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Analysis of Flow Data from Miller Creek, Duluth, MN

by

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Abstract

This report summarizes an analysis of flow and precipitation data for Miller Creek, a trout stream in Duluth, MN, which was undertaken in support of the MPCA-mandated temperature TMDL. The main goals of this analysis were to determine the availability and quality of Miller Creek flow data and to characterize typical summer low flow conditions to be used in subsequent stream temperature analysis. Flow data from the three existing flow aging sites (lower, middle, upper) on Miller Creek were analyzed, along with precipitation data from the Duluth International Airport. The analyses of flow and precipitation data suggest that the flow data at the lower site are relatively consistent for all years, except 2007. Flow data from the middle site for the periods 1997-2003 and 2004-2007 have different character, with the 2004-2007 data from the middle site considered suspect. Flow data from the upper site (Kohl's) in 1997 and 1998 appear reasonable, but a rating curve does not exist to translate stage data to flow for 2003 – 2007. Relationships between stream flows and precipitation have been established at weekly timescales and are reasonable ($r^2 = 0.70$), but with RMSEs similar in magnitude to the mean flows.

Based on 1997 and 1998 data, weekly-averaged flows at the middle and upper gaging sites are, on average, 92% and 77% of the lower site, respectively. This suggests that a large fraction of the flow in Miller Creek originates from the upper portion of the watershed, upstream of the Kohl's site. A statistical analysis of five years of flow data from the Miller Creek lower site indicates that low flows in the range of 1 to 2 cfs are quite common at weekly time scales. Therefore a rainfall event of moderate magnitude may be expected to have a significant impact on stream flow and temperature at the lower site. Although the flow record is relatively short (5 years), the results of a frequency analysis suggest that weekly mean flows near zero are possible with a 10 year return period.

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1. Introduction

Miller Creek is a trout stream which originates near Duluth International Airport, flows through the cities of Hermantown and Duluth, MN and discharges into St. Louis Bay (Figure 1.1). Despite a highly urbanized watershed, Miller Creek has a naturally reproducing Brook Trout fishery. Miller Creek is temperature impaired and was recently put on the list of impaired waters by the Minnesota Pollution Control Agency (MPCA). This report summarizes an analysis of flow and precipitation data for Miller Creek, which was undertaken in support of the MPCA-mandated temperature TMDL. Several previous studies have included information and/or analyses of the geomorphology and hydrologic characteristics of Miller Creek (Fitzpatrick et al. 2006, Schomberg et al. 2000, South St. Louis SWCD 2001, 2002). Prominent hydrologic features of the 9.4 square mile watershed include relatively high levels of impervious surfaces (22%) and extensive wetlands in the upper portion of the watershed (Figure 1.1) that interact are believed to supply much of the hydrologic storage for the watershed.

Stream flow data are a prerequisite for stream temperature analysis. Low flow during dry weather periods can be associated with high stream temperatures due to heating either from the atmosphere or by surface runoff from impervious surfaces. Reliable low flow data are required to estimate the magnitude of baseflow inputs from shallow groundwater and wetland sources, which are important for maintaining coldwater stream habitat (South St. Louis SWCD, 2001). Low flow data are also used in stream temperature models to establish an appropriate initial (pre-storm) condition for analyses of stormwater thermal impacts. The main goals of this analysis were (1) to determine the availability and quality of Miller Creek flow data and to characterize typical summer low flow conditions to be used in stream temperature analysis.

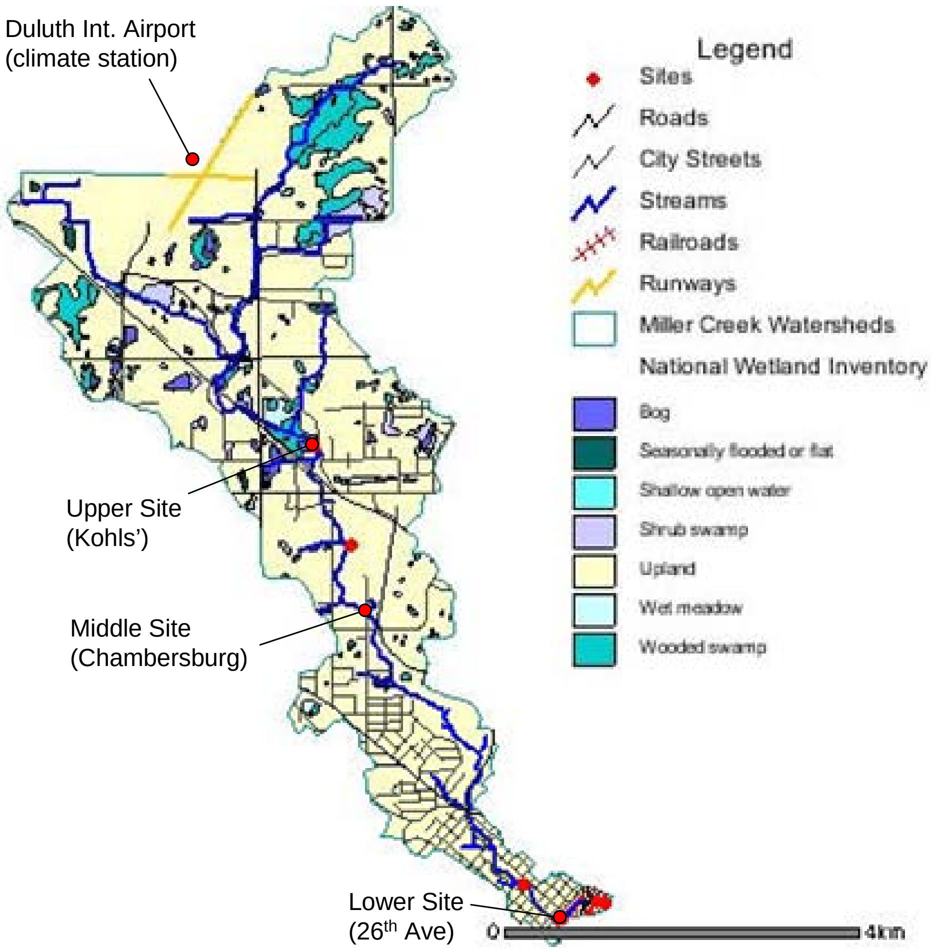

Figure 1.1. Map of the Miller Creek watershed, showing the three flow gaging stations. Figure adapted from graphical data obtained from *www.duluthstreams.org.*

2. Availability of flow and precipitation data

Flow data for Miller Creek were obtained from the South St. Louis Soil and Water Conservation District (SWCD). Locations and time periods for which data are available are summarized in Table 2.1. The primary gaging site for Miller Creek is at 26th Avenue (Figure 1.1), and is sometimes referred to as the lower site in this report. Some flow data also exist for sites at Chambersburg Avenue (middle site), and near Kohl's Department Store (upper site). At all three sites, flow data were available for 1997 and 1998. After 1998, some stage data were available for the middle and upper sites, but reliable rating curves are not available to calculate discharge at these sites. For the lower site, the rating curve was recently updated by MPCA and South St. Louis SWCD personnel, so that flow data were available for 2007 and 2008. However, the 2007/2008 flow data given in this report are still classified as preliminary data. The available stage and flow data are summarized in Table 2.1.

