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An Assessment Of Long-Term Changes In The Characterisitcs Of Precipitation In The Upper Midwest

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AN ASSESSMENT OF LONG-TERM CHANGES IN THE CHARACTERISITCS OF PRECIPITATION IN THE UPPER MIDWEST

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For the Degree of Master of Science, Geospatial Sciences in Geography and Geology

By

Blake Lea

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AN ASSESSMENT OF LONG-TERM CHANGES IN THE CHARACTERISTICS OF PRECIPITATION IN THE UPPER MIDWEST

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ABSTRACT

As climate change progresses, many forecasts for the upper Midwest predict increases in annual precipitation, but with a shift in seasonal patterns that will leave the summer months drier with less frequent, higher magnitude storm events. Changes in precipitation patterns have the potential to alter the sediment budget and discharge patterns in watersheds. The purpose of this study was to determine the effects changes in frequency, magnitude, duration, and intensity of precipitation might have on streamflow and sediment budgets in the upper Midwest. This analysis was carried out using hourly precipitation data from 1948 to 2013 from 23 sites and 8 river basins in Minnesota, Wisconsin, North Dakota, South Dakota, Nebraska, and Iowa. The hourly precipitation data provide a high-resolution archive that is ideal for analyzing changing patterns in rainfall at multiple scales: including decadal, yearly, monthly, and individual storm event. The upper Midwest is experiencing decreasing storm durations, decreasing numbers of storm events, increasing average rainfall intensities, increasing maximum rainfall intensities, increasing amounts of rainfall per storm, and increasing average annual precipitation. These data demonstrate that significant changes in precipitation and streamflow patterns have occurred over the past 60 years. The observed changes are consistent with the predictions derived from various climate models and, as such, may lend support to forecasts of additional shifts in precipitation patterns in the coming decades. Understanding and quantifying these changes, particularly the trend of shorter more intense storms, has large implications on the sediment budget and discharge patterns of upper Midwest watersheds.

KEYWORDS: climate, precipitation, hydrology, flooding, erosion, sediment transport

This abstract is approved as to form and content

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Chairperson, Advisory Committee
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INTRODUCTION

Changes in regional climate, such as precipitation patterns, can disrupt the stability of a landscape's erosional regime (Peizhen et al. 2001) and consequently alter the hydrology and sediment budgets of streams and rivers. Groisman et al. (2001), Karl and Knight (1998), Kunkel et al. (1999), and Pryor et al., (2014) studied precipitation patterns across the upper Midwest and reported increasing amounts of total annual precipitation. Research has identified that the contiguous United States has seen a nationwide 7-10% increase in annual precipitation over the past century with the largest increases recorded during the most recent 30-year period (Groisman et al. 2001; Karl and Knight 1998). Pryor et al. (2014) even noted that some regions have seen precipitation increase by 20% over the last century. However, little research has focused on how the characteristics of precipitation are changing in concert with these increases. Determining what types of changes in precipitation patterns are occurring, and at what rate these changes are happening, provides much needed information to help us adapt to future changes in our climate.

Hourly precipitation data sources are a high-resolution archive that are ideal for analyzing changing patterns in rainfall at multiple temporal scales, including decadal, yearly, monthly, and individual storm trends. Hourly precipitation data offers information about storm intensities that is lost by aggregating over the longer time periods that are typically used for analyses correlating precipitation rates with flooding (Muschinski and Katz 2013). Flash flooding-rainfall events typically occur over short time periods and

therefore the use of higher resolution precipitation data is critical for increasing our understanding of these events (Brooks and Stensrud 2000).

One of the possible effects of increasing annual precipitation is an increase in streamflow. There is a strong link between precipitation and streamflow and it is expected that warming of the atmosphere will have major effects on flooding patterns (IPCC 2013), but the link between precipitation and flooding is complex and involves many variables. These variables include soil moisture, seasonality, changing land use (agricultural and urban), the melting rate of snow, the character of precipitation events (intensity, duration, and total precipitation), and the physical characteristics of drainage basins (Kunkel et al. 1999). Research has shown that the characteristics of precipitation are just as important as the total amount of rainfall when it comes to its effects on soil moisture and streamflow (Trenberth 2011). This indicates that observed changes in the characteristics of precipitation, even in regions that are not experiencing changes in total rainfall, could play a significant role in annual streamflow patterns.

BACKGROUND

One of the main causes of atmospheric warming is the emission of greenhouse gases that trap heat in the atmosphere, including carbon dioxide (CO_2) and methane (CH_4). Climate science predicts that if the Earth continues to warm, wet regions will continue to get wetter and dry regions will continue to get drier (Allen and Soden 2008). This is because warming of the Earth's atmosphere speeds up the hydrologic cycle leading to, among other things, an alteration in precipitation patterns (Figure 1). A warmer atmosphere can affect precipitation patterns, because warmer temperatures cause more water vapor to be absorbed into the atmosphere.

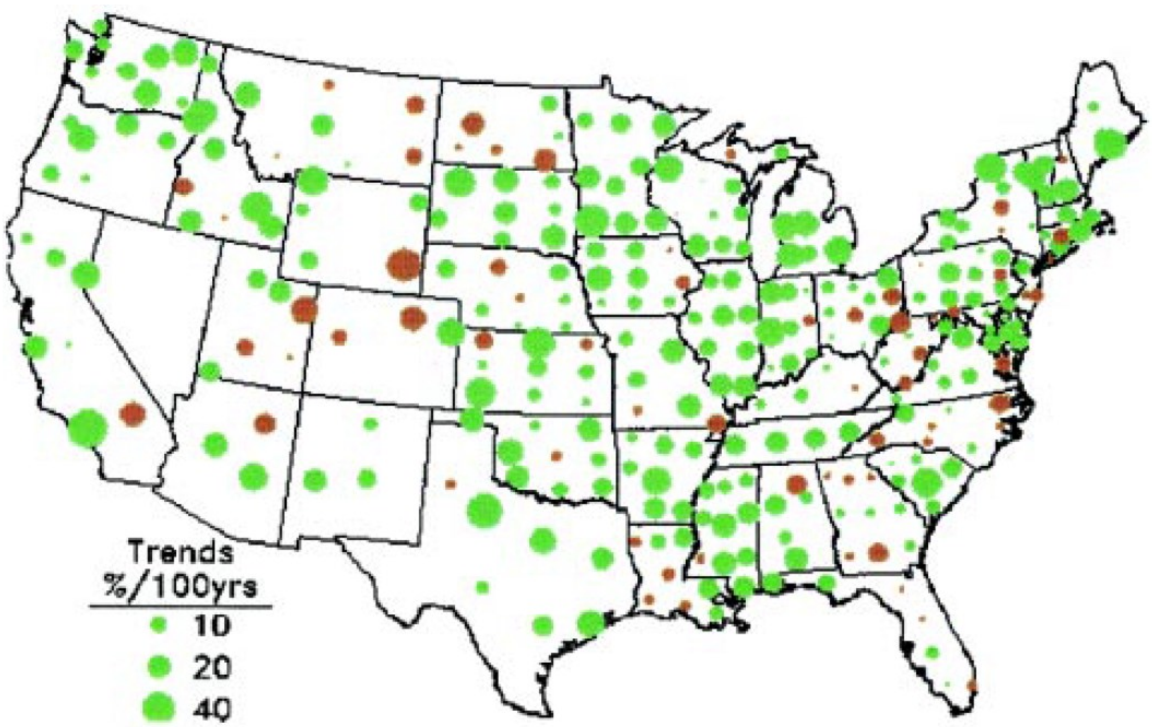

Figure 1. Annual precipitation trends (1900–98) for the contiguous United States (Groisman et al. 2001).

Changes in precipitation patterns, such as more intense rainfall, lead to increased overland flow and have the potential to alter the sediment budget in watersheds by changing the recurrence interval of flooding events and creating more opportunities to erode the landscape. More intense rainfall events cause more erosion on the landscape, because of the increased amount of surface runoff/overland flow. Surface runoff occurs when the infiltration rate of soil is greater than the rainfall rate. Rainfall events that lead to surface runoff often lead to localized flooding. The damages caused by flooding can be an expensive problem. For example, in the summer of 2008, extensive flooding in Iowa, Wisconsin, and Indiana caused total damages estimated at $15 billion (Budikova et al. 2010). Iowa was the hardest hit by this flooding and it sustained nearly two-thirds of the monetary costs (Budikova et al. 2010). Analysis of precipitation data will be a key part of developing a better understanding of the relationship between rainfall and flooding events and can help with decisions about future adaptations needed to mitigate climate change.

Climate Change

Climate in the upper Midwest is controlled largely by latitude, continental location, large scale circulation patterns, and proximity to large bodies of water, such as the Great Lakes. Short-term weather patterns are governed by the position of the polar jet stream and the movements of warm, humid air masses from the Gulf of Mexico. Understanding how short-term and long-term patterns are changing is a key aspect of producing accurate climate predictions.

Natural Factors. Four different air masses from three different source regions primarily affect the climate of the Midwest (Figure 2). The air mass types are continental

polar (NW Canada), maritime tropical (southern US/ Gulf of Mexico), continental polar (Hudson Bay/NE Canada), and maritime polar (Rocky Mountains/Pacific Northwest) (Shadbolt et al. 2006). It is also possible, but less likely, that airflow can originate from the western Atlantic Ocean and the southwestern United States (Shadbolt et al. 2006). Each of these different air masses bring with them different weather patterns: warm, cold, wet, or dry.

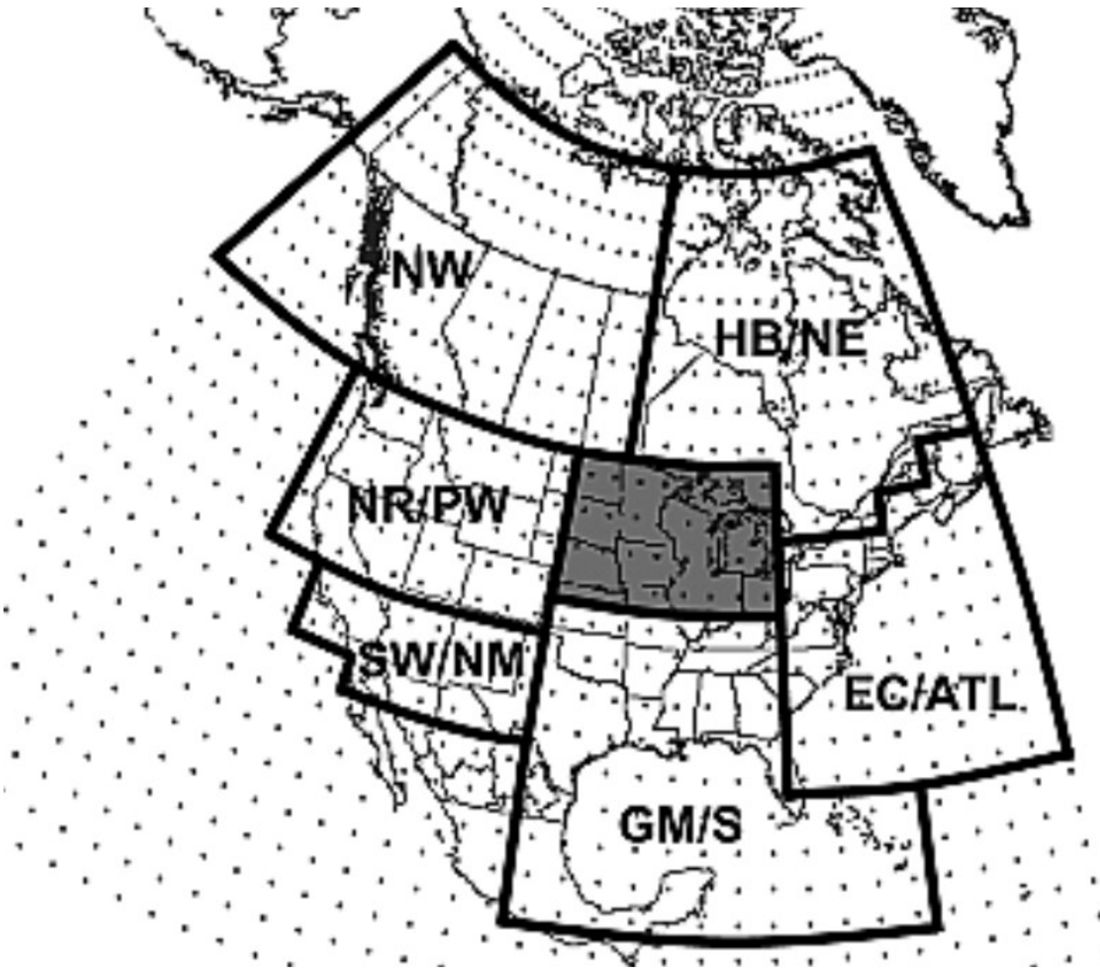

Figure 2. Map of the composite air mass source regions for the upper Midwest (Shadbolt et al. 2006).

The climate of the Midwest is also affected by atmospheric-oceanic interactions such as the El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). In the Midwest, the negative phase of ENSO (El Niño) tends to cause fewer storms and milder than average temperatures. During the positive phase of ENSO (La Niña) temperatures in the Midwest are often much above or below normal temperatures, and it tends to be wetter than normal (Andresen et al. 2012). During the positive phase of NAO the Midwest may have above average temperatures and above normal precipitation totals (Kingston et al. 2006).

The Great Lakes also have an influence on climate in the upper Midwest. This is governed by "lake effect" influences that moderate temperatures, increase cloud cover, and increase precipitation in downwind areas (Andresen et al. 2012). Temperatures in locations near the Great Lakes are increased during the winter and decreased during the summer compared to inland locations, due to the moderating effects of the lakes.

Changes in a region's albedo (the ratio of reflected radiation from the surface to incident radiation upon it) can alter regional temperatures by reflecting or absorbing more energy from the sun (Bonan 2008). Therefore, land cover that is darker in color (decreasing albedo) can increase air temperatures and land cover that is lighter in color (increasing albedo) can decrease air temperatures. Different forest types have different albedo effects on their region. Tropical rainforests are known to lower nearby temperatures by evaporative cooling despite lowering the albedo. Boreal forests are known to increase temperatures due to their low albedo. The effects of temperate forests on temperature are not well understood (Bonan 2008).

Greenhouse gas concentrations are at levels unprecedented in the past 800,000 years (IPCC 2014). The concentrations of these gases have varied greatly over the earth's history due to natural processes, with concentrations likely reaching as high as 10 times the current concentrations during parts of the Paleozoic Era (Berner 1998), but the rate of change has increased exponentially in recent decades due to human activity (IPCC 2014). The changes in natural greenhouse gas concentrations are largely driven by the carbon cycle and the amount of plant life on the planet. Concentrations of CO_2 in the atmosphere were mostly stable over the scale of human history before 1850. After 1850, anthropogenic emissions of CO_2 have increased exponentially (IPCC 2014).

Milankovitch cycles are caused by cyclical changes in eccentricity (elliptical orbit around the sun), the tilt of the axis (obliquity), and the Earth's rotation on its axis (precession). Each of these variations occur at different time scales. The Milankovitch cycles can compound their effects, or cancel each other out, to drive changes in climate (Bennett 1990). Milankovitch cycles are acknowledged to be the major factor determining the timing of ice ages over the last several million years (Berger et al. 2005). These cycles are also thought to be partially responsible for the onset of what is known as "Snowball Earth" sometime within the last billion years, during which the Earth was almost fully covered in ice (Hoffman and Schrag 2002).

Human Factors. The rate of global temperature increase has accelerated in recent decades (IPCC 2014). These trends are correlated with increased greenhouse gas concentrations in the atmosphere. The magnitude of future warming depends on the trajectory of future changes in greenhouse gas concentrations, which will largely be a function of fossil fuel combustion (Pryor et al. 2014).

As described in the IPCC (2014), combustion of fossil fuels and industrial processes contribute about 76% of the total anthropogenic greenhouse gas emissions. These greenhouse gas emissions have a long residence time in the atmosphere. Estimates suggest that 40% of the anthropogenic CO_2 emitted since 1750 has remained in the atmosphere, and the other 60% has been stored in the ocean, plant life, rocks, and soils. IPCC (2014) estimates also show that over half of the observed increases in global average surface temperatures from 1951 to 2010 can be attributed to rising greenhouse gas concentrations, with the resulting warming from these emissions ranging from 0.5°C to 1.3°C.

Anthropogenic aerosols exert a radiative effect on climate that is globally comparable to that of greenhouse gases, but opposite in effect. Their cooling influence on climate is due to their ability to scatter shortwave radiation and therefore increase the planet's albedo (Charlson et al. 1992). Aerosol emissions are mostly the result of industrial activities and are distributed unevenly around the planet, with the largest concentrations in the more highly-industrialized northern hemisphere. The concentrations of atmospheric aerosols, primarily sulfate (SO_4^{2-}), have increased exponentially since 1850 (Charlson et al. 1992).

Forests also influence climate through exchanges of energy, water, carbon dioxide, and other chemicals with the atmosphere (Bonan 2008). Deforestation affects climate by releasing the carbon stored in plants and soils, decreasing the amount of evapotranspiration in some regions, and by altering the albedo (Bala et al. 2007). The ability of forests to store large amounts of carbon and sustain the water cycle through

evapotranspiration allows for them to help mitigate climate change if managed properly (Bonan 2008).

In the midwestern United States large land areas were converted to cropland after settlement in the 1850s and the area of cropland continued to expand into the late 1900s when it reached around 80% of the total land area (Ramankutty and Foley 1999). Models have shown that the conversion from native vegetation to cropland has decreased air temperatures due to increased albedo and evapotranspiration (Bonan 2001). Increased evapotranspiration results in decreased temperatures, because larger portions of solar inputs are converted into latent heat instead of sensible heat (Stohlgren et al. 1998).

Climate Models. Much progress has been made since the introduction of early climate models in the 1960s and 1970s. As described in Bonan (2008), these first generation climate models did not represent vegetation and used a simplified "bucket" model for the hydrological cycle where excess precipitation was runoff after the soil reached its water holding capacity. The second generation of climate models, introduced in the mid-1980s, were able to model vegetation and the hydrologic cycle. The third generation of climate models, introduced in the mid-1990s, include the biochemistry of photosynthesis and can simulate the carbon cycle. Not only do the more recent climate models include more variables, but they also include improved spatial resolutions. The inclusion of more climatic variables and finer spatial resolutions means that current models are significantly more robust than previous models.

Precipitation

Warming of the earth's atmosphere related to global climate change is likely to cause fluctuations in the hydrologic cycle. The most likely consequence of changing precipitation patterns in a warming climate is a scenario where wet regions will continue to get wetter and dry regions will continue to get drier (Allen and Soden 2008). Understanding changes in the characteristics of precipitation that have already occurred can provide evidence for predictions of what types of changes we can expect in the future.

Types of Precipitation. As described in Petersen et al. (2010), there are four types of cloud forming processes that lead to precipitation events: orographic uplift, convectional lifting, frontal lifting, and radiative cooling. Orographic uplift occurs when air is forced upward into the atmosphere (e.g. mountain ranges) and cools due to decreasing pressure and temperature at higher elevations. Convectional lifting occurs when the air at the ground surface is heated and becomes lighter and warmer than the surrounding air, causing it to rise and cool below its dew point. Frontal lifting occurs when two different air masses meet and the warmer and wetter air mass is lifted above the colder and drier air mass. The last type of cloud forming process is radiative cooling. Radiative cooling occurs at night when the ground and surface air radiate heat to space. Clouds generated from radiative cooling typically remain near the surface.

Changing Precipitation. In a warming climate the water cycle is accelerated and this can lead to changes in precipitation patterns. In the contiguous United States studies have found that many regions have begun to experience different precipitation patterns and that many regions are affected differently (Groisman et al. 2001; Kunkel et al. 1999).

A warming climate leads to an acceleration of the water cycle due to increased evaporation rates and also an increased amount of water vapor the atmosphere is capable of holding. Models predict that a warmer atmosphere with increased atmospheric moisture will lead to a more intense water cycle, but it is noted that the predictions of climate models may underestimate the amplification of the extremes of precipitation due to the model's apparent underestimation of the current rate of warming (Allen and Soden 2008). The IPCC (2014) noted that there is a "medium confidence" level that anthropogenic forces are contributing to intensification of precipitation globally and a "high confidence" that precipitation has increased in the upper Midwest since 1951. Pryor et al. (2014) noted that some regions have seen precipitation increase by 20% over the last century, with much of this change driven by the intensification of the heaviest rainfalls. Pryor et al. (2014) also notes that the trend toward more intense precipitation events is projected to continue as climate change progresses. Predicting future trends for precipitation intensities is done mostly by calculating the rates of change over historical time periods. Groisman et al. (2001) note that a 7-10% increase in annual precipitation amounts is due to increasing spring, summer, and fall precipitation, and that winter precipitation is either decreasing or remaining constant in most regions. Groisman et al. (2001) also found that the largest increases in precipitation have occurred in the Southwest, Midwest, and Great Lakes regions. This is supported by the results of Trenberth et al. (2003), which found that rainfall intensities less than about the 85th percentile are decreasing in relative frequency, while heavy rains are increasing at close to the Clausius-Clapeyron rate of 7% per 1 degree Celsius of atmospheric warming. Because Pryor et al. (2014) found that much of the Midwest has warmed by 0.83 °C

(1.5 °F) from 1900 to 2010, the results from Groisman et al. (2001), Karl and Knight (1998), and Trenberth et al. (2003) are in line with what is expected.

Hourly precipitation data offers information about storm intensities that is lost by averaging over the longer time periods that are typically used for analyses correlating precipitation rates with flooding (Muschinski and Katz 2013). Flash flooding rainfall events typically occur over short time periods and, therefore, the use of higher temporal and spatial resolution precipitation data is essential (Brooks and Stensrud 2000). Examining the relationship between precipitation and flooding across multiple watersheds will create a better understanding of the combined effects of climate change, changing land use, artificial drainage, crop conversions, and other variables.

Hitchens et al. (2013) tested hourly gage-adjusted radar precipitation totals to determine the ability of radar to increase the spatial resolution of precipitation data. They found that adjusted radar precipitation totals produced improved estimates of the recurrence of extreme precipitation events because of the finer grid spacing, despite covering a shorter time period of events. For recent precipitation and flooding events, the finer grid spacing of hourly gage-adjusted radar precipitation totals could improve the accuracy of the recurrence interval for extreme events. However, for the purpose of this study adjusted radar precipitation totals do not have a long enough period of record to be useful.

Hydrology

Changing precipitation patterns can alter the hydrology of watersheds, but changes to the landscape in recent history (tile drainage, wetland removal, increased

urban areas, etc.) also alter hydrology. Understanding how changes in the characteristics of precipitation and land use are affecting the hydrological patterns in multiple watersheds can help us understand what to expect if the current patterns continue.

Flooding. The links between extreme precipitation events and flooding events are strong, but can be complicated due to the large number of environmental variables that govern how much precipitation becomes runoff. The amount of rainfall that becomes runoff varies based on soil moisture, seasonality, changing land use (agricultural and urban), the melting rate of snow, the character of precipitation events (intensity, duration, and total precipitation), and the physical characteristics of drainage basins (Kunkel et al. 1999). We know that the characteristics of precipitation are just as important as the total amount of rainfall when it come to the effects on the soil moisture and stream flow (Trenberth 2011). All of these variables are changing on multiple time scales (seasonal, yearly, decadal, etc.) and lead to limitations in the ability of hydrologists to accurately predict the responses of streams to precipitation events in the future. Kunkel et al. (1999) noted that no single characteristic of precipitation can be highly correlated with historical flooding frequencies. However, extreme flooding events have been occurring with increasing frequency since the second half of the 19^{th} century (Dasgupta et al. 2010). This is likely due to both changing precipitation patterns and changes to the landscape that alter hydrologic systems. Increased use of annual and native plants that transpire more water than row crops can help to reduce runoff and water yields in watersheds (Lenhart et al. 2011). The implementation of best management practices (BMPs) can also help to reduce runoff and water yields after precipitation events, which can reduce the peak discharge and lower the costs of the associated damages from major flooding events.

Changes to the Landscape. Drain tiles are a connected underground network of pipes used to remove excess water from poorly drained agricultural land (Figure 3). The introduction of drain tiles across large portions of agricultural land in the Midwest helps to increase agricultural production by lowering the water table, which allows proper root development for crops. Schottler et al. (2013) found that increased implementation of drain tile systems played the primary role in increased discharge in the Minnesota River basin. Schottler et al. (2013) also link the expansion of agricultural drainage systems with the increasing erosive power of rivers and the widening of river channels. Another factor is the increase in impervious land cover due to urbanization, which decreases infiltration and leads to increased connection to the natural stream network, causing increased amounts of runoff to reach streams faster than it would in the unaltered watershed (Burton and Pitt 2001). The convergence of these two behaviors and the knowledge that shorter storms can be more intense highlight the vulnerability of regions downstream of these changes to erosion.

Figure 3. A tile drainage system flowing directly into an agricultural drainage ditch. Credit: Todd Royer

STUDY AREA

The study area for this project is the upper Midwest, defined here as Wisconsin, Iowa, Minnesota, Nebraska, South Dakota, and North Dakota (Figures 4 and 5). The study area was chosen to provide detail about changes in precipitation and streamflow trends in the region surrounding southern Minnesota. Altogether, this area spans 1,124,412 km^2 (434,138 mi^2) with many different types of climates, soils, geology, and land uses. Elevations for the 23 precipitation stations in this study range from 204.8 to 1209.1 meters above sea level (672 to 3967 feet above sea level) (Table 1). The physiographic terrain (Figure 4) of the upper Midwest is generally flat. Average annual temperatures in the region can range anywhere from 0 °C to 13 °C (Figure 6). From 1900 to 2010 average air temperatures in the Midwest increased by about 0.83°C (1.5 °F) and the rate of increase has dramatically accelerated since 1980 (Pryor et al., 2014). There is a correlation between increasing temperatures in the Midwest and more intense precipitation (IPCC 2014). Along with the intensification of precipitation, much of the upper Midwest is experiencing increasing annual precipitation amounts (Figure 1). Changes in the characteristics of precipitation have to potential to alter the hydrology of river basins. Eight United States Geological Survey (USGS) stations were studied for changes in hydrologic patterns (Table 2)

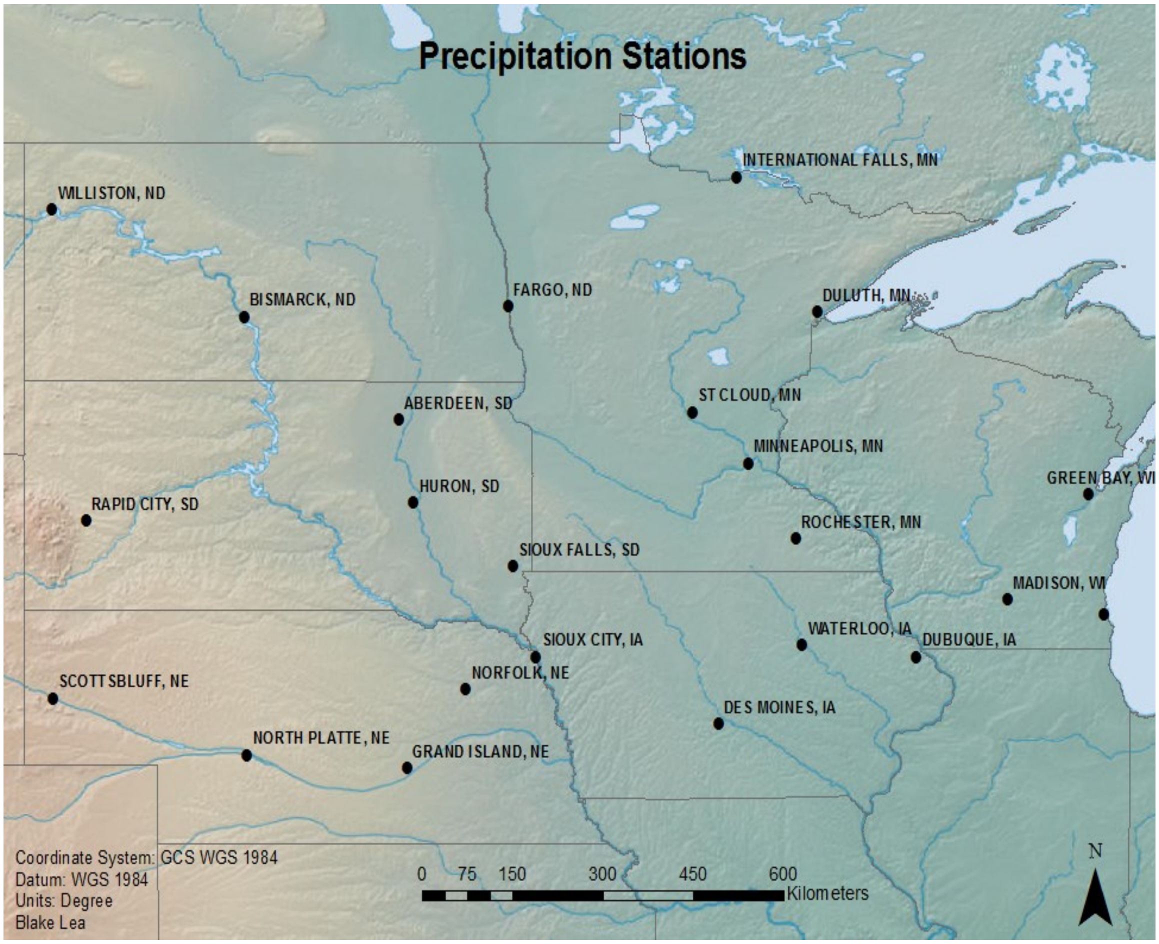

Figure 4. Map of precipitation stations with physiographic terrain

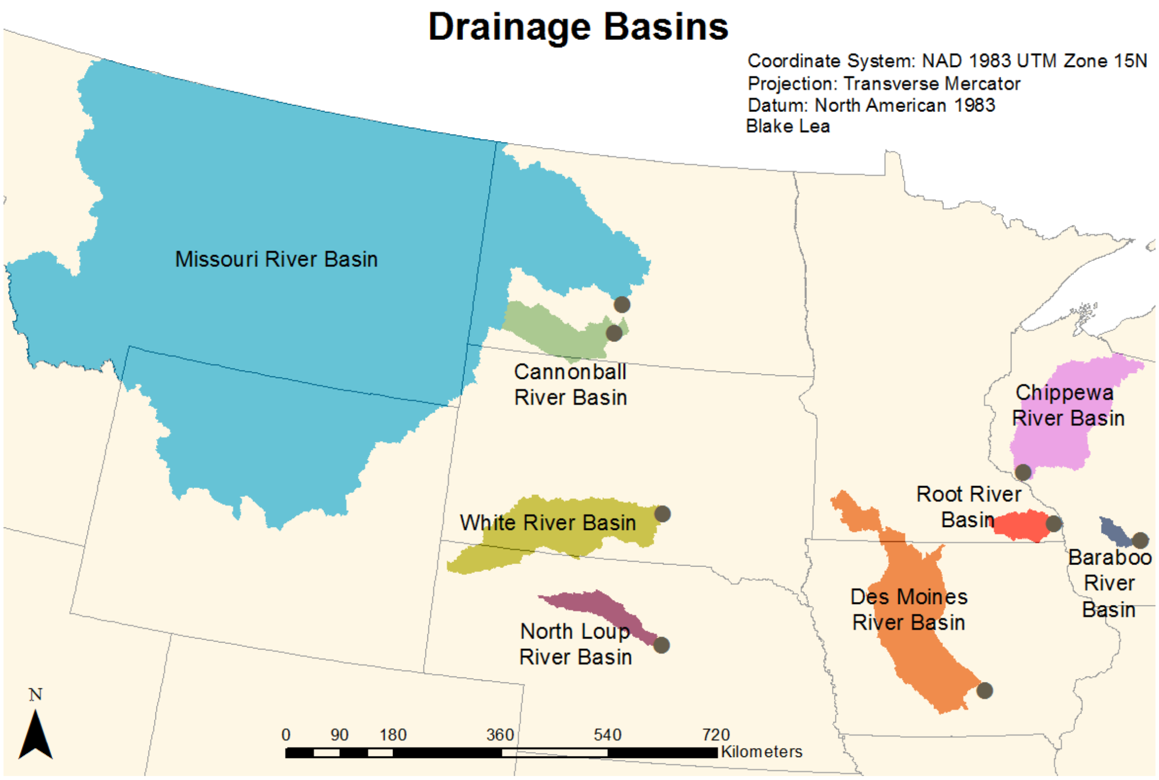

Figure 5. Map of the drainage basins and discharge stations used in this study.

Table 1. Locations, elevations, station ID, and station names for precipitation stations.

Station Name	ID	Elevation	Latitude	Longitude
Minneapolis St Paul Intl Airport MN	215435	254.2	44.9	-93.2
Duluth Intl Airport MN	212248	434.9	46.8	-92.2
International Falls Intl Airport MN	214026	359.4	48.6	-93.4
Rochester Intl Airport MN	217004	395.3	43.9	-92.5
St Cloud Regional Airport MN	217294	307.5	45.5	-94.1
Green Bay Intl Airport WI	473269	207.9	44.5	-88.1
Madison Dane Co Regional Airport WI	474961	266.1	43.1	-89.3
Milwaukee Mitchell Intl Airport WI	475479	204.8	43.0	-87.9
Des Moines Intl Airport IA	132203	285.9	41.5	-93.7
Dubuque Regional Airport IA	132367	321.9	42.4	-90.7
Sioux City Gateway Airport IA	137708	333.8	42.4	-96.4
Waterloo Municipal Airport IA	138706	264.6	42.6	-92.4
Bismarck Municipal Airport ND	320819	506.9	46.8	-100.8
Fargo Hector Intl Airport ND	322859	273.1	46.9	-96.8
Williston Sloulin Field Intl Airport ND	329425	577.9	48.2	-103.6
Aberdeen Regional Airport SD	390020	395.9	45.5	-98.4
Huron Regional Airport SD	394127	395.0	44.4	-98.2
Rapid City Regional Airport SD	396937	981.5	44.2	-103.1
Sioux Falls Foss Field SD	397667	434.0	43.6	-96.7
Grand Island Regional Airport NE	253395	561.1	41.0	-98.3
Norfolk Karl Stefan Airport NE	255995	470.6	42.0	-97.4
North Platte Regional Airport NE	256065	850.1	41.1	-100.7
Scottsbluff W B Heilig Field Airport NE	257665	1209.1	41.9	-103.6

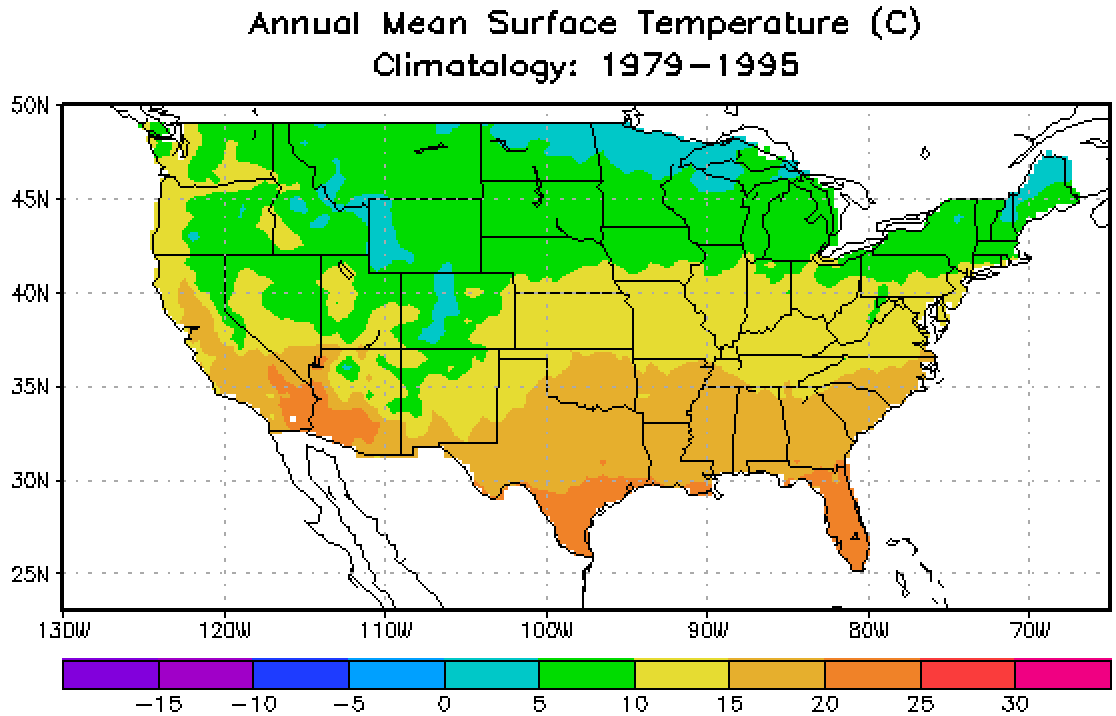

Figure 6. Average annual temperature map of the United States from NOAA.

Table 2. Locations, station ID, and station names for discharge stations.

Site	Near	USGS Gaging Station	Latitude	Longitude
Root River	Houston, Mn	05385000	43.8	-91.6
Baraboo River	Baraboo, Wi	05405000	43.5	-89.6
Chippewa River	Durand, Wi	05369500	44.6	-92.0
Des Moines River	Tracy, Ia	05488500	41.3	-92.9
Missouri River	Bismarck, Nd	06342500	46.8	-100.8
Cannonball River	Breien, Nd	06354000	46.4	-100.9
White River	Oacoma, Sd	06452000	43.7	-99.6
North Loup	Taylor, Ne	06786000	41.8	-99.4

The upper Midwest was predominantly grassland, savanna, and forest before European settlement. With the onset of westward expansion of settlement in North America around 1850 about 1.68 million km^2 of grassland/savanna/steppe and 1.4 million km^2 of forest has been cleared for agricultural use (Ramankutty and Foley 1999). In the Midwestern United States large land areas of native prairie and forest were converted to cropland after initial European settlement in the 1850s, and the conversion of prairie and forest to cropland is continuing today in some regions (Ramankutty and Foley 1999). In the upper Midwest this conversion of native vegetation and grasslands to cropland, especially soybeans, since 1940 may have played a large role in increased streamflow volumes (Zhang and Schilling 2006). The conversion of native land cover to cropland leads to a large decrease in potential evapotranspiration from May-June and an increase in potential evapotranspiration from July-August (Schottler et al. 2013). The changes in the seasonal potential evapotranspiration result in a small decrease of potential evapotranspiration annually.

Land use data from the USGS DS 240: Enhanced Historical Land-Use and Land-Cover Data Set indicates that the predominant land use across the study area is agricultural, but can be highly variable based on climate and soil type from region to region (Table 3). In the river basins included in this study, agricultural land use varied from 12.0% to 93.9% of the area and developed area varied from 0.0% to 1.4%. Changes in the amount of agricultural and developed land in a basin are commonly linked to increased runoff and flash flooding, which can lead to increasing annual discharges and discharge to precipitation ratios.

Table 3. Approximate land use percentages for the watersheds in this study.

Watershed	Drainage Area (km2)	Agricultural	Forest	Rangeland	Developed	Water	Other
Des Moines River	32,321	93.9 %	3.7 %	0.0 %	1.4 %	0.8%	0.1 %
Root River	3,238	77.6 %	21.7 %	0.0 %	0.6 %	0.1 %	0.0 %
North Loup River	6,087	12.0 %	0.0 %	87.4 %	0.0 %	0.6 %	0.0 %
Missouri River	482,774	23.4 %	15.8 %	57.3 %	0.3 %	1.2 %	2.0 %
Cannonball River	10,619	66.4 %	0.2 %	33.2 %	0.0 %	0.1 %	0.0 %
White River	25,680	23.6 %	4.2 %	67.6 %	0.1 %	0.3 %	4.3 %
Baraboo River	1,577	71.9 %	25.6 %	0.0 %	1.3 %	0.8 %	0.4 %
Chippewa River	23,444	34.6 %	60.8 %	0.0 %	0.7 %	3.9 %	0.1 %

Agricultural BMPs are designed to reduce sediment loads, reduce storm water volumes, reduce peak discharge responses to rainfall events, and increase the lag time between peak rainfall and peak discharge by keeping water on the landscape longer. Since the foundation of the Soil Conservation Service (now the NRCS) in 1935, in response to the Dust Bowl, the agricultural community began to place a higher importance on conservation practices. The use of agricultural BMPs greatly expanded in the 1970s, in response to deteriorating water quality in rivers and the Clean Water Act (CWA). However, while agricultural BMPs are effective at reducing sediment loads and increasing lag times, they only have a small impact on runoff amounts and dissolved pollutant loads (Rao et al. 2009).

Using the Köppen-Geiger climate classification maps created by Peel et al. (2007) North America can be divided into twenty-four climate zones (Figure 7). These zones are delineated based on average monthly temperature and precipitation. Peel et al. (2007) also discuss the added benefits that could come from including elevation in the classification process. The zones are broken into five dominant climate types by land area in North America, each with a separate set of subcategories, Cold (54.5%), Arid (15.3%), Temperate (13.4%), Polar (11%), and Tropical (5.9%) (Peel et al., 2007). North America is dominated by Cold climate types and this holds true for the upper Midwestern states of Minnesota, Wisconsin, Iowa, North Dakota, South Dakota, and Nebraska. The three major climate types present in the upper Midwest are Dfa - Cold (Hot Summer), Dfb - Cold (Warm Summer), and BSk - Arid (Steppe-Cold). These classifications of climate types highlight regions with similar temperature and precipitation.

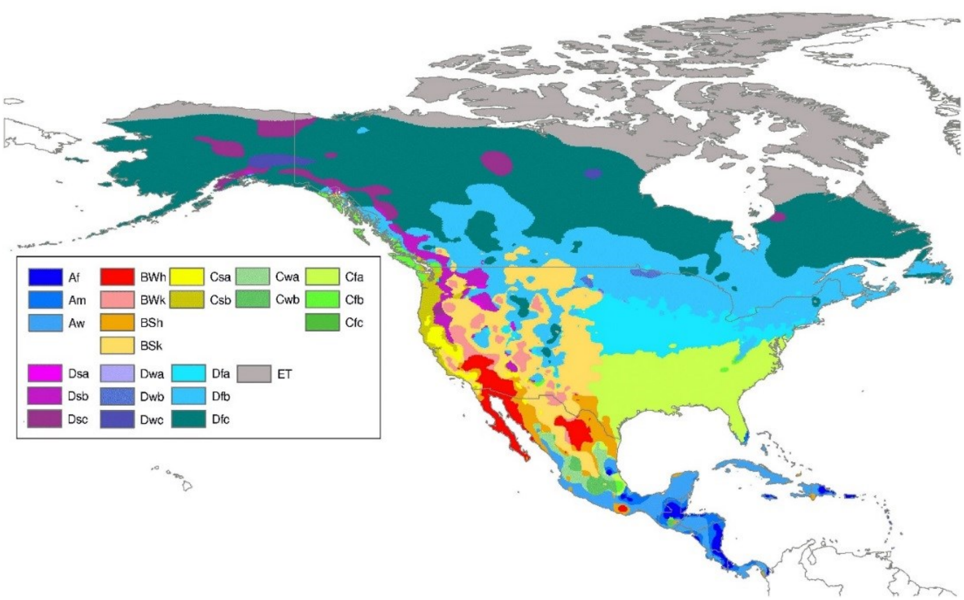

Figure 7. Köppen-Geiger climate type map of North America (Peel et al. 2007). The three major climate types present in the upper Midwest are Dfa - Cold (Hot Summer), Dfb - Cold (Warm Summer), and BSk - Arid (Steppe-Cold).

METHODS

The following methods were used to determine if significant changes in hourly precipitation data could be observed and if changes in precipitation patterns or land use were causing significant changes in streamflow patterns across the upper Midwest. To do this, hourly precipitation data and daily discharge data were collected and analyzed for locations across the region. Results were then analyzed for statistically significant trends and changes between various temporal periods. The use of hourly precipitation data requires intensive processing due to the large volume of data points. Each of the 23 hourly precipitation stations had approximately 30,000 recorded precipitation events over the period of record (around 700,000 recorded precipitation events for all sites).

Precipitation

Precipitation data were collected from the National Climatic Data Center's (NCDC's) DSI 3240 hourly precipitation database. Many of the precipitation stations in the NCDC's DSI 3240 database transitioned from the Belfort Universal rain gauge (reports in hundredths of an inch) (Figure 8) to the Fisher-Porter rain gauge (reports in tenths of an inch) starting around 1963. This change was made because the reporting technology of the Fisher-Porter rain gauge was better than that of the Belfort Universal rain gauge at the time. However, some sites at major airports record precipitation in hundredths of an inch throughout the entire period of record (1948-2013). These sites were selected for this study to ensure uniformity between the analyses.

Figure 8. Belfort Universal 5-780 precipitation gauge (Tumbusch 2003).

Precipitation data is subject to recording errors and it is important to perform QA/QC analyses on the dataset before performing trend analyses (Brooks and Stensrud 2000). The Belfort Universal precipitation gages that have been used in the past by the National Weather Service and the Federal Aviation Administration are known to have occasional mechanical problems which can lead to losing data for extended time periods. Tumbusch (2003) found that data loss for the Belfort Universal precipitation gages varied considerably from one gage to another, with two experimental locations showing losses of 57 and 37 days for a 525-day time period. Wind can also play a role in the amount of precipitation recorded at a specific site, with shielded and unshielded gages recording very different amounts of precipitation during heavy wind.

Due to some of the difficulties that come with hourly precipitation data the locations chosen for analysis were screened for time periods with missing data during the period of record. Locations with missing data for a period greater than 3 consecutive years were excluded from further analyses. There are 21 other types of measurement and quality flags that are used in the DSI 3240 dataset, however, for the sites we selected for final analyses the occurrence of these flags was uncommon. Months and years with less than 95% of the period were excluded from the trend analyses. The 95% cutoff was used because requiring a month to have no missing data periods resulted in the loss of too many months for the trend analyses. The 95% cutoff requires that a month with 30 days has no more than 36 hours of missing data and sensitivity analyses show that precipitation totals for months using the 95% cutoff had little to no difference from precipitation totals from other sources.

Precipitation data was collected from the NCDC's DSI 3240 database, the Minnesota Climatology Working Group, and the PRISM Climate Group and analyzed to ensure the accuracy of the NCDC's DSI 3240. Annual and monthly rainfall totals from these sources were compared for multiple sites that were located in close proximity to each other. This was done to ensure that no data might have been missing for a time period and not flagged.

Once the 23 precipitation stations were chosen for analysis (Appendix A), the hourly data was processed in a spreadsheet to discern the various characteristics of precipitation on an individual storm basis. First, the data were grouped into unique storm events. For the purpose of this project we have defined a unique storm event as having a minimum time gap of 3 hours between previous and subsequent precipitation. This

definition for unique storm events was chosen because frontal precipitation dominates across the upper Midwest and it seemed plausible that slow moving fronts could go 2 consecutive hours without measurable precipitation. It was also determined that if no precipitation was recorded over a 3 hour time period a significant decrease in soil moisture and increase in the infiltration capacity of the soils would occur. The sensitivity of the calculated characteristics to changes in the number of hours used for the time gap of a unique storm event were tested for 5 sites from different regions of the study area. Time gaps of 1, 2, 3, 4, 5, 10, 15, and 24 hours were used for the sensitivity analysis and the results were graphed to show the changes in the results based on the different definitions of a unique storm event (Figure 9 and Appendix B). While the changes in the time gap led to changes in the values of some of the variables, it is important to note that these changes typically did not affect which time period was experiencing more intense precipitation patterns. Therefore, it is likely that if a different time gap was chosen and this study was replicated the results would be very similar. Once the unique storm events were identified, we calculated the total precipitation for each storm (sum), event duration (hours from start of the precipitation event to the finish), maximum intensity (hour of each unique storm event with the greatest precipitation total), and average intensity (total storm precipitation divided by event duration). The results from each unique storm event were then averaged on monthly, seasonal (Dec-Feb, Mar-May, Jun-Aug, and Sep-Nov), annual, decadal, and approximately 30-year time periods (1948-1979 and 1980-2013) to examine temporal changes in the characteristics of precipitation (Table 4, Table 5, and Appendix A). The approximately 30-year time periods were used because they divided the data in half and provided a convenient way to look at changes in average values.

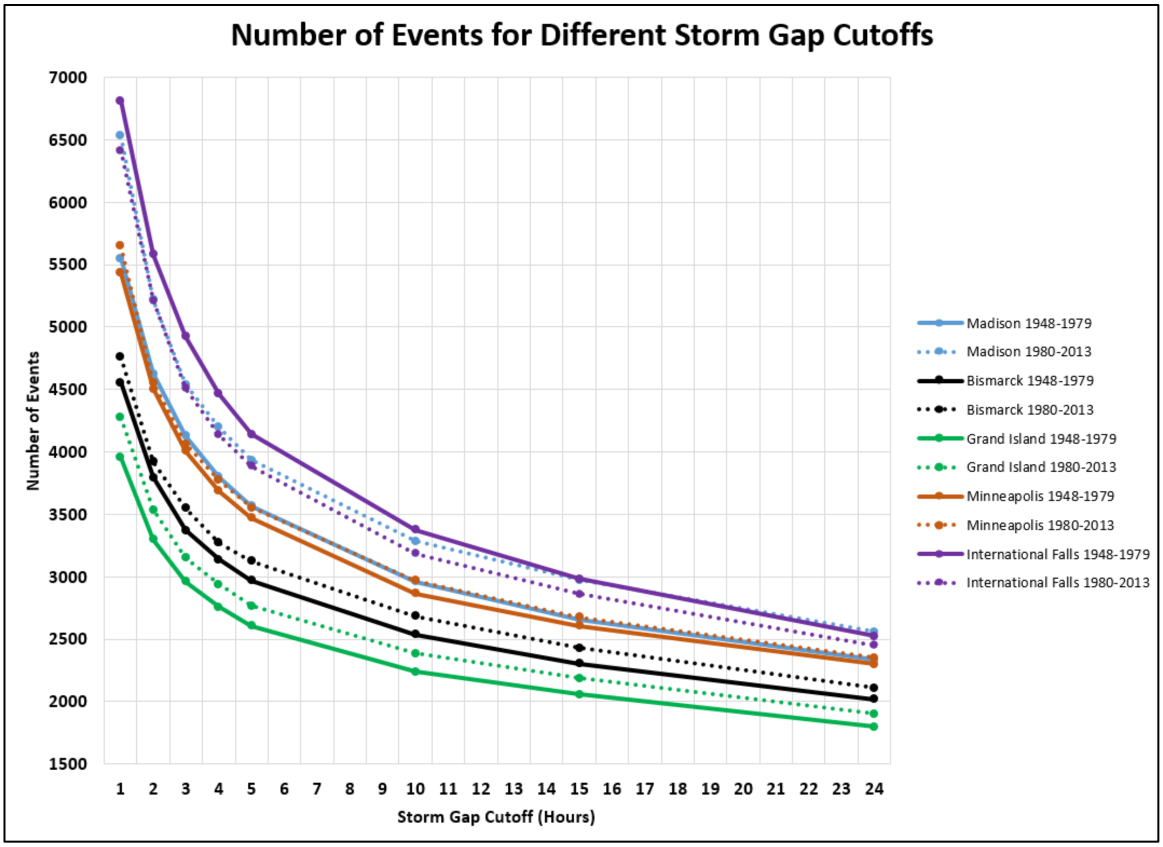

Figure 9. Sensitivity analysis example for the annual number of events.

Table 4. Precipitation characteristics from 1948-1979 for Des Moines, Iowa.

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.26	4.61	0.12	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.09	3.00	0.04	0.02
3rd quartile	0.31	6.00	0.14	0.06
Median	0.09	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.53	9.00	0.22	0.10
90th percentile	0.73	11.00	0.30	0.13
95th percentile	1.06	15.00	0.50	0.21
99th percentile	2.13	24.00	1.00	0.40
January	0.13	5.13	0.03	0.02
February	0.15	5.62	0.04	0.02
March	0.20	5.68	0.06	0.03
April	0.26	5.13	0.11	0.05
May	0.31	4.07	0.16	0.07
June	0.33	3.42	0.19	0.09
July	0.34	3.30	0.19	0.09
August	0.37	3.76	0.20	0.08
September	0.33	4.54	0.15	0.07
October	0.26	4.93	0.10	0.05
November	0.24	5.80	0.07	0.03
December	0.12	5.00	0.04	0.02
1940s	0.25	4.29	0.11	0.05
1950s	0.25	4.44	0.11	0.05
1960s	0.26	4.68	0.12	0.06
1970s	0.28	4.75	0.12	0.06

Table 5. Precipitation characteristics from 1980-2013 for Des Moines, Iowa.

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.28	4.63	0.13	0.06
1st quartile	0.02	1.00	0.02	0.01
2nd quartile	0.09	3.00	0.05	0.03
3rd quartile	0.34	6.00	0.15	0.07
Median	0.09	3.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.58	8.00	0.24	0.10
90th percentile	0.80	11.00	0.34	0.14
95th percentile	1.18	15.00	0.54	0.22
99th percentile	2.14	24.00	0.98	0.44
January	0.11	4.50	0.03	0.02
February	0.14	5.54	0.04	0.02
March	0.20	5.01	0.07	0.03
April	0.30	5.37	0.11	0.05
May	0.30	4.11	0.14	0.07
June	0.37	3.34	0.22	0.10
July	0.39	3.66	0.22	0.10
August	0.41	3.97	0.22	0.10
September	0.31	4.19	0.14	0.06
October	0.27	5.17	0.11	0.05
November	0.25	6.15	0.07	0.03
December	0.17	5.76	0.05	0.02
1980s	0.27	4.80	0.12	0.05
1990s	0.28	4.68	0.13	0.06
2000s	0.28	4.43	0.13	0.06
2010s	0.31	4.50	0.16	0.07

Exceedance probabilities of each of the characteristics of precipitation were calculated based on decadal and the approximately 30-year time periods and plotted in graphs (Figure 10, Figure 11, and Appendix C). This was done by ranking all of the events during a given time period from largest to smallest and then dividing the event's rank by the total number of events during the period, plus one. These analyses help to provide insight into possible shifts in the magnitude of precipitation between the time periods. The graphs for total rainfall per storm event, maximum hourly rainfall intensity per storm, and average hourly rainfall intensity per storm only show the top 25% of storm events and exclude the lower 75% of events from the graph. The bottom 75% of events were removed from the graphs because after the top 25% of events the lines tend to converge (Appendix C). The graphs for storm event durations contain all events, because there are noticeable differences throughout the dataset.

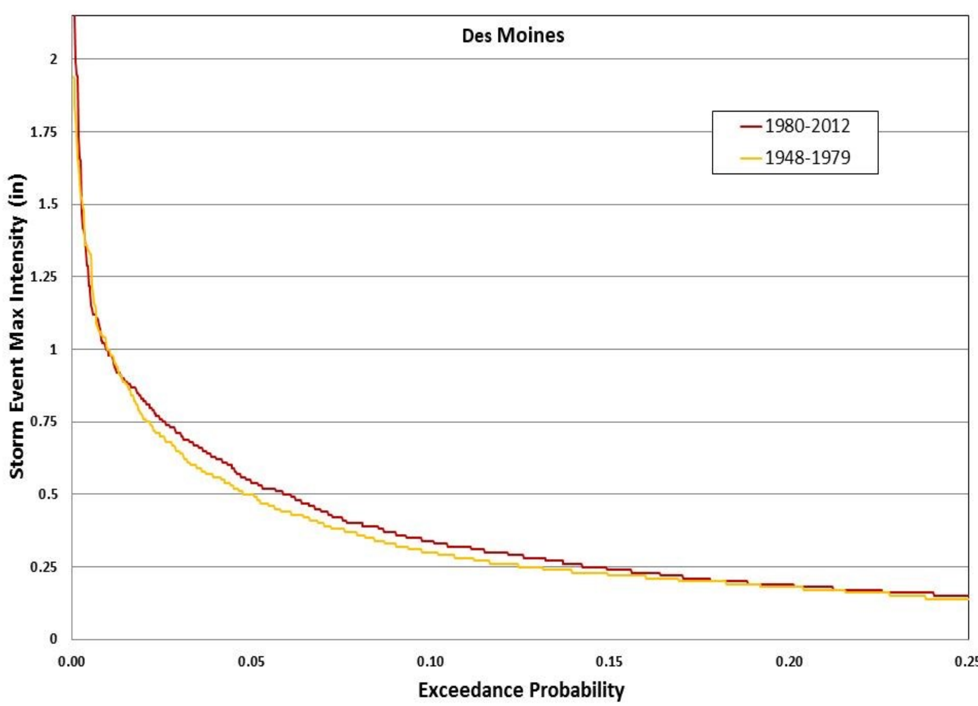

Figure 10. Exceedance probability curve for the top 25% of events from each period.

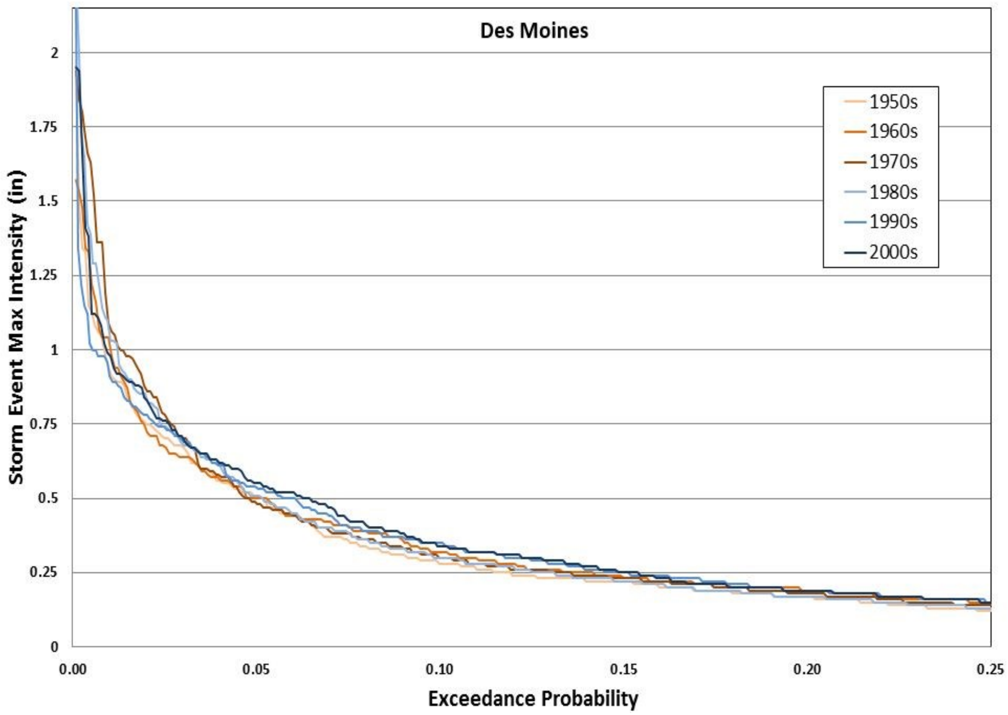

Figure 11. Exceedance probability curve for the top 25% of events from each decade.

Precipitation maps were interpolated using the ArcGIS Kriging tool. Maps were created using data from 1948-1979 and 1980-2013. Once the data were brought into ArcMAP, the Kriging tool (in the spatial analysis toolbox) was used to create a raster dataset of similar precipitation values. Next the rasters were passed through the Filter (spatial analysis) tool 4-10 times in order to smooth the boundaries. The Contour tool was used to make the zones with similar characteristics of precipitation easier to perceive. Due to large variations in the values for different locations, only the characteristics that clearly show some type of spatial pattern have final products from this analysis. The characteristics without a strong spatial pattern resulted in maps that had very convoluted patterns and provided no insight into the changes in precipitation that are occurring across the region. Maps were created for average storm durations, average precipitation

per storm, average annual precipitation, and the amount of precipitation in a 90th percentile storm for each of the two time periods (Figure 12 and Appendix D).

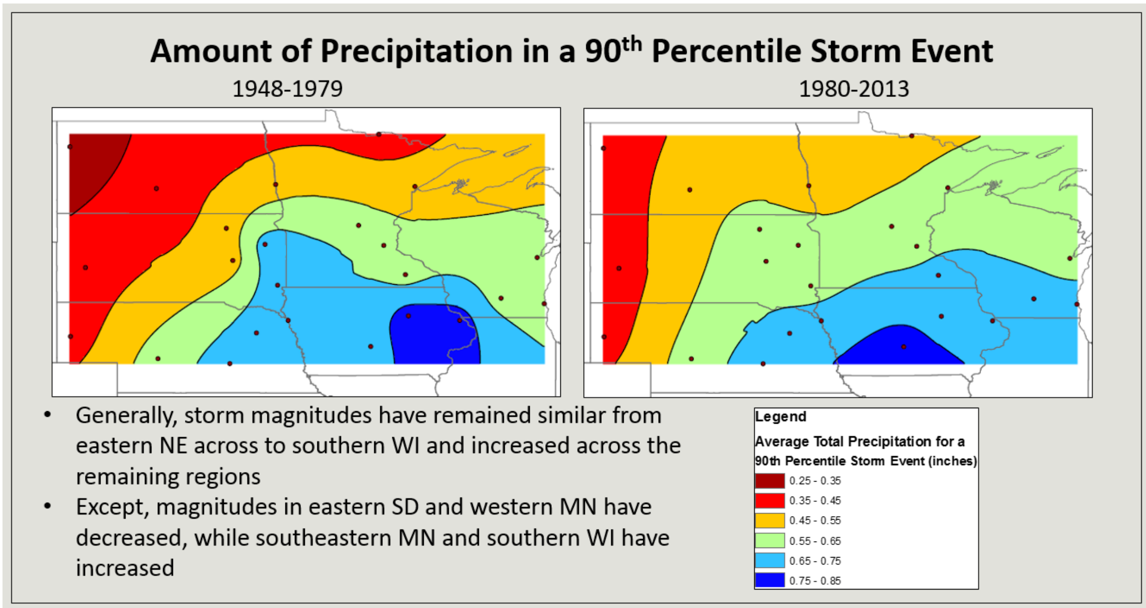

Figure 12. 90th percentile storm event map created using the ArcGIS Kriging tool.

Discharge

Daily discharge data were obtained for 8 locations from the USGS (Table 2) and the collocated monthly precipitation data from the location of the discharge site was collected from the PRISM climate group at Oregon State University. Discharge locations were selected from each of the six states where hourly precipitation data was collected. Discharge locations were screened to ensure that locations had a mostly continuous record from 1935-2013 to maintain consistency throughout the analysis. The locations selected for final analyses were also selected to represent a diverse range of land use and climate that represents the upper Midwest.

Discharge and precipitation data collected for analysis were converted from original units to the total volume of water in km^3 for monthly and yearly time scales. The average total volume of water on a yearly and monthly basis were compared for two approximately 40-year time periods (1935-1974 and 1975-2013) to see if the annual or seasonal trends of discharge changed over the period of record (Appendices E and F). Discharge data were divided into the approximately 40-year time periods, because it divided the amount of data that was readily available for all of the selected sites in half and was a convenient way to look at before and after (Figure 13, Appendix E, and Appendix F). The two 40-year time periods are similar to those used by Schottler et al. (2013). They chose these periods due to the shift from forage crops to row crop agriculture and the increasing implementation of drain tiles. Changes in the ratio of discharge volume to precipitation volume were calculated for the basins in this study. Discharge-to-precipitation ratios give us an indication of how much precipitation within a basin is conveyed to surface water. Increases in this ratio over time indicate that more precipitation is conveyed to surface water, likely due to decreasing residence time on the landscape or more intense precipitation (Figure 14 and Appendix F). The discharge and precipitation data were also plotted on decadal time scales to ascertain if the volume of water discharged exhibited any increasing or decreasing trends (Figure 15, Figure 16, and Appendix F).

