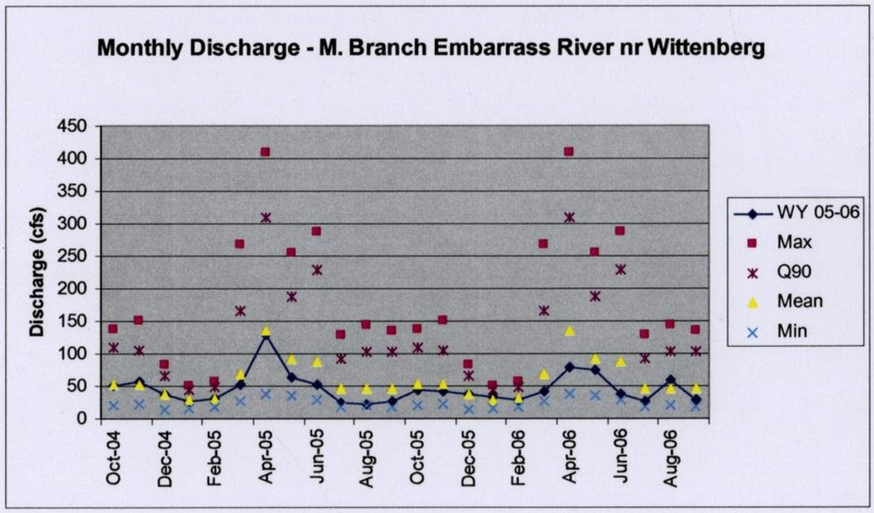

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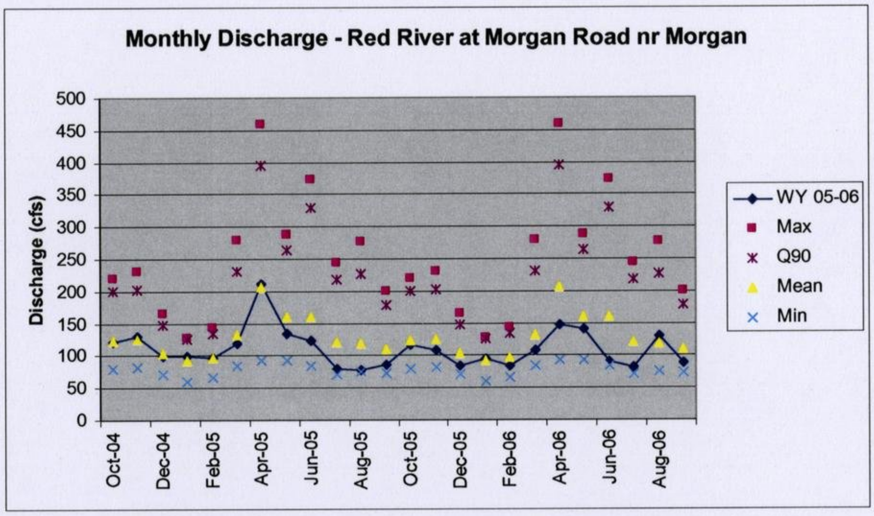
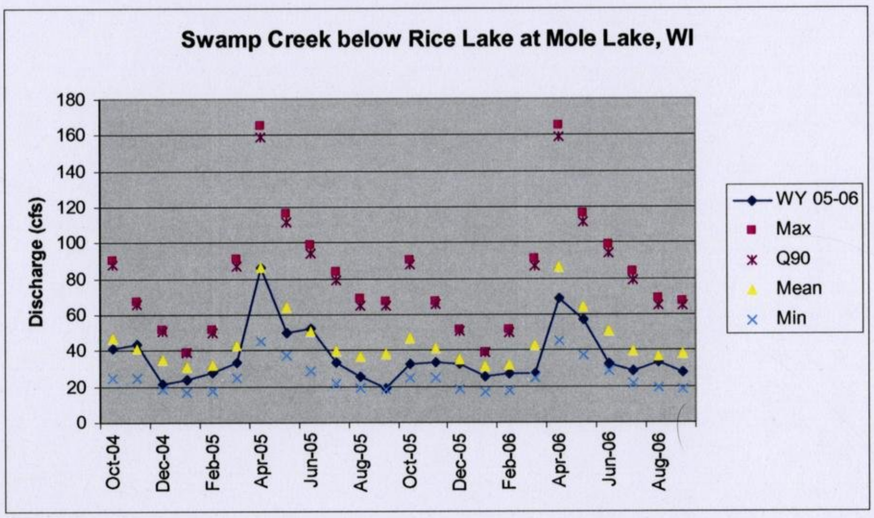