Hourly precipitation data were obtained for the Duluth International Airport for 1997 – 2008 from NOAA (http://www.ncdc.noaa.gov/oa/climate/isd/index.php). In addition, 5 minute precipitation data were obtained from MnDOT for a roadside weather station (RWIS) on Highway 53 at Anderson Road, very close to the Chambersburg flow station, for May – October 2007 and 2008 (www.d.umn.edu/~tkwon/RWISarchive/RWISarchive.html). Data from this station are available only after 2005. Finally, the upper MPCA flow gaging site at Kohl's includes a tipping bucket rain gage. Hourly precipitation data are available from the Kohl's site for 1997-1998, while 15 minute precipitation data are available for 2003-2005 and 2008.

Table 2.1. Flow and stage data available for Miller Creek, 1997 – 2008. The table gives the date range (month/day) for each station in each year. Data for 2003-2005 are listed here for completeness, but were not considered reliable and were not used in the final analyses.

	Lower Site (26th Ave)	Middle Site (Chambersburg)	Upper Site (Kohl's)
1997	Flow, 5/1 - 9/4	Flow, 7/15 – 12/31	Flow, 3/20 – 5/29 6/17-11/30
1998	Flow, 5/1 -11/24	Flow, 1/1 -11/24	Flow, 3/20-4/30 7/11 – 11/24
2003	Stage, 8/6 – 9/30	Stage, 8/5 – 11/14	Stage, 6/6-7/8 9/19-11/14
2004	Stage, 4/20 – 8/7 Inverted stage, 8/7 – 11/7	Stage, 4/18 – 11/29	Stage, 4/18-11/23
2005	Inverted Stage, 4/22 – 8/9 Stage, 8/26 – 11/18	Stage, 4/19 – 8/9	Stage, 4/19-11/16
2007	Flow, 4/16 – 10/9 10/19 – 11/.7	Stage, 4/3 – 9/1	Stage, 4/1-11/15
2008	Flow, 5/1 – 11/10	Stage, 2/2 – 10/23	Stage, 5/1 – 10/23

3. Relationships between stream flows at the three stream gaging stations, 1997-1998.

The Miller Creek flow data were analyzed at daily, weekly and monthly time scales to help determine the quality of the data. Table 3.1 gives monthly-averaged flow at the three stations for all available data in 1997, 1998, 2007 and 2008. Time series of daily flow data from the three sites for 1998 show that the three sites have a similar dynamic flow response to rainfall events; peak flows increase going from upstream to downstream (Figure 3.1). However, at low flow (< 1 cfs), the relationships between the stations are less consistent; at very low flows the middle site occasionally reads lower flows than the lower site (Figure 3.1, lower panel). Measurement errors or small water losses may account for these discrepancies. Figure 3.2 gives an example of the response of Miller Creek to a 2.5" rainfall event in September 13 and 14, 1998 with a 1 hour time resolution. The complete storm response takes several days, with the peak daily flow at the upper site about 45% of the lower site for the largest peak.

Relationships between the three gaging stations were examined at daily and weekly time scales for 1997 and 1998. Plots of the relationships between the average daily flow at the lower, middle and upper stations are given in Figure 3.3, while Figure 3.4 gives the same relationships for weekly averaged flow. At both daily and weekly time scales, the relationships between stations are quite good, particularly between the lower and middle flow stations. The slopes of the linear fits suggest that, on average, the flow at the middle site is about 80% of the flow at the lower station, and flow at the upper station is about 70-75% of the lower station. This suggests that most of the streamflow comes from the portion of the watershed above the Kohl's MPCA station.

Table 3.1. Mean monthly stream flow (cfs) at the Miller Creek lower (26th Ave), middle (Chambersburg), and upper (Kohl's) stream gaging sites for 1997/98 and 2007/08, and total monthly precipitation (cm) at Duluth International Airport.

	1997				**1998**			
Month	Precip	Lower	Middle	Upper	Precip	Lower	Middle	Upper
1	0.84				0.91	0.7	0.2	
2	0.25				5.51	10.8	8	26.9
3	1.55			11.1	4.65	23.7	16.4	15.2
4	2.62			47.9	3.58	21	17.8	14.9
5	4.83	10.3		6.6	5.61	2.7	2.2	
6	11.56	14.7		15.6	15.42	13.5	13.7	
7	4.75	11	3.7	5.4	4.37	1.4	1	0.5
8	3.20	1.9	1.6	1.0	6.58	2	1.6	1.0
9	4.45	2.1	1.7	1.6	8.46	3.2	2.6	2.0
10	5.82	3.4	3.4	2.5	10.41	11.9	10.7	10.2
11	1.09	3.6	2.7	2.3	8.69	27.2	21.1	21.4
12	0.33	1.3	0.2	0.4	2.13			
	2007				**2008**			
Month	Precip	Lower	Middle	Upper	Precip	Lower	Middle	Upper
1	0.36				0.58			
2	1.88				0.51			
3	4.01				0.56			
4	4.45	16.5			7.42			
5	8.59	6.4			6.91	12.9		
6	5.69	5.8			10.92	18.7		
7	4.14	1.0			11.25	4.3		
8	1.04	0.8			6.17	2.7		
9	9.91	5.6			12.17	8.2		
10	12.83				13.77	9.4		
11	1.27				3.25			
12	2.72				4.93			