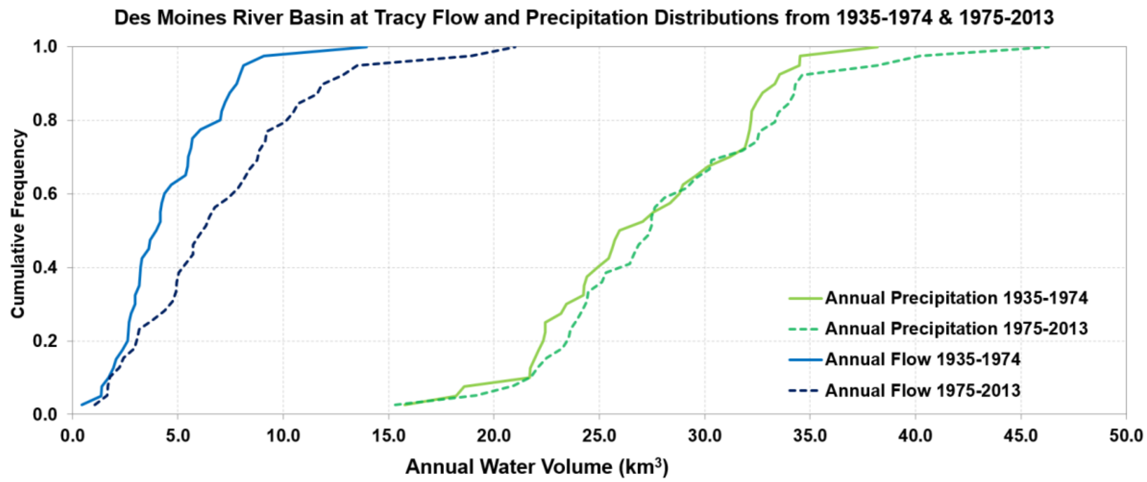

Figure 13. Cumulative frequency of annual flow and discharge volumes in the Des Moines River basin.

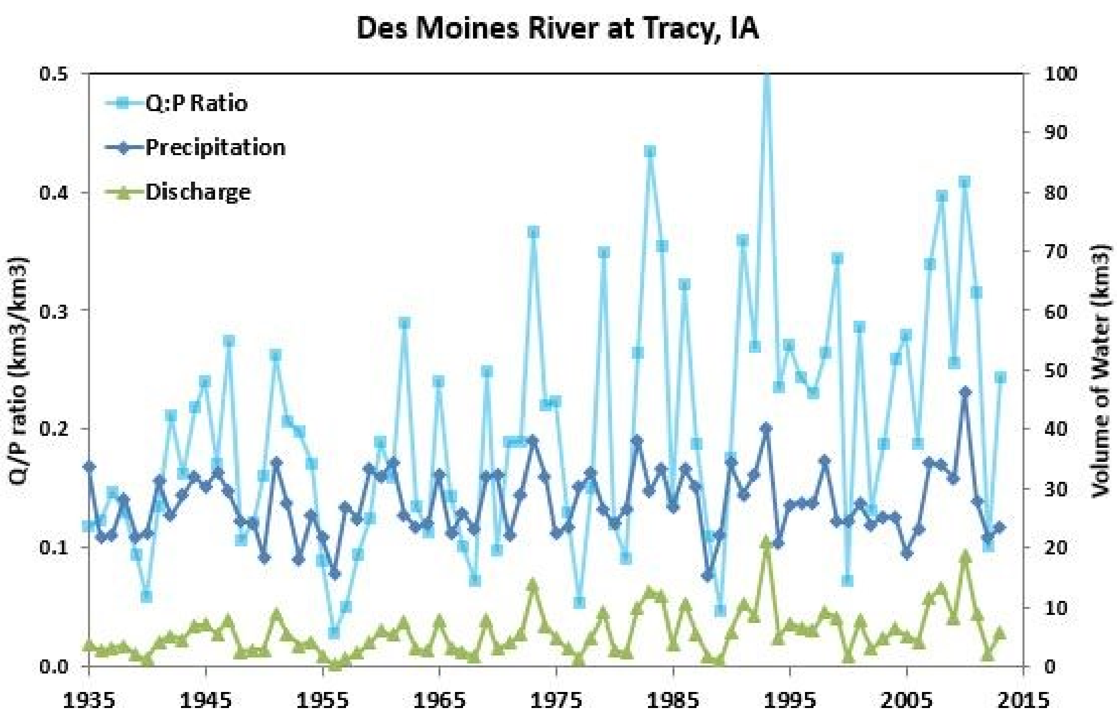

Figure 14. Annual discharge volume, precipitation volume, and discharge-to-precipitation ratios for the Des Moines River basin.

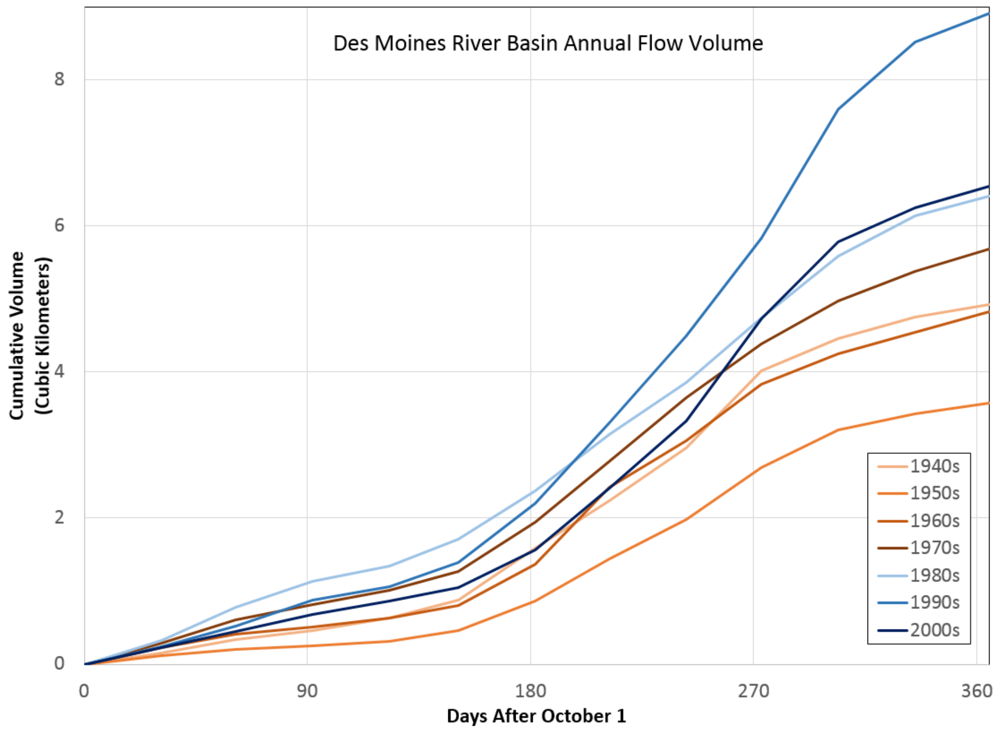

Figure 15. Decadal cumulative flow volumes for the Des Moines River basin.

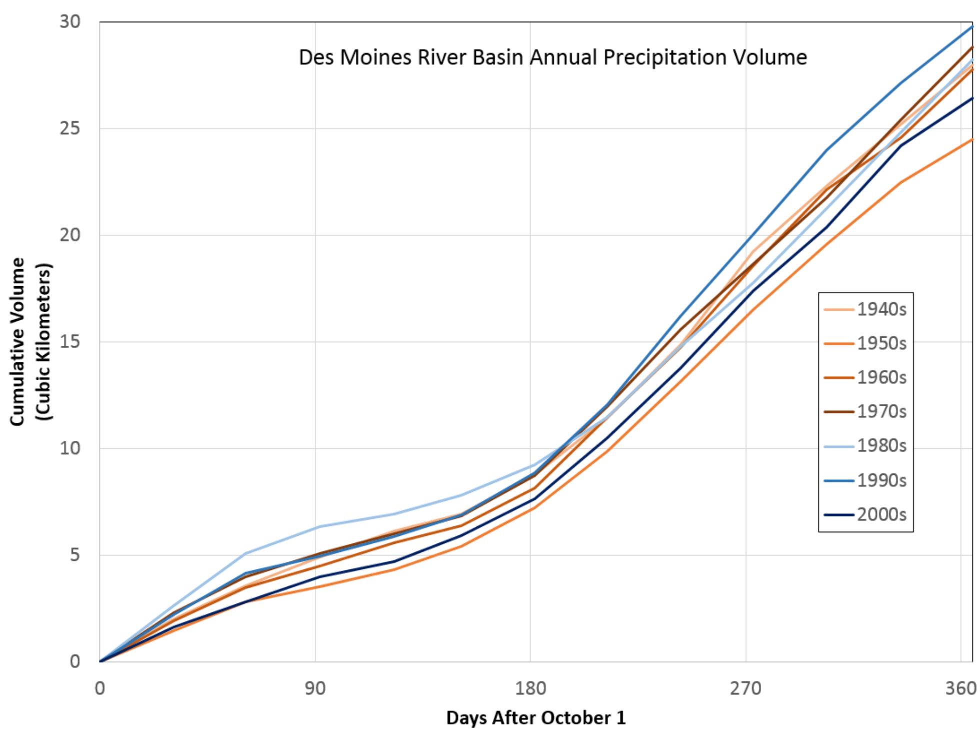

Figure 16. Decadal cumulative precipitation volumes for the Des Moines River basin.

Statistical Analyses

Once the precipitation and discharge data were processed, Kendall-Theil nonparametric regression tests were computed in Minitab (Helsel and Hirsch 2002). Two separate macros were used to carry out annual and seasonal/monthly statistics. The Kendall-Theil nonparametric regression tests were used to determine if the changes in the variables were statistically significant and to determine their rate of change over the period of record. The Kendall-Theil nonparametric regression test was used because it produces similar results to normal ordinary least squares type regression methods under ideal conditions (normal distribution of data) and better results when the dataset is not ideal due to outliers within the dataset. Helsel and Hirsch (2002) noted that only small departures from normal distribution are need to produce conditions that favor the use of the more robust Kendall-Theil nonparametric regression tests. Due to the non-normality of environmental data it was determined that this method would produce the best results.

A p-value of 0.05 is the most common cutoff chosen to determine statistical significance. A p-value of 0.05 means that given a random dataset you would obtain the observed pattern no more than 5% of the time. For this study we used a p-value of 0.1 as the cutoff for significance, because environmental data are not truly random and we did not want to miss any possible significant trends for the periods of record. Crawford and Lee (2015) used the Kendall-Theil nonparametric regression test to check for trends in ion concentrations of groundwater samples and also chose a p-value of 0.1 as their cutoff for significance. Using a p-value of 0.1 instead of 0.05 adds a few extra sites that are significant to each of the analyses (Tables 4, 6, and 7), but for most of the analyses sites were statistically significant at the 0.05 level or below. Table 7, for example, highlights

12 variables as statistically significant using the p-value of 0.1, but only 1 of those p-values (precipitation volume for the Missouri River basin upstream of Bismarck, ND) is greater than 0.01.

Table 6. Summary table of the statistical analyses of precipitation data from all locations on an annual basis.

Direction of Change	Total Annual Rainfall	Total Rainfall per Event	Storm Duration	Avg. Hourly Rainfall Intensity	Max Hourly Rainfall Intensity	Annual Event Count
Increasing (*Significant)	16 (*7)	16 (*4)	5 (*1)	13 (*5)	18 (*5)	14 (*3)
Decreasing (*Significant)	7 (*0)	7 (*2)	18 (*3)	10 (*3)	5 (*2)	9 (*2)

Table 7. Example of a monthly precipitation dataset from Rochester, MN.

	Average Total Rainfall per Storm (mm)	Total Rainfall (mm)	Duration (hr)	Max Intensity (mm/hr)	Average Intensity (mm/hr)
January	2.30	22.10	5.09	0.69	0.40
February	2.37	21.08	4.61	0.82	0.45
March	4.06	48.01	5.45	1.39	0.65
April	6.21	82.04	5.33	2.18	1.05
May	6.37	91.95	4.04	3.02	1.45
June	7.99	119.13	3.48	4.46	2.06
July	9.10	116.08	2.98	5.63	2.82
August	9.45	115.06	3.58	5.09	2.25
September	7.20	87.88	3.92	3.40	1.58
October	5.28	56.90	4.83	1.87	0.84
November	4.79	49.02	6.07	1.34	0.61
December	3.02	30.99	5.38	0.86	0.44
Annual	6.04	840.24	4.45	2.80	1.32

RESULTS AND DISCUSSION

The results and discussion of this research describe, with an emphasis on the statistical trends of the characteristics of precipitation and discharge volumes, how climatic patterns have shifted over the period of record. This section will help explain what characteristics of precipitation are driving the observed shifts in annual precipitation amounts and the primary causes of changes to the hydrologic regime for the study area.

Precipitation

The changes in the characteristics of precipitation were highly variable across the region (Tables 6-8, Figure 17, and Appendix G). The overall trend for the upper Midwest is increasing amounts of total annual rainfall (Tables 6-8 and Figure 5). The greatest increase in total rainfall amounts is occurring in the fall. The general trend is also upward for both summer and spring although there is greater spatial variation and more nuance in the pattern of change. Total annual precipitation during the winter months is primarily decreasing across the upper Midwest. These results are similar to those of Groisman et al. (2001) who found precipitation totals during the 20th century have increased significantly (7-15%) in the contiguous United States in all seasons, except winter, and also determined the number of extreme rainfall events are growing with the largest increases occurring in the Southwest, Midwest, and Great Lakes regions.

Table 8. Summary table of the statistical analyses of the characteristics of precipitation from all locations on a seasonal basis for the whole time period. Numbers in parentheses (*) indicate significant statistical trends and numbers outside of parentheses indicate the trend of sites that are not statistically significant.

	Winter	Spring	Summer	Fall
Annual Rainfall				
Increasing	5 (*1)	17 (*0)	15 (*1)	20 (*8)
Decreasing	18 (*5)	6 (*0)	8 (*1)	3 (*0)
Rainfall per Event				
Increasing	6 (*0)	13 (*4)	8 (*1)	16 (*2)
Decreasing	17 (*3)	10 (*0)	15 (*1)	7 (*1)
Max Hourly Rainfall				
Increasing	16 (*3)	20 (*6)	10 (*1)	17 (*1)
Decreasing	7 (*0)	3 (*1)	13 (*1)	5 (*2)
Average Hourly Rainfall				
Increasing	18 (*8)	19 (*4)	8 (*3)	11 (*2)
Decreasing	5 (*0)	4 (*2)	15 (*4)	12 (*3)
Storm Event Duration				
Increasing	3 (*0)	7 (*0)	12 (*2)	18 (*2)
Decreasing	20 (*7)	16 (*3)	11 (*1)	5 (*1)
Annual Number of Events				
Increasing	5 (*1)	12 (*0)	15 (*2)	19 (*7)
Decreasing	18 (*8)	11 (*1)	8 (*1)	3 (*0)

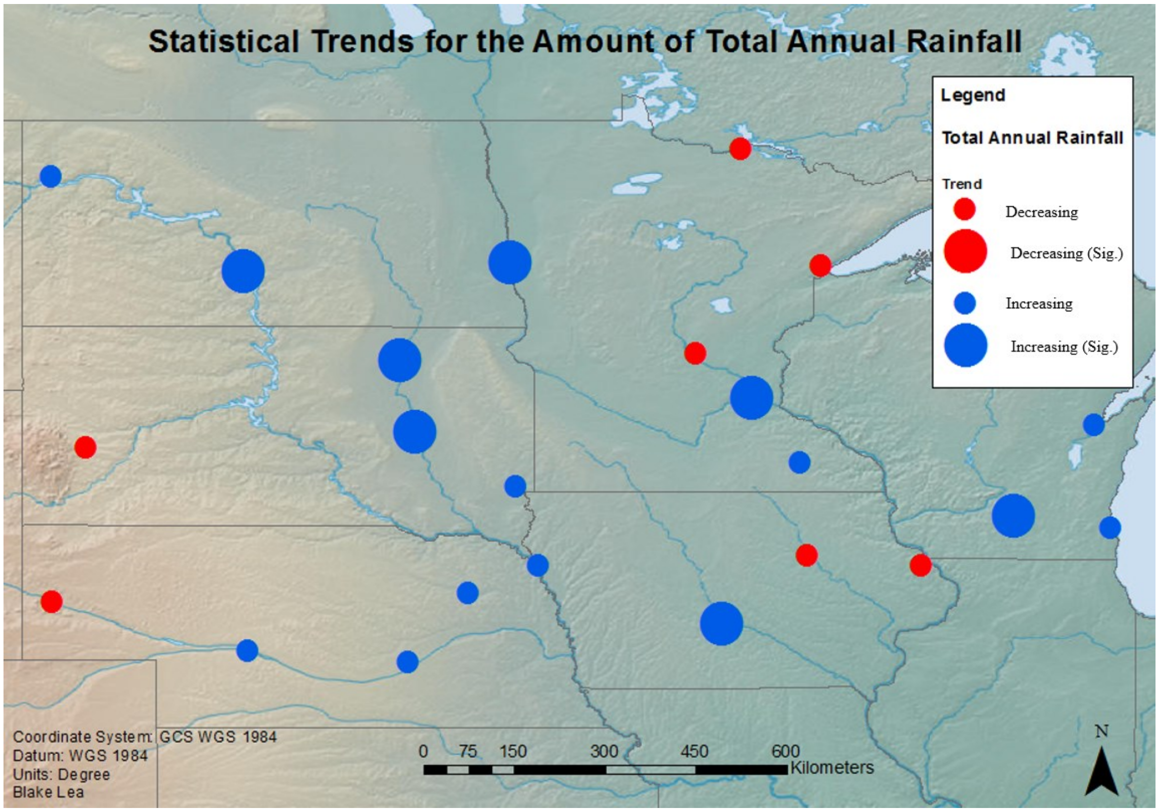

Figure 17. Regional trends for statistical analysis of total annual rainfall.

My analyses also point to increasing extreme rainfall rates based on increasing maximum storm intensities and the increases in the amount of rainfall occurring during a 90th percentile storm event (Figure 10, Figure 11, and Appendix C). Many of the figures in Appendix C show increasing rainfall intensities and decreasing storm durations. These figures also highlight that while regional increases are seen across the upper Midwest for each of the four precipitation characteristics that were analyzed using the kriging tool, the most drastic increase is occurring in the largest (90th percentile or larger) events (Figure 12). The figures in Appendix D also support the conclusion that the most significant increases in precipitation amounts are occurring in the most extreme rainfall events. Observation of the figures in Appendix D indicates that regions with intense precipitation are predominantly shifting north and west across the study area.

In the upper Midwest the increases in total annual precipitation are the result of increasing storm intensities, increasing amounts of rainfall in the most extreme events, and increasing numbers of storm events in the summer and fall. Rainfall intensities are increasing the most in the spring and winter months. The characteristic of precipitation that is the most responsible for the increasing amounts of total annual rainfall is the increase in maximum hourly storm intensities. The increases in total annual rainfall are occurring even though the duration of storm events are decreasing across much of the region. The observed pattern of increasing rainfall totals and intensities combined with decreasing storm durations is consistent with observations of an acceleration in the warming of the Earth's atmosphere and accompanying changes in the overall hydrologic cycle (Held and Soden 2006; Villarini et al. 2001; Voss et al. 2002).

Seasonal shifts in rainfall totals are highly variable across the region. Winter and fall show the most consistent changes. The amount of total winter precipitation in the upper Midwest is decreasing (Table 8). Eighteen of the 23 sites have experienced general decreases in winter precipitation total, with statistically significant decreases at 5 of the 18 stations (Table 8). The sites where winter precipitation is increasing are mostly located in the southern and southeastern parts of the upper Midwest. Two factors likely contribute to the increases at these sites: changes in the jet stream (Archer and Caldeira 2008; Woolings and Blackburn 2012) and decreasing ice cover on Lake Michigan leading to increased lake effect precipitation events (Andresen et al. 2012). When the jet stream shifts northward during the winter, it allows warm, moist air masses from the Gulf of Mexico to move into the southeastern region of the study area.

Spring and summer precipitation totals are generally increasing, but not in a statistically significant manner. Seventeen of the 23 sites are increasing in the spring and 15 of the 23 sites are increasing in the summer. Fall precipitation totals show the clearest pattern of increase, with 8 of the 23 stations experiencing statistically significant upward changes (Table 8) and 12 additional locations showing overall increases. The pattern for the amount of rainfall per event follows the same general trends as rainfall totals with winter rainfall amounts per event decreasing and all others increasing or stable (Table 8). However, spring shows the most significant increase while fall shows only a slight increase. Rainfall intensities are decreasing in the summer and are increasing or stable (Table 8 and Table 8). The increase in the total amount of fall precipitation is due to a combination of longer storm durations and more storm events (Table 8 and Table 8). Conversely, in the spring the changes are due to more rain per event (Table 8).

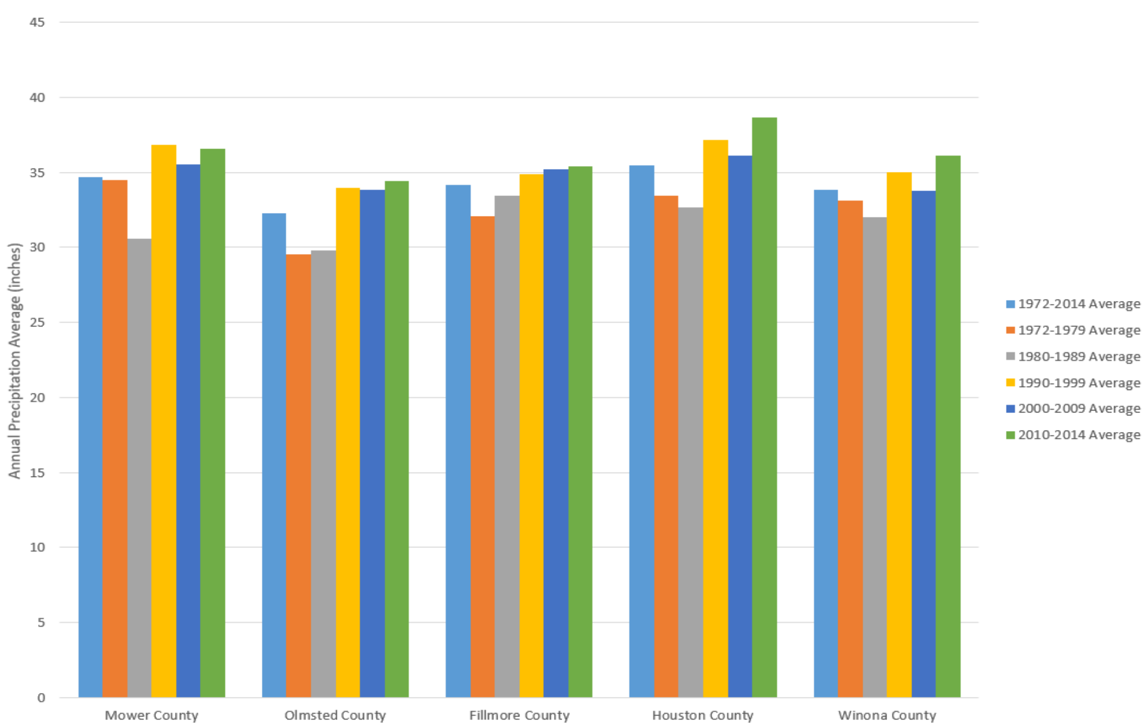

Figure 18. Southeast Minnesota decadal precipitation averages.

For the data in Figure 18, no statistically significant trends were found. However, it seems visible that there is an increasing tendency to the data. This suggests that the statistical methods used in this study to determine if there were changes in the characteristics of precipitation might not completely separate the noise from the signal.

Discharge

Analyses of historical discharge patterns of 8 river basins in the upper Midwest show that both discharge and precipitation patterns have been significantly altered across the region. Based on the analyses, 4 of the 8 river basins are experiencing statistically significant increases in the annual volume of discharge, 5 of the 8 river basins are experiencing statistically significant increases in the annual volume of precipitation, and 3 of the 8 river basins are experiencing statistically significant increases in the annual ratio of discharge volume divided by precipitation volume. It is interesting to note that based on my statistical analyses of the three variables all statistically significant trends are for increasing discharge/precipitation volumes and increasing ratios of flow volume to precipitation volume with no statistically significant decreasing trends. Of the 8 gaging stations analyzed the 3 stations that are located the farthest north are the only ones experiencing slight decreasing trends (not statistically significant) in annual flow volumes and annual ratios of flow volume to precipitation volume (Table 9 and Appendix E). All 8 locations had either a significant increase in annual precipitation volume or a slight increase, none of the locations used in this analysis had a decreasing trend for annual precipitation.

Table 9. Summary table of statistical analyses of precipitation and streamflow data for each basin.

		Flow Volume		Precipitation Volume		Flow/ Precipitation Ratio	
Site	Mean Annual Flow (km^3)	p-Value	Slope	p-Value	Slope	p-Value	Slope
Root River	0.6982	**0.00**	**0.0056**	**0.01**	**0.007**	**0.00**	**0.0011**
Baraboo River	0.368	**0.00**	**0.0021**	**0.01**	**0.003**	**0.00**	**0.0009**
Chippewa River	6.959	0.67	Not Sig.	0.55	Not Sig.	0.33	Not Sig.
Des Moines River	5.843	**0.00**	**0.0520**	0.38	Not Sig.	**0.00**	**0.0019**
Cannonball River	0.222	0.60	Not Sig.	0.18	Not Sig.	0.28	Not Sig.
Missouri River	19.954	0.71	Not Sig.	**0.10**	**0.404**	0.26	Not Sig.
White River	0.534	0.20	Not Sig.	**0.00**	**0.043**	0.68	Not Sig.
North Loup River	0.443	**0.00**	**0.0015**	**0.00**	**0.012**	0.63	Not Sig.

The Des Moines, Root, and Baraboo Rivers are all experiencing significant increases in the ratio of flow volume to precipitation volume (Table 9 and Appendix E). These are also the 3 basins with the highest percent of row crop agriculture used in the

study. Schottler et al. (2013) found that the expansion of row crop agriculture and agricultural drainage systems played a larger role in increased flow from sub-watersheds of the Minnesota River basin than increasing precipitation. My results support the conclusions of Schottler et al. (2013) and show that basins with less row crop agriculture can experience decreasing flow volumes even when precipitation is increasing (Table 9).

The Des Moines River basin is interesting because it has no significant trend in annual precipitation and has statistically significant increasing trends in annual discharge volume and annual discharge-to-precipitation ratio. Since this is the watershed with both the highest percent of row crop agriculture and urbanization used in this study, it provides direct evidence that land surface changes are the primary cause for the increase in the annual flow volume for this basin. It is likely that the use of agricultural drainage systems to enhance crop production is more responsible for increasing discharge volumes than urbanization, because agriculture accounts for a much larger percent of the land cover (93.9%) than developed land (1.4%). Total annual discharge in the Des Moines River basin showed an increase of 56.2% between the two time periods (1935-1974 and 1975-2013) with the largest increase occurring during the summer months (Table 10 and Appendix E). March is the only month that is experiencing a decrease in discharge volume, despite seeing an increase in precipitation. This is possibly due to decreased snow cover in the region (Kunkel et al. 2009) or increased snowmelt events (Groisman et al. 2001). Decreased snow cover and increased snowmelt events over the winter, due to a warmer climate, can significantly decrease the discharge of snowmelt events that historically occurred in March.

Table 10. Des Moines River near Tracy, IA basin monthly and annual flow and precipitation volumes summary table.

Precipitation Volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.941	1.115	0.763	-0.352	-31.54%
Feb	0.972	0.880	1.067	0.187	21.23%
Mar	1.775	1.747	1.803	0.056	3.23%
Apr	2.851	2.790	2.912	0.122	4.38%
May	3.492	3.460	3.524	0.064	1.85%
Jun	3.708	3.752	3.662	-0.090	-2.41%
Jul	3.232	3.171	3.294	0.123	3.87%
Aug	3.229	2.857	3.610	0.753	26.35%
Sep	2.746	2.847	2.642	-0.205	-7.19%
Oct	1.987	1.888	2.088	0.201	10.63%
Nov	1.685	1.567	1.806	0.239	15.27%
Dec	1.071	1.063	1.080	0.018	1.68%
Annual	27.688	27.137	28.253	1.116	4.11%
Flow volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.159	0.133	0.186	0.054	40.30%
Feb	0.238	0.227	0.249	0.022	9.71%
Mar	0.622	0.624	0.620	-0.004	-0.68%
Apr	0.809	0.701	0.919	0.218	31.10%
May	0.794	0.639	0.953	0.314	49.10%
Jun	0.967	0.797	1.142	0.346	43.38%
Jul	0.813	0.467	1.169	0.702	150.22%
Aug	0.483	0.285	0.685	0.400	140.11%
Sep	0.287	0.210	0.366	0.156	74.35%
Oct	0.229	0.191	0.267	0.075	39.38%
Nov	0.242	0.184	0.301	0.118	64.04%
Dec	0.200	0.116	0.288	0.172	148.74%
Annual	5.843	4.573	7.144	2.571	56.22%

The Root and Baraboo River basins both show statistically significant increases in annual precipitation, annual discharge volume, and annual discharge-to-precipitation ratio. While all three variables are increasing at a significant rate, the increase in the annual discharge-to-precipitation ratio indicates that some factors other than precipitation are responsible for the increasing discharge volumes. Land cover in both of these basins is greater than 70% agricultural, indicating that agricultural practices are likely responsible for some of the increasing discharge volumes. Total annual discharge in the Root River basin showed an increase of 44.5% between the two time periods (1935-1974 and 1975-2013) with the largest increase occurring during the summer months (Appendix E). Total annual discharge in the Baraboo River basin showed an increase of 26.1% between the two time periods (1935-1974 and 1975-2013) with the largest increase also occurring during the summer months (Appendix E). Schottler et al. (2013) found that rivers, in a similar setting to the Root and Baraboo, with increasing discharge volumes have experienced increasing channel widths due to increased erosive power (Figure 19).

Figure 19. Channel widening pattern in the Root River Basin in Minnesota.

The North Loup River basin shows a statistically significant increase in annual precipitation and annual discharge volume. However, the annual discharge-to-

precipitation ratios show no statistically significant change. This basin has relatively little row crop agriculture and urbanization, so it is likely that increases in annual precipitation are the major factor in annual discharge increases. Discharge volumes are increasing in all months and precipitation volumes are increasing in all months, except June and September. Total annual discharge in the North Loup River basin showed an increase of 15.8% between the two time periods (1935-1974 and 1975-2013) with the largest increase occurring during the summer and fall (Appendix E).

The Cannonball River basin shows no statistically significant change in annual precipitation volume, annual discharge volume, and annual discharge-to-precipitation ratios. However, winter and fall discharge volumes show strong increases over the period and the fall also shows an increase in precipitation volumes. The Cannonball River also displays very unusual increases in flow and precipitation volumes during the month of October. Decreases in discharge volumes in June and July are likely all that is preventing a statistically significant increase in annual discharge volume. Total annual discharge in the Cannonball River basin showed an increase of 6.4% between the two time periods (1935-1974 and 1975-2013) with the largest increase occurring during the winter and fall (Appendix E).

The Missouri River basin shows a statistically significant increase in annual precipitation volume and no statistically significant change in annual flow volume and annual discharge-to-precipitation ratio. Monthly precipitation volumes show a strong increase from July to December. Monthly discharge volumes are decreasing from March to June and increasing for the rest of the year, except October. Total annual discharge in the Missouri River basin showed an increase of 0.1% between the two time periods

(1935-1974 and 1975-2013) with the largest increase occurring during the winter months (Appendix E).

The White River basin shows a statistically significant increase in annual precipitation volume and no statistically significant change in annual flow volume and annual discharge-to-precipitation ratio. Total annual discharge in the White River basin showed an increase of 19.2% between the two time periods (1935-1974 and 1975-2013) with the largest increase occurring during the winter months (Appendix E). Despite the large increase in the percentage of total annual discharge it does not show a statistically significant increasing trend due to large variations in discharge volume year to year. Discharge volumes are increasing in all months, except March and June, and the decreases for those months are relatively small. Precipitation volumes are increasing in all months, except February, June, and December, and the decreases for those months are also relatively small.

The Chippewa River basin shows no statistically significant change in annual precipitation volume, annual discharge volume, and annual discharge-to-precipitation ratios. Although the Chippewa River basin has not experienced any statistically significant annual changes, it has seen some major shifts in seasonal patterns. Monthly precipitation volumes have decreased or stayed about the same from May through August and all other months have increased. Monthly discharge volumes have decreased in March and May through July and all other months have increased. So while the annual pattern in the Chippewa River basin has remained stable (0% increase between the two time periods), the results show less precipitation and discharge in the late spring through mid-summer and increased precipitation and discharge most of the rest of the year.

It is interesting to note that in 7 of the 8 river basins (excluding the North Loup River basin in Nebraska) March is often the only month that is experiencing a decrease in discharge volume or one of very few (Appendix E). The decrease in March discharge volumes is occurring even though we observe an increase in precipitation volumes for the month of March in all basins, except the Root River basin. Probable causes for this trend are that we are experiencing a decreasing number of snow melt flooding events in March or that we are receiving more precipitation as snowfall that does not correlate to increasing discharge. As noted in Groisman et al. (2001), earlier snowmelt during the past several decades (Figure 20) can lead to situations where increasing precipitation volumes are not reflected in discharge trends. The analyses in this study support the idea that this is occurring in the upper Midwest in March. Kunkel et al. (2009) also found an increasing trend of low snowfall years since 1950 that are a consequence of increasing temperatures, because for high snowfall to occur you need an influx of cold and wet air masses.

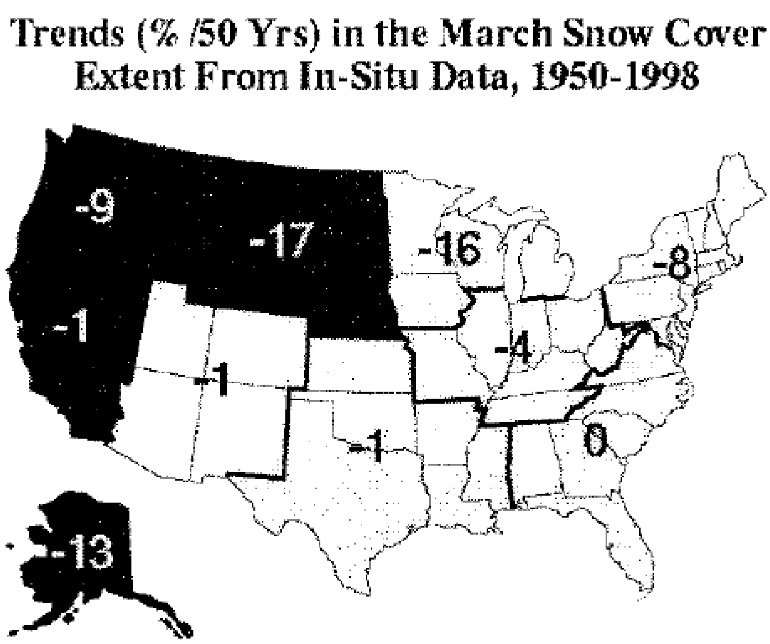

Figure 20. March snow cover trends for the United States (Groisman et al. 2001).

The relationship between precipitation and discharge for each basin are graphed in Figure 21 and Appendix H. The R^2 values in these graphs indicate the strength of the relationship between discharge and precipitation. Basins with higher R^2 values indicate that precipitation can be used to describe more of the variation in discharge from year to year. The general pattern is for increasing R^2 values in the most recent 30-year period.

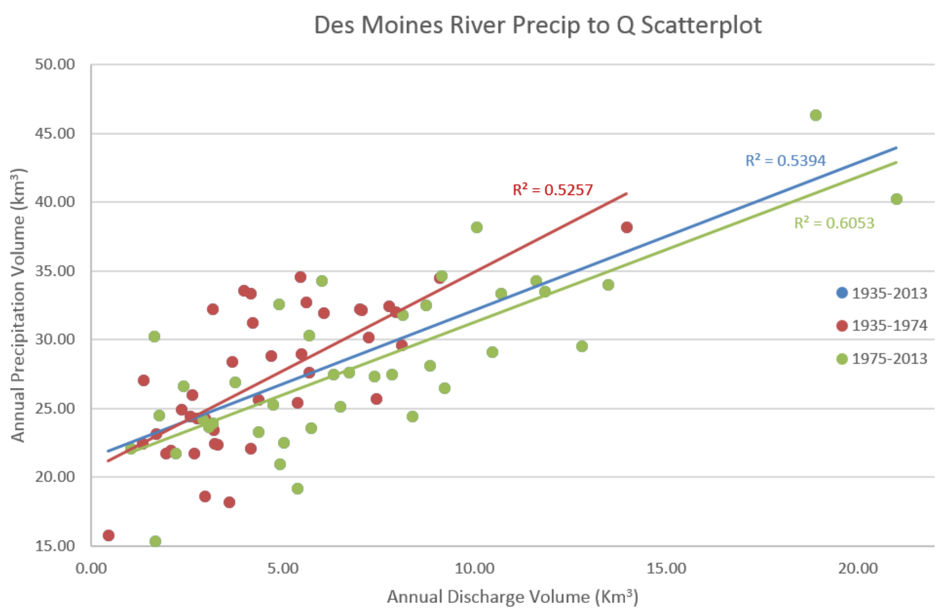

Figure 21. Precipitation to discharge correlation for the Des Moines River basin.

The months of October, November, and December are experiencing increasing precipitation in all 8 river basins (excluding the White River basin in December) and increasing discharge in all 8 river basins (excluding the Missouri River basin in October) (Appendix E). The increased precipitation volumes are especially noticeable in the western part of the study region. It is possible that increasing air temperatures are causing decreasing snowfall (Kunkel et al. 2009), and also allowing for increasing liquid precipitation and decreasing frozen precipitation. This causes a more rapid discharge

response due to decreased residence time on the landscape and the observed increasing precipitation and discharge volumes in the late fall/early winter

CONCLUSIONS

The results of this research indicate that the upper Midwest is experiencing an intensification of precipitation events and increasing annual rainfall. This study helps fill a gap in our understanding of how the increases in annual precipitation are occurring in concert with changes in the characteristics of the rainfall across the upper Midwest. Increasing hourly rainfall intensities, especially for the most extreme events, are causing annual precipitation totals to increase across the region. The increasing annual precipitation amounts are coming from shorter duration, more intense, and greater magnitude storm events. The greatest increase in precipitation amounts are occurring in the top 10-15 percentile of storm events. These findings support the conclusions of both Groisman et al. (2001) and Karl and Knight (1998) of increasing extreme precipitation events. This study also provides insight into how changes in precipitation, streamflow, and land use are interconnected. It is evident that increased agricultural land use is contributing to increased discharge volumes in river basins across the region. The combination of more intense rainfall and decreasing water residence times on the land surface due to anthropogenic influences across the landscape will likely lead to the increasing erosive capability of rivers.

Increasing annual precipitation, especially more intense rainfall with higher runoff, should lead to measurable increases in annual streamflow in nearby river basins. However, it is difficult to separate the influences of changing climate, land use, tile drainage, and urbanization on streamflow (Kunkel et al. 1999; Trenberth et al. 2003). My findings show that both changes in precipitation and changes in land use can cause

significant increases in the streamflow of river basins across the upper Midwest. As described in Schottler et al. (2013), patterns of increasing annual discharge volumes have a direct correlation to the widening of river channels and their sediment core analyses support the idea that the proportion of non-field sediment is increasing in basins with increased discharge volumes. The ability to predict expected increases in flood magnitudes and frequency based on changes in climate and land use will be critical to mitigate future damage from flooding and to assist with land use management. While it can be difficult to separate the direct influences of changing precipitation and land use over time, broad interpretations into their underlying significance can be made using this research. Additional analyses could provide increased certainty of these conclusions.

This research could be improved upon by including higher resolution (15 minute) precipitation data from the NCDC's DSI 3260 dataset. The DSI 3260 dataset was not utilized, because it is not available before the 1970s. The higher resolution 15 minute data also involves more processing because of all the additional data points included. The use of 1 hour precipitation data does not give information about maximum 1 hour rainfall totals, because it does not specify when initial rainfall occurred within a given hour. However, the sheer number of events used in this study hopefully averages out the noise within hourly events. This research could also benefit from additional analyses of the physical characteristics of each of the river basins. The most obvious physical characteristics that were not considered in this study are the stream gradients within the basin, underlying geology, and soil types. The inclusion of these variables in the analysis could help in understanding some of the nuances between locations that we are unable to explain using the current methods.

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APPENDICES

Appendix A: Precipitation characteristics

Appendix A-1. Des Moines, Iowa precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.26	4.61	0.12	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.09	3.00	0.04	0.02
3rd quartile	0.31	6.00	0.14	0.06
Median	0.09	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.53	9.00	0.22	0.10
90th percentile	0.73	11.00	0.30	0.13
95th percentile	1.06	15.00	0.50	0.21
99th percentile	2.13	24.00	1.00	0.40
January	0.13	5.13	0.03	0.02
February	0.15	5.62	0.04	0.02
March	0.20	5.68	0.06	0.03
April	0.26	5.13	0.11	0.05
May	0.31	4.07	0.16	0.07
June	0.33	3.42	0.19	0.09
July	0.34	3.30	0.19	0.09
August	0.37	3.76	0.20	0.08
September	0.33	4.54	0.15	0.07
October	0.26	4.93	0.10	0.05
November	0.24	5.80	0.07	0.03
December	0.12	5.00	0.04	0.02
1940s	0.25	4.29	0.11	0.05
1950s	0.25	4.44	0.11	0.05
1960s	0.26	4.68	0.12	0.06
1970s	0.28	4.75	0.12	0.06

Des Moines, Iowa precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.28	4.63	0.13	0.06
1st quartile	0.02	1.00	0.02	0.01
2nd quartile	0.09	3.00	0.05	0.03
3rd quartile	0.34	6.00	0.15	0.07
Median	0.09	3.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.58	8.00	0.24	0.10
90th percentile	0.80	11.00	0.34	0.14
95th percentile	1.18	15.00	0.54	0.22
99th percentile	2.14	24.00	0.98	0.44
January	0.11	4.50	0.03	0.02
February	0.14	5.54	0.04	0.02
March	0.20	5.01	0.07	0.03
April	0.30	5.37	0.11	0.05
May	0.30	4.11	0.14	0.07
June	0.37	3.34	0.22	0.10
July	0.39	3.66	0.22	0.10
August	0.41	3.97	0.22	0.10
September	0.31	4.19	0.14	0.06
October	0.27	5.17	0.11	0.05
November	0.25	6.15	0.07	0.03
December	0.17	5.76	0.05	0.02
1980s	0.27	4.80	0.12	0.05
1990s	0.28	4.68	0.13	0.06
2000s	0.28	4.43	0.13	0.06
2010s	0.31	4.50	0.16	0.07

Appendix A-2. Dubuque, Iowa precipitation characteristics (1951-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.31	4.78	0.14	0.07
1st quartile	0.03	2.00	0.02	0.02
2nd quartile	0.12	3.00	0.05	0.03
3rd quartile	0.35	6.00	0.16	0.08
Median	0.12	3.00	0.05	0.03
Mode	0.02	1.00	0.01	0.01
85th percentile	0.60	9.00	0.25	0.12
90th percentile	0.83	11.00	0.35	0.16
95th percentile	1.22	15.00	0.55	0.24
99th percentile	2.44	24.00	1.00	0.46
January	0.15	5.26	0.04	0.02
February	0.17	5.63	0.05	0.03
March	0.27	6.08	0.08	0.04
April	0.31	5.11	0.12	0.06
May	0.34	3.99	0.17	0.09
June	0.33	3.19	0.19	0.10
July	0.38	3.22	0.23	0.11
August	0.44	3.73	0.24	0.11
September	0.42	4.56	0.19	0.08
October	0.33	5.35	0.12	0.06
November	0.32	6.14	0.10	0.04
December	0.20	6.23	0.05	0.03
1950s	0.29	4.75	0.13	0.06
1960s	0.37	4.86	0.16	0.08
1970s	0.27	4.72	0.12	0.06

Dubuque, Iowa precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.27	4.84	0.12	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.10	3.00	0.05	0.03
3rd quartile	0.32	6.00	0.14	0.06
Median	0.10	3.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.55	9.00	0.22	0.10
90th percentile	0.75	11.00	0.31	0.14
95th percentile	1.08	15.00	0.50	0.21
99th percentile	2.06	24.36	1.01	0.42
January	0.11	5.31	0.03	0.02
February	0.16	5.88	0.04	0.02
March	0.20	5.34	0.07	0.03
April	0.27	5.45	0.11	0.05
May	0.27	4.22	0.13	0.06
June	0.32	3.54	0.18	0.08
July	0.40	3.47	0.22	0.11
August	0.43	3.96	0.23	0.11
September	0.32	4.37	0.16	0.07
October	0.29	5.88	0.10	0.04
November	0.24	6.05	0.07	0.03
December	0.17	5.67	0.05	0.02
1980s	0.26	5.11	0.11	0.05
1990s	0.26	4.76	0.12	0.06
2000s	0.27	4.65	0.12	0.06
2010s	0.32	4.88	0.14	0.06

Appendix A-3. Sioux City, Iowa precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.24	4.51	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.27	6.00	0.12	0.06
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.49	8.00	0.20	0.09
90th percentile	0.69	10.00	0.30	0.13
95th percentile	1.02	14.60	0.48	0.20
99th percentile	1.89	26.00	1.01	0.46
January	0.09	4.81	0.02	0.01
February	0.13	5.40	0.03	0.02
March	0.18	6.35	0.05	0.02
April	0.22	4.75	0.09	0.04
May	0.26	4.10	0.13	0.06
June	0.34	3.44	0.19	0.09
July	0.37	3.21	0.22	0.11
August	0.32	3.49	0.18	0.08
September	0.30	4.35	0.15	0.07
October	0.28	5.40	0.10	0.05
November	0.17	5.35	0.05	0.02
December	0.11	4.98	0.03	0.02
1940s	0.32	4.68	0.15	0.08
1950s	0.24	4.49	0.11	0.05
1960s	0.23	4.50	0.11	0.05
1970s	0.24	4.54	0.11	0.05

Sioux City, Iowa precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.24	4.30	0.11	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.28	5.00	0.13	0.06
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.48	8.00	0.22	0.10
90th percentile	0.68	10.00	0.30	0.14
95th percentile	1.05	13.00	0.47	0.21
99th percentile	1.93	23.00	0.98	0.46
January	0.09	4.30	0.03	0.02
February	0.09	4.26	0.03	0.02
March	0.20	5.41	0.06	0.03
April	0.26	5.40	0.09	0.04
May	0.30	4.51	0.14	0.06
June	0.29	3.37	0.18	0.09
July	0.31	2.90	0.20	0.10
August	0.31	3.22	0.18	0.09
September	0.29	4.17	0.13	0.06
October	0.25	5.10	0.09	0.04
November	0.19	5.36	0.06	0.03
December	0.10	4.43	0.03	0.02
1980s	0.24	4.64	0.10	0.05
1990s	0.23	4.24	0.11	0.05
2000s	0.26	4.12	0.13	0.06
2010s	0.23	4.05	0.12	0.06

Appendix A-4. Waterloo, Iowa precipitation characteristics (1956-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.30	4.63	0.14	0.06
1st quartile	0.03	1.00	0.02	0.01
2nd quartile	0.10	3.00	0.05	0.03
3rd quartile	0.34	6.00	0.15	0.08
Median	0.10	3.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.58	9.00	0.25	0.11
90th percentile	0.81	11.00	0.35	0.15
95th percentile	1.24	15.00	0.54	0.24
99th percentile	2.37	22.00	1.19	0.49
January	0.11	5.14	0.03	0.02
February	0.15	5.30	0.04	0.02
March	0.23	6.13	0.07	0.03
April	0.31	5.35	0.12	0.06
May	0.29	4.04	0.13	0.07
June	0.35	3.29	0.22	0.10
July	0.45	3.39	0.25	0.12
August	0.37	3.30	0.21	0.10
September	0.39	4.58	0.19	0.08
October	0.33	5.61	0.12	0.05
November	0.25	5.80	0.08	0.03
December	0.15	5.25	0.04	0.02
1950s	0.27	4.33	0.13	0.06
1960s	0.33	4.59	0.15	0.07
1970s	0.27	4.77	0.12	0.06

Waterloo, Iowa precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.27	4.46	0.13	0.06
1st quartile	0.02	1.00	0.02	0.01
2nd quartile	0.09	3.00	0.05	0.03
3rd quartile	0.33	6.00	0.14	0.07
Median	0.09	3.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.56	8.00	0.24	0.11
90th percentile	0.74	10.00	0.33	0.15
95th percentile	1.13	14.00	0.54	0.23
99th percentile	2.11	21.36	0.97	0.48
January	0.10	4.80	0.03	0.02
February	0.13	5.17	0.04	0.02
March	0.18	4.70	0.06	0.03
April	0.29	5.30	0.12	0.05
May	0.29	4.16	0.14	0.06
June	0.38	3.57	0.23	0.10
July	0.43	3.21	0.25	0.12
August	0.39	3.70	0.22	0.10
September	0.27	4.02	0.13	0.06
October	0.27	4.95	0.10	0.04
November	0.21	5.51	0.06	0.03
December	0.14	5.33	0.04	0.02
1980s	0.27	4.63	0.13	0.06
1990s	0.27	4.40	0.13	0.06
2000s	0.26	4.32	0.12	0.06
2010s	0.28	4.62	0.14	0.06

Appendix A-5. Duluth, Minnesota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.19	4.47	0.08	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.02	0.02
3rd quartile	0.18	6.00	0.08	0.04
Median	0.05	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.35	8.00	0.14	0.06
90th percentile	0.53	11.00	0.20	0.09
95th percentile	0.83	15.00	0.34	0.15
99th percentile	1.73	26.00	0.74	0.37
January	0.08	4.26	0.02	0.01
February	0.08	4.61	0.02	0.01
March	0.14	5.65	0.03	0.02
April	0.18	5.60	0.05	0.03
May	0.21	4.47	0.09	0.04
June	0.27	3.49	0.15	0.08
July	0.29	3.09	0.17	0.09
August	0.31	4.02	0.15	0.07
September	0.23	4.28	0.10	0.05
October	0.20	4.90	0.07	0.03
November	0.13	4.68	0.03	0.02
December	0.10	5.04	0.03	0.02
1940s	0.08	1.02	0.08	0.08
1950s	0.19	4.41	0.08	0.04
1960s	0.19	4.75	0.08	0.04
1970s	0.19	4.57	0.08	0.04

Duluth, Minnesota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.20	4.52	0.08	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.06	3.00	0.03	0.02
3rd quartile	0.22	6.00	0.09	0.04
Median	0.06	3.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.39	8.00	0.16	0.07
90th percentile	0.56	11.00	0.22	0.10
95th percentile	0.90	15.00	0.35	0.14
99th percentile	1.83	24.00	0.74	0.32
January	0.08	4.39	0.02	0.01
February	0.07	4.38	0.03	0.01
March	0.12	5.09	0.04	0.02
April	0.20	5.30	0.07	0.03
May	0.21	4.49	0.09	0.04
June	0.29	4.09	0.13	0.06
July	0.26	3.15	0.15	0.07
August	0.29	3.50	0.15	0.08
September	0.28	4.64	0.12	0.06
October	0.20	5.21	0.06	0.03
November	0.18	6.13	0.05	0.02
December	0.08	4.51	0.02	0.01
1980s	0.20	4.80	0.08	0.04
1990s	0.21	4.50	0.09	0.04
2000s	0.19	4.24	0.08	0.04
2010s	0.22	4.51	0.09	0.04

Appendix A-6. International Falls, Minnesota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.16	4.23	0.07	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.02	0.02
3rd quartile	0.16	5.00	0.07	0.04
Median	0.05	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.29	8.00	0.12	0.06
90th percentile	0.42	10.00	0.17	0.08
95th percentile	0.69	13.00	0.29	0.14
99th percentile	1.51	23.00	0.69	0.34
January	0.06	4.25	0.02	0.01
February	0.07	4.28	0.02	0.01
March	0.10	4.87	0.03	0.02
April	0.14	4.89	0.04	0.03
May	0.19	4.64	0.09	0.04
June	0.25	3.56	0.13	0.07
July	0.28	3.28	0.16	0.08
August	0.23	3.50	0.12	0.06
September	0.23	4.03	0.11	0.05
October	0.17	4.64	0.05	0.03
November	0.09	4.78	0.03	0.01
December	0.07	4.40	0.02	0.01
1940s	0.17	4.24	0.08	0.04
1950s	0.15	4.35	0.06	0.03
1960s	0.17	4.38	0.08	0.04
1970s	0.16	3.97	0.07	0.04

International Falls, Minnesota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.16	4.21	0.07	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.02	0.02
3rd quartile	0.17	5.00	0.07	0.04
Median	0.05	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.30	8.00	0.12	0.06
90th percentile	0.45	10.00	0.18	0.08
95th percentile	0.72	14.00	0.32	0.13
99th percentile	1.47	23.00	0.67	0.30
January	0.06	4.22	0.02	0.01
February	0.07	4.14	0.02	0.01
March	0.10	4.67	0.03	0.02
April	0.16	4.85	0.05	0.03
May	0.18	4.31	0.08	0.04
June	0.23	3.63	0.11	0.06
July	0.26	3.28	0.16	0.08
August	0.23	3.33	0.13	0.07
September	0.21	4.48	0.08	0.04
October	0.15	4.81	0.05	0.02
November	0.16	5.40	0.04	0.02
December	0.06	3.92	0.02	0.01
1980s	0.16	4.33	0.07	0.04
1990s	0.16	4.24	0.07	0.04
2000s	0.18	3.95	0.08	0.04
2010s	0.17	4.34	0.07	0.04

Appendix A-7. Minneapolis, Minnesota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.21	4.46	0.09	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.03	0.02
3rd quartile	0.24	6.00	0.10	0.05
Median	0.07	3.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.40	8.00	0.17	0.08
90th percentile	0.55	10.00	0.24	0.11
95th percentile	0.87	14.00	0.39	0.18
99th percentile	1.59	24.00	0.81	0.37
January	0.09	4.88	0.02	0.01
February	0.12	5.70	0.03	0.02
March	0.16	5.84	0.05	0.02
April	0.18	5.03	0.07	0.03
May	0.22	3.81	0.11	0.06
June	0.27	3.32	0.16	0.08
July	0.32	3.02	0.19	0.10
August	0.32	3.55	0.17	0.08
September	0.23	4.21	0.11	0.05
October	0.22	5.03	0.08	0.04
November	0.16	5.62	0.04	0.02
December	0.09	4.90	0.03	0.02
1940s	0.20	3.93	0.09	0.05
1950s	0.20	4.48	0.09	0.05
1960s	0.21	4.54	0.10	0.05
1970s	0.20	4.43	0.10	0.05

Minneapolis, Minnesota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.24	4.42	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.04	0.02
3rd quartile	0.26	6.00	0.11	0.06
Median	0.07	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.46	8.00	0.20	0.09
90th percentile	0.63	10.00	0.28	0.13
95th percentile	1.00	14.00	0.46	0.20
99th percentile	2.08	23.00	0.93	0.39
January	0.08	4.72	0.03	0.01
February	0.10	4.86	0.03	0.02
March	0.16	5.39	0.05	0.03
April	0.22	4.93	0.09	0.04
May	0.26	4.48	0.11	0.06
June	0.32	3.63	0.17	0.08
July	0.36	2.97	0.21	0.11
August	0.37	3.45	0.20	0.09
September	0.27	3.93	0.13	0.06
October	0.24	5.01	0.09	0.04
November	0.18	5.99	0.05	0.02
December	0.11	4.71	0.03	0.02
1980s	0.23	4.68	0.10	0.05
1990s	0.23	4.36	0.10	0.05
2000s	0.24	4.25	0.12	0.06
2010s	0.25	4.31	0.12	0.06

Appendix A-8. Rochester, Minnesota precipitation characteristics (1960-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.22	4.46	0.10	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.03	0.02
3rd quartile	0.24	6.00	0.10	0.05
Median	0.07	3.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.43	8.00	0.18	0.08
90th percentile	0.62	10.00	0.25	0.11
95th percentile	0.92	14.60	0.40	0.18
99th percentile	1.79	24.00	0.93	0.43
January	0.09	5.11	0.03	0.01
February	0.09	4.77	0.03	0.02
March	0.17	5.62	0.05	0.02
April	0.20	5.04	0.07	0.04
May	0.24	4.20	0.13	0.06
June	0.30	3.57	0.17	0.09
July	0.34	3.09	0.20	0.09
August	0.31	3.61	0.18	0.09
September	0.28	4.21	0.13	0.06
October	0.26	5.05	0.09	0.04
November	0.16	5.16	0.05	0.02
December	0.09	4.64	0.03	0.02
1960s	0.21	4.14	0.10	0.05
1970s	0.23	4.75	0.10	0.05

Rochester, Minnesota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.24	4.45	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.04	0.02
3rd quartile	0.27	6.00	0.12	0.06
Median	0.07	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.47	8.00	0.20	0.09
90th percentile	0.65	10.00	0.30	0.13
95th percentile	1.03	14.00	0.46	0.20
99th percentile	1.86	25.00	0.97	0.43
January	0.09	5.09	0.03	0.02
February	0.09	4.61	0.03	0.02
March	0.16	5.45	0.05	0.03
April	0.24	5.33	0.09	0.04
May	0.25	4.04	0.12	0.06
June	0.31	3.48	0.18	0.08
July	0.36	2.98	0.22	0.11
August	0.37	3.58	0.20	0.09
September	0.28	3.92	0.13	0.06
October	0.21	4.83	0.07	0.03
November	0.19	6.07	0.05	0.02
December	0.12	5.38	0.03	0.02
1980s	0.23	4.76	0.11	0.05
1990s	0.23	4.47	0.11	0.05
2000s	0.25	4.16	0.12	0.05
2010s	0.23	4.31	0.11	0.05

Appendix A-9. St. Cloud, Minnesota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.23	4.71	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.03	0.02
3rd quartile	0.27	6.00	0.11	0.05
Median	0.07	3.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.47	9.00	0.19	0.09
90th percentile	0.63	11.00	0.28	0.12
95th percentile	0.97	15.00	0.47	0.19
99th percentile	2.02	25.00	0.95	0.45
January	0.09	4.87	0.02	0.01
February	0.11	5.55	0.03	0.02
March	0.15	6.11	0.04	0.02
April	0.22	5.92	0.07	0.03
May	0.26	4.45	0.12	0.05
June	0.35	3.58	0.21	0.10
July	0.31	3.17	0.20	0.11
August	0.40	3.76	0.22	0.10
September	0.26	4.34	0.12	0.06
October	0.27	5.67	0.09	0.04
November	0.16	5.66	0.04	0.02
December	0.08	4.78	0.02	0.01
1940s	0.23	5.18	0.12	0.06
1950s	0.25	4.76	0.12	0.06
1960s	0.22	4.66	0.10	0.05
1970s	0.22	4.66	0.10	0.05

St. Cloud, Minnesota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.23	4.50	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.04	0.02
3rd quartile	0.27	6.00	0.11	0.05
Median	0.07	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.46	8.00	0.19	0.09
90th percentile	0.62	10.00	0.27	0.12
95th percentile	0.95	14.00	0.43	0.19
99th percentile	1.83	23.00	0.94	0.41
January	0.08	4.46	0.02	0.02
February	0.10	5.50	0.03	0.02
March	0.16	5.43	0.05	0.03
April	0.26	5.98	0.09	0.04
May	0.25	4.45	0.11	0.05
June	0.28	3.50	0.15	0.07
July	0.28	3.04	0.18	0.09
August	0.36	3.29	0.21	0.10
September	0.31	4.21	0.15	0.07
October	0.23	4.98	0.08	0.04
November	0.16	5.67	0.04	0.02
December	0.10	5.05	0.03	0.02
1980s	0.24	4.54	0.11	0.05
1990s	0.22	4.51	0.10	0.05
2000s	0.23	4.45	0.10	0.05
2010s	0.23	4.47	0.11	0.05

Appendix A-10. Grand Island, Nebraska precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.25	4.38	0.12	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.03
3rd quartile	0.29	5.00	0.12	0.06
Median	0.08	3.00	0.04	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.51	8.00	0.22	0.10
90th percentile	0.69	10.00	0.31	0.14
95th percentile	1.05	14.00	0.47	0.22
99th percentile	2.07	24.42	1.09	0.48
January	0.09	4.95	0.03	0.02
February	0.13	5.33	0.04	0.02
March	0.20	6.26	0.05	0.03
April	0.26	4.84	0.11	0.05
May	0.31	4.21	0.16	0.08
June	0.36	3.43	0.21	0.10
July	0.29	3.09	0.18	0.09
August	0.29	3.06	0.18	0.09
September	0.29	3.94	0.13	0.06
October	0.20	4.50	0.08	0.04
November	0.19	5.55	0.06	0.03
December	0.14	5.62	0.03	0.02
1940s	0.21	4.31	0.11	0.06
1950s	0.25	4.27	0.12	0.06
1960s	0.26	4.37	0.13	0.06
1970s	0.25	4.51	0.11	0.05

Grand Island, Nebraska precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.26	4.14	0.13	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	2.00	0.05	0.03
3rd quartile	0.30	5.00	0.14	0.07
Median	0.08	2.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.52	7.00	0.24	0.11
90th percentile	0.70	9.00	0.33	0.15
95th percentile	1.12	13.00	0.54	0.25
99th percentile	2.31	23.00	1.09	0.47
January	0.08	4.47	0.03	0.02
February	0.10	5.09	0.03	0.02
March	0.20	5.48	0.07	0.03
April	0.26	4.63	0.10	0.05
May	0.33	4.12	0.16	0.08
June	0.34	3.02	0.20	0.10
July	0.33	2.90	0.21	0.10
August	0.35	3.26	0.20	0.10
September	0.25	3.72	0.12	0.06
October	0.24	4.95	0.10	0.05
November	0.21	5.25	0.06	0.03
December	0.12	4.75	0.04	0.02
1980s	0.28	4.70	0.13	0.06
1990s	0.27	4.10	0.14	0.07
2000s	0.25	3.76	0.13	0.06
2010s	0.24	3.85	0.12	0.06

Appendix A-11. Norfolk, Nebraska precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.26	4.49	0.12	0.06
1st quartile	0.03	1.00	0.02	0.01
2nd quartile	0.09	3.00	0.05	0.03
3rd quartile	0.30	6.00	0.13	0.06
Median	0.09	3.00	0.05	0.03
Mode	0.01	1.00	0.01	0.01
85th percentile	0.50	8.00	0.23	0.11
90th percentile	0.67	10.00	0.30	0.14
95th percentile	1.04	14.00	0.46	0.22
99th percentile	2.12	23.00	1.03	0.42
January	0.10	5.27	0.03	0.02
February	0.14	5.72	0.03	0.02
March	0.20	6.02	0.06	0.03
April	0.21	4.64	0.08	0.04
May	0.30	4.03	0.15	0.07
June	0.41	3.66	0.21	0.10
July	0.36	3.24	0.21	0.10
August	0.29	3.25	0.18	0.09
September	0.28	4.27	0.12	0.06
October	0.25	4.99	0.10	0.05
November	0.15	5.15	0.04	0.02
December	0.13	5.91	0.03	0.02
1940s	0.29	5.24	0.13	0.07
1950s	0.24	4.38	0.12	0.06
1960s	0.26	4.39	0.12	0.06
1970s	0.26	4.58	0.12	0.06