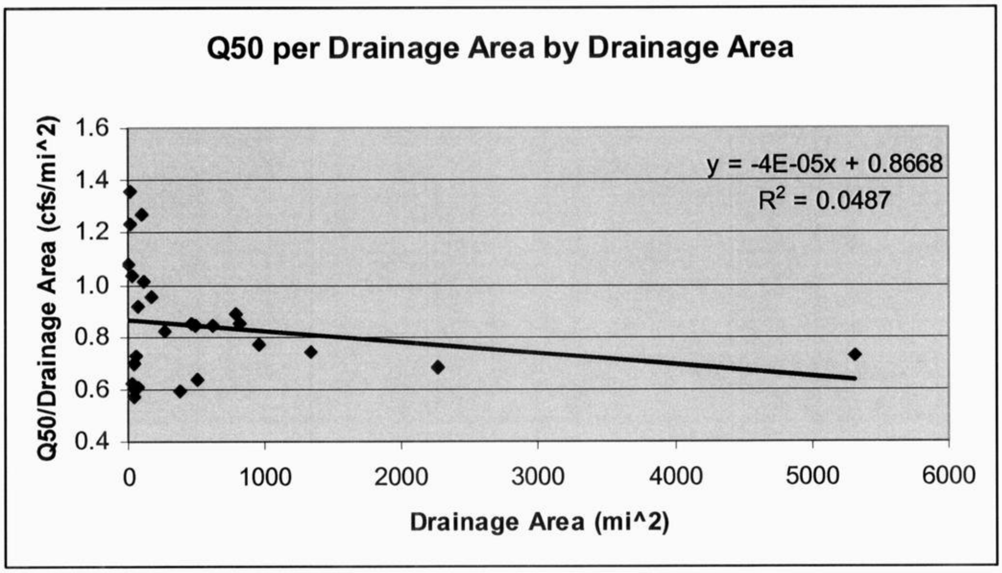


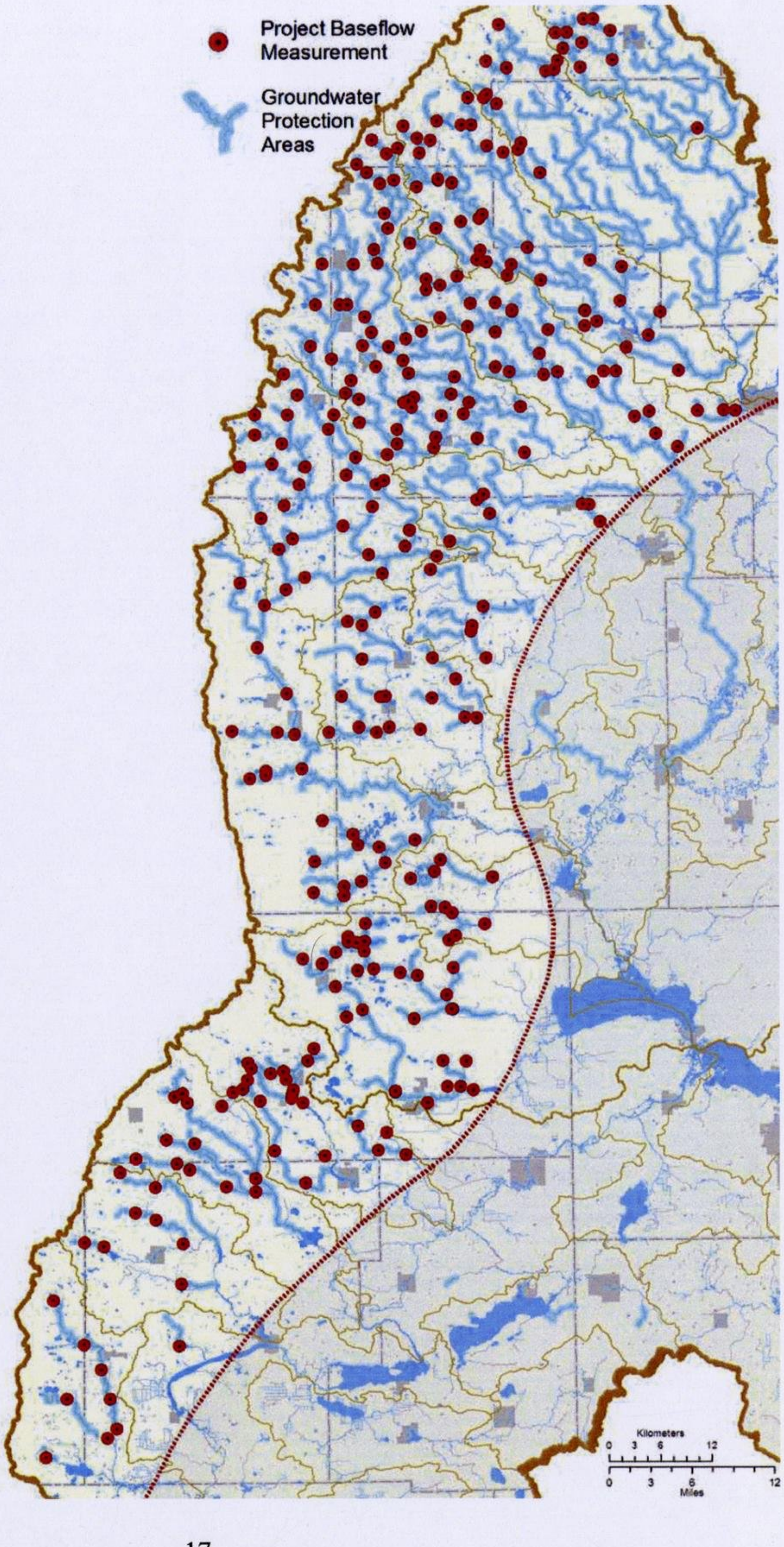
Figure 11. Q_{50} per drainage area at USGS daily gauge stations

III. BASEFLOWS MEASURED IN HEADWATERS STREAMS

Discharge measurements were taken at 304 sites during baseflow conditions from within the Western Fox-Wolf watershed (Figure 12). Discharge was measured at least once at each site during the summer of 2005. Forty six of these sites were selected from 17 sub-watersheds for repetitive measurement that continued until October 2006. Discharges were collected by velocity – cross section methods using a Marsh-McBirney flow meter to record velocity. Care was taken to ensure that field measurements were not taken within at least three days of rain. For repetitive flow measurements sites, we sought to collect measurements at all sites within a two-day window so that measurements could be comparable. On average repetitive measurements were made 14 times per site. Individual measurements, averages, and measurement point locations are archived in ArcGIS map document and geodatabase files included with this report.

We also attempted to measure continuous discharge at eleven sites using Solinst recording pressure transducers. The pressure transducers were installed from June 2005 to October 2005 and April 2006 to November 2006. Unfortunately, due to the extremely low flows in the streams, we were unable to develop useful correlations between discharge and water level; therefore, these data are not included within this report.

Figure 12 Baseflow measurement sites for this study.



IV. IMPLICATIONS OF 2005-6 BASEFLOW MEASUREMENTS

Baseflow per cumulative stream length

We examined baseflow discharge per stream length relationships as a potential tool for WDNR staff to estimate baseflow at ungauged sites. Previous methods for estimating low-flow or baseflow discharge based on watershed area (e.g., Holmstrom, 1980; Gebert, 1982; Gebert and Holmstrom, 1977) do not apply because they were developed for stream reaches with greater discharge than those that were the focus of this study, and are difficult to implement for headwaters streams because of discrepencies between topographic watersheds and groundwater contributing areas. Stream length was determined as the cumulative length of perennial channel upstream from a measurement point using ArcGIS, i.e., cumulative stream length included all tributaries. For baseflow measurement sites with multiple discharge measurements, the measurements were averaged. We also provide estimates of the amount of cumulative stream length needed to produce a discharge of 10 cfs, which might act as a sort of trigger for what stream stretches are deemed more or less sensitive to depletion from groundwater pumping.

Figure 13 shows the 304 project baseflow site discharges simultaneously regressed against cumulative stream length. The regression exhibits the expected increasing trend and indicates that baseflow increases by 0.48 cfs per mile of cumulative stream length. The regression further implies that the cumulative streamlength required to produce 10 cfs is about 15 miles. However, the regression coefficient of only 0.43 indicates the correlation is weak. Addtionally, data above and below the trendline indicate a non uniformity and suggests that

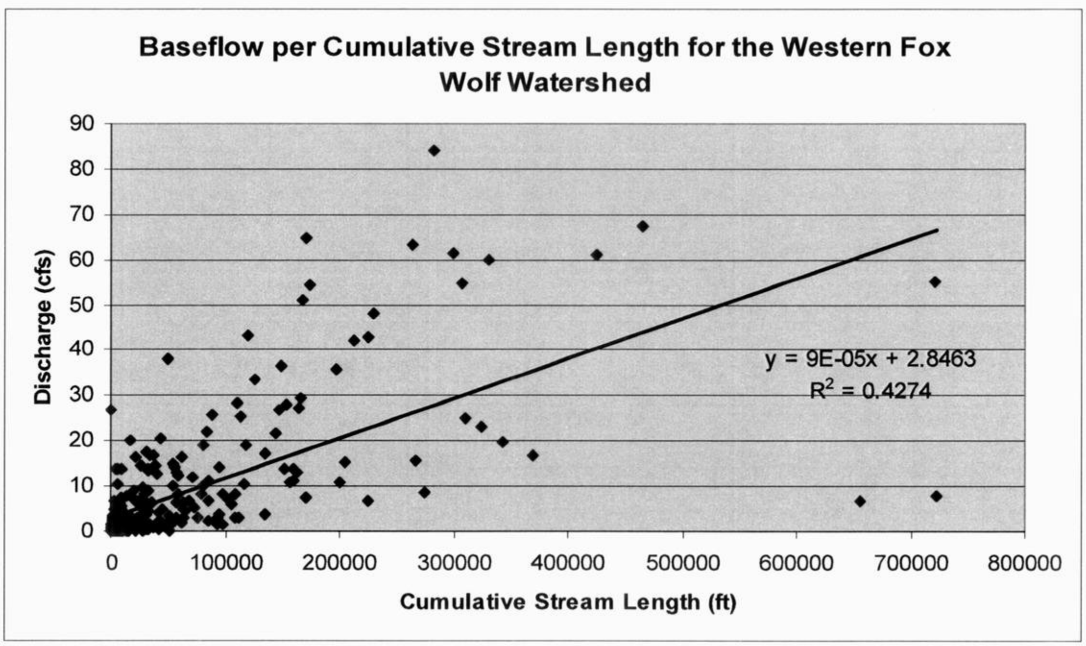


Figure 13. Baseflow discharge compared with cumulative stream length. Note the correlation is poor (R^2 <0.5) when all data points are considered simultaneously.

the data should be separated. Hence, data in Figure 13 were separated by watershed region (watersheds are shown in Figure 3). The regressions that result from separating the data according to watershed are shown in Figure 14 for each watershed and are summarized in Table 3. Also shown in Figure 14 are 90% regression prediction bands developed using the Working-Hotelling formula (Chou, 1969 p. 612).

