MN DEPT OF NATURAL RESOURCES

Chippewa River Watershed Hydrology Analysis

An Addendum to the MPCA WRAPS Report

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Hydrology

Hydrologic conditions (*e.g.,* precipitation, runoff, storage, and annual water yield) and the disturbance of natural pathways (*e.g.,* tiling, ditching, land use changes, and loss of water storage) has become one driver of many impairments in Minnesota watersheds (MPCA 2012). These disturbances coupled with an increase in precipitation (*i.e.,* total, frequency, and magnitude) have resulted in issues with: increased bank erosion, excess sediment, habitat degradation, and disturbance of natural flow regime.

Hydrologic modification is the alteration or addition of water pathways and associated changes in volume by human activity. Those modifications can dramatically alter discharge due to changes in volume, timing, connectivity, or flow rates; particularly if the area was not a flow pathway in the past. The types of hydrologic modifications are vast, including: the draining and filling of wetlands and lakes, ditching or draining formerly hydrologically disconnected basins, adding impervious surfaces across the basin, increasing drainage for increased transport of water (*i.e.,* in urban and agricultural areas), straightening or constricting a natural flow path or river, and changing the timing and rate of delivery within the hydrologic system. Any increase in stream power (*e.g.* due to change in peak flows or increased frequency of bankfull flows) will generate an increase in water yield (Lane 1955).

Reduced surface storage, increased conveyance, increased effective drainage area, and modified crop rotations supporting soybeans over perennial grasses and small grains have all altered the dynamics of watershed hydrology. In addition, these changes have generally increased the annual water discharged from these watersheds while also dramatically altering the return interval for various flow stages (Schottler 2014).

In extensively drained landscapes, such as the agricultural Midwest of the United States, the connection of isolated basins has inflated total surface water discharge and increased the density of linear drainage networks (Ter Haar & Herricks, 1989, Haitjema 1995, Magner et al. 2004). Many streams in the region are in disequilibrium due to past and current land-use change with corresponding hydrologic responses, as well as direct channel modifications (Lenhart 2007).

These modifications have not occurred at a constant rate, but in episodes or events, such as construction of the public drainage system from 1912-1920 (Lenhart 2007, 2008) and continue today through repair, upgrade, and increased amount of impervious surfaces and subsurface drainage. Construction of subsurface tile and surface ditch drainage systems in the early 1900s increased contributing drainage areas, resulting in proportionally greater volumes of water delivered to rivers (Leach and Magner 1992, Kuehner 2004, Lenhart 2008). The effects of these suites of changes are cumulative, interrelated, and tend to compound across different spatial and temporal scales (Spaling & Smit 1995, Aadland et al. 2005, Blann et al. 2009). The contribution of subsurface drainage to aquatic ecosystem affects may be difficult to isolate relative to other agricultural impacts (Blann et al. 2009). Cumulatively, these changes in hydrology, geomorphology, nutrient cycling, and sediment dynamics have had profound implications for aquatic ecosystems and biodiversity (Blann et al. 2009).

The hydrologic analysis found in this report focuses on surface-water components of the hydrologic cycle, rainfall-runoff relationships, open-channel flow, flood hydrology, and statistical and probabilistic methods in hydrology. In addition, one of the goals of this report is to outline connections between stream gaging data, analyses, and trends to land use patterns to demonstrate how changes in land use and drainage patterns affect hydrology throughout the watershed. This will be accomplished through comparative analysis of gage data from several subwatersheds within the Chippewa River major watershed.

Finally, this report will also include information detailing groundwater use trends and a groundwater usage for the watershed was reviewed by compiling all reported permitted usage. All permit data were collected through the State Water Use Data System (SWUDS).

Hydrology Methods

In order to understand and evaluate the hydrologic processes within a watershed, several types of analyses are used to examine the relationships between flow (i.e. discharge) and precipitation. Groundwater levels and usage over time is also reviewed. The analysis methods can evaluate and measure changes within a system by reviewing statistical variations and trends over time.

Discharge Analysis

Flow data sets are collected by the USGS and MPCA/DNR stream gage network for various watersheds. Site-specific stream flow data are calculated using continuous stream stage measurements and periodic stream flow measurements. These data are plotted and charted to allow for statistical analysis and are used to create hydrographs, flow duration curves, and other visual representations of the period of record.

Watershed discharge data can be used to review daily, monthly, seasonal, annual and long-term trends within a watershed and examine changes in the discharge characteristics such as periods of low or zero flow, flood frequency, base flow volume, and seasonal variability. Primary discharge data for the Chippewa River were collected at the USGS site 05304500 near Milan in Chippewa County. Additional data collected at a number of additional site throughout the watershed were used for comparative and trend analyses; including: three sites on the Chippewa River Mainstem (site 05301930 near Cyrus, 05303500 near Benson, and site 05303040 near Clontarf), Site 26038001 (MPCA) on Shakopee Creek, site 05303470 on the East Branch Chippewa River, and site 5304800 on Dry Weather Creek were used for comparative analysis.

Precipitation

Precipitation data for this watershed were obtained via the Gridded Precipitation Analysis tool from the Minnesota Climatology Working Group. All precipitation data are acquired through the Minnesota State Climatology Office. Precipitation data are used to examine long-term trends within a watershed, and the relationship and response of discharge, runoff, and baseflow conditions relative to recorded precipitation totals.

Double Mass Curve

A double mass curve is an analysis based on a cumulative comparison of an independent and dependent variable. This is useful in hydrologic data as it allows the examination of the relationship between two variables. This technique was used to compare precipitation and stream discharge relationships (annual and seasonal) and well elevation fluctuations relative to precipitation. When plotted, a straight line indicates consistency in the relationship, a break in the slope would mean a change in the relationship.

When used with long-term discharge data sets, the curve can demonstrate when the change in the relationship began to occur. All double mass curves (DMCs) presented are normalized runoff (i.e. discharge/watershed area) and monthly precipitation in inches. All discharge values are converted to inches by dividing total volume by the watershed area (the annual discharge converted to acre–ft. and then to inches of runoff over the watershed). Additional information on double mass curve development and interpretation can be found on the following website: http://pubs.usgs.gov/wsp/1541b/report.pdf.

Watershed Setting

The Chippewa River Watershed covers approximately 2,085 square miles (i.e. 1.33 million acres) in parts of eight counties (Ottertail, Grant, Douglas, Pope, Stevens, Swift, Chippewa, and Kandiyohi) west-central Minnesota. The Chippewa River is the largest (in terms of watershed size) individual tributary to discharge to the Minnesota River.

Precipitation

Precipitation data have been collected at various stations throughout the watershed for significant periods of time; however, there was difficulty in locating a single continuous data set for the area over the last 120 years. Additionally, spatial patterns of precipitation can vary considerably over a watershed so using a single precipitation monitoring station to represent an entire watershed may introduce significant uncertainty (Schottler et al. 2013). As such, precipitation data for the Chippewa River Watershed (Figure 1) was obtained from the Minnesota Climatology office, who utilized precipitation grids to assemble a basin-averaged monthly precipitation data set. More information on precipitation grids can be obtained from the Minnesota Climatology Working Group at the following website: http://climate.umn.edu/gridded_data/precip/monthly/explain_grids.htm

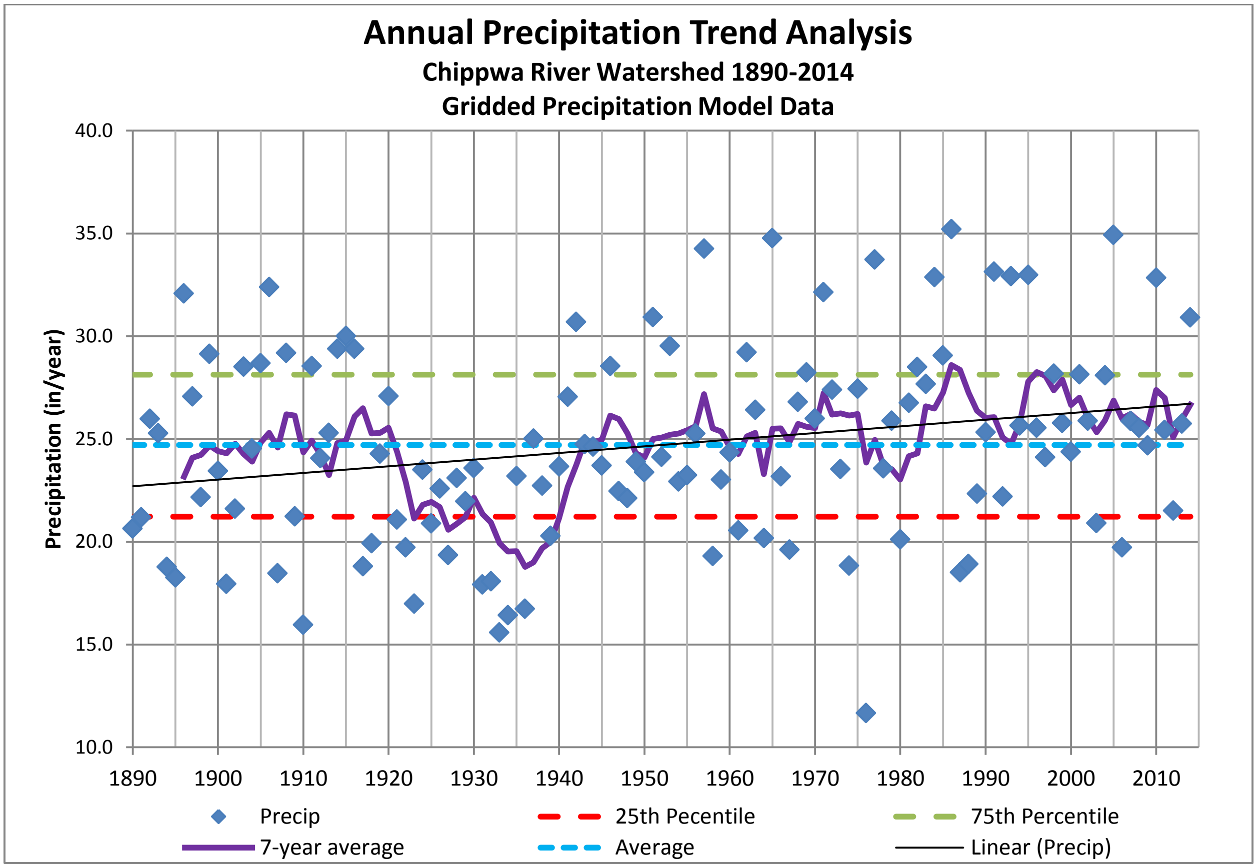

Figure 1: Precipitation for the Chippewa River Watershed from Precipitation Grid Analysis

The precipitation data for the Chippewa River Watershed (Figure 1) includes monthly data from January 1890 to May 2015. This data outlines several historic trends, including significant dry to drought conditions lasting from approximately 1920 to 1940. Since1940 the yearly precipitation totals have been widely variable, with higher than average precipitation in the early 1980's and 1990's. The highest recorded annual precipitation value was in 1986 (35.21"), and the lowest recorded in 1976 (11.66"). While individual stations in the watershed (i.e., Benson, Milan, Montevideo, and Glenwood) show slight variation in totals and trends, the gridded precipitation model better relays totals over the entire watershed. While there is significant variability of the annual total values, the seven-year moving average is largely within the 25th-75th percentile values, with the exception of the drought period of the 1930s. If the moving average had shown significant change outside of this range, it would indicate a significant change in the long-term precipitation trend. A linear regression of this data does indicate a slight increase in annual precipitation volume of approximately 10% over the period of record, which is consistent with the findings of other studies on western Minnesota watersheds (Schottler 2013).

Palmer Hydrological Drought Index

Climate trends in west-central Minnesota were also analyzed using the Palmer Hydrological Drought Index (PHDI), using data collected from the National Center for Environmental Information (www.ncdc.noaa.gov). The PHDI is a series of calculations based on hydrological cumulative drought and wet conditions, and more directly relates to hydrological impacts to surface and groundwater features (groundwater conditions, reservoir levels, etc.), which take longer to develop and recover from drought conditions than a weather pattern which can change far more quickly. For this analysis, the PHDI was used over the Palmer Drought Severity Index (PDSI), which is designed to measure meteorological drought and wet conditions, and not the more long-term hydrological impacts. Essentially, the PHDI was developed to reflect long-term hydrological moisture anomalies, and will typically respond more slowly to precipitation pattern changes than the PDSI. (Source: http://www.ncdc.noaa.gov/oa/climate/research/prelim/drought/palmer.html). The PHDI data for the Chippewa River watershed is displayed in Figure 2.

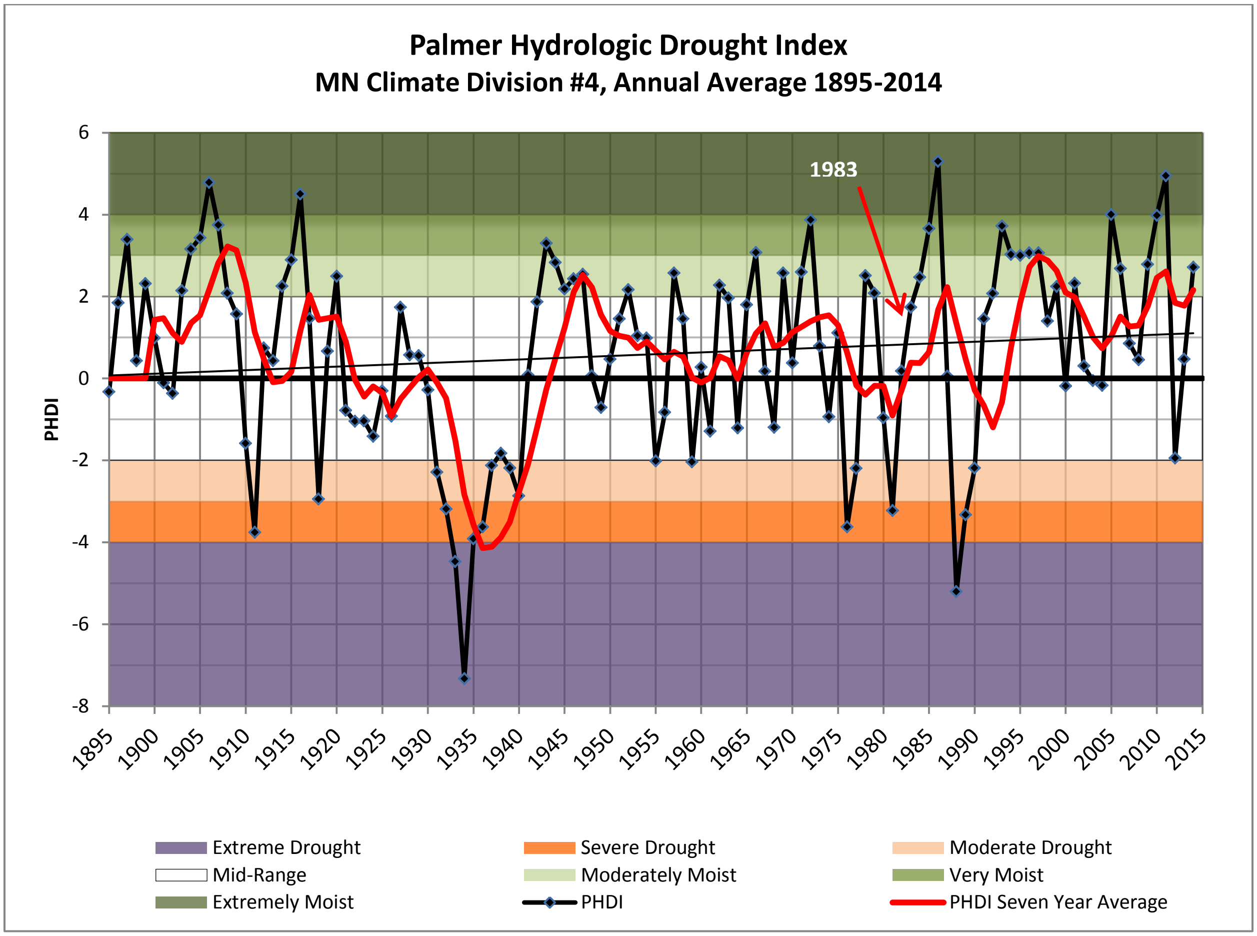

Figure 2: Palmer Hydrologic Drought Index 1895-2015

The data displayed in Figure 2 are similar to the precipitation trends displayed in Figure 1, with similar highs and lows in response to long-term hydrologic trends. These data indicated hydrologic deficits and surpluses, and should be more indicative of trends in lakes and groundwater monitoring wells. While highly variable, several longer-term trends are noticeable; including the dry to drought conditions were present throughout the 1920s and 1930's, and moist to very moist conditions persistent from 1903-1909, 1992-1999, and 2005-2011. The PHDI ratings remain within the mid-range of scores for the majority of the period of record, with no significant pattern showing long-term increases in hydrologic surplus. In addition, the trend of the seven-year moving average of PHDI scores from 2000-2014 is very similar to the period from 1900-1920 as the average ranges from mid-range to moderately moist, indicating that trends such as the recent moist period have been noted in the historical record, and are not directly indicative of increased precipitation within the watershed. A linear regression of the long-term data does indicate a slight upward trend in PHDI scores since 1895, which is consistent with the slight increase in annual precipitation since 1895.