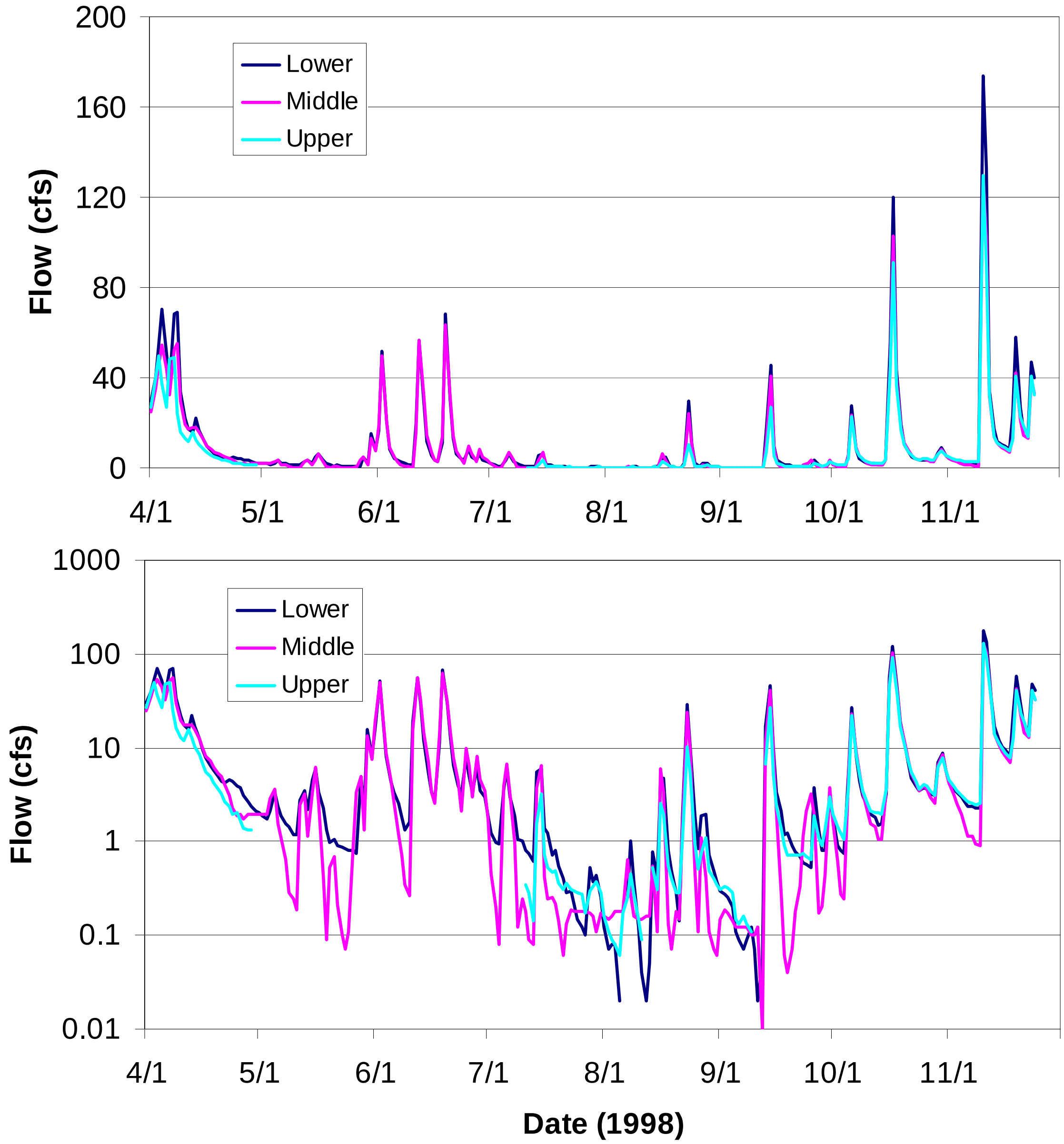

Figure 3.1. Time series of daily flow at the three Miller Creek gaging stations from April to November 1998. The semi-log plot (lower panel) gives better resolution of low flows.

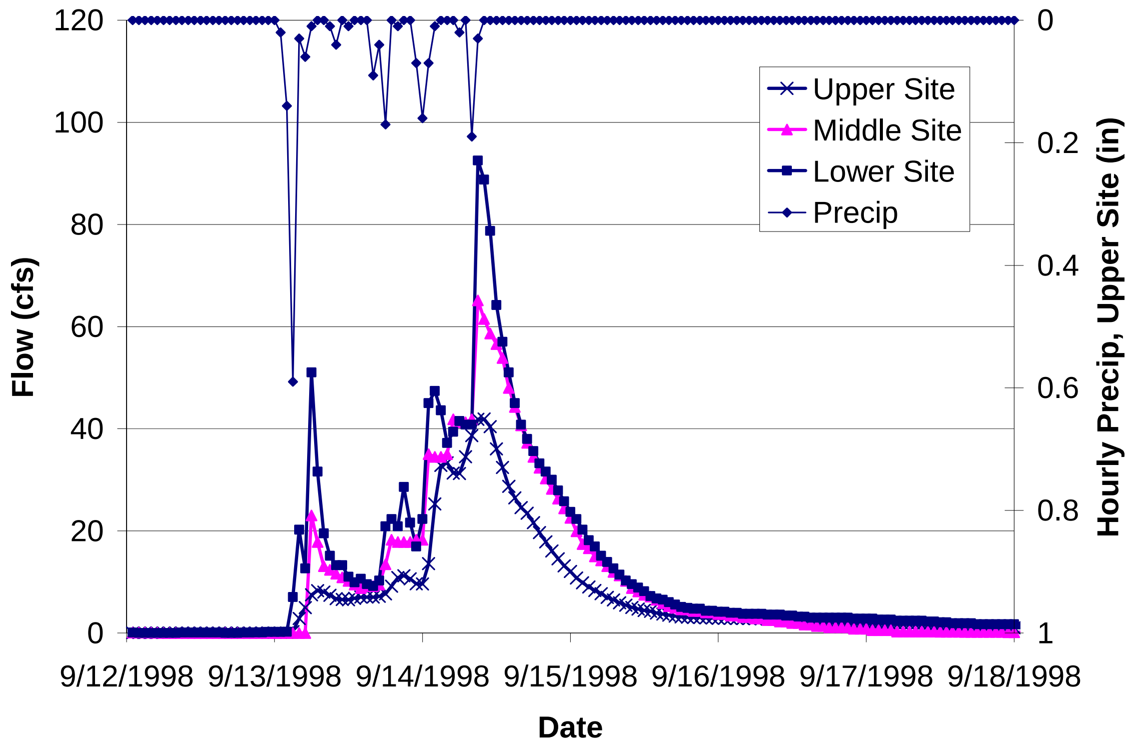

Figure 3.2. Time series of hourly precipitation from the Miller Creek upper site and flow at the three gaging stations for September 12-18, 1998.

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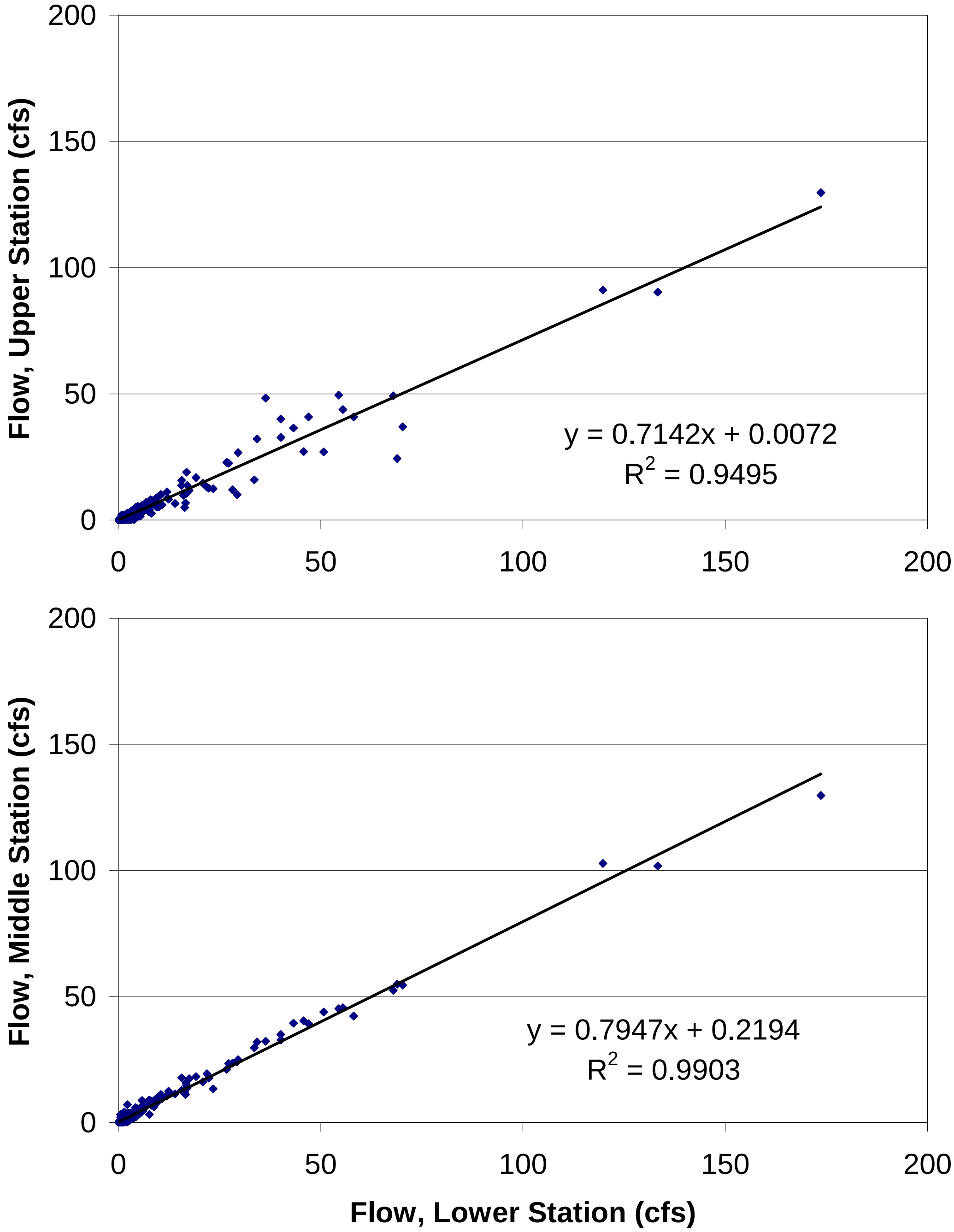

Figure 3.3. Average daily flow at the upper site (upper panel) and middle site (lower panel) vs. average daily flow at the lower site (26th Ave.).