Correlation coefficients for the watershed specific baseflow – cumulative streamlength relationship were in general quite good. Correlation coefficients were < 0.70 for only two watersheds, the North Branch and Mainstem of the Embarrass River ($r^2 = 0.69$) and the Red River ($r^2 = 0.36$). The regressions indicate that baseflow discharge increases by an average 1.5 cfs per cumulative stream mile (range of 0.26 to 10.6 cfs per mile) and that an average 17.1 cumulative stream miles (range of 0.98 to 38.13) are required to generate 10 cfs of baseflow. Note that some of the measurement data points in figure 14 are outside of the prediction bands even for regressions that show a high degree of linearity. In many of these streams the regression is aided by the larger cumulative stream length values, because in fact there is significant scatter among cumulative stream length values of less than 5000 ft. Care should be given when predicting discharge in this range of a river.

Comparison Against USGS Miscellaneous Spot Discharge Measurements

The USGS miscellaneous spot discharge (Section II) measurements in the western Fox Wolf were mainly taken during low-flow periods and thus should at least be roughly comparable to the measurements made in this study. Thirty-five of this project's discharge measurement locations coincided (±200 feet) with USGS miscellaneous spot discharge locations. The average of the discharge values for collocated locations was compared in Figure 15. The high correlation coefficient (0.94) indicated excellent agreement.

Temporal Behavior of Baseflow during 2005-6

Repetitive discharge measurements made at 46 sites indicate that baseflow varied greatly at larger scales (corresponding to larger cumulative stream length) during 2005-6, but not much nearer to stream headwaters. This finding perhaps has implications for determining what stream stretches require more or less intensive monitoring to quantify the variability of baseflow.

The variability of baseflow with scale is illustrated in Figure 16 using the Wolf at Langlade and Evergreen River watersheds as an example. Baseflows there at individual sites were measured up to 13 times. Discharges at baseflow measurement sites varied by a factor of 8 where the cumulative stream length was about 42 miles, by a factor of 3 where the cumulative stream length was 5 miles, and by a factor of only 1.5 where the cumulative stream length was about a mile. Discharge at small cumulative stream length is shown in detail in Figure 17. We hypothesize that the consistency of baseflow in headwaters streams, relative to downstream locations, is mainly due to groundwater recharge pulses being more quickly dampened in headwaters, because

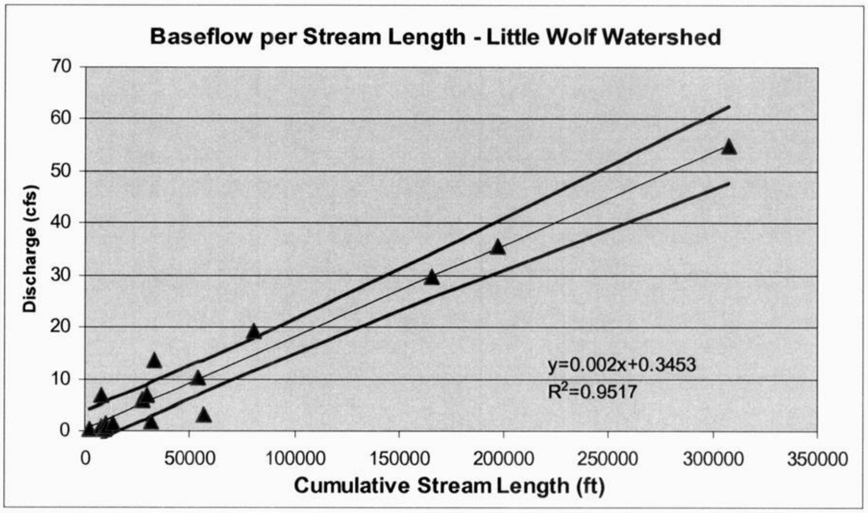
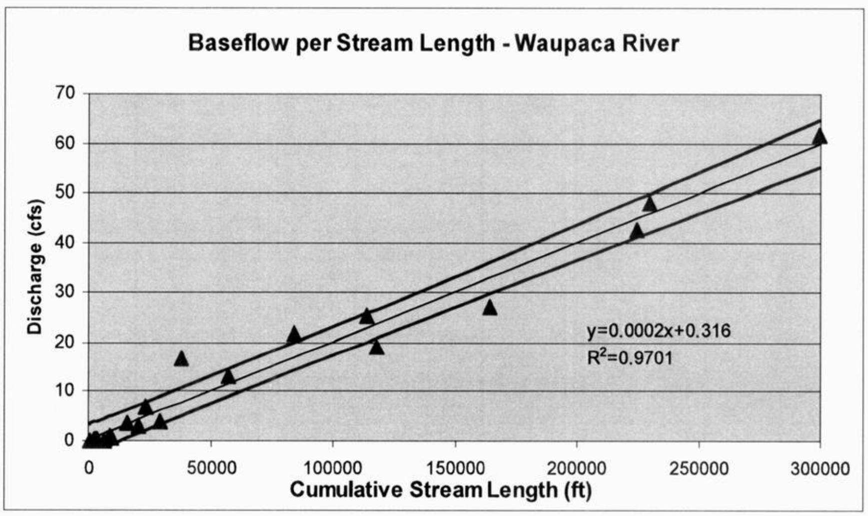
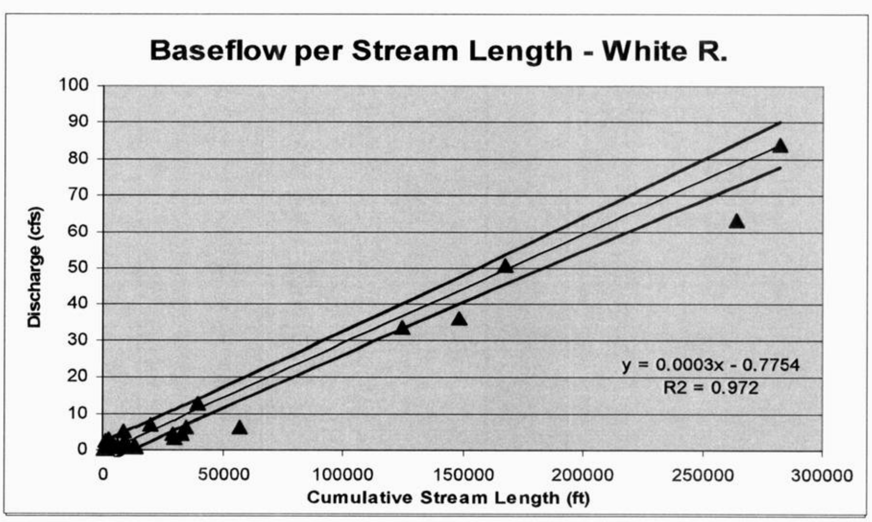
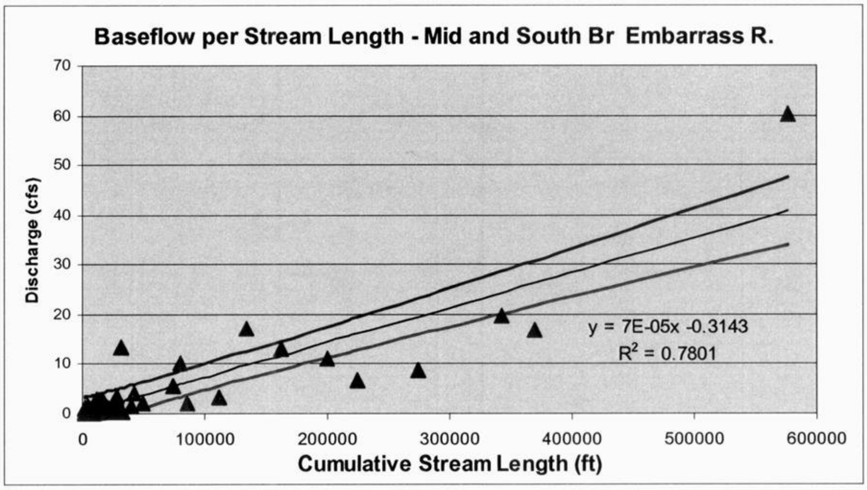