Several analyses were directed at defining the relationship between precipitation and stream discharge. Figure 2 is of particular interest in regards to this relationship, as it can be used as a tool to outline longer-term climate trends. Specifically, 1983 was highlighted as the index scores begins to go up into the moderately moist range and continues up into extremely moist by 1986 and declining to severe drought by 1988. This time period corresponds with when we begin to see baseflow discharge increase in the Chippewa River, deviating from the historical trends (Figure 5). If discharge in the Chippewa River is tied solely to precipitation and independent of other variables, then the runoff/discharge relationship should revert back to historical mean following the drop in total precipitation in 1987. The specifics of this relationship will be further demonstrated later in this analysis.

With specific interest in the baseflow/discharge relationship, PHDI scores during winter months (December through February, Figure 3) were evaluated. During winter months, runoff is tied up in snow/ice, and river flow is made up primarily of baseflow from groundwater.

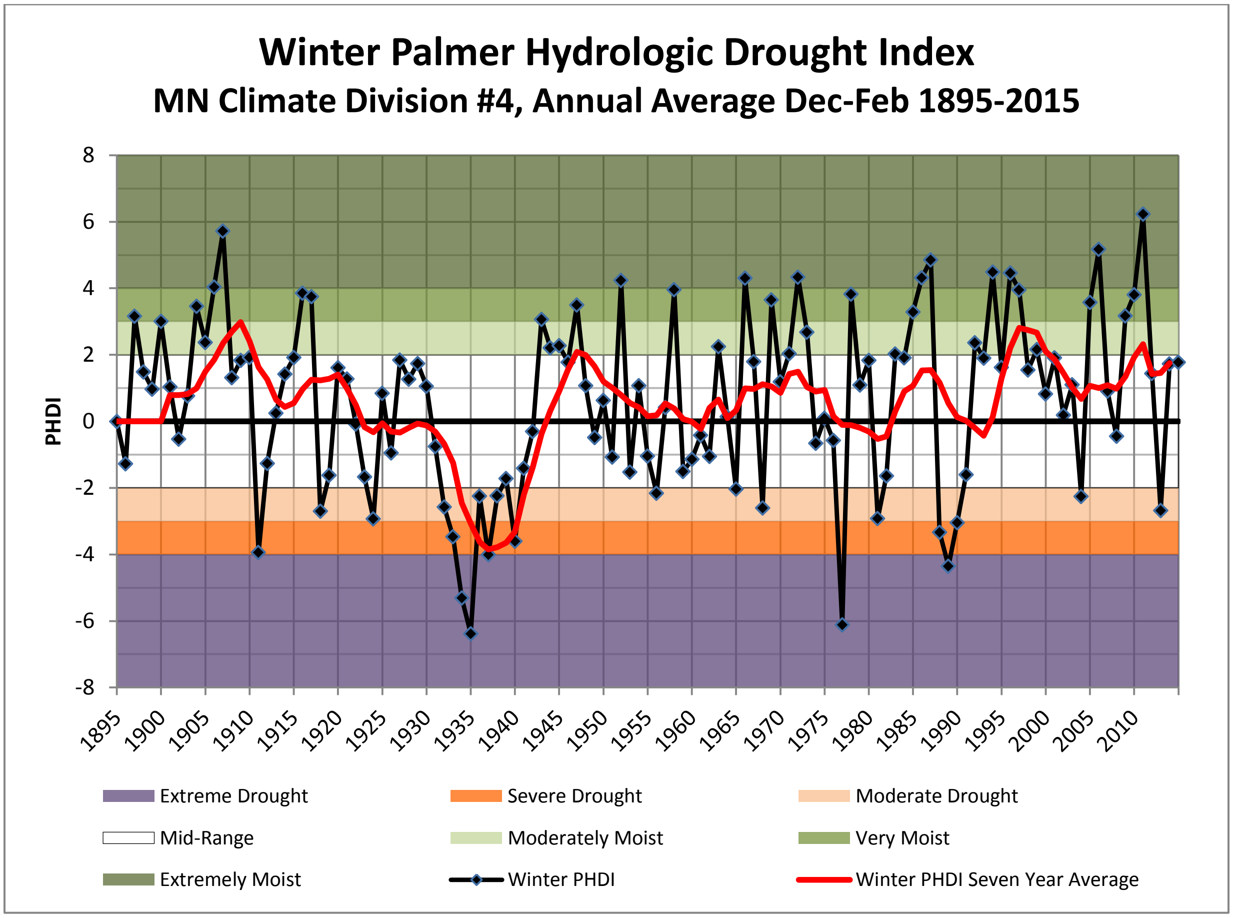

Figure 3: Winter PHDI

Figure 3 shows long-term winter PHDI trends are similar to annual PHDI scores; however, trends do vary slightly from annual scores in the shorter term, (i.e., 1903-1907, 1982-1988, 1992-1995, 2008-2012). In the referenced instances, winter PHDI scores differ in magnitude from annual PHDI scores (maximum score in 2011 vs. max annual PHDI score in 1986). This may be related to individual large precipitation events that provide runoff over longer time periods vs. long-term wet trends that provide continual recharge to groundwater over extended periods; the latter is more likely to result in increased baseflow discharge over the winter months. During the periods referenced above, stream discharge did not fall below 100 cfs over the winter period, and were the only sequential year periods to display this trend (Figure 4).

Number of Storm Events Over Time

Changes to single event intensity and proportionality such as increases in precipitation rate, total precipitation within a single 24-hour period, and number of high intensity events over a given time period can have a significant effect on flows within the river. While these variables were considered as a portion of this report, a specific analysis pertaining to storm intensity was not conducted, due to limitations of the data (only precip totals over a 24-hour period were available, not hourly totals for historic data), among other reasons. This analysis was limited to a comparison of high volume events per year using daily precipitation data from 1900-2010 at three long-term stations (Milan, Morris, and Fergus Falls) within or immediately adjacent to the watershed boundaries. While there are other stations located within the Chippewa River Watershed, these three stations were used as they were the only stations in the area displaying relatively complete data sets from 1900-2010. Daily data from the National Weather Service Cooperative Observer Reporting Stations were used for this report. The goal of the trend analysis is to determine if this watershed is receiving increasing numbers of significant rain events over time. (Source: http://www.dnr.state.mn.us/climate/historical/acis_stn_meta.html)

Table 1: Storm event summary for the Chippewa River Watershed Area.

Table 1	**1”+ Rain Event**			**2"+ Rain Event**			**3"+ Rain Event**			**4"+ Rain Event**		
	Location			**Location**			**Location**			**Location**		
Decade	**Milan**	**Morris**	**Fergus Falls**	**Milan**	**Morris**	**Fergus Falls**	**Milan**	**Morris**	**Fergus Falls**	**Milan**	**Morris**	**Fergus Falls**
1900-1909	47	38	46	10	5	9	2	0	2	0	0	1
1910-1919	38	43	41	3	6	10	1	1	5	0	1	0
1920-1929	47	35	43	2	3	5	1	1	2	0	1	1
1930-1939	32	36	33	5	8	7	0	2	0	0	1	0
1940-1949	42	39	47	8	9	11	0	1	4	0	0	0
1950-1959	55	42	44	10	8	9	2	3	1	0	1	0
1960-1969	47	50	46	9	8	6	1	1	0	0	0	0
1970-1979	44	52	41	11	10	5	1	2	2	1	0	0
1980-1989	46	60	47	8	9	5	0	1	1	0	0	0
1990-1999	54	52	54	9	7	7	3	4	1	1	1	1
2000-2009	52	58	58	11	8	12	2	3	1	0	0	0
Total	504	505	500	86	81	86	13	19	19	2	5	3

Given the information above, several trends (or lack thereof) become apparent. In analysis of very large events (3+ inches of rain over a 24-hour period), no pattern was evident, indicating the distribution of these events was relatively random. In review of the smaller events (1+ inch of rain over 24-hour period), data indicate a gradually increasing trend in the number of small storm events per decade at all three stations (Figure 4). While the number of events across the watershed did not consistently increase from decade to decade, the trend of the three-decade average was increasing.

Trend analyses of this assessment will also be referenced in relation to with stream discharge data and runoff rates later in this report, however a more in-depth analysis on a larger scale will be required if event intensity is to be attributed as a potential cause for stream discharge.

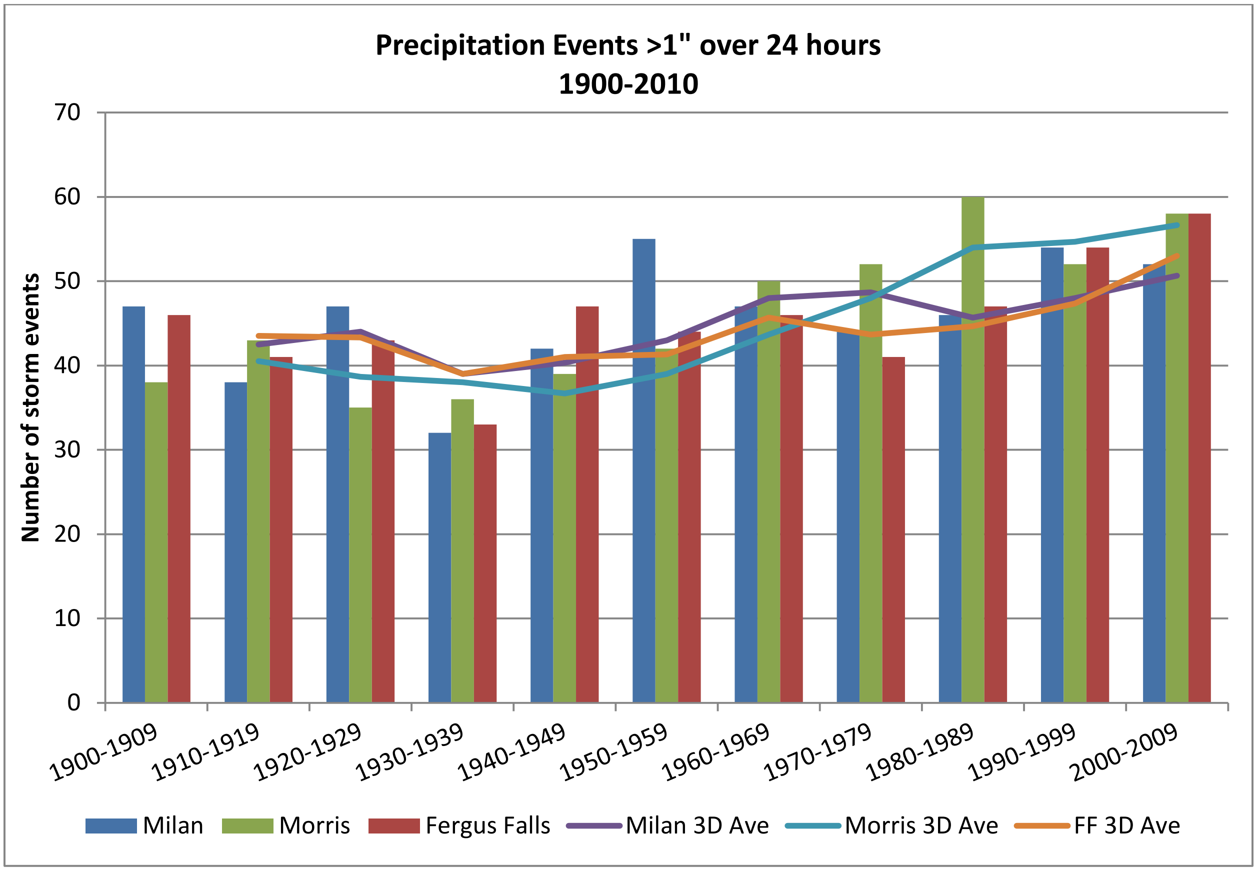

Figure 4: 1-inch or greater storm events by decade, 1900-2010

Precipitation summary

Several methods of analysis of annual precipitation and climate data show slight increases (approximately 15%) in precipitation and a slight increase in the number of moderate storm events, which is consistent with other studies in this portion of the state. The relationship of precipitation to runoff and discharge within the Chippewa River will be examined in the next portion of this report.

Discharge Analysis

Stream discharge data is has been continuously collected by USGS on the Chippewa River mainstem near Milan in Chippewa County at the Minnesota Highway 40 crossing since 1937. This long-term data set (>30 years) allows for in-depth analysis of changes in discharge over time. Long-term data allow for more robust and reliable analysis within a watershed and allow for various calculations pertaining to discharge and precipitation relationships. Additional data including daily, monthly, annual and peak flow statistics have been computed and complied by the USGS for the site.

All discharge data were plotted out using monthly and annual average flow values for the period of record to create a hydrograph. A hydrograph is a chart showing the rate of flow (*i.e.* discharge) over time at a sample location. Once plotted, the data can be examined for changes over time. In plotting a trend of the daily mean flow values for the period of record, a linear regression indicates a gradually increasing daily mean discharge since the beginning of the period of record in 1937 (Figure 5).

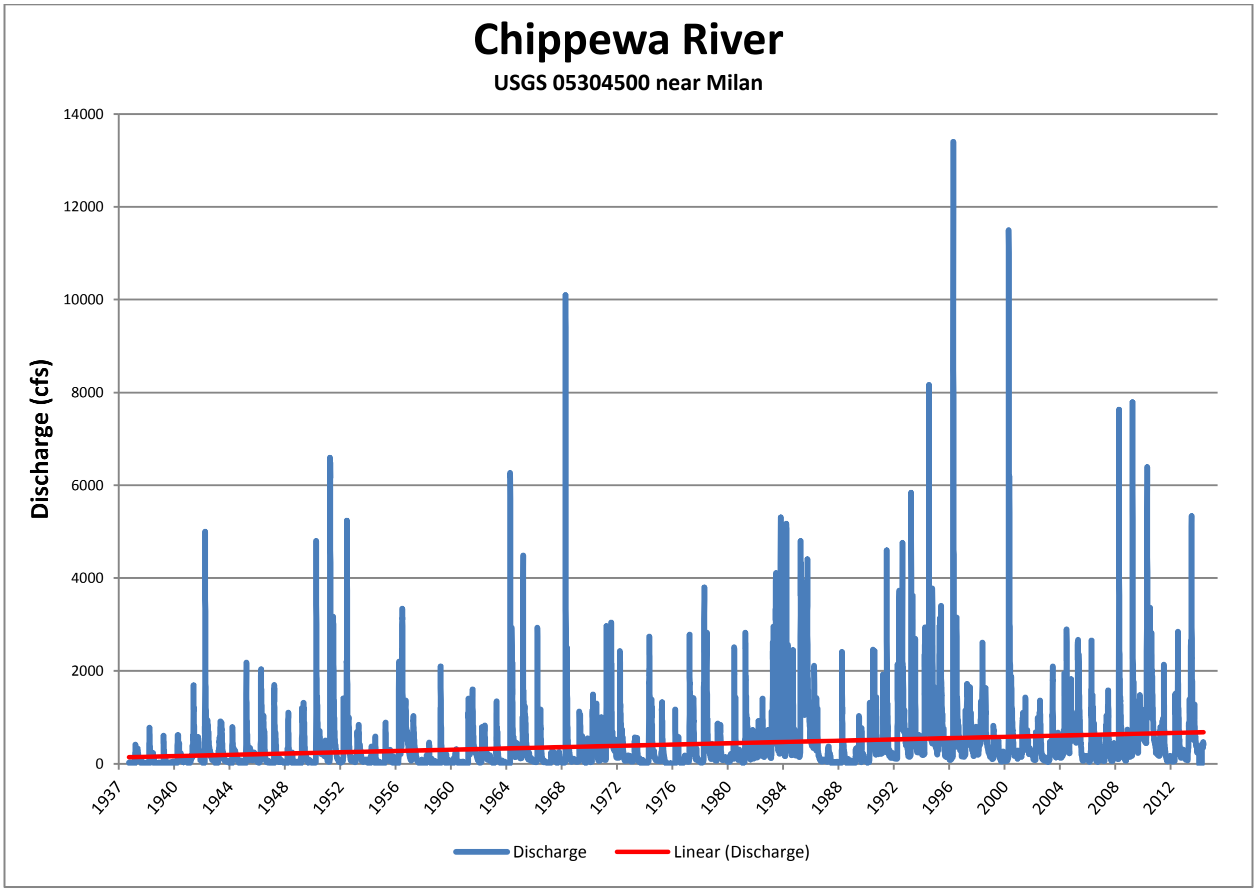

Figure 5: Daily Discharge for the Chippewa River at Milan

Discharge relationships are complex, and not likely the result of a change to any one single aspect of the hydrosphere. One goal of this report is to closely examine the available information to determine which watershed factors are most closely related to any changes in discharge over time. The most obvious potential factor that could create a corresponding rise in discharge would be increasing precipitation. As observed in Figure 1, while annual precipitation totals do vary widely in during the period of record, the seven-year moving average has remained for the most part within the 25-75% bounds, with regression analysis indicating a 10% increase in annual precipitation since 1895 (15% since 1937). To further analyze this relationship, precipitation trends were examined in concert with monthly discharge volumes over the total watershed and in annual total discharge versus total precipitation (Figure 6).

