Trends and change points in Wisconsin's streamflow

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ABSTRACT

Models suggest changes in climate and precipitation for Wisconsin and the upper Midwest will impact stream discharge. Of particular concern is that increased high flows will lead to disasters affecting local economies, elicit mental health problems, increase stress disorders, and impact recreational and drinking water. In order to better understand past streamflow in Wisconsin, we organized a study that evaluated trends and change points in peak and mean annual streamflow in Wisconsin's streams and rivers that had a minimum of 50 consecutive years of USGS stream gage data. Results showed that peak streamflow has decreased or remains unchanged at 96 percent of gages. Mean annual streamflow increased at 35 percent of the gages, while 65 percent of gages showed no change. Change points for peak annual flow occur in 1980 and 2005 and indicate decreased flow, whereas mean annual change points show increased flow in southern Wisconsin between 1971 and 1973 and decreased flow in northern Wisconsin streams between 1987 and 2005. Understanding past and projected streamflow is important for the future management of Wisconsin's water resources and the

associated economic and social implications of a changing hydrology.

1. INTRODUCTION

A report by the Wisconsin Initiative on Climate Change Impacts (WICCI) states that Wisconsin's mean temperature and precipitation have changed over the last 60 years (WICCI, 2011). The report forecasts that temperature will increase by as much as 4° C by 2055. The WICCI report states that hydrologic changes in Wisconsin could mean more high water events that cause flooding. In addition, the WICCI report also forecasts that the amount of days over 32° C will increase, which will increase evapotranspiration and the need for irrigation, which has the potential to lower water levels and decrease streamflow during the absence of rainfall. Anticipated changes in streamflow because of temperature and precipitation changes over the next few decades are not distinct to Wisconsin, but rather to multiple states in the upper Midwest (Kunkel et al. 1999; Easterling and Karl 2001; Hayhoe et al. 2010; Kunkel et al. 2013).

Increased peak annual flow or flooding can be caused by changes in climate, land use/land cover, and water management or water use (Peterson et al. 2013). Deciphering how the aforementioned changes impact flooding is difficult to tease out because often a change in one factor influences the other (Peterson et al. 2013). In spite of this difficulty, identifying the potential relationship among climatic metrics and water use on high water flows is important because each year flooding in the United States costs billions of dollars in disaster relief (Flood Damage in the United States 2003). For example, the 2008 June floods that impacted Wisconsin and much of the upper Midwest cost over five billion dollars in damage (National Weather Service 2009).

In addition to the economic impact of floods, numerous social impacts exist. The Associated Programme on Flood Management (2013) lists social impacts including: (1) loss of life and property; (2) loss of livelihoods; (3) decreased purchasing and production power; (4) mass migrations; (5) psychosocial effects; (6) economic growth hindrance; and

(7) political implications. Stanke et al. (2012) noted that the effect of flooding on mental health disorders (depression, anxiety, and psychological distress) in high-to-low income countries occur after the disaster. Individuals that have been forced to relocate because of a flood may not have a sense of comfort in their new home (Gruntfest 1995). These flood ramifications can have a detrimental effect in an individual's ability to succeed in basic everyday activities for a long period of time.

The two most well-known community relocations in Wisconsin that resulted from
multiple flooding events on the Kickapoo River occurred in Soldiers Grove and Gays Mills. The Soldiers Grove downtown relocation project took place during the late 1970s and into the mid-1980s. It is seen as a highly successful community-developed relocation effort. However, a survey conducted shortly after the relocation was complete found that community spirit had been lowered because of the relocation (Tobin 1992). The Village of Gays Mills Comprehensive Plan 2010-2030 discusses the implementation of a resident and business relocation plan that has been, in part, prompted by recent large scale flooding events in 2007 and 2008. Recognizing the societal impacts of relocation, the plan calls for a preservation of the small town atmosphere through a connected community.

The increase in heavy precipitation expected over the next few decades in Wisconsin increases human health risk (Patz et al. 2008; WICCI 2011). The most obvious direct health impact from flooding is death, albeit, not common. Heavy precipitation and associated flooding provides an increased risk of waterborne disease, especially to recreational water users (Patz et al., 2008). In order to protect individual's health, stormwater and sewage infrastructure needs to be upgraded to accommodate increased water amounts (WICCI 2011).

Numerous models have forecasted major changes in climate for Wisconsin that would have direct implications on the hydrologic cycle. Increased magnitude and precipitation frequency is projected to increase floods in Wisconsin. Undoubtedly the effects of the flooding will have negative implications for economics, mental health, and physical health. To better understand the streamflow history of the state of Wisconsin a study was designed to investigate whether trends in peak and mean annual streamflow are occurring in Wisconsin. The ultimate objective of this research is to provide an understanding of trends and change points in Wisconsin streamflow and address societal concerns resulting from an altered surface hydrology.

Examining time-series trends in hydrological data is not a novel approach to understanding streamflow trends. In fact, trends and change points have been analyzed on many of the gages in our study (Potter 1991; Gebert and Krug 1996; Juckem et al. 2008; Villarini et al. 2011). However, our study differs because we used ecoregions as the spatial arrangement for understanding trends and change points. Ecoregions provide a broad-scale framework that allows for understanding the spatial organization of data. Variables used to delineate ecoregions are geology, climate, land use, soils, and potential natural vegetation. The variables used to construct ecoregions are known to influence hydrologic processes, such as streamflow. For example, in Minnesota precipitation has increased across the state but the streamflow response has been varied by ecoregion (Lenhart et al. 2011).