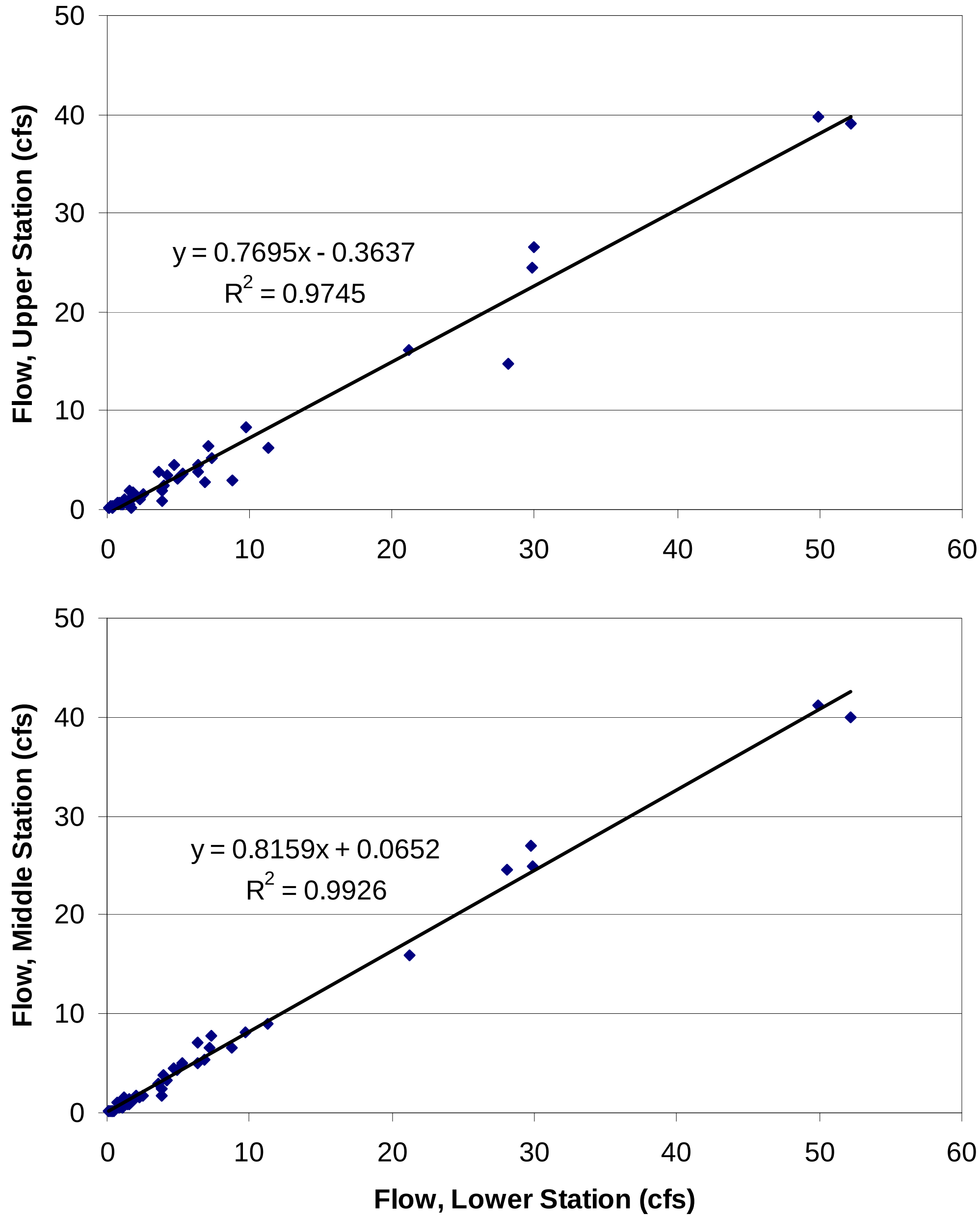

Figure 3.4. Average weekly flow at the middle site (Chambersburg) and upper site (Kohl's) vs. average weekly flow at the lower site (26th Ave.).

4. Relationships between stream flow and precipitation

Precipitation records were obtained for three stations in the Miller Creek watershed, including hourly data from the Duluth International airport, 15 minute and 1 hour data from the Kohl's MPCA gaging site, and 5 minute data from the MnDOT station at Anderson Rd. and Highway 53. The locations of these three sites in the watershed can be seen in Figure 1.1, where the MnDOT site is very close to the Chambersburg gaging station shown on the map. Monthly precipitation totals are summarized for 1997/98 and 2007/08 in Table 4.1. Monthly and annual totals for the raw MnDOT precipitation data were 2-2.5 times higher than the other two stations, and it is believed that data given in inches on the MnDOT web site may actually be in cm. Therefore, all MnDOT data shown in this report was reduced by a factor of 2.54 from the raw data. Note that precipitation data from the Kohl's site was typically not available until mid-July, and no data are available for 2007 from the Kohl's site.

The correlation of precipitation data from the three precipitation gages was compared at daily time scales. Correlation of the airport and Kohl's data varied between years from 0.60 to 0.89 (Table 4.2). An example of the correlation of daily rainfall between the airport and Kohl's site is given in Figure 4.1. For the two years (2007, 2008) of available precipitation data from the MnDOT station at Anderson Road, the correlation coefficients to the airport data were 0.56 and 0.71, slightly lower than the Kohl's to airport correlations. This is not surprising, since the Kohl's station is closer to the airport than the MnDOT station (Figure 1.1).

Relationships between stream flow and precipitation in Miller Creek were examined to determine if available precipitation data gives a good representation of streamflow, given the high climate gradients of the Duluth area. A weekly time scale was selected, based the flow dynamics exemplified in Figure 3.1. Correlations of the three flow gaging sites to the airport precipitation data are given in Figure 4.2, with the middle gaging site (Chambersburg showing the best correlation to precipitation (R^2=0.75). For the lower flow gage (26th), the relation of flow to precipitation was similar for 1997/98 and 2007/08 (Figure 4.3), indicating that recent adjustments to the rating curve have resulted in 2007/08 flow data that is consistent with the 1997/98 data. Figure 4.4 compares the correlation of weekly flows at the lower site to the three precipitation gages, with flows showing the best correlation to the Kohl's site (R^2=0.82). The ability of the polynomial relationships given in Figure 4.4 to predict stream flow at the lower gaging site from observed precipitation at weekly time scales was tested for individual years, with the results given in Table 4.3. Precipitation data from the Kohl's site gave the best results, with an overall RMSE of 3.1 cfs, compared to 5.5 cfs for precipitation data from the Duluth airport and 6.0 cfs for precipitation data from the MnDOT station.