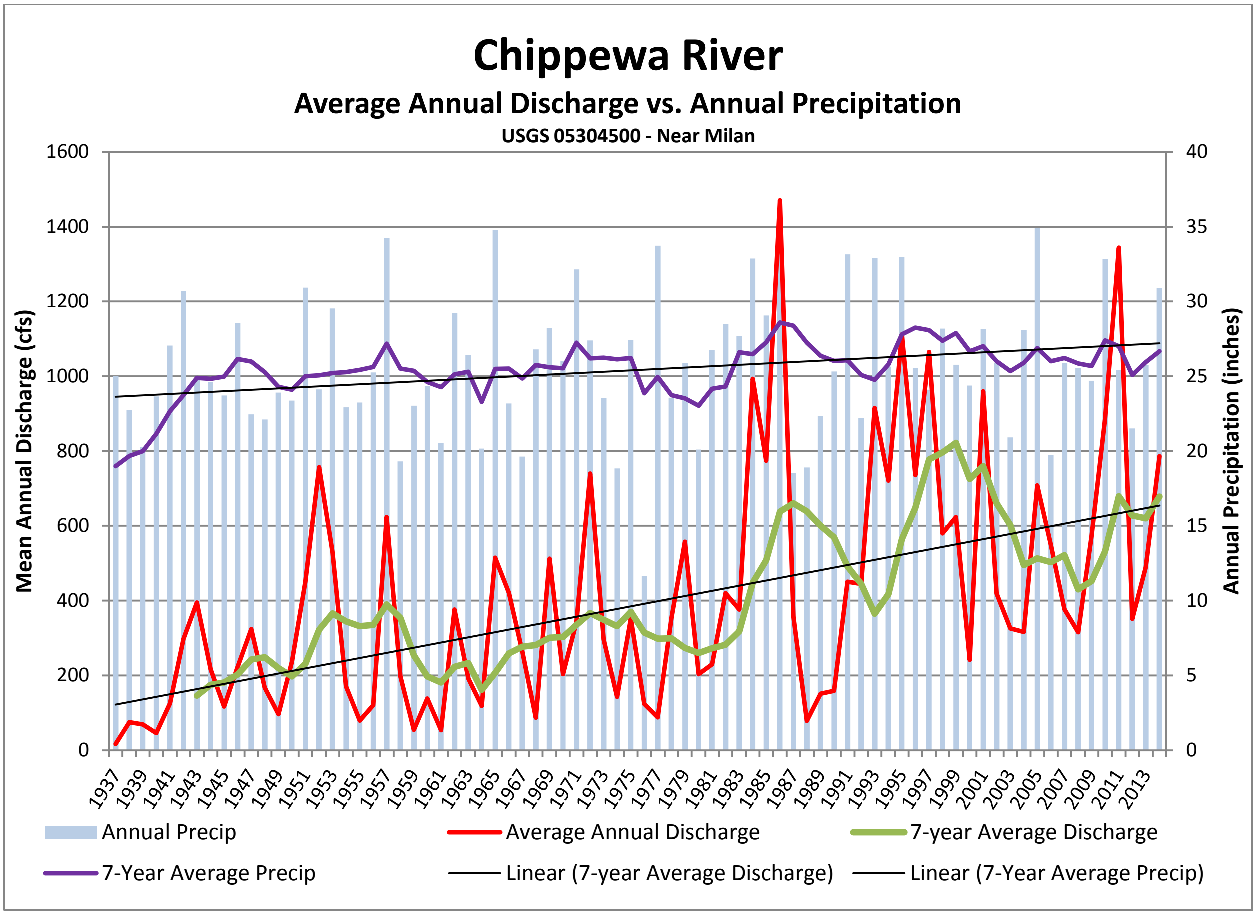

Figure 6 – Annual Average Discharge vs. Annual Precipitation

The hydrograph (Figure 6) depicts mean annual discharge and monthly precipitation totals over time. Once again, there is a slight increasing trend in aveage average precipitation, relatively steady over the period of record. Average annual discharge is increasing on a much steeper slope over the same time period. As discussed earlier, while there is a slight increase in average annual precipitation over time (approximately 10% over the period of record, or 0.13%/yr since 1937, per the seven-year moving average), the increase in average discharge is over 360% since 1938 per the seven-year moving average, or 4.8% per year. This increase in discharge is significantly higher than what can be directly attributed to increases in precipitation over the watershed. When plotted so as to compare total annual discharge and precipitation totals, the change in the relationship over time becomes more apparent.

It is apparent that years with prolonged high-discharge periods or prolonged drought periods can create significant variation within the average daily mean data, which is why the 7-year moving average is used to indicate a longer-term data trends. While it is apparent that the both precipitation and average stream flow are increaseing over time, discharge is increasing at a higher rate than precipitation.

Double Mass Curve

The DMCs were developed from the Chippewa River data. As described earlier in this report, precipitation and discharge data can be used in cumulative comparison to develop the double mass curve to examine runoff and stream discharge relationships (annual and seasonal) relative to rainfall within the watershed. When plotted, a straight line indicates consistency in the relationship over time, and a break or change in slope would mean a change in the relationship. This technique was used to compare precipitation and stream discharge relationships (*i.e.* annual and seasonal) over the period or record (Figure 6). Monthly basin-averaged precipitation totals from the Chippewa River Watershed gridded precipitation model were obtained from the Minnesota Climatology Working Group. Monthly average discharge at the Milan gaging station was converted to calculate runoff from the upstream watershed.

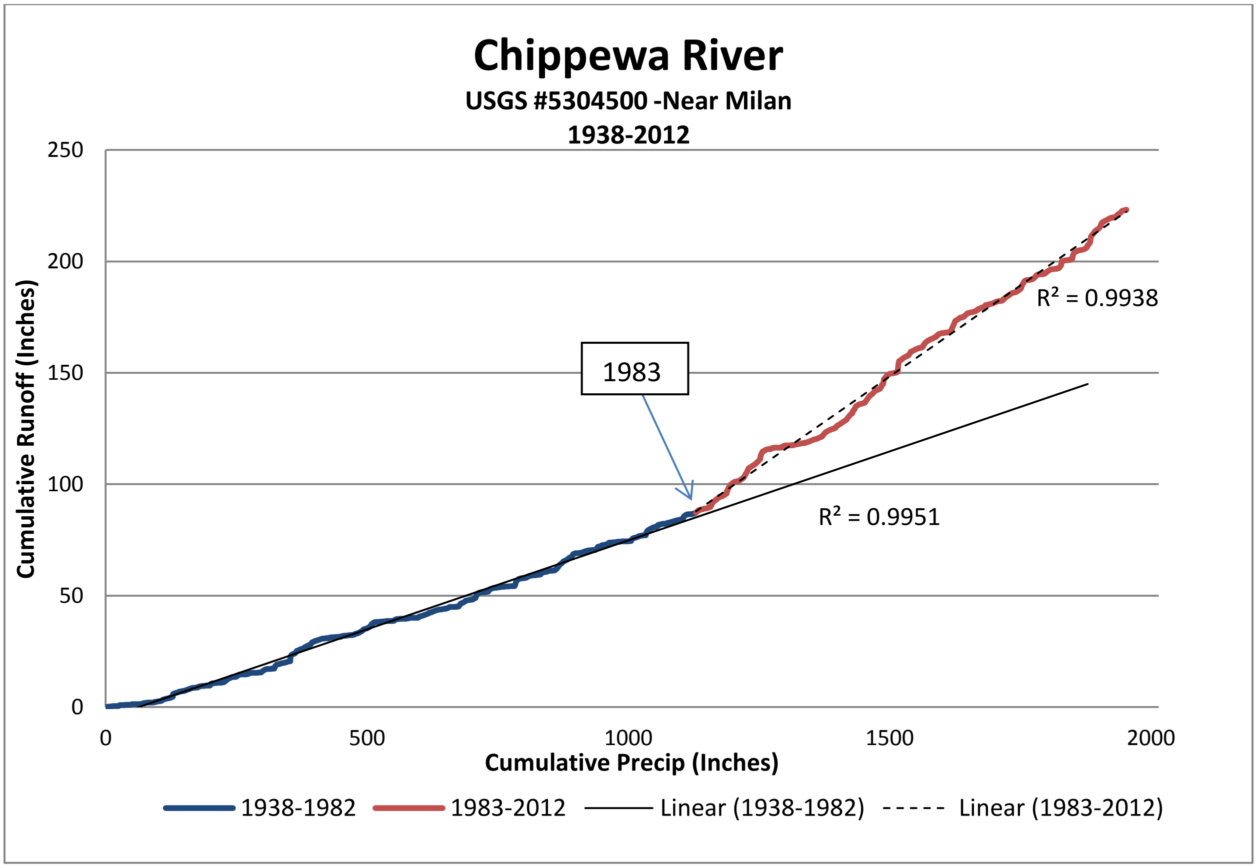

Figure 7 – Double Mass Curve, Chippewa River mainstem near Milan

The curve shows a fairly constant relationship between runoff and precipitation from 1938 to 1982; however, a significant change in slope is noted beginning in 1983, indicating increased discharge in relation to precipitation. Following 1983, the relationship is again relatively constant from 1983 to 2012, albeit at a higher slope than historically seen. This change in the relationship indicates runoff is increasing relative to the amount of rain. Over the period of record, both significantly low (<25th percentile) and high (>75th percentile) annual precipitation volumes were observed, suggesting wet or dry conditions were not completely responsible for changes to this relationship.

The runoff/precipitation relationship displayed in Figure 7 echoes earlier calculations indicating while precipitation has slightly increased both in annual total and in number of significant events over the period of record and may be at least in part of a small portion of increased discharge in the Chippewa River, does not account for the entirety of increases in discharge since 1982. This figure, combined with the previously referenced analyses, outlines that there has been a significant change in the runoff/precipitation relationships on the landscape within the Chippewa River Watershed, resulting in increased streamflow since 1983.

This relationship is also evident in a comparison of monthly average flows between the two periods (Figure 8). Discharge data for all month's post-1982 indicates increased discharge. As there are annual precipitation amounts both greater than 75th and lower than 25th percentiles (Figure 1), moderate/served drought and moist years (Figures 2 & 3), and significant high flow intervals (Figure 5) in both the 1937-1982 and 1983-2012 periods, this increase in average monthly discharge noted in Figures 7 and 8 cannot solely be attributed to precipitation change, nor related to disproportionate weighting from a single high flow period. This information indicates significant hydrologic alteration within the watershed that is changing the runoff/precipitation relationship watershed wide.

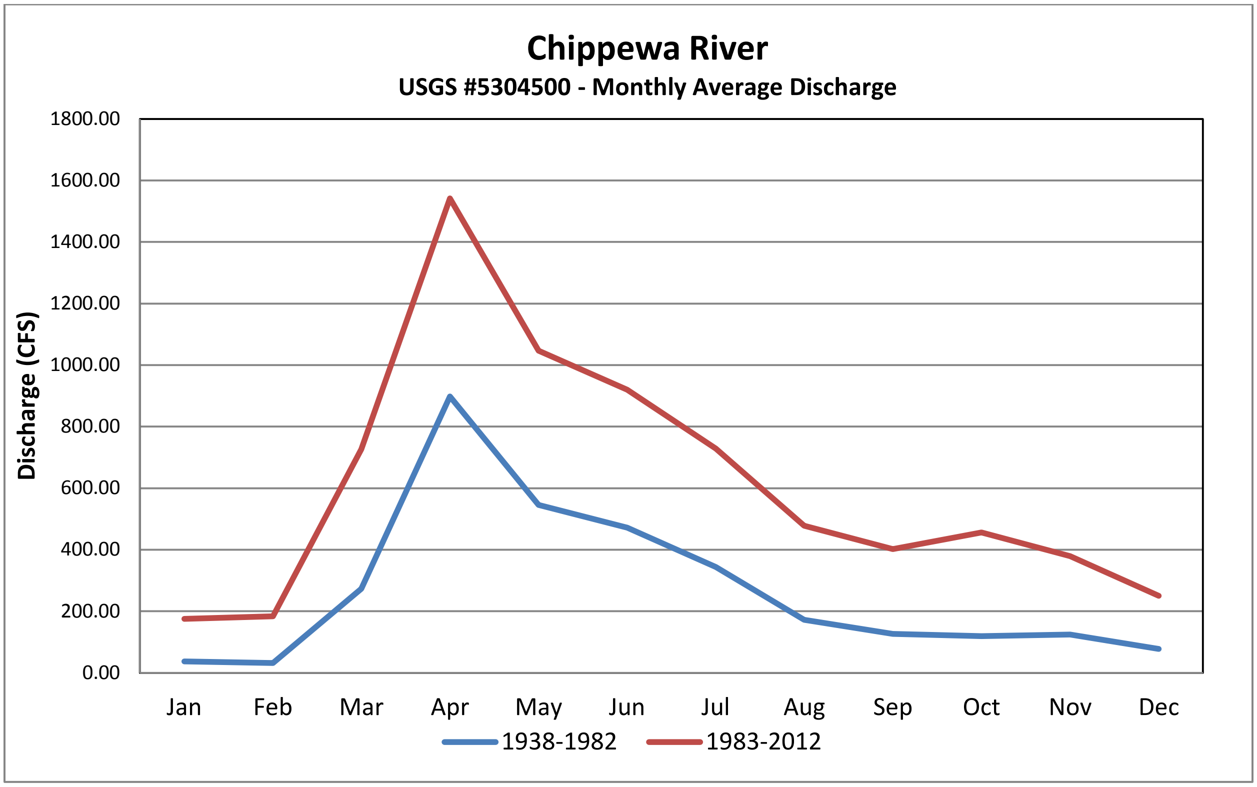

Figure 8 – Monthly average discharge

As a portion of this analysis, the timing of discharge over the period of record was also addressed. For these analyses, average discharge and average precipitation per month were determined and compared on a 10-year scale to remove some of the year-to-year variability and perceive a longer-term trend. For the Figures 9-12, it is apparent that discharge is increasing within the river over multiple time periods given year, and rising annual average discharge (Figure 6) is not simply related to increased flows in one specific month. Discharge is increasing in the months of March and April (Figure 9) May and June (Figure 10) and appears to be increasing independent of the average precipitation value. The relationship is most evident in the 1970s and 1980s when the average precipitation has decreased or remained steady from the previous decade while average discharge has increased.

This same inverse relationship is somewhat noted in the July and August data (Figure 11), but is much more prevalent over the 1980's in the October and November data (Figure 12).