Numerous studies have investigated regional streamflow trends and their relationship to climate change (Lettenmaier et al. 1994; Changnon and Kunkel 1995; Lins and Slack 1999; Douglas et al. 2000; Groisman et al. 2001; McCabe and Wolock 2002; Milly et al. 2002; Milly et al. 2005; Niemann and Eltahir 2005; Pagano and Garen 2005; Lins and Slack 2005; Zhu and Day, 2005; Small et al., 2006; Kumar et al., 2009; Villarini et al., 2009; Villarini and Smith, 2010; Patterson et al. 2012). General consensus is that low and moderate streamflows are increasing while increases in annual peak streamflow have not been well established. The increase in low and moderate flows may be a result of increasing precipitation in the United States (Karl and Knight 1998; Kunkel 2003).

In the Upper Mississippi River and Lower Missouri River basin Olsen et al. (1999) found that increasing streamflow trends exist in peak annual streamflow. In contrast, Villarini et al. (2011) examined flood frequency distribution in the upper Midwest and found that where significant differences exist they are indicative of change points and not monotonic trends. Results of both studies, however, suggest that

anthropogenic climate change has not led to increased magnitude flooding. In Minnesota, increased peak streamflow has been documented and these peak streamflows are occurring in the summer, which are attributed to more frequent heavy rainfall events (Novotny and Stefan 2007). Groisman et al. (2001) found that high streamflow during the month of peak flow in the eastern U.S. has increased and is correlated to the frequency of heavy precipitation. A study in the New England region reports that 25 of 28 long-term gages in watersheds with little human influence show increasing trends in peak annual streamflow (Collins 2009). Based on the published literature, it appears that the U.S. regional signature of peak streamflow trends is stronger than that presented on the continental scale.

2. METHODS

2.1. *Site Selection Criteria*

The purpose of this study was to analyze the most up-to-date streamflow records in the state of Wisconsin that had a minimum record of peak and mean annual streamflow of 50 consecutive years. Stream gages that were missing data (i.e., yearly peak or mean annual) were not used in the analyses. We selected 50 years of record as the framework for streamflow analyses because the timeframe is close to the 57 years of data (1950-2006) that is used to discuss climate change in Wisconsin without sacrificing the number of stream gages (WICCI 2011). In addition, a minimum of 50 years of data is suggested when investigating relationships between streamflow and climate change (Robson et al. 2000). The peak annual and mean annual streamflow metrics were selected for analysis for three reasons: (1) peak streamflow provide a flood-pulse which provides a rejuvenation to stream habitat; (2) large floods are destructive and have economic and social ramifications for individuals impacted; and (3) mean annual flow provides a baseline for average streamflow.

Sites were obtained from the USGS Statewide Streamflow database of Wisconsin (USGS Current Water Data of Wisconsin 2015). Two hundred and thirty-nine gages are listed in the Real-Time Table. Thirty-seven gages had either 50 consecutive years of peak streamflow or mean annual and mean monthly streamflow. Twenty-seven of the 37 gages were used in the study (Fig. 1). Ten gages were excluded because: (1) multiple gages duplicated streamflow trends by occurring on the same stream (i.e., Wisconsin River); and (2) they encompassed a drainage area (i.e., Mississippi River) that was not indicative of changes occurring in Wisconsin. Gages with the largest drainage area were removed if multiple gages existed on the same stream. Site characteristics used in this study are listed in Table 1.

Fig. 1. Stream gage locations in with a minimum of 50-years consecutive years of streamflow data. Regional boundaries are Level III ecoregions of Wisconsin (Omernik, 1987).

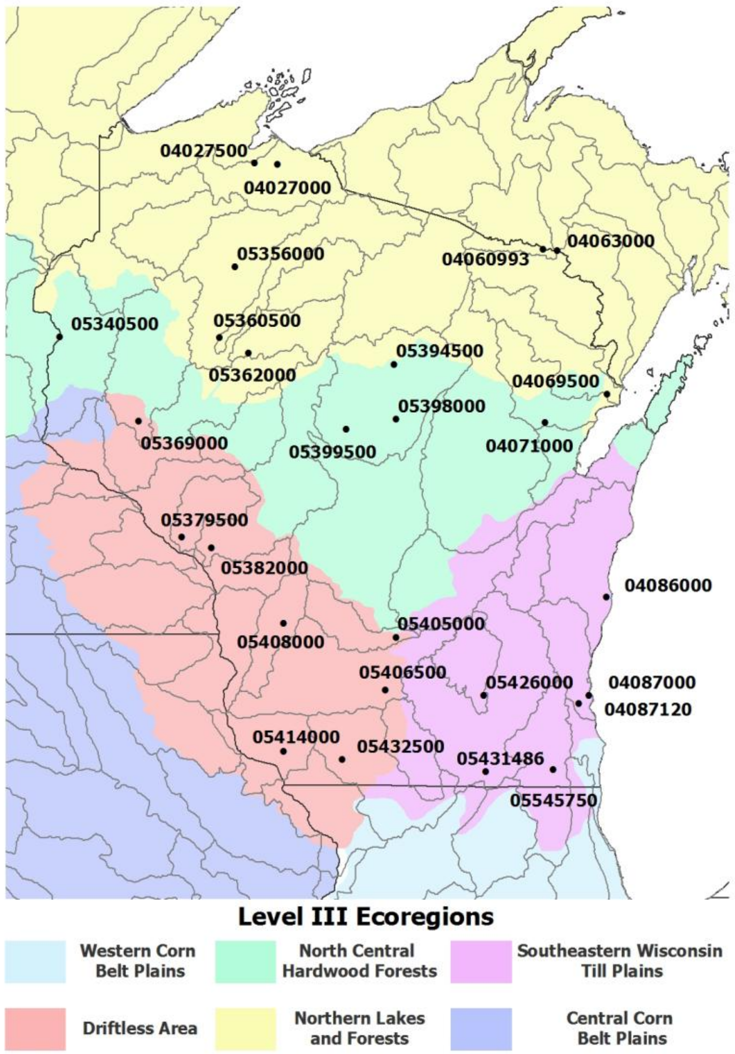


Table 1. Site characteristics of stream gauges used in this study.