The correlation of streamflow to precipitation was also explored for daily time scales, as shown in Figure 4.5 for the lower gaging site and precipitation data from the Kohl's site in 2008. Correlation was weak at daily time scales if flow and precipitation were averaged over the same 24 hour period (R^2=0.14), however, if precipitation was averaged over a 24 hour period centered 12 hours prior to the flow averaging period, correlation improved (R^2=0.50).

Table 4.1. Monthly precipitation totals, in cm, for the three rain gaging sites in the Miller Creek watershed. Months labeled n/a mean that partial or no data was available for that month and station.

1997	DLH	Kohls	MnDOT	1998	DLH	Kohls	MnDOT
May	1.90	n/a	n/a	May	2.21	n/a	n/a
June	5.17	n/a	n/a	June	6.13	n/a	n/a
July	4.33	n/a	n/a	July	1.72	n/a	n/a
August	1.26	1.78	n/a	August	2.59	2.96	n/a
September	1.75	2.05	n/a	September	3.06	2.22	n/a
2007	DLH	Kohls	MnDOT	2008	DLH	Kohls	MnDOT
May	8.59	n/a	3.82	May	6.91	n/a	6.94
June	5.69	n/a	5.66	June	10.92	n/a	14.18
July	4.14	n/a	2.84	July	11.25	n/a	7.45
August	1.04	n/a	2.44	August	6.17	7.47	8.80
September	9.91	n/a	7.94	September	12.17	11.68	10.69

Table 4.2. Relationships (slope, r^2) between daily rainfall totals at Duluth International Airport (independent variable), the Kohl's gaging site or the MnDOT station (dependent variables) for 1997-2005.

DLH to Kohl's

	1997	1998	2008
Slope	1.07	0.84	0.80
r^2	0.89	0.86	0.60

DLH to MnDOT

	2007	2008
Slope	0.83	1.0
r^2	0.56	0.71

Table 4.3. Root-mean-square error (RMSE) of average weekly flows calculated from precipitation data at the Duluth airport (DLH), the Kohl's gaging site, and the MnDOT station using the polynomial fits given in Figure 4.3. All RMSEs are given in cfs.

	RMSE (cfs)		
Year	DLH	Kohls	MnDOT
1997	6.0	1.5	-
1998	4.3	2.5	-
2007	3.7	-	2.7
2008	7.4	4.8	8.1
All	5.5	3.1	6.0

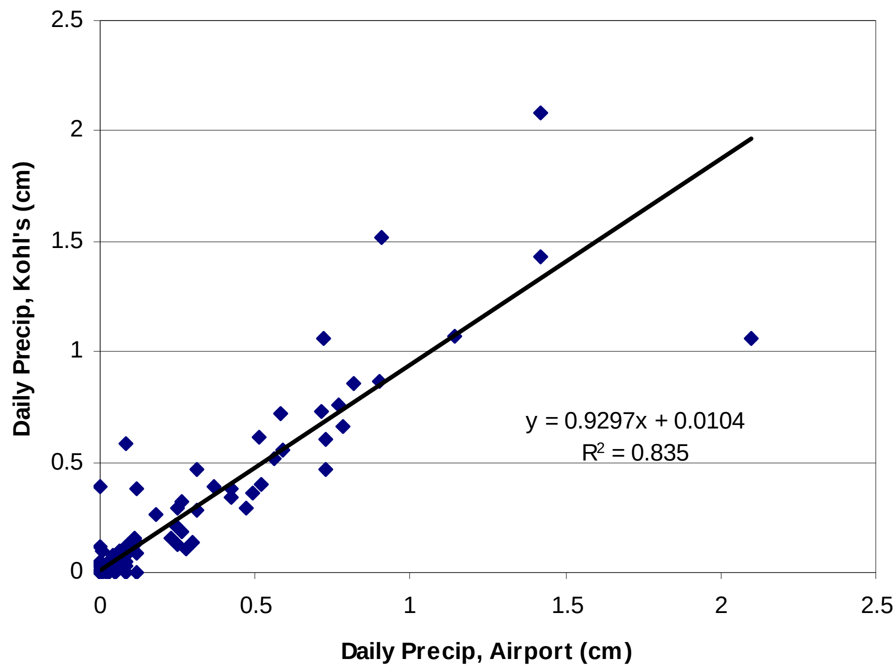

Figure 4.1. Daily precipitation total at the Kohl's site vs. daily precipitation at Duluth International airport for 2005.

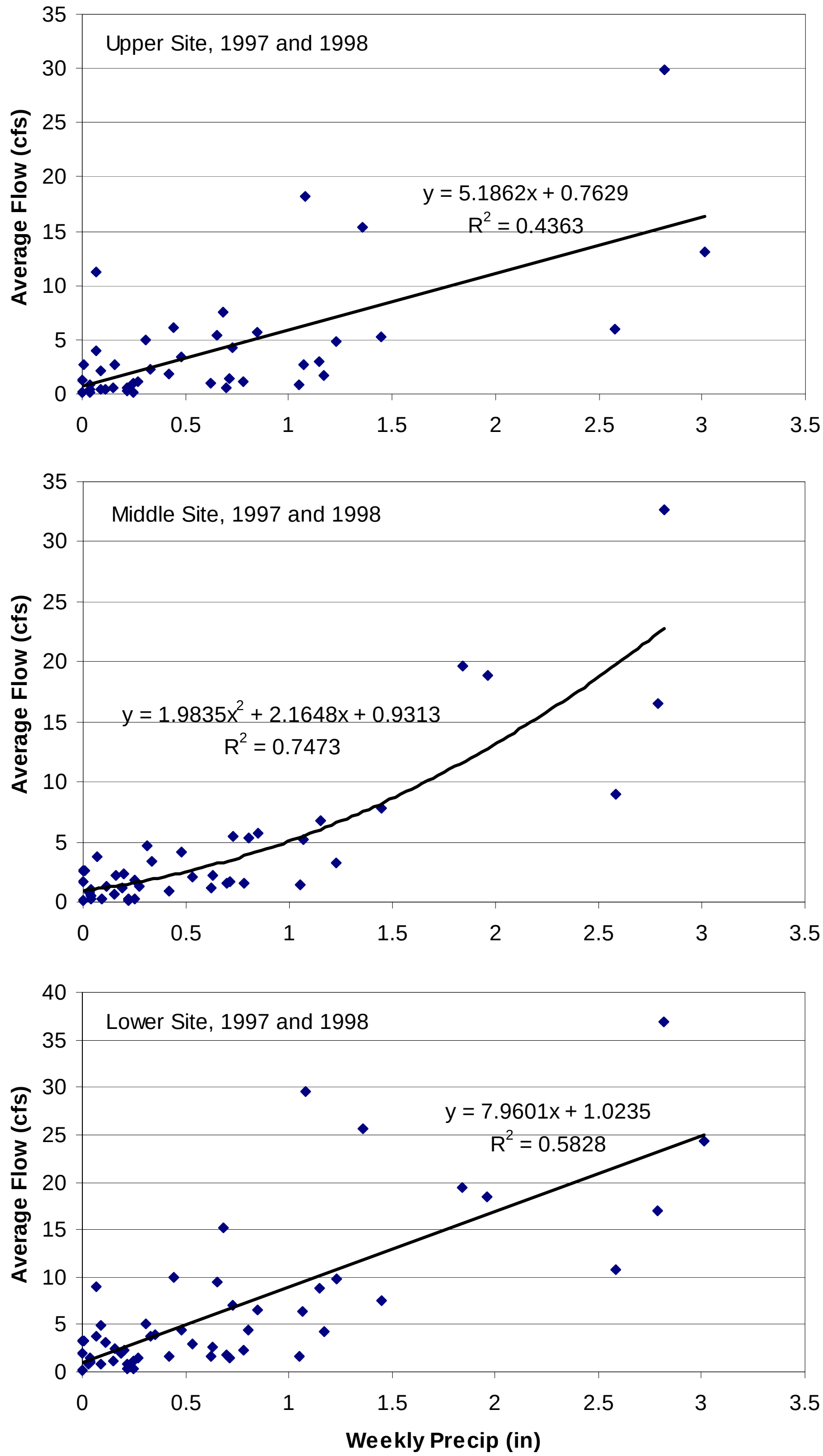

Figure 4.2. Weekly average flow at the lower, middle and upper gaging sites vs. weekly precipitation (DLH) for 1997 and 1998.