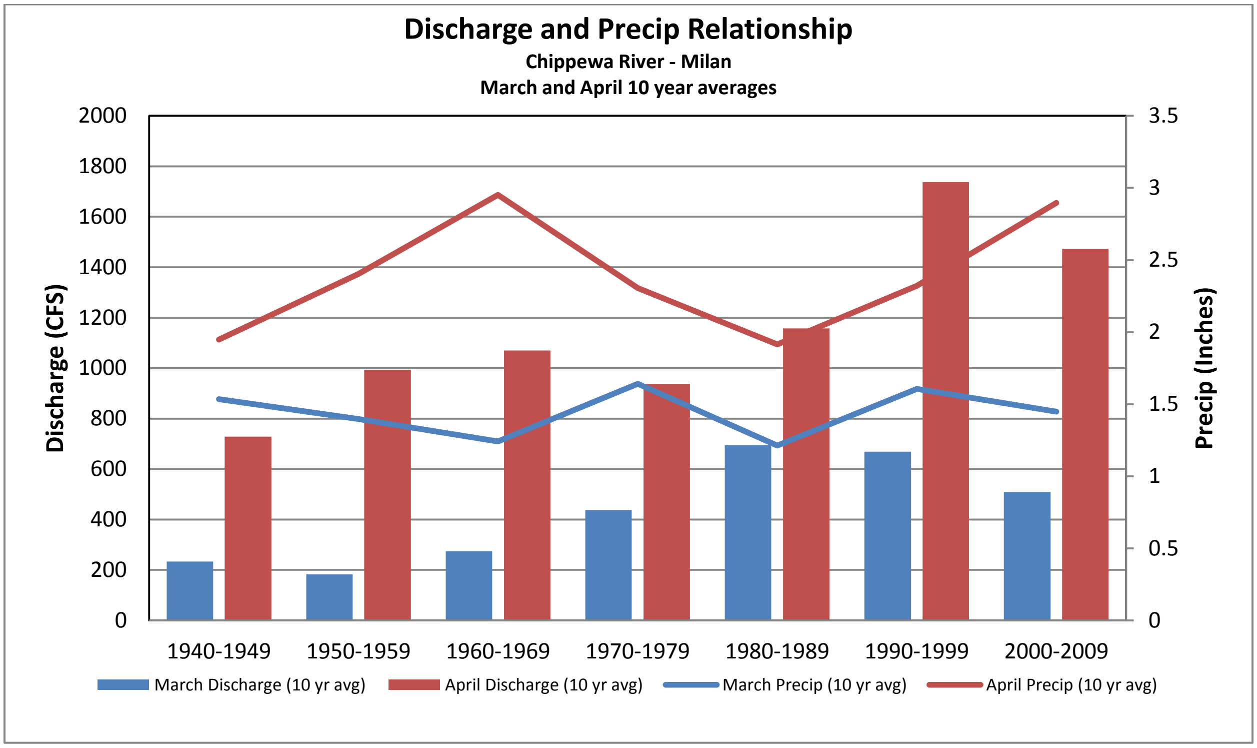

Figure 9: March-April Precipitation/Discharge Relationship

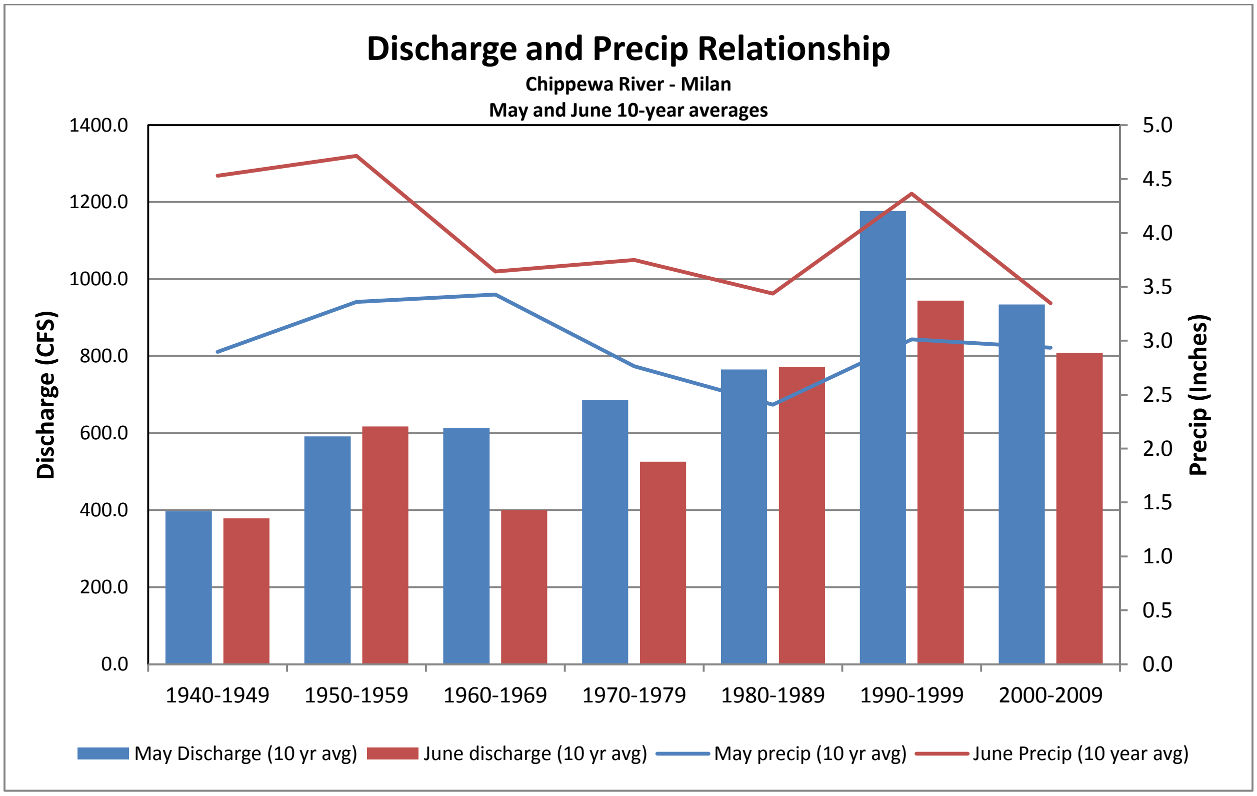

Figure 10: May-June Precipitation/Discharge Relationship

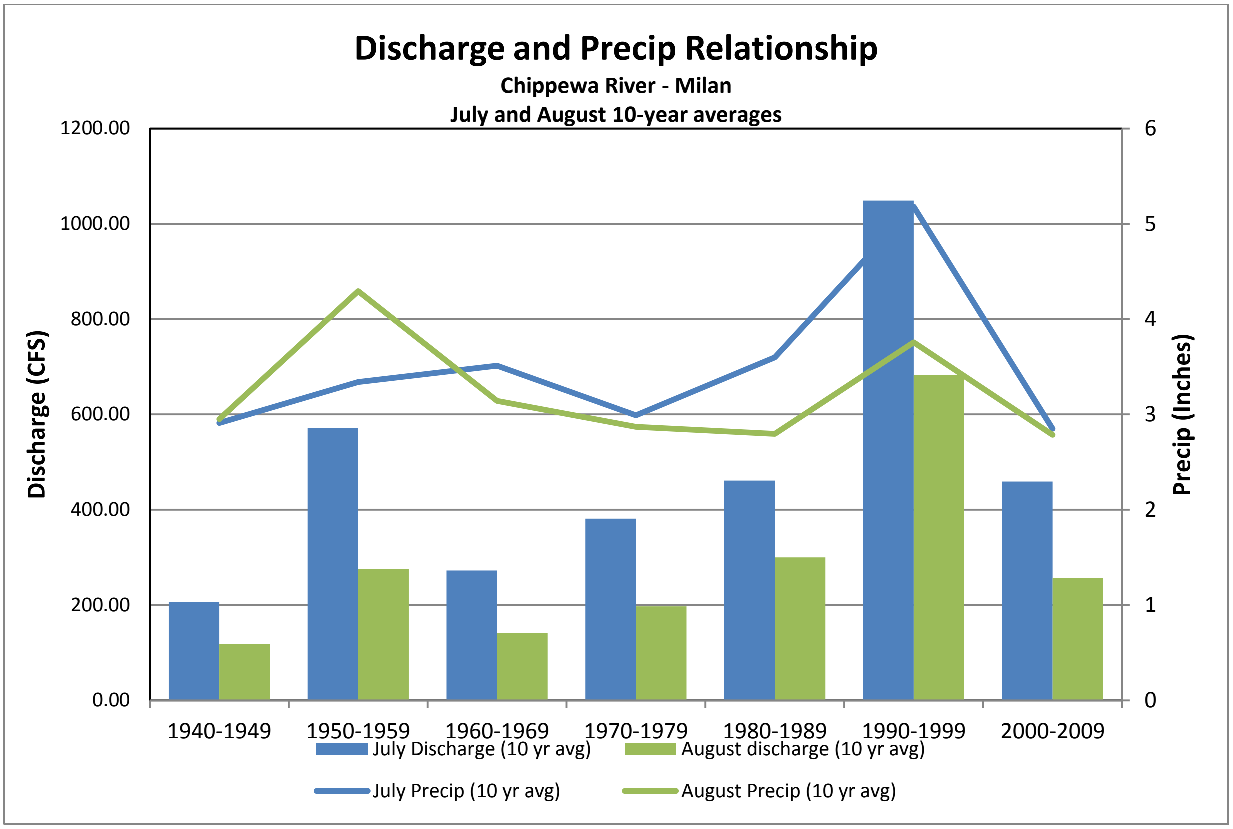

Figure 11: July-August Precipitation/Discharge Relationship

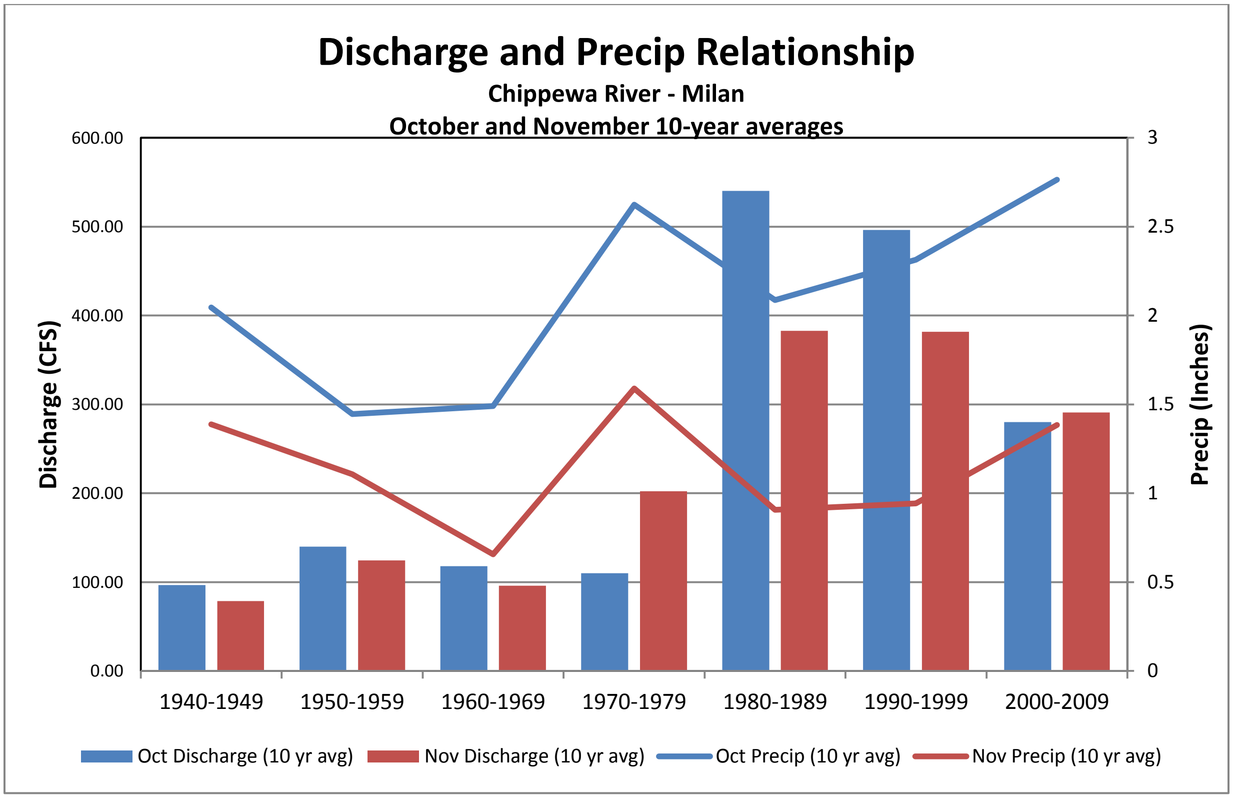

Figure 12: October – November Precipitation/Discharge Relationship

The information in Figures 9-12 supports the previous analyses in that discharge is increasing disproportionately to precipitation within the Chippewa River Watershed, and outlines that it is occurring at various points throughout the water year. As previously suggested, if precipitation is not the sole primary cause for rising discharge, additional hydrologic alteration on a watershed scale must be occurring that is changing the runoff precipitation relationship.

Duration Curves

Discharge data are also used to create a flow duration curve, which is a cumulative frequency curve that shows the rate of recurrence with which a specific flow volume was exceeded or equaled in a given period of record. For this analysis, daily mean flow data were used to create the flow duration curve for the Chippewa River. Duration curves can be used to examine discharges relationships and in assessing long-term trends; specifically, how often the flow volume exceeds high (*i.e.* 10th percentile) and/or low (*i.e.* 90th percentile) flow conditions for the watershed.

In general, a curve with a steep slope throughout indicates a highly variable stream whose discharge is derived from direct runoff. A flat slope indicates the potential presence of surface or ground-water storage, which can help meter out the flow at a slower rate. The curve for the Chippewa River (Figure 12) is relatively flat, indicating significant effects from surface and groundwater storage on runoff relationships, including prolonged duration flows resulting from storage, and some buffering of flows due to the number of basins present in the watershed. It should be noted, however, that while portions of the curve do exhibit high slope, such as during low flow conditions (*i.e.* below Q_{90}) this curve does not progress to when zero flow conditions would be recorded.

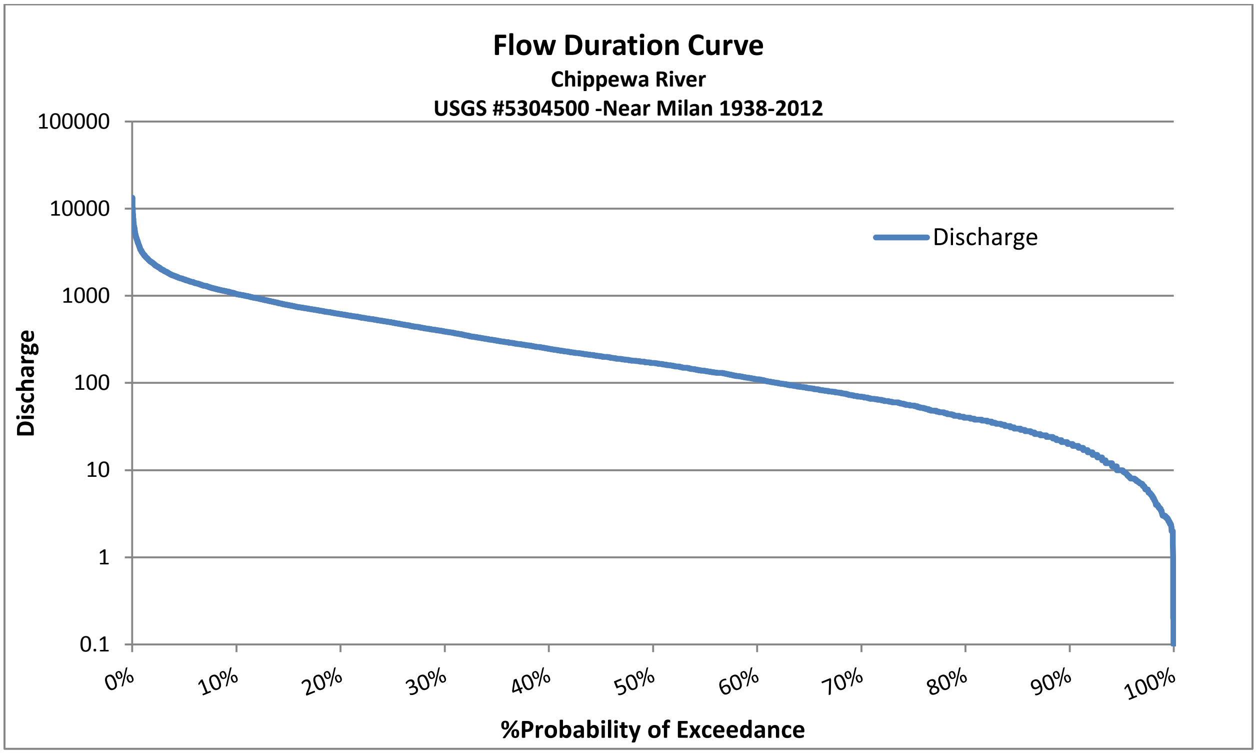

Figure 13: Flow Duration Curve for the Chippewa River at Milan

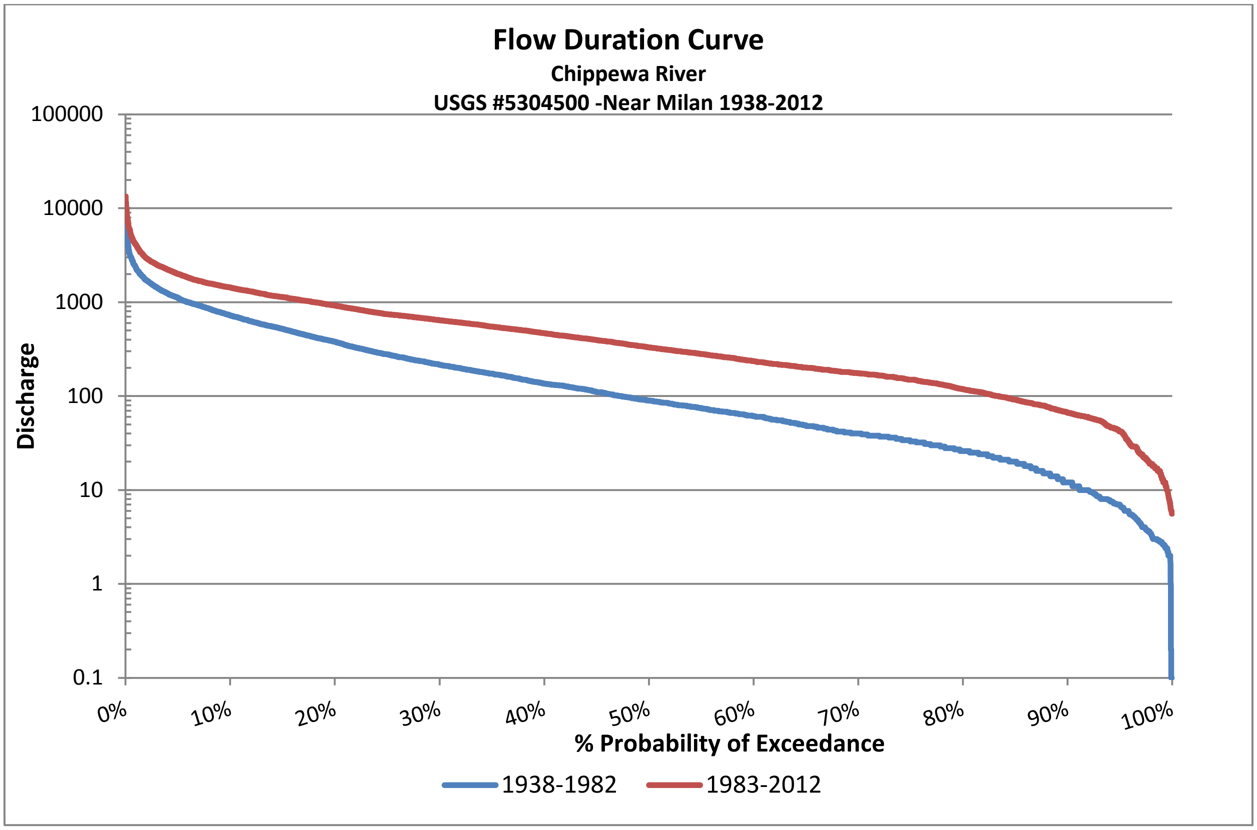

Figure 14: Flow duration curve comparison.