Norfolk, Nebraska precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.25	4.43	0.12	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.29	6.00	0.13	0.06
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.51	8.00	0.22	0.10
90th percentile	0.70	10.00	0.31	0.14
95th percentile	1.13	14.00	0.52	0.22
99th percentile	2.01	24.00	0.99	0.47
January	0.09	4.35	0.03	0.02
February	0.12	5.12	0.04	0.02
March	0.19	5.73	0.06	0.03
April	0.26	5.32	0.10	0.04
May	0.29	4.29	0.13	0.06
June	0.35	3.35	0.20	0.09
July	0.32	2.93	0.21	0.11
August	0.34	3.30	0.19	0.09
September	0.29	4.19	0.14	0.06
October	0.23	5.13	0.09	0.04
November	0.22	5.82	0.06	0.03
December	0.12	5.24	0.03	0.02
1980s	0.25	4.77	0.11	0.05
1990s	0.28	4.67	0.13	0.06
2000s	0.26	4.12	0.12	0.06
2010s	0.21	3.81	0.11	0.06

Appendix A-12. North Platte, Nebraska precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.22	3.98	0.11	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	2.00	0.04	0.02
3rd quartile	0.25	5.00	0.12	0.06
Median	0.07	2.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.41	7.00	0.20	0.11
90th percentile	0.62	9.00	0.28	0.14
95th percentile	0.96	13.00	0.48	0.23
99th percentile	1.80	22.00	1.01	0.47
January	0.08	4.14	0.02	0.01
February	0.09	4.53	0.03	0.02
March	0.16	5.62	0.05	0.02
April	0.20	4.63	0.08	0.04
May	0.29	4.19	0.13	0.07
June	0.35	3.39	0.20	0.10
July	0.29	2.63	0.20	0.11
August	0.25	2.64	0.17	0.09
September	0.24	3.74	0.13	0.07
October	0.19	4.72	0.07	0.03
November	0.12	4.29	0.04	0.02
December	0.10	4.76	0.03	0.02
1940s	0.24	4.47	0.11	0.06
1950s	0.22	3.99	0.12	0.06
1960s	0.22	3.74	0.12	0.06
1970s	0.21	4.13	0.10	0.05

North Platte, Nebraska precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.21	3.97	0.11	0.06
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	2.00	0.04	0.02
3rd quartile	0.24	5.00	0.11	0.06
Median	0.07	2.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.43	7.00	0.20	0.10
90th percentile	0.63	9.00	0.30	0.14
95th percentile	0.91	13.00	0.48	0.22
99th percentile	1.67	23.53	0.95	0.44
January	0.07	4.13	0.02	0.01
February	0.10	5.29	0.03	0.02
March	0.14	4.65	0.05	0.03
April	0.24	5.14	0.09	0.04
May	0.25	4.04	0.12	0.06
June	0.28	2.89	0.18	0.09
July	0.28	2.80	0.20	0.10
August	0.25	2.76	0.16	0.09
September	0.20	3.56	0.10	0.05
October	0.20	4.31	0.08	0.04
November	0.13	5.37	0.04	0.02
December	0.11	5.58	0.03	0.02
1980s	0.17	6.59	0.03	0.02
1990s	0.22	3.82	0.11	0.06
2000s	0.21	3.83	0.11	0.06
2010s	0.23	3.82	0.13	0.06

Appendix A-13. Scottsbluff, Nebraska precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.15	3.78	0.08	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.03	0.02
3rd quartile	0.15	4.00	0.08	0.04
Median	0.05	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.30	7.00	0.13	0.07
90th percentile	0.42	9.00	0.19	0.11
95th percentile	0.66	14.00	0.32	0.18
99th percentile	1.26	24.24	0.74	0.46
January	0.07	4.20	0.02	0.02
February	0.06	4.61	0.02	0.01
March	0.11	4.90	0.03	0.02
April	0.15	4.86	0.05	0.03
May	0.21	3.99	0.10	0.06
June	0.22	2.70	0.14	0.08
July	0.21	2.15	0.16	0.10
August	0.13	2.32	0.09	0.06
September	0.15	3.26	0.07	0.04
October	0.16	4.79	0.06	0.04
November	0.11	4.83	0.03	0.02
December	0.09	4.80	0.03	0.02
1940s	0.10	1.00	0.10	0.10
1950s	0.16	3.87	0.08	0.04
1960s	0.15	3.74	0.08	0.05
1970s	0.16	4.35	0.07	0.04

Scottsbluff, Nebraska precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.16	4.01	0.08	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.03	0.02
3rd quartile	0.17	5.00	0.08	0.04
Median	0.05	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.30	7.00	0.13	0.06
90th percentile	0.42	9.00	0.18	0.09
95th percentile	0.66	14.00	0.30	0.15
99th percentile	1.43	24.00	0.76	0.40
January	0.08	4.59	0.03	0.02
February	0.09	4.92	0.03	0.02
March	0.13	5.20	0.04	0.02
April	0.18	5.05	0.06	0.03
May	0.19	3.89	0.09	0.05
June	0.23	3.06	0.14	0.08
July	0.20	2.57	0.13	0.08
August	0.15	2.43	0.11	0.07
September	0.15	3.78	0.07	0.04
October	0.15	4.58	0.06	0.03
November	0.11	4.52	0.04	0.02
December	0.09	5.26	0.02	0.02
1980s	0.17	4.43	0.08	0.04
1990s	0.17	4.02	0.09	0.05
2000s	0.15	3.60	0.07	0.04
2010s	0.15	3.83	0.07	0.04

Appendix A-14. Bismarck, North Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.14	4.04	0.07	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.04	2.00	0.02	0.01
3rd quartile	0.14	5.00	0.06	0.03
Median	0.04	2.00	0.02	0.01
Mode	0.01	1.00	0.01	0.01
85th percentile	0.26	7.00	0.11	0.06
90th percentile	0.40	9.00	0.16	0.08
95th percentile	0.63	14.00	0.27	0.14
99th percentile	1.34	24.00	0.69	0.36
January	0.05	4.35	0.02	0.01
February	0.06	4.02	0.02	0.01
March	0.09	4.95	0.02	0.01
April	0.17	5.53	0.05	0.03
May	0.20	4.43	0.09	0.05
June	0.22	3.27	0.13	0.07
July	0.21	2.67	0.14	0.08
August	0.18	2.71	0.11	0.06
September	0.17	3.81	0.08	0.04
October	0.16	5.09	0.05	0.02
November	0.07	4.17	0.02	0.02
December	0.05	4.24	0.02	0.01
1940s	0.15	4.38	0.07	0.04
1950s	0.14	4.28	0.06	0.03
1960s	0.15	3.88	0.07	0.04
1970s	0.13	3.93	0.06	0.03

Bismarck, North Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.16	3.88	0.08	0.04
1st quartile	0.01	1.00	0.01	0.01
2nd quartile	0.04	2.00	0.02	0.02
3rd quartile	0.15	5.00	0.07	0.04
Median	0.04	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.30	7.00	0.13	0.06
90th percentile	0.45	9.00	0.19	0.09
95th percentile	0.72	13.00	0.32	0.15
99th percentile	1.52	23.00	0.79	0.37
January	0.05	3.35	0.02	0.01
February	0.06	3.51	0.02	0.01
March	0.10	4.70	0.03	0.02
April	0.15	4.87	0.05	0.03
May	0.21	4.30	0.09	0.04
June	0.23	3.40	0.12	0.07
July	0.27	2.95	0.17	0.08
August	0.25	2.80	0.15	0.08
September	0.19	3.63	0.08	0.04
October	0.17	5.23	0.05	0.02
November	0.08	4.24	0.03	0.02
December	0.06	4.26	0.02	0.01
1980s	0.15	3.95	0.07	0.04
1990s	0.17	3.83	0.08	0.04
2000s	0.16	3.76	0.08	0.04
2010s	0.18	4.09	0.08	0.04

Appendix A-15. Fargo, North Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.18	4.05	0.09	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.02	0.02
3rd quartile	0.19	5.00	0.08	0.04
Median	0.05	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.34	7.00	0.15	0.07
90th percentile	0.50	9.00	0.21	0.10
95th percentile	0.81	13.00	0.35	0.17
99th percentile	1.71	22.00	0.93	0.36
January	0.06	4.10	0.02	0.01
February	0.05	3.49	0.02	0.01
March	0.11	4.97	0.03	0.02
April	0.21	5.56	0.06	0.03
May	0.20	3.95	0.09	0.04
June	0.26	3.27	0.16	0.08
July	0.32	2.72	0.20	0.10
August	0.26	3.22	0.16	0.08
September	0.21	3.81	0.10	0.05
October	0.22	5.18	0.08	0.03
November	0.13	5.03	0.03	0.02
December	0.07	4.54	0.02	0.01
1940s	0.15	3.68	0.08	0.04
1950s	0.18	3.89	0.09	0.04
1960s	0.19	4.27	0.08	0.05
1970s	0.19	4.07	0.09	0.04

Fargo, North Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.19	4.22	0.09	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.03	0.02
3rd quartile	0.20	5.00	0.08	0.04
Median	0.05	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.36	7.00	0.14	0.07
90th percentile	0.52	10.00	0.21	0.10
95th percentile	0.85	14.00	0.37	0.16
99th percentile	1.79	25.00	0.92	0.38
January	0.07	4.03	0.02	0.01
February	0.07	4.14	0.02	0.02
March	0.13	5.57	0.04	0.02
April	0.15	4.62	0.05	0.03
May	0.22	4.39	0.10	0.05
June	0.28	3.49	0.15	0.07
July	0.27	3.16	0.16	0.08
August	0.25	3.07	0.16	0.08
September	0.26	4.24	0.12	0.05
October	0.24	5.85	0.07	0.03
November	0.11	5.12	0.03	0.02
December	0.07	3.93	0.02	0.01
1980s	0.17	4.19	0.08	0.04
1990s	0.19	4.13	0.09	0.04
2000s	0.21	4.25	0.09	0.04
2010s	0.20	4.39	0.09	0.05

Appendix A-16. Williston, North Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.13	3.90	0.06	0.03
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.04	2.00	0.02	0.02
3rd quartile	0.13	5.00	0.06	0.03
Median	0.04	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.24	7.00	0.10	0.05
90th percentile	0.33	9.00	0.14	0.07
95th percentile	0.55	13.00	0.24	0.12
99th percentile	1.39	24.00	0.57	0.30
January	0.05	3.50	0.02	0.01
February	0.06	4.13	0.02	0.01
March	0.07	4.26	0.02	0.01
April	0.15	5.20	0.05	0.03
May	0.17	4.17	0.07	0.04
June	0.21	3.48	0.12	0.06
July	0.20	2.53	0.14	0.07
August	0.18	2.95	0.10	0.05
September	0.17	3.95	0.07	0.03
October	0.14	4.22	0.04	0.02
November	0.08	4.58	0.02	0.02
December	0.06	4.34	0.02	0.01
1940s	0.10	3.94	0.04	0.02
1950s	0.13	3.82	0.06	0.03
1960s	0.14	3.87	0.07	0.04
1970s	0.13	4.00	0.06	0.03

Williston, North Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.13	3.79	0.06	0.03
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.04	2.00	0.02	0.02
3rd quartile	0.13	5.00	0.06	0.03
Median	0.04	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.24	7.00	0.10	0.05
90th percentile	0.35	8.00	0.15	0.07
95th percentile	0.55	12.00	0.24	0.12
99th percentile	1.26	22.00	0.60	0.28
January	0.06	4.03	0.02	0.01
February	0.06	3.65	0.02	0.01
March	0.08	3.90	0.03	0.02
April	0.13	4.09	0.04	0.02
May	0.19	4.57	0.08	0.04
June	0.20	3.57	0.10	0.06
July	0.23	2.84	0.15	0.08
August	0.15	2.69	0.09	0.06
September	0.14	3.79	0.06	0.03
October	0.14	4.82	0.04	0.02
November	0.09	4.23	0.03	0.02
December	0.06	3.77	0.02	0.01
1980s	0.13	3.79	0.06	0.03
1990s	0.13	3.84	0.06	0.03
2000s	0.13	3.63	0.06	0.03
2010s	0.16	4.06	0.08	0.04

Appendix A-17. Aberdeen, South Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.19	4.17	0.10	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.06	3.00	0.03	0.02
3rd quartile	0.21	5.00	0.10	0.05
Median	0.06	3.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.37	7.00	0.17	0.08
90th percentile	0.52	9.00	0.24	0.12
95th percentile	0.82	13.00	0.41	0.21
99th percentile	1.57	25.00	0.88	0.46
January	0.07	4.08	0.03	0.02
February	0.10	5.12	0.03	0.02
March	0.14	5.16	0.05	0.03
April	0.20	5.24	0.07	0.03
May	0.23	4.20	0.11	0.05
June	0.28	3.60	0.16	0.08
July	0.30	2.61	0.21	0.11
August	0.22	2.84	0.14	0.08
September	0.22	3.90	0.12	0.05
October	0.22	5.49	0.08	0.05
November	0.11	4.60	0.04	0.02
December	0.07	4.43	0.02	0.01
1940s	0.19	3.92	0.11	0.07
1950s	0.22	4.62	0.11	0.06
1960s	0.19	4.07	0.09	0.05
1970s	0.17	3.94	0.09	0.05

Aberdeen, South Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.21	4.17	0.10	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.06	2.00	0.03	0.02
3rd quartile	0.22	5.00	0.10	0.05
Median	0.06	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.41	7.00	0.17	0.08
90th percentile	0.57	10.00	0.26	0.11
95th percentile	0.90	14.00	0.43	0.19
99th percentile	1.83	24.00	1.09	0.45
January	0.07	4.29	0.02	0.01
February	0.08	4.90	0.03	0.02
March	0.13	5.16	0.04	0.02
April	0.22	5.58	0.08	0.04
May	0.27	4.66	0.12	0.05
June	0.27	3.53	0.16	0.07
July	0.29	2.92	0.20	0.10
August	0.27	2.92	0.18	0.10
September	0.26	4.17	0.12	0.06
October	0.24	5.13	0.08	0.04
November	0.09	4.29	0.03	0.02
December	0.07	3.64	0.02	0.01
1980s	0.21	4.38	0.10	0.05
1990s	0.21	4.14	0.11	0.05
2000s	0.21	3.83	0.10	0.05
2010s	0.19	4.62	0.09	0.05

Appendix A-18. Huron, South Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.19	4.23	0.09	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.03	0.02
3rd quartile	0.21	5.00	0.09	0.04
Median	0.05	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.37	7.00	0.15	0.07
90th percentile	0.52	10.00	0.23	0.10
95th percentile	0.84	14.00	0.34	0.16
99th percentile	1.65	25.00	0.81	0.37
January	0.06	3.66	0.02	0.01
February	0.11	5.28	0.03	0.02
March	0.16	5.88	0.04	0.02
April	0.20	5.34	0.07	0.03
May	0.23	4.10	0.11	0.05
June	0.27	3.49	0.15	0.07
July	0.24	2.65	0.16	0.09
August	0.22	2.98	0.14	0.07
September	0.22	3.91	0.10	0.05
October	0.23	5.37	0.09	0.04
November	0.12	4.76	0.03	0.02
December	0.09	4.43	0.02	0.01
1940s	0.19	3.35	0.10	0.06
1950s	0.18	4.35	0.08	0.04
1960s	0.20	4.12	0.10	0.05
1970s	0.19	4.35	0.08	0.04

Huron, South Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.22	4.28	0.10	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.06	2.00	0.03	0.02
3rd quartile	0.24	5.00	0.10	0.05
Median	0.06	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.43	7.70	0.19	0.09
90th percentile	0.62	10.00	0.27	0.12
95th percentile	0.97	14.00	0.45	0.20
99th percentile	1.89	25.18	0.94	0.46
January	0.08	4.38	0.02	0.01
February	0.09	4.58	0.03	0.02
March	0.16	5.34	0.05	0.03
April	0.23	5.53	0.08	0.03
May	0.24	4.16	0.10	0.05
June	0.31	3.50	0.17	0.09
July	0.29	3.01	0.19	0.10
August	0.27	2.88	0.17	0.09
September	0.28	4.32	0.14	0.06
October	0.23	5.38	0.07	0.03
November	0.14	4.86	0.04	0.02
December	0.08	4.54	0.03	0.02
1980s	0.21	4.28	0.10	0.05
1990s	0.23	4.57	0.11	0.05
2000s	0.22	3.85	0.11	0.05
2010s	0.22	4.56	0.10	0.05

Appendix A-19. Rapid City, South Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.15	4.03	0.07	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.02	0.02
3rd quartile	0.15	5.00	0.07	0.04
Median	0.05	2.00	0.02	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.28	7.00	0.12	0.06
90th percentile	0.40	9.00	0.17	0.08
95th percentile	0.68	13.00	0.28	0.14
99th percentile	1.40	26.53	0.69	0.37
January	0.06	3.80	0.02	0.01
February	0.07	4.57	0.02	0.01
March	0.12	5.26	0.03	0.02
April	0.18	5.54	0.05	0.03
May	0.19	4.37	0.08	0.04
June	0.22	3.04	0.12	0.07
July	0.20	2.53	0.13	0.08
August	0.17	2.45	0.12	0.07
September	0.16	3.94	0.06	0.04
October	0.17	5.57	0.05	0.03
November	0.08	4.38	0.02	0.02
December	0.06	4.04	0.02	0.01
1940s	0.16	4.20	0.07	0.04
1950s	0.14	3.84	0.07	0.04
1960s	0.16	4.01	0.07	0.04
1970s	0.15	4.22	0.06	0.04

Rapid City, South Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.16	4.16	0.07	0.04
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.05	2.00	0.03	0.02
3rd quartile	0.16	5.00	0.07	0.04
Median	0.05	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.29	8.00	0.12	0.06
90th percentile	0.40	10.00	0.17	0.09
95th percentile	0.66	14.00	0.27	0.14
99th percentile	1.47	28.00	0.68	0.30
January	0.04	3.47	0.02	0.01
February	0.07	4.22	0.02	0.01
March	0.11	5.52	0.03	0.02
April	0.19	6.00	0.05	0.03
May	0.23	4.67	0.09	0.05
June	0.18	3.12	0.11	0.06
July	0.17	2.62	0.11	0.07
August	0.18	2.63	0.12	0.07
September	0.16	3.99	0.08	0.04
October	0.19	5.08	0.05	0.03
November	0.15	5.43	0.04	0.02
December	0.06	3.94	0.02	0.01
1980s	0.15	4.41	0.07	0.04
1990s	0.16	4.28	0.07	0.04
2000s	0.15	3.77	0.07	0.04
2010s	0.17	3.96	0.08	0.05

Appendix A-20. Sioux Falls, South Dakota precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.23	4.35	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.04	0.02
3rd quartile	0.26	5.00	0.11	0.06
Median	0.07	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.46	8.00	0.20	0.09
90th percentile	0.65	10.00	0.28	0.13
95th percentile	0.99	14.00	0.45	0.20
99th percentile	1.95	26.00	0.89	0.43
January	0.08	4.82	0.02	0.01
February	0.13	5.21	0.03	0.02
March	0.18	5.68	0.05	0.03
April	0.25	5.16	0.08	0.04
May	0.25	3.84	0.12	0.06
June	0.29	3.27	0.16	0.08
July	0.28	2.82	0.18	0.09
August	0.32	3.14	0.19	0.09
September	0.36	4.60	0.16	0.07
October	0.25	4.99	0.10	0.05
November	0.16	5.61	0.04	0.02
December	0.11	4.88	0.03	0.02
1940s	0.21	3.95	0.10	0.05
1950s	0.23	4.19	0.11	0.05
1960s	0.24	4.55	0.11	0.06
1970s	0.23	4.35	0.10	0.05

Sioux Falls, South Dakota precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.22	4.18	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.06	2.00	0.03	0.02
3rd quartile	0.24	5.00	0.10	0.05
Median	0.06	2.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.43	8.00	0.19	0.09
90th percentile	0.64	10.00	0.27	0.12
95th percentile	0.99	14.00	0.48	0.21
99th percentile	1.96	23.00	0.98	0.42
January	0.07	3.83	0.02	0.02
February	0.08	4.52	0.03	0.01
March	0.16	4.92	0.06	0.03
April	0.25	5.35	0.09	0.04
May	0.24	4.13	0.12	0.06
June	0.29	3.30	0.17	0.08
July	0.29	2.82	0.18	0.09
August	0.31	3.28	0.18	0.09
September	0.27	4.16	0.14	0.07
October	0.23	4.87	0.09	0.04
November	0.18	5.58	0.05	0.02
December	0.09	4.22	0.03	0.02
1980s	0.20	4.31	0.09	0.04
1990s	0.23	4.18	0.11	0.05
2000s	0.24	4.08	0.12	0.06
2010s	0.23	4.10	0.11	0.06

Appendix A-21. Green Bay, Wisconsin precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.21	4.60	0.09	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.25	6.00	0.10	0.05
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.43	9.00	0.17	0.08
90th percentile	0.57	10.00	0.23	0.11
95th percentile	0.86	14.00	0.36	0.16
99th percentile	1.55	24.00	0.70	0.36
January	0.10	5.03	0.03	0.02
February	0.11	4.86	0.03	0.02
March	0.17	5.59	0.05	0.03
April	0.24	5.79	0.08	0.04
May	0.24	4.22	0.11	0.05
June	0.25	3.37	0.14	0.08
July	0.30	3.12	0.18	0.09
August	0.25	3.24	0.14	0.07
September	0.26	4.04	0.13	0.06
October	0.23	5.11	0.08	0.04
November	0.18	5.24	0.05	0.03
December	0.13	5.90	0.03	0.02
1940s	0.20	4.77	0.09	0.04
1950s	0.21	4.57	0.09	0.05
1960s	0.21	4.40	0.10	0.05
1970s	0.20	4.78	0.09	0.04

Green Bay, Wisconsin precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.21	4.52	0.10	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.04	0.02
3rd quartile	0.25	6.00	0.11	0.05
Median	0.07	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.44	8.00	0.18	0.08
90th percentile	0.60	10.00	0.24	0.11
95th percentile	0.91	14.00	0.38	0.17
99th percentile	1.62	23.00	0.76	0.39
January	0.09	4.83	0.03	0.02
February	0.11	4.89	0.03	0.02
March	0.17	5.10	0.05	0.03
April	0.21	4.90	0.07	0.04
May	0.22	4.20	0.10	0.05
June	0.30	3.70	0.16	0.08
July	0.29	3.27	0.17	0.08
August	0.29	3.58	0.17	0.09
September	0.25	4.14	0.12	0.06
October	0.24	5.10	0.09	0.04
November	0.20	5.93	0.06	0.03
December	0.12	5.20	0.04	0.02
1980s	0.21	4.67	0.10	0.05
1990s	0.21	4.38	0.09	0.05
2000s	0.20	4.44	0.09	0.05
2010s	0.27	4.75	0.12	0.06

Appendix A-22. Madison, Wisconsin precipitation characteristics (1948-1979)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.23	4.43	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.28	6.00	0.12	0.06
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.47	8.00	0.20	0.09
90th percentile	0.64	10.00	0.28	0.12
95th percentile	0.98	14.00	0.42	0.19
99th percentile	1.99	22.00	0.90	0.42
January	0.11	5.13	0.03	0.02
February	0.13	5.18	0.04	0.02
March	0.17	5.24	0.06	0.03
April	0.23	4.70	0.09	0.04
May	0.26	4.02	0.12	0.07
June	0.32	3.22	0.18	0.09
July	0.38	3.30	0.22	0.11
August	0.33	3.32	0.19	0.09
September	0.27	4.04	0.12	0.06
October	0.25	4.88	0.10	0.05
November	0.19	4.93	0.07	0.03
December	0.15	5.58	0.04	0.02
1940s	0.21	4.35	0.10	0.04
1950s	0.24	4.49	0.11	0.06
1960s	0.23	4.29	0.11	0.05
1970s	0.23	4.51	0.10	0.05

Madison, Wisconsin precipitation characteristics (1980-2013)

Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.24	4.70	0.11	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.29	6.00	0.11	0.05
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.49	9.00	0.20	0.09
90th percentile	0.68	11.00	0.28	0.12
95th percentile	1.00	15.00	0.46	0.19
99th percentile	1.99	24.00	1.02	0.43
January	0.10	4.87	0.03	0.02
February	0.14	5.46	0.04	0.02
March	0.19	5.23	0.06	0.03
April	0.24	5.19	0.09	0.04
May	0.25	4.11	0.13	0.06
June	0.35	3.80	0.20	0.09
July	0.33	3.09	0.20	0.10
August	0.39	3.76	0.22	0.10
September	0.29	4.29	0.14	0.06
October	0.25	5.36	0.09	0.04
November	0.21	5.80	0.06	0.03
December	0.16	6.02	0.04	0.02
1980s	0.23	4.66	0.11	0.05
1990s	0.24	4.71	0.11	0.05
2000s	0.26	4.68	0.11	0.05
2010s	0.25	4.90	0.11	0.05

Appendix A-23. Milwaukee, Wisconsin precipitation characteristics (1948-1979)

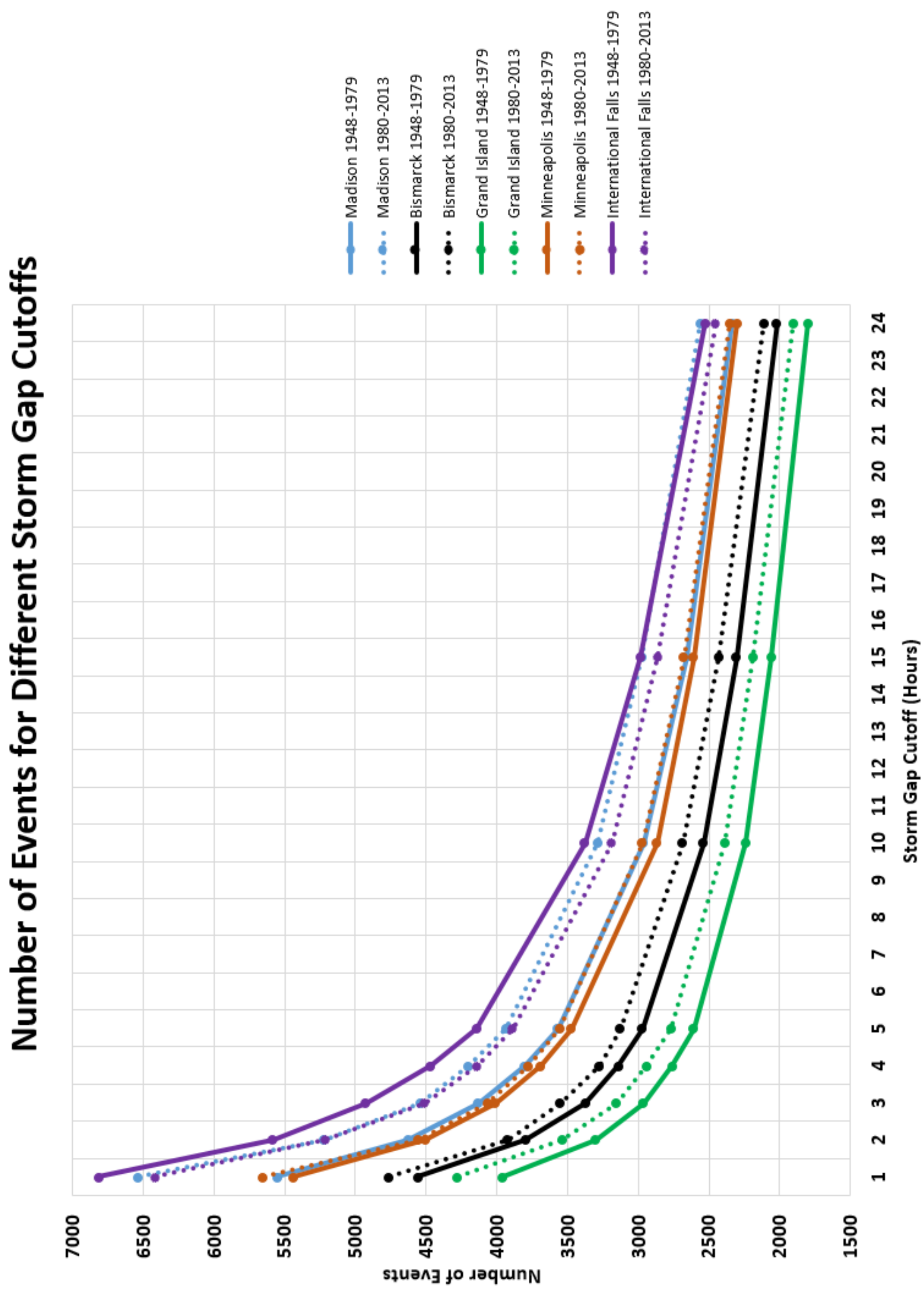
Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.22	4.59	0.09	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.07	3.00	0.03	0.02
3rd quartile	0.26	6.00	0.10	0.05
Median	0.07	3.00	0.03	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.44	9.00	0.18	0.08
90th percentile	0.61	11.00	0.24	0.10
95th percentile	0.94	15.00	0.38	0.16
99th percentile	1.74	24.44	0.81	0.34
January	0.14	5.24	0.04	0.02
February	0.13	5.16	0.04	0.02
March	0.20	5.69	0.06	0.03
April	0.24	4.91	0.09	0.04
May	0.20	4.00	0.10	0.05
June	0.28	3.30	0.16	0.08
July	0.33	3.29	0.18	0.09
August	0.28	3.21	0.17	0.08
September	0.28	3.99	0.13	0.06
October	0.23	5.11	0.09	0.04
November	0.19	5.19	0.06	0.03
December	0.17	5.79	0.04	0.02
1940s	0.19	4.57	0.08	0.04
1950s	0.23	4.66	0.10	0.05
1960s	0.21	4.34	0.10	0.05
1970s	0.22	4.77	0.09	0.04

Milwaukee, Wisconsin precipitation characteristics (1980-2013)

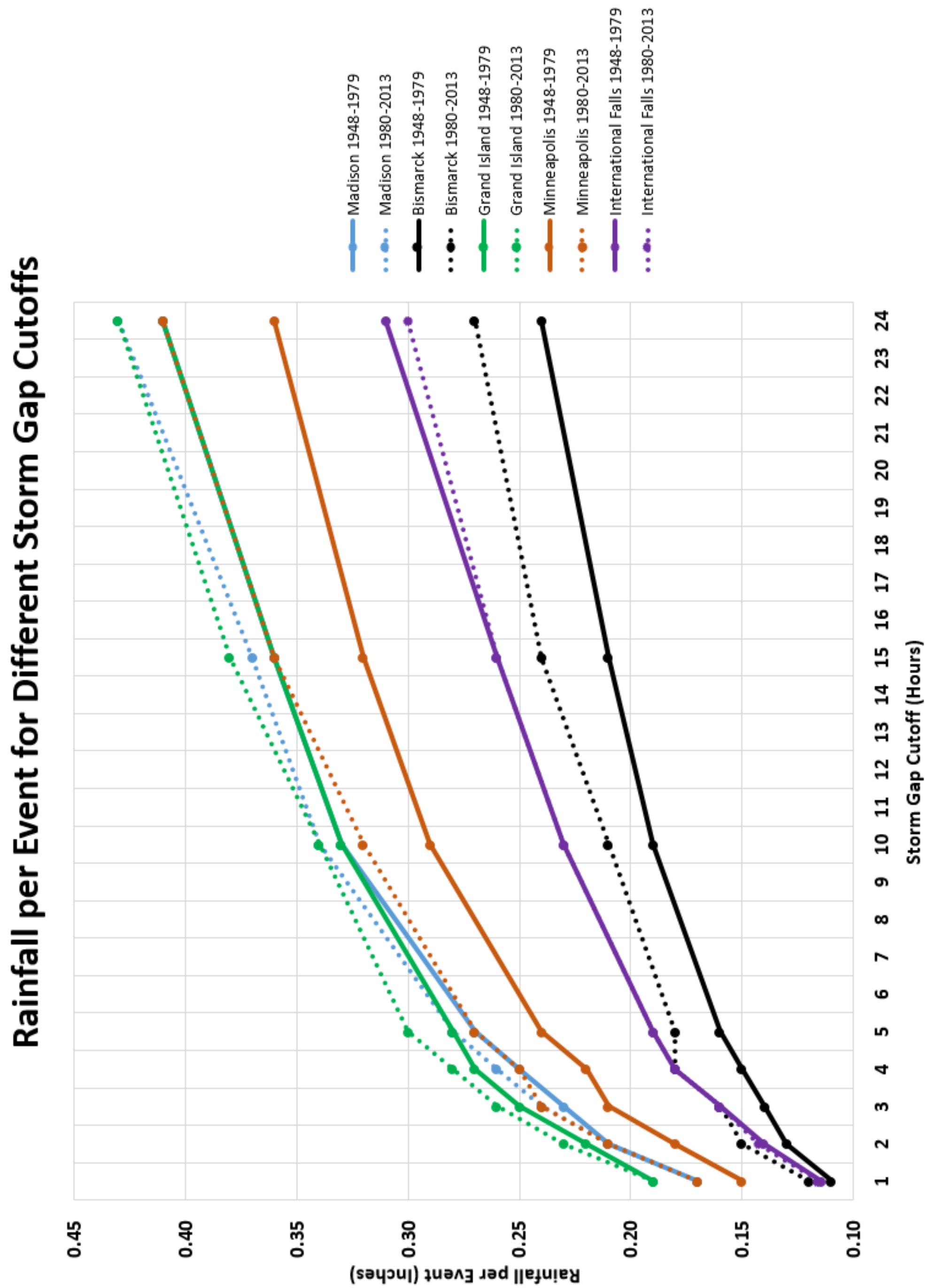
Characteristic	Total Rainfall (IN)	Duration (HR)	Maximum Storm Intensity (IN/HR)	Average Storm Intensity (IN/HR)
Average	0.24	4.68	0.10	0.05
1st quartile	0.02	1.00	0.01	0.01
2nd quartile	0.08	3.00	0.04	0.02
3rd quartile	0.30	6.00	0.12	0.05
Median	0.08	3.00	0.04	0.02
Mode	0.01	1.00	0.01	0.01
85th percentile	0.50	9.00	0.20	0.08
90th percentile	0.68	11.00	0.26	0.11
95th percentile	1.01	15.00	0.41	0.17
99th percentile	1.78	23.00	0.82	0.38
January	0.13	5.52	0.04	0.02
February	0.16	5.64	0.04	0.02
March	0.18	4.90	0.06	0.03
April	0.27	5.23	0.09	0.04
May	0.24	4.18	0.11	0.05
June	0.30	3.44	0.17	0.08
July	0.31	3.17	0.20	0.10
August	0.34	3.57	0.19	0.08
September	0.29	4.49	0.13	0.06
October	0.24	5.12	0.09	0.04
November	0.22	5.27	0.07	0.03
December	0.18	5.82	0.05	0.02
1980s	0.25	4.93	0.11	0.05
1990s	0.23	4.67	0.10	0.05
2000s	0.23	4.48	0.10	0.05
2010s	0.25	4.52	0.12	0.06

Appendix B. Sensitivity analyses for unique event definition

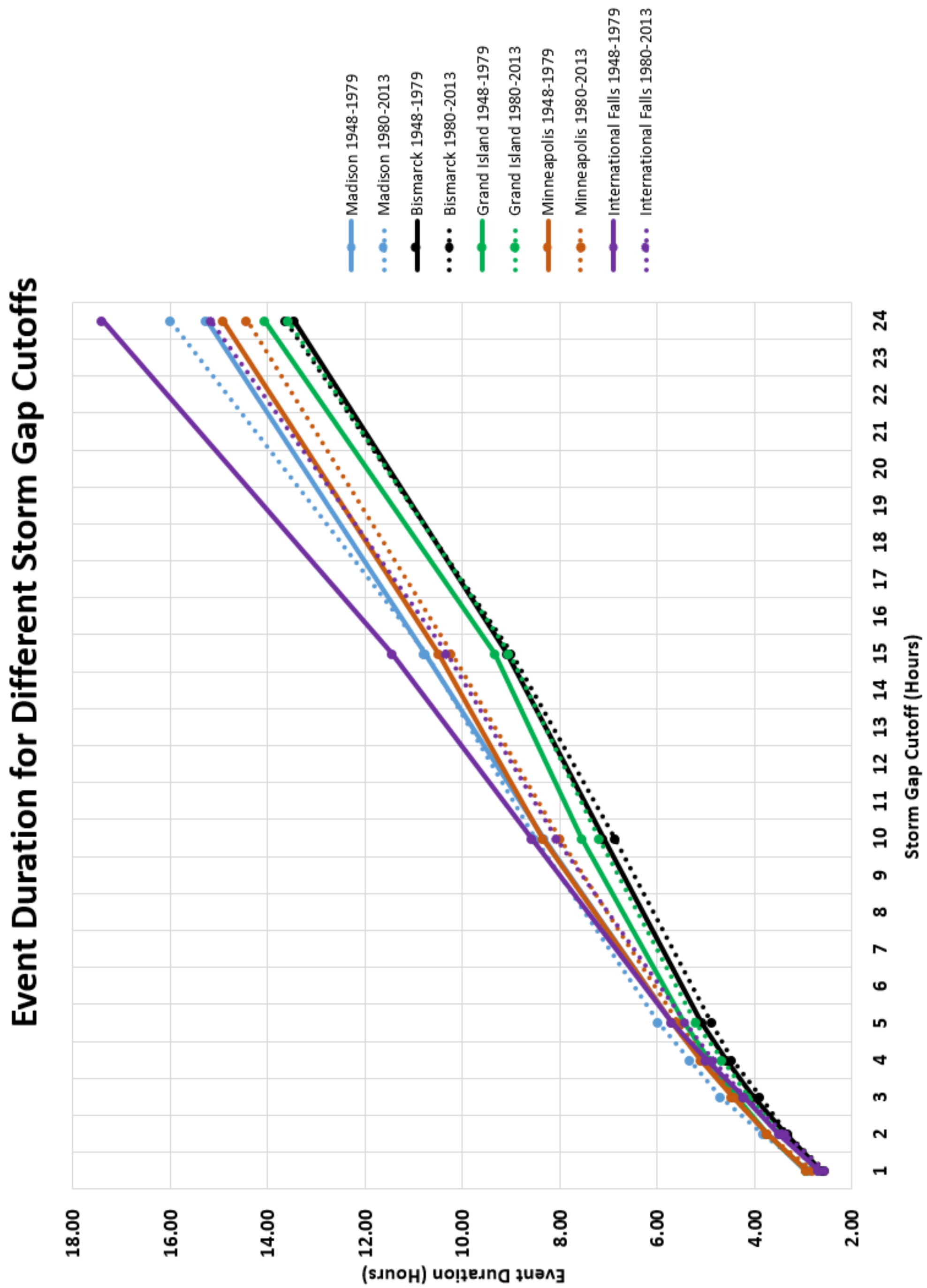
Appendix B-1. Highlights the differences in the number of events for the different time gap definitions for unique storm events. Increasing the time gap leads to a reduction in the number of events for each of the time periods. Solid lines represent the period of 1948-1979 and dashed lines represent the period of 1980-2013. Lines are also color coded to a specific location.



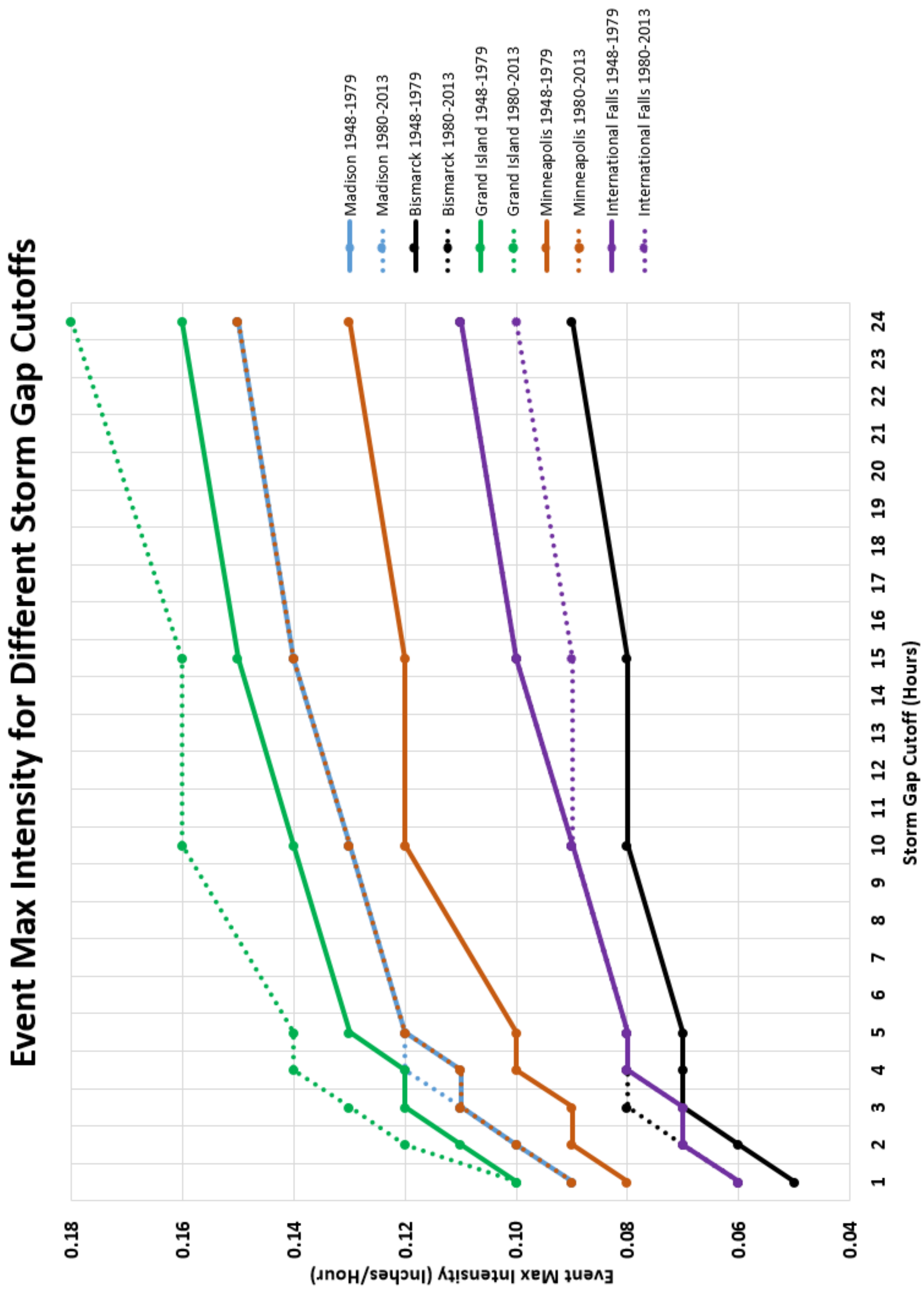
Appendix B-2. Highlights the differences in the amount of rainfall per event for the different time gap definitions for unique storm events. Increasing the time gap leads to an increase in the amount of rainfall per event for each of the time periods. Solid lines represent the period of 1948-1979 and dashed lines represent the period of 1980-2013. Lines are also color coded to a specific location.



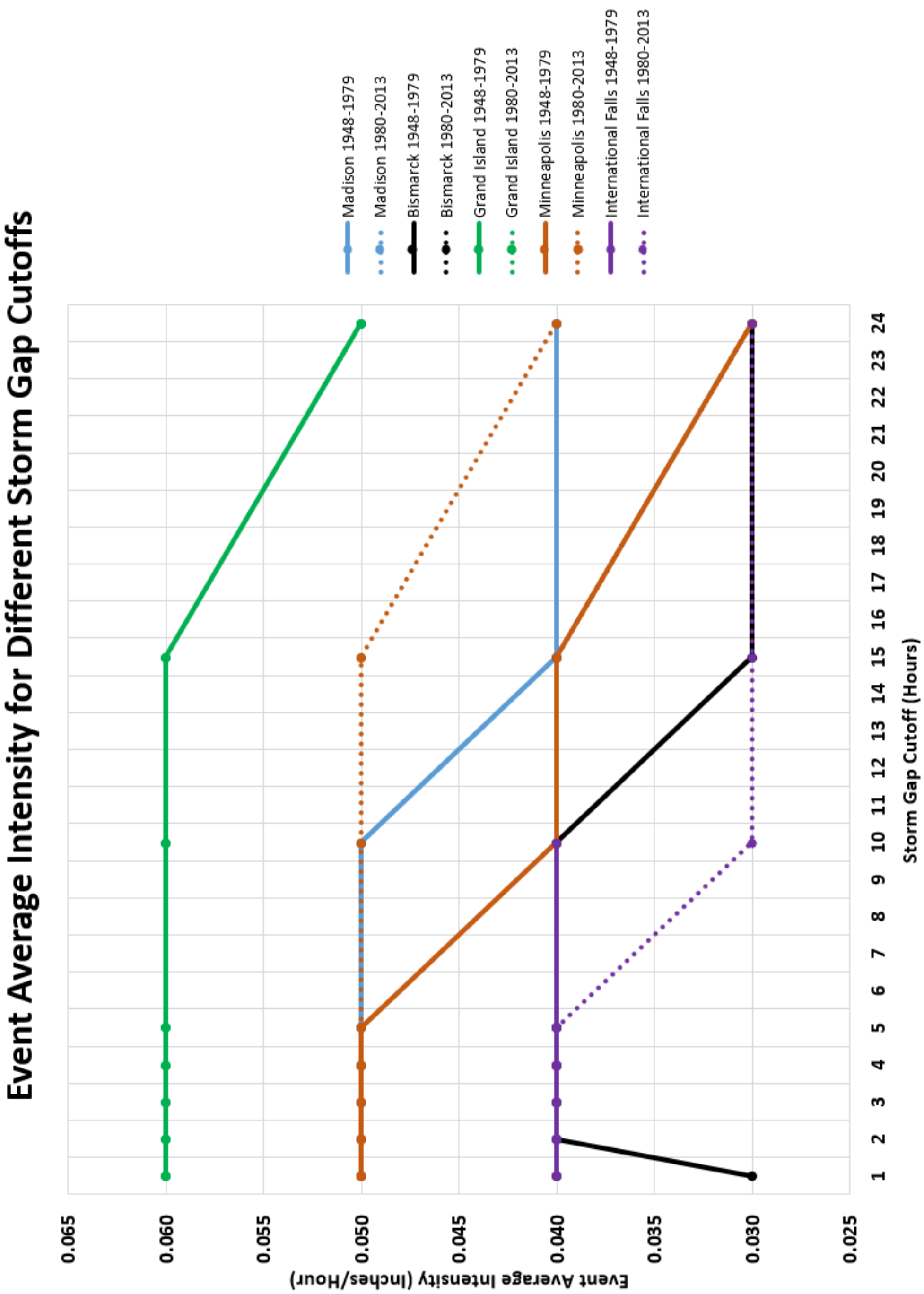
Appendix B-3. Highlights the differences in the duration of events for the different time gap definitions for unique storm events. Increasing the time gap leads to an increase in the average duration of events for each of the time periods. Solid lines represent the period of 1948-1979 and dashed lines represent the period of 1980-2013. Lines are also color coded to a specific location.



Appendix B-4. Highlights the differences in the max intensity of a storm event for the different time gap definitions for unique storm events. Increasing the time gap leads to an increase in the max intensity per event for each of the time periods. Solid lines represent the period of 1948-1979 and dashed lines represent the period of 1980-2013. Lines are also color coded to a specific location.

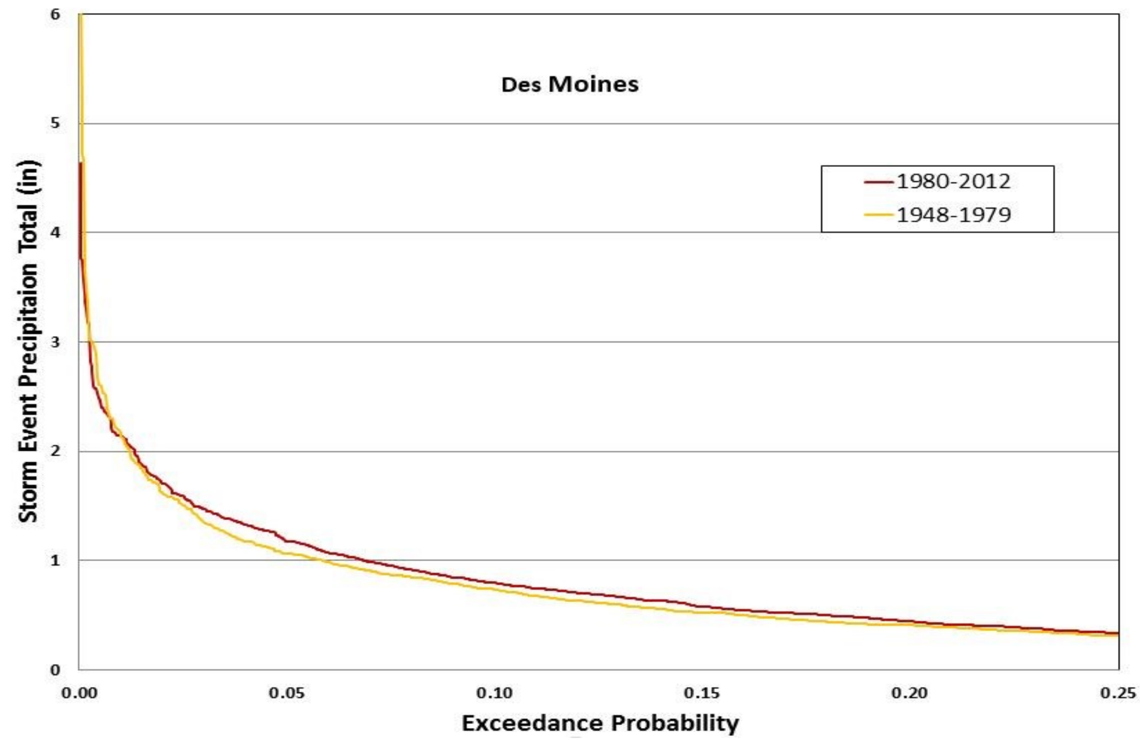


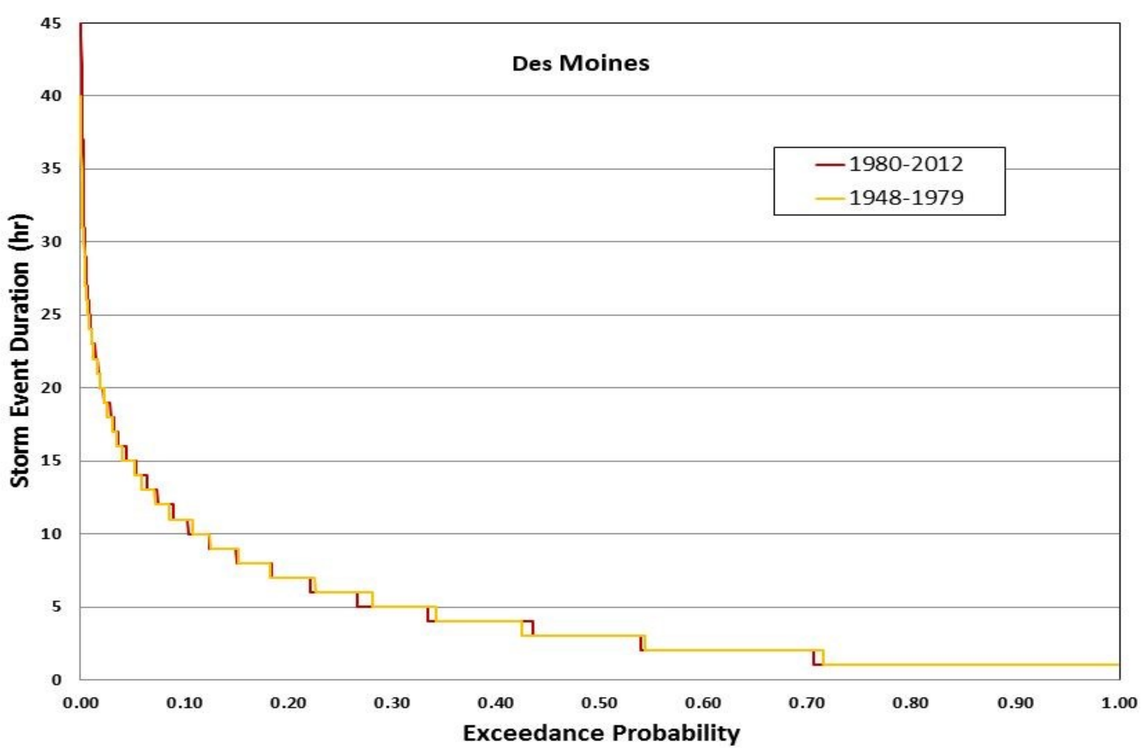
Appendix B-5. Highlights the differences in the average intensity of a storm event for the different time gap definitions for unique storm events. Increasing the time gap leads to only small increases or decreases in the average intensity per event for each of the time periods. Solid lines represent the period of 1948-1979 and dashed lines represent the period of 1980-2013. Lines are also color coded to a specific location.

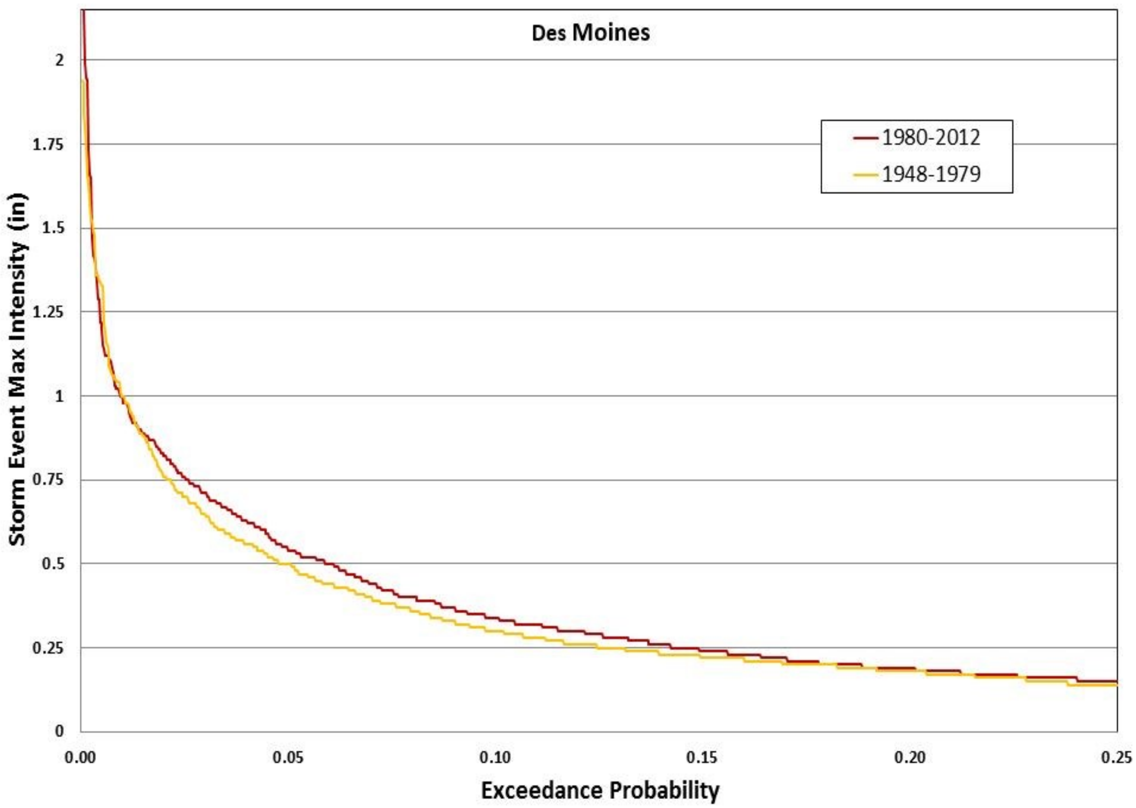


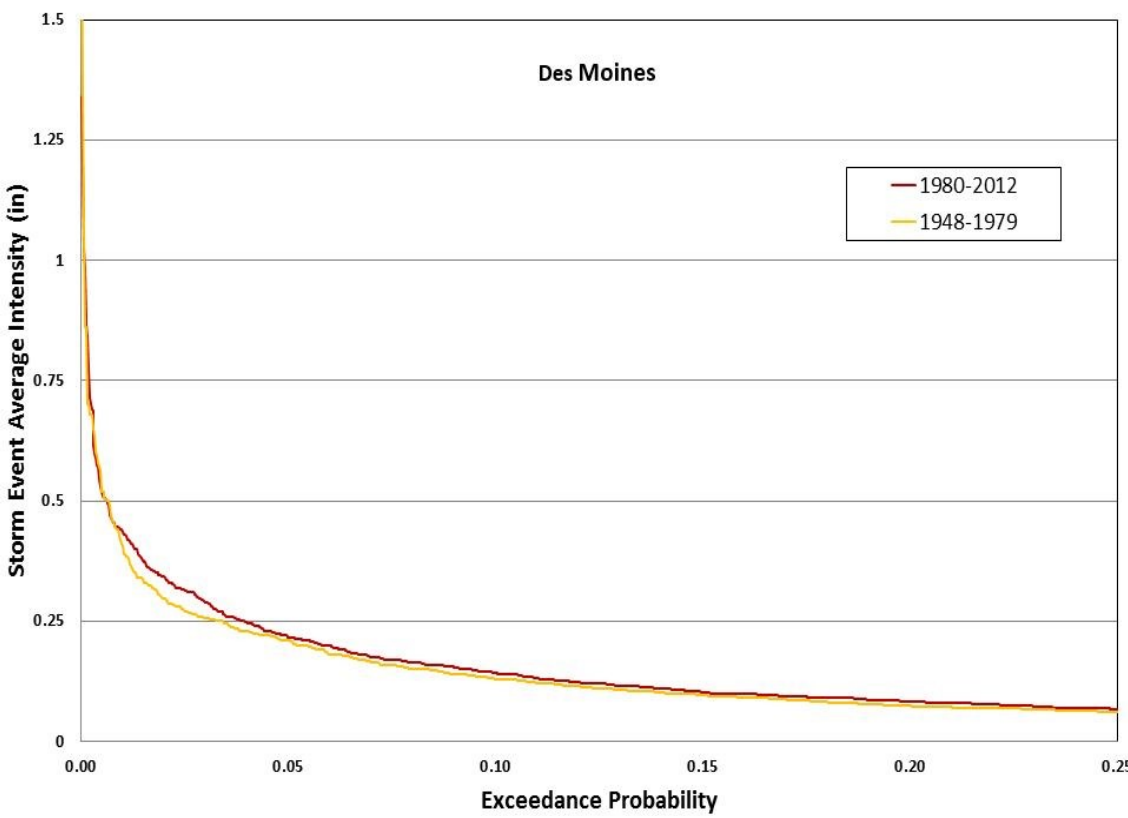
Appendix C: Exceedance probability curves for precipitation stations

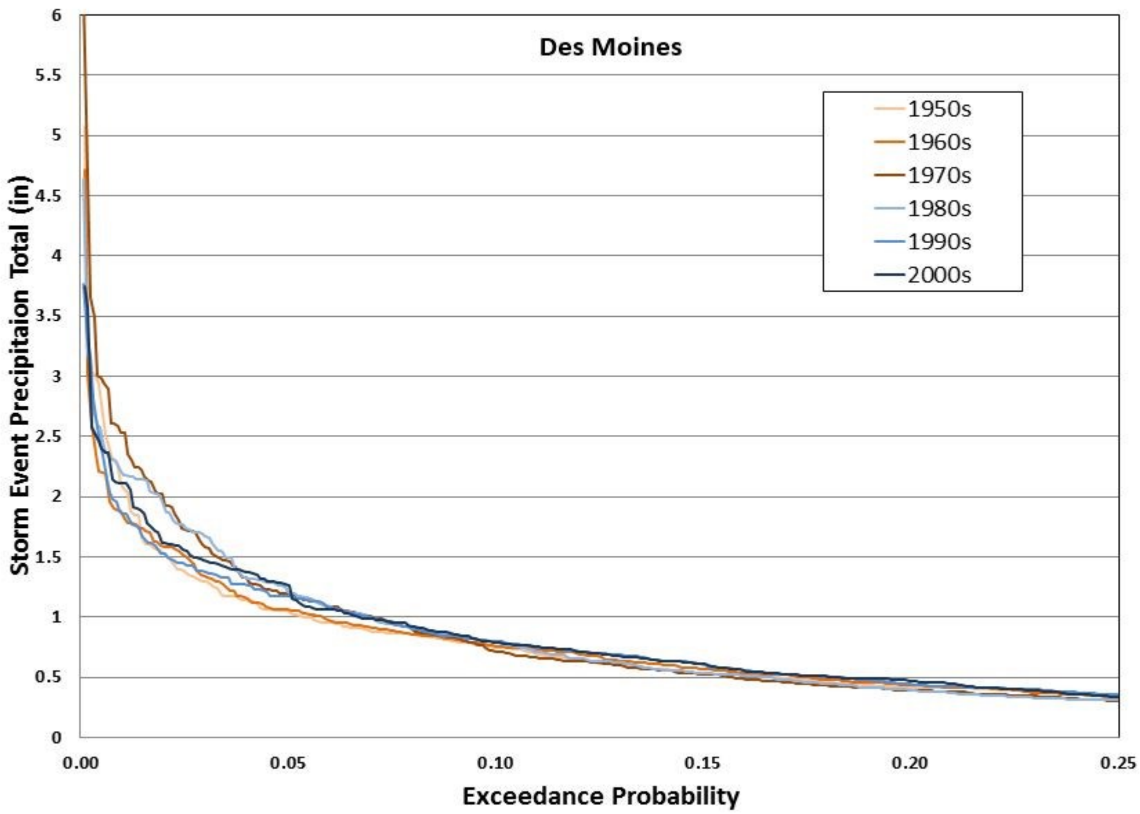
Appendix C-1. Exceedance probabilities of the characteristics of rainfall in Des Moines.