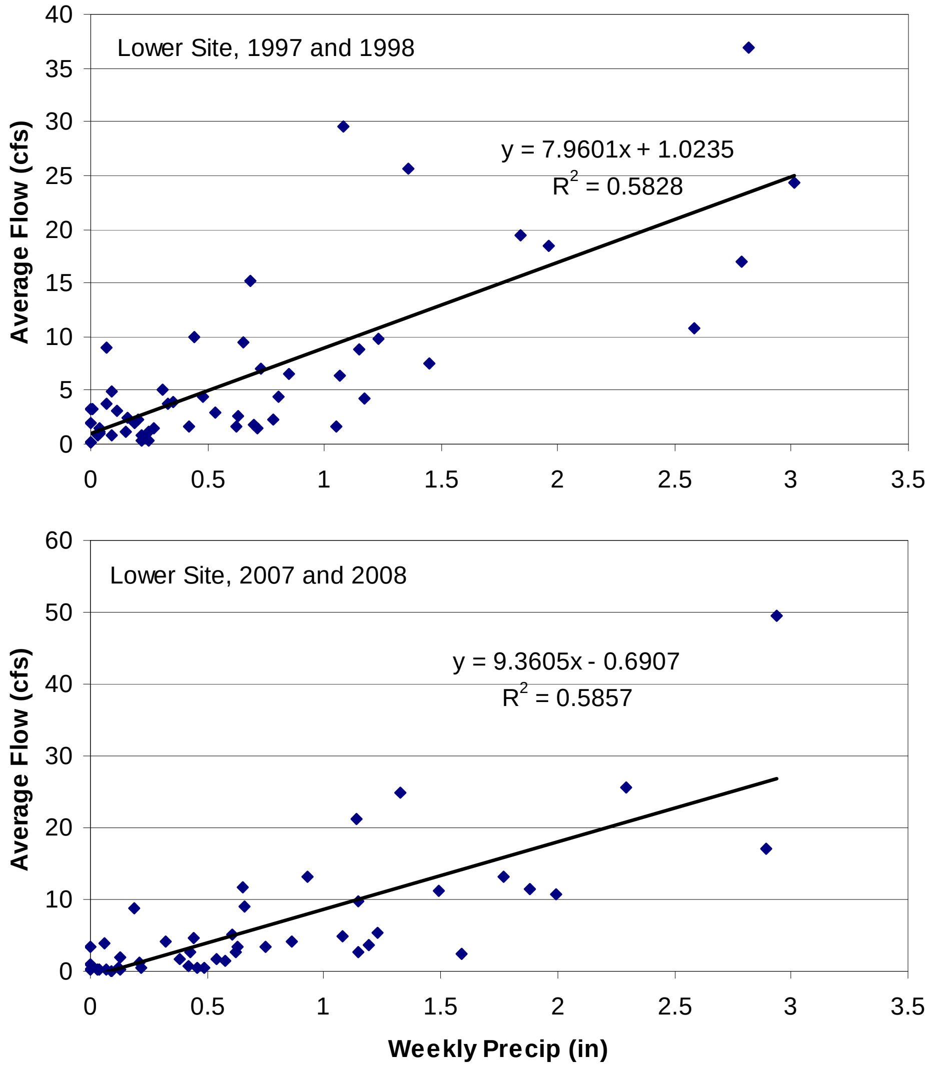

Figure 4.3. Weekly average flow at the lower gaging site vs. weekly precipitation (DLH) for 1997/98 (upper panel) and 2007/08 (lower panel).

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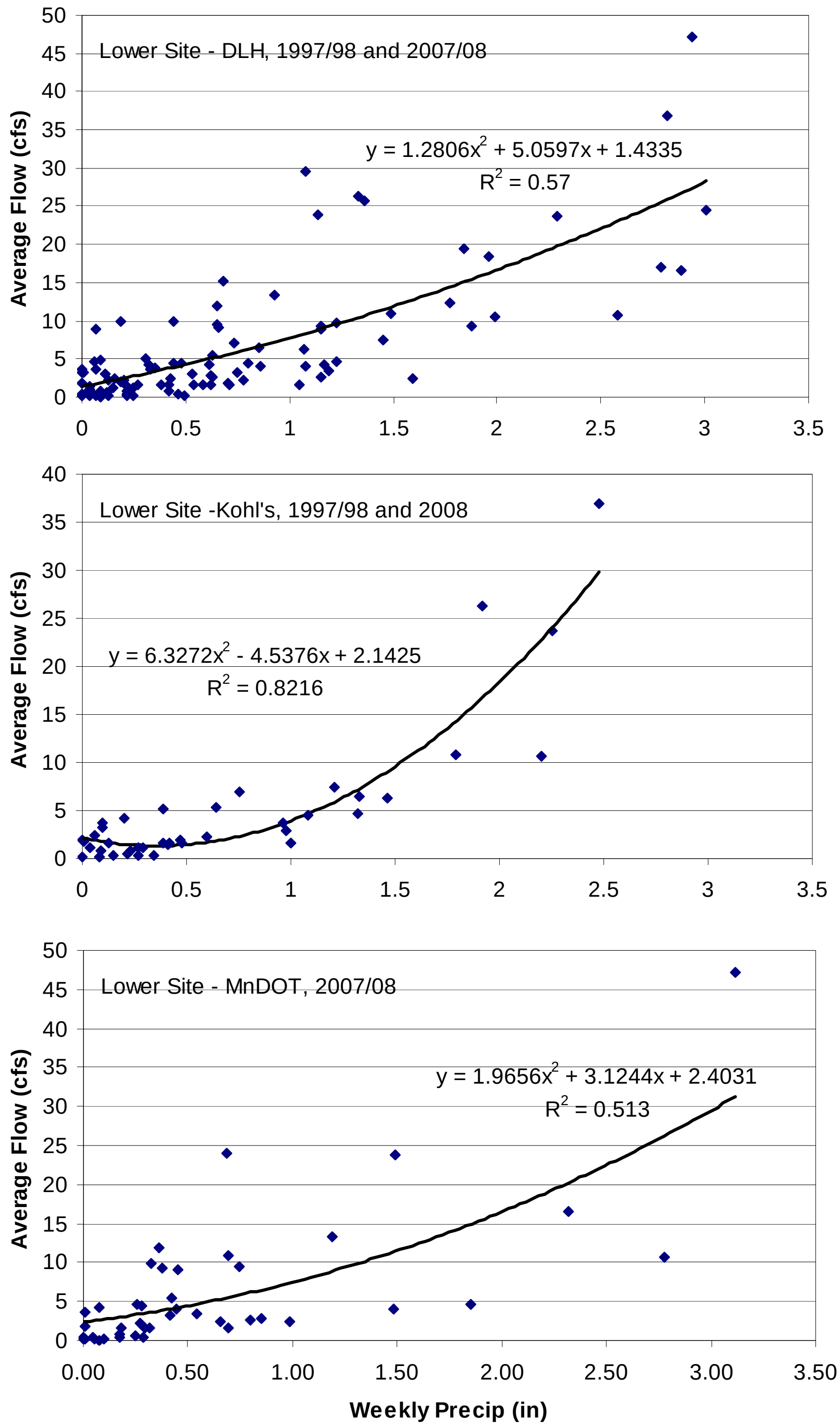

Figure 4.4. Average weekly flow at the lower gage vs. weekly precipitation using precipitation data from Duluth Int. Airport (upper panel), the Kohl's gaging site (center panel), and the MnDOT roadside station (lower panel).