As the double mass curve in Figure 7 indicated a significant change in the precipitation/runoff relationship beginning in approximately 1982-83, flow duration data for these two periods was separated to determine if a significant disparity is present. As shown in Figure 14, a significant difference is noted in the flow duration curve for these two periods, indicating that flows since 1983 have significantly increased over the period of record.

Using the duration data, trends can be analyzed for various flow conditions. The high flow and low flow periods were plotted to examine if the number of days at the flow conditions has changed over time. It both cases, both the high and low flow conditions have changed significantly over time. The number of days at or below low flow (*i.e.* Q_{90}) conditions has gone down over time (Figure 15), indicating an increase in baseflow over historical conditions. This is the same relationship demonstrated in the double mass curve calculations (Figure 7). Similarly, the number of days at high flows (*i.e.* $>Q_{10}$) has increased over time (Figure 16), indicating increase in inputs to the system. As described in earlier sections, while there has been an increase in precipitation within the watershed, the increase in discharge outlined in these datasets is not proportional the precipitation changes.

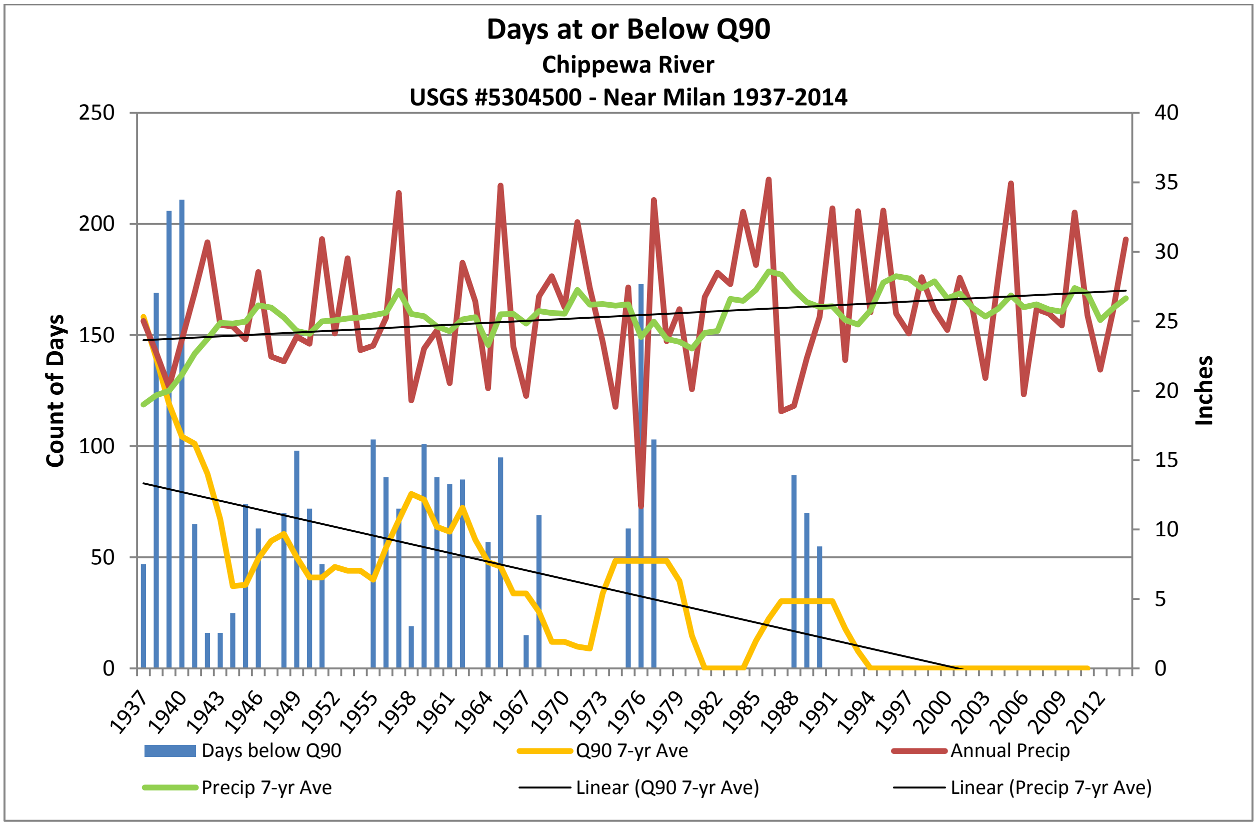

Figure 15: Days at which stream discharge is at or below Q90 discharge

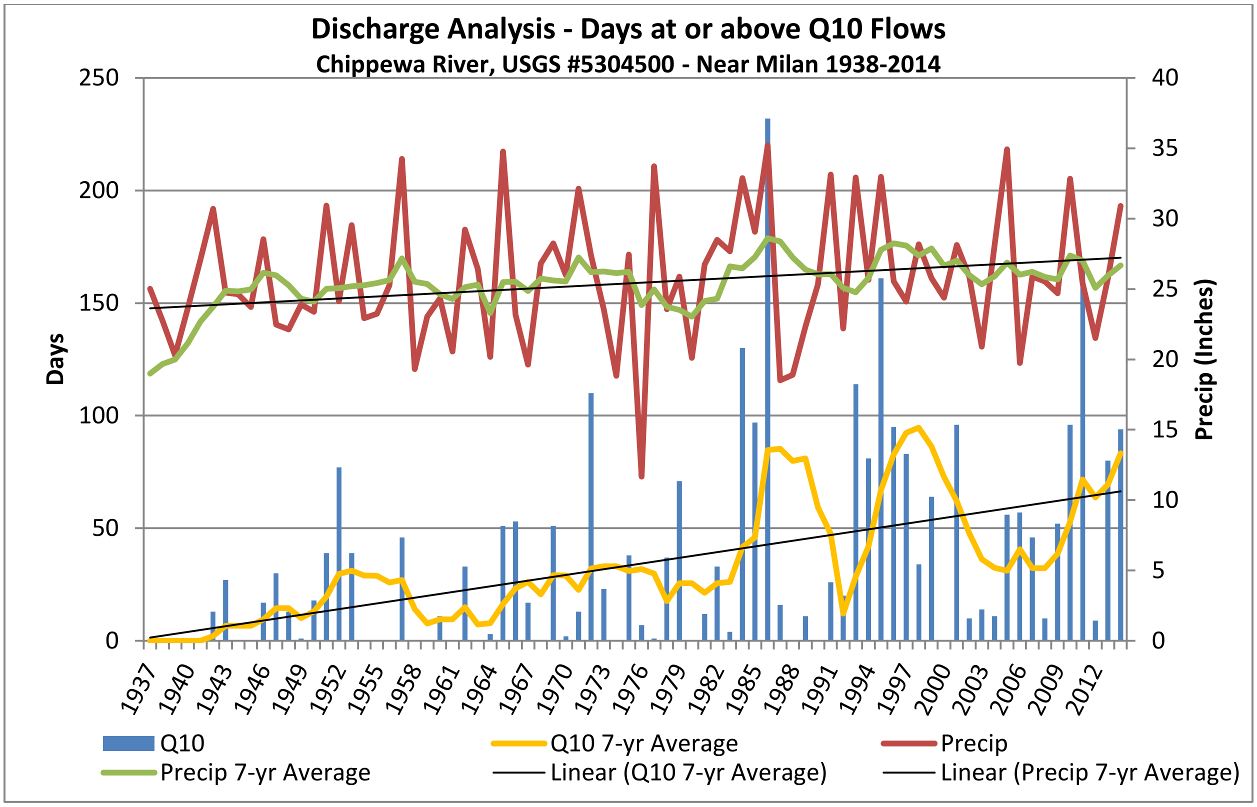

Figure 16: Days at which stream discharge exceeds Q10 discharge

The data in Figures 15 and 16 indicate that discharge within the watershed has increased significantly over time, with more days at high flows (>Q10) and far fewer days at low flow (<Q90). Following a direct comparison of statistical exceedances from the flow durations curves (Figure 14), it is apparent that all flows have significantly increased for the Chippewa River at the Milan gaging station. Of particular note, are the low flows (80-90%), which have increased 300% to 400%+ since 1982 (Table 2). This increase in flows represents significant hydrologic alteration within the watershed, and as previously stated, cannot be solely attributed to the slight increase in observed precipitation. At this point, it is evident that additional factors, including some form of significant hydrologic alteration has occurred within this watershed resulting increased runoff to the river per unit precipitation.

Flow percentile	**Discharge**	
	1937-1982	**1983-2012**
10	722	1430
20	380	920
30	216	643
40	136	468
50	90	331
60	61	235
70	40	175
80	26	119
90	12	67

Table 2: Changes to Exceedance Probabilities

Discharge summary

Various separate analyses have shown that discharge within the stream is increasing at a rate disproportionate to precipitation. Most notably, beginning in 1983, the cumulative runoff ratio has increased, resulting in higher average monthly discharge, as well as increased occurrence and duration of high flow events and fewer low flow periods, even in response to several short periods of moderate drought. As increases in discharge cannot be solely attributed to precipitation, the changes to runoff ratio

Land use analysis

Several separate analyses have determined that significant changes to land use and cover (Schilling et al. 2008) and cropping patterns (Schottler 2013) can lead to significant changes to runoff/precipitation relationships within predominantly agricultural watersheds. Along these lines, an analysis of land use patterns and changing crop rotations over time is compared to the timing of significant changes to discharge within the Chippewa River. In addition, an analysis of land use characteristics in comparison to discharge data in several Chippewa River subwatersheds is used to outline a relationship between land use patterns and runoff data.

Land use/land cover (LULC) data for the Chippewa River Watershed was collected from the National Agricultural Statistics Services' Cropscape website (website: http://nassgeodata.gmu.edu/CropScape/). The data for 2014 indicate that approximately 56% of the watershed was cultivated in row crop (corn and soybeans), with ~10% in other crops (small grains, alfalfa, hay). Nearly 30% of the watershed is open water, forest, or grass/prairie, while appoximately 5% is considered developed (Figure 18). In the case of the Chippewa River Watershed, comprehensive land use information is available from 2006 to 2014, but is much more intermittent prior to 2006. As this period of time is relatively short, it is difficult establish longer-term trends in land use over time.

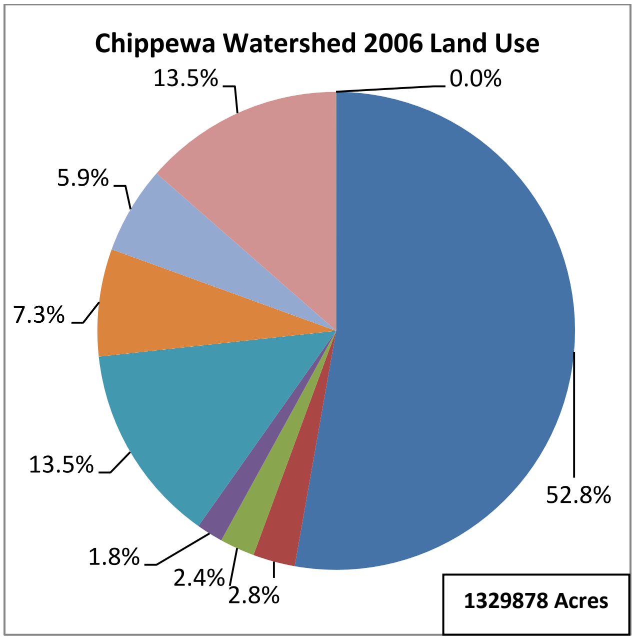

Figure 17: Chippewa Watershed 2006 Land Use

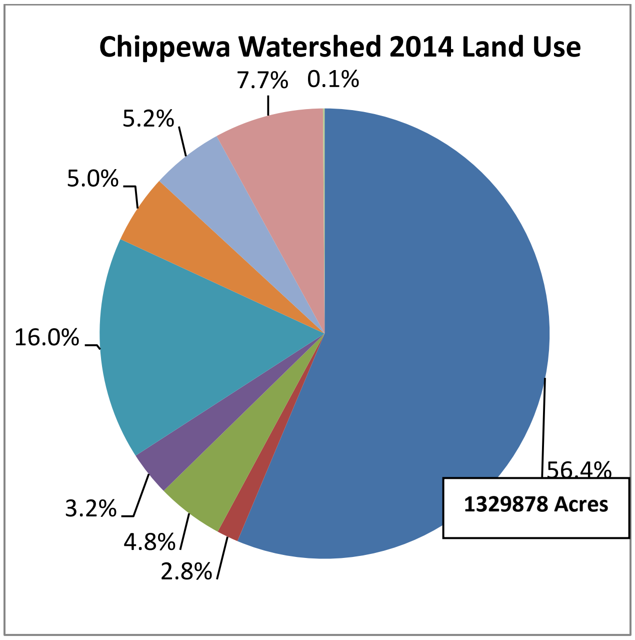

Figure 18: Chippewa Watershed 2014 Land Use

■ Corn/Beans ■ Small Grains ■ Alfalfa/Hay
■ Other Crops ■ Open Water/Wetland ■ Developed
■ Forest ■ Grass/Pasture ■ Other

Following analysis of the changes in LULC in the Chippewa River Watershed between 2006 and 2014, one of the most notable differences lie in the in the Grass/Pasture category. A 50% decrease of 75635 acres was noted in this category, while Corn/Beans, Hay/Alfalfa, and Other Crops all showed marked increases of 47179 acres, 32572 acres, and 18463 acres, respectively. Small grain acreage (wheat, oats, barley, etc…) stayed about the same over the same period. The drop in Grass/Pasture may coincide with CRP grassland conversion as multiple series of contracts have expired and land was re-entered into production.

While Figures 17 and 18 demonstrate a wide range of land uses/land cover within the watershed, this breakdown varies greatly between subwatersheds within the basin (Figures 19-26). The data for these four subwatersheds (Watershed Upstream of Cyrus / Upper Chippewa, Shakopee Creek, East Branch Chippewa, and Dry Weather Creek) were included as some overlapping stream gage information exists for comparison. In order to include these comparisons, it was appropriate to compare land use patterns within these watersheds to determine if a potential relationship between stream discharge ratio and land use exists. In comparing land use between 2006 and 2014, it should be noted that the same trends emerge in all subwatersheds as were noted for the main watershed, including marked decreases in Grass/Pasture areas, and corresponding increases in Corn/Beans, Alfalfa /Hay, and Other Crops. This information indicates that more land was in production (values range from 1-10%) in each subwatershed in 2014 than in 2006.