USGS Number	USGS Name	Regulation/HCDN[1]	Drainage Area (km^2)	Maximum Years of Record	Period of Continuous Record
05545750	Fox River near New Munster, WI	No Listing	2,100	73	1940-2012
05432500	Pecatonica River at Darlington, WI	No Listing	707	73	1940-2012
05431486	Turtle Creek at Carvers Rock by Clinton, WI	Seasonal-Dams	515	73	1940-2012
05426000	Crawfish River at Milford, WI	Low Flow Fluctuation-Dams	1,974	81	1932-2012
05414000	Platte River near Rockville, WI	No Listing	368	78	1935-2012
05408000	Kickapoo River at La Farge, WI	HCDN-2009	689	74	1939-2012
05406500	Black Earth Creek at Black Earth, WI	No Listing	118	59	1954-2012
05405000	Baraboo River near Baraboo, WI	No Listing	1,577	70	1943-2012
05399500	Big Eau Pleine River at Stratford, WI	HCDN-2009	580	76	1937-2012
05398000	Wisconsin River at Rothschild, WI	Power Plants and Reservoirs	10,412	68	1945-2012
05394500	Prairie River near Merrill, WI	No Listing	477	73	1940-2012
05382000	Black River near Galesville, WI	Power Plant and Diversion	5,387	88	1932-2012
05379500	Trempealeau River at Dodge, WI	No Listing	1,665	78	1935-2012
05369000	Red Cedar River at Menomonie, WI	Power Plants	4,584	88	1925-2012
05362000	Jump River at Sheldon, WI	HCDN-2009	1,492	97	1916-2012
05360500	Flambeau River near Bruce, WI	Power Plants and Reservoirs	4,817	61	1952-2012
05356000	Chippewa River at Bishops Bridge Near Winter, WI	Moose Lake and Lake Chippewa	2,046	89	1923-2012
05340500	St. Croix River at St. Croix Falls, WI	Diurnal Fluctuation-Power Plants	16,162	103	1910-2012
04087120	Menomonee R. at Wauwatosa, WI	No Listing	319	51	1962-2012
04087000	Milwaukee River at Milwaukee, WI	Occasional Regulation at Dam	1,803	99	1915-2012
04086000	Sheboygan River at Sheboygan, WI	Diurnal fluctuation-Power Plants	1,083	62	1951-2012
04071000	Oconto River near Gillett, WI	No Listing	1,826	99	1914-2012
04069500	Peshtigo River at Peshtigo, WI	Diurnal Fluctuation-Power Plants	2,797	59	1954-2012
04063000	Menominee River near Florence, WI	Power Plants and Reservoirs	4,558	98	1915-2012
04060993	Brule River at US 2 near Florence, WI	Mine Pumpage Prior to Aug. `77	948	68	1945-2012
04027500	White River near Ashland, WI	Diurnal Fluctuation-Hydro Plant	780	64	1949-2012
04027000	Bad River near Odanah, WI	HCDN-2009	1,546	64	1949-2012

[1] Information taken from the "Remarks" section of the USGS gaging station website that describes characteristics of the site location. HCDN-Hydro Climate Data Network (HCDN-2009) sites taken from Lins (2012).

When investigating streamflow trends and change points, regulation associated with flow diversion, power plants, and reservoirs must be considered. Peak streamflow in regulated basins are influenced by runoff from the unregulated portion of the basin and by the water produced as runoff from the regulated portion of the basin (Asquith 2001). Mean annual streamflow in regulated basins can be influenced seasonally when reservoirs volumes fluctuate and when water is captured in one year and released the following years (Stuefer et al. 2011). Multiple databases have been constructed representing stream gages that are suitable for analyzing trends and change points in a climatic context (Wallis et al. 1991; Slack and Landweher 1992; Lins 2012). The most recent database is the USGS Hydro-Climatic Data Network and lists 743 gages, of which 10 exist in Wisconsin, however, only four met the criteria to be used in our study. In order to remove as much of the regulation as possible we used sites with the smallest drainage area and compared trends and change points by ecoregion. Assessing trends and change points by ecoregion allows for a regional perspective that could be biased by the results of regulated basins solely. Conditions of regulated streamflow of the gages used in this study are noted in Table 1.

2.2 *Ecoregions*

Level III ecoregions of the state of Wisconsin are used to help describe spatial and temporal patterns that were derived from the analyses. Variables used to comprise ecoregions are geology, climate, land use, soils, and potential natural vegetation (Omernik 1987). Six level III ecoregions exist in the state and include the Western Corn Belt Plains, Northern Lakes and Forests, North Central Hardwood Forests, Driftless Area, Southeastern Wisconsin Till Plains, and the Central Corn Belt Plains (Fig. 1). Below is a brief description about the Level III ecoregions of Wisconsin (Omernik et al. 2000).