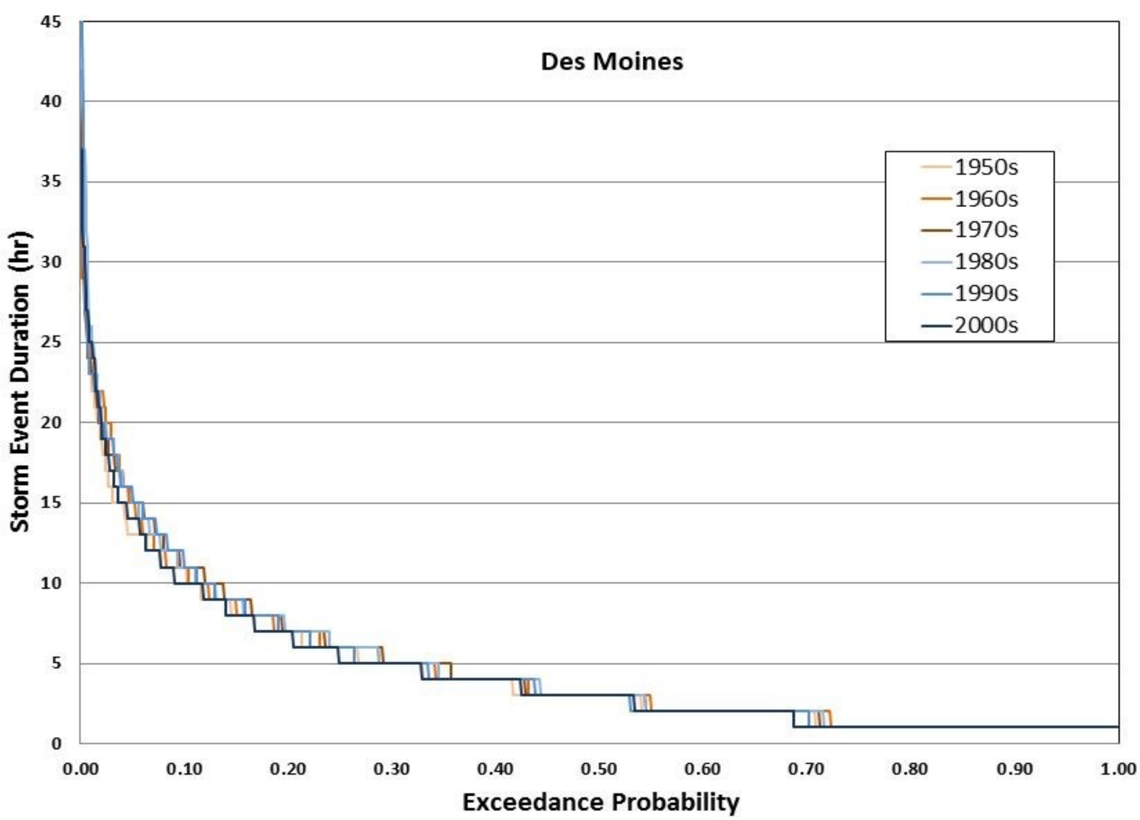


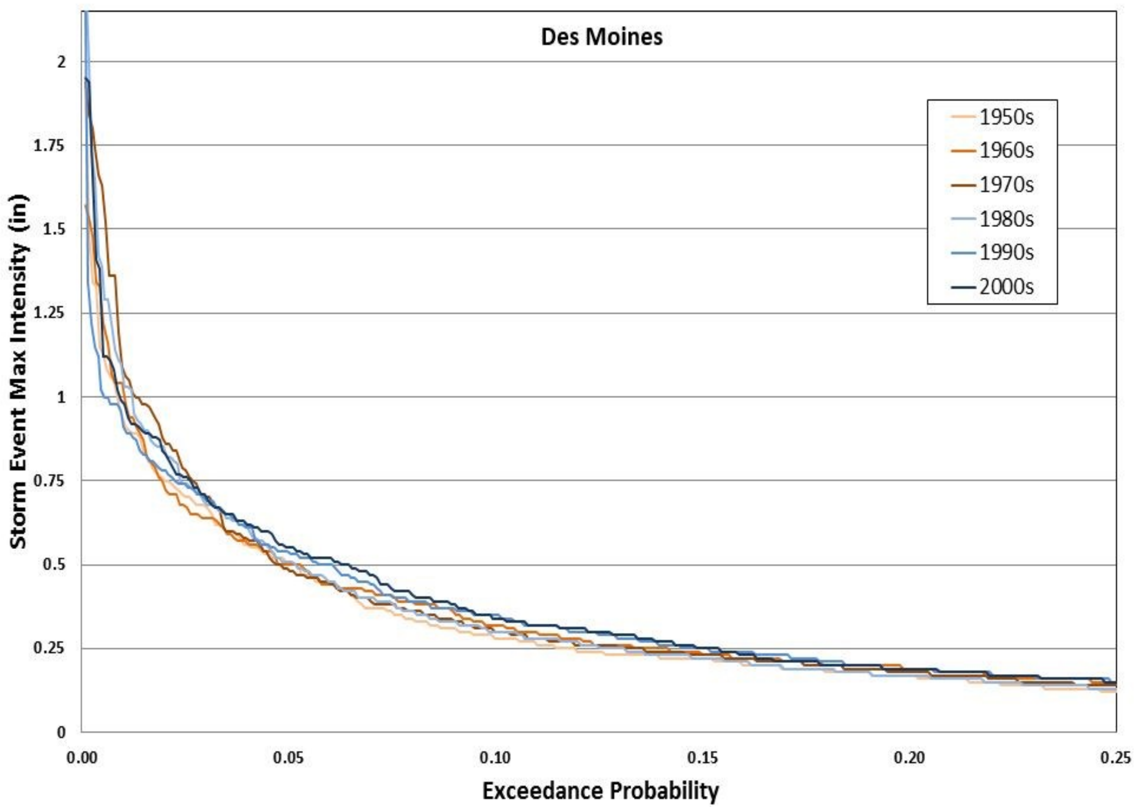



Des Moines
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0.00
0.05
0.10
0.15
0.20
0.25

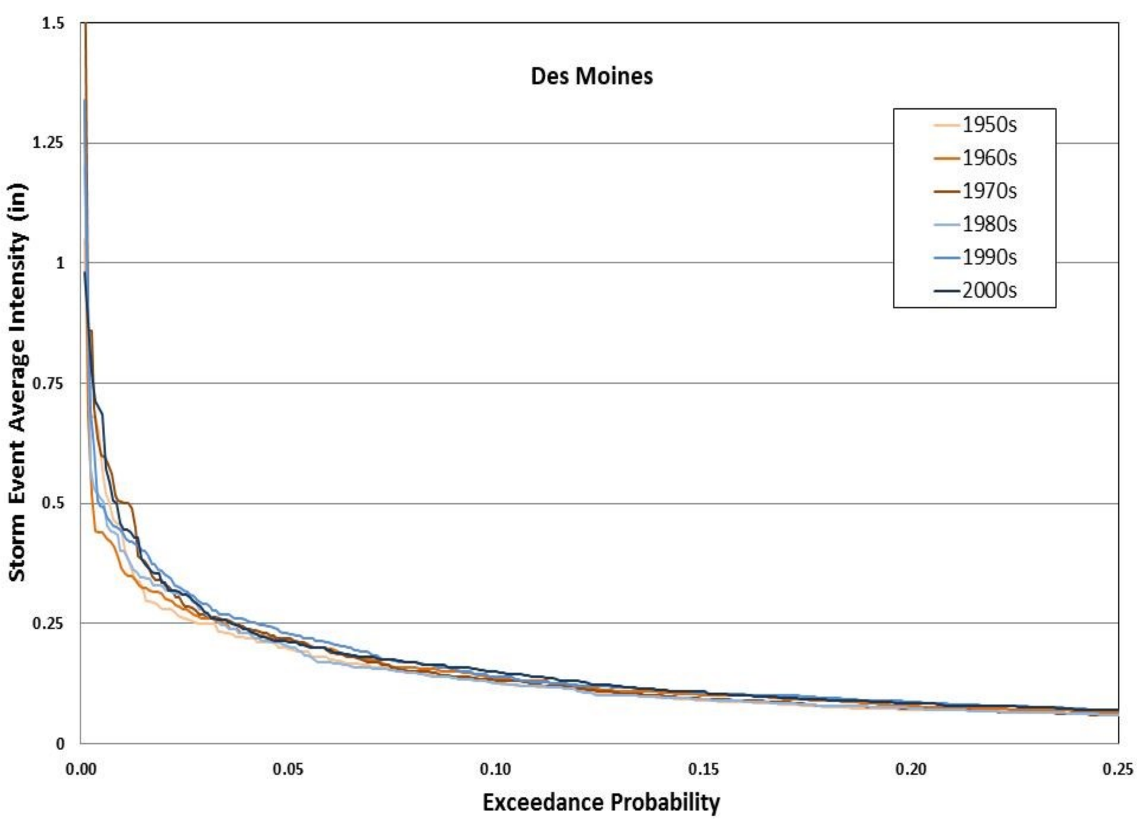

Des Moines
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
0.00
0.05
0.10
0.15
0.20
0.25


Des Moines
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
0.00
0.05
0.10
0.15
0.20
0.25


Des Moines
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

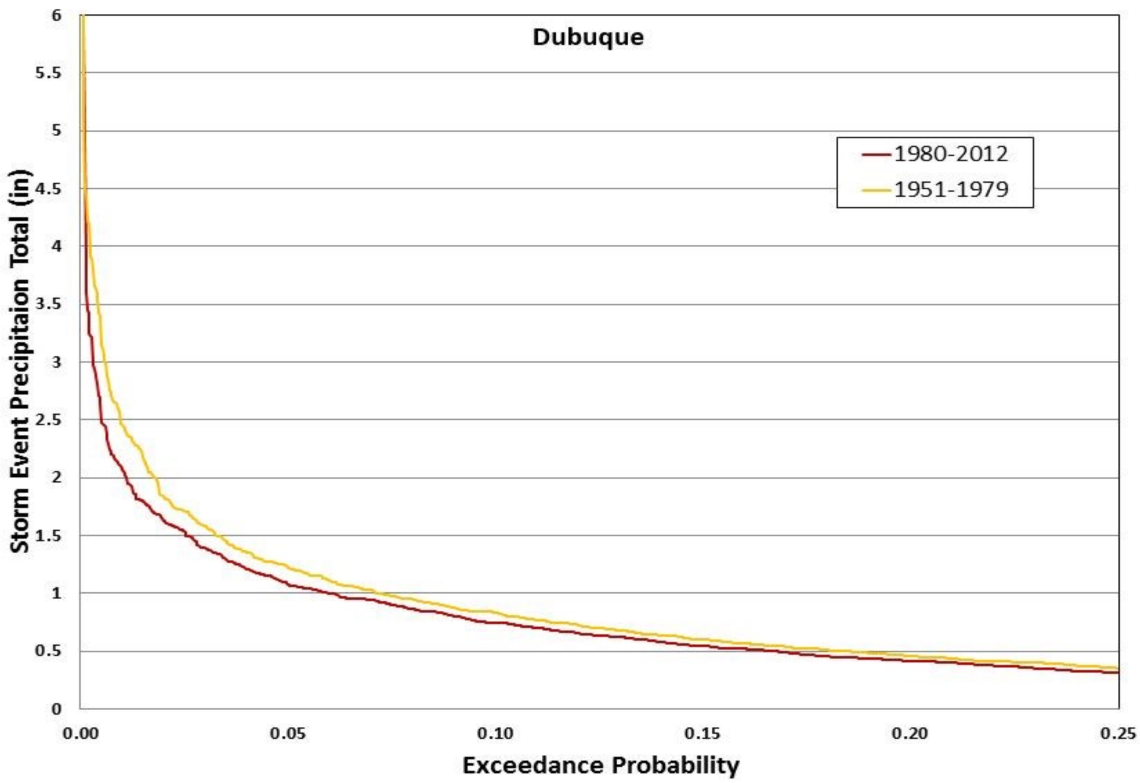


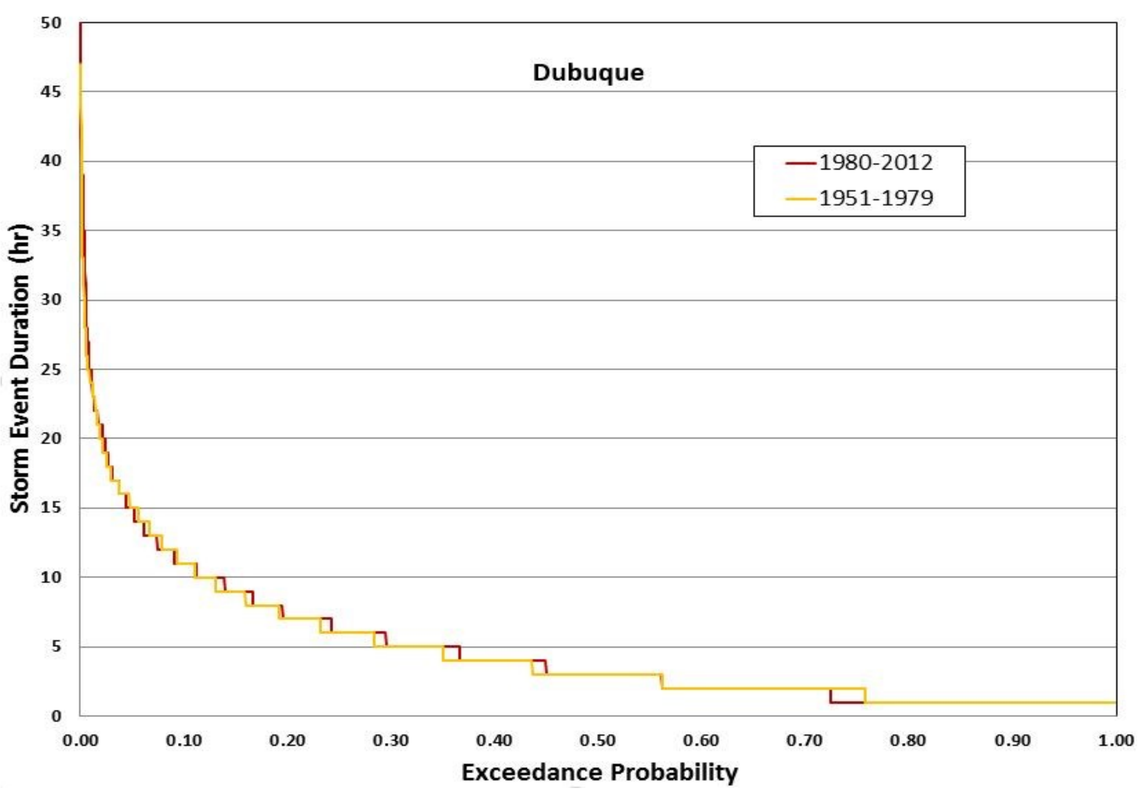
Des Moines
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Max Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0.00
0.05
0.10
0.15
0.20
0.25

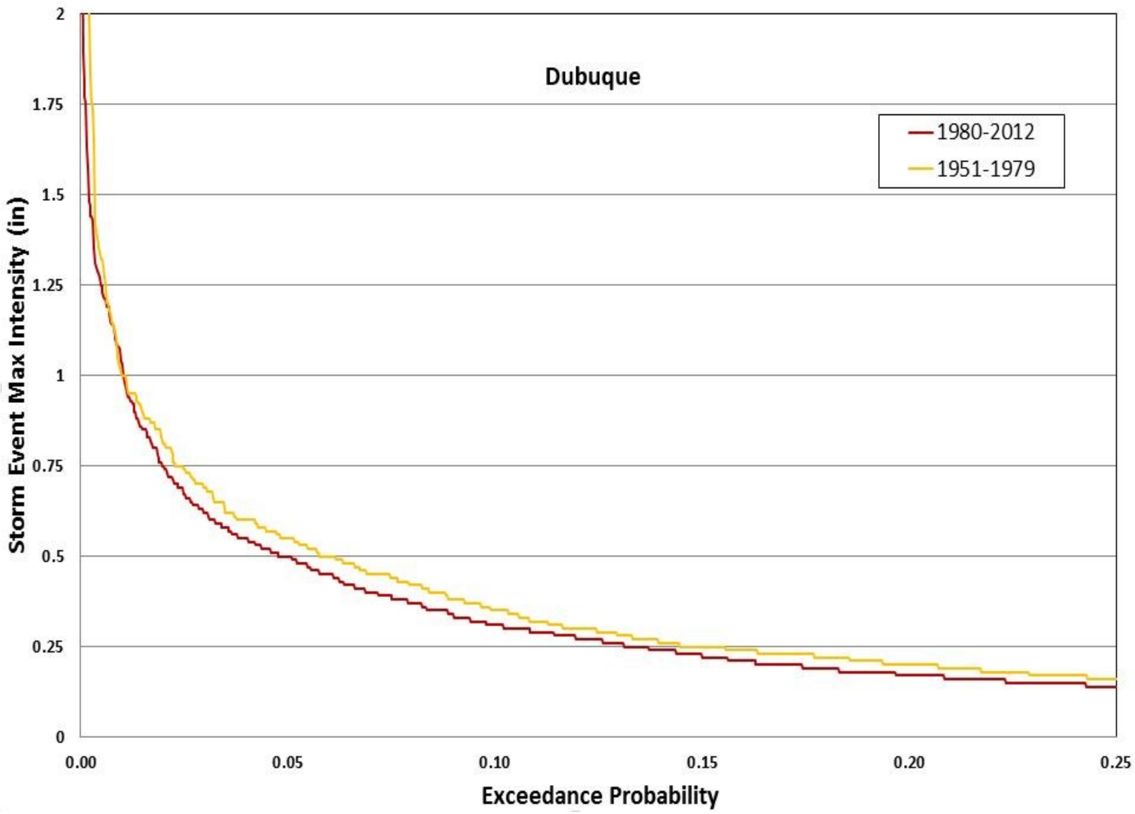


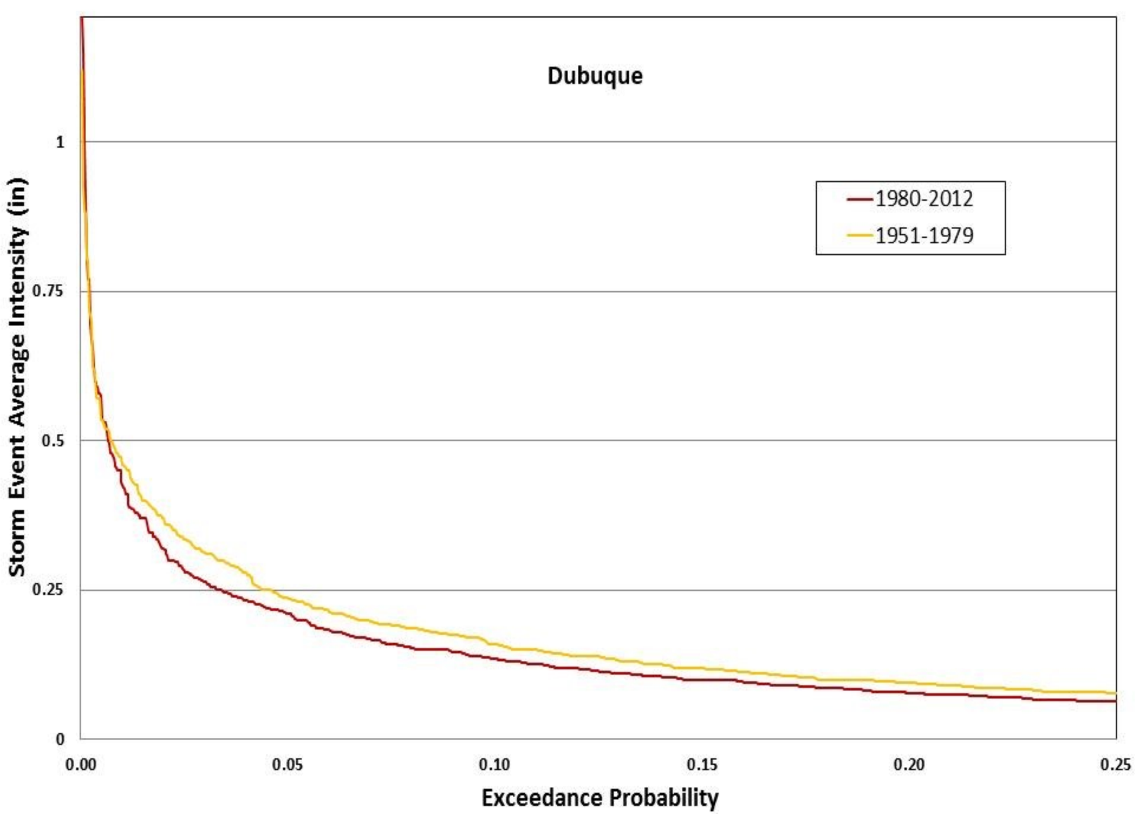
Des Moines
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Average Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
0.00
0.05
0.10
0.15
0.20
0.25

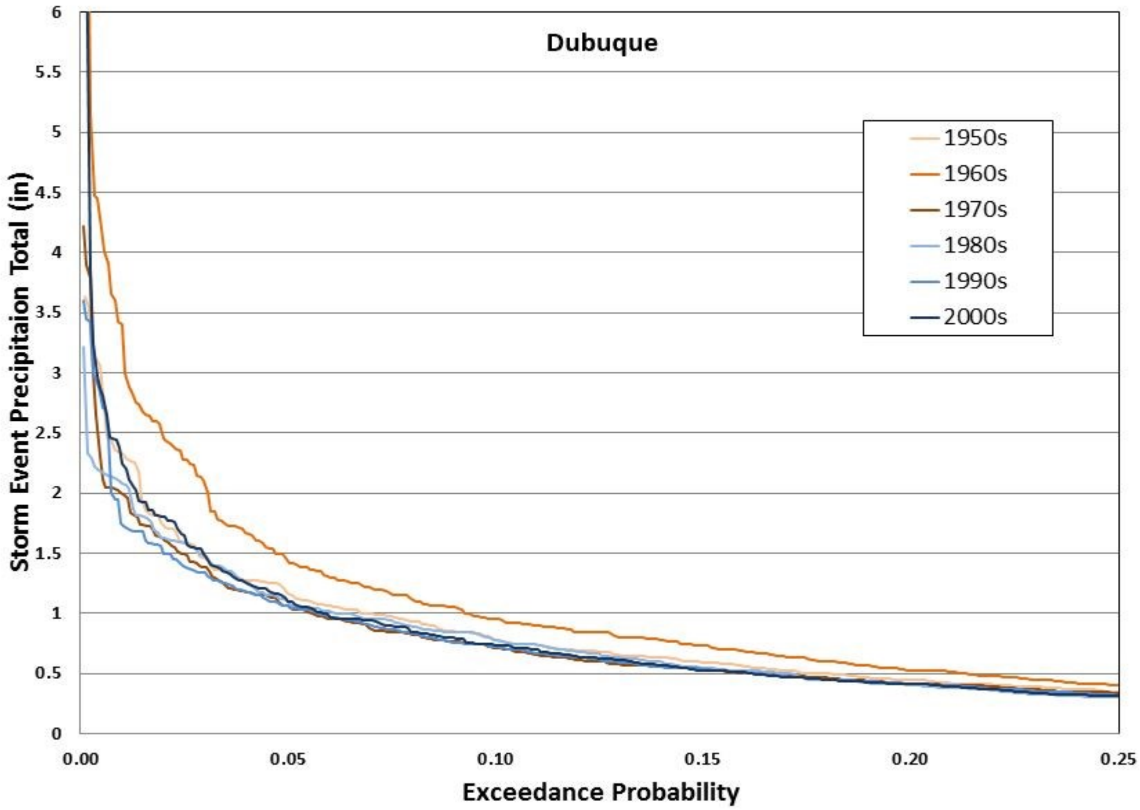
Appendix C-2. Exceedance probabilities of the characteristics of rainfall in Dubuque.

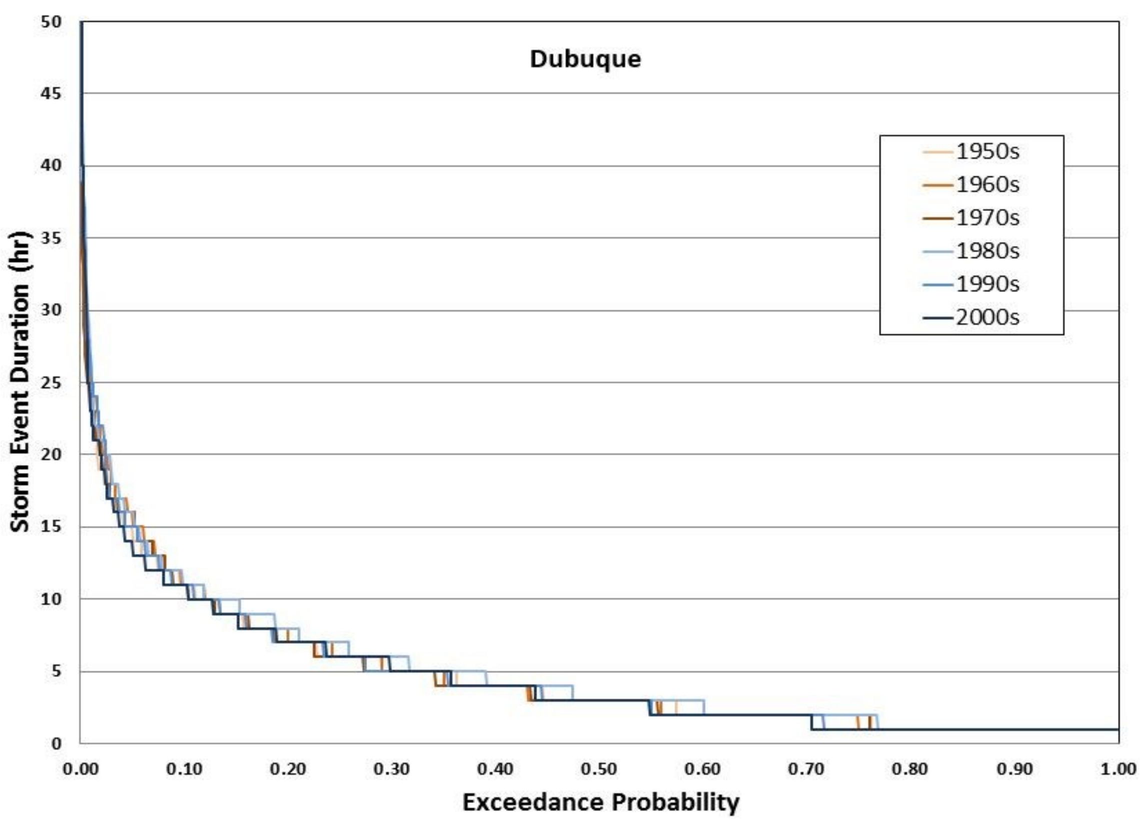


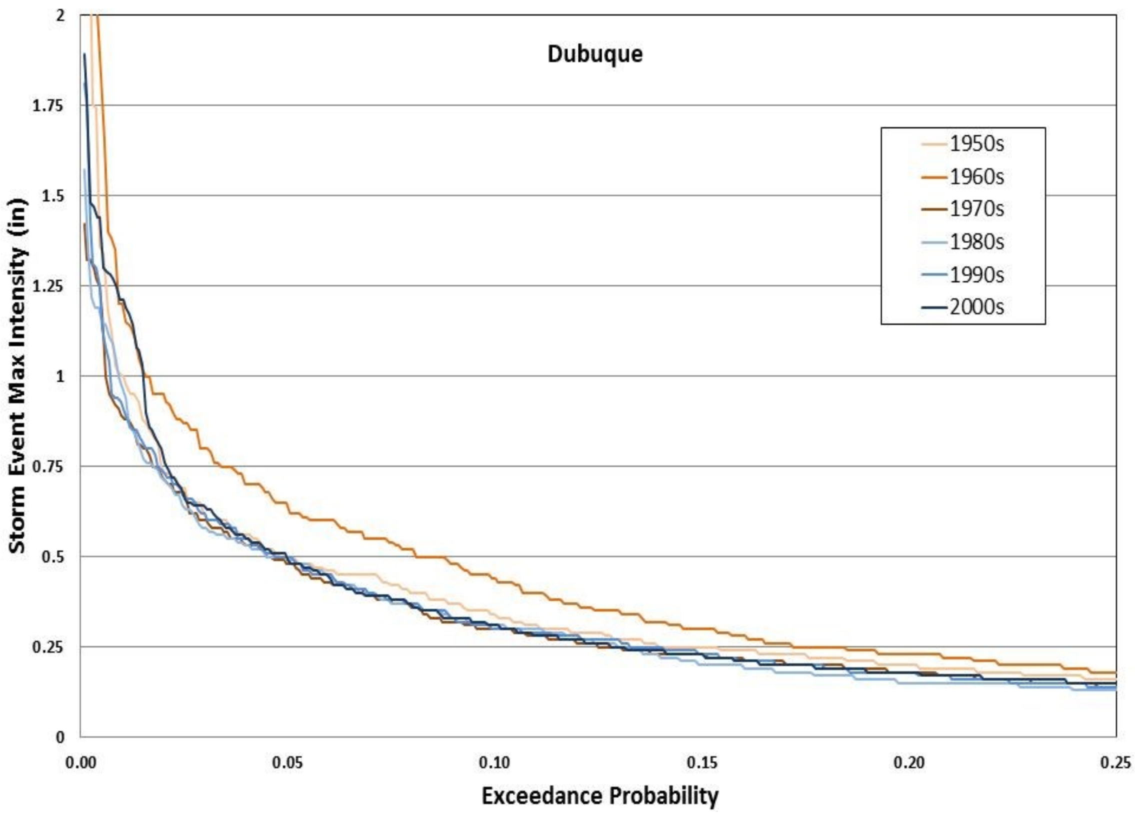


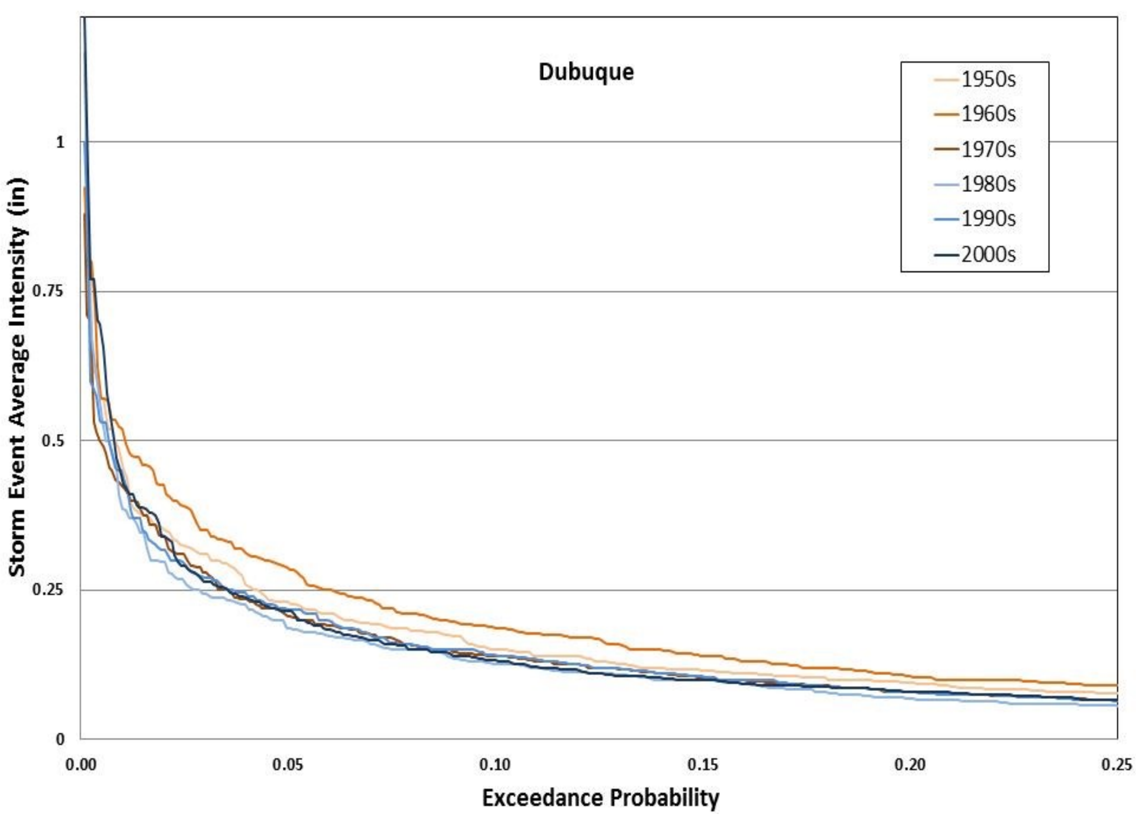

Dubuque
1980-2012
1951-1979
Storm Event Max Intensity (in)
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Dubuque
1980-2012
1951-1979
Storm Event Average Intensity (in)
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

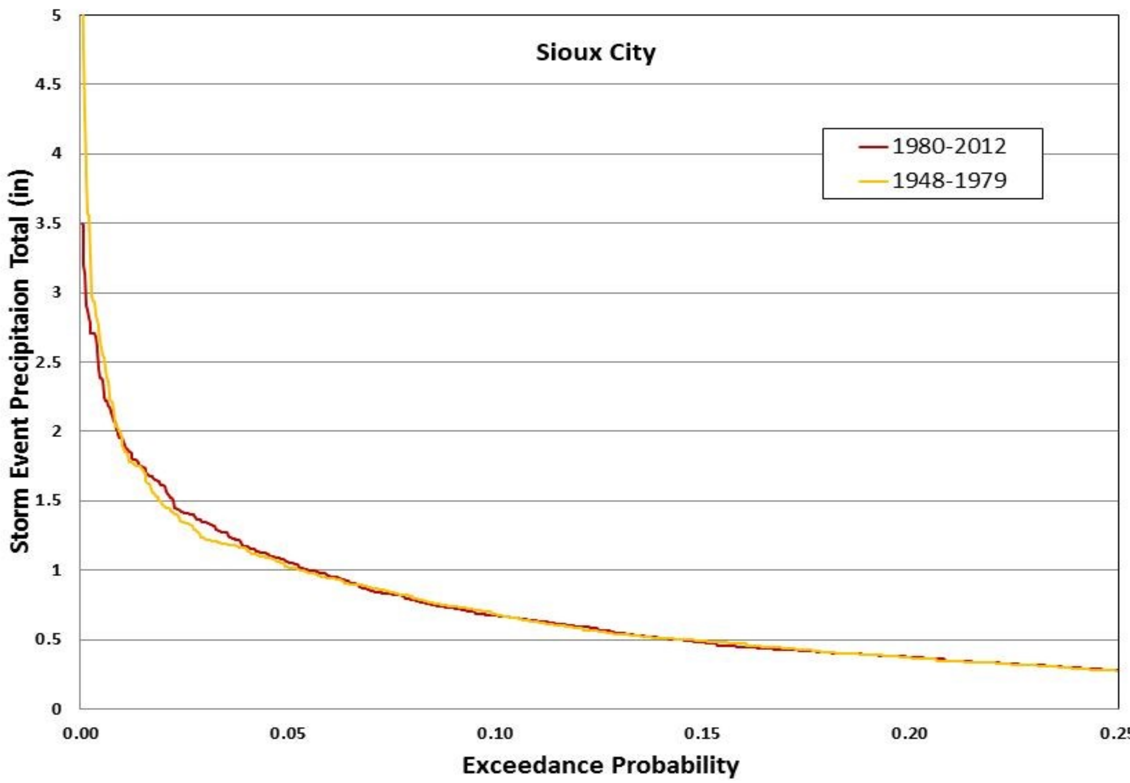

Dubuque
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
0.00
0.05
0.10
0.15
0.20
0.25

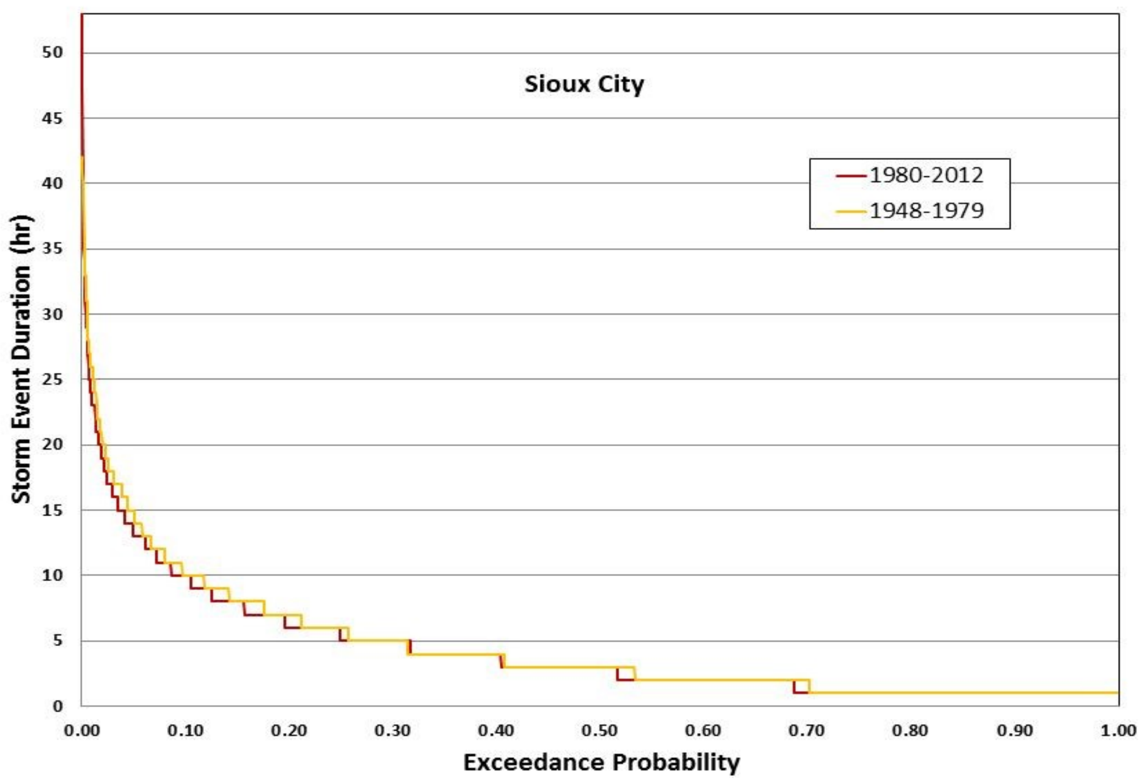

Dubuque
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

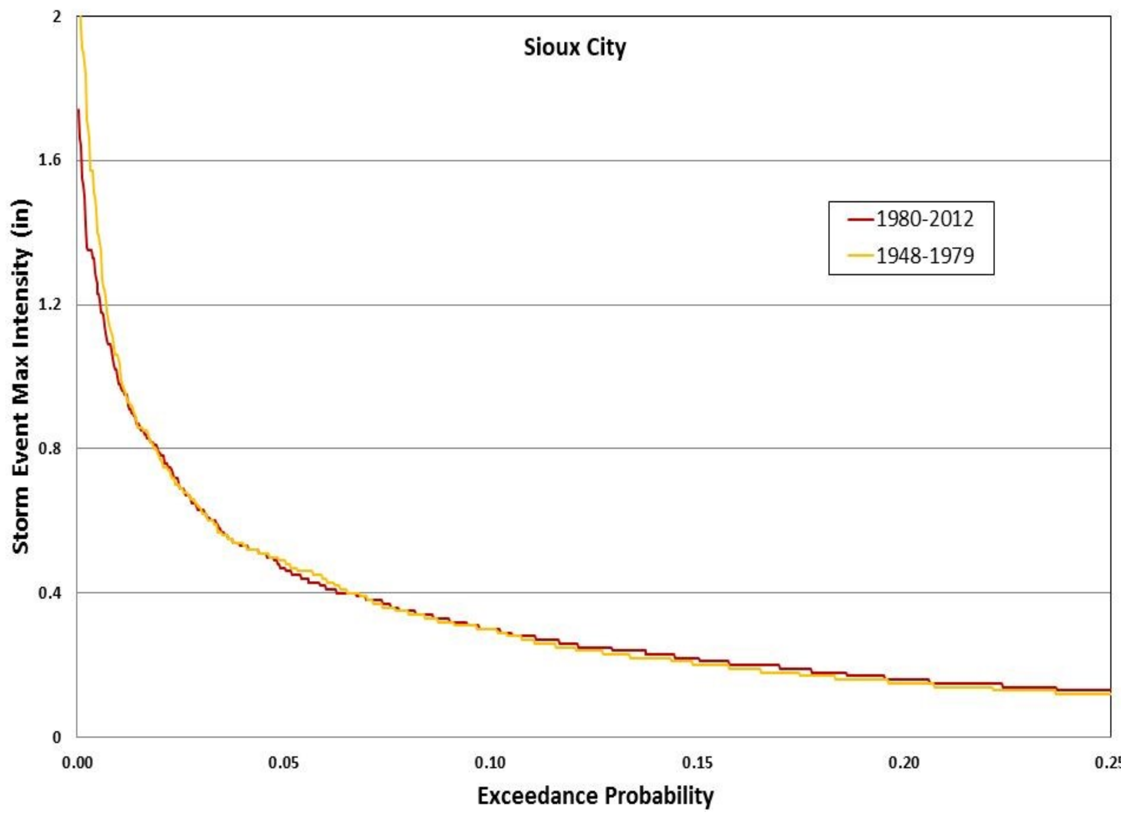

Dubuque
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Max Intensity (in)
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

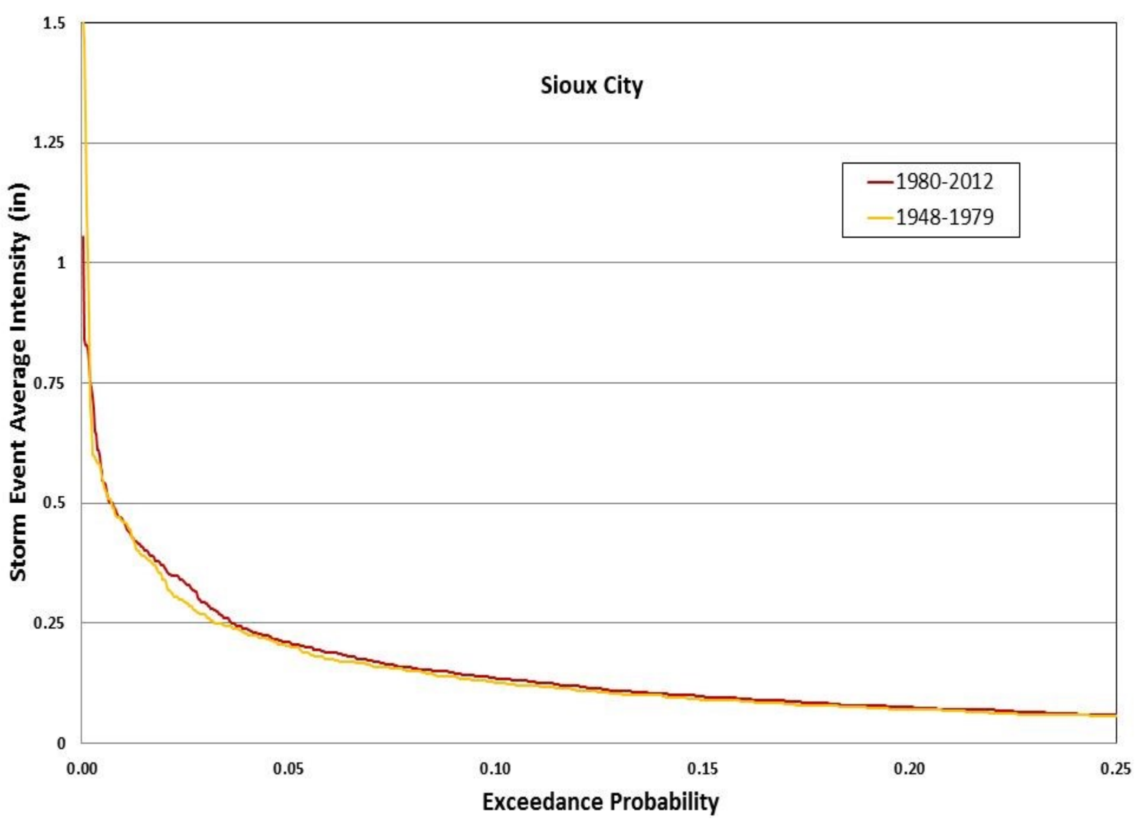

Dubuque
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Average Intensity (in)
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

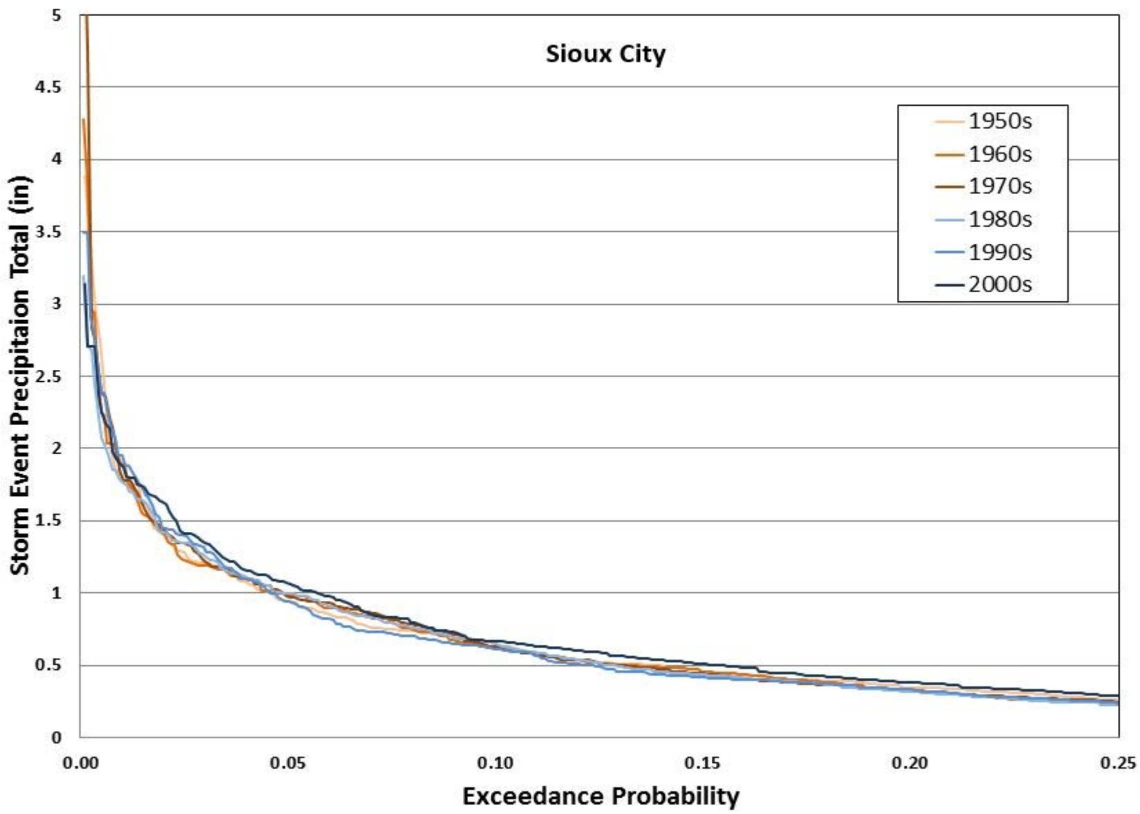
Appendix C-3. Exceedance probabilities of the characteristics of rainfall in Sioux City.

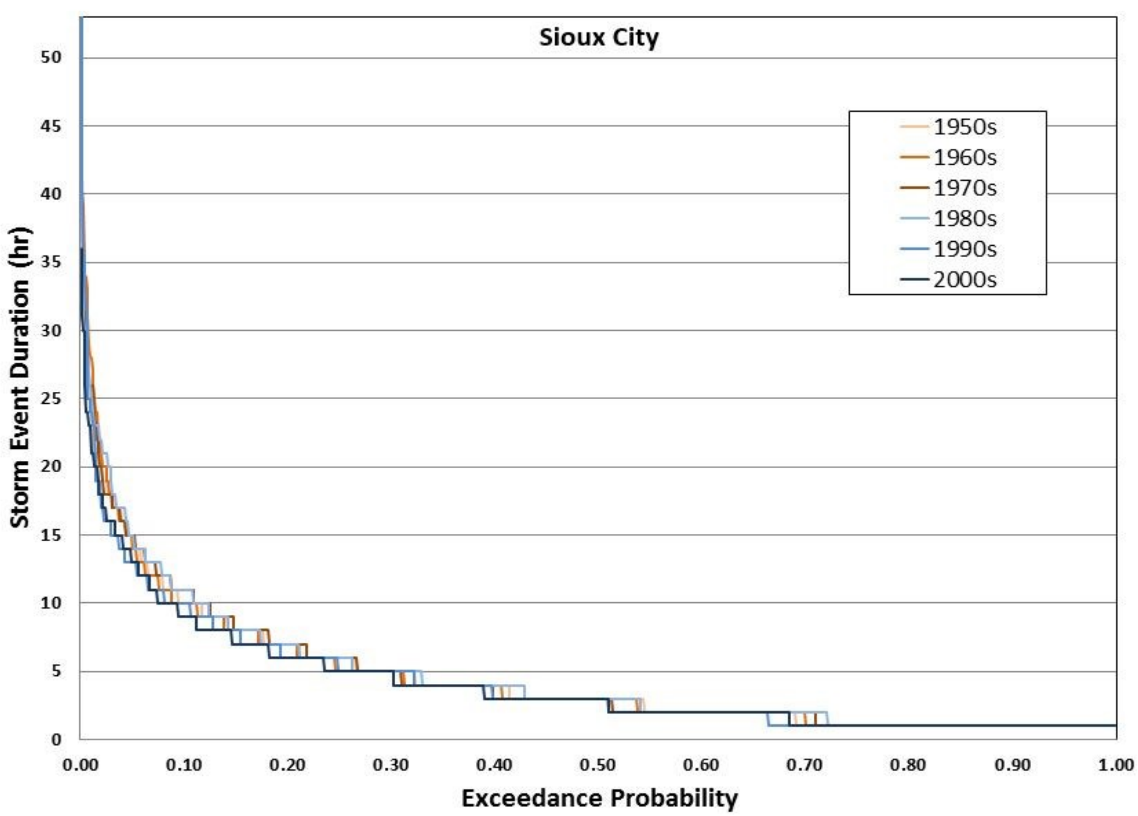


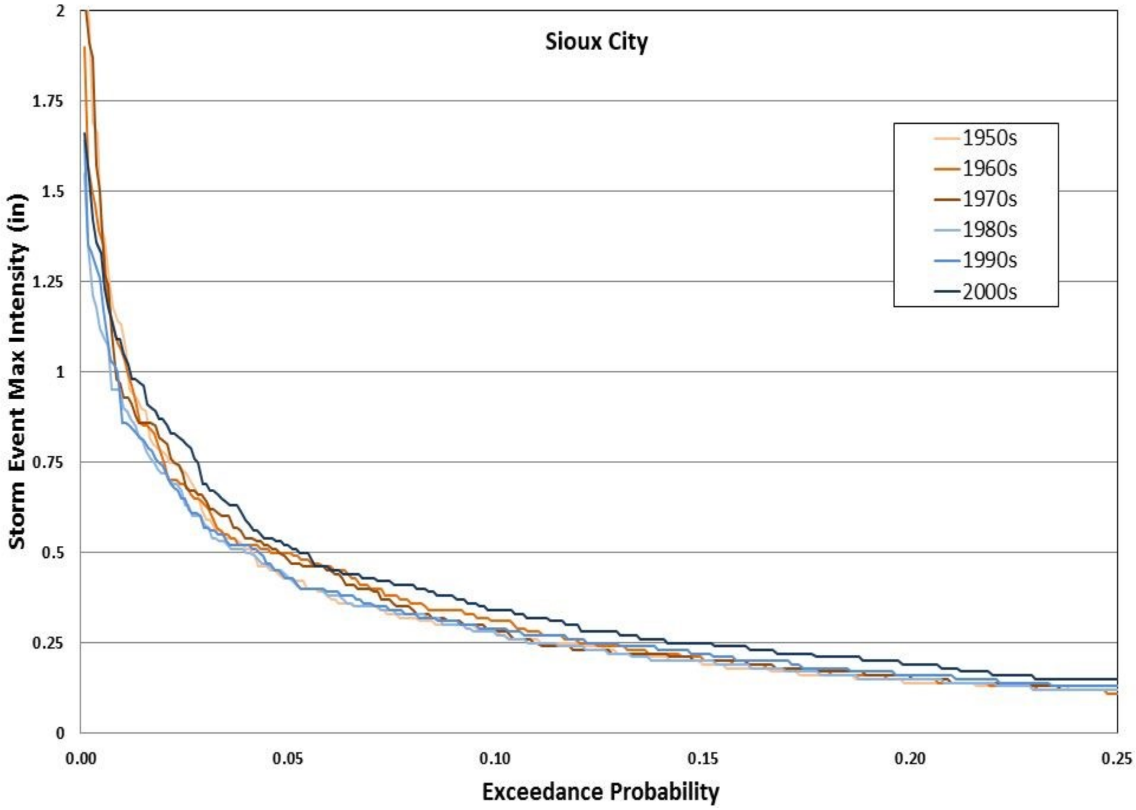


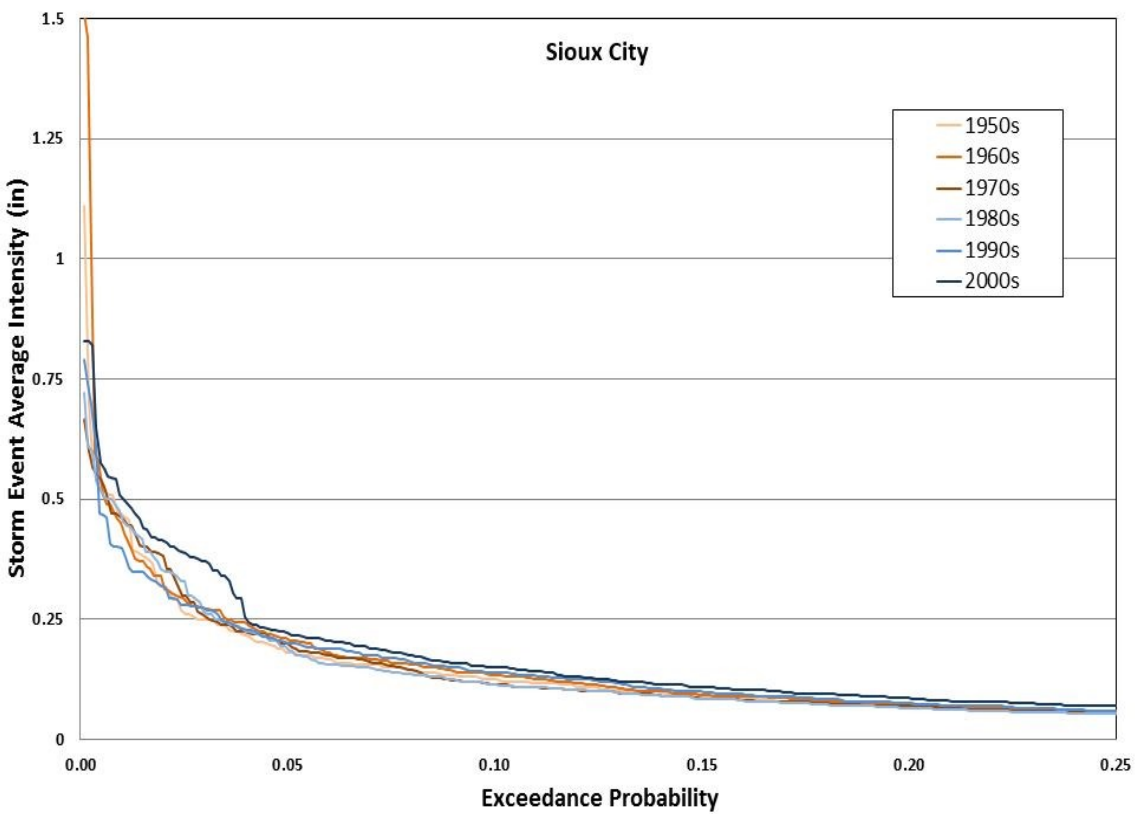

Sioux City
1980-2012
1948-1979
Storm Event Max Intensity (in)
2
1.6
1.2
0.8
0.4
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Sioux City
1980-2012
1948-1979
Storm Event Average Intensity (in)
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

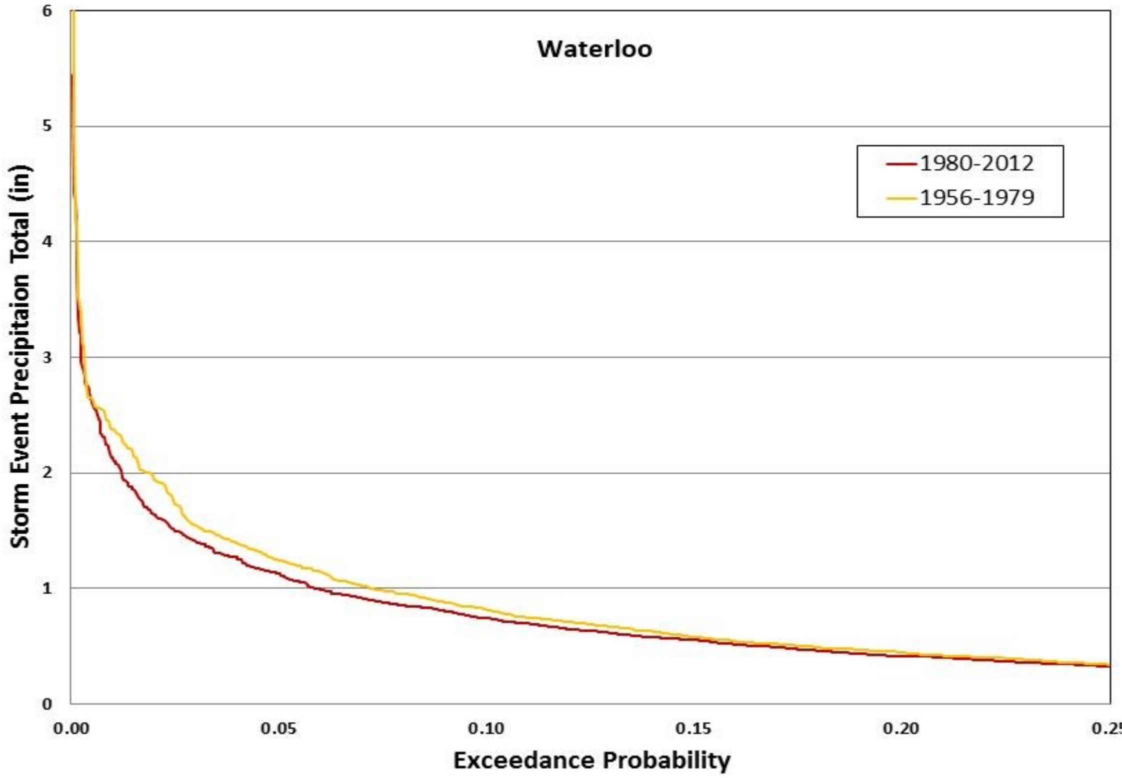

Sioux City
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.00
0.05
0.10
0.15
0.20
0.25

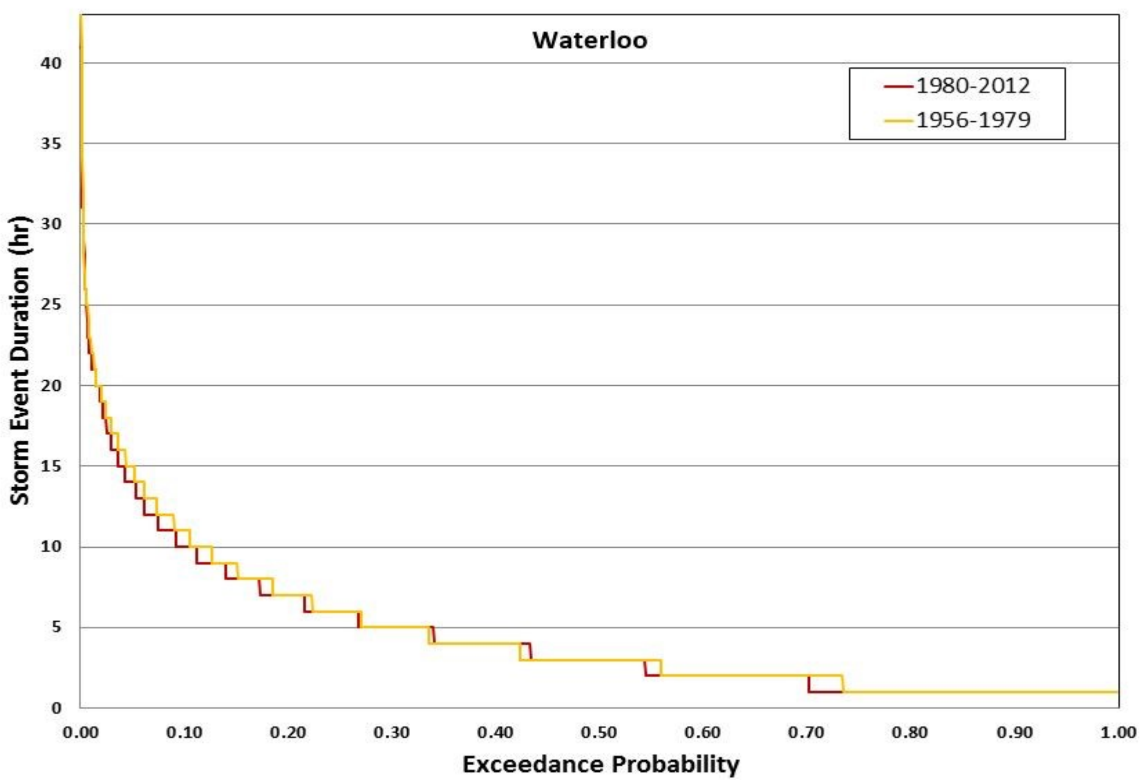

Sioux City
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

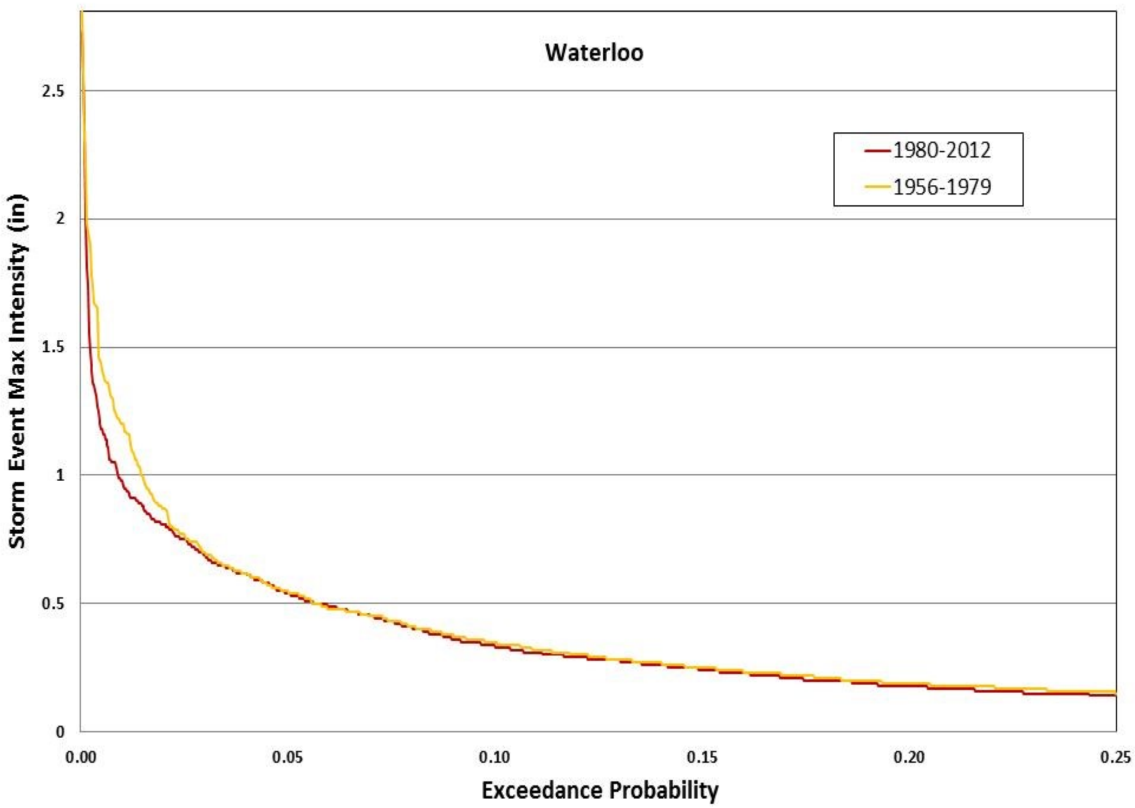

Sioux City
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

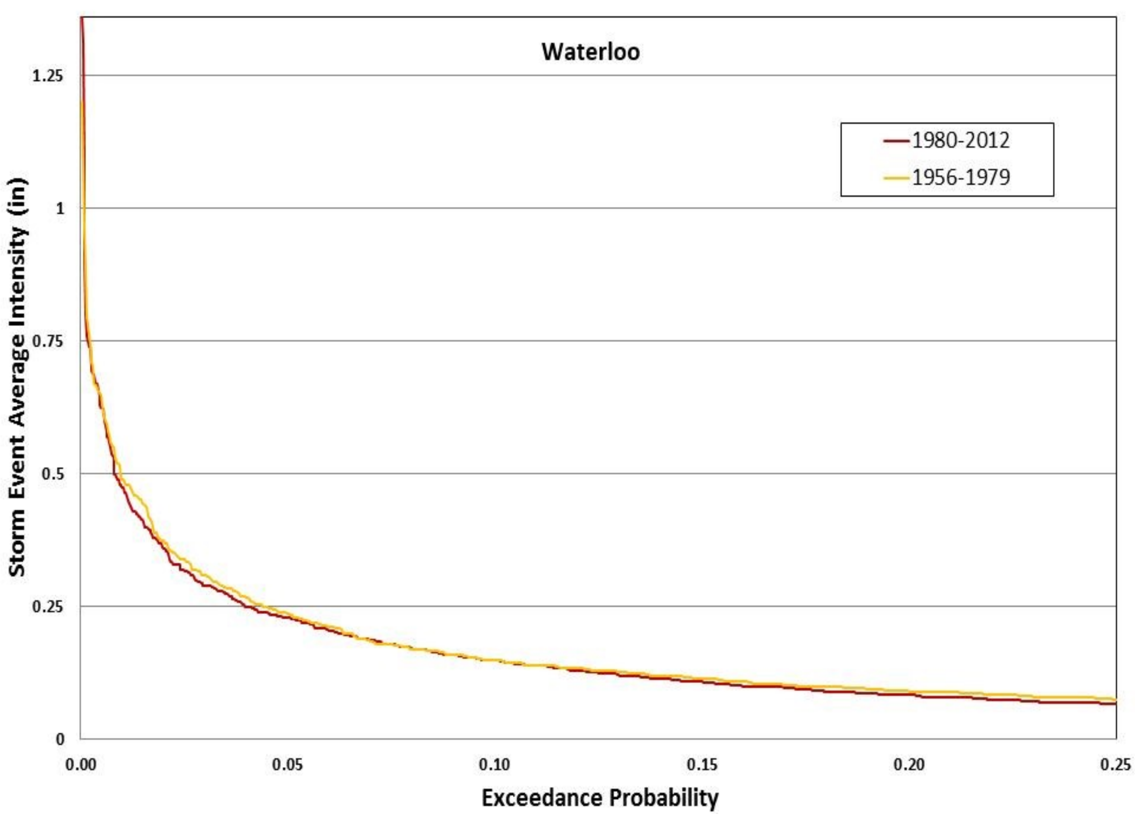

Sioux City
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

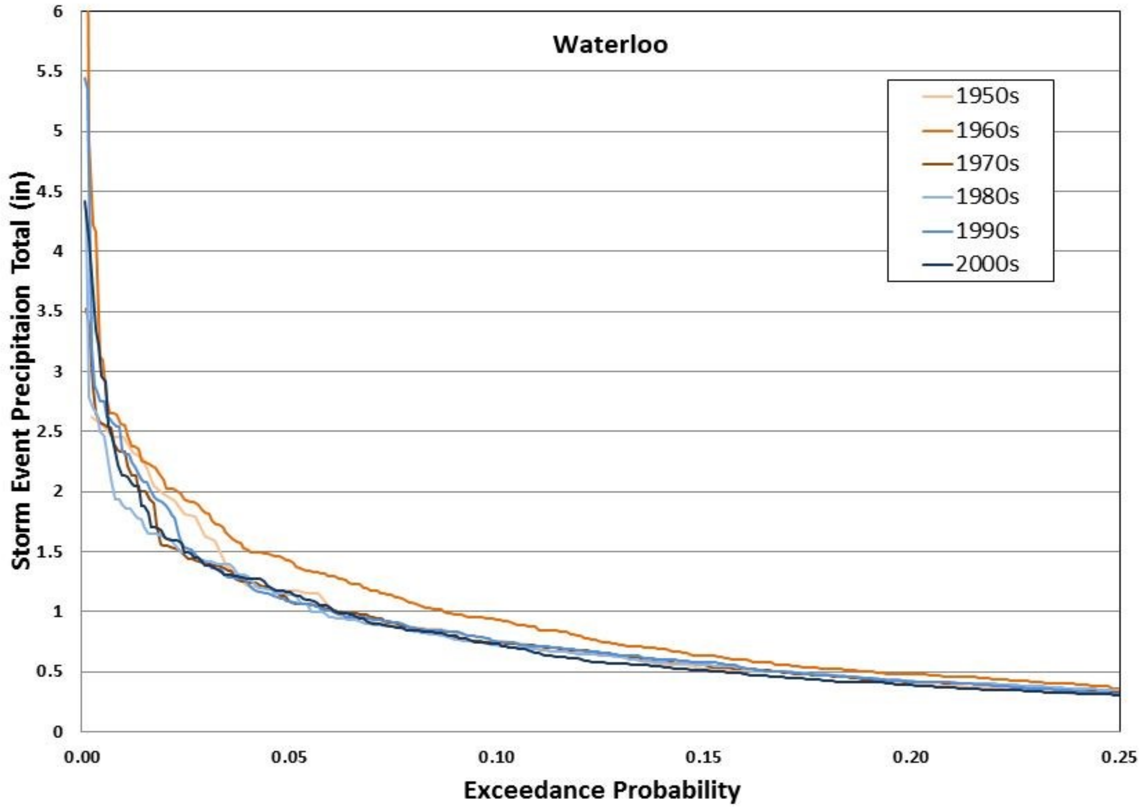
Appendix C-4. Exceedance probabilities of the characteristics of rainfall in Waterloo.