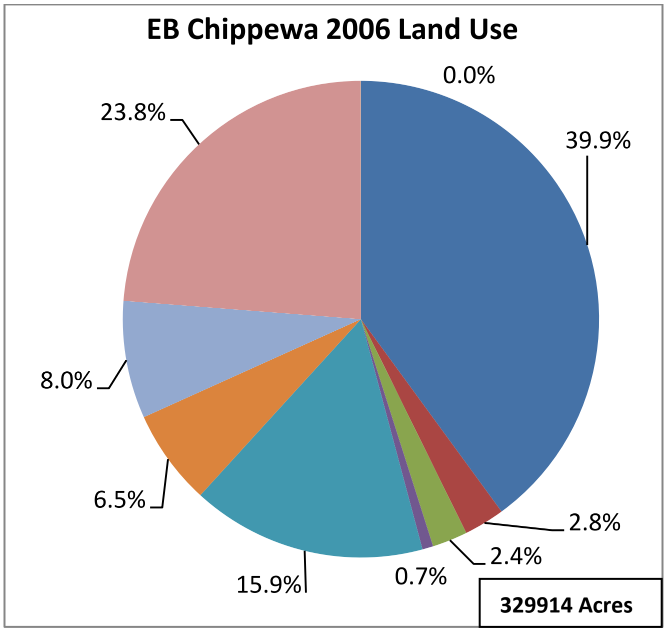

Figure 19: EB Chippewa 2006 Land Use

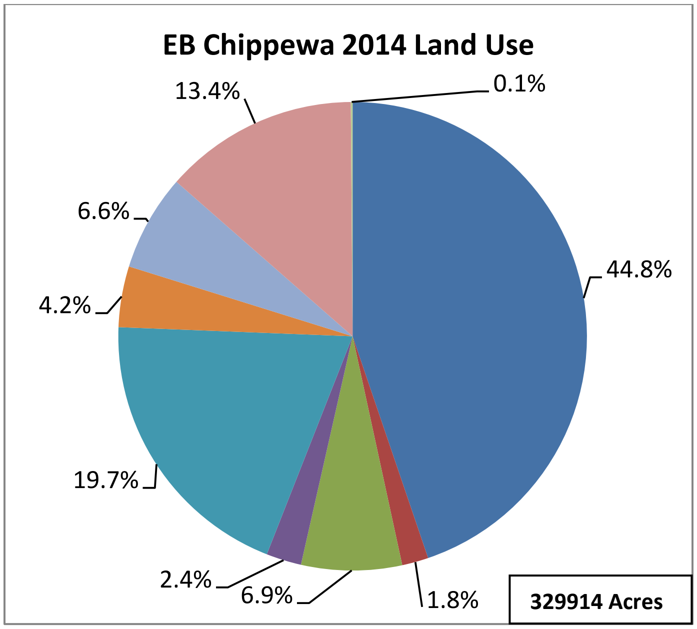

Figure 20: EB Chippewa 2014 Land Use

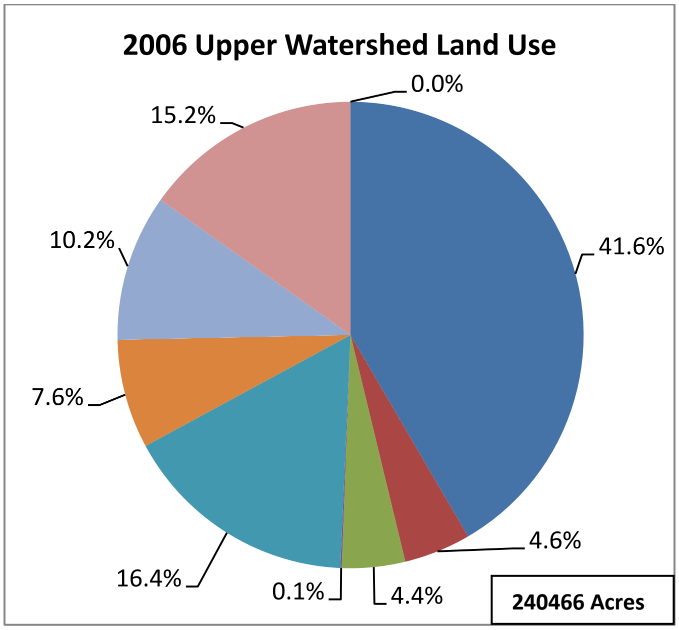

Figure 21: 2006 Upper Watershed Land Use

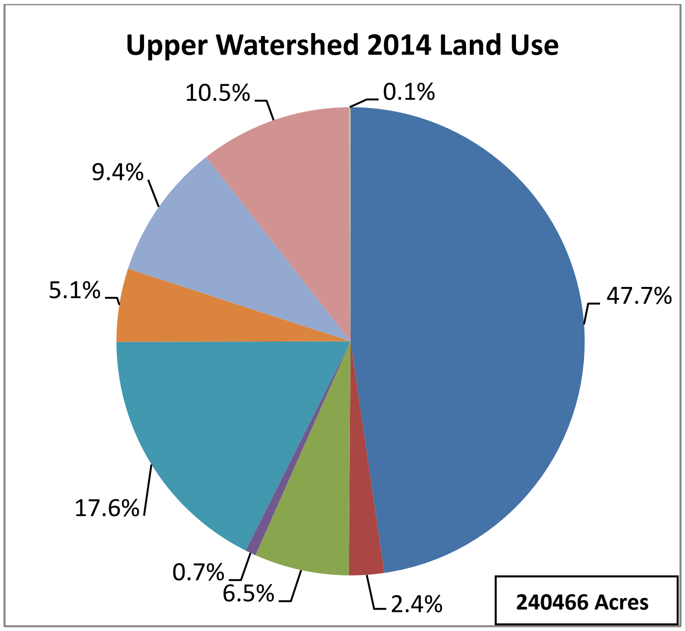

Figure 22: Upper Watershed 2014 Land Use

🟦 Corn/Beans 🟥 Small Grains 🟩 Alfalfa/Hay
🟪 Other Crops 🟦 Open Water/Wetland 🟧 Developed
🟦 Forest 🟥 Grass/Pasture 🟩 Other

Interestingly, all watersheds show a marginal increase in open water/wetland acreage in as well (Figures 17-26). Additional analysis indicates that this correlates to an increase in herbaceous wetland acreage. More information will need to be gathered to determine the specific cause of this trend.

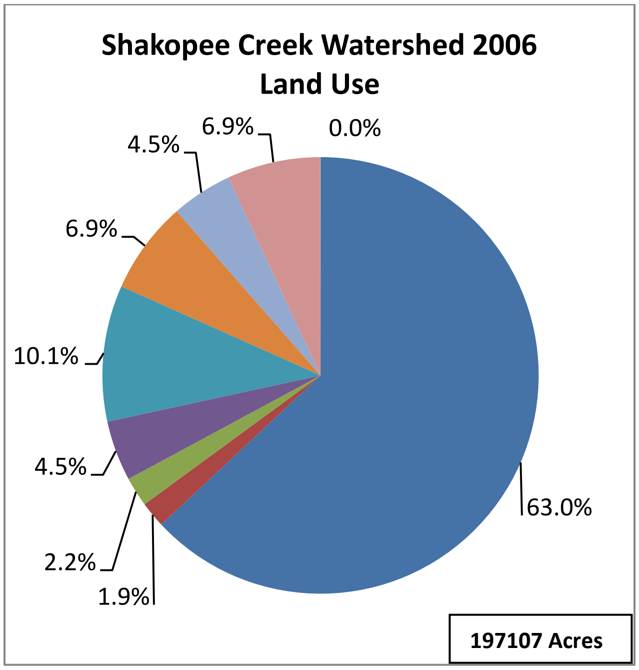

Figure 23: Shakopee Creek Watershed 2006 Land Use

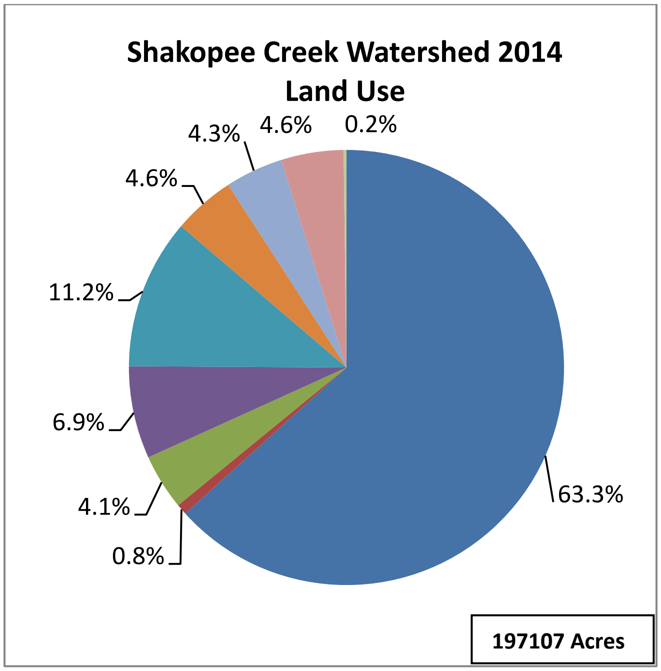

Figure 24: Shakopee Creek Watershed 2014 Land Use

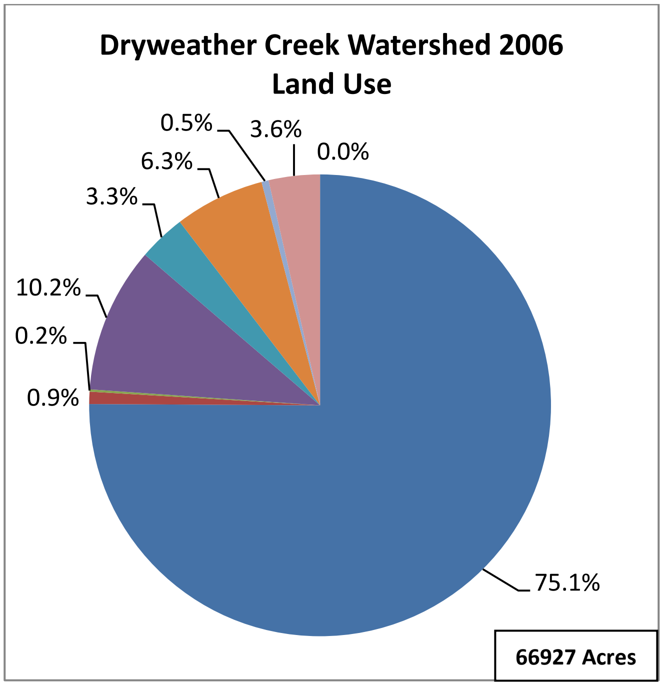

Figure 25: Dry Weather Creek Watershed 2006 Land Use

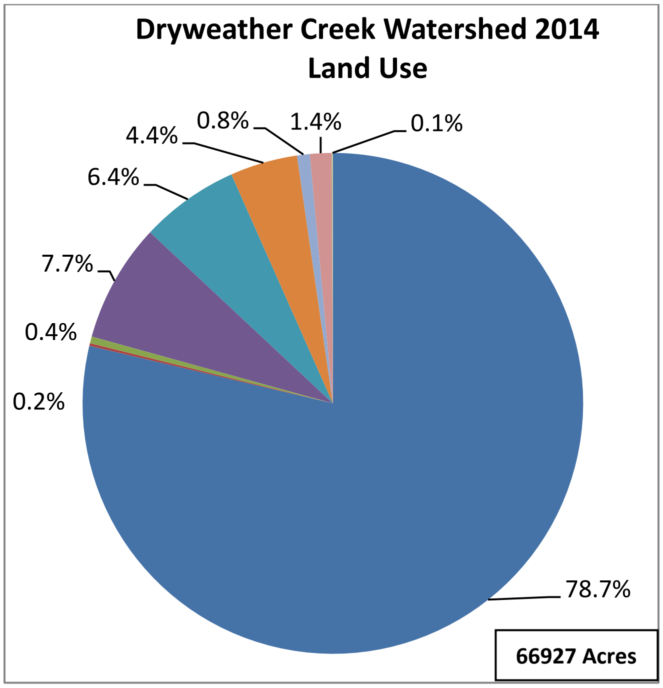

Figure 26: Dry Weather Creek Watershed 2014 Land Use

Observation of land use trends indicate more land is placed in production has been placed in production in recent years. As ET and runoff response are significantly different for row cropped land than grassland or wetland, it is expected that as more land is placed in production, the hydrologic response from each of these subwatersheds will change as well. Along these lines, runoff response was compared in three subwatersheds (Dry Weather Creek, East Branch Chippewa River, and Shakopee Creek) from 2004-2012 (Figure 31).

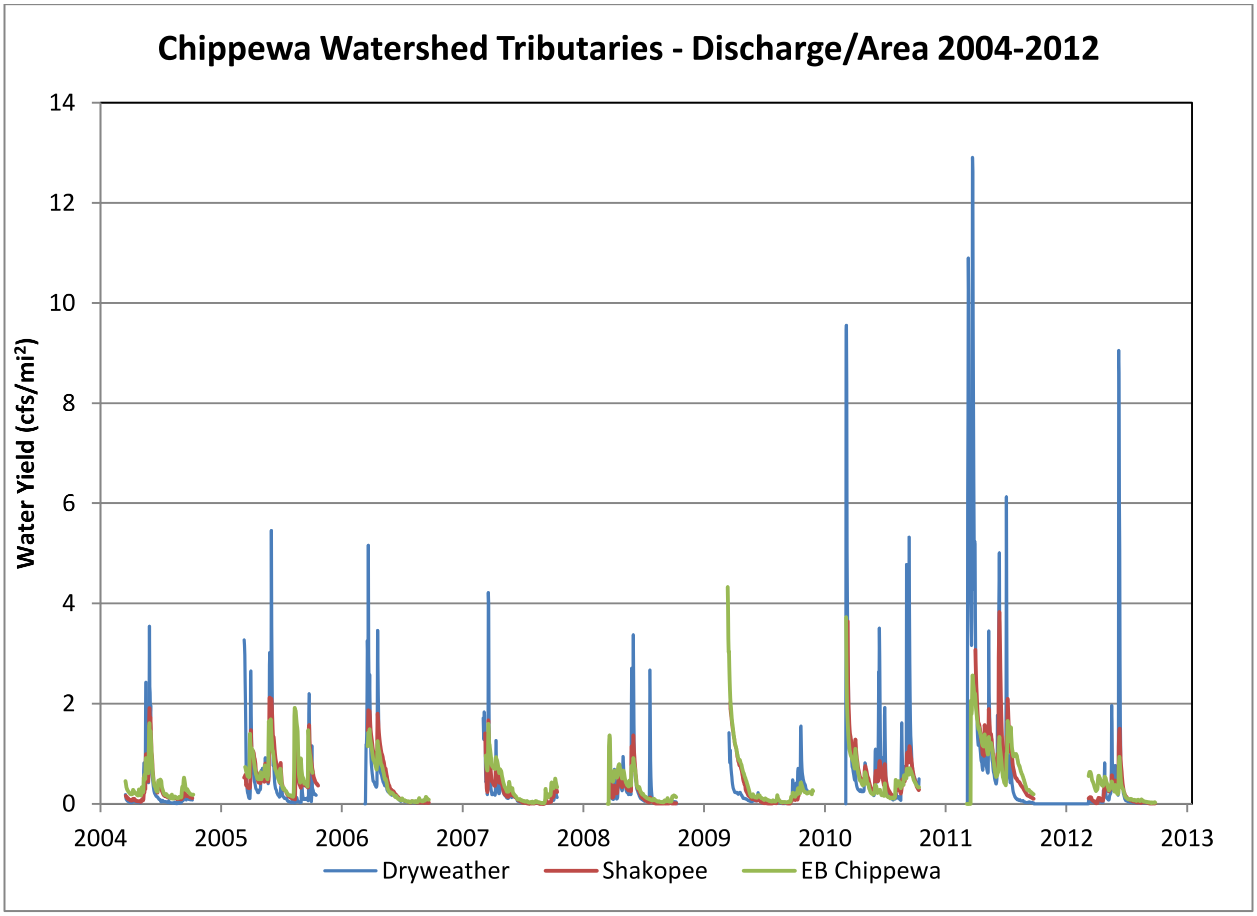

Figure 27: Chippewa River Watershed Tributaries - Discharge/Area 2004-2012

Figure 27 displays the runoff per square mile (referred to as water yield), between the three selected subwatersheds from 2004-2012. Data gathered from all subwatersheds does show variation in the water yield over a given year or in response to various events, however, differences in magnitude of response are noted between the subwatersheds. Of these watersheds, Dry Weather Creek consistently displays the highest water yield, and is the only watershed with water yield values exceeding 5 cfs/mi^2. As per the LULC data displayed in Figures 19-26, Dry Weather Creek also has the highest percentage of land in row crop production of the subwatershed studied, as well as far less open water acreage than the other two watersheds. Along these lines, the East Branch Chippewa River Watershed, which has the highest open water acreage and lowest cropland percentages of the subwatersheds, consistently displays the lowest water yield values. This information indicates that a direct relationship may exist between these land use composition and discharge within the mainstem tributaries.

While precipitation was not consistent over these watersheds from 2004-2012, this comparison is made over longer periods of time instead of in response to a single event to eliminate bias caused by short-term analysis. The consistency displayed in this relationship over time indicates that conditions in these watersheds are such that this relationship is similarly displayed each year.