Figure 14. Baseflows per cumulative stream length in 11 subwatersheds of the western Fox-Wolf basins.







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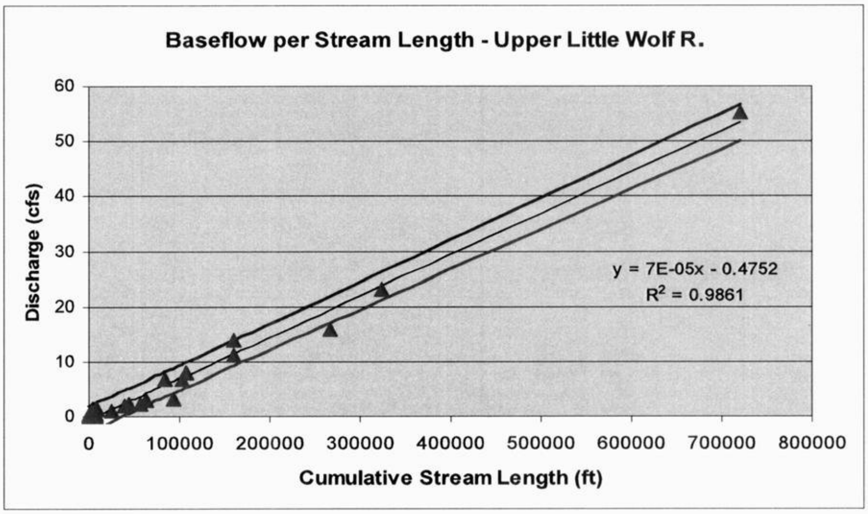

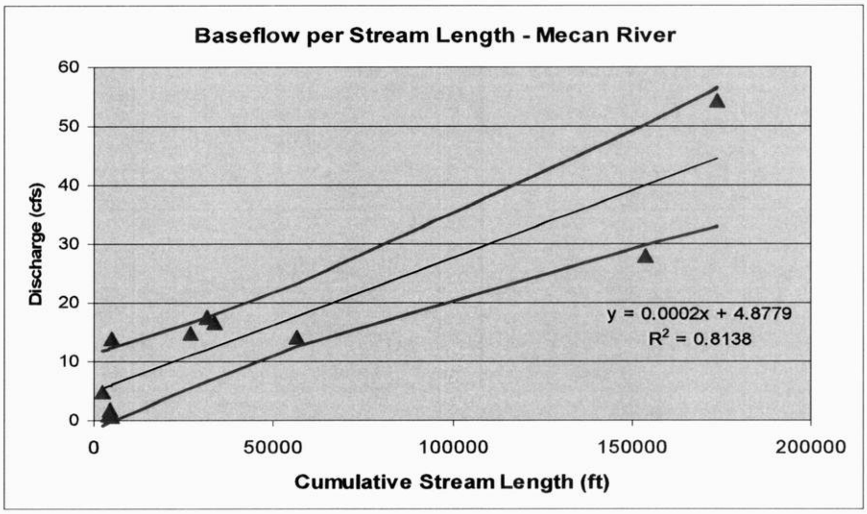

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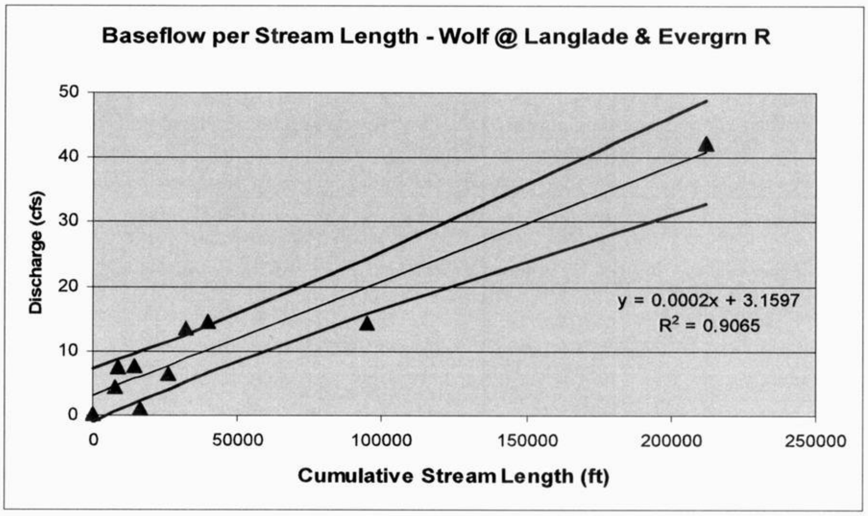