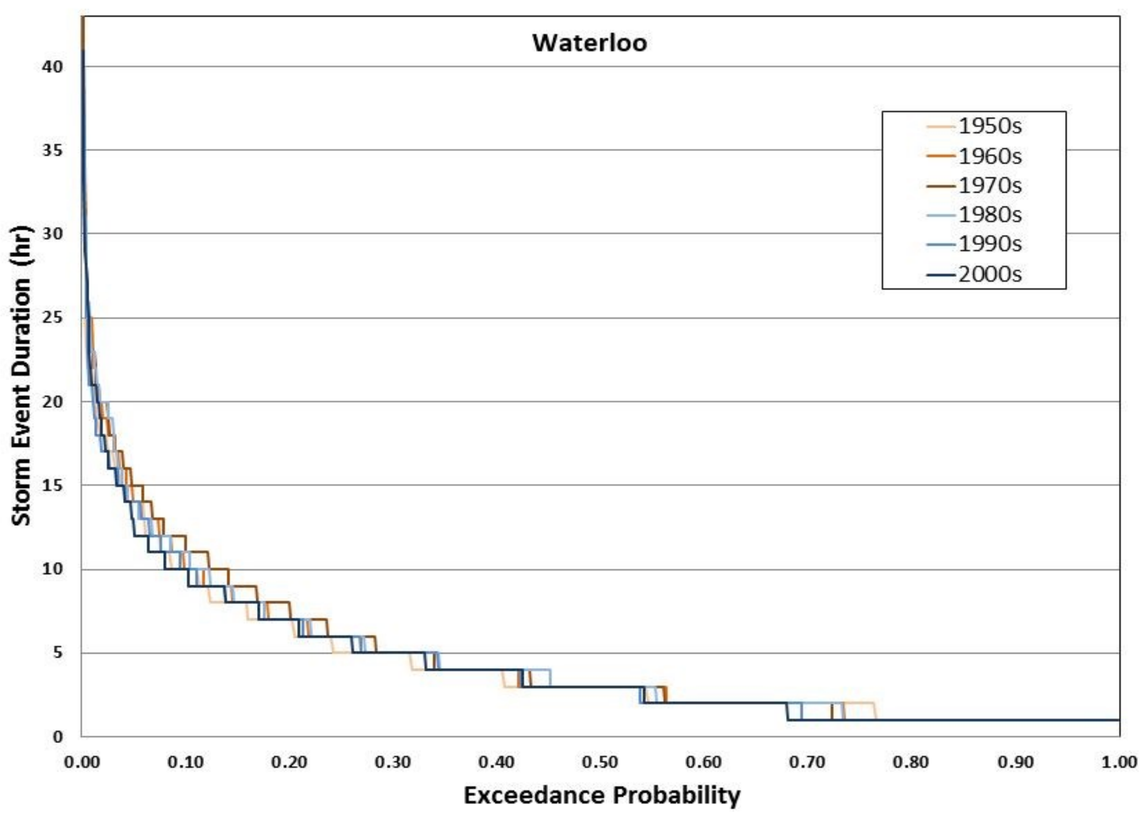


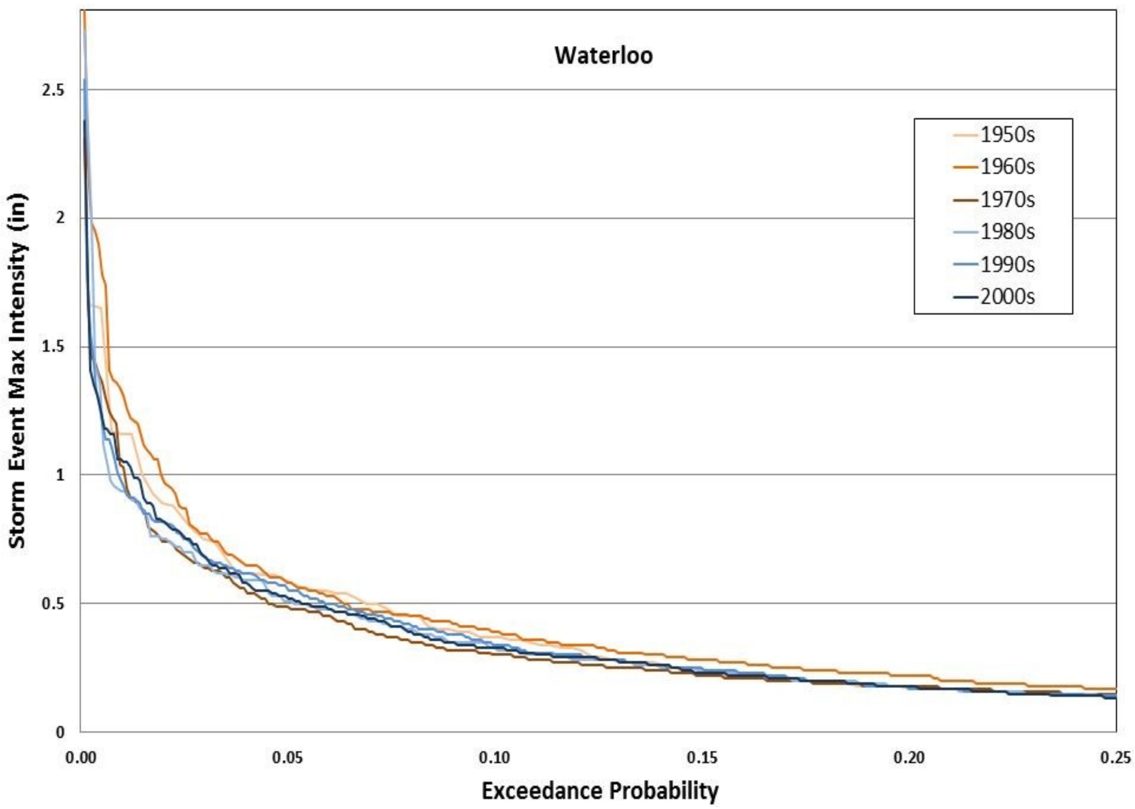



Waterloo
1980-2012
1956-1979
Storm Event Max Intensity (in)
0
0.5
1
1.5
2
2.5
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

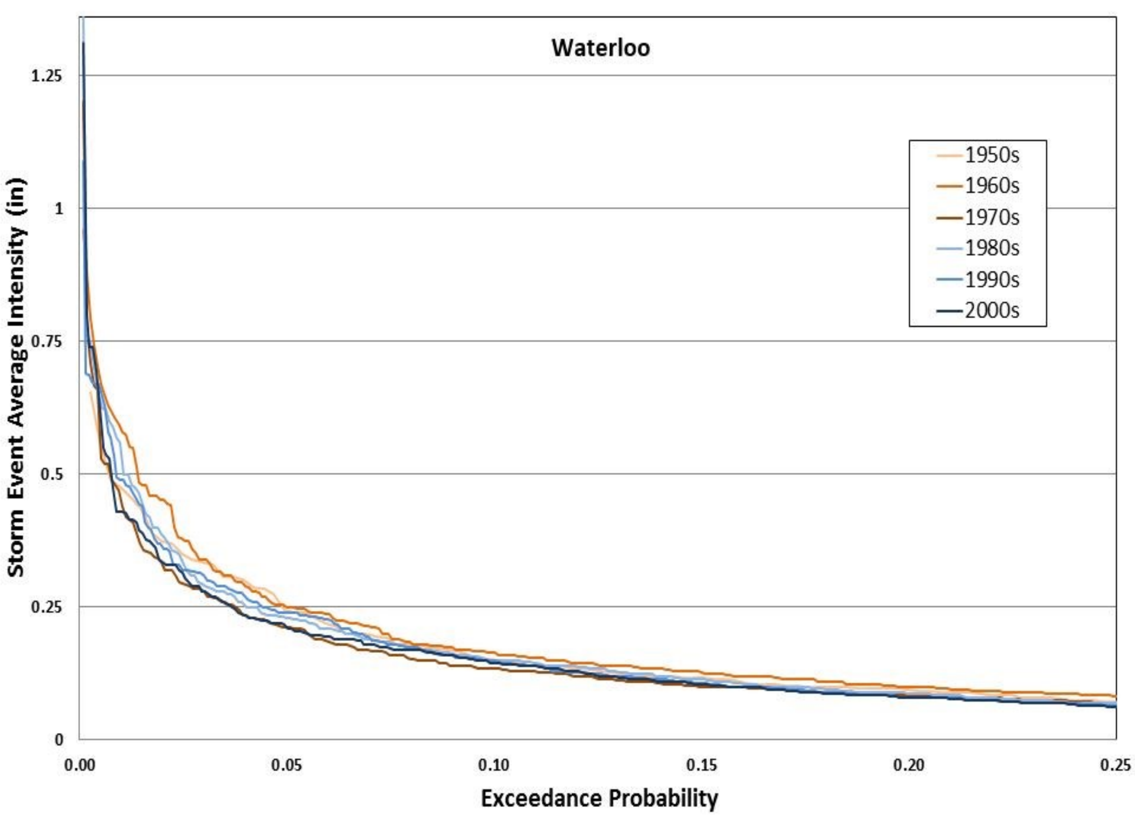

Waterloo
1980-2012
1956-1979
Storm Event Average Intensity (in)
0
0.25
0.5
0.75
1
1.25
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Waterloo
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Waterloo
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
40
35
30
25
20
15
10
5
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Exceedance Probability

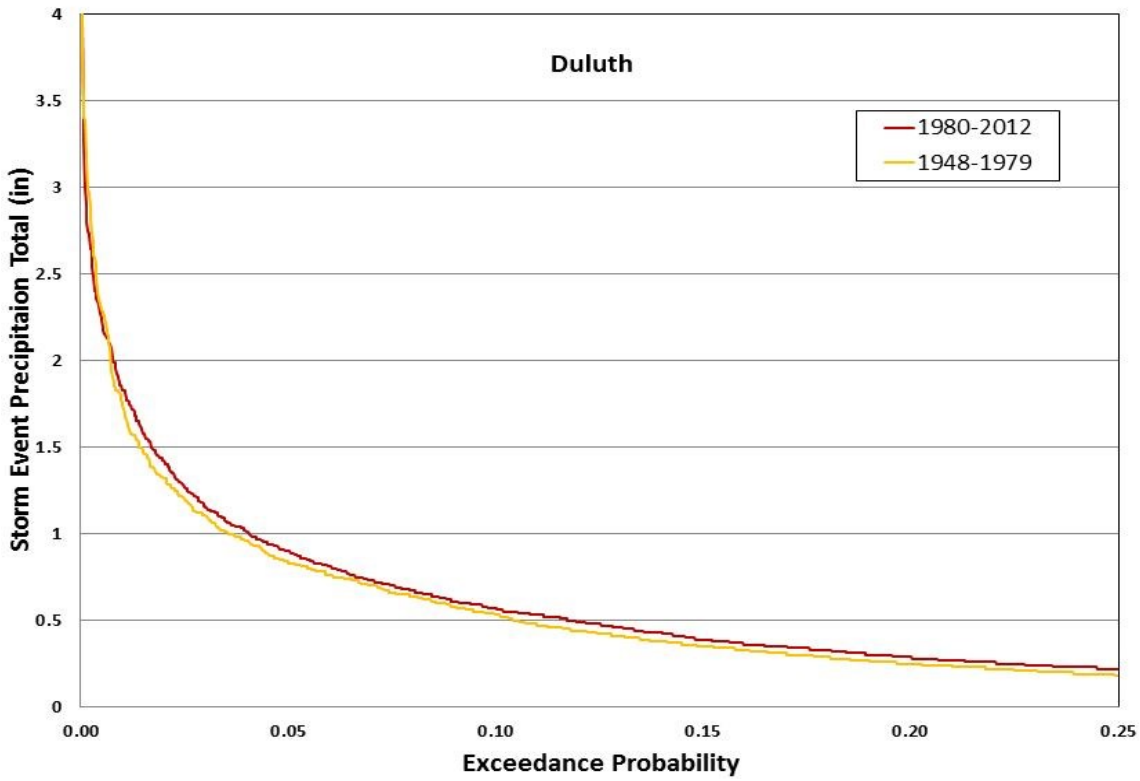


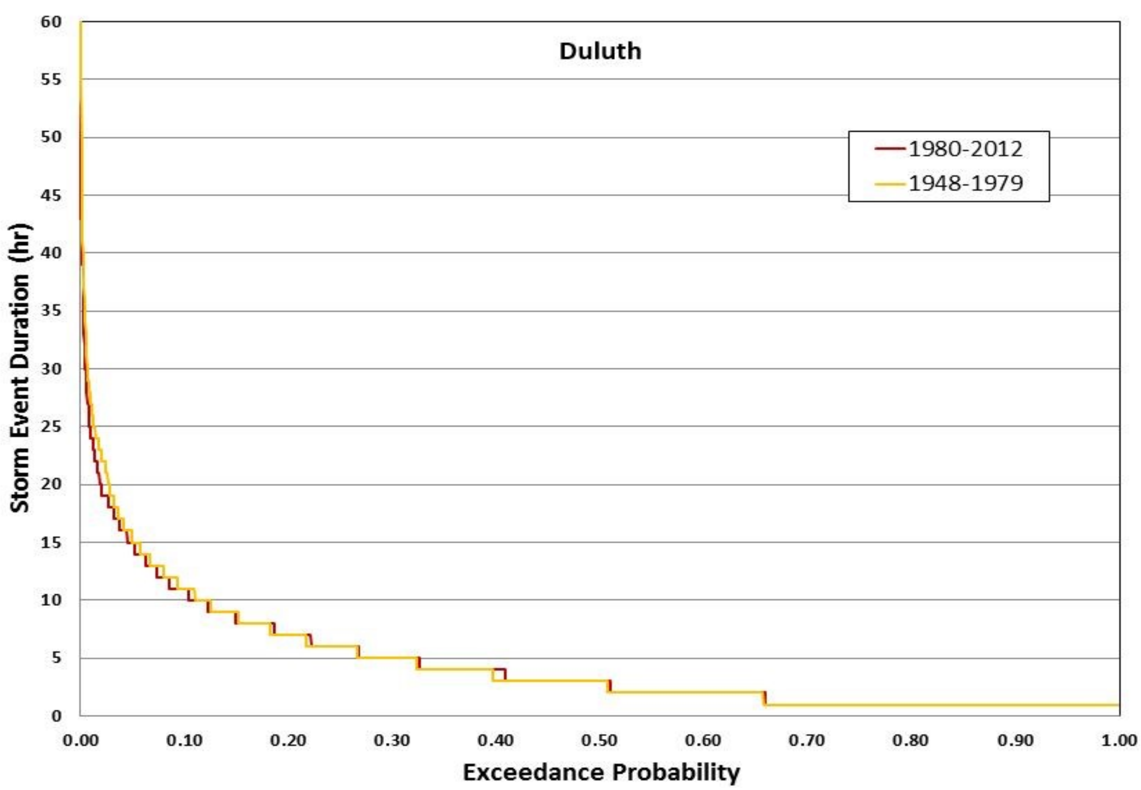
Waterloo
Storm Event Max Intensity (in)
0
0.5
1
1.5
2
2.5
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s

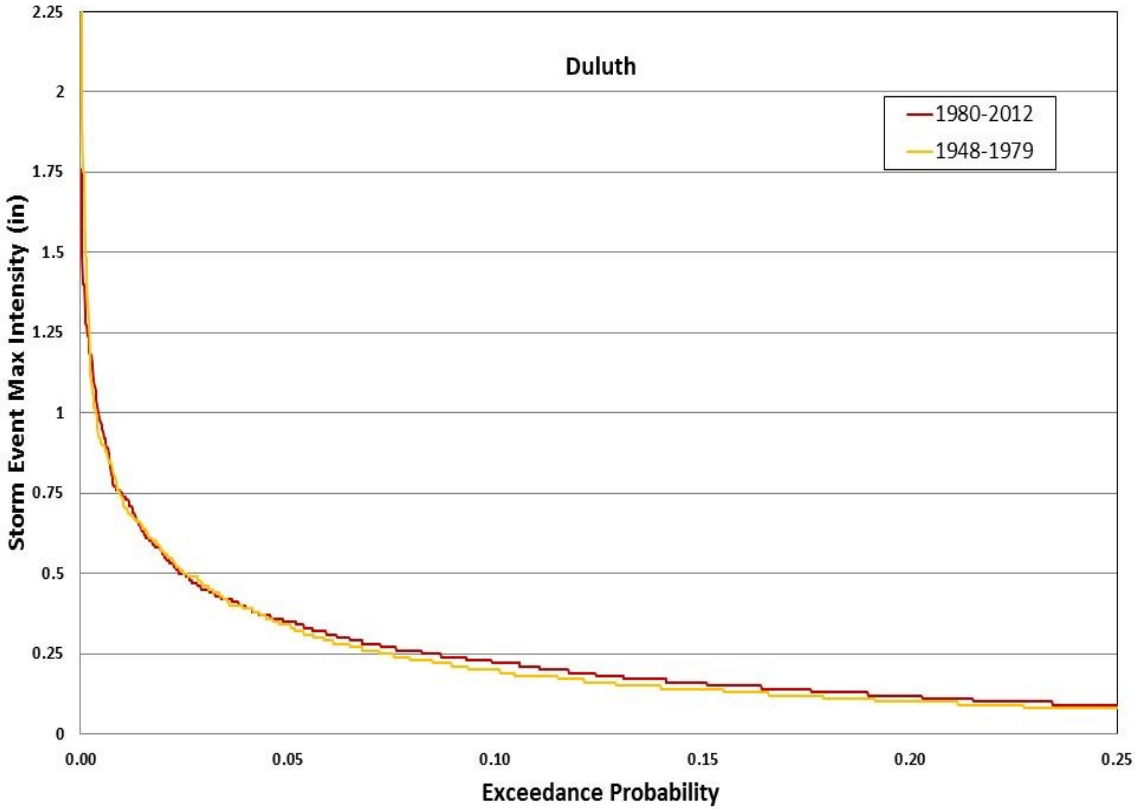


Waterloo
Storm Event Average Intensity (in)
0
0.25
0.5
0.75
1
1.25
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s

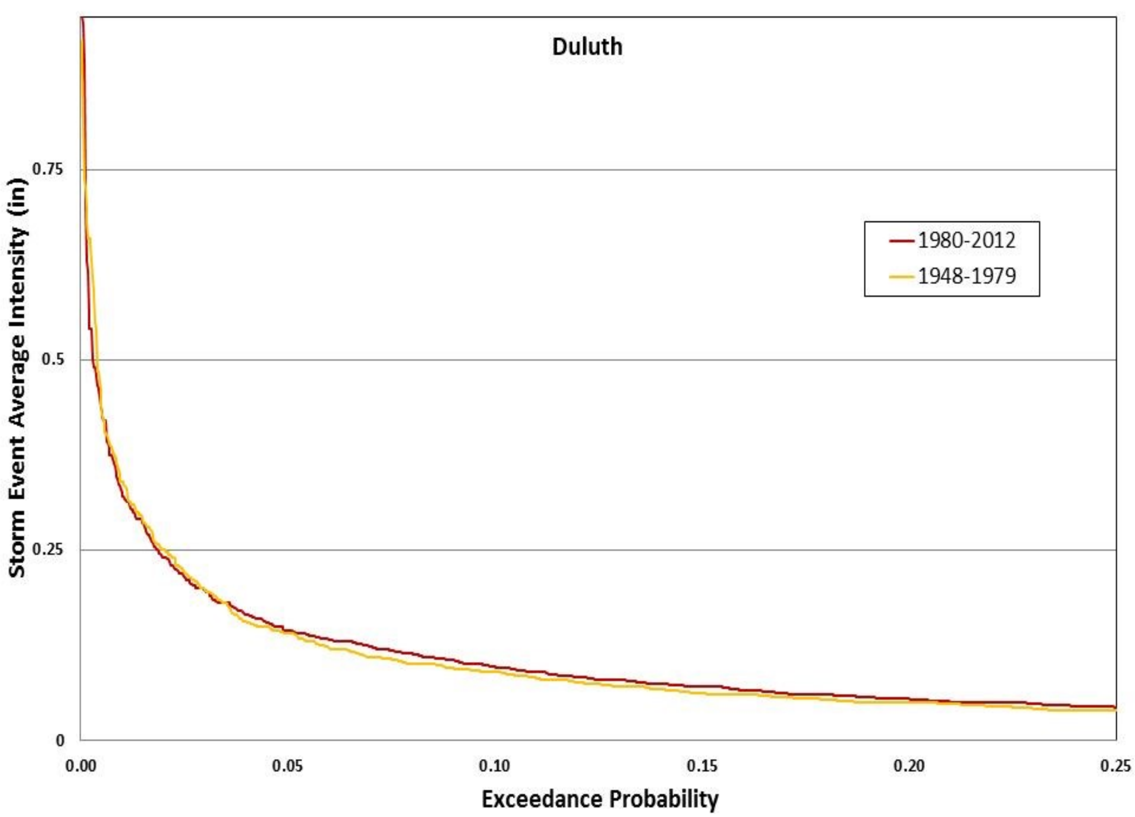
Appendix C-5. Exceedance probabilities of the characteristics of rainfall in Duluth.



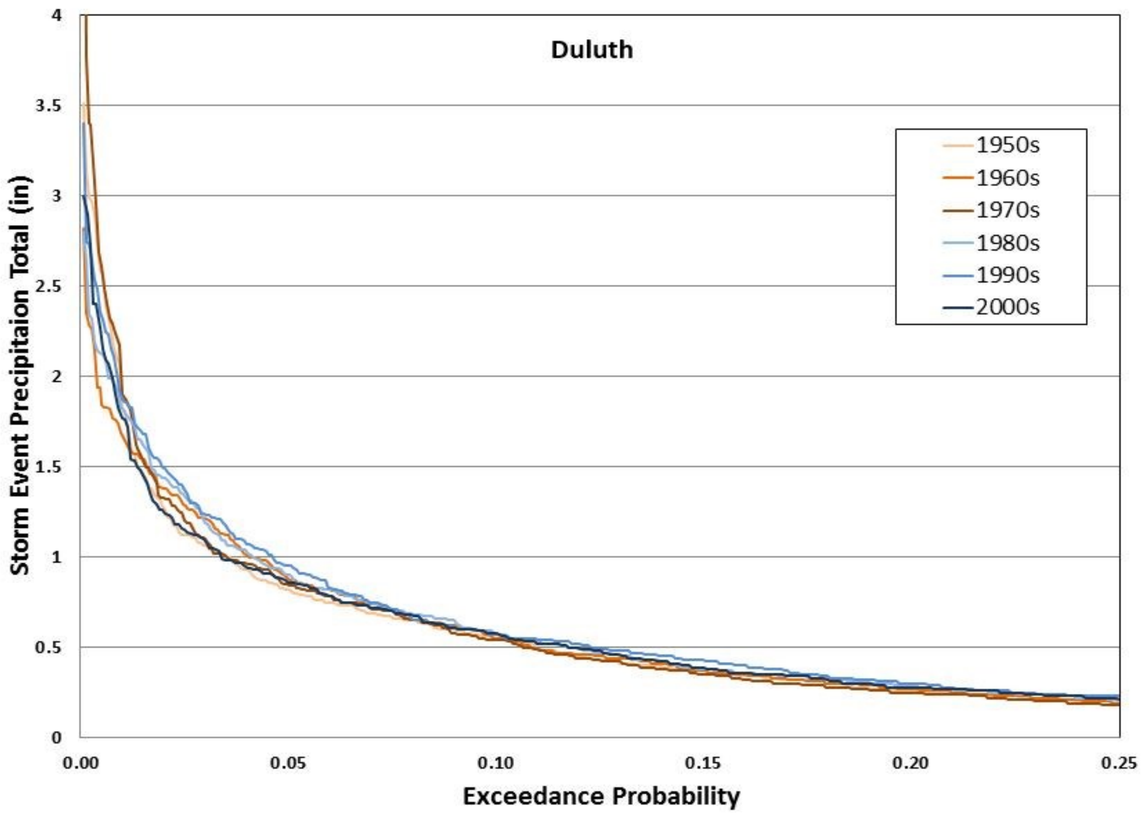




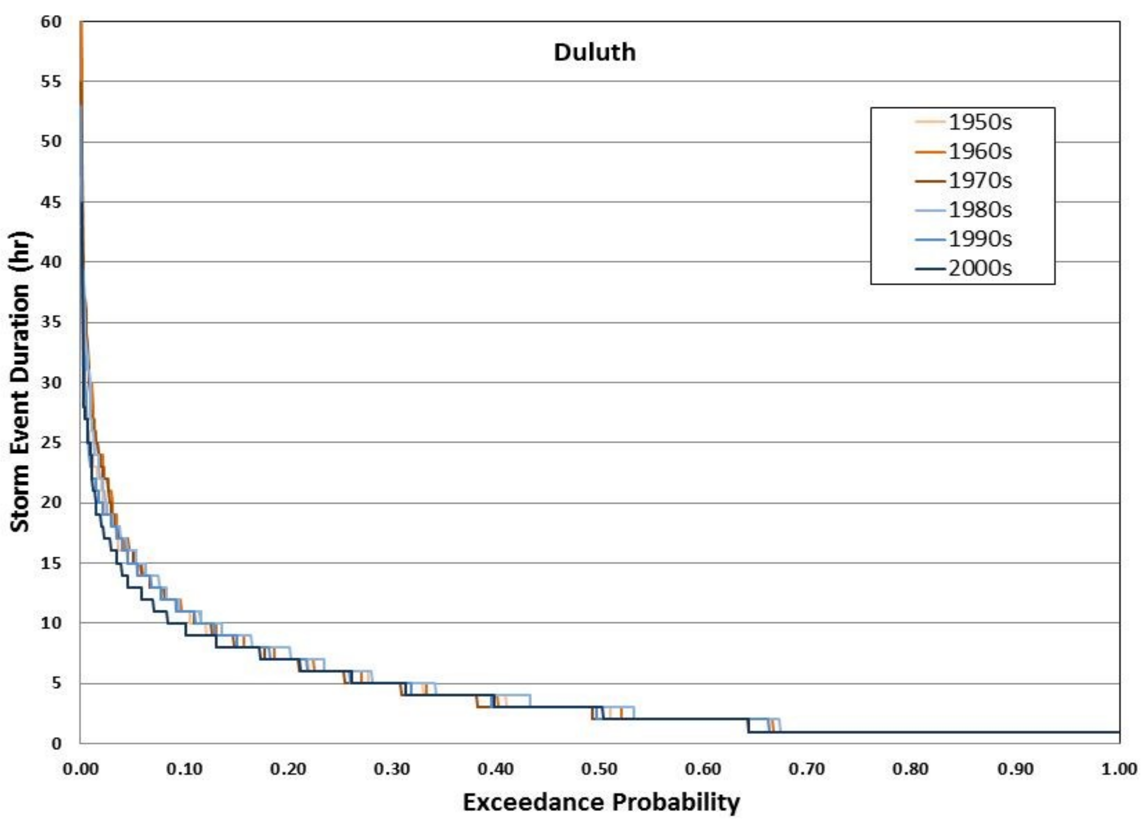
Duluth
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25



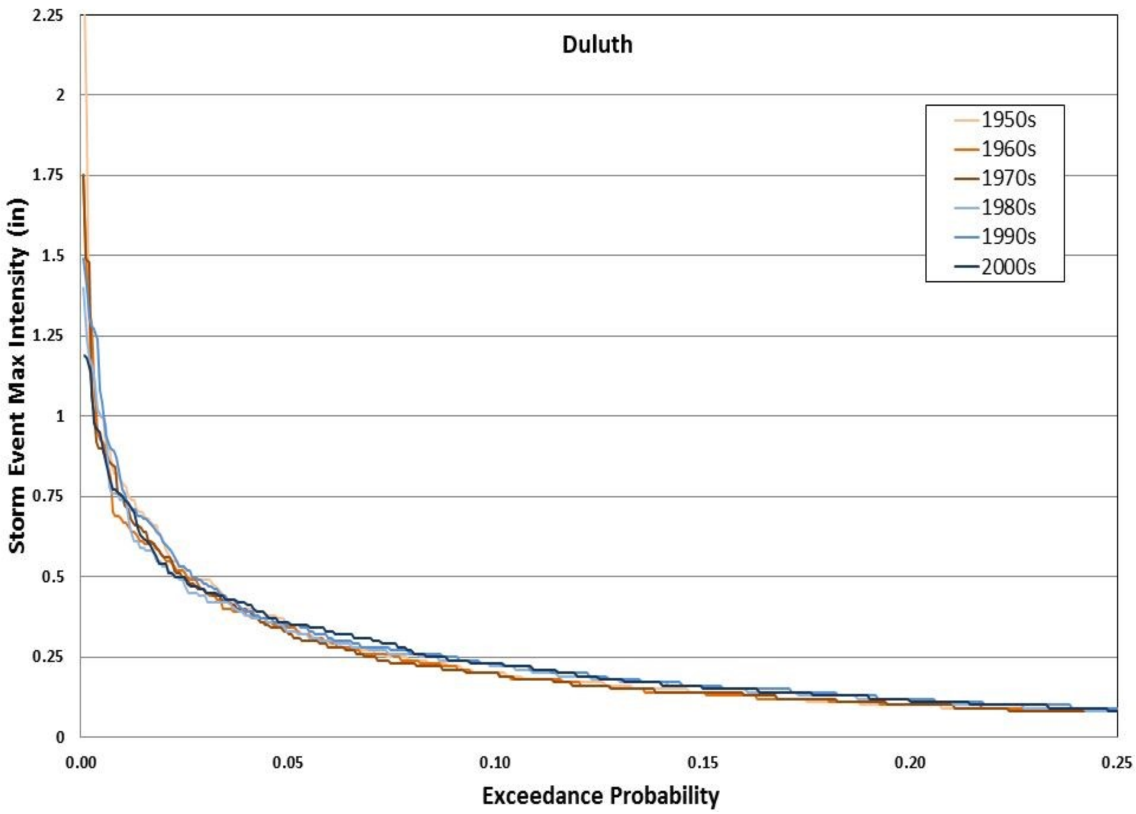
Duluth
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

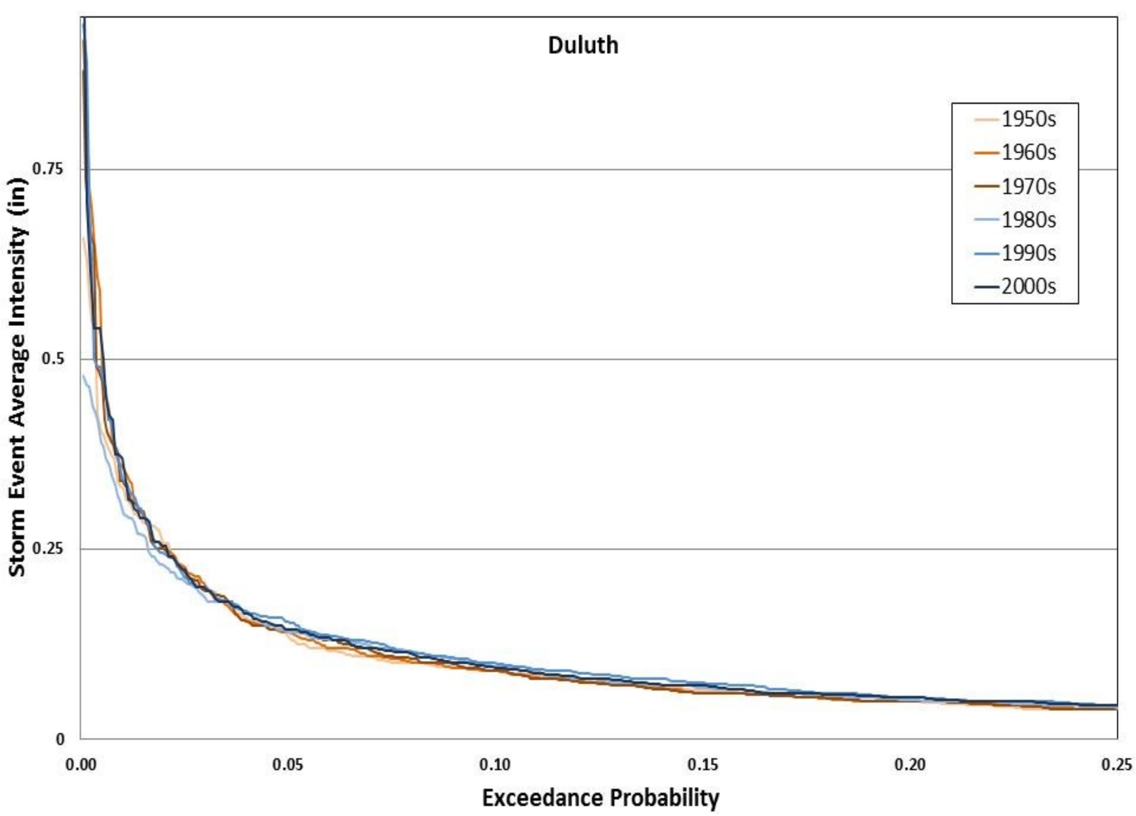


Duluth
Storm Event Precipitaion Total (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.5
1
1.5
2
2.5
3
3.5
4
0.00
0.05
0.10
0.15
0.20
0.25

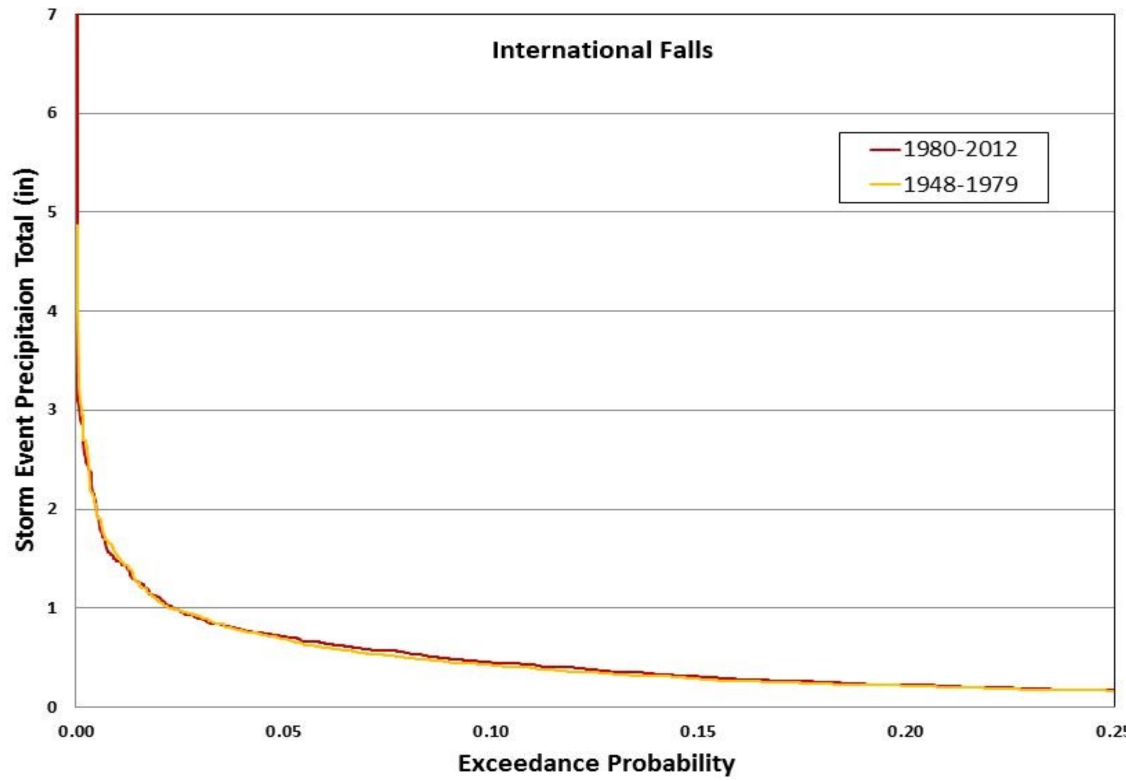


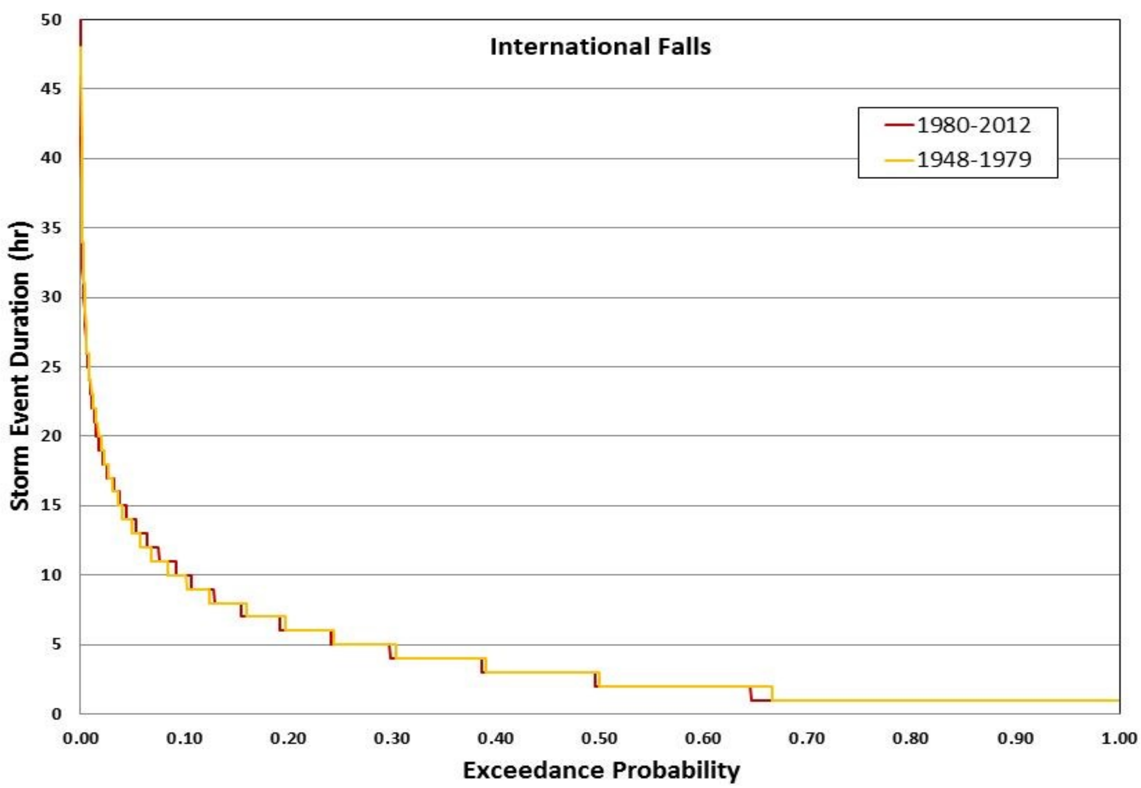
Duluth
Storm Event Duration (hr)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
5
10
15
20
25
30
35
40
45
50
55
60
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

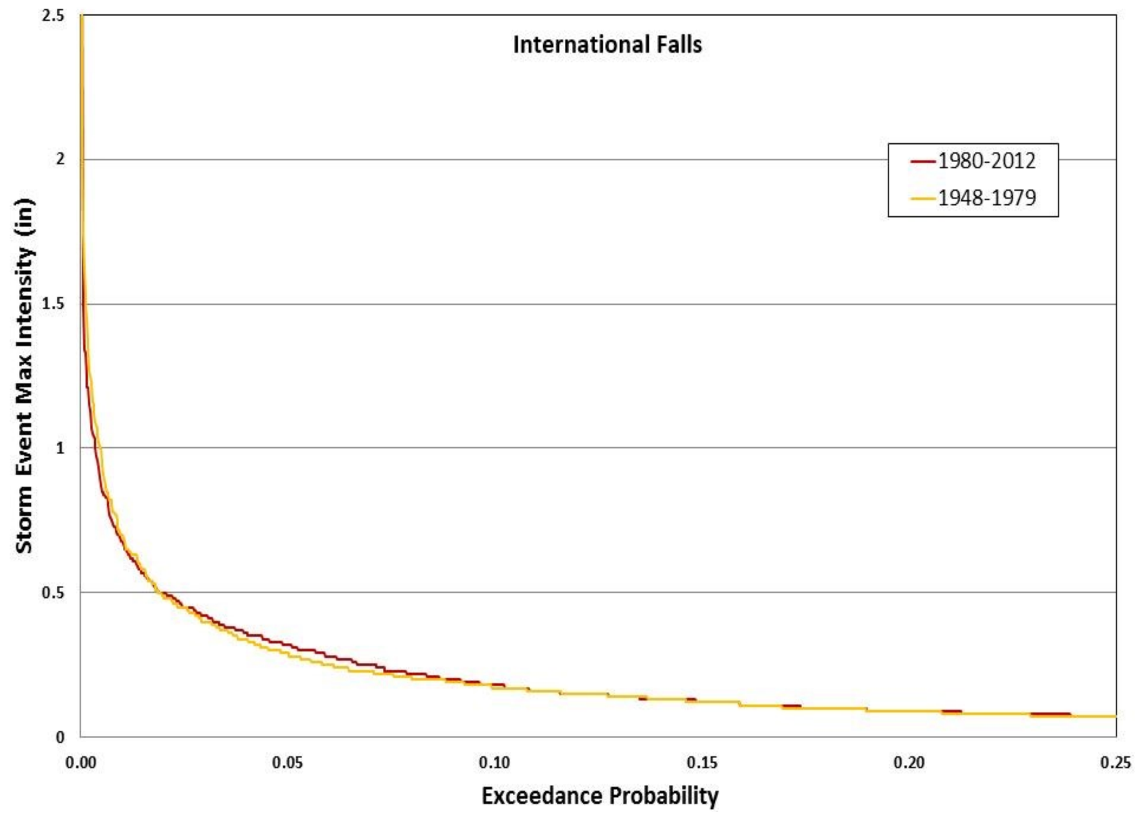

Duluth
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Max Intensity (in)
Exceedance Probability
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

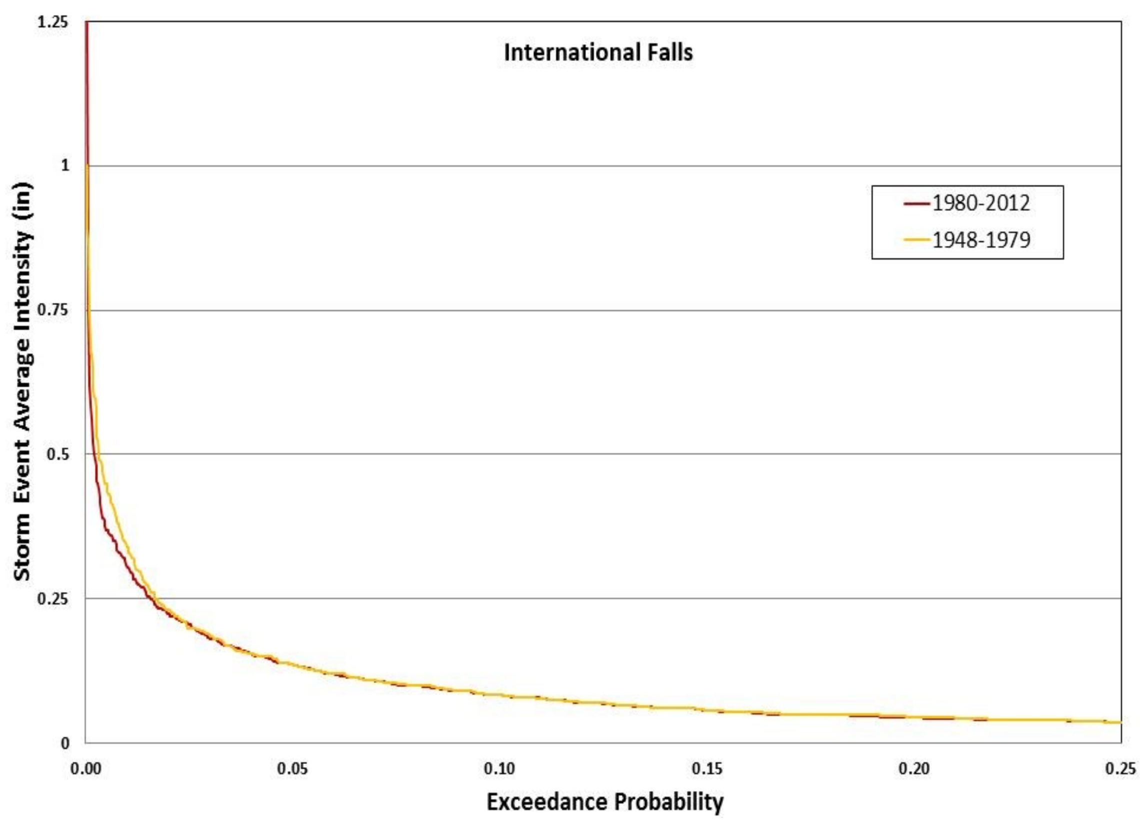

Duluth
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Average Intensity (in)
Exceedance Probability
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

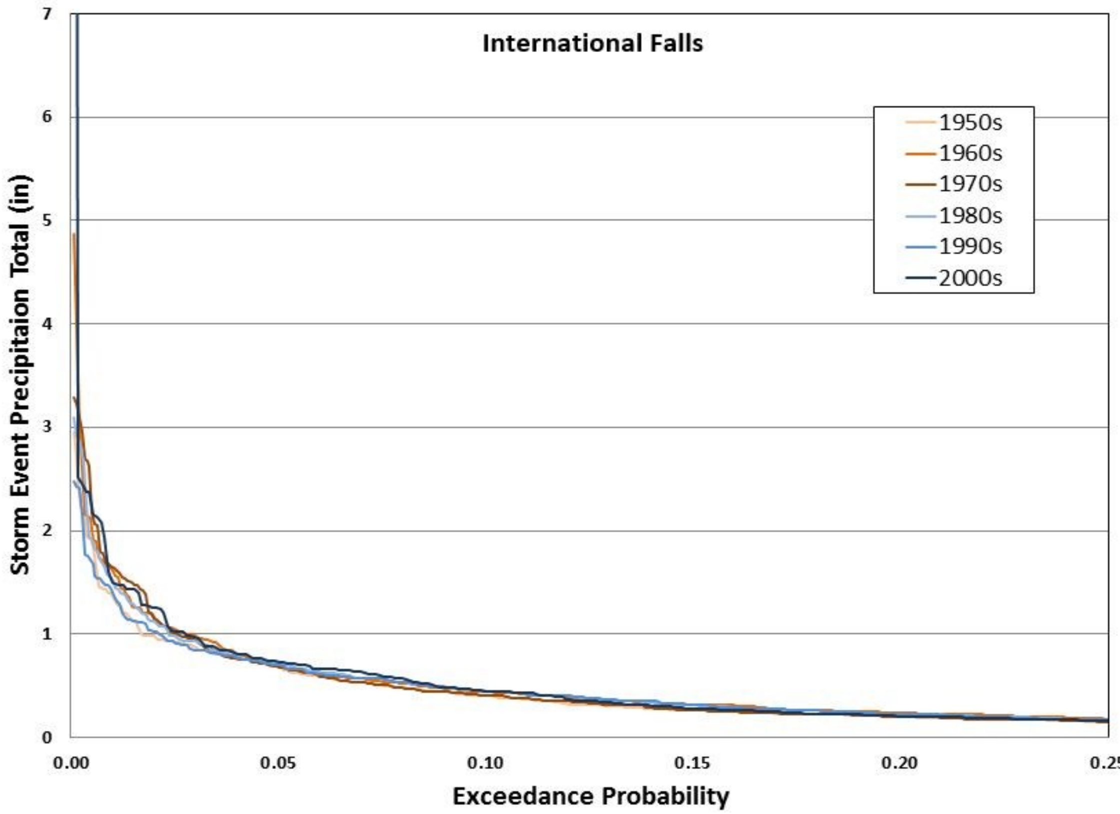
Appendix C-6. Exceedance probabilities of the characteristics of rainfall in International Falls.

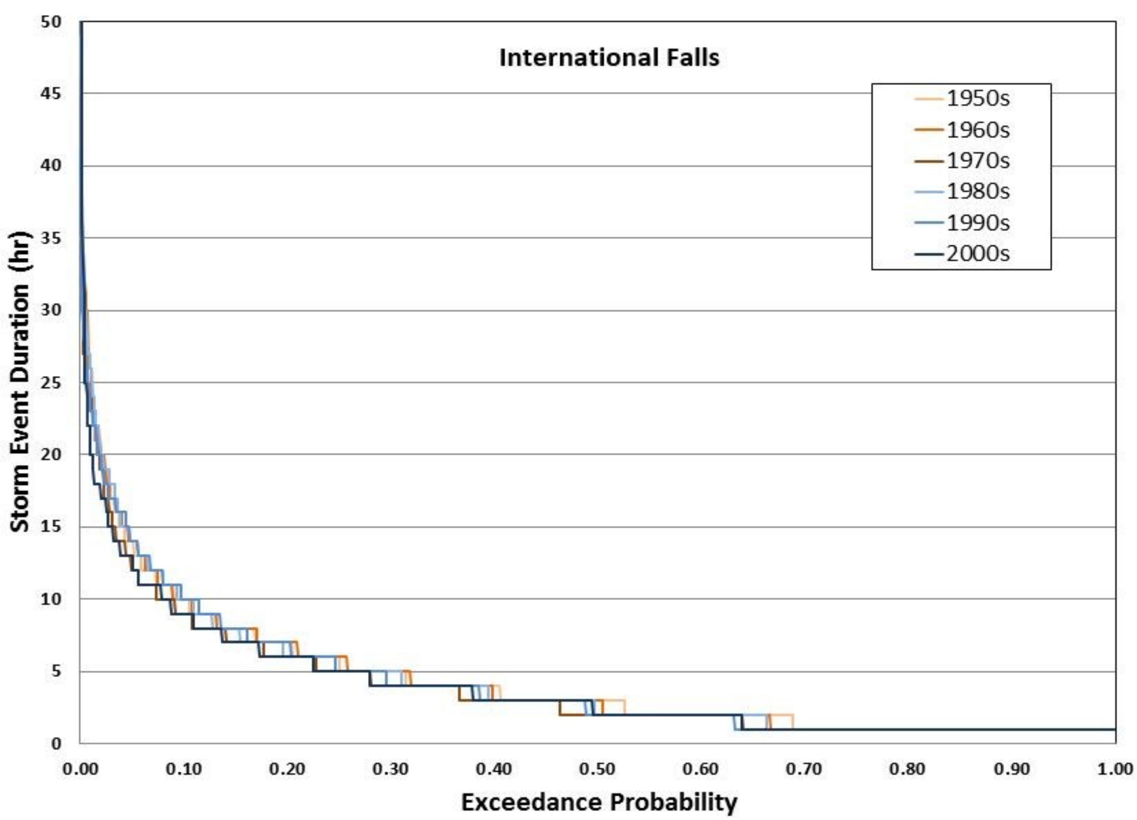


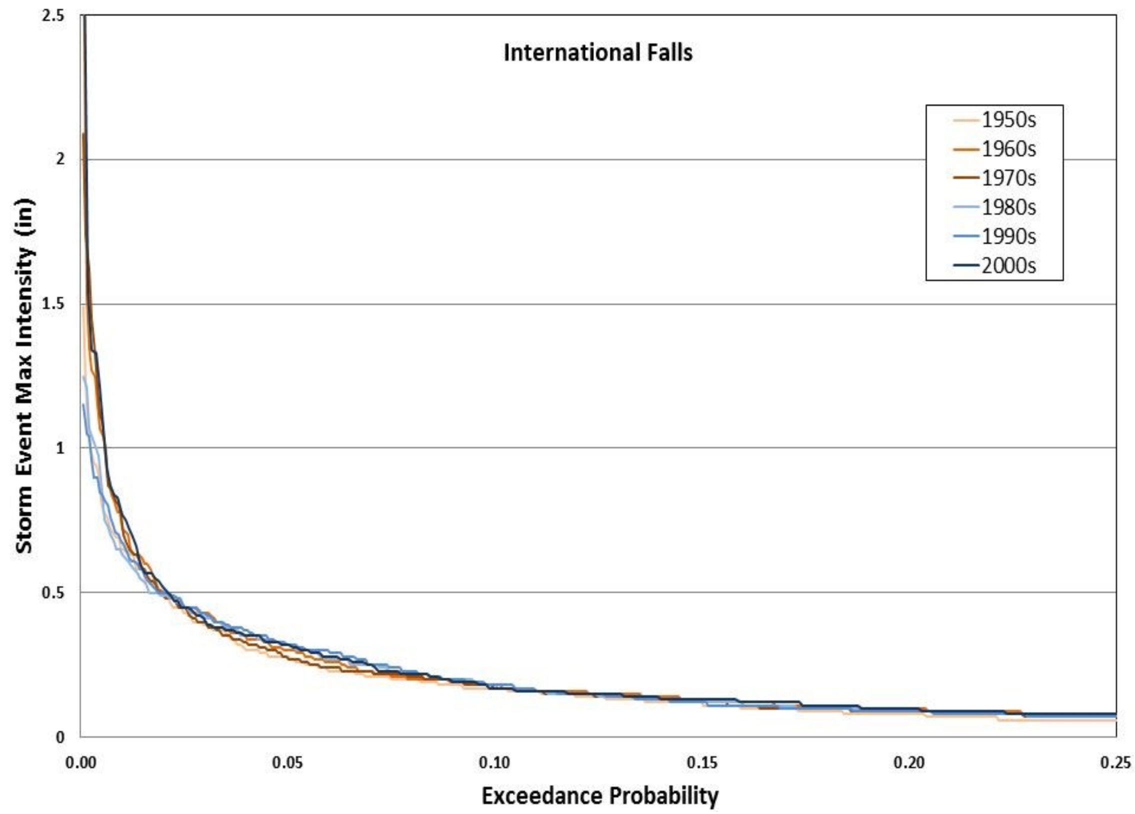


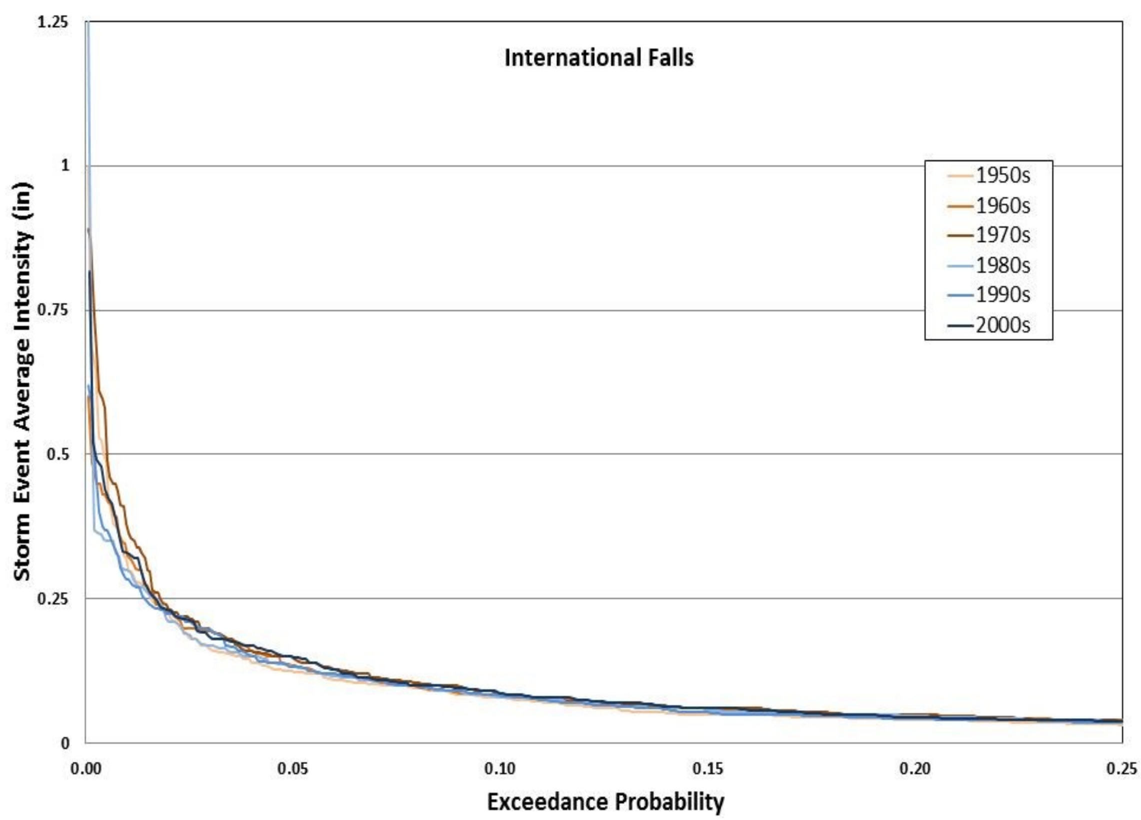

International Falls
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25


International Falls
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

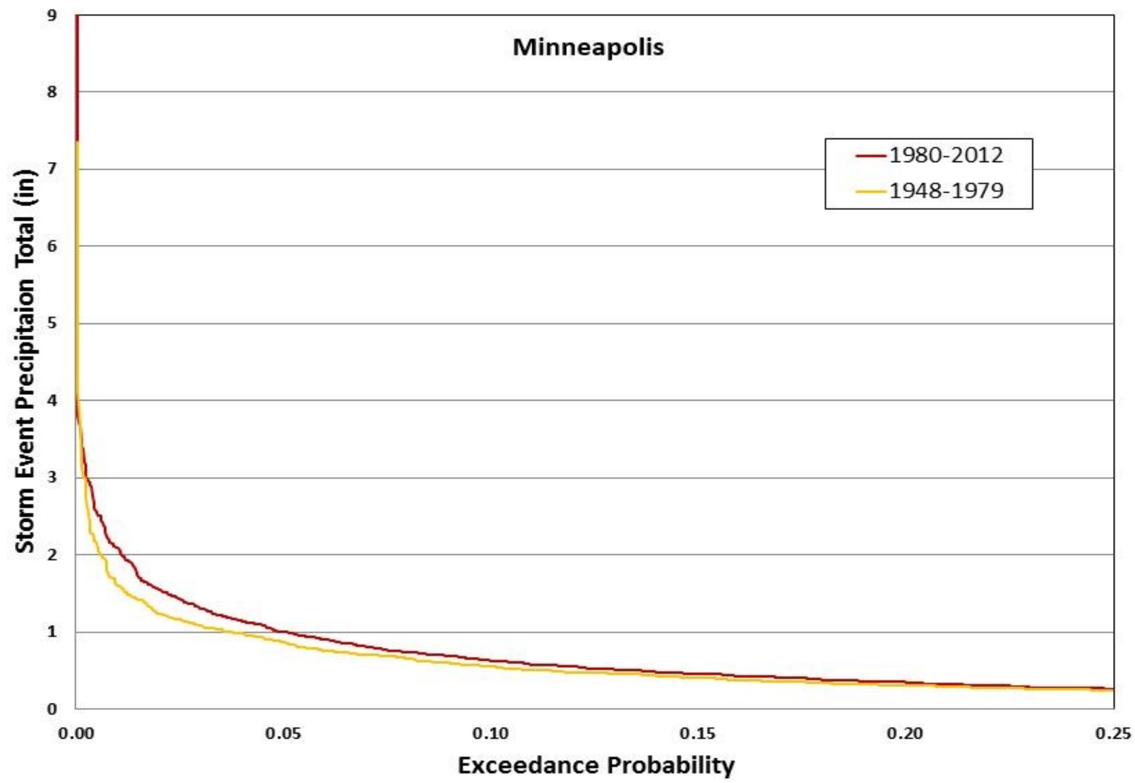

International Falls
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
1
2
3
4
5
6
7
0.00
0.05
0.10
0.15
0.20
0.25