The Western Corn Belt Plains ecoregion is primarily (75%) cropland agriculture. Corn and soybeans are the predominant crops produced. The topography is gently rolling till plains and hilly loess plains. The Northern Lakes and Forests ecoregion has nutrient poor glacial

soils. Conifers and hardwood forests dominant the vegetated landscape in this region. Streams originate from lakes and wetlands. The density of streams in the Northern Lakes and Forests ecoregions is less than ecoregions to the south. The North Central Hardwood Forests ecoregion is a transition zone ecoregion between the Northern Lakes and Forests and the agricultural ecoregions to the south. Land use and land cover consists primarily of a mosaic of forests, wetlands and lakes, and cropland agriculture. The topography is rolling till plains, lacustrine basins, outwash plains and rolling to hilly moraines. The Driftless Area ecoregion is the only ecoregion in Wisconsin without evidence of glaciation during the last two-million years. The lack of glaciation has produced an ecoregion that is more topographically expressive (i.e., hills and valleys) than the rest of the state. Livestock, dairy farming, and cropland agriculture are the dominant land uses in the Driftless Area ecoregion. Few lakes and wetlands exist in the Driftless Area and the stream density is greater than ecoregions to the east. The Southeastern Wisconsin Till Plains ecoregion represents a mosaic vegetation pattern between the hardwood forests and oak savannas of the Driftless Area ecoregion and the prairies of the Central Corn Belt Plains ecoregion to the south. Cropland is the dominant land use in the low relief Southeastern Wisconsin Till Plains ecoregion. The Central Corn Belt Plains ecoregion exists in a small section of southeast Wisconsin and is predominately agriculture with an increasing amount of land becoming urbanized.

2.3 *Statistical Analyses*

We used a trend-free pre-whitened Mann-Kendall (TFPW-MK) test to examine whether trends in peak and mean annual streamflow existed for the gages in Wisconsin that had a minimum of 50 consecutive years of data (Table 2). Because time-series data often exhibits serial correlation or lag-1 autocorrelation (AR(1)), the Mann-Kendall test needs to be pre-whitened before statistical trends can be assigned to the time-series data (von Storch 1995; Yue et al. 2002).

Table 2. Results of the TFPW Mann-Kendall test for peak annual and mean annual streamflow.

USGS Number	Peak Streamflow Trends[1]	P-value[2]	Kendall's Tau[3]	Autocor-relation[4]	Mean Annual Streamflow Trends[1]	P-value[2]	Kendall's Tau[3]	Autocor-relation[4]
05545750	O	0.175	0.110	0.014	NED			
05432500	_	0.000	-0.329	-0.032	O	0.445	0.062	0.228
05431486	O	0.068	-0.147	0.156	O	0.083	0.140	0.509
05426000	O	0.970	-0.003	0.059	+	0.001	0.249	0.215
05414000	_	0.000	-0.347	0.070	O	0.802	0.020	0.253
05408000	_	0.003	-0.238	-0.012	O	0.187	0.106	0.339
05406500	O	0.348	-0.085	0.081	+	0.000	0.331	0.396
05405000	O	0.119	-0.129	0.008	+	0.005	0.231	0.222
05399500	_	0.023	-0.180	-0.147	O	0.933	-0.007	0.176
05398000	O	0.495	0.057	0.009	O	0.657	-0.038	0.306
05394500	O	0..767	0.024	0.187	O	0.241	-0.095	0.361
05382000	O	0.080	-0.134	-0.045	O	0.397	0.065	0.180
05379500	_	0.016	-0.187	-0.097	+	0.002	0.247	0.392
05369000	O	0.528	-0.046	-0.050	+	0.045	0.147	0.452
05362000	O	0.847	-0.014	0.139	O	0.912	0.008	0.244
05360500	O	0.605	0.046	0.266	O	0.463	-0.066	0.339
05356000	O	0.121	0.112	0.125	O	0.913	0.008	0.391
05340500	+	0.019	0.157	0.185	+	0.012	0.170	0.424
04087120	O	0.088	0.167	0.280	+	0.016	0.236	0.170
04087000	O	0.978	-0.002	0.076	+	0.021	0.160	0.265
04086000	O	0.367	0.080	0.112	+	0.031	0.190	0.108
04071000	NED				O	0.154	-0.098	0.392
04069500	_	0.012	-0.228	0.068	O	0.207	-0.114	0.285
04063000	_	0.014	-0.170	0.161	O	0.123	-0.107	0.339
04060993	O	0.147	-0.122	0.086	O	0.053	-0.162	0.498
04027500	O	0.469	0.063	0.147	O	0.107	-0.140	0.478
04027000	O	0.213	-0.108	0.044	O	0.109	-0.139	0.306

Failure to perform the pre-whitened procedure may assign more statistically significant trends to the time-series data because of the serial correlation influence (von Storch 1995). A trend package in the statistical program R ('zyp' package) was used to analyze for trend and pre-whiten where lag-1 autocorrelation exists. The 'zyp' package uses the methodology described in Yue et al. (2002) as the statistical output. Wu et al. (2008) concisely summarize the methodological steps taken from Yue et al. (2002) and that are incorporated in the 'zyp' package. They are summarized as follows:

(1) Estimate the slope of the of time series using Theil-Sen Approach and detrend the series if necessary;
(2) Compute the lag-1 serial coefficients of the time series and then remove the AR(1) component from the series. This is referred to as the TFPW procedure;

(3) Blend the identified slope and residuals. The blended series keeps the trend from being influenced by the AR(1);
(4) The Mann-Kendall test is applied to the blended series and testing for significance at the $\alpha = 0.05$ level.