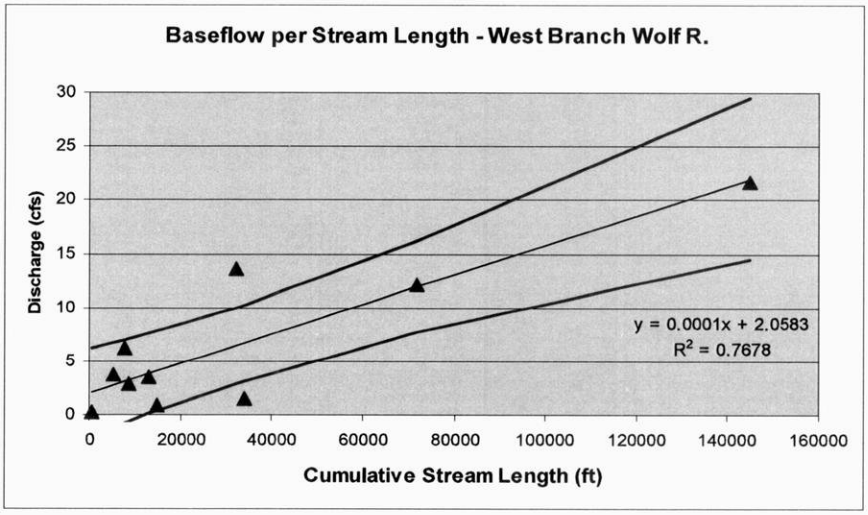

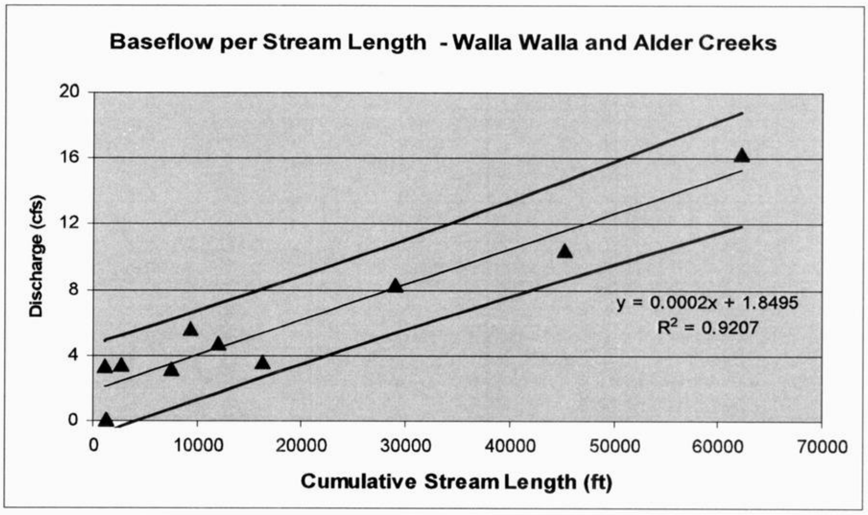

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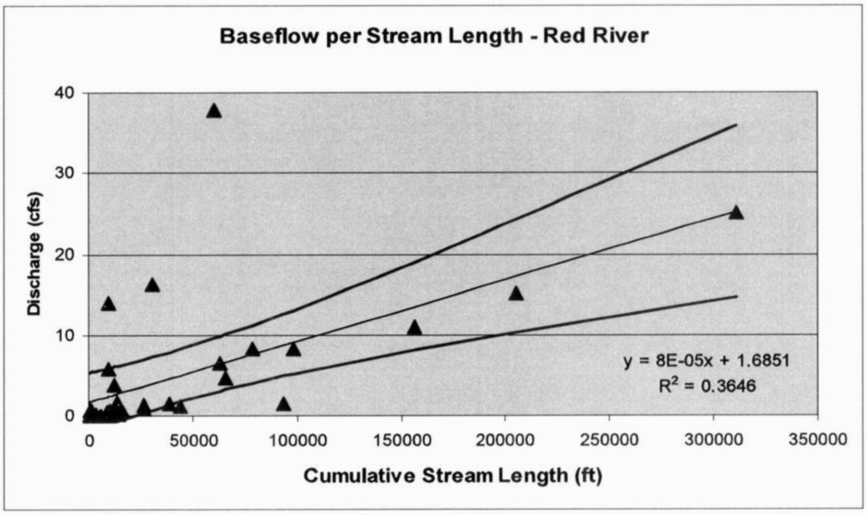

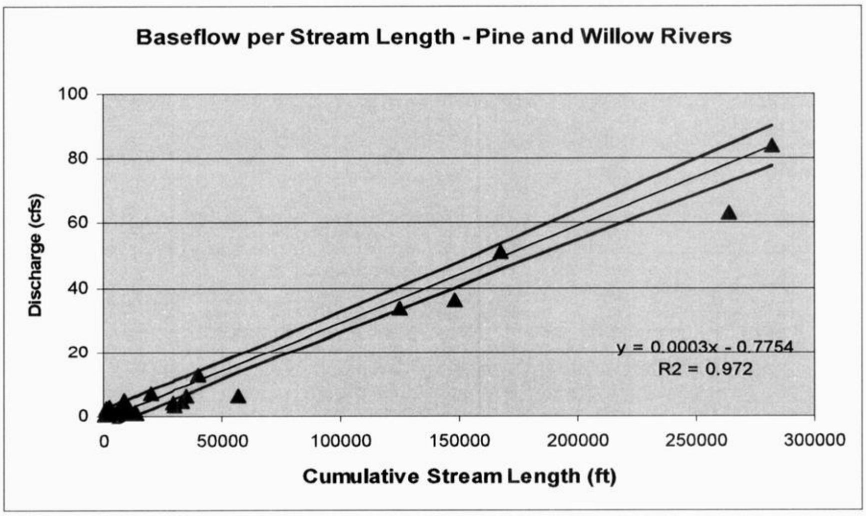

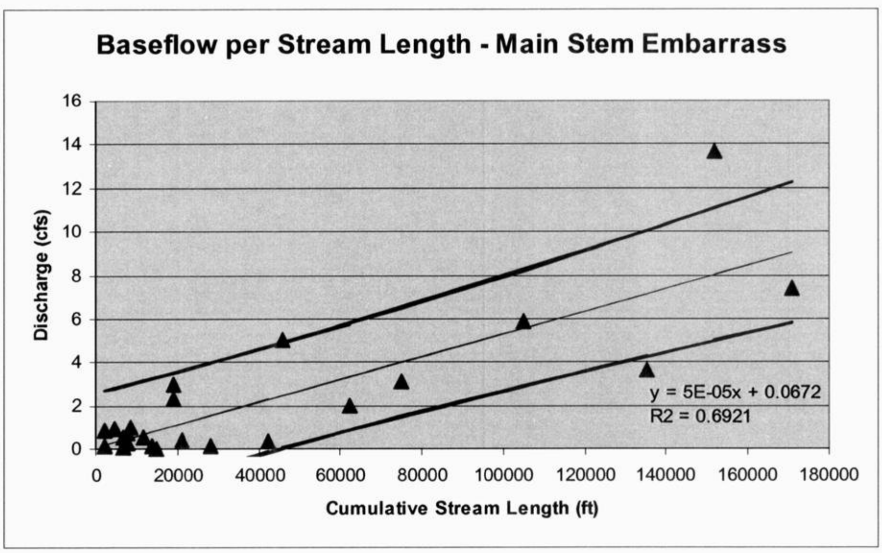

Table 3. Cumulative streamlength (*L)* as an indicator of baseflow discharge (*Q*) for western Fox-Wolf watersheds (Figure 14). Watersheds with poor regression fits ($R^2 < 0.5$) are indicated by (*). The variables presented in the equation are *Q* and *L* which represent baseflow discharge and streamlength (using meters for units), respectively.