An increase in water yield is also apparent from upstream to downstream within the Chippewa River Mainstem (Figure 28). In order to make true comparison and handle these two units as separate watershed areas, calculations for this dataset include removing discharge data as recorded at the Cyrus station from discharge values collected at Milan. This allows for comparison of these two areas as separate entities. In comparing the watershed upstream of Cyrus to the watershed at Milan, it is apparent that water yield from the rest of the watershed is consistently much higher than values calculated for the upper watershed. The upper watershed and Chippewa River Watershed as a whole also display similar land use relationships as the previous subwatershed comparison, with watershed upstream of Cyrus displaying higher open water/wetland and grass/pasture acreage and lower row crop acreage than the full watershed (Figures 17-26). It should also be noted that water yield from Dry Weather Creek exceeds watershed water yield in nearly all cases (Figures 27 and 28). This may indicate that altered hydrology is a very large issue within the Dry Weather Creek Watershed.

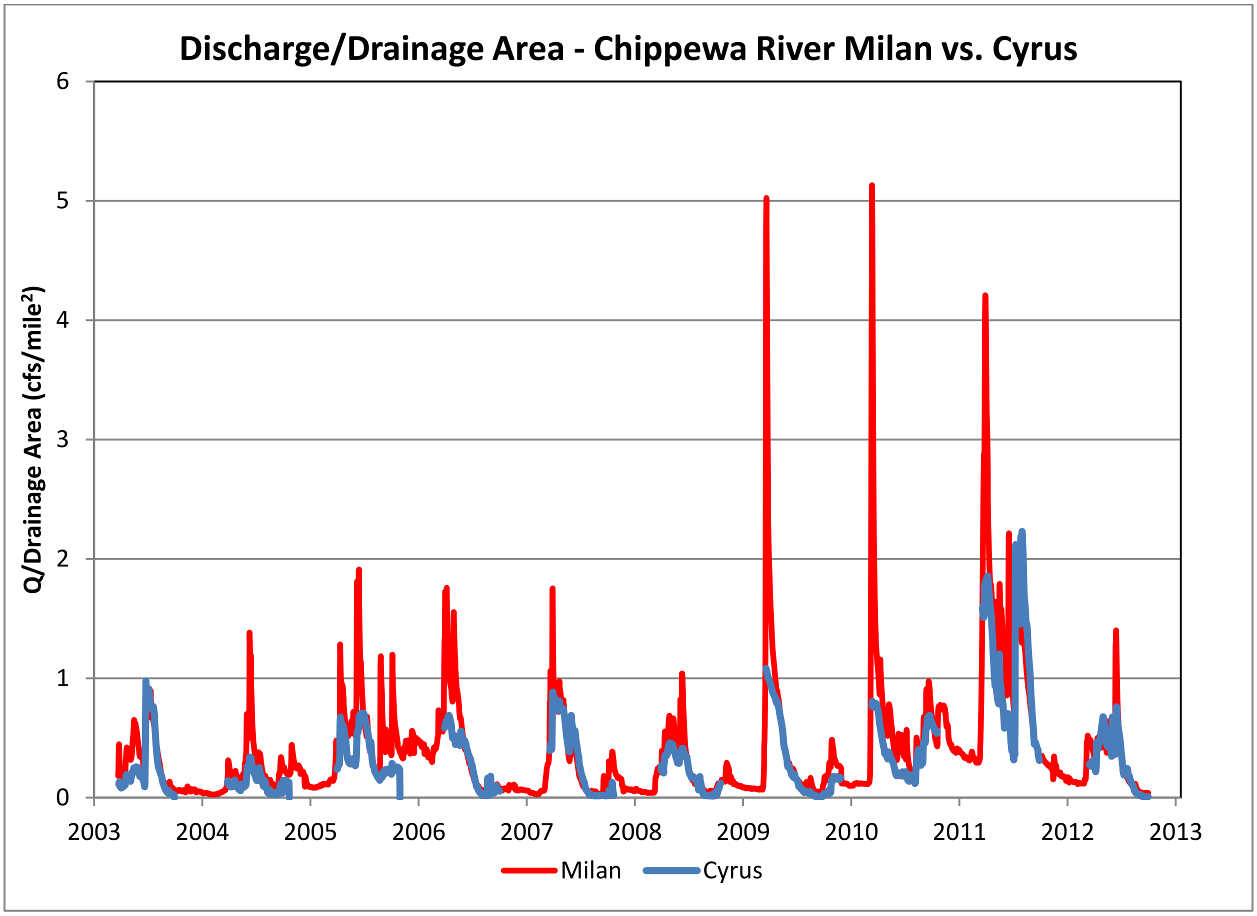

Figure 28: Discharge/Drainage Area - Chippewa River Milan vs. Cyrus

Altered surficial hydrology, specifically channelization, pattern drainage and connection of historically landlocked areas, does play a significant role in changing flow dynamics, however, these changes have not yet been quantified at the time of this report. Additional data on this topic will be gathered and incorporated in to this report in the future.

Historical Cropping information.

As previously stated, comprehensive land use data prior to 2006 is limited, however, data pertaining to acres of crop harvested per county per year since 1921 is available from the U.S. Department of Agriculture's National Agricultural Statistics Service (source: www.nass.usda.gov). In order to make determine if conversion to predominantly row crop can be potentially related to increases in discharge from the landscape, historical cropping data was analyzed. This data was used to compare acres in production for seven major crop types: Corn, soybeans, wheat, oats, barley, alfalfa, and hay (Figures 27-30). Information was available for other crop types, however, for the purposes in this report, only these seven were selected as they are likely historically the largest crop types in this watershed. In addition, these figures are county-wide, with very little means to separate the data via major watershed boundary. As such, data for three counties predominantly within the Chippewa River Watershed were considered, while others (Douglas, Grant, Kandiyohi, and Ottertail) had smaller percentages of total county area within the watershed. As there was not a viable means of separating data for the areas within from areas outside the watershed boundary, these counties were not assessed at this time.

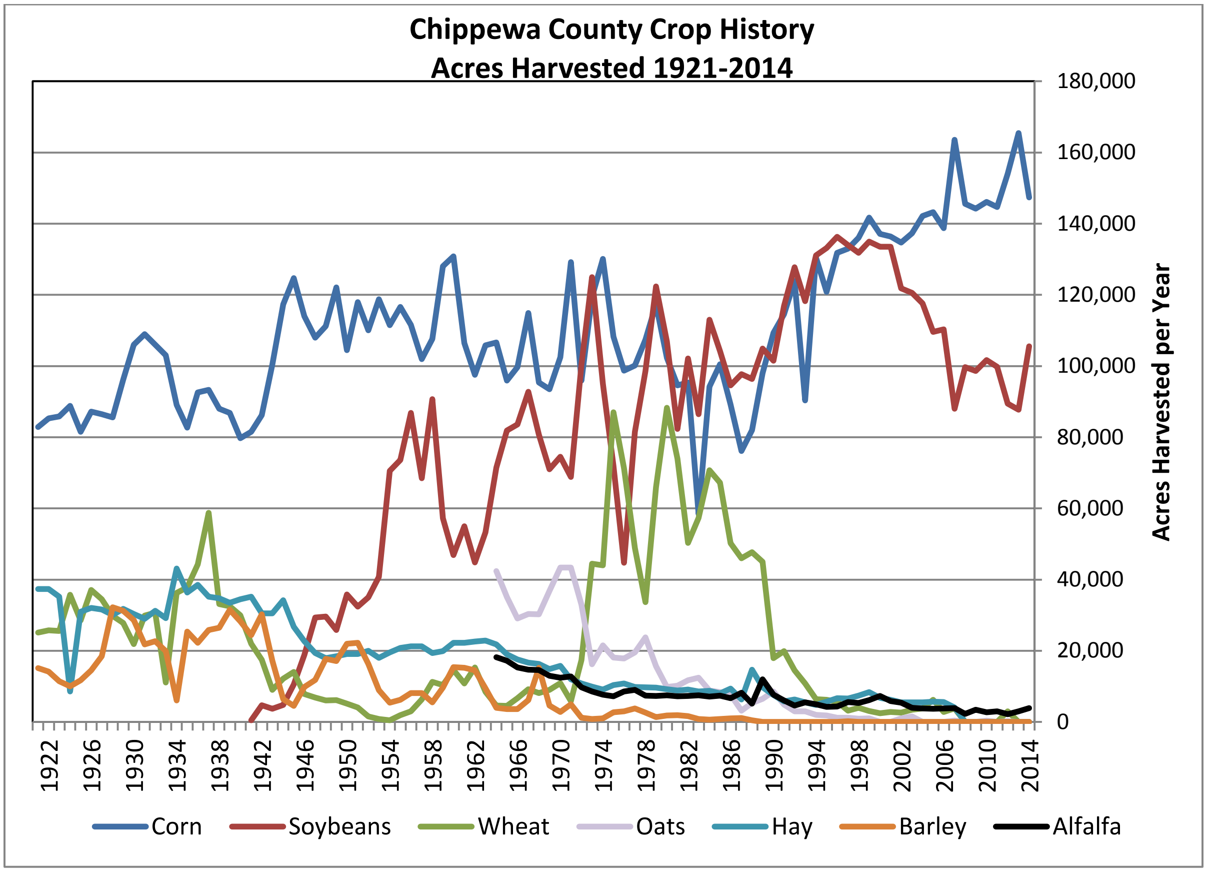

Figure 29: Chippewa County Crop History

The data in Figures 29-31 are very similar in that all three counties show corn and soybean acreage are increasing while wheat and other small grain acreage has gradually decreased since the beginning of the period of record in 1921 (Oats and alfalfa data only available to 1963). Soybeans in particular are of note as acres harvested have increased from virtually none in the 1940's to nearly 300,000 acres between the three counties analyzed. While a specific inflection point in land use cannot pinpointed in relation to the changing discharge/precipitation relationship noted in Figure 7, it is apparent that significant changes have occurred in land use over time that may have contributed to changes in discharge within the stream.

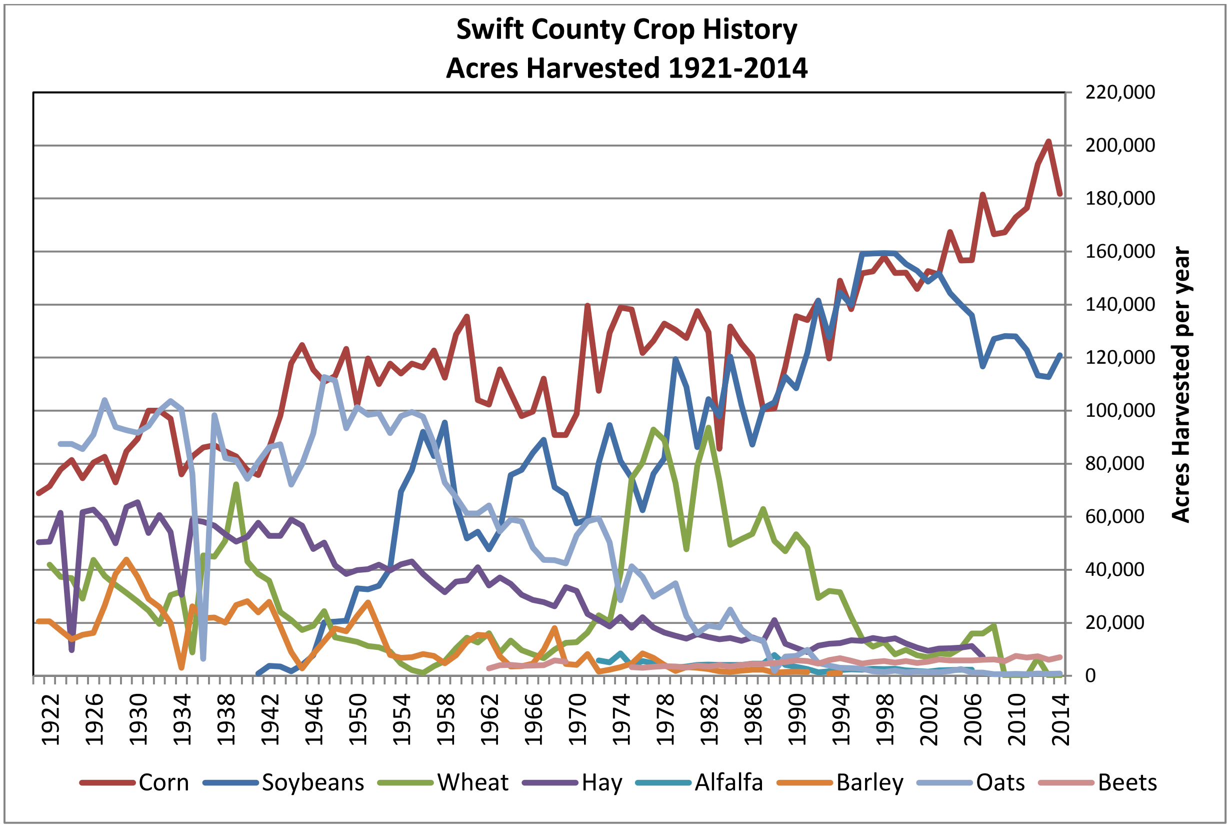

Figure 30: Swift County Crop History

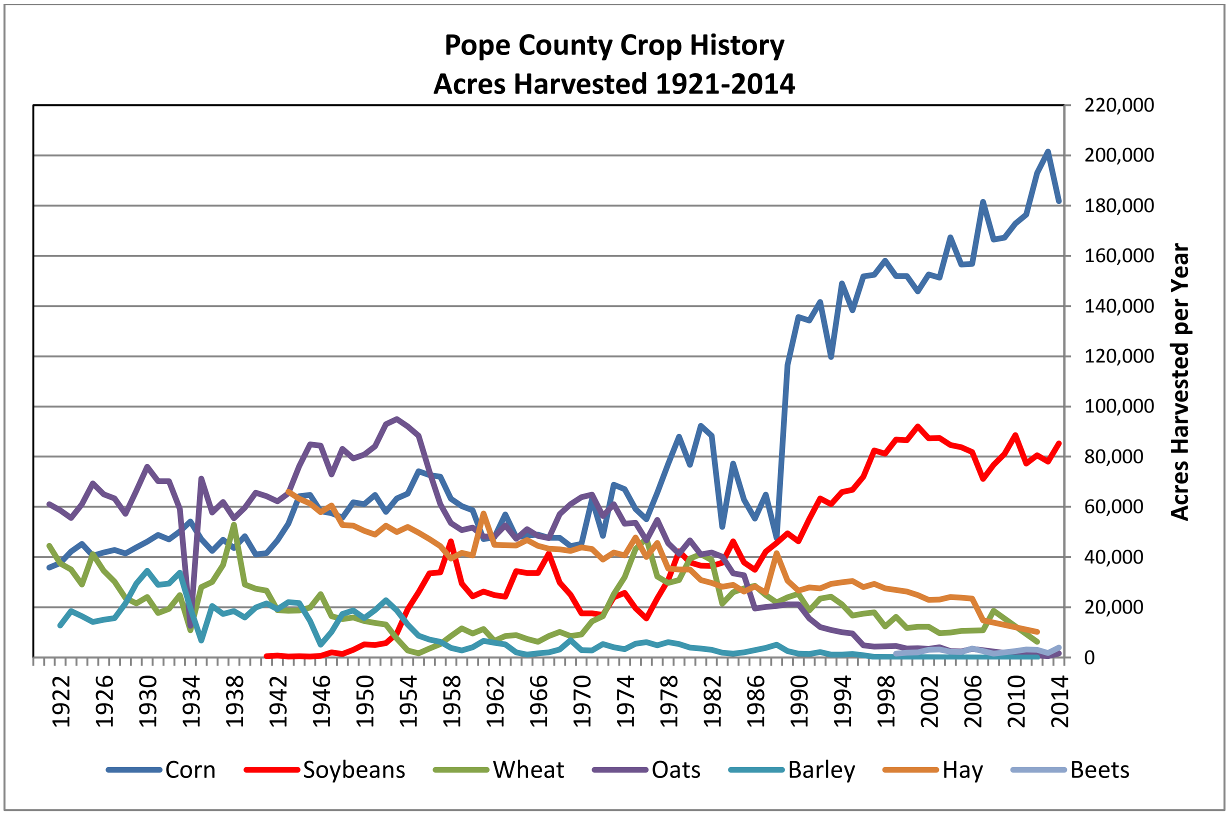

Figure 31: Pope County Crop History

As the runoff characteristics of land in row crop production are significantly different than small grain crops like alfalfa and wheat, conversion of cropping practices to predominantly row crop will change hydrologic response in the subwatersheds and the basin as a whole.