A single change point analysis (1963-2012) on peak and mean annual streamflow was conducted. We used the nonparametric change point model package (i.e., 'cmp' package) in R to test for a single change point in the data (Ross, forthcoming). The 'cmp' package was used because the observations are processed sequentially and not batched (Ross, forthcoming). If a change point is established in the data then no more analysis of the time series data occurs. Within the 'cmp' package a Mann-Whitney test was used to identify a single change point in peak and mean annual streamflow.

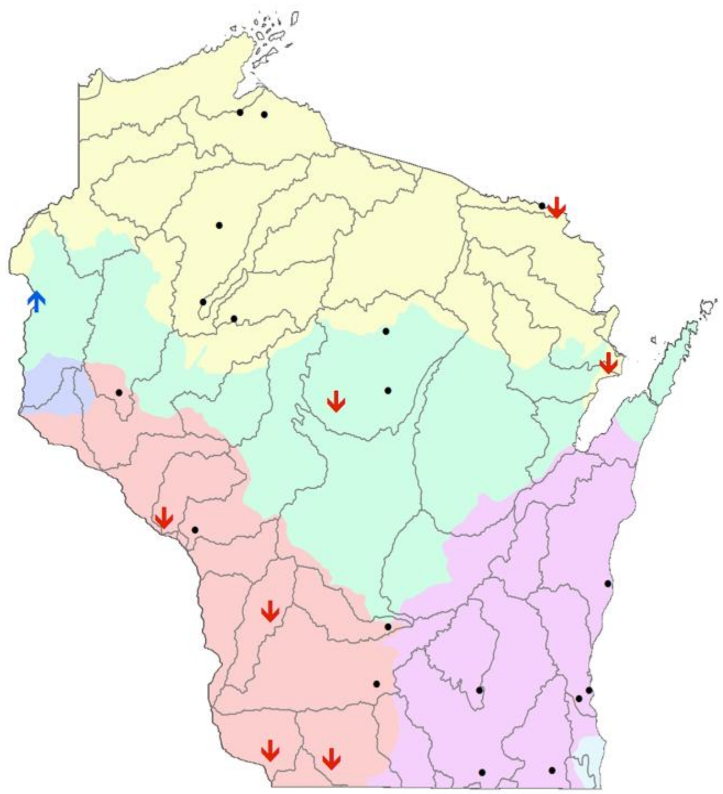
A change point in a hydrologic time series occurs when there is an abrupt change in the data (Kundzewicz and Robson 2004). We used the non-parametric Mann-Whitney test because it makes no assumptions about the normality of the data, but the assumption of independence in the data should be accepted. The assumption of independence is violated if serial correlation exists in the data (Kundzewicz and Robson 2004). We tested for AR(1) using the Durbin-Watson test statistic. A 1 percent significance test was used for identifying serial correlated data. Streamflow data that was serial correlated was not used in the analysis.

3. RESULTS AND DISCUSSION

3.1 *Peak Streamflow Trends*

Peak streamflow trends for significance were evaluated at $\alpha = 0.05$. Peak streamflow increased at one gage (4%), decreased at 7 gages (30%), and showed no change at 18 gages (66%) (Fig. 2). Four of the seven gages with decreased peak streamflow are in the Driftless Area ecoregion, while the other three gages are in the Northern Lakes and Forest ecoregion and the North Central Hardwood Forests ecoregion. The only stream gage that showed an increase in peak streamflow was in the North Central Hardwood Forests ecoregion.

Fig. 2. Peak streamflow trends in Wisconsin. Blue (up arrow) represents single gage that has increased streamflow, while red (down) arrows represent gages that have decreased streamflow. The solid black dot represents no statistical difference in peak streamflow.



The peak streamflow trend results calculated for Wisconsin are similar to other reported studies in the United States. Previous studies report that increased peak streamflow trends are less prevalent across the United States than increased minimum and median streamflow (Lins and Slack 1999; Douglas et al. 2000; McCabe and Wolock 2002; Lins and Slack 2005; Small et al. 2006; Villarini and Smith 2010). While increasing trends in peak streamflow are limited in Wisconsin, a change in climate resulting in greater floods is a major concern (WICCI, 2011).

The 2011 WICCI report states that climate change is expected to increase the magnitude and frequency of precipitation events that would lead to higher peak streamflows (i.e., magnitude) in Wisconsin streams and rivers. Higher peak streamflows are expected to occur in watersheds that flood in late winter or early spring (WICCI, 2011). More intense storms are likely in the spring when agricultural fields are bare, which will promote overland flow and increased streamflow. Precipitation patterns from 1950-2006 were compared for the state of Wisconsin (Kucharik et al. 2010; WICCI 2011). The results of these studies are that mean annual precipitation has increased 50-100 mm in the central and southern portions of the state and decreased in the far north by 20-60 mm since 1950.