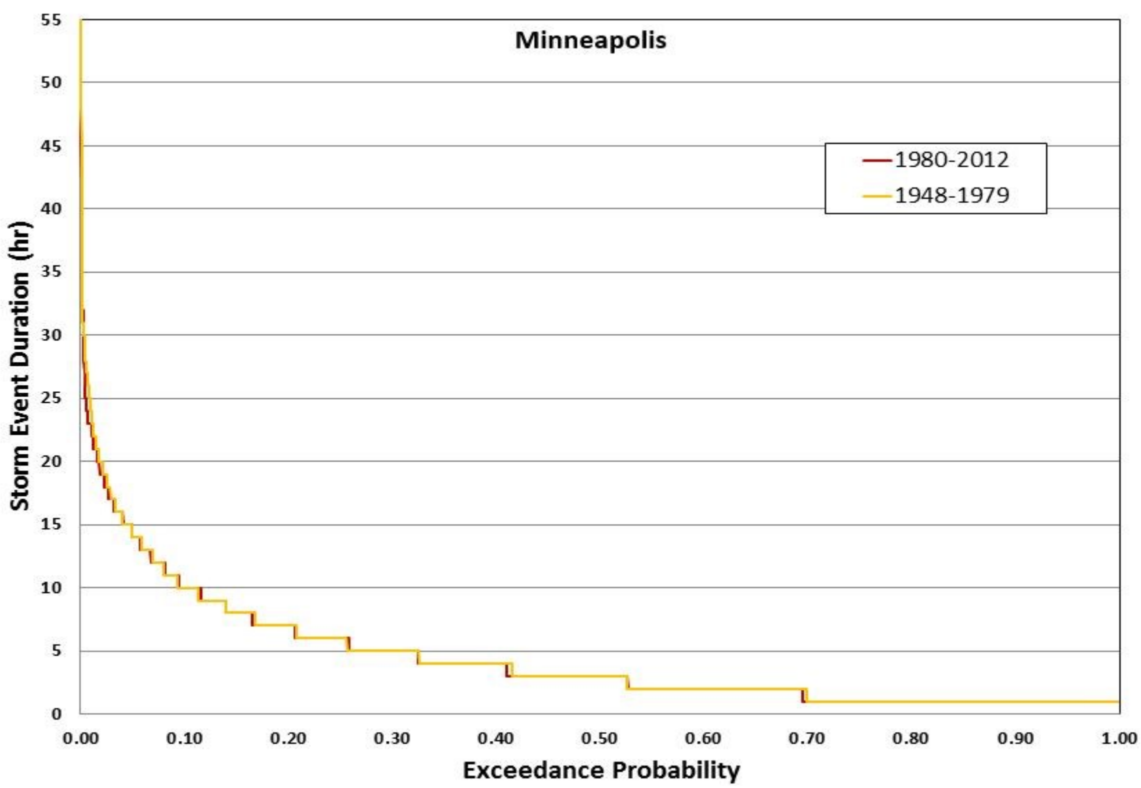

International Falls
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

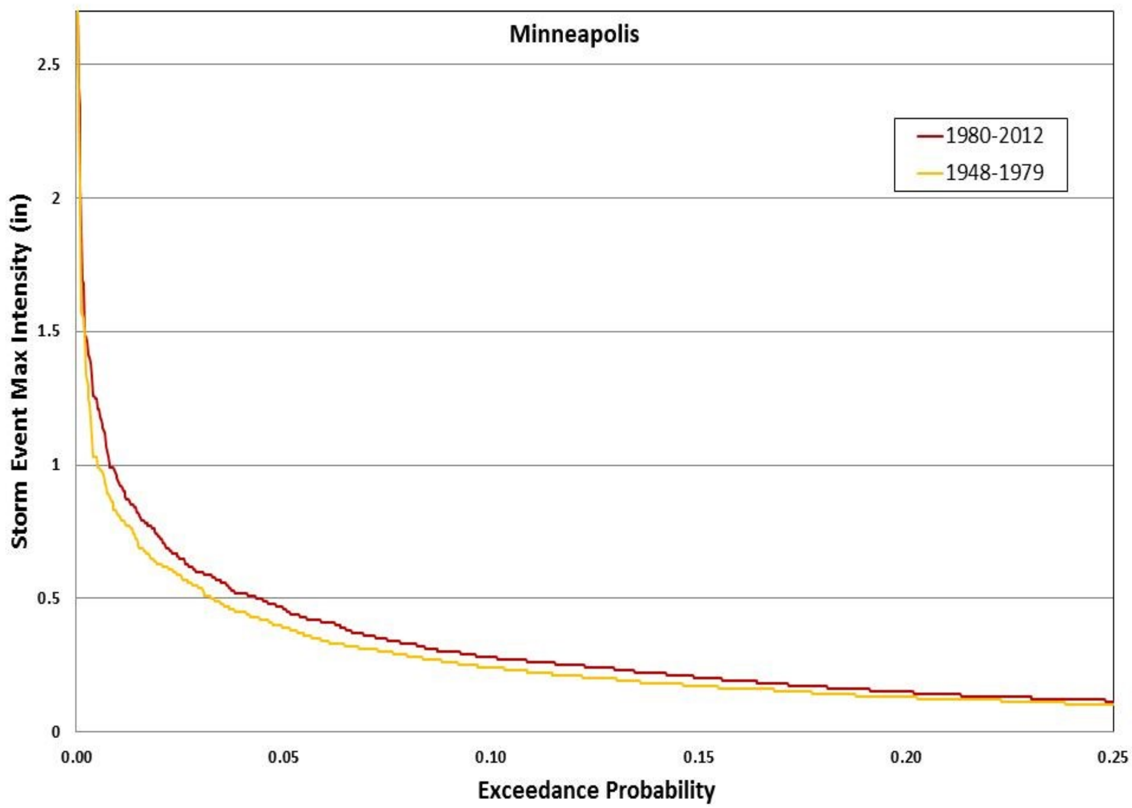

International Falls
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

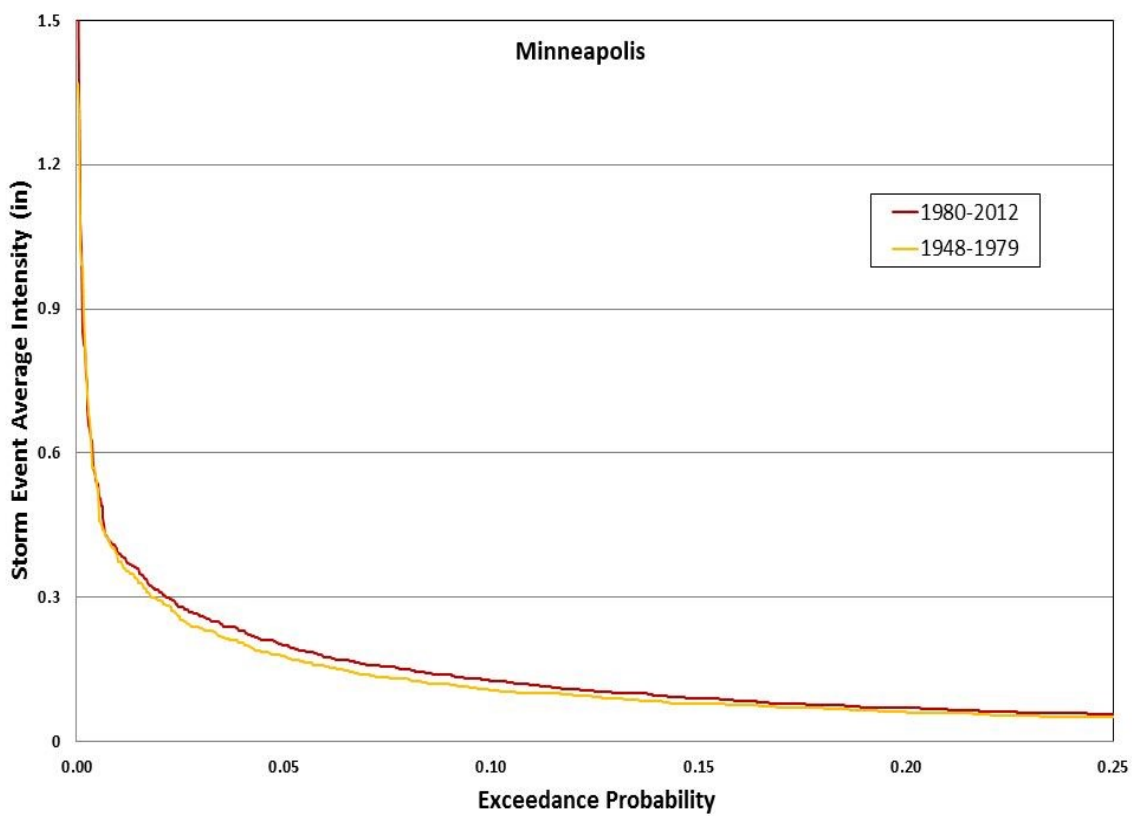

International Falls
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

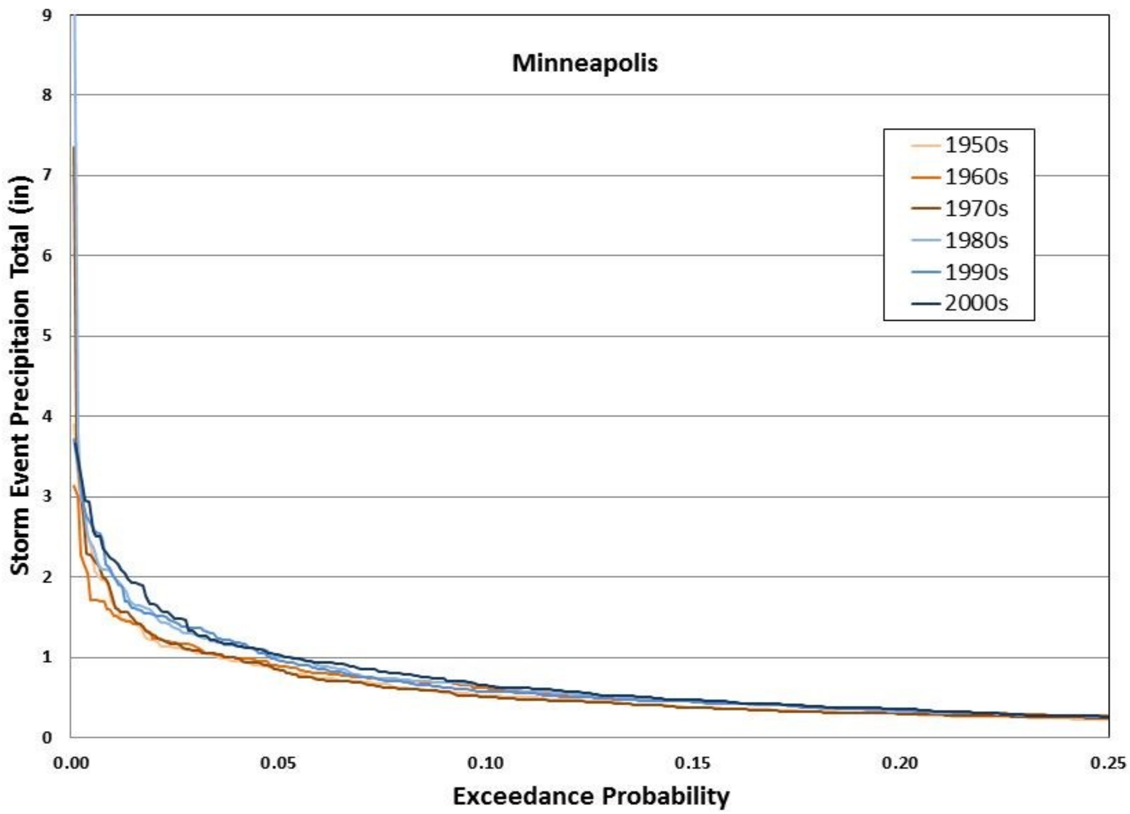
Appendix C-7. Exceedance probabilities of the characteristics of rainfall in Minneapolis.

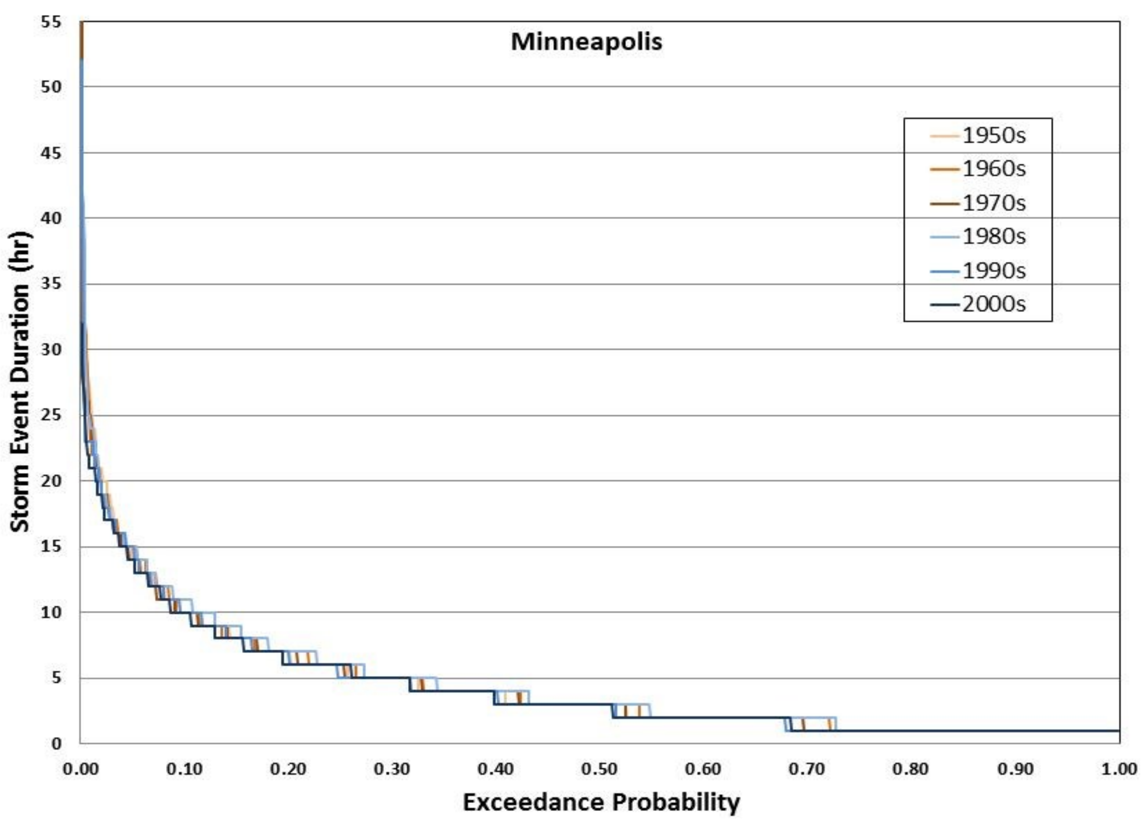


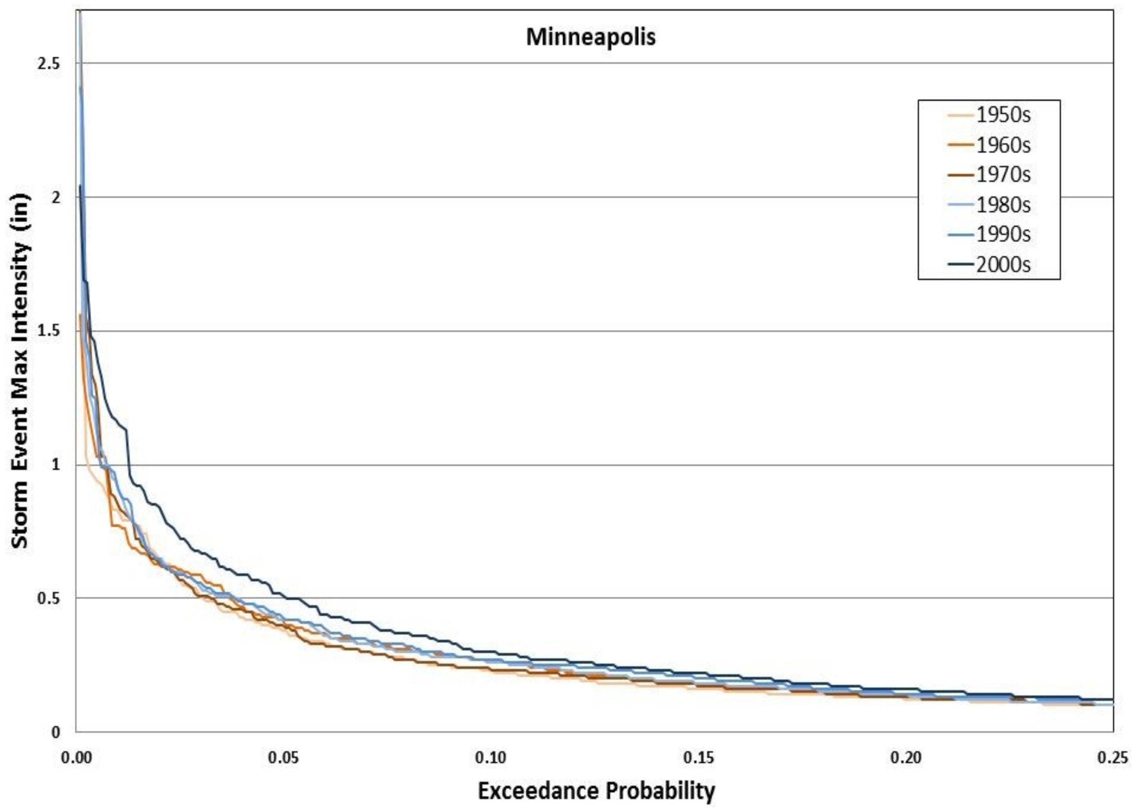


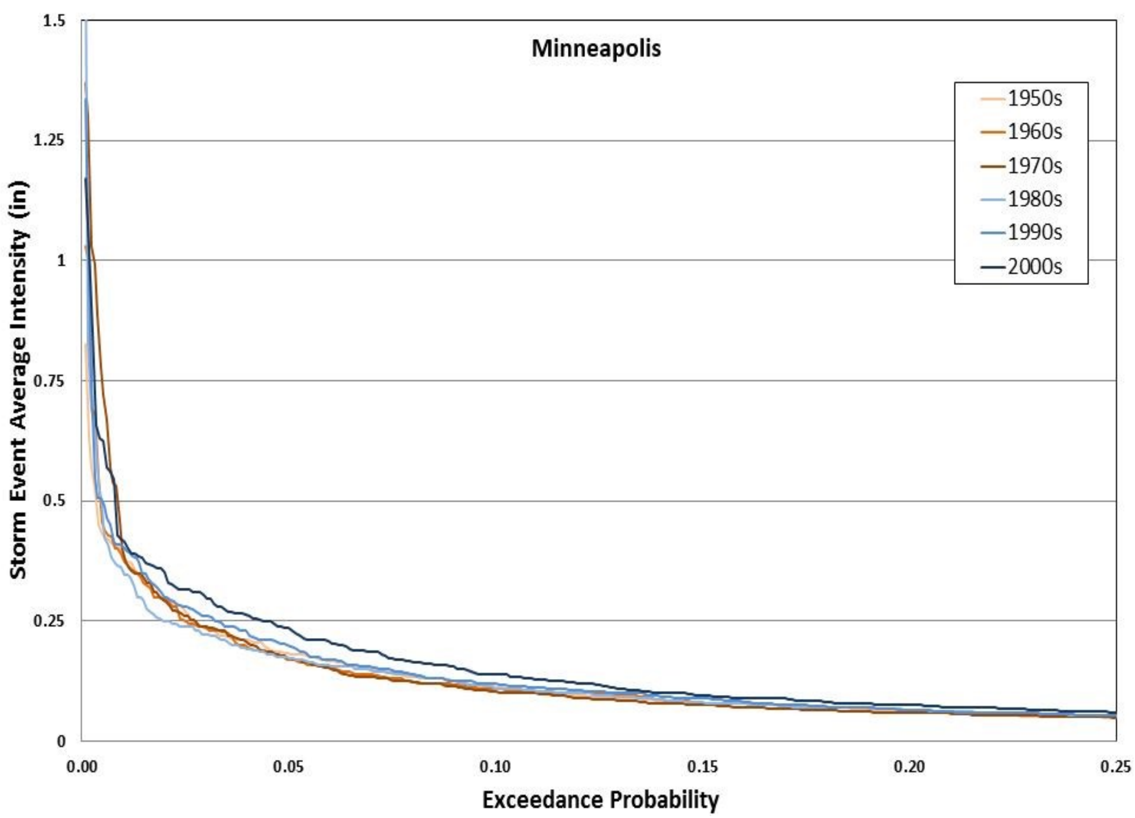

Minneapolis
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25


Minneapolis
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1.5
1.2
0.9
0.6
0.3
0
0.00
0.05
0.10
0.15
0.20
0.25

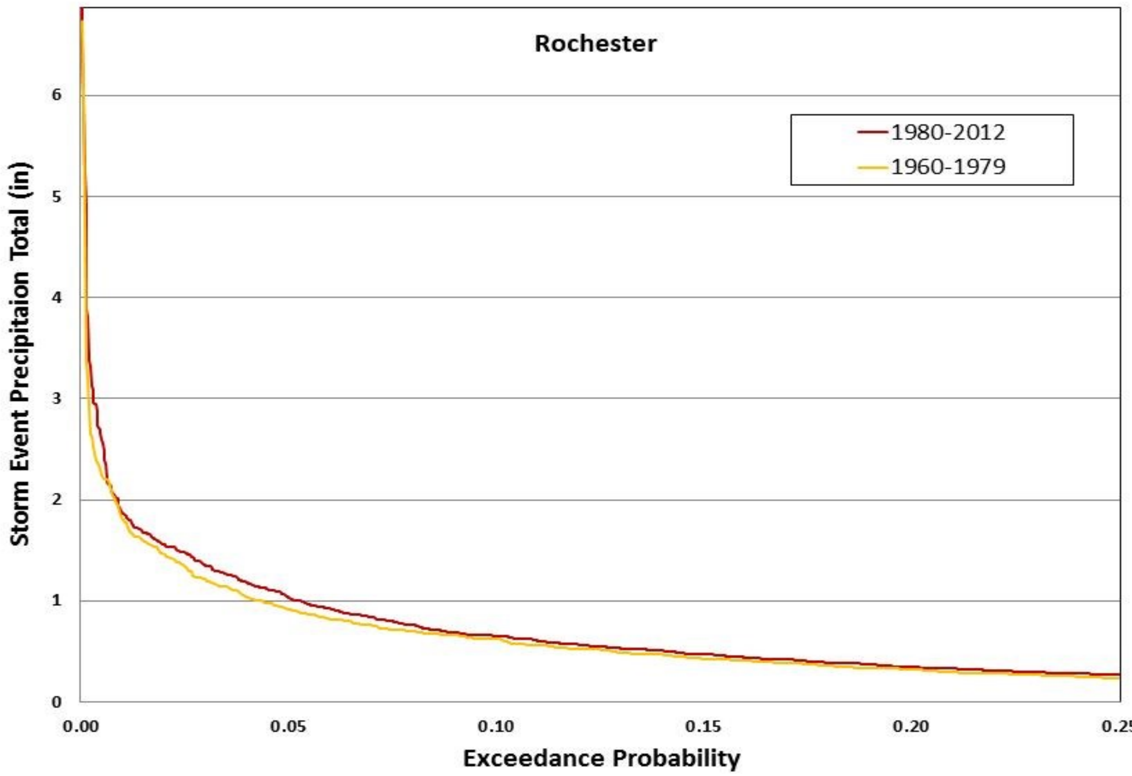

Minneapolis
Storm Event Precipitaion Total (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
1
2
3
4
5
6
7
8
9
0.00
0.05
0.10
0.15
0.20
0.25

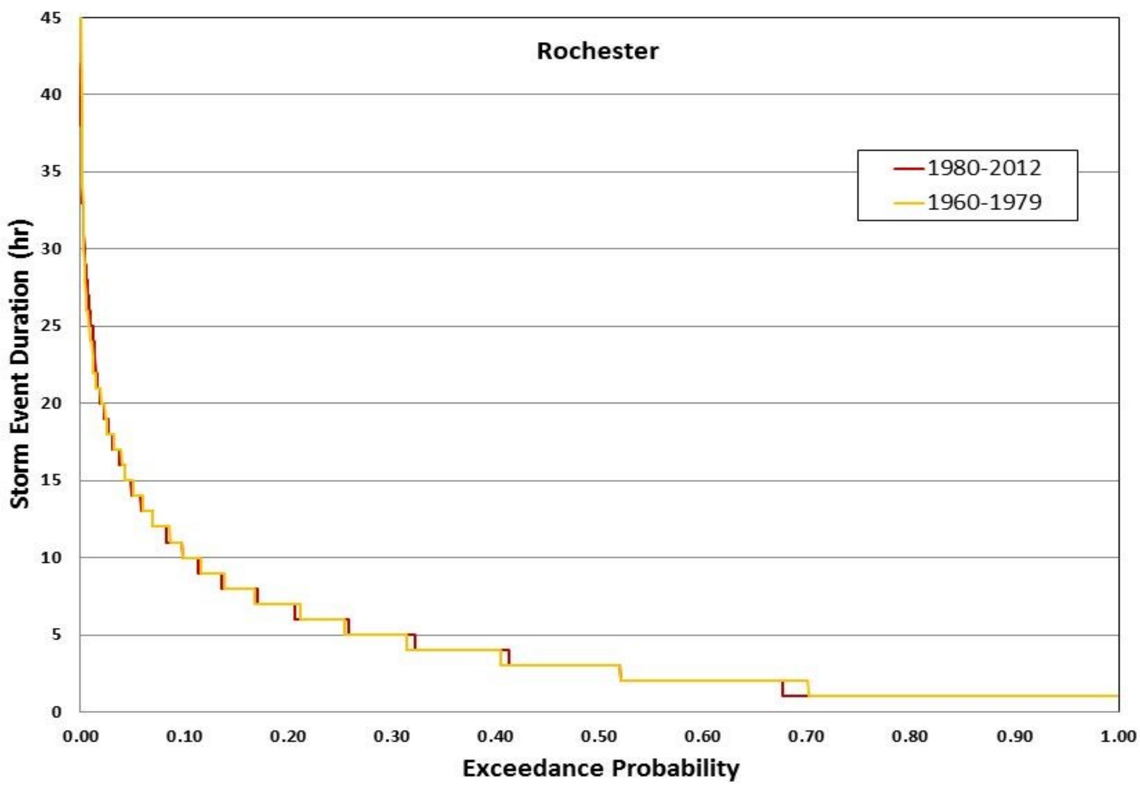

Minneapolis
Storm Event Duration (hr)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
5
10
15
20
25
30
35
40
45
50
55
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

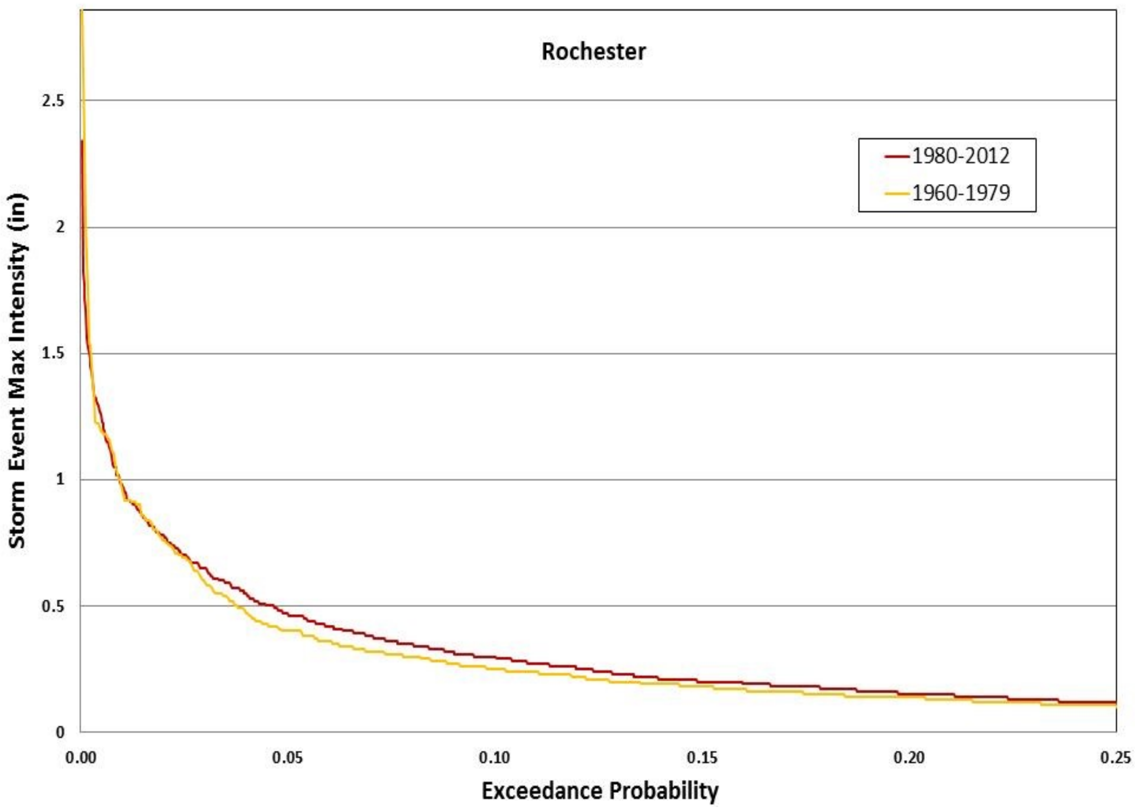

Minneapolis
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.5
1
1.5
2
2.5
0.00
0.05
0.10
0.15
0.20
0.25


Minneapolis
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.25
0.5
0.75
1
1.25
1.5
0.00
0.05
0.10
0.15
0.20
0.25

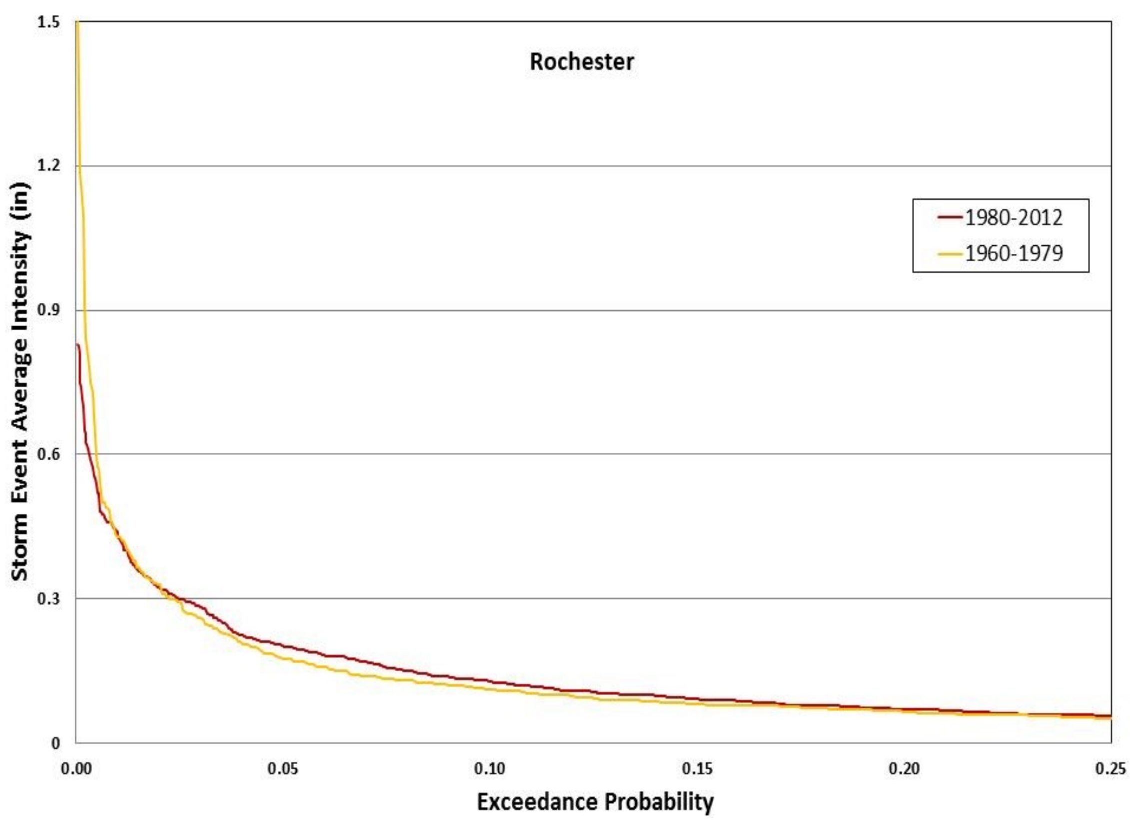
Appendix C-8. Exceedance probabilities of the characteristics of rainfall in Rochester.



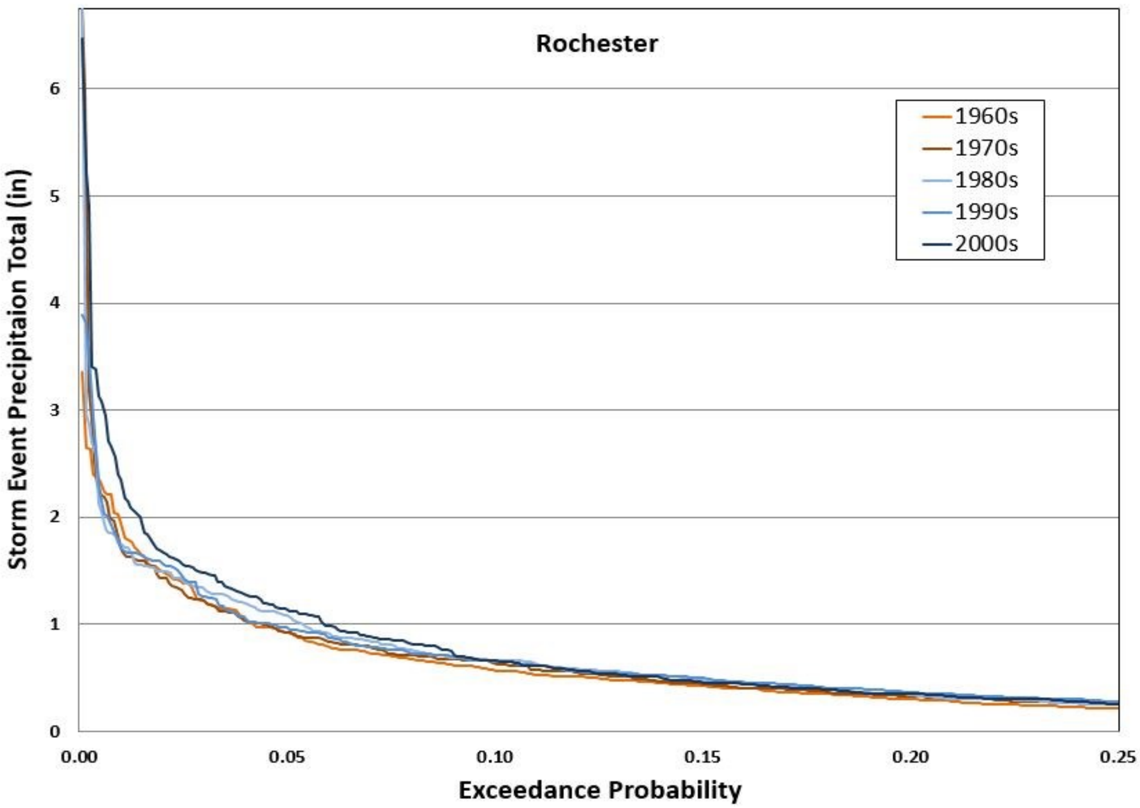


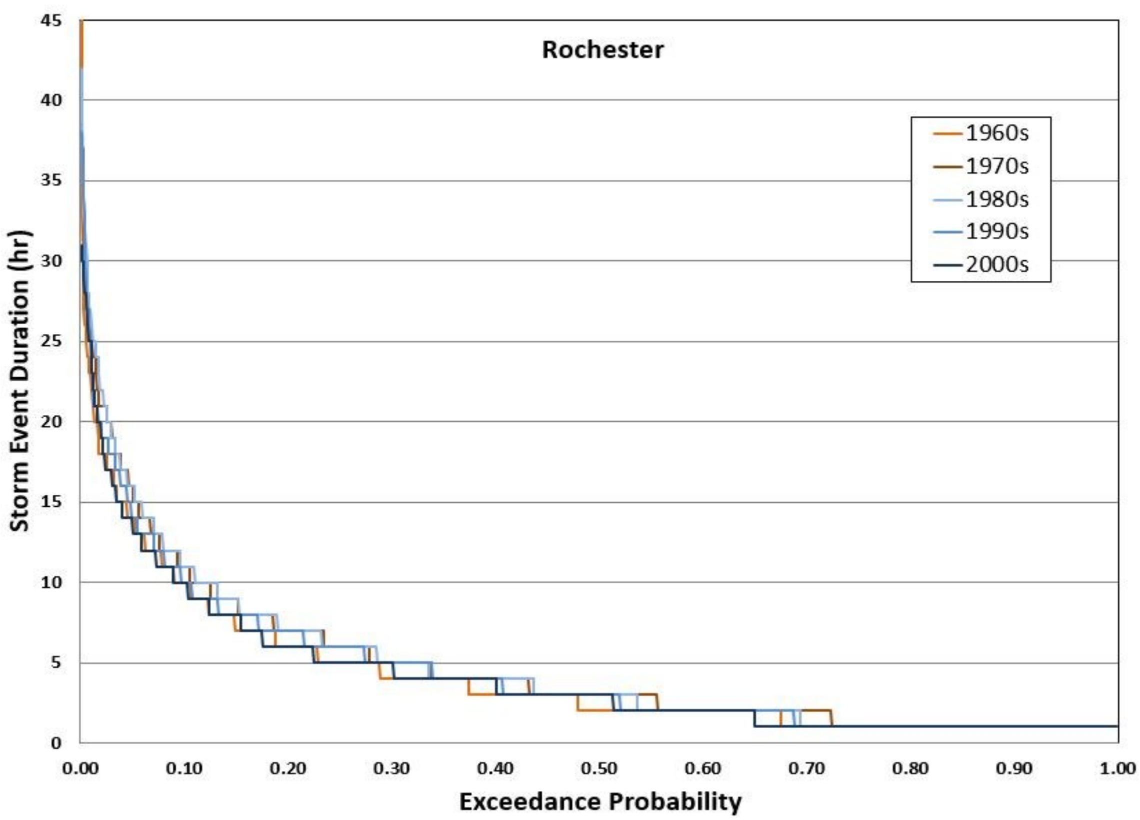


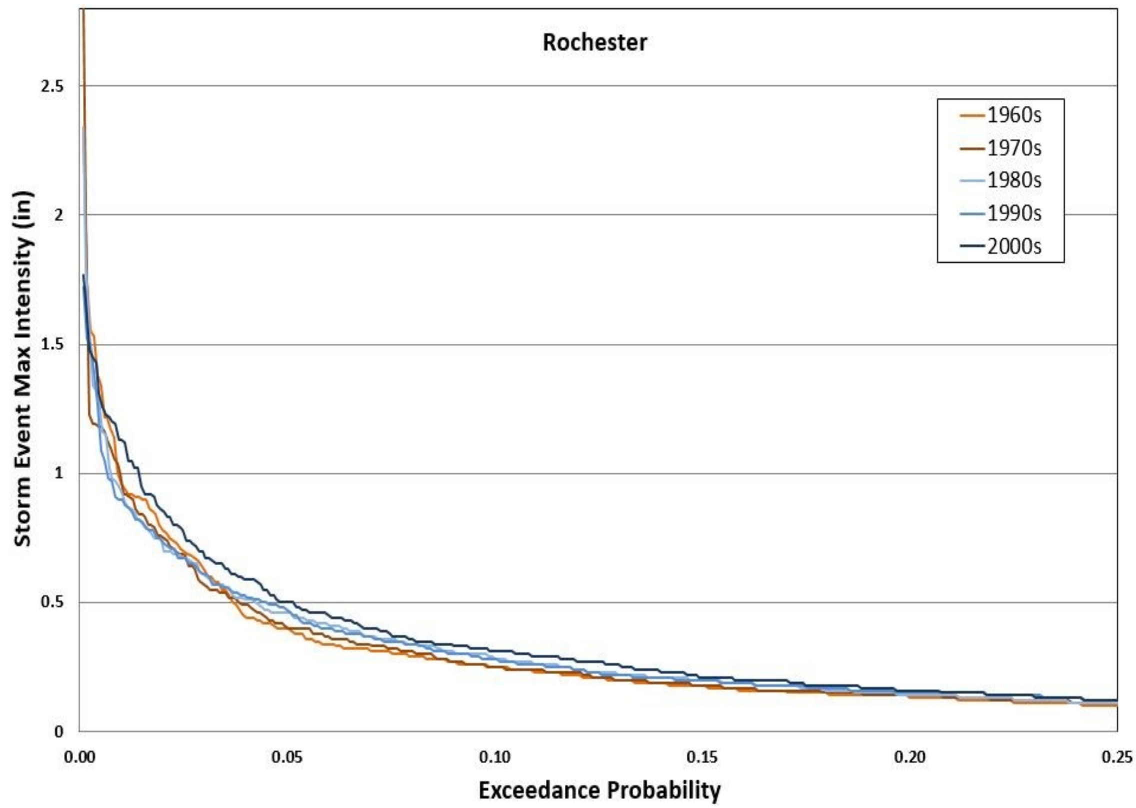
Rochester
1980-2012
1960-1979
Storm Event Max Intensity (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
0.00
0.05
0.10
0.15
0.20
0.25

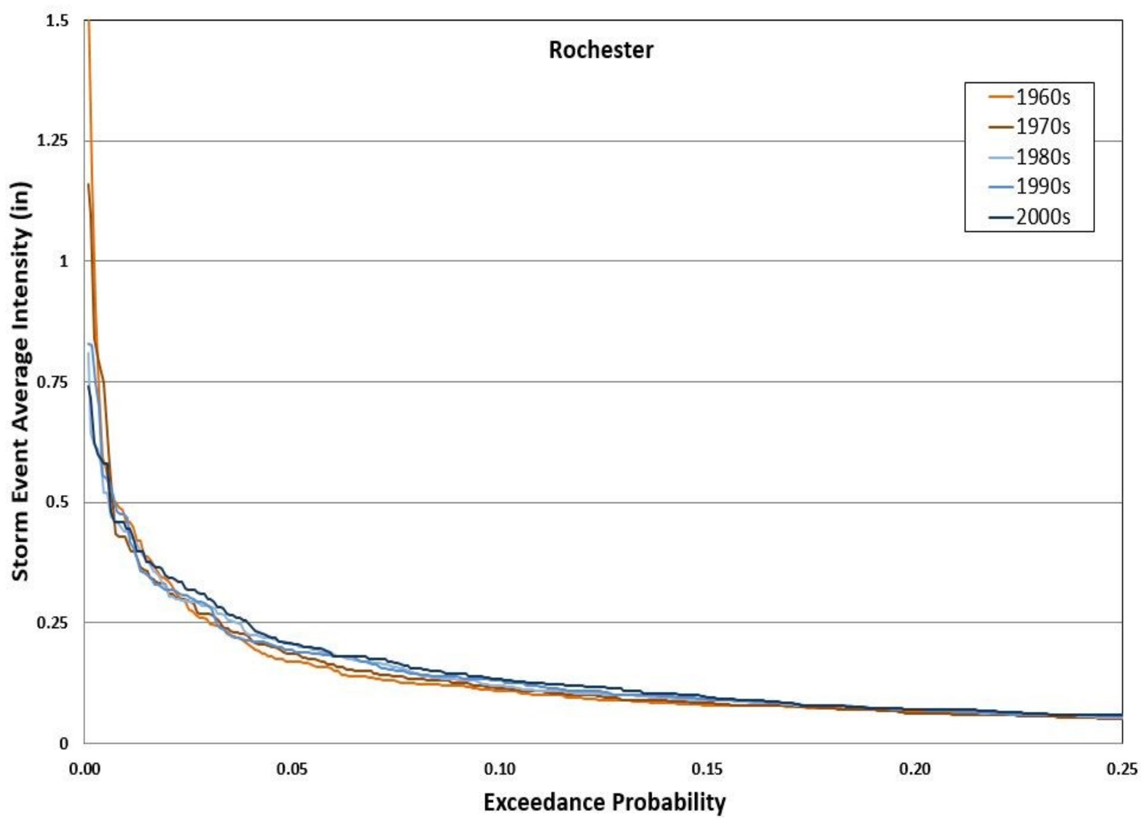


Rochester
1980-2012
1960-1979
Storm Event Average Intensity (in)
Exceedance Probability
0
0.3
0.6
0.9
1.2
1.5
0.00
0.05
0.10
0.15
0.20
0.25

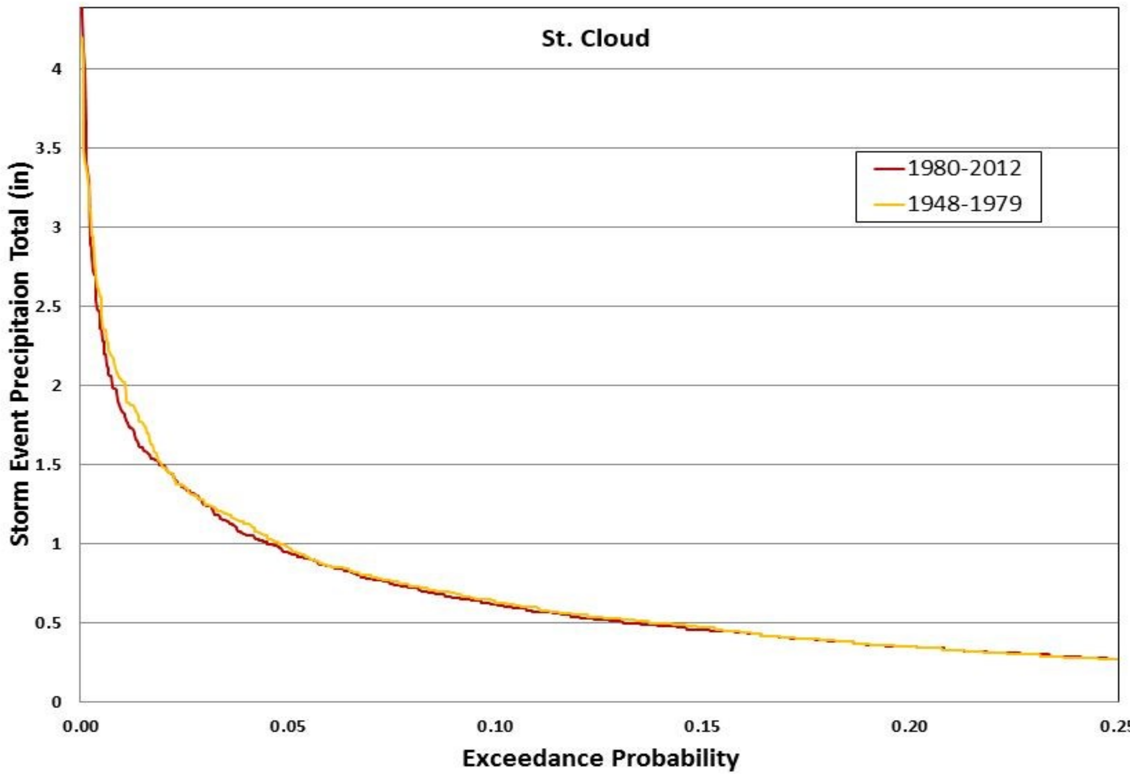

Rochester
Storm Event Precipitaion Total (in)
Exceedance Probability
1960s
1970s
1980s
1990s
2000s
0
1
2
3
4
5
6
0.00
0.05
0.10
0.15
0.20
0.25

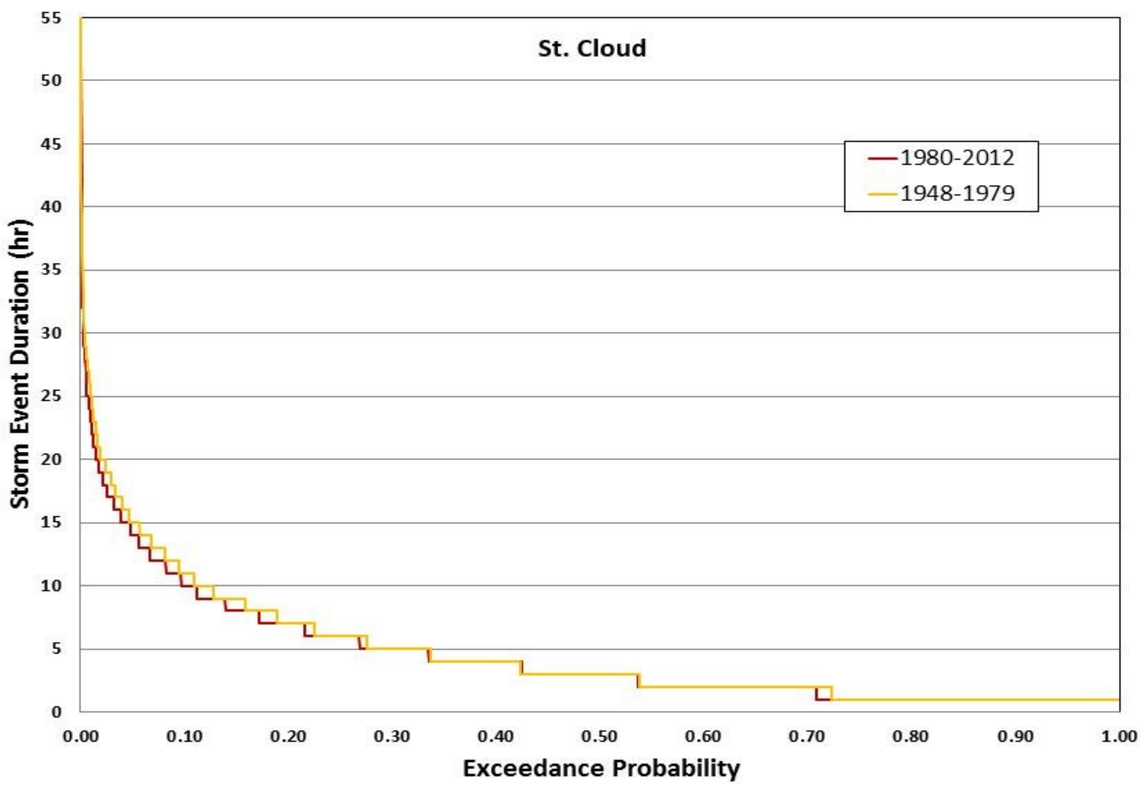

Rochester
Storm Event Duration (hr)
Exceedance Probability
1960s
1970s
1980s
1990s
2000s
0
5
10
15
20
25
30
35
40
45
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

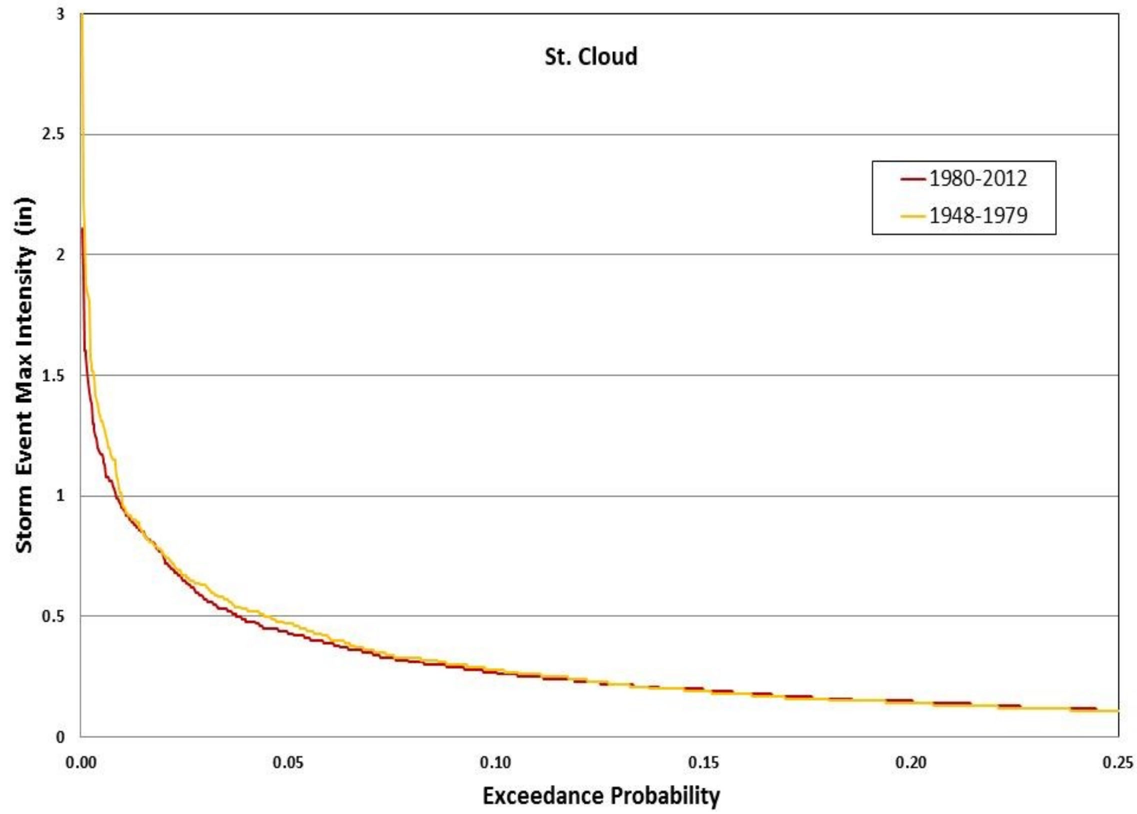

Rochester
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Storm Event Max Intensity (in)
Exceedance Probability
1960s
1970s
1980s
1990s
2000s


Rochester
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Storm Event Average Intensity (in)
Exceedance Probability
1960s
1970s
1980s
1990s
2000s

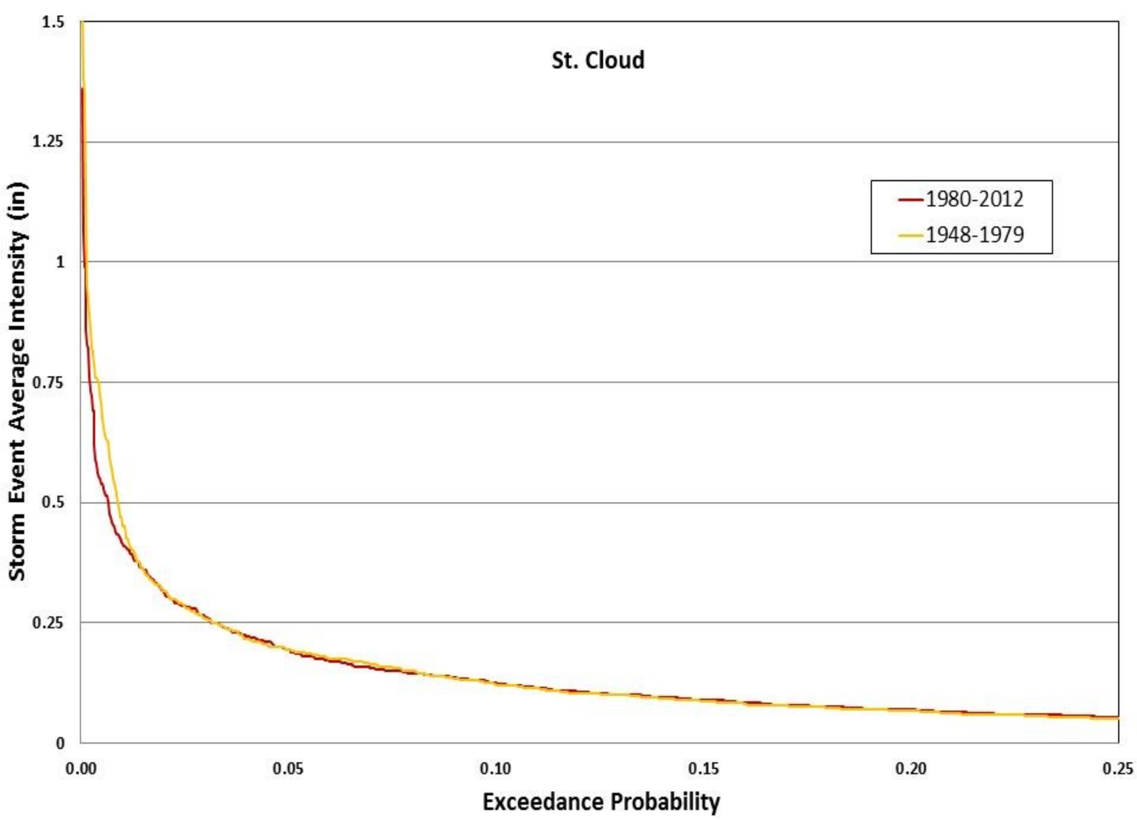
Appendix C-9. Exceedance probabilities of the characteristics of rainfall in St. Cloud.