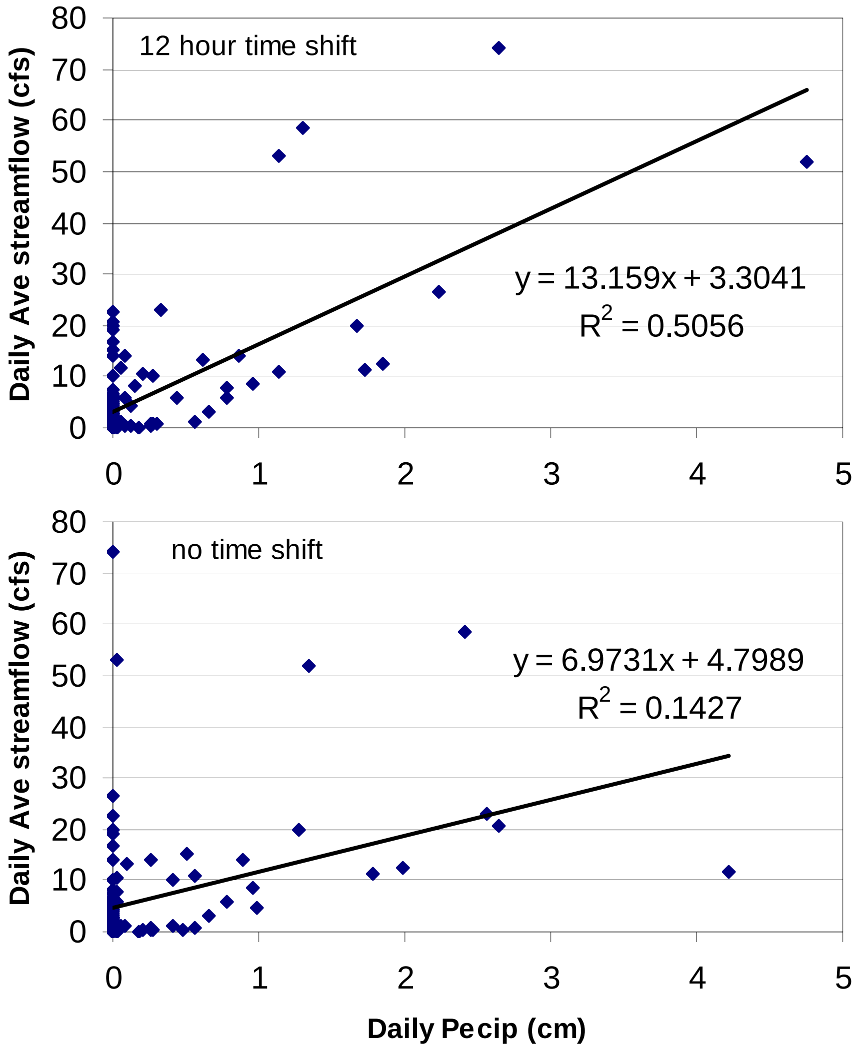

Figure 4.5. Daily average flow at the lower gaging sites vs. daily precipitation from the Kohl's gaging site in 2008. For the data shown in the upper panel, daily average flow was calculated using a 12 hour lag time.

5. Statistical analysis of streamflow data from the lower stream gaging site

Monthly averages of precipitation and flow for 1997-1998 and 2007-2008 show significant month to month variations in precipitation and in stream flow (Figure 5.1). August and September, on average, have the lowest flows. The July and August precipitation totals are significantly lower for the four year flow record compared to the 12 year record (1997-2008). Average precipitation for the full 12 year record (1997-2008) shows less month to month variation than the 4 year partial record, suggesting that the four year flow record may not represent typical hydrologic conditions in Miller Creek. Precipitation data from the Duluth International airport are also summarized in Table 5.2.

Daily flow data from the lower site for the years 1997-1998 and 2007-2008 were analyzed to determine mean and median daily flows, and average weekly low flows with 2 and 10 year return periods (7Q2, 7Q10). The 7Q2 and 7Q10 low flows were determined using a Pearson Type III distribution, using procedures given by Martin et al. (1999). The results are summarized in Table 5.1 for both July-September and May-October. Since only 4 years of flow data were used in the analysis, the 7Q10 flows are likely to have substantial uncertainty. Higher flows during rainfall events make the mean flows (3.6 cfs and 5.9 cfs) higher than the median flows (1.5 cfs and 2.0 cfs). Histograms of daily flows at the lower site are given in Figure 5.2. The skew of the flow data towards low flows (1 to 2 cfs) is evident in the plots, and the median flow values for the two periods (1.5 and 2.0 cfs) are confirmed as representing typical (common) low flow values.

Table 5.1. Flow statistics (mean, median, 7Q2, and 7Q10) for the Miller Creek lower gaging site for July- September and May-October, using data from the years 1997-1998 and 2007-2008.

Lower Site				
	Mean Flow (cfs)	Median Flow (cfs)	7Q2 Low Flow (cfs)	7Q10 Low Flow (cfs)
July - September	3.7	0.88	0.13	0.05
May - October	7.0	2.4	0.13	0.05

Table 5.2. Monthly and annual precipitation, in cm, at Duluth International Airport for the 4 years of flow records (1997/98, 2007/08) and for a 12 year average (1997-2008).

	1997	1998	2007	2008	4 year Ave.	12 year Ave.	12 year St. Dev.
May	4.83	5.61	8.59	6.91	6.48	7.71	2.02
June	11.6	15.4	5.69	10.9	10.9	9.97	3.65
July	4.75	4.37	4.14	11.3	6.13	8.33	5.57
August	3.20	6.58	1.04	6.17	4.25	6.77	4.26
September	4.45	8.46	9.91	7.92	7.68	8.34	3.16
October	5.82	10.4	12.8	7.42	9.12	7.16	3.39
July-Sept.	12.4	19.4	15.1	25.4	18.1	23.4	11.2
Full Year	41.3	76.3	56.9	62.9	59.3	63.2	12.6