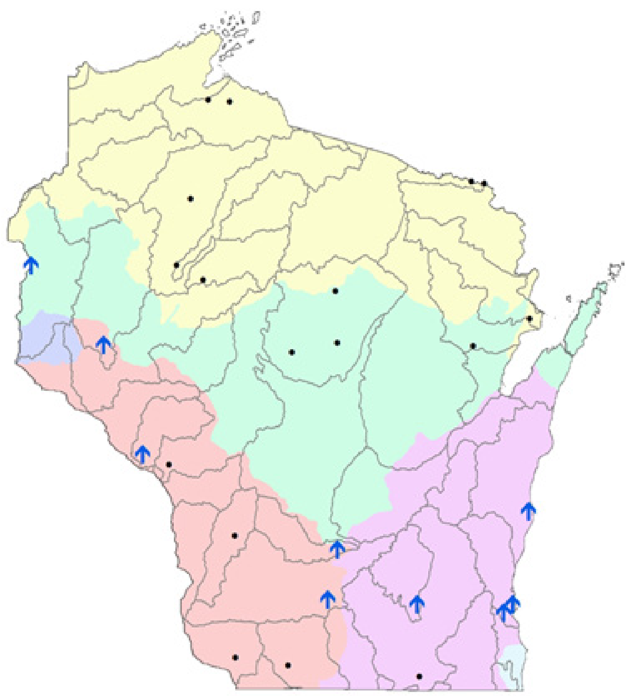
Peak streamflow in the Driftless Area decreased at 50 percent of its gages even with increases in mean annual precipitation, which suggests that mean annual precipitation does not influence peak streamflow. Gebert and Krug (1996) examined streamflow trends on six gages in the Driftless Area and found results similar to ours. Possible reasons for decreased peak flow are changes in agricultural practices that increased water infiltration into the soil and decreased overland flow to streams (Potter 1991; Krug 1996; Gebert and Krug 1996). Prior to conservation measures applied to the highly dissected watersheds of the Driftless Area, high gradient slopes were farmed which left the soil more susceptible to soil erosion and runoff, which would have increased peak annual flows within the region. A gage on the Menominee River and Peshtigo River in the Northern Lake and Forests show peak streamflow decreasing. Precipitation in the north-central part of Wisconsin decreased by 20-60 mm per year since 1950 or has remained relatively constant (Kucharik et al. 2010).

The St. Croix River at St. Croix Falls, Wisconsin was the only gage where peak streamflow increased. The gage on the St. Croix receives water from a much larger drainage area than the rest of the gages used in this study (Table 1). Sixty percent of the basin is in Wisconsin and 40 percent is in Minnesota. Much of the watershed draining the St. Croix has witnessed a decrease in mean annual precipitation. One reason that may have led to the increase in peak streamflow at the St. Croix gage includes an increase in suburban development in the lower portion of the watershed. The St. Croix River Watershed Conservation Priorities Report of 2006 states that an increase in impervious features is impacting the natural flow hydrology of the landscape.

3.2 *Mean Annual Streamflow Trends*

Mean annual streamflow trends for significance were evaluated at α = 0.05. Across Wisconsin mean annual streamflow increased at nine gages (35%) and decreased and showed no change at the remaining 17 gages (65%) (Fig. 3). A distinct spatial pattern emerged when the gages were mapped (Fig. 3). Most gages where mean annual streamflow increased are located in the southern part of Wisconsin, which are predominantly located in the Driftless Area and Southeastern Wisconsin Till Plains ecoregions. The spatial pattern described for increases in mean annual streamflow mimic the changes in precipitation outlined by the WICCI report (2011).

Fig 3. Mean annual streamflow trends. Blue (up arrow) represents gages that have increased streamflow. Increasing trends exist primarily in the Driftless Area and Southeastern Wisconsin Till Plains ecoregions. The solid black dot represents no statistical difference in streamflow.



While areas of increased precipitation in Wisconsin correlate well with increased mean annual streamflow, additional factors may have impacted streamflow trends in southern Wisconsin over the last 50 years. Changes in agricultural land management could have increased mean annual streamflow. The change in agricultural practices in the mid-1930s in southern Wisconsin ecoregions resulted in decreased soil erosion and increased infiltration, which decreased flood peaks and increased mean annual streamflow (Gebert and Krug 1996; Knox 2001; Juckem et al. 2008). Studies in Iowa and the Mississippi River basin report that annual base flow, annual minimum flow, annual minimum flow percentage, and annual discharge have increased at many Midwestern gages during the second half of the 20th century (Schilling and Libra 2003; Zhang and Schilling 2006). They attribute this change to improved conservation practices, greater artificial drainage, increased row crop production, and channel incision.

Precipitation in much of the Northern Lakes and Forests ecoregion has decreased over the last 50 years. Watras et al. (2014) reported that unusually low water levels have been observed in northern Wisconsin lakes over the last decade (i.e., 1990-2012). The decreased precipitation has not led to a statistically significant decrease in mean annual discharge over the last 50 years. Mean annual streamflow, however, decreased to record low levels over the last decade at numerous gages in the Northern Lakes and Forests ecoregions. If long-term dry periods continue in Northern Wisconsin over the next few decades the ecological health of aquatic systems in northern Wisconsin could be impaired.

3.3 *Change Point Analysis*

Change points were established statistically using a significance value of α = 0.05. Three gages showed a change point in peak annual streamflow (Table 3). The peak streamflow change of all three gages indicated a decrease in flow (Table 3). Two of the gages were located on the Menominee River and the Peshtigo River in the Northern Lakes and Forest ecoregion (Fig. 4). Change points for the two rivers were identified in 2005. The other change point that occurred was on the Platte River near

Rockwell in 1980. The Platte River is located in the Driftless Area ecoregion. Only one change point was identified in the Driftless Area even though four statistically significant trends in peak streamflow were identified. The rivers in the Driftless Area ecoregion are not highly regulated by dams or diversions. A reason why the other three gages did not indicate change points is because they drain an area substantially larger than the Platte River and smaller basins will respond more rapidly to climatic and land use change.