Watershed Name	Trendline equation	R^2 value	Cumulative Stream Miles for 10 cfs
S. Branch of Little Wolf	$Q=0.002L+0.3453$	0.95	0.98
Upper Little Wolf	$Q=7X10^{-5}L -0.4752$	0.99	25.77
Middle and South Branch of Embarrass River	$Q=7X10^{-5}L-0.3143$	0.78	26.21
White River	$Q=0.0003L-0.7754$	0.97	5.82
Mecan River	$Q=0.0002L+4.8779$	0.81	14.09
Pine and Willow Rivers	$Q=0.0003L-0.7754$	0.97	6.80
Walla Walla and Alder Creek	$Q=0.0002L+1.8495$	0.92	11.22
Waupaca River	$Q=0.0002L+0.316$	0.97	9.17
Wolf River/Langlade and Evergreen Rivers	$Q=0.0002L+3.1597$	0.91	12.46
West Branch Wolf	$Q=0.0001L+2.0583$	0.77	22.84
North Branch and Mainstem of Embarrass River*	$Q=5X10^{-5}L + 0.0672$	0.69	38.13
Red River*	$Q=8X10^{-5}L +1.6851$	0.36	31.52
Average of all			**17.1**

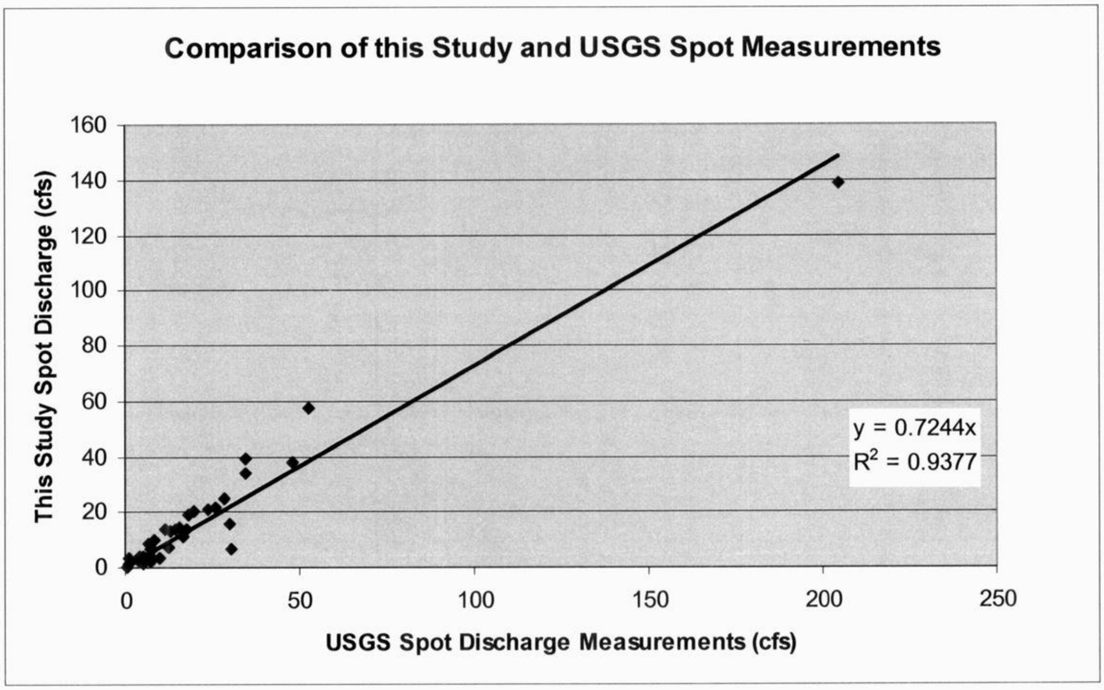

Figure 15. Comparison of this study and USGS spot discharges.

their contributing areas are small relative to downstream locations.

Baseflow discharge patterns were similar to the Wolf-Evergreen in other watersheds of the western Fox-Wolf. If we choose somewhat arbitrarily a range of 5 cfs as an indicator of relatively stable discharge conditions, a characteristic cumulative stream length can be determined smaller than which baseflow variability would be expected to be small. For the Wolf at Langlade and Evergreen River watersheds, this characteristic cumulative stream length is 17000 feet. For other watersheds, this length was between 1000 and 20,000 feet (Table 4). (These statistics were not developed for the North Branch and Mainstem of the Embarrass River watershed and the Walla Walla and Alder Creek watershed due to insufficient data.)

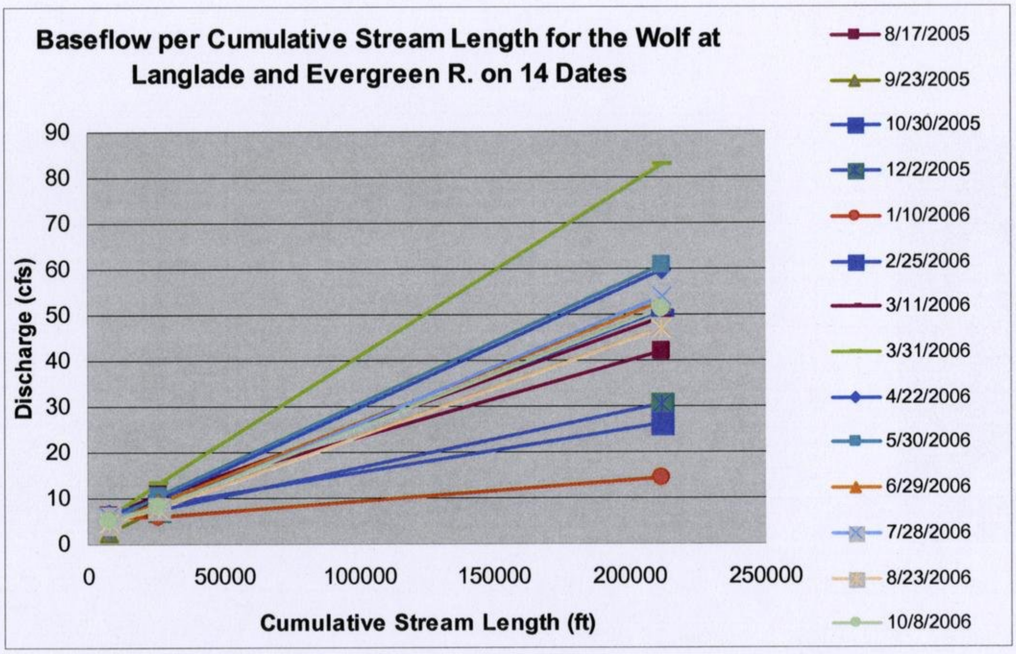

Figure 16. Baseflow per cumulative stream length for the Wolf at Langlade and Evergreen Rivers watershed on 14 dates. Note the small degree of variability at small cumulative stream lengths.

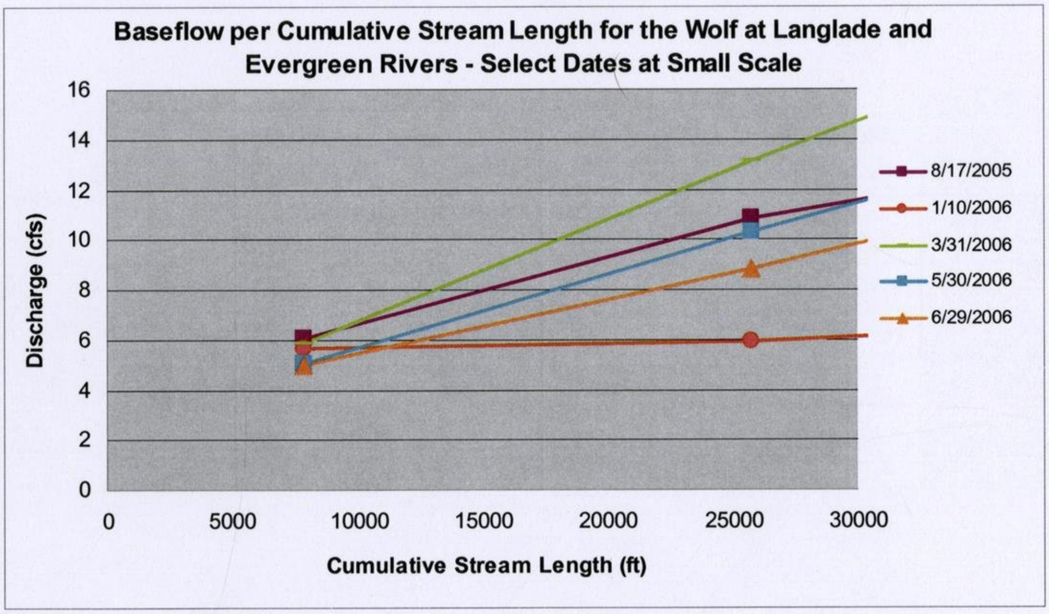

Figure 17. Baseflow per cumulative stream length at small scale.