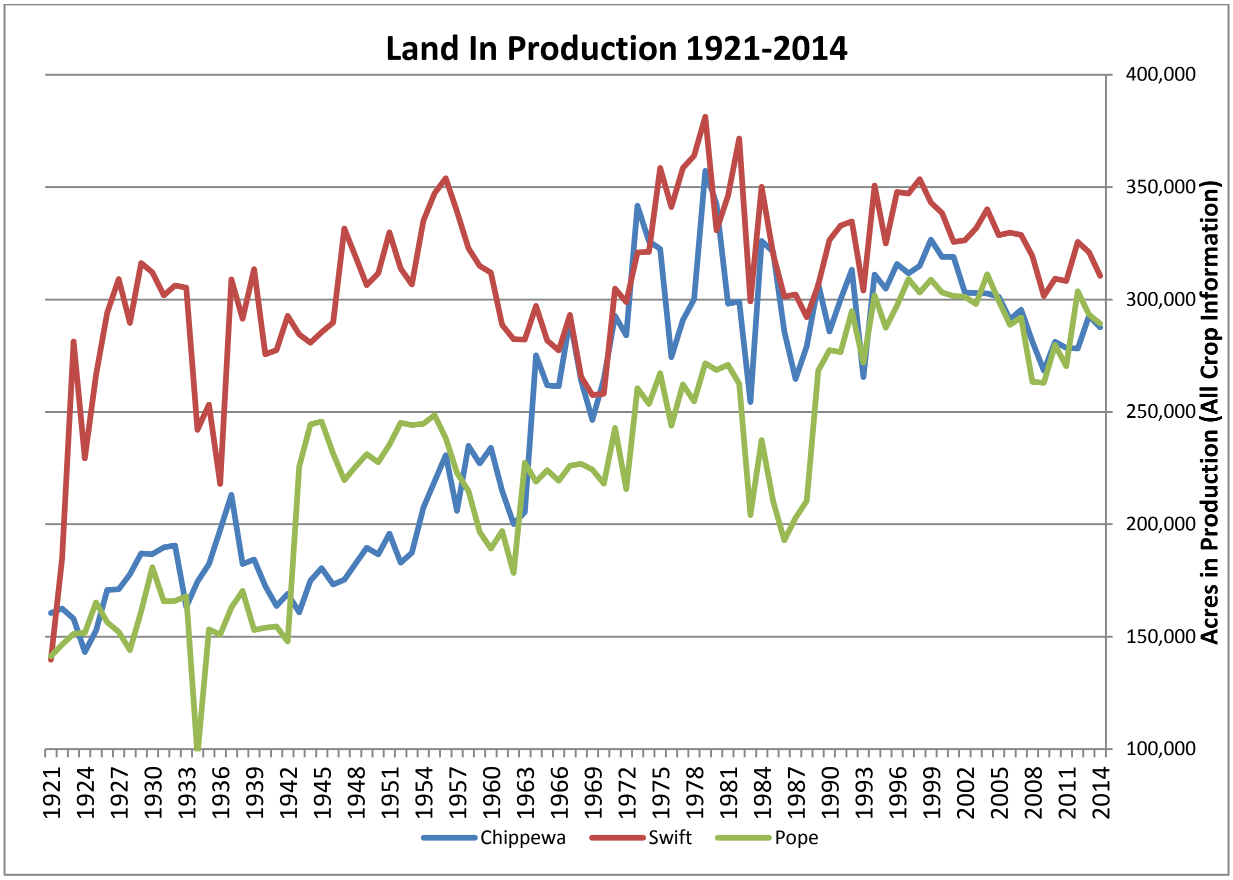

Figure 31: Land in Production by County

Observation of land use trends indicate significantly more land is placed in production in Chippewa and Pope Counties than historically noted (Figure 31), which appears to be a continuation of the trends noted between 2006 and 2014 in Figures 17-26. As ET and runoff response are significantly different for row cropped land than grassland or wetland, it is expected that as more land is placed in production, the hydrologic response from each of these subwatersheds will begin to change as well.

Ground Water Usage

Lastly, groundwater usage for the watershed was reviewed by compiling all reported permitted usage. All permit data was collected through the SWUDS. The largest appropriation/usage category in the Chippewa River Watershed is high-capacity crop irrigation (Figure 32) from groundwater resources (Figures 33 and 34). Additional future analyses will take a closer look into the relationship between withdrawals and effects to surface water resources, and long term sustainability of groundwater resources; however, these issues are not covered in this analysis.

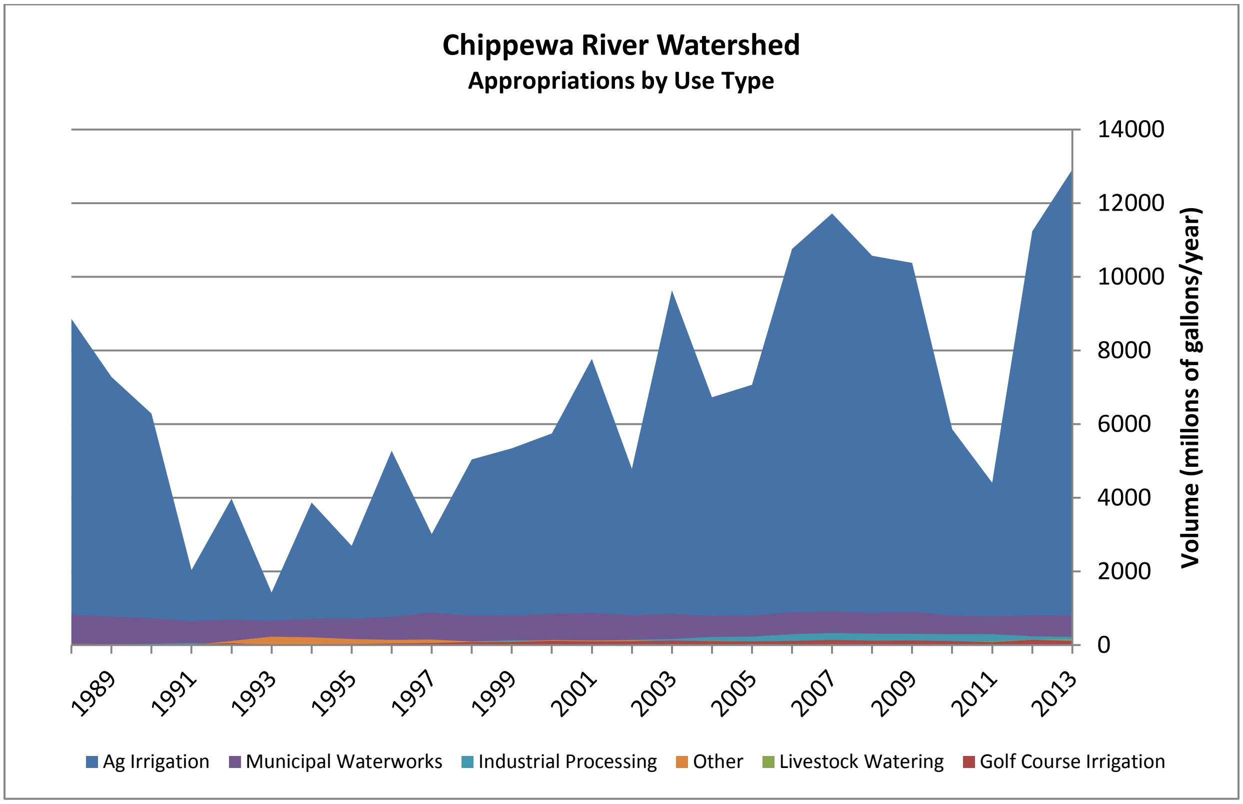

Figure 32: Appropriations Volume by Use Type

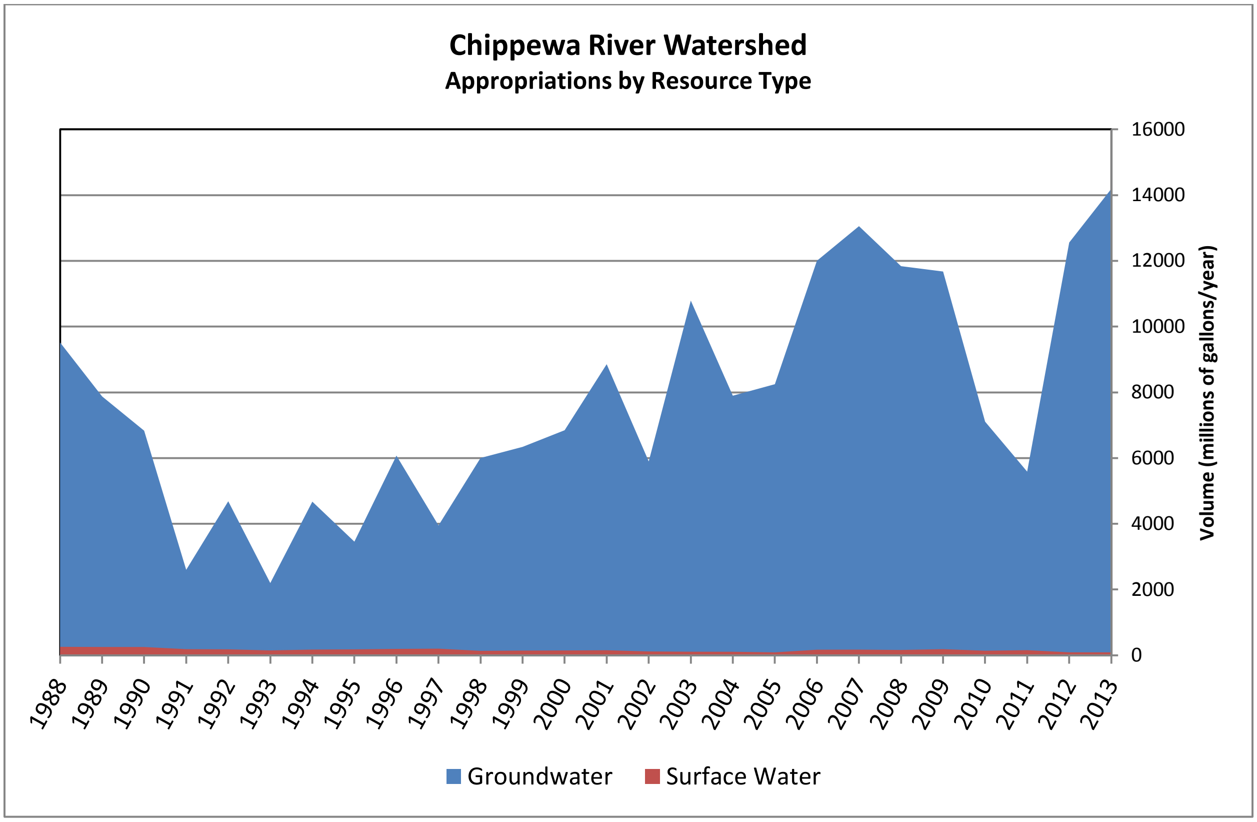

Figure 33: Appropriations by Resource

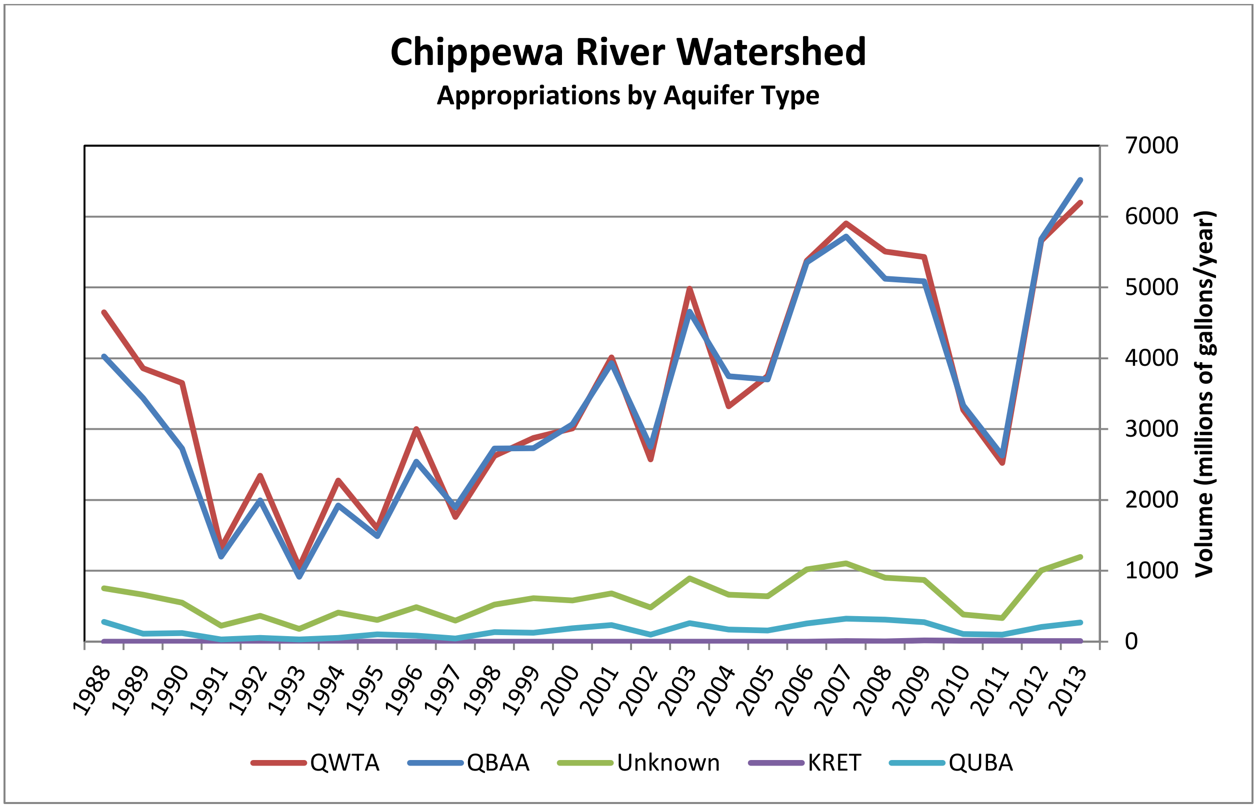

Figure 34: Appropriations by Aquifer Type

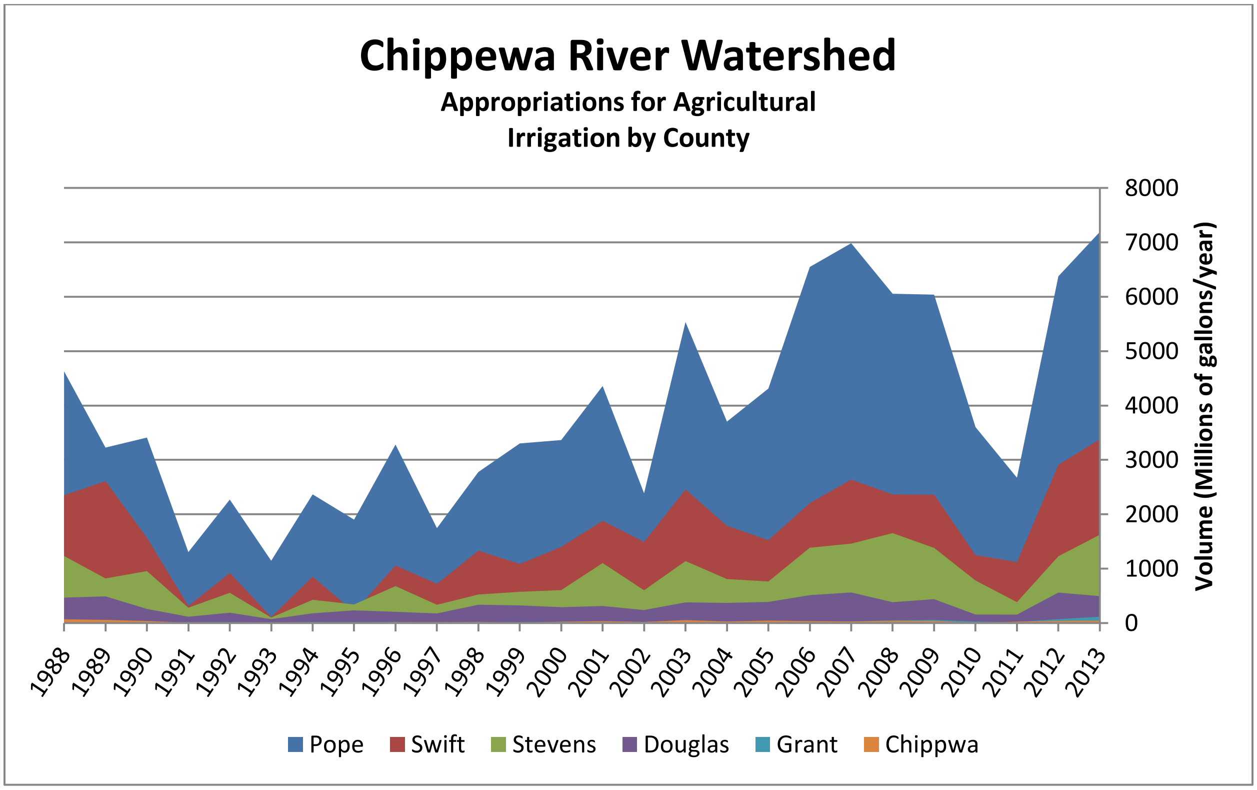

Figure 35: Appropriations for Agricultural Irrigation by County

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