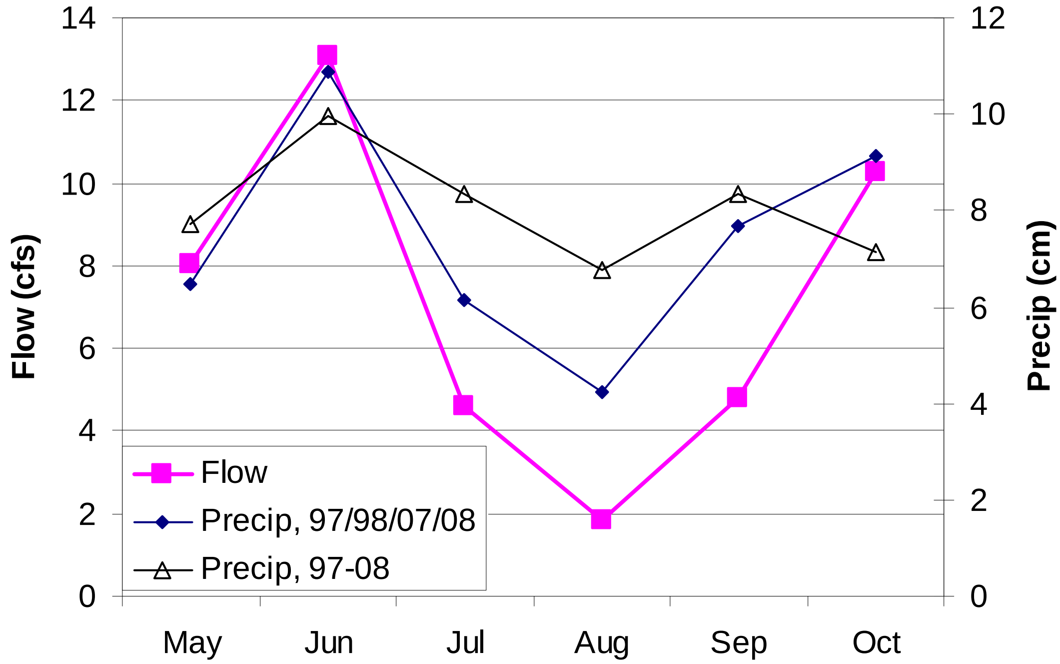

Figure 5.1. Average monthly flow at the lower stream gaging station of Miller Creek and average monthly precipitation at the Duluth International Airport. Monthly average precipitation is given for a partial record corresponding to the flow record (1997-1998 and 2007-2008) and for all years 1997-2008.

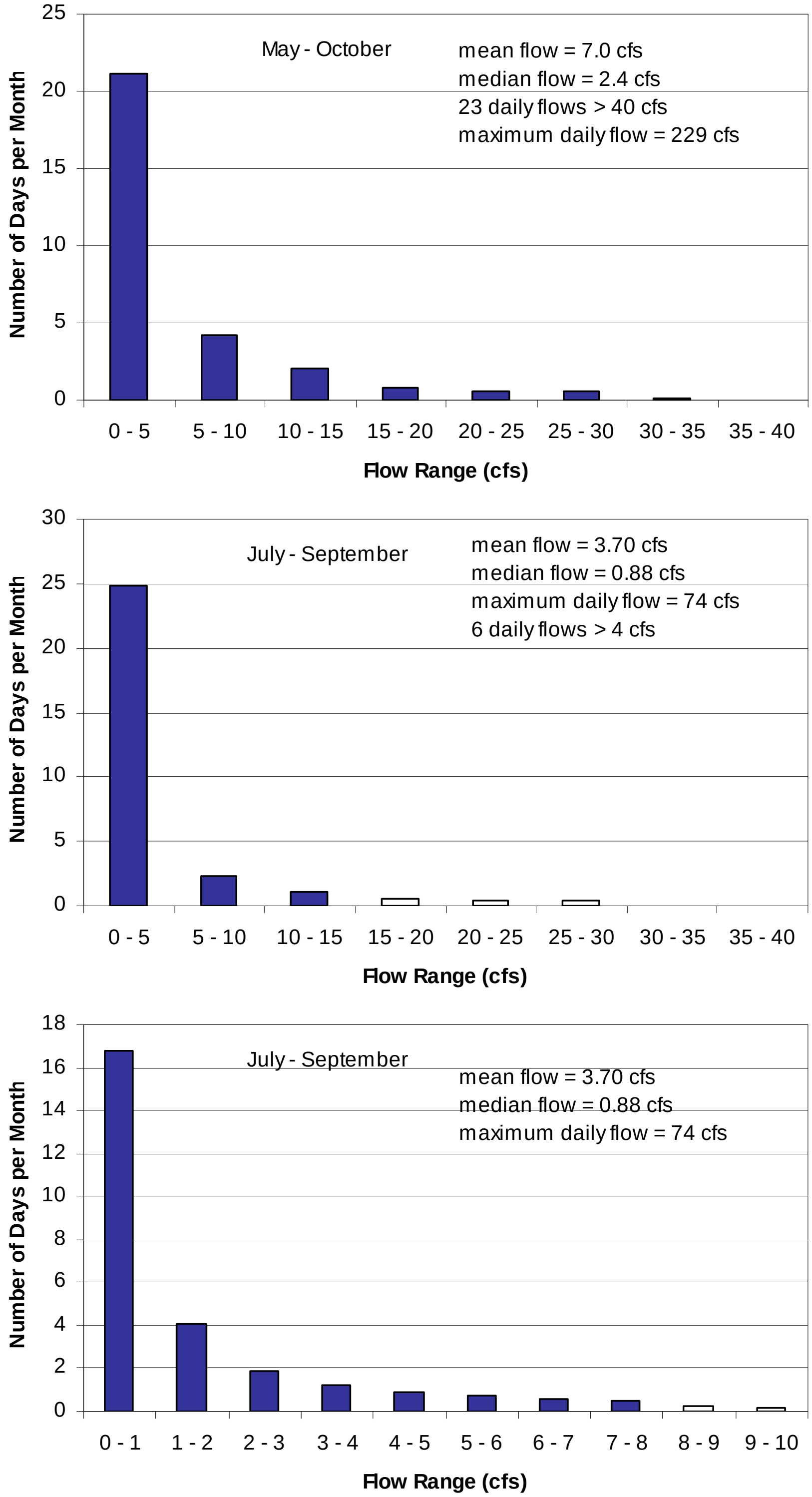

Figure 5.2. Histograms of daily stream flows at the Miller Creek lower stream gaging site for four years of data: 1997/98 and 2007/08.

6. Conclusions

1) The analyses of flow and precipitation data suggest that the flow data at the lower site are relatively consistent for the years 1997, 1998, 2007 and 2008.

2) 1997-1998 data for the middle stream gaging site (Chambersburg) have lower average weekly flow than the data for the middle and lower stream gaging sites and are therefore considered consistent. Since a good rating curve has not been established for the middle site, stream gage data from 2003 through 2008 are currently not usable for flow studies.

3) 1997-1998 data for the upper stream gaging site (Kohl's) have lower average weekly flow than the data for the middle and lower stream gaging sites, and appear to be reliable. Since a good rating curve has not been established for the upper site, stream gage data from 2003 through 2007 are not usable for flow studies.

4) Relationships given in Figure 3.4 relate mean weekly flows at the three stream gaging sites. Based on 1997 and 1998 data, weekly-averaged flows at the middle and upper gaging sites are, on average, 82% and 77% of the lower site, respectively. This suggests that a large fraction of the flow in Miller Creek originates from the upper portion of the watershed, upstream of the Kohl's Department Store site.

5) Relationships between stream flow at the lower site and precipitation have been established at weekly timescales and are reasonable, with r^2 of 0.57 for precipitation data from the airport and 0.82 for precipitation from the Kohl's site However, RMSE of the relationships (3.0 and 5.5 cfs for airport and Kohl's, respectively) are similar in magnitude to the mean flows (3.7 cfs for the lower gaging sites). Precipitation data from the upper gaging site (Kohl's) were found to be a slightly better predictor of flow at the lower site, however, the airport has a much more complete data set.

6) A statistical analysis of five years of flow data from the Miller Creek lower site indicates that low flows in the range of 1 to 2 cfs are quite common at weekly time scales. Therefore a rainfall event of moderate magnitude may be expected to have a significant impact on stream flow and temperature at the lower site.

7) Although the flow record is relatively short (4 years), the results of a frequency analysis suggest that weekly mean flows less than 0.1 cfs are possible with a 10 year return period.

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Acknowledgments

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