Fig. 4. Change point detection representing spatial and temporal patterns in peak annual streamflow.

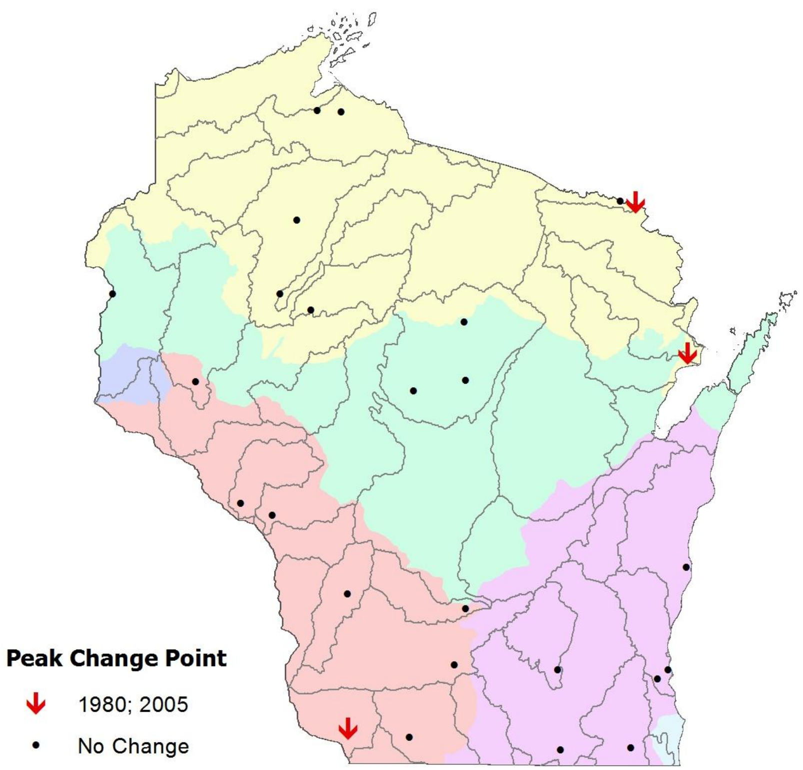
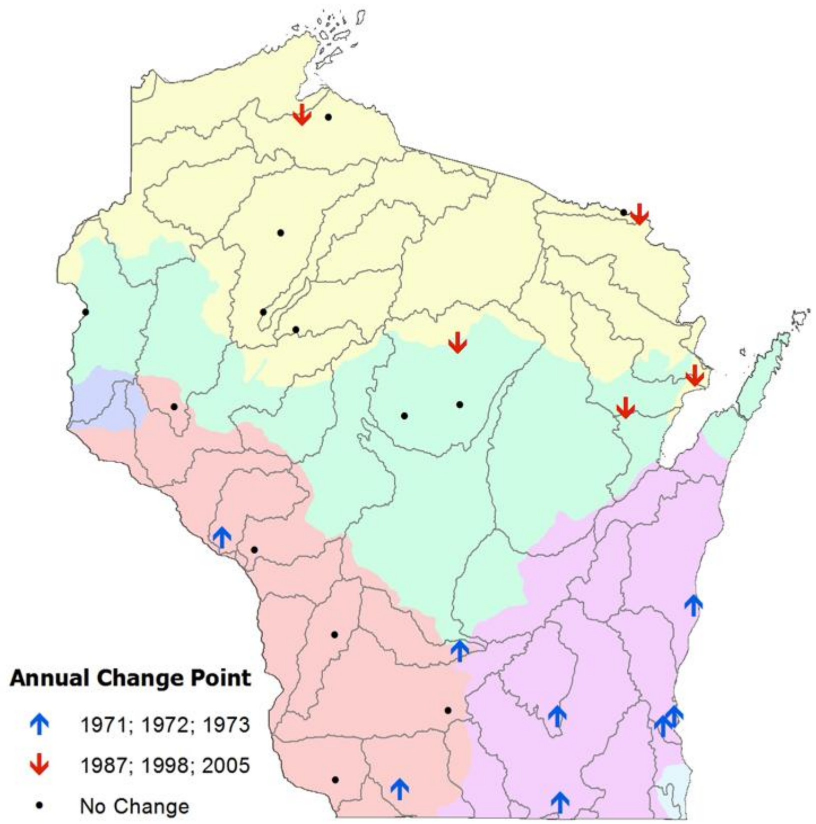


Table 3. Stream gages that indicated a change point for peak annual and mean annual streamflow.