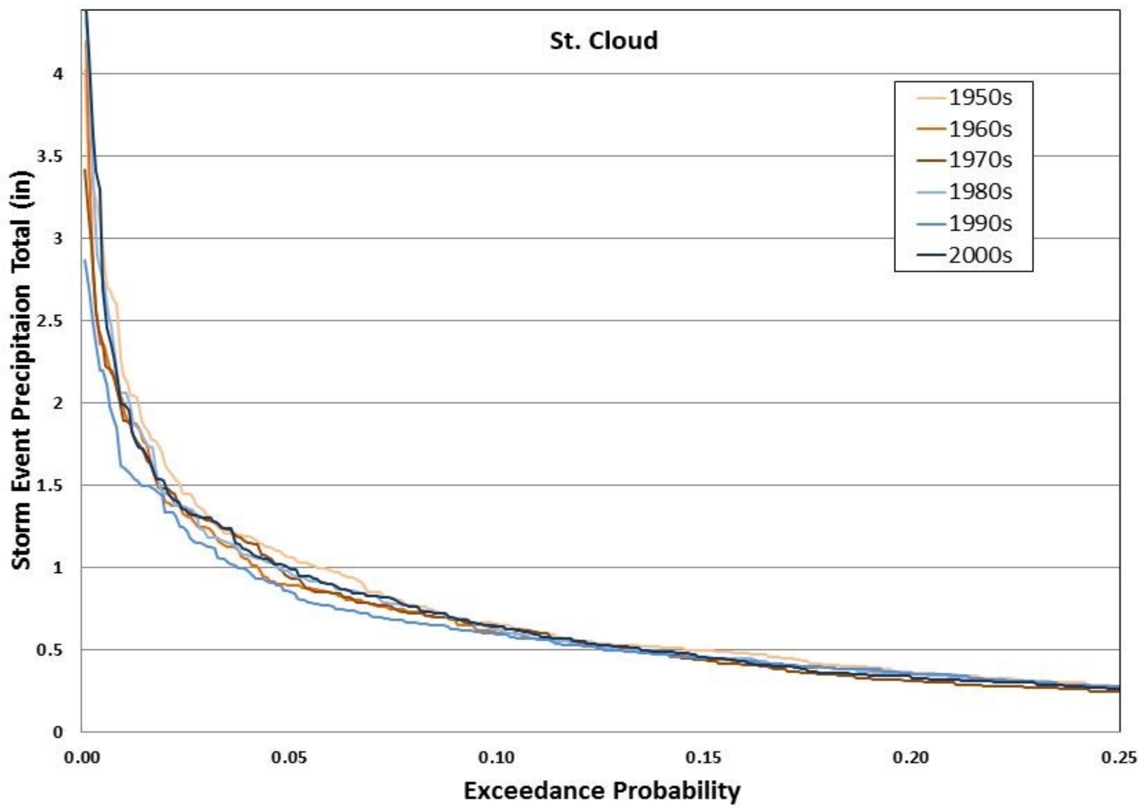




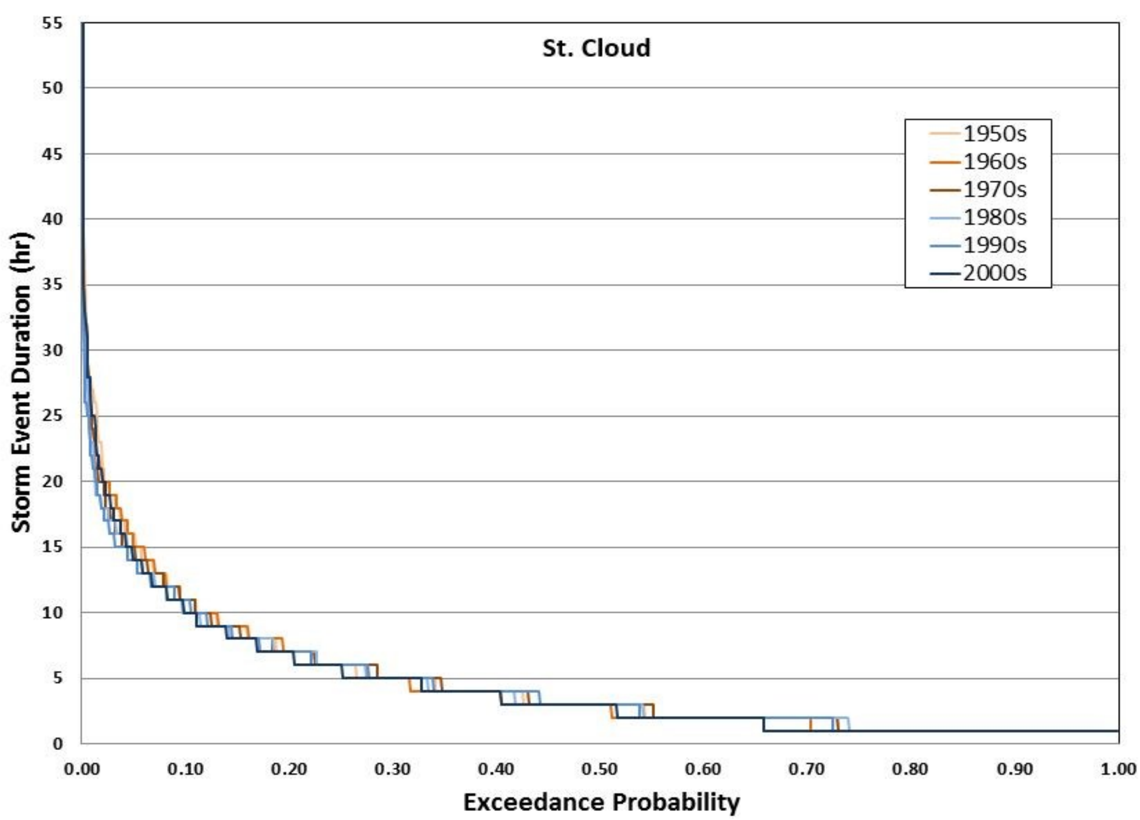
St. Cloud
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
0.00
0.05
0.10
0.15
0.20
0.25



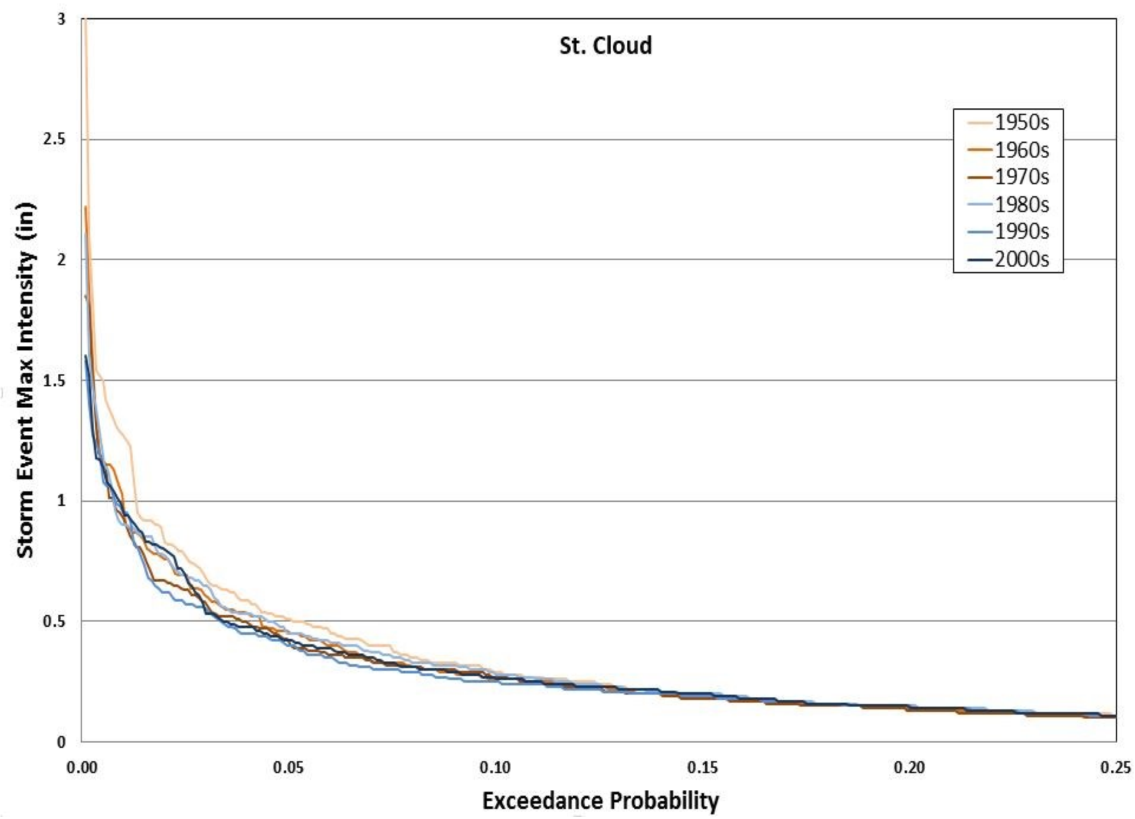
St. Cloud
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
0.00
0.05
0.10
0.15
0.20
0.25

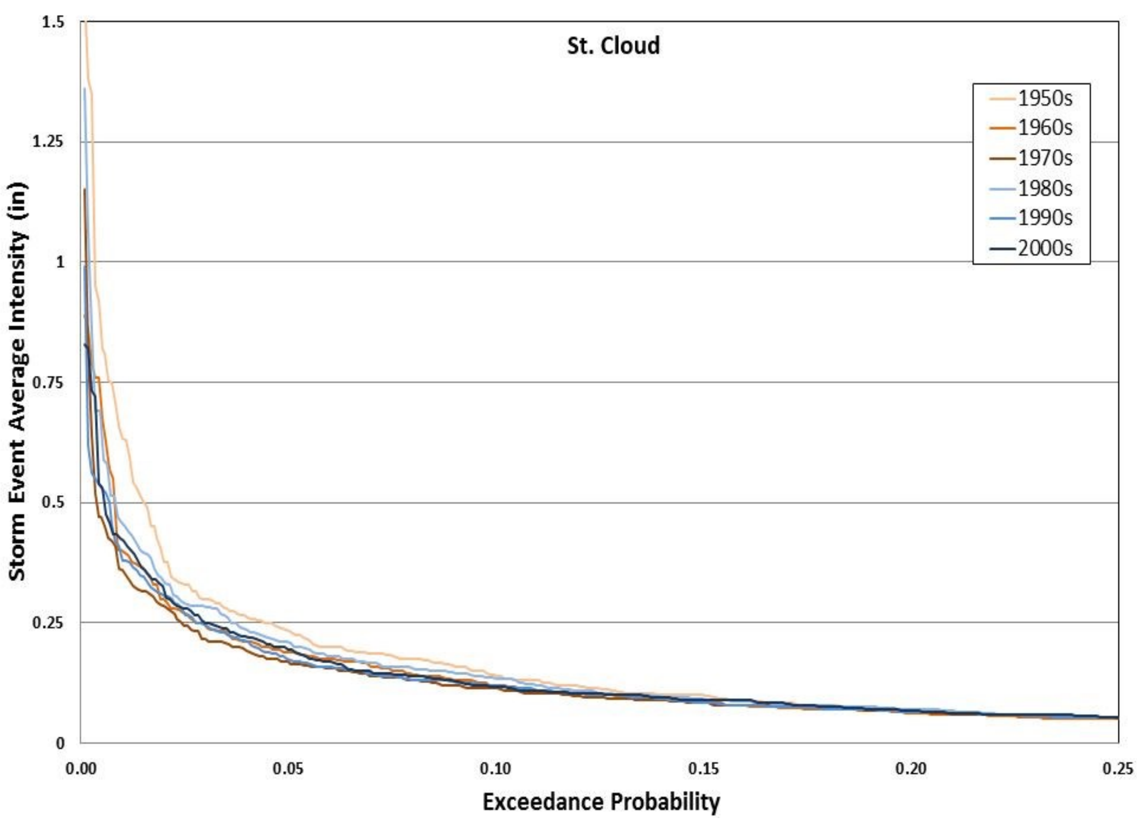


St. Cloud
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
0
0.5
1
1.5
2
2.5
3
3.5
4
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

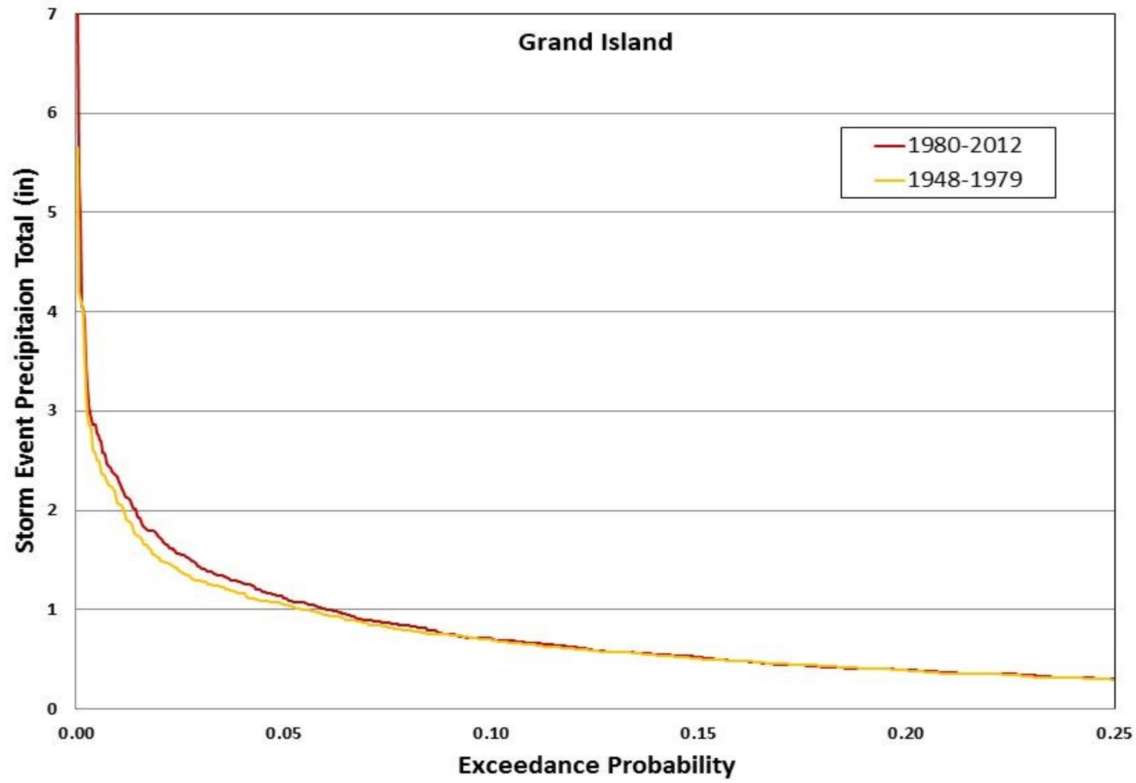


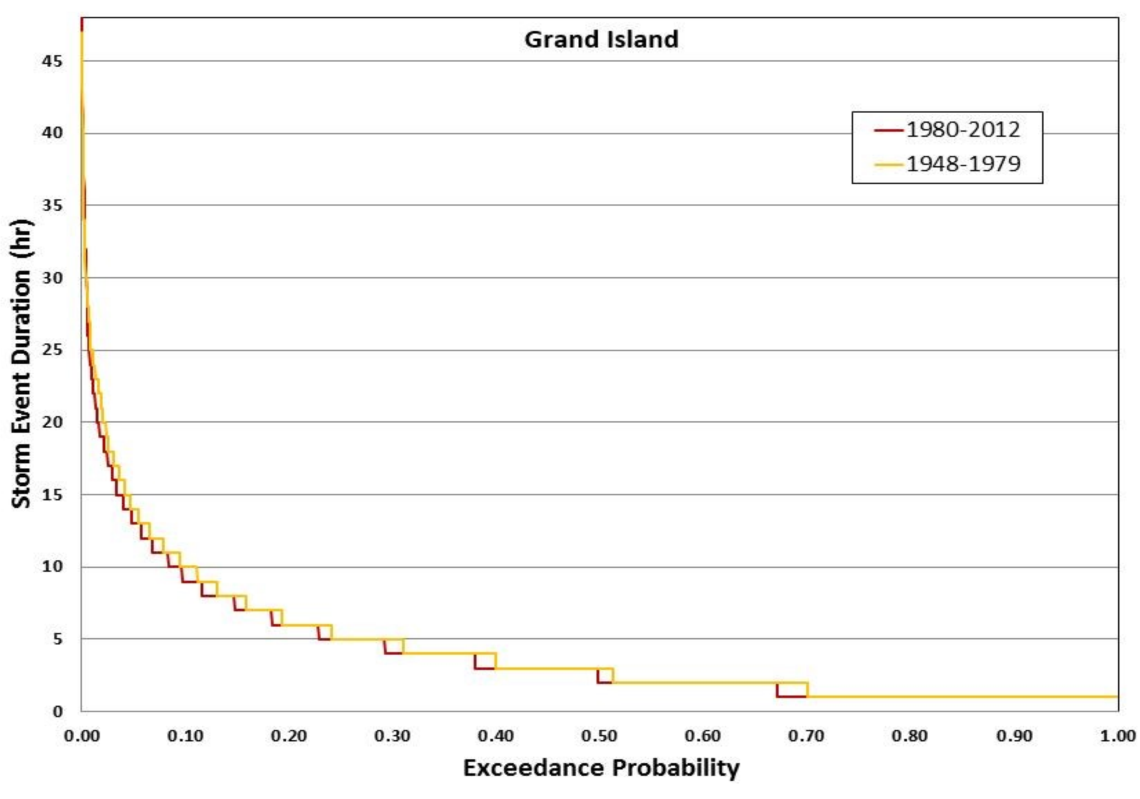
St. Cloud
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
0
5
10
15
20
25
30
35
40
45
50
55
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Exceedance Probability

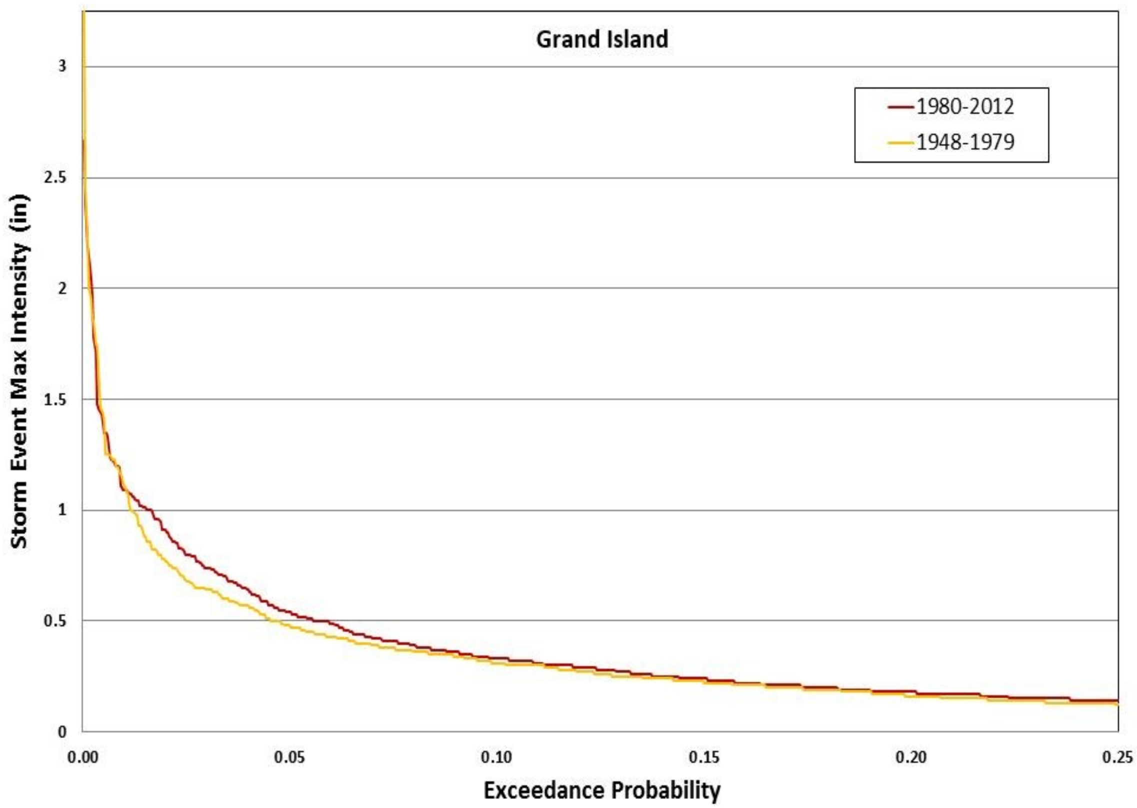

St. Cloud
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Max Intensity (in)
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

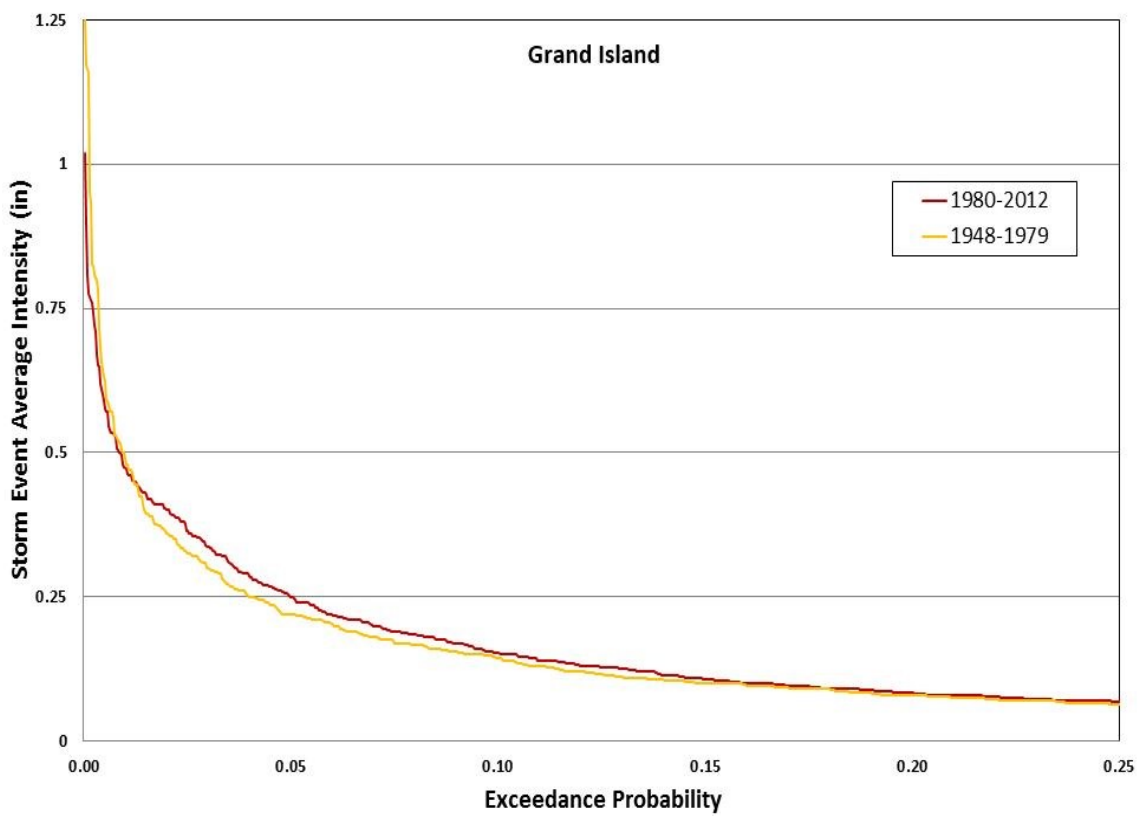

St. Cloud
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Average Intensity (in)
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

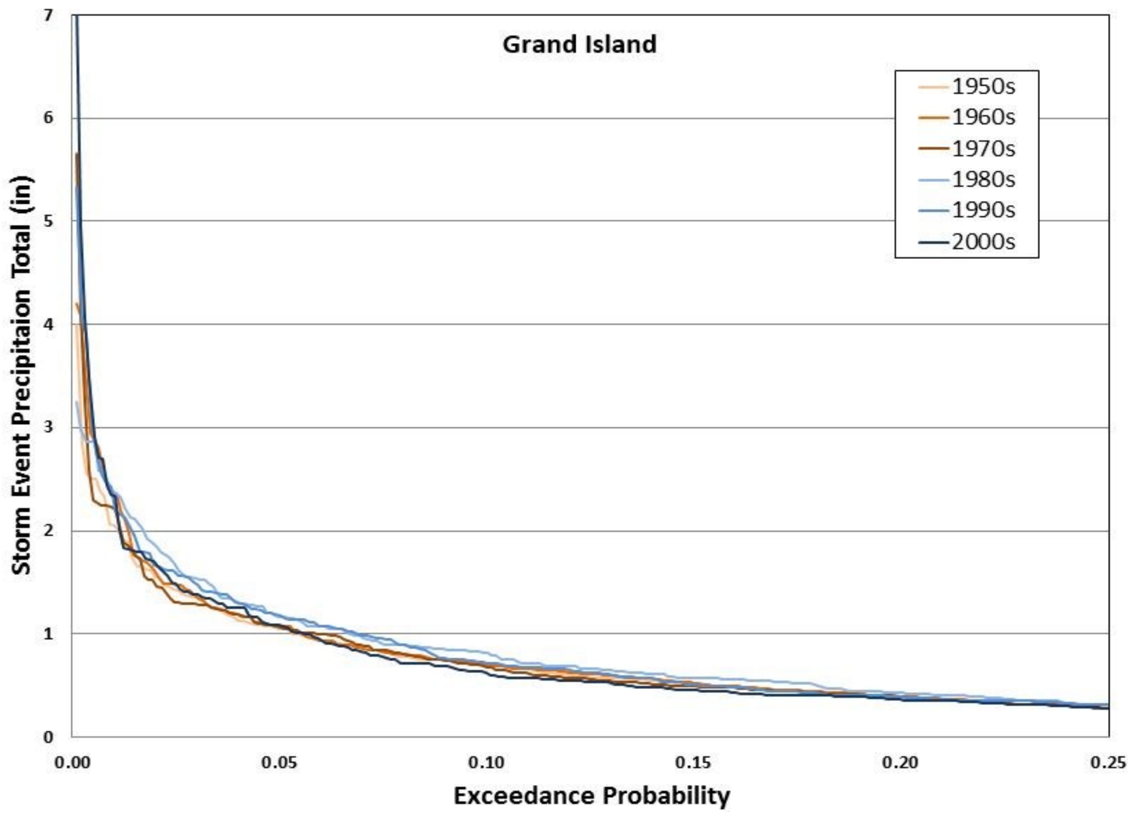
Appendix C-10. Exceedance probabilities of the characteristics of rainfall in Grand Island.

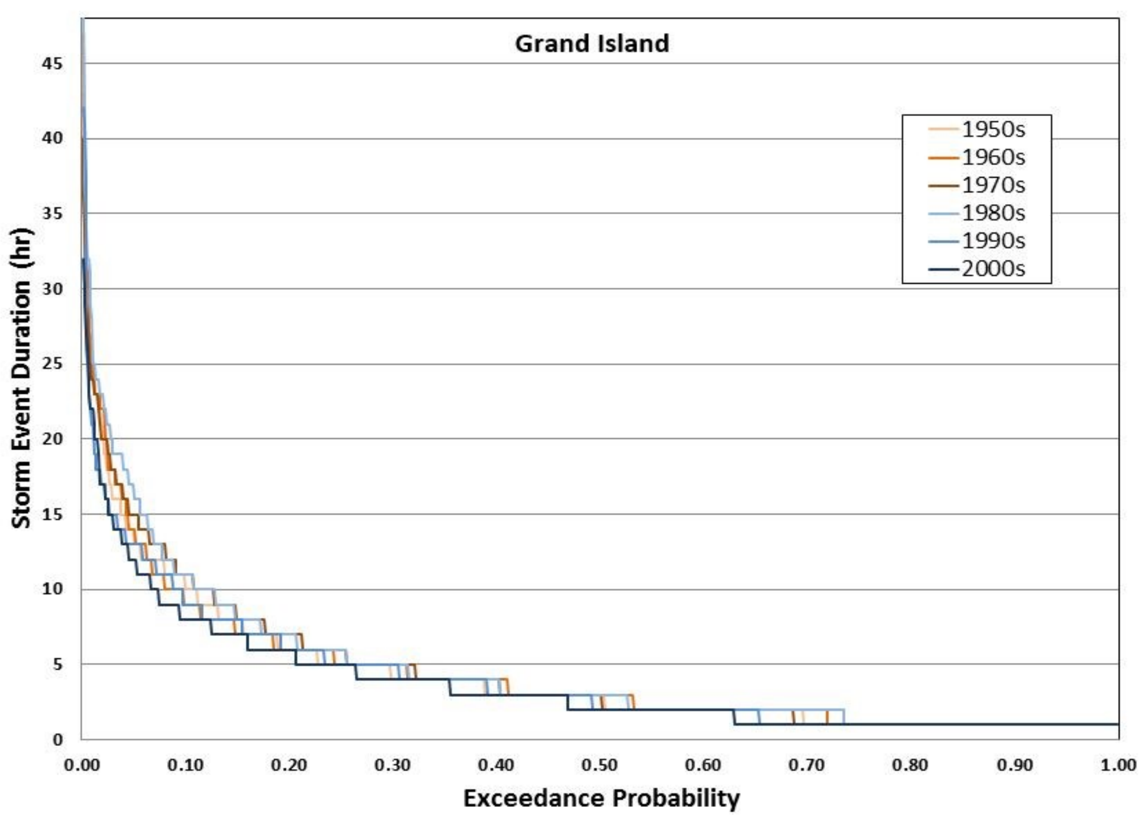


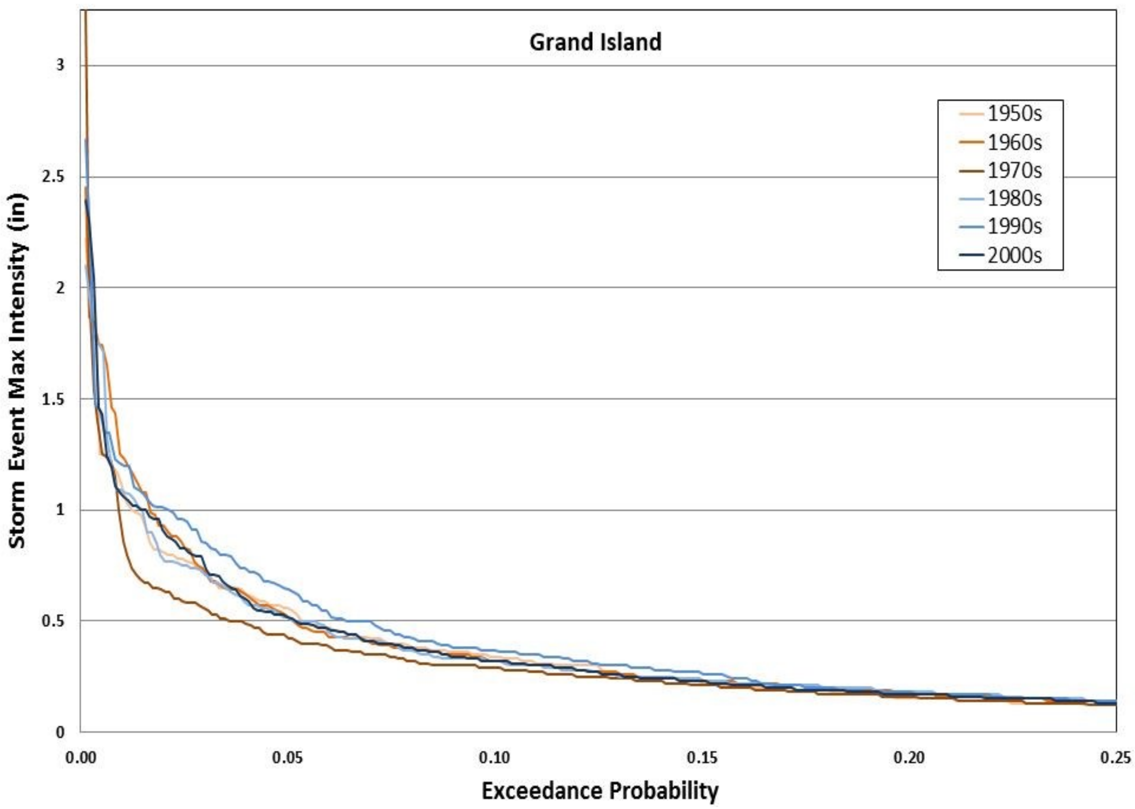



Grand Island
1980-2012
1948-1979
Storm Event Max Intensity (in)
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

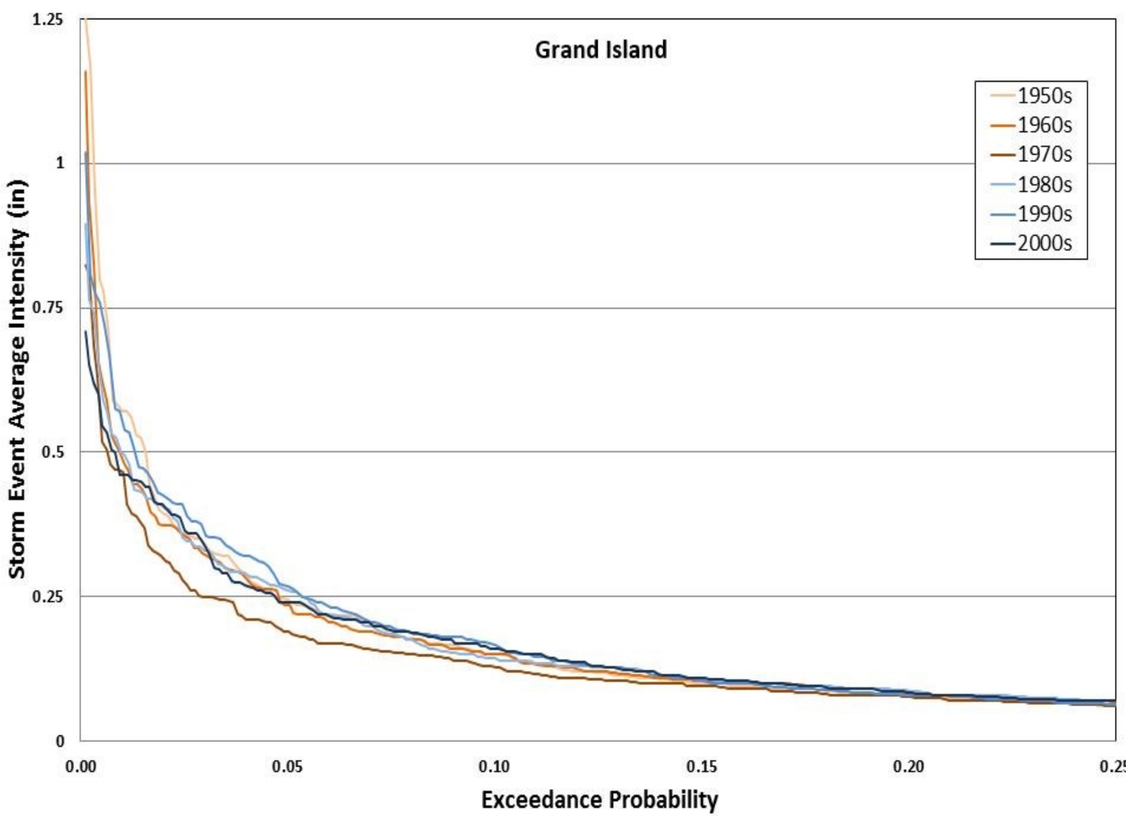

Grand Island
1980-2012
1948-1979
Storm Event Average Intensity (in)
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Grand Island
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
1
2
3
4
5
6
7
0.00
0.05
0.10
0.15
0.20
0.25


Grand Island
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

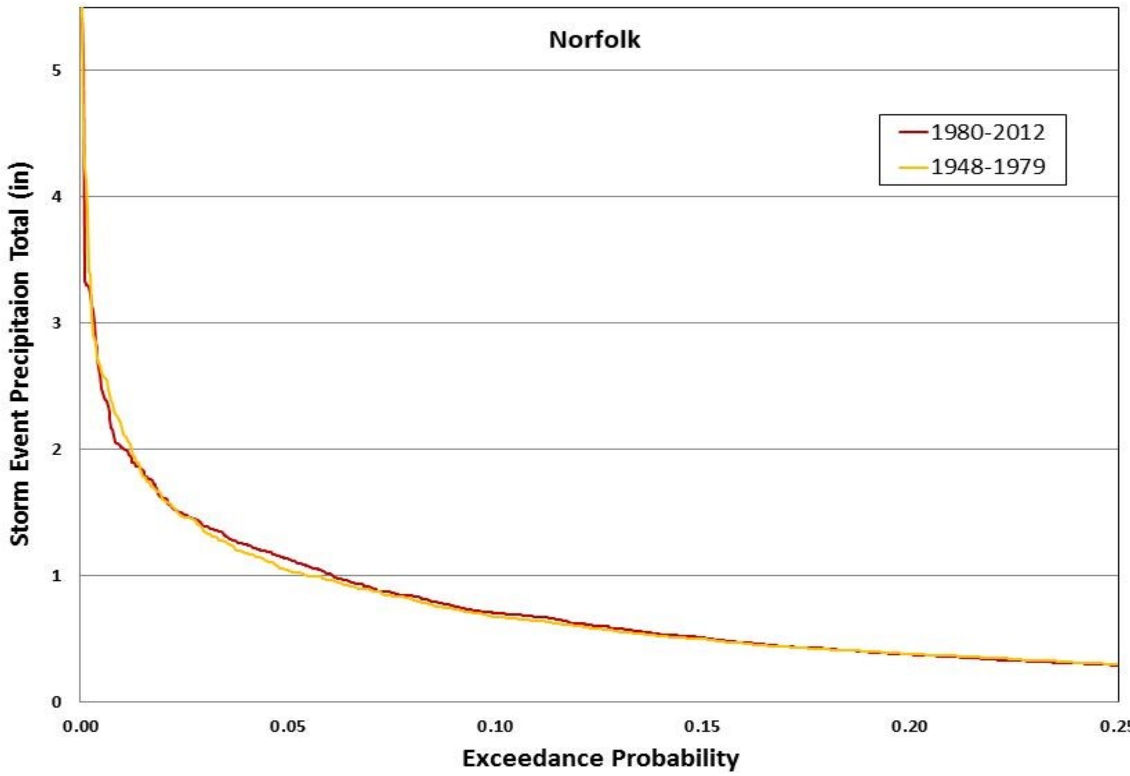


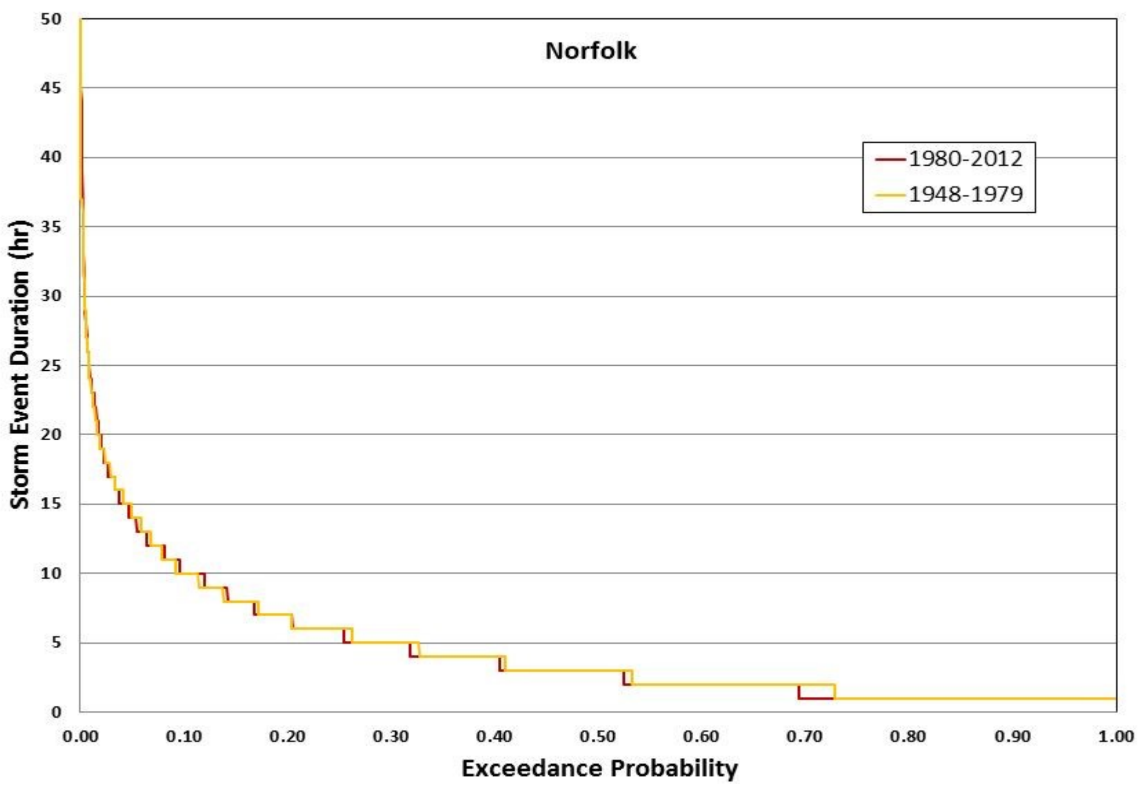
Grand Island
Storm Event Max Intensity (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

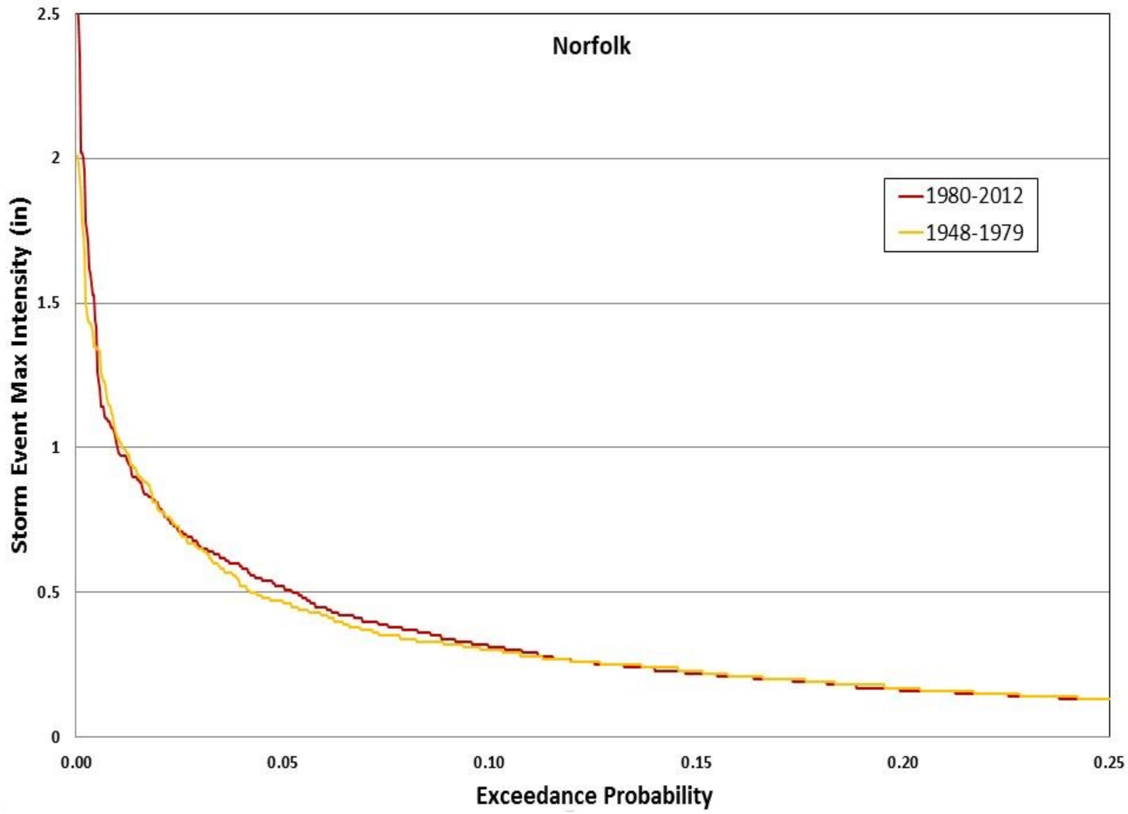


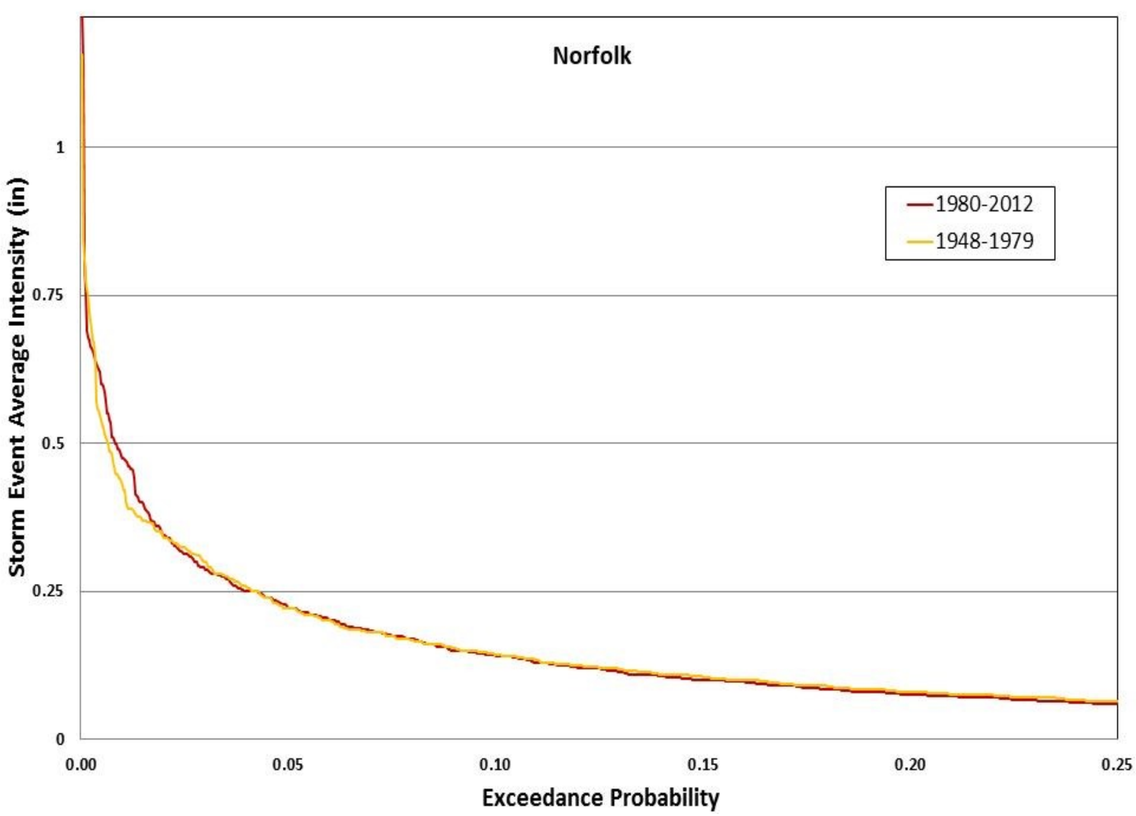
Grand Island
Storm Event Average Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

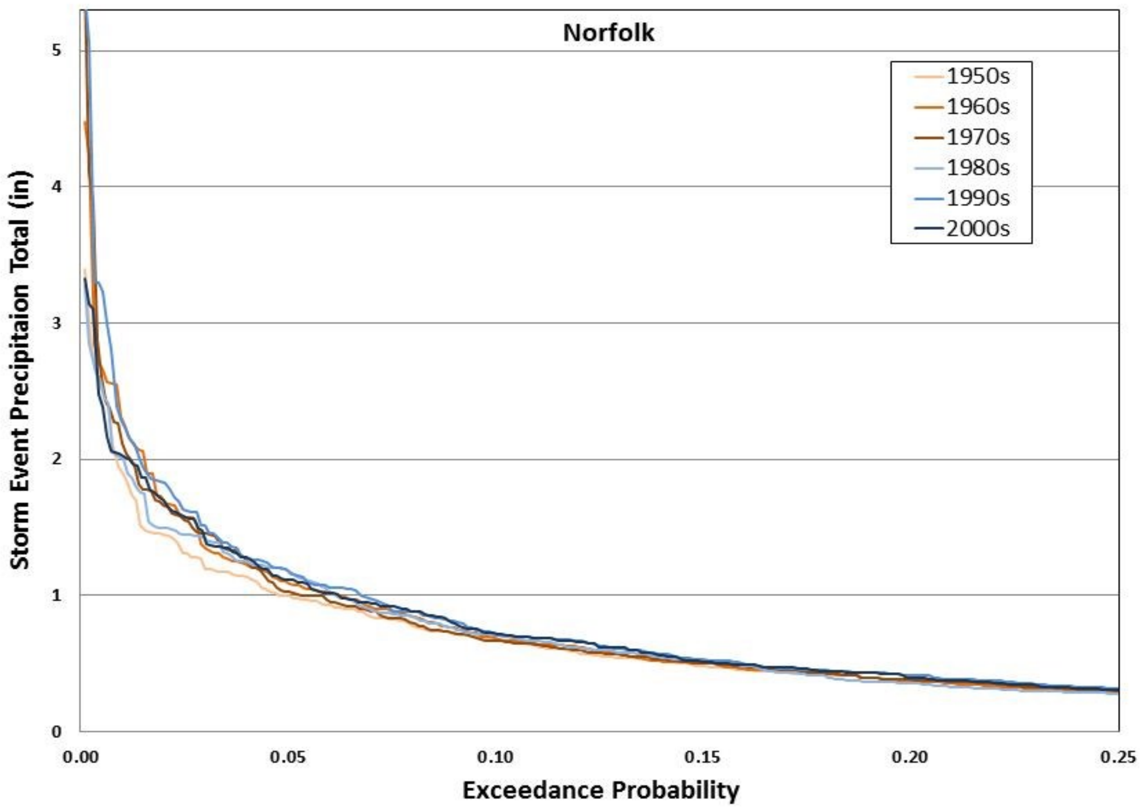
Appendix C-11. Exceedance probabilities of the characteristics of rainfall in Norfolk.

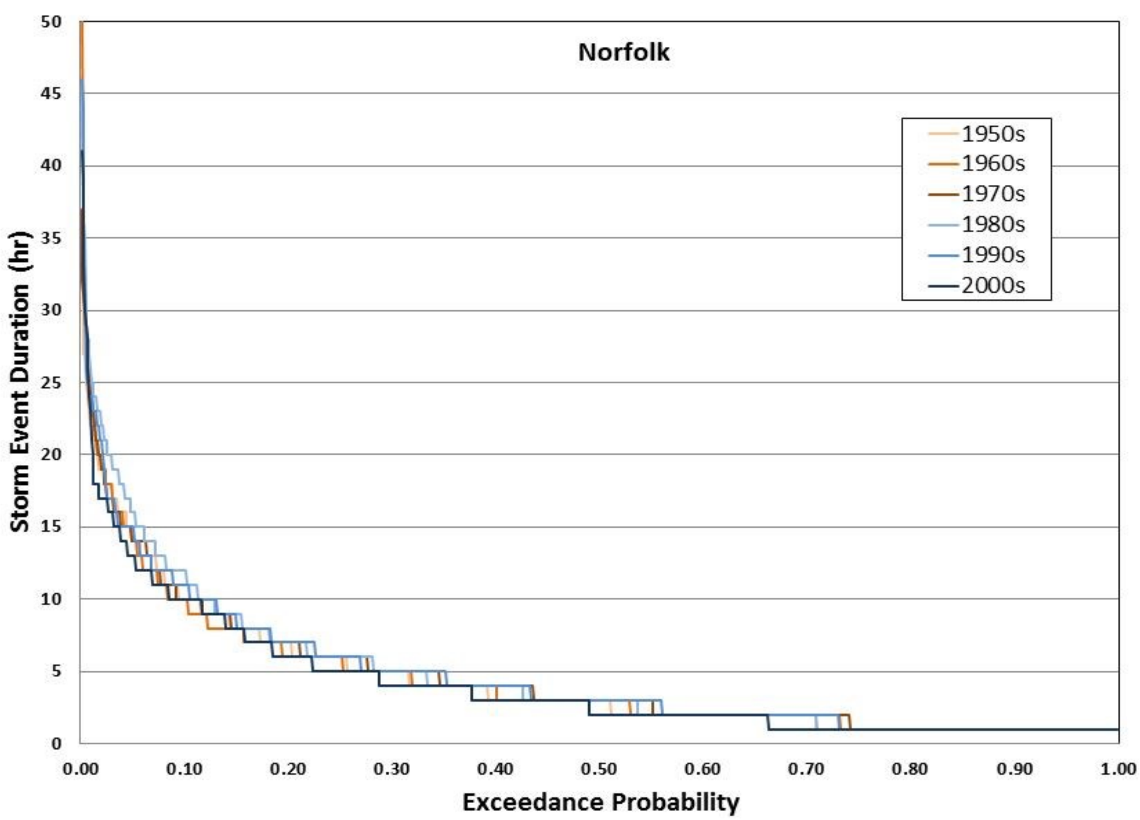


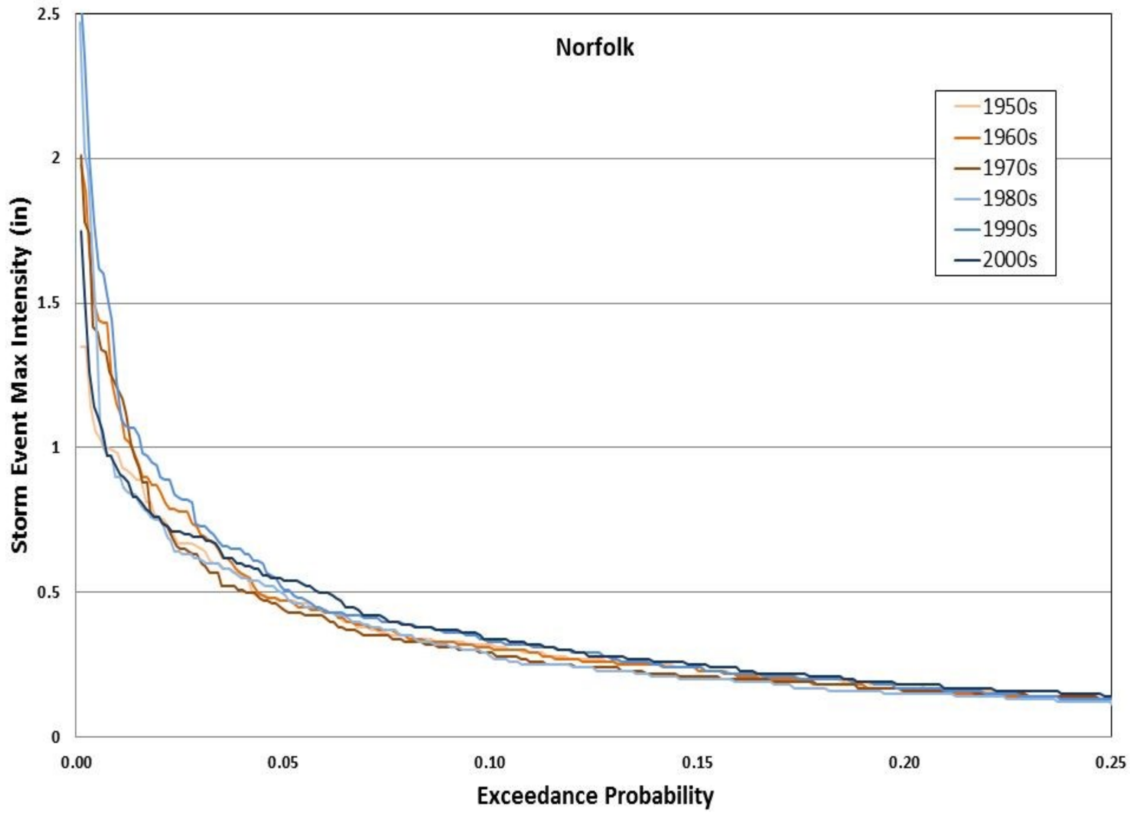


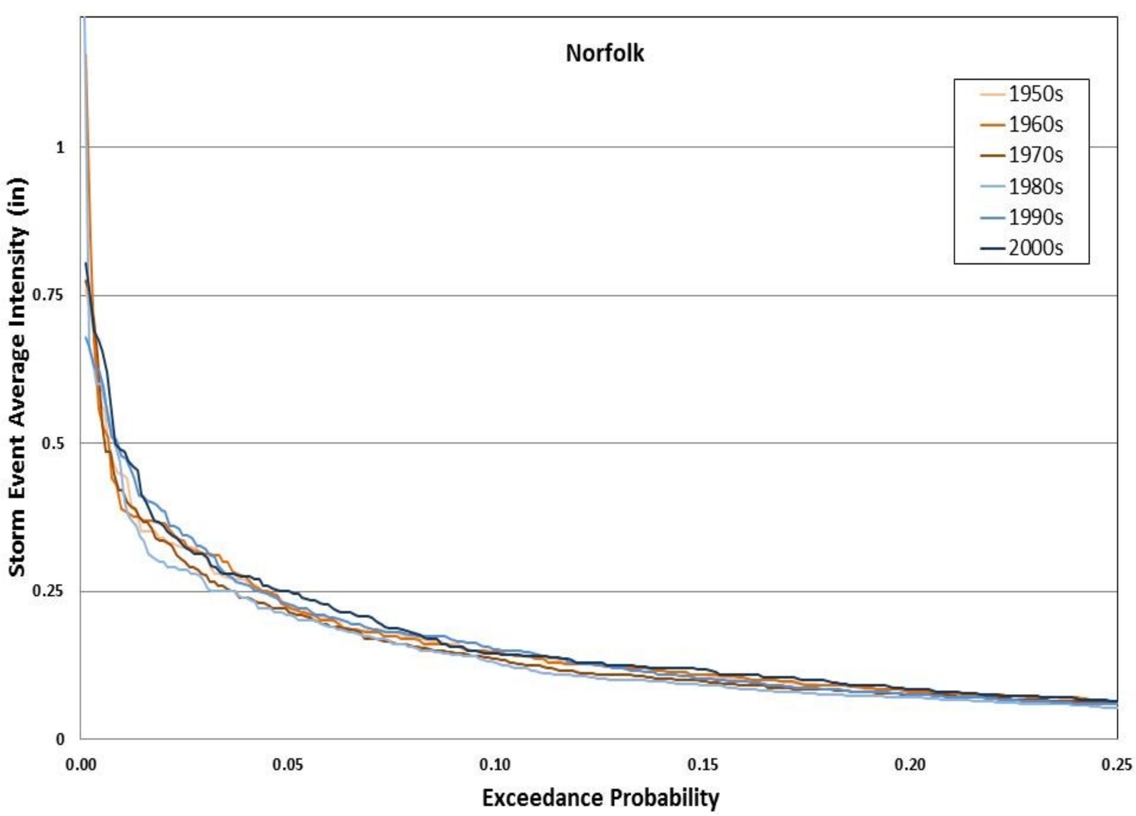

Norfolk
1980-2012
1948-1979
Storm Event Max Intensity (in)
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Norfolk
1980-2012
1948-1979
Storm Event Average Intensity (in)
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

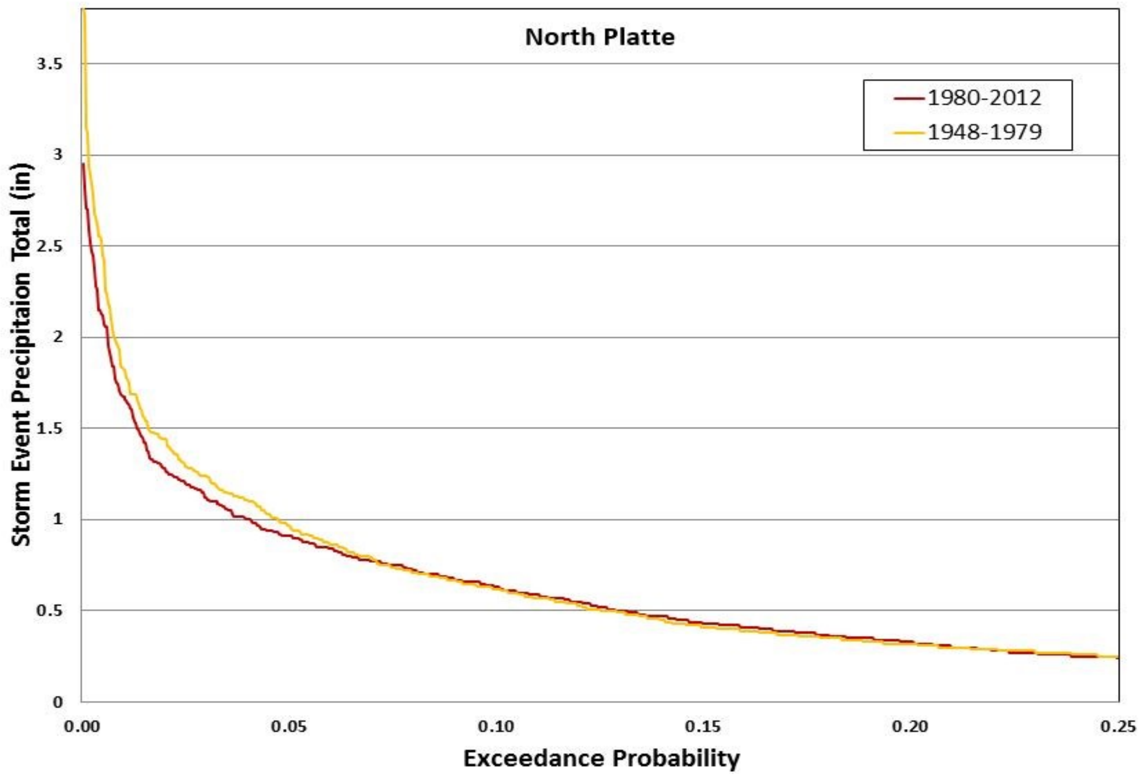

Norfolk
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability

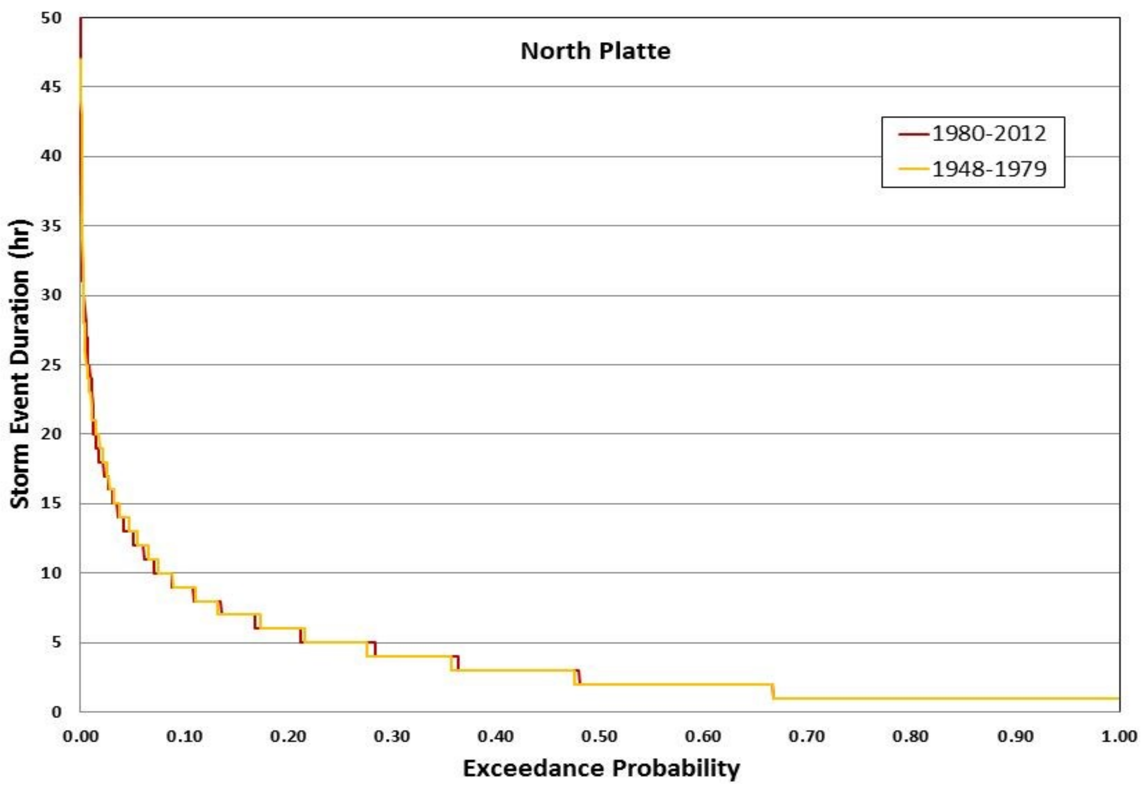

Norfolk
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability

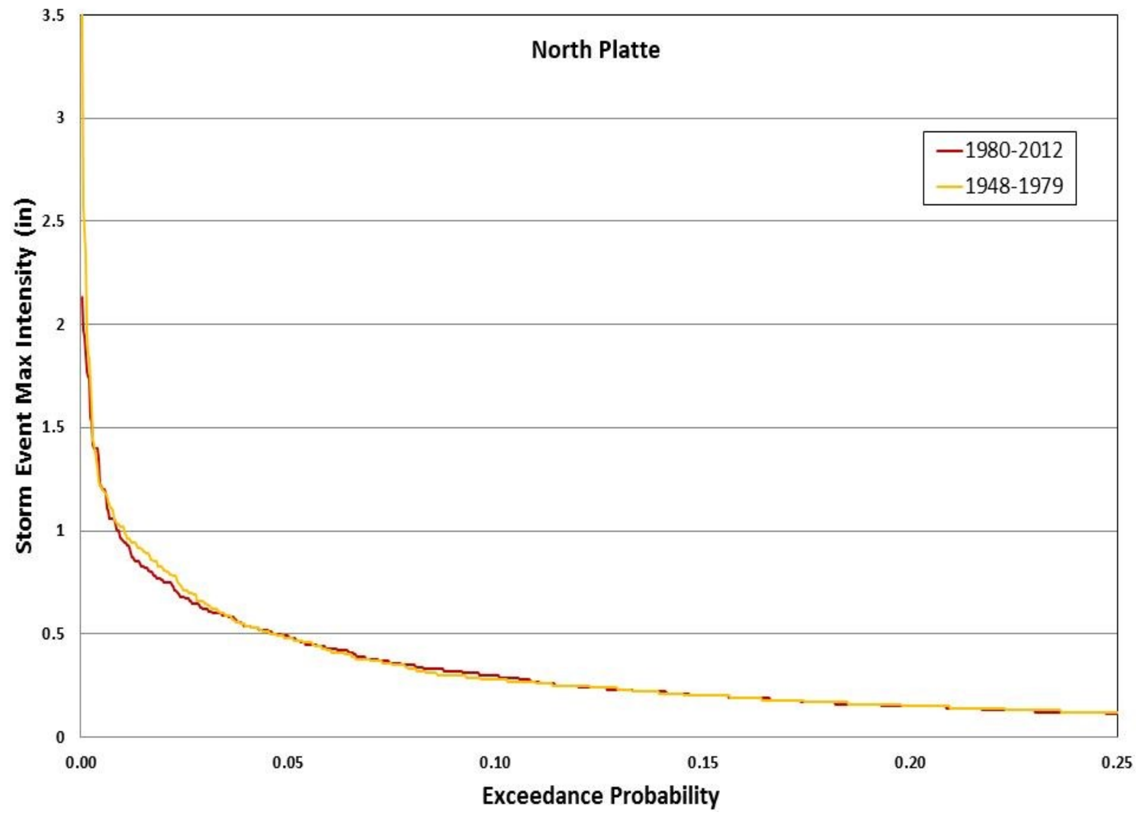

Norfolk
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.5
1
1.5
2
2.5
0.00
0.05
0.10
0.15
0.20
0.25

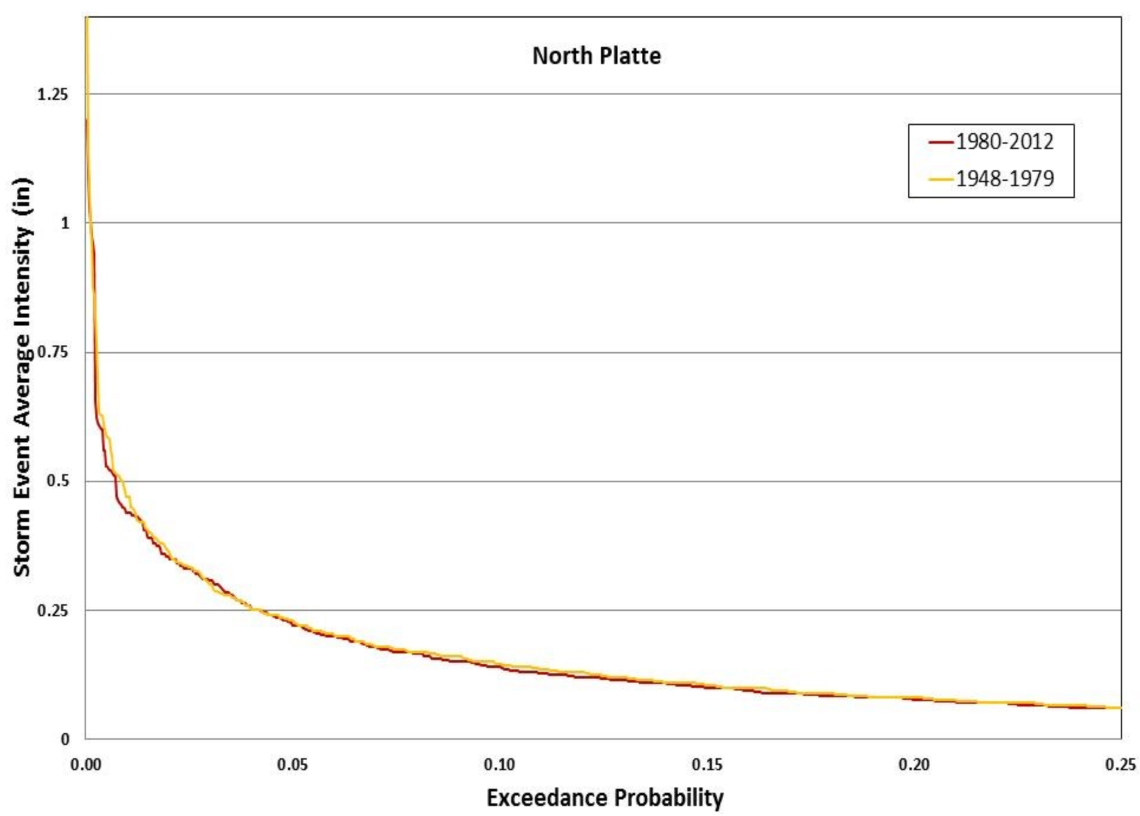

Norfolk
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.25
0.5
0.75
1
0.00
0.05
0.10
0.15
0.20
0.25

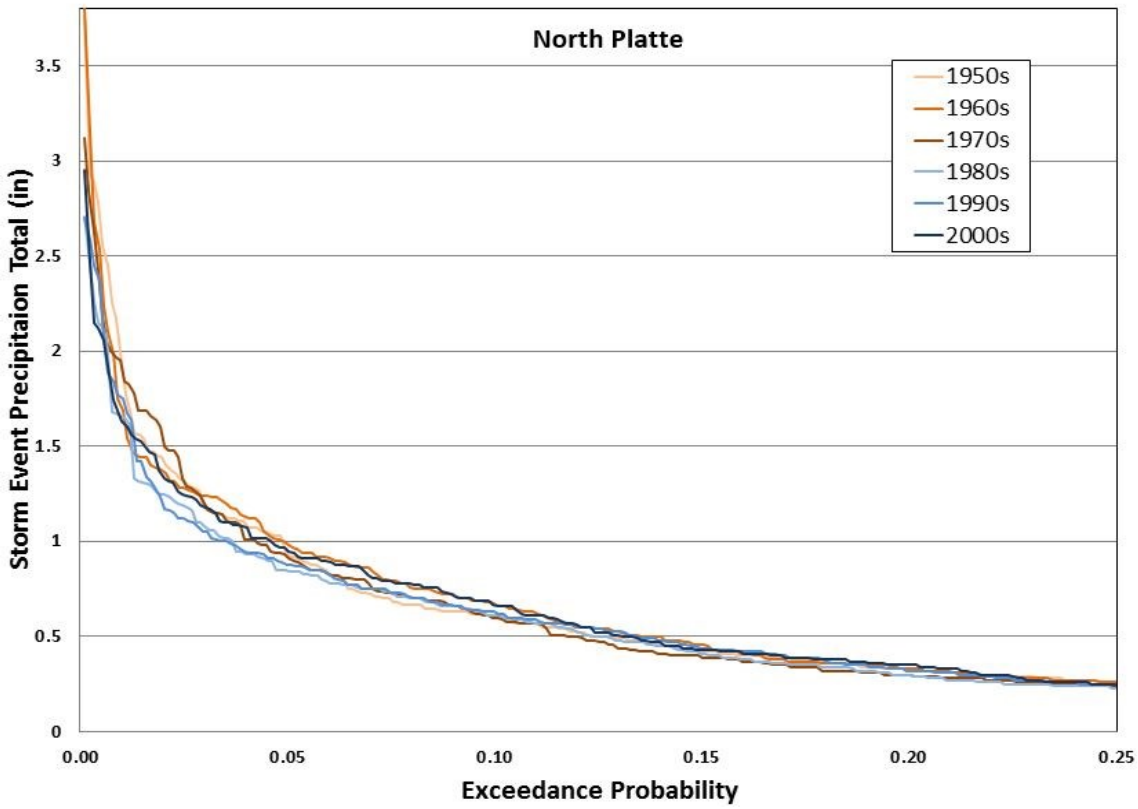
Appendix C-12. Exceedance probabilities of the characteristics of rainfall in North Platte.