Table 4. Cumulative stream length where baseflow varied by < 5 cfs during 2005-6 for some watersheds in the western Fox-Wolf.

Watershed Name	Stream length (ft) where flow varies ±5 cfs	Sites	Dates
S. Branch of Little Wolf	1000	17	19
Upper Little Wolf	8000	30	23
Middle and South Branch of Embarrass River	20,000	48	18
White River	8000	22	17
Mecan River	1000	11	20
Pine and Willow Rivers	10,000	29	22
Walla Walla and Alder Creek	Insufficient data	10	2
Waupaca River	10,000	20	25
Wolf River/Langlade and Evergreen Rivers	17,000	10	15
West Branch Wolf	15000	10	15
North Branch and Mainstem of Embarrass River	Insufficient data	23	3
Red River	5000	35	19

V. CONCLUSION

This project (1) compiled and interpreted existing USGS daily discharge and miscellaneous spot discharge measurements, (2) measured stream discharges during baseflow periods at 304 sites during 2005-6, (3) regressed project baseflows against cumulative streamlength as a simple predictive variable with potential use for estimating discharge at ungauged sites, and (4) compared project measured baseflows against those previously measured.

Existing information from daily discharge and spot discharge measurements were insufficient to adequately paint the baseflow picture in headwaters streams in the western Fox-Wolf basin. However, they had utility in helping to describe 2005-6 discharge conditions, and also suggest that at larger scales, baseflow in the western Fox Wolf basin averages about 0.83 cfs per mi^2 of watershed.

Project baseflows made during this study reflect drier than normal conditions. Precipitation during the project period was near normal to moderately dry, but summers were drier. USGS daily discharge gauges in 2005 and 2006 averaged the 21^{st} and 9^{th} percentiles of annual average flow, respectively.

While this project filled in a substantial amount of the baseflow information void, WDNR staff will likely be called upon to infer baseflow at ungaged sites. From 2005-6 baseflow measurements, we developed regression equations that relate baseflow discharge to cumulative streamlength on a watershed-by-watershed basis. These regressions can be used to infer baseflow at ungauged sites by computing (in a GIS) the cumulative amount of streamlength that lies upstream of a point of interest, and then using the most appropriate watershed regression relationship to compute an estimated baseflow at that point. The regression relationships indicated that streams in the western Fox-Wolf gain baseflow at an average of 1.5 cfs per cumulative stream mile (range of 0.26 to 10.6 cfs per mile). Further, an average 17.1 cumulative stream miles (range of 0.98 to 38.13) are required to generate 10 cfs of baseflow.

Comparisons of baseflows measured in this study agreed well with low flow measurements at 35 sites used by the USGS from the 1930s until 2006, bolstering confidence in both data sets. Repetitive measurements made at select sites indicated that baseflow variability is small near headwaters streams, but increases greatly in the lower reaches of a system. This suggests that efforts to quantify baseflow variability are better spent in larger stream reaches.

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Appendix Table I. Discharge statistics for select USGS daily flow gauges.

						-------------- For Entire Record --------------			
Gauge no	Gauge name	Drainage area (mi2)	Daily record start	Daily record end	Years of record	Average annual discharge (cfs)	Q50 mean	Q50 Stan Dev	Q50 per Drainage area
4075000	Wolf nr White Lake	485.0	10/1/1936	9/30/1938	3	417.4	409.7	184.9	0.84
4077400	Wolf near Shawano	816.0	10/1/1986	9/30/2000	15	767.8	691.7	169.4	0.85
4079000	Wolf at New London	2260.0	10/1/1914	9/30/2006	93	1791.4	1543.8	837.9	0.68
4074950	Wolf at Langlade	463.0	10/1/1967	9/30/2006	39	438.2	392.0	131.5	0.85
4077000	Wolf at Keshena Falls	788.0	10/1/1912	9/30/1985	74	764.5	696.7	233.2	0.88
4075500	Wolf above W Br Wolf	616.0	10/1/1928	9/30/1962	35	569.2	518.3	188.7	0.84
4081000	Waupaca nr Waupaca	265.0	10/1/1917	9/30/1985	51	238.6	217.6	35.5	0.82
4076500	W Br Wolf nr Keshena	163.0	10/1/1929	9/30/1931	3	167.6	155.1	48.5	0.95
4076000	W Br Wolf at Neopit	93.2	10/1/1912	9/30/1916	5	130.2	118.2	24.5	1.27
4073405	W Br White nr Wautoma	38.9	10/1/1963	9/30/1965	2	22.1	22.0	2.8	0.57
4080798	Tomorrow nr Nelsonville	44.0	10/1/1994	9/30/1995	2	29.1	30.6	8.9	0.70
4074548	Swamp Cr below Rice Lake	56.8	10/1/1978	9/30/2006	9	45.5	41.0	14.2	0.72
4074538	Swamp Cr above Rice Lake	46.3	10/1/1978	9/30/2006	13	31.0	27.8	11.0	0.60
4079700	Spaulding nr Big Falls	5.6	10/1/1965	9/30/1966	2	6.3	6.0	5.0	1.08
4077630	Red nr Morgan	114.0	10/1/1993	9/30/2006	14	128.8	115.5	27.3	1.01
407809265	Mid Br Embarrass nr Wittenberg	76.3	10/1/1990	9/30/2006	17	59.7	46.5	24.0	0.61
4072750	Lawrence nr Westfield	13.4	11/1/1967	9/30/1973	5	17.1	16.5	0.8	1.23
4079602	L Wolf nr Galloway	22.6	10/1/1974	9/30/1979	6	17.1	14.1	10.5	0.62
4080000	L Wolf at Royalton	507.0	10/1/1915	9/30/1985	59	405.1	320.5	155.8	0.63
4073365	Fox at Princeton	962.0	10/1/2002	9/30/2005	4	804.1	741.1	237.1	0.77
4082400	Fox at Oshkosh	5310.0	10/1/1991	9/9/2007	15	4161.5	3848.3	1690.8	0.72
4073500	Fox at Berlin	1340.0	10/1/1899	9/30/2006	108	1142.0	994.7	448.8	0.74
4075365	Evergreen below Evergreen Falls	64.5	10/1/2004	9/30/2006	3	59.2	58.8	13.7	0.91
4075200	Evergreen nr Langlade	8.1	10/1/1968	9/30/1973	6	12.0	11.0	1.1	1.35
4080950	Emmons nr Rural	25.1	10/1/1969	9/30/1974	6	26.8	25.9	1.7	1.03
4078500	Embarrass nr Embarrass	384.0	10/1/1920	9/30/2006	78	295.4	227.7	137.4	0.59

Appendix Table II. 2005 and 2006 discharge statistics for select USGS daily flow gauges.