	USGS Number	Change Point	Pre-Change Point Median (cfs)	Post-Change Point Median (cfs)	Durbin-Watson: 1% Significance
a. peak annual	04063000	2005	8,150	4,430	1.935
	04069500	2005	3,970	3,130	1.892
	05414000	1980	9,700	1,980	1.942
b. mean annual	04027500	2005	263	236	1.322
	04063000	1987	2,022	1,427	1.383
	04069500	1998	1,237	677	1.444
	04071000	1998	729	441	1.359
	04086000	1973	253	288	1.782
	04087000	1971	382	492	1.552
	04087120	1972	68	116	1.566
	05379500	1971	442	516	1.244[1]
	05394500	2005	177	126	1.606
	05405000	1972	235	430	1.712
	05426000	1973	405	520	1.499
	05432500	1973	155	214	1.717

Twelve gages showed a change point in mean annual streamflow (Table 3). Seven of the change points indicated an increased mean annual flow, while five indicated a decreased mean annual flow (Fig. 5). A distinct spatial and temporal pattern is evident when investigating mean annual streamflow change points. The seven change points that identify an increase in mean annual exist in the Southeastern Wisconsin Till Plains and the Driftless Area ecoregions. All seven of the gages identify change points between 1971 and 1973. Considering that these change points occur across two ecoregions and encompass two-years of change streamflow regulation was ruled out as a potential cause of the changes. In addition, four of the seven gages have no listing of regulation on the USGS website (Table 1). The change points detected in the southern part of the state correlate well with results by Juckem et al. (2008) which show an increase in precipitation and baseflow around 1970. Whereas, the five gages that identify a change point where mean annual streamflow is decreasing are in the Northern Lakes and Forests and the North Central Hardwood Forests. Change points for decreasing mean annual streamflow are identified much later (i.e., 1987, 1998, 2005) than those that portray increases in mean annual streamflow (Fig. 5). The decline in precipitation in northern Wisconsin over the last couple of decades has decreased mean annual streamflow. Regulation was ruled out as a contributing factor in establishing chain points in the northern Wisconsin ecoregions because regulation is primarily diurnal and change points correlate well with known decreases in precipitation over the last two decades (Table 1) (Watras et al. 2014).

Fig. 5. Change point detection representing spatial and temporal patterns in mean annual streamflow.



3.4 *Ecoregions and Streamflow*

The variables used to construct ecoregions are geology, climate, land use, soils, and potential natural vegetation (Omernik 1987). Establishing the relationship among ecoregion and streamflow hydrology is not an easy task. A few reasons for this include: (1) stream gages may record discharge data from surface waters draining watersheds of different ecoregions; (2) the number of stream gages within different ecoregions vary; (3) ecoregion boundaries extend past state boundaries; (4) streams flowing through contrasting ecoregions will vary in how they are regulated; and (5) the variables comprising ecoregions are generally homogeneous, but a certain amount of heterogeneousness exists (i.e., land use or precipitation) in ecoregions which influences the hydrologic variables that control streamflow. Understanding these limitations is critical when trying to establish ecoregions as a spatial framework to understand streamflow trends, however, ecoregions provide a broad scale spatial framework by which management strategies can be developed.

Rivers and streams are often studied in a hierarchical context (Frissell et al. 1986). The broad-scale variables that constitute ecoregions influence the morphology of the watershed, which influences the stream network and hydraulics and ultimately aquatic ecosystem function (Poff 1997; Splinter et al. 2010). Alteration of the natural flow regime of the river or stream through climatic changes or stream regulation impacts stream habitat and the community structure of the stream (Monk et al. 2007). Understanding how streams respond to changes in streamflow by ecoregions is important because ecoregions provide organization necessary for more detailed analyses of stream habitat. For example, habitat and ecological processes are impacted by changes in peak and mean annual streamflow (Armitage and Cannan 2000). Continued research is necessary to evaluate how changes in streamflow trends have impacted stream morphology and habitat among ecoregions in Wisconsin.

4. CONCLUSION

Analyzing the spatial and temporal variability of streamflow trends in Wisconsin is important considering the WICCI report states that future climate change may have a large impact on water resources in Wisconsin. A summary of the results are: (1) increased peak streamflow is not occurring in Wisconsin; (2) increased mean annual streamflow is occurring in southern Wisconsin ecoregions; and (3) change points for mean annual flow occurred between 1971 and 1973 in the Driftless Area ecoregion and between 1987 and 2005 in the Northern Lakes and Forests ecoregion and the North Central Hardwood Forest ecoregion.

Trends in peak streamflow are generally not changing in Wisconsin. The trends (increasing or decreasing) in peak streamflow that are occurring do not appear to be caused by changes in mean annual precipitation or changes in the frequency of heavy rainfall. Although peak streamflow trends are not occurring, there is no doubt that large destructive floods have occurred over the last decade in Wisconsin. The lack of a trend does not suggest that large floods will not occur in the forthcoming years and when these floods occur they cause economic hardship for individuals and communities.

Mean annual streamflow is increasing in Wisconsin's southern ecoregions (i.e., Driftless Area and the Southeastern Wisconsin Till Plains) because of a complex interaction of changed agricultural practices and land use management and increased precipitation. A decrease in precipitation in northern Wisconsin triggered change points starting in the late 1980s and continued into the mid-2000s. Although no significant trends were established for mean annual flow in the Northern Lakes and Forests ecoregion or the North Central Hardwood Forests ecoregions, change points established from decreased mean annual flow document lower stream levels than normal.

The social ramifications of a changing hydrology in Wisconsin, caused by climate change, have the ability to negatively impact individuals. Large magnitude flooding causes the economic decline of communities that can take years (or decades) to recover from. Individuals with direct impact of the flooding can suffer anxiety and a host of stress

disorders never encountered prior to the flooding. In addition, the potential of decreased water quality and an increased risk of water borne diseases are problematic as population and health related costs continue to increase.

If the projected climate models for the upper Midwest are correct then changes in high intensity precipitation and temperature are forthcoming and distinct changes to the hydrologic cycle are eminent. Future management strategies need to consider and explicitly document the social implications of flooding in order to protect the lives of the potential individuals impacted, which is often not addressed as it should be.

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