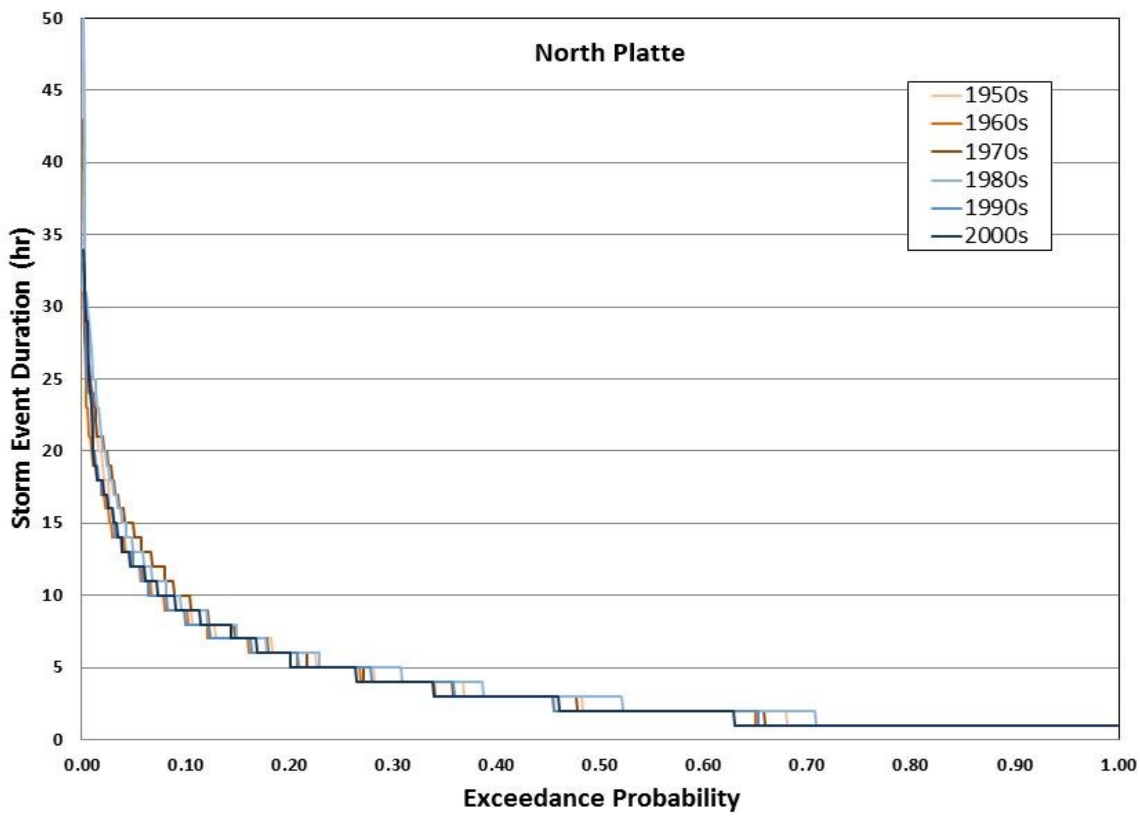


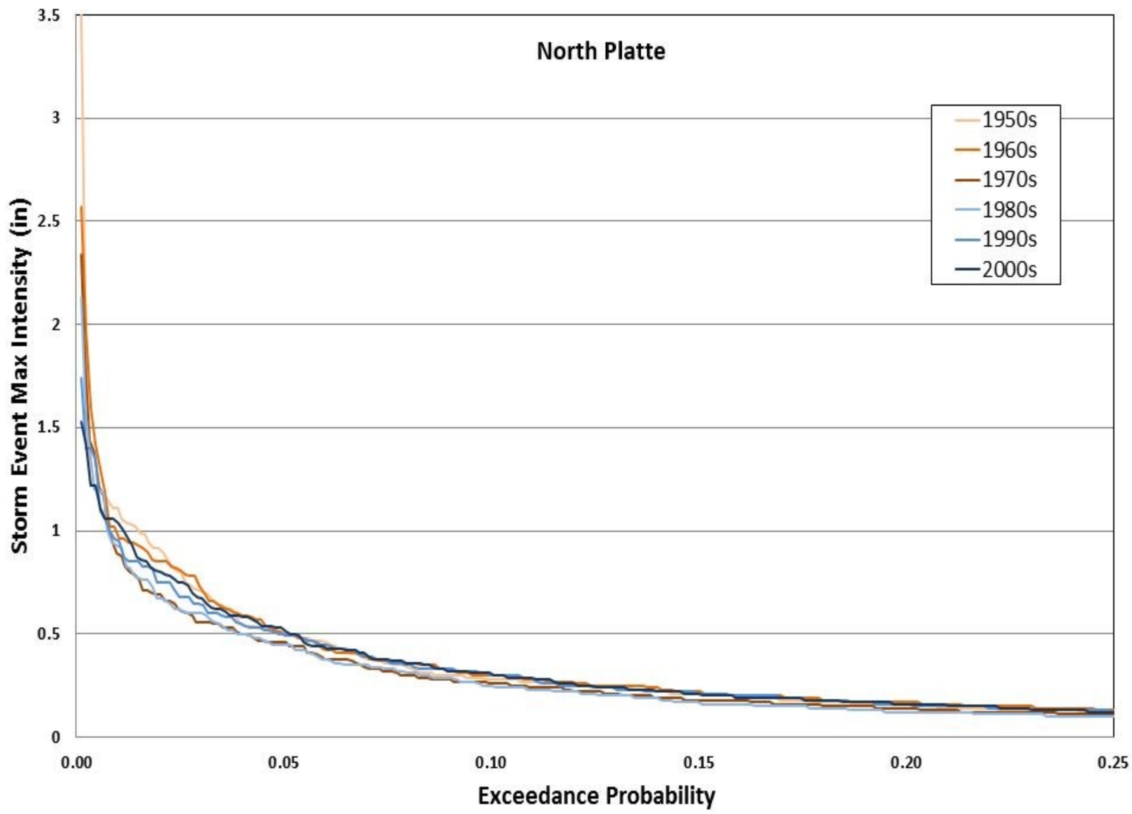


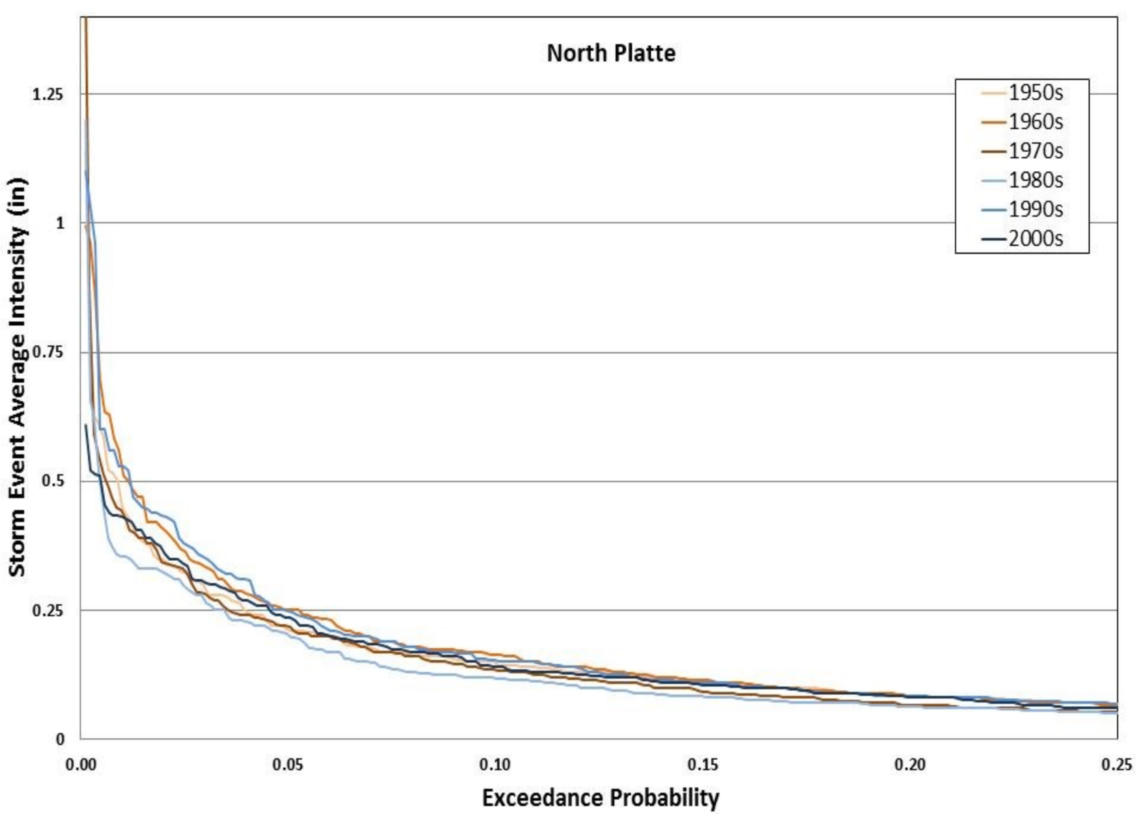

North Platte
1980-2012
1948-1979
Storm Event Max Intensity (in)
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


North Platte
1980-2012
1948-1979
Storm Event Average Intensity (in)
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

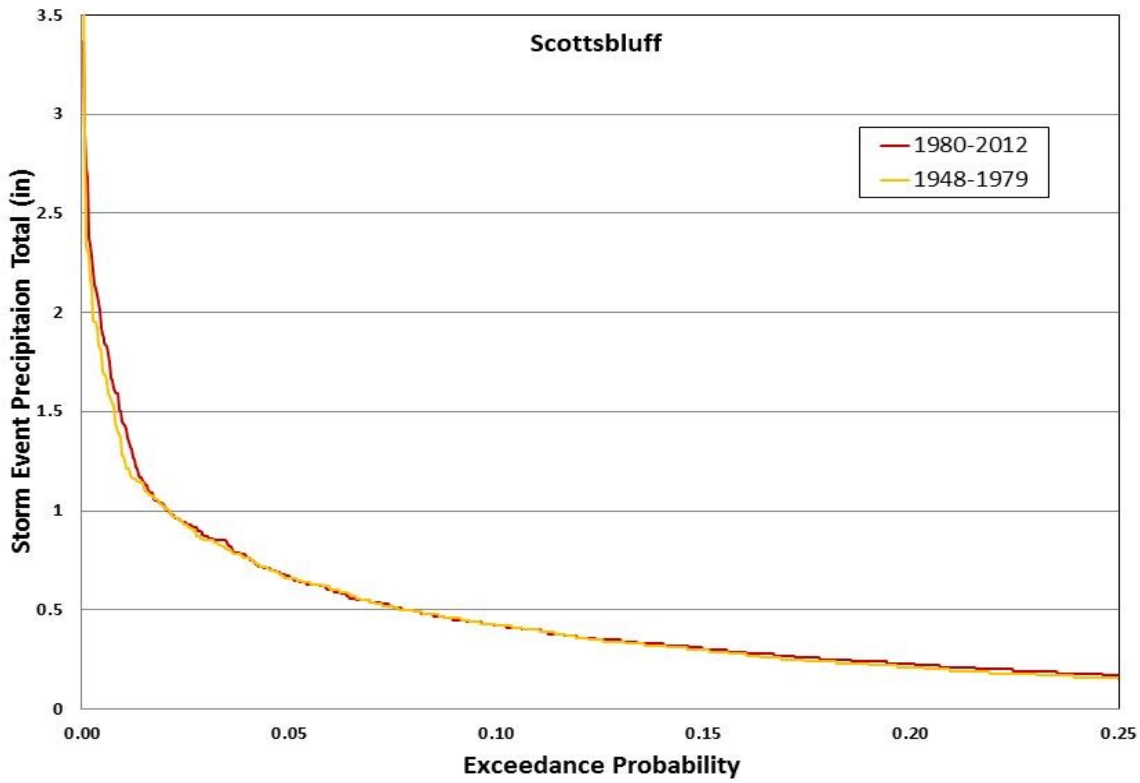

North Platte
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
0.00
0.05
0.10
0.15
0.20
0.25

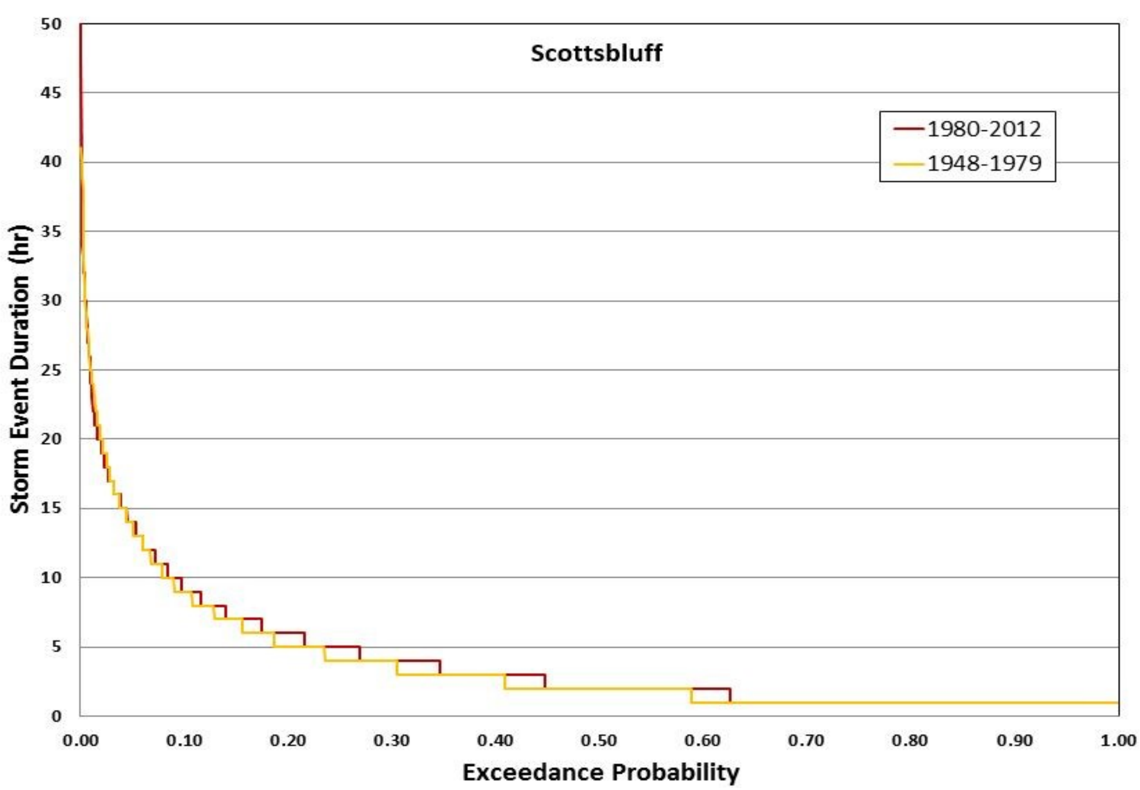

North Platte
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

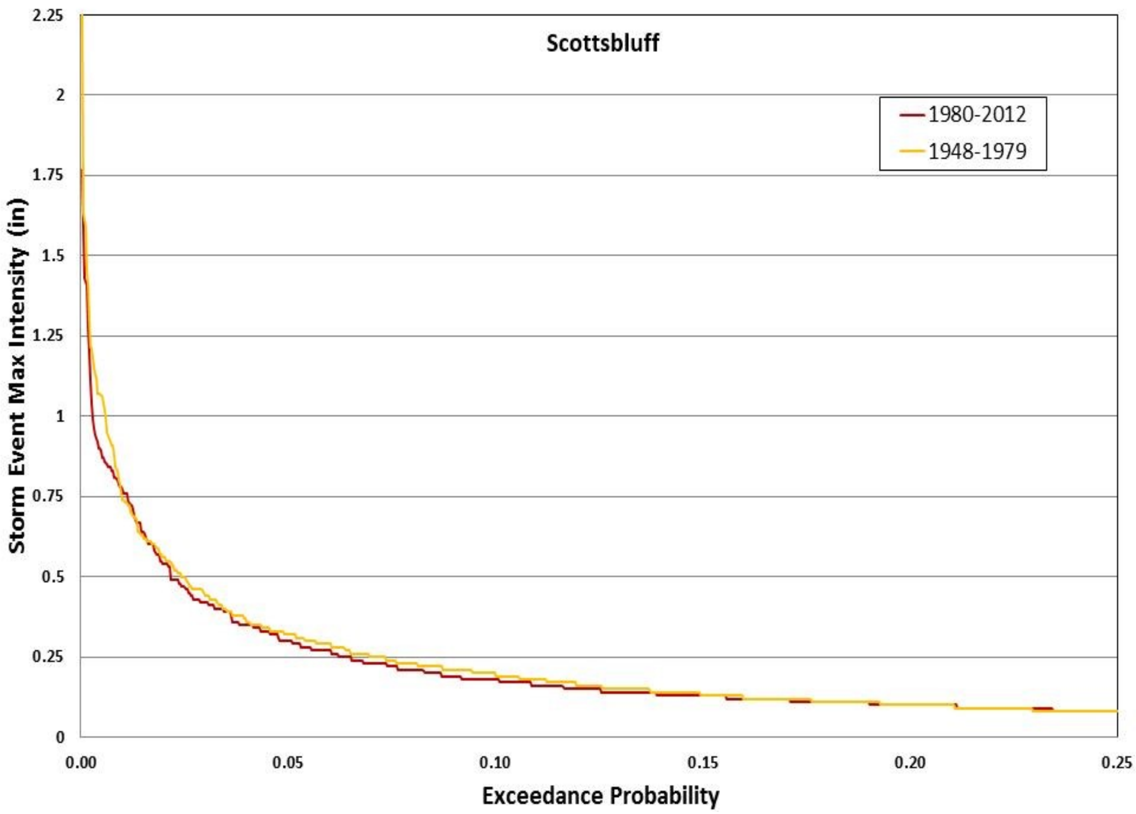

North Platte
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Max Intensity (in)
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

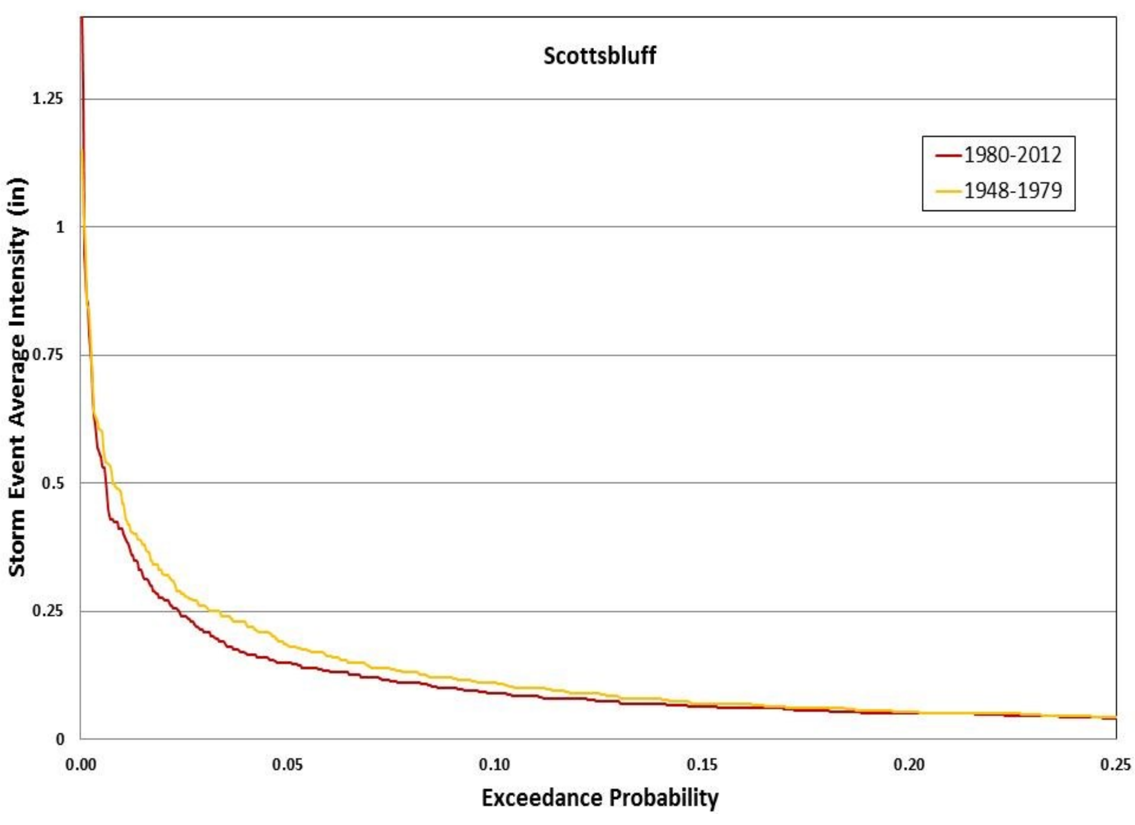

North Platte
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Average Intensity (in)
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

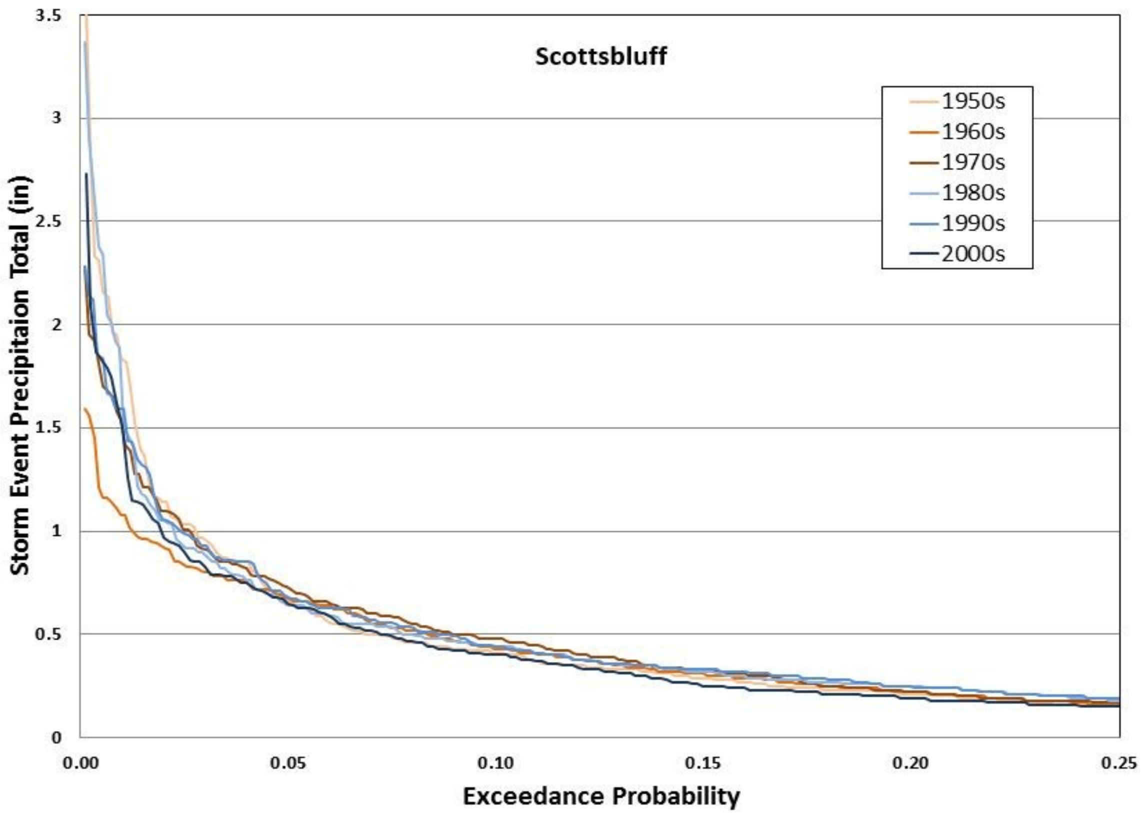
Appendix C-13. Exceedance probabilities of the characteristics of rainfall in Scottsbluff.

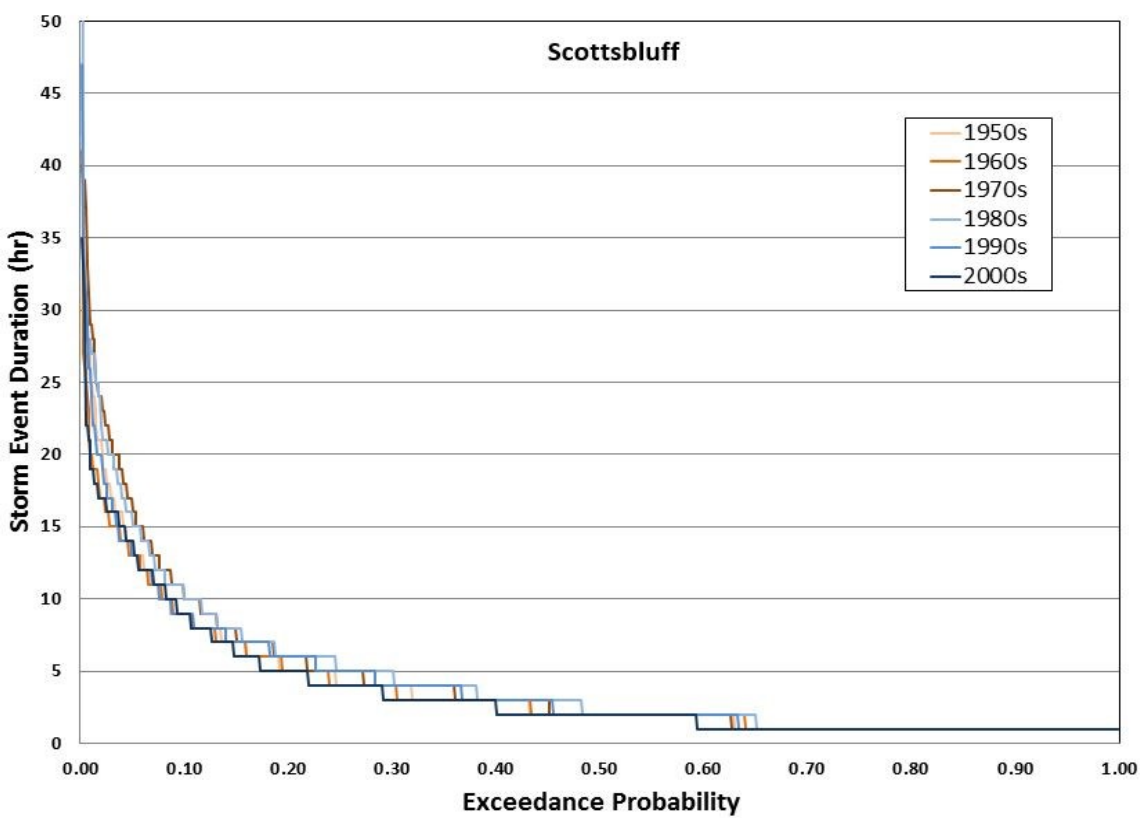


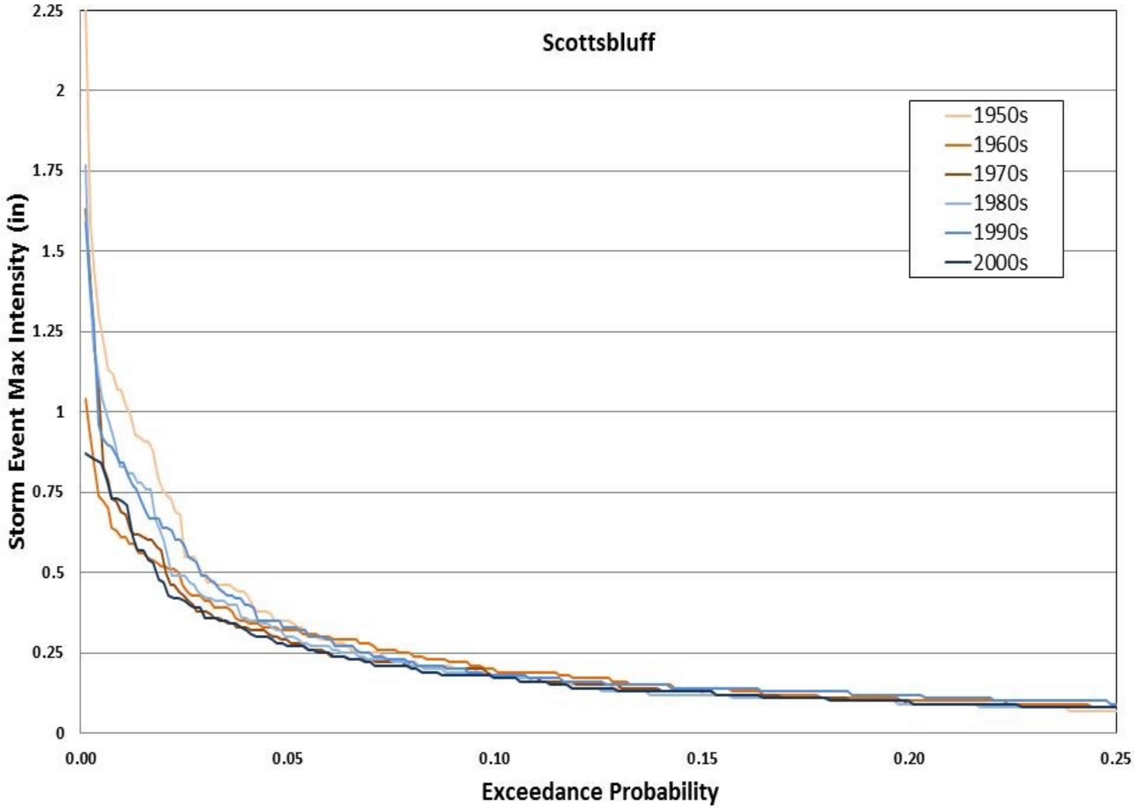


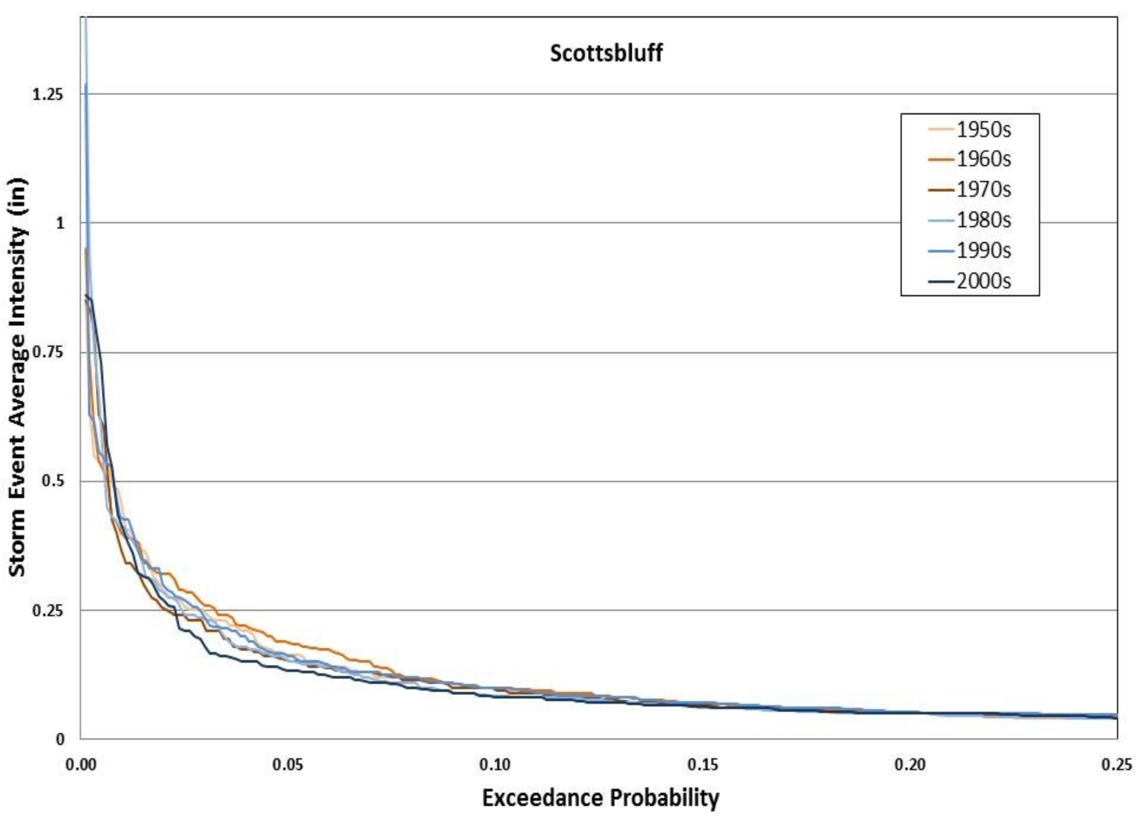

Scottsbluff
1980-2012
1948-1979
Storm Event Max Intensity (in)
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability


Scottsbluff
1980-2012
1948-1979
Storm Event Average Intensity (in)
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

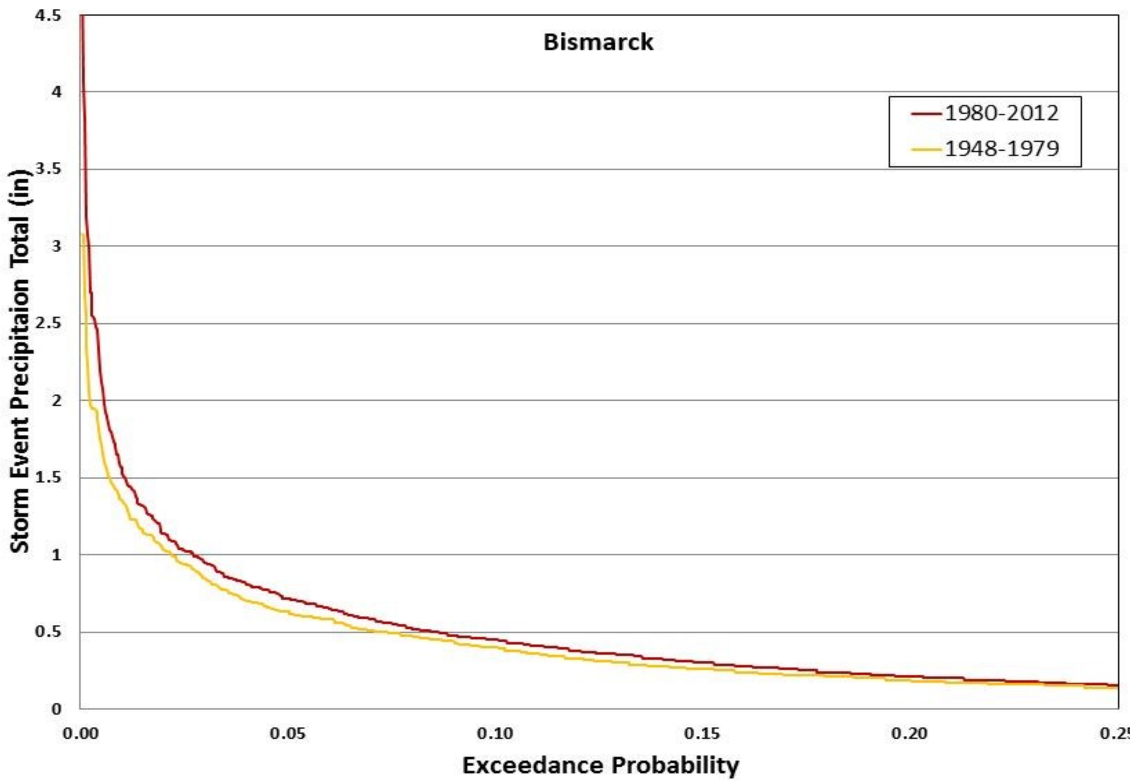

Scottsbluff
Storm Event Precipitaion Total (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

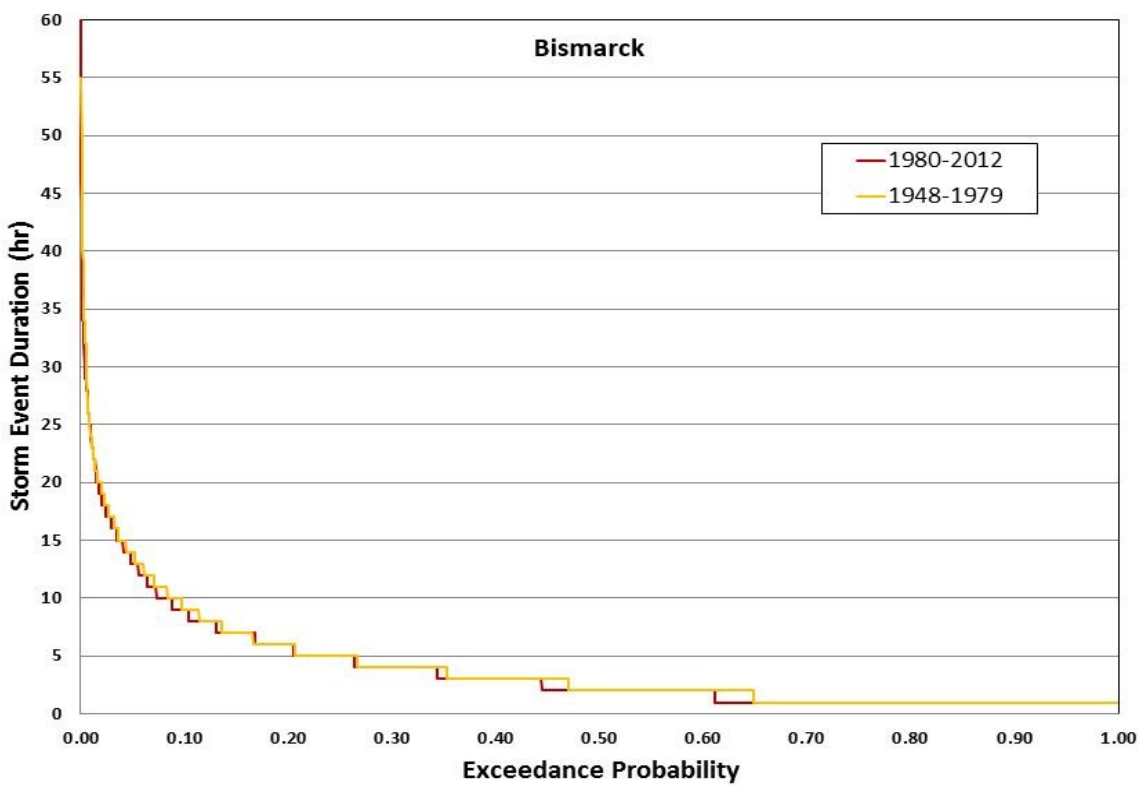

Scottsbluff
Storm Event Duration (hr)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
50
45
40
35
30
25
20
15
10
5
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

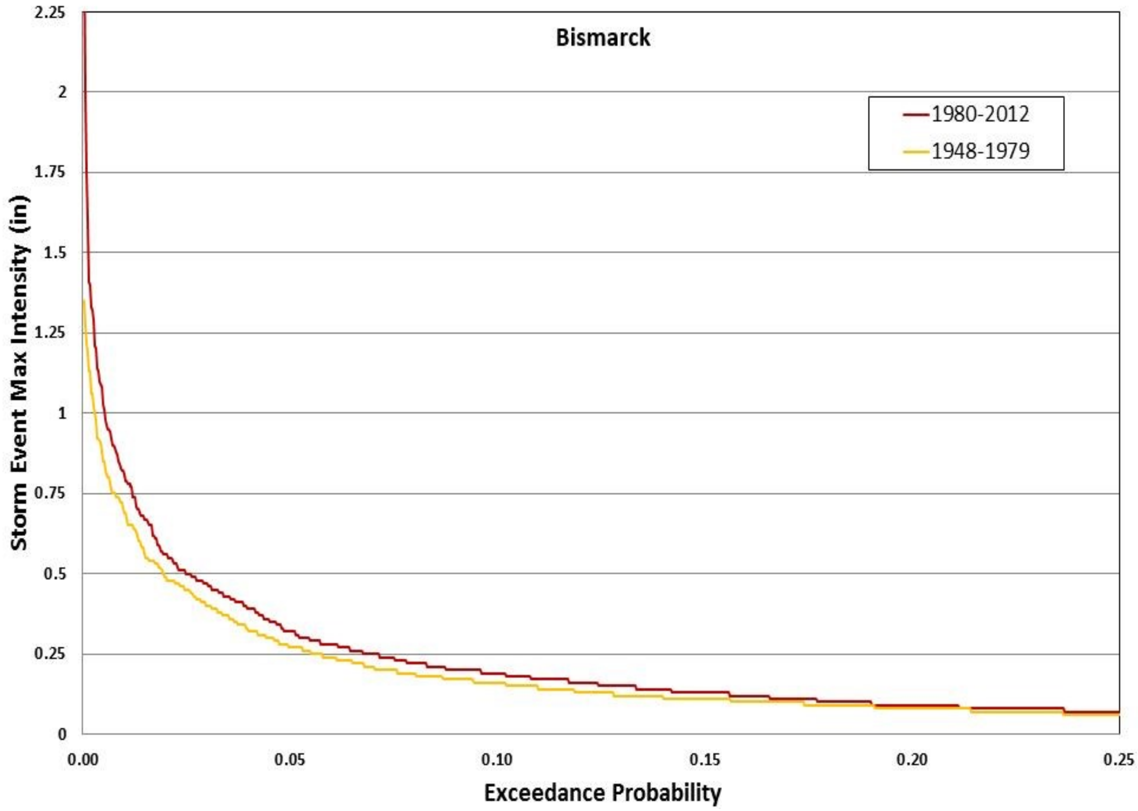

Scottsbluff
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
0.00
0.05
0.10
0.15
0.20
0.25

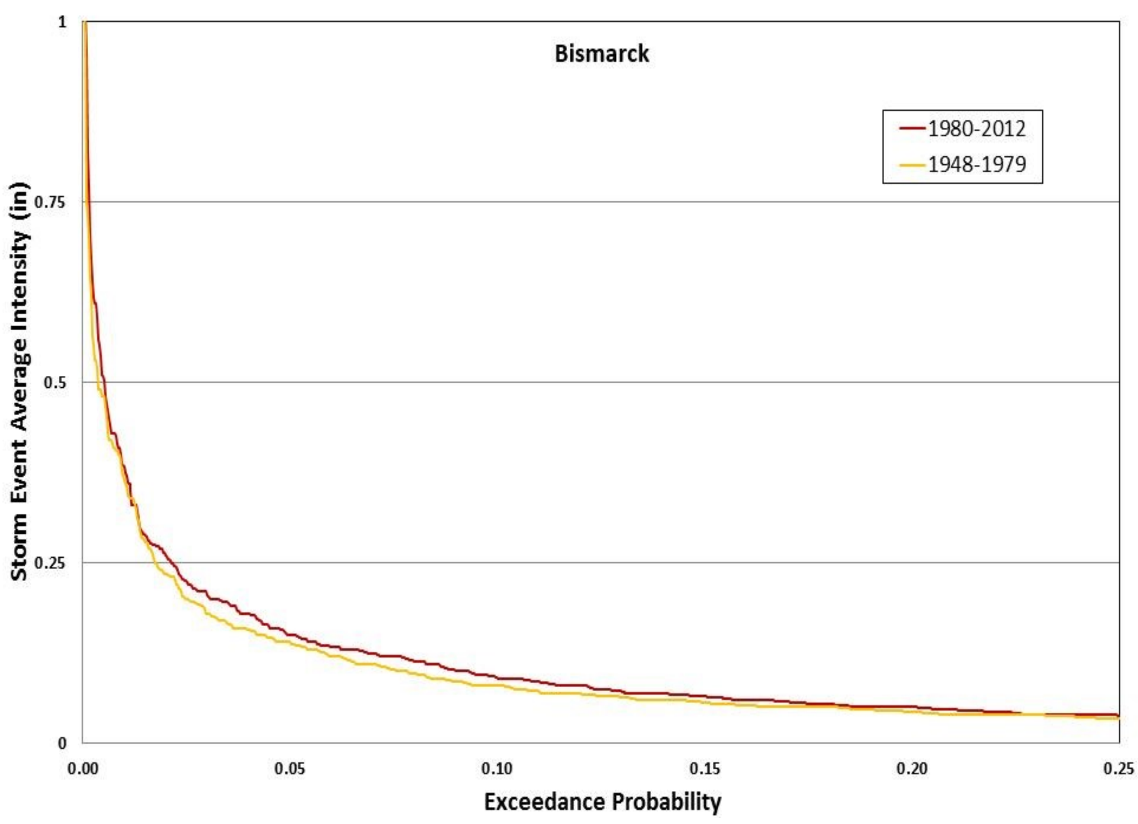

Scottsbluff
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.25
0.5
0.75
1
1.25
0.00
0.05
0.10
0.15
0.20
0.25

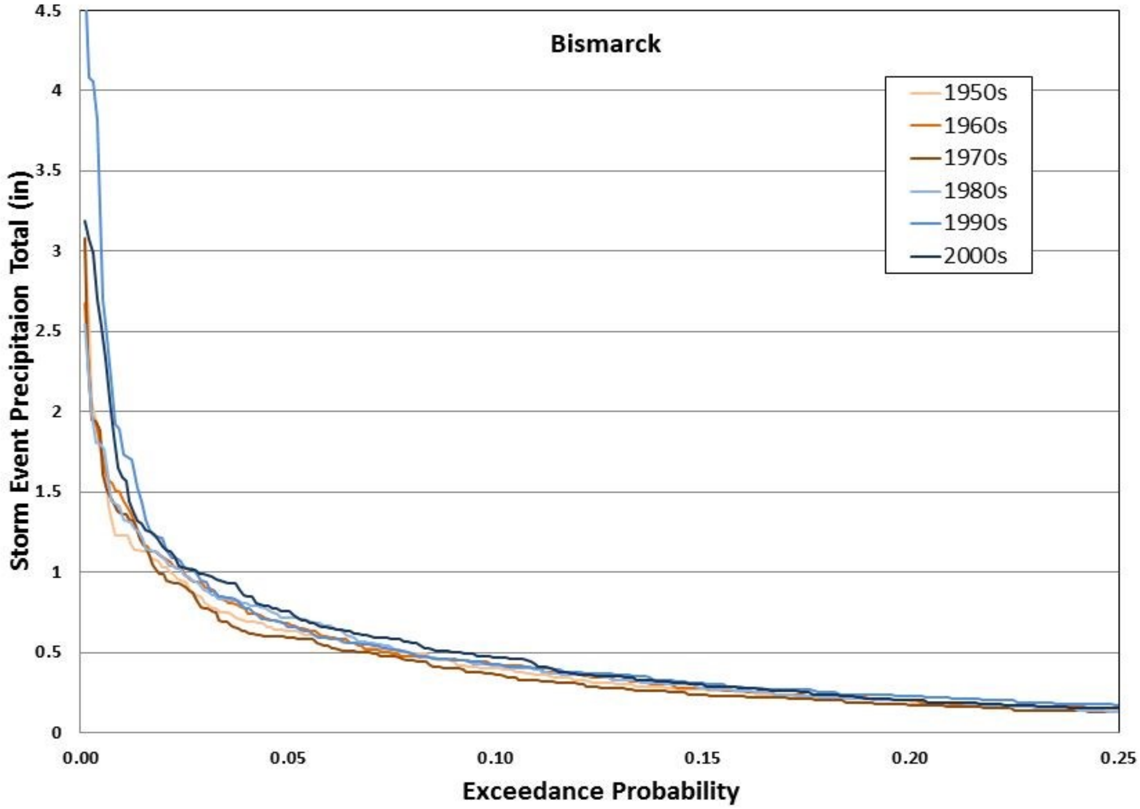
Appendix C-14. Exceedance probabilities of the characteristics of rainfall in Bismarck.

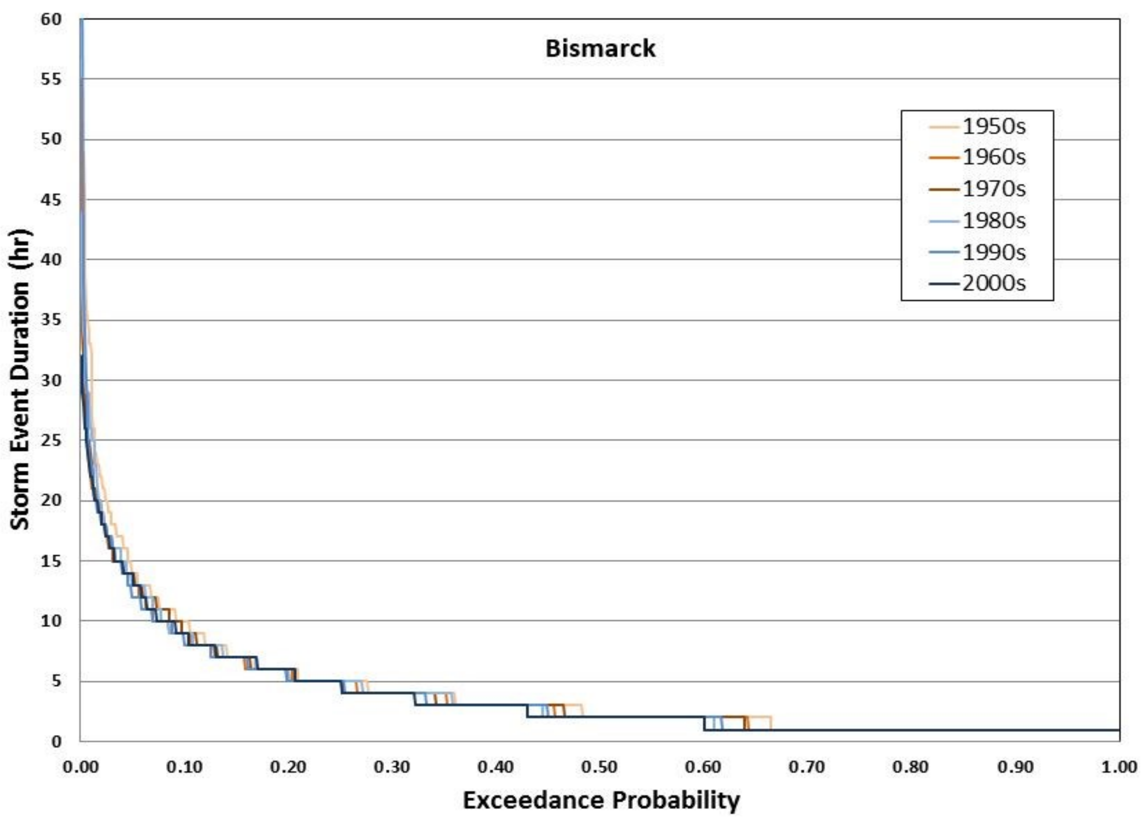


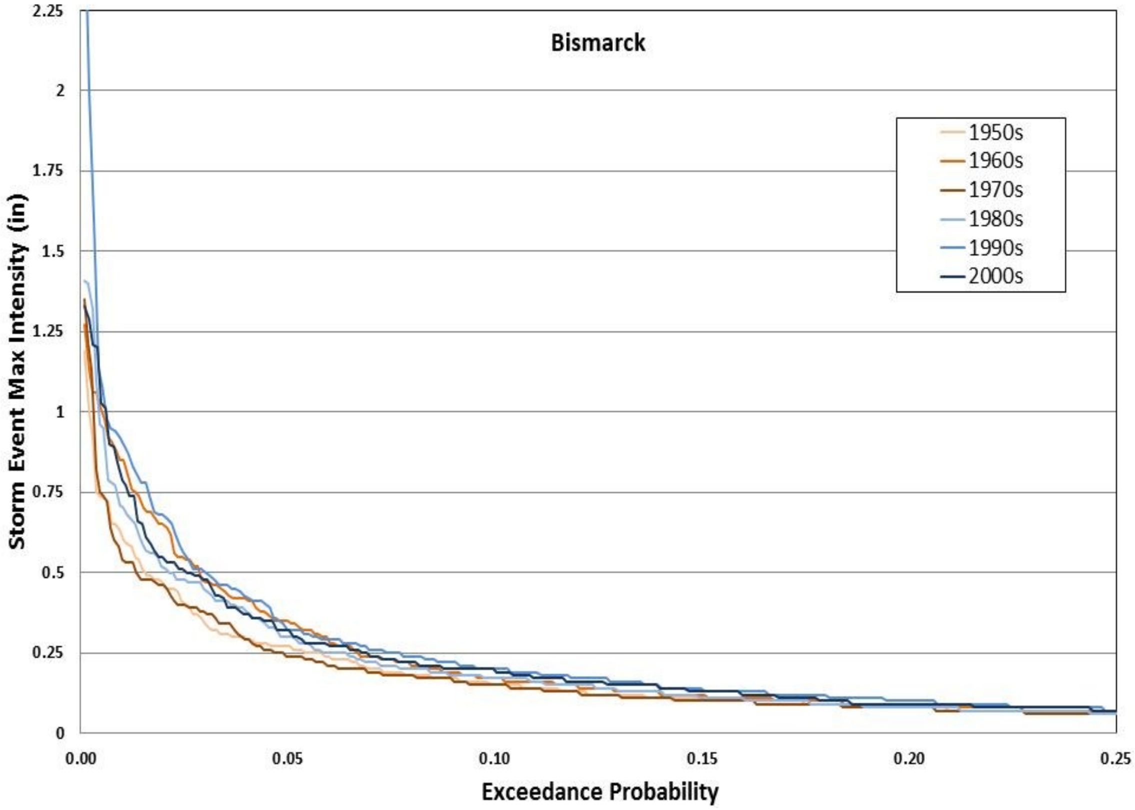


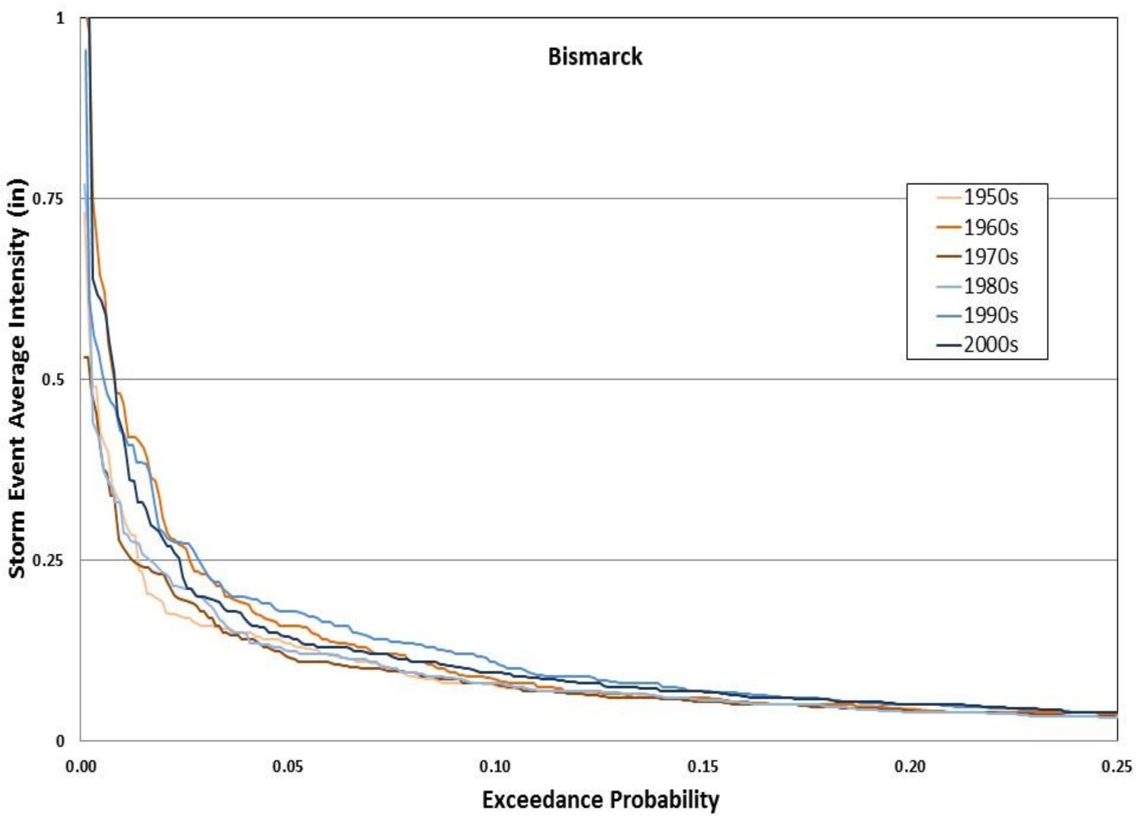

Bismarck
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25


Bismarck
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

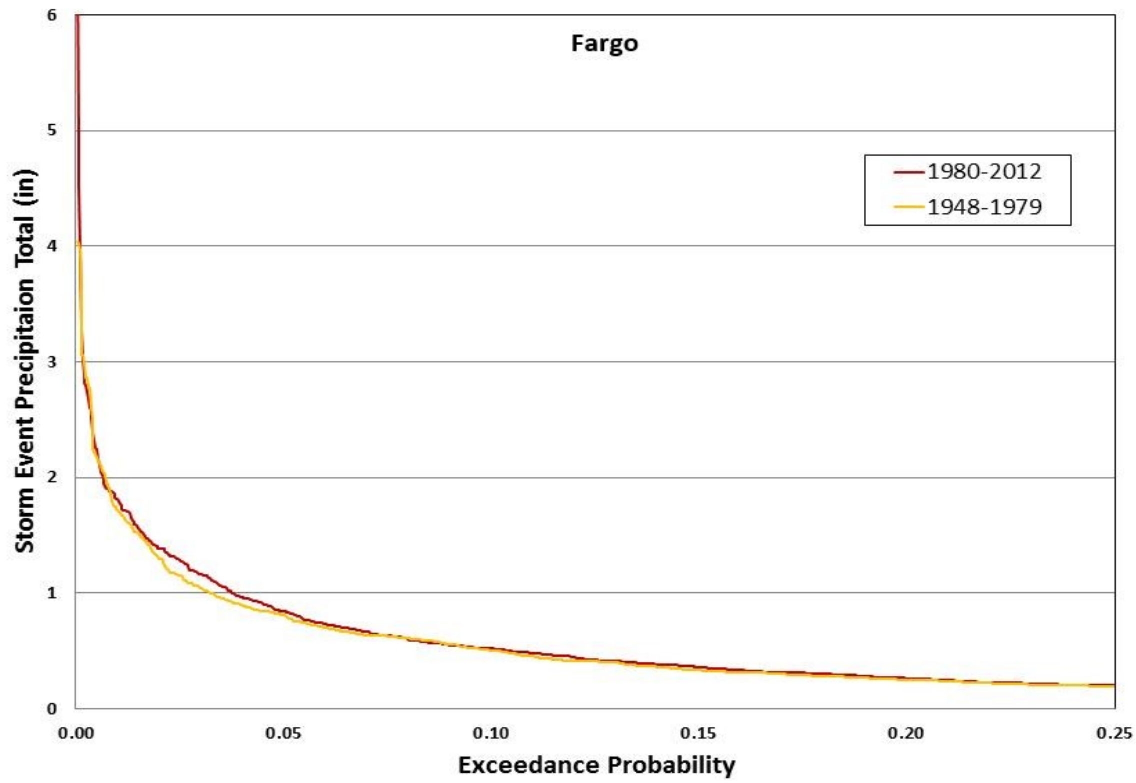

Bismarck
Storm Event Precipitaion Total (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