		2005 Discharge (cfs)		2006 Discharge (cfs)	
Gauge no	Gauge name	Average	Percentile	Average	Percentile
4075000	Wolf nr White Lake	---	---	---	---
4077400	Wolf near Shawano	---	---	---	---
4079000	Wolf at New London	1386.0	21.7%	1312	14.1%
4074950	Wolf at Langlade	341.6	10.5%	319.9	0.0%
4077000	Wolf at Keshena Falls	---	---	---	---
4075500	Wolf above W Br Wolf	---	---	---	---
4081000	Waupaca nr Waupaca	---	---	---	---
4076500	W Br Wolf nr Keshena	---	---	---	---
4076000	W Br Wolf at Neopit	---	---	---	---
4073405	W Br White nr Wautoma	---	---	---	---
4080798	Tomorrow nr Nelsonville	---	---	---	---
4074548	Swamp Cr below Rice Lake	38.0	12.5%	35.3	0.0%
4074538	Swamp Cr above Rice Lake	25.7	16.6%	23.7	0.0%
4079700	Spaulding nr Big Falls	---	---	---	---
4077630	Red nr Morgan	114.1	30.7%	105.8	7.6%
407809265	Mid Br Embarrass nr Wittenberg	47.2	25.0%	43.7	6.2%
4072750	Lawrence nr Westfield	---	---	---	---
4079602	L Wolf nr Galloway	---	---	---	---
4080000	L Wolf at Royalton	---	---	---	---
4073365	Fox at Princeton	694.2	33.3%	---	---
4082400	Fox at Oshkosh	3105.0	7.1%	3,056	0.0%
4073500	Fox at Berlin	961.1	28.9%	867.5	19.6%
4075365	Evergreen below Evergreen Falls	59.2	50.0%	53.2	0.0%
4075200	Evergreen nr Langlade	---	---	---	---
4080950	Emmons nr Rural	---	---	---	---
4078500	Embarrass nr Embarrass	229.6	24.6%	209.8	16.8%

Appendix III: Project and USGS collocated sites and cumulative stream length

Project vs. Spot Q and Stream Length

Project Locations				USGS Spot Locations			
Wolf-Langlade and Evergreen River Watershed							
Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Evergreen Creek @ Hwy 64	15	6.523	25738.16	Evergreen Creek nr. Langlade	6	7.796	25738.16
West Branch of the Wolf River Watershed							
Site Name	# samples	Ave Q (cfs)	Steam Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Rabe Creek @ 5th Ave.	1	3.724	5123.36	Rabe Creek nr. Polar	4	3.998	5123.36
Little West Branch Wolf River @ Hwy 47	12	21.714	144877.6	Little West Branch Wolf River @ Hwy 47	1	25.7	144877.6
Noseum Creek @ Hwy 47	1	3.47	12946.16	Noseum Creek nr. Zoar	1	1.14	12946.16
Red River Watershed							
Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Mayking Creek @ CTH S	1	13.884	9298.8	Mayking Creek nr. Pholx	6	14.58	9298.8
Red River (just after confluence)	1	37.78	60315.92	Red River nr. Antigo	27	48.14	60315.92
Silver Creek @ Silver Creek Road	2	8.276	78523.2	Silver Creek @ Silver Creek Road	1	7.47	78523.2
West Branch Red River @ Hwy 47	15	3.757	12319.68	West Branch Red River nr Phlox	8	5.27	12319.68
West Branch Red River @ Murphys Road	13	25.008	310317.52	West Branch Red River Below SDP(?) nr. Bowler	2	28.15	310317.52
West Branch Red River @ Cty D	2	8.217	98085.12	West Branch Red River nr. Mattoon	4	6.83	98085.12
North and Main Stem Embarrass River Watershed							
Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
North Branch Embarrass River @Cty D	2	13.63	151864	North Branch Embarrass River @ Bowler	14	17.61	151864
Mill Creek @ Mill Creek Road	1	7.374	170848.64	Mill Creek nr Pella	12	12.29	170848.64
Middle and South Branch Embarrass River Watershed							
Site Name	# samples	Ave Q (cfs)	Steam Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
South Branch Embarrass River @ Cty M	1	6.74	225208.08	South Branch Embarrass River nr. Wittenberg (downstream)	2	30.6	225208.08
South Branch Embarrass River @ Cty OO	1	3.152	112205.52	South Branch Embarrass River nr. Wittenberg	11	9.74	112205.52
Tiger Creek @ Mohawk Street	1	0.083	7724.4	Tiger Creek @ Wittenberg	6	0.602	7724.4

Upper Little Wolf River Watershed

Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Little Wolf River @ Benvent Road	12	0.023	7759.19	Little Wolf River nr. Galloway	1	0.49	7759.19
Little Wolf River @ River Drive	14	1.823	39629.27	Little Wolf River nr. Galloway (downstream)	1	4.14	39629.27
Little Wolf River @ Franzen Road	1	3.067	93313.65	Little Wolf River @ Galloway	16	7.56	93313.65
Holt Creek @ Bobsoing Road	1	2.222	44130.58	Holt Creek nr Galloway	9	7.38	44130.58
Little Wolf @ 49	5	6.704		Little Wolf River nr. Galloway (further downstream)	2	7.18	
Little Wolf River @ CTH P	1	15.756	266164.70	Little Wolf River @ Norske	3	30.13	266164.70
Comet Creek @ Bergen Road	1	11.053	160305.12	Comet Creek nr. Big Falls	12	16.61	160305.12

South Branch Little Wolf River Watershed

Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Peterson Creek @ Q	21	18.660		Peterson Creek nr. Scandinavia	15	18.01	

Waupaca River Watershed

Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Emmons Creek @ Rustic Road 23	20	19.961	377201	Emmons Creek nr. Rural	1	19.62	377201
Waupaca River @ Harrington Road	6	138.678		Waupaca River nr. Waupaca	40	204.88	

Pine and Willow Creek Watershed

Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Wild Rose Fish Hatchery @ Hwy 22	1	1.05	8842	Trib from Fish Hatchery	2	4.94	8842
Willow Creek @ CTH S	14	39.27	148409	Willow Creek nr. Redgranite	17	34.33	148409

White River Watershed

Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Bird Creek @ Hwy 21	15	9.84	32241	Bird Creek @ Wautoma	5	8.08	32241
Lunch Creek @ Deerborne Drive	15	13.83	85715	Lunch Creek nr. Neshkoro	15	11.14	85715
West Branch White River @ 22	1	20.49	44183	West Branch White River nr. Wautoma	1	23.5	44183

Mecan River Watershed

Site Name	# samples	Ave Q (cfs)	Stream Length (ft)	Site Name	# samples	Ave Q (cfs)	Stream Length (ft)
Chaffee Creek @ JJ	15	14.19	27024	Chaffee Creek nr. Richford	4	15.43	27024
Chaffee Creek @ 14th	21	33.88	153862	Chaffee Creek nr. Neshkoro	18	34.65	153862
Mecan @ GG	7	12.82	4852	Mecan River nr. Richford	22	12.77	4852
Mecan River @ 14th Avenue	15	57.46	173668	Mecan River nr. Richford (downstream)	4	52.48	173668
Schmudlack Creek @ Cottonville Road	15	1.14		Schmudlack Creek nr. Richford	3	1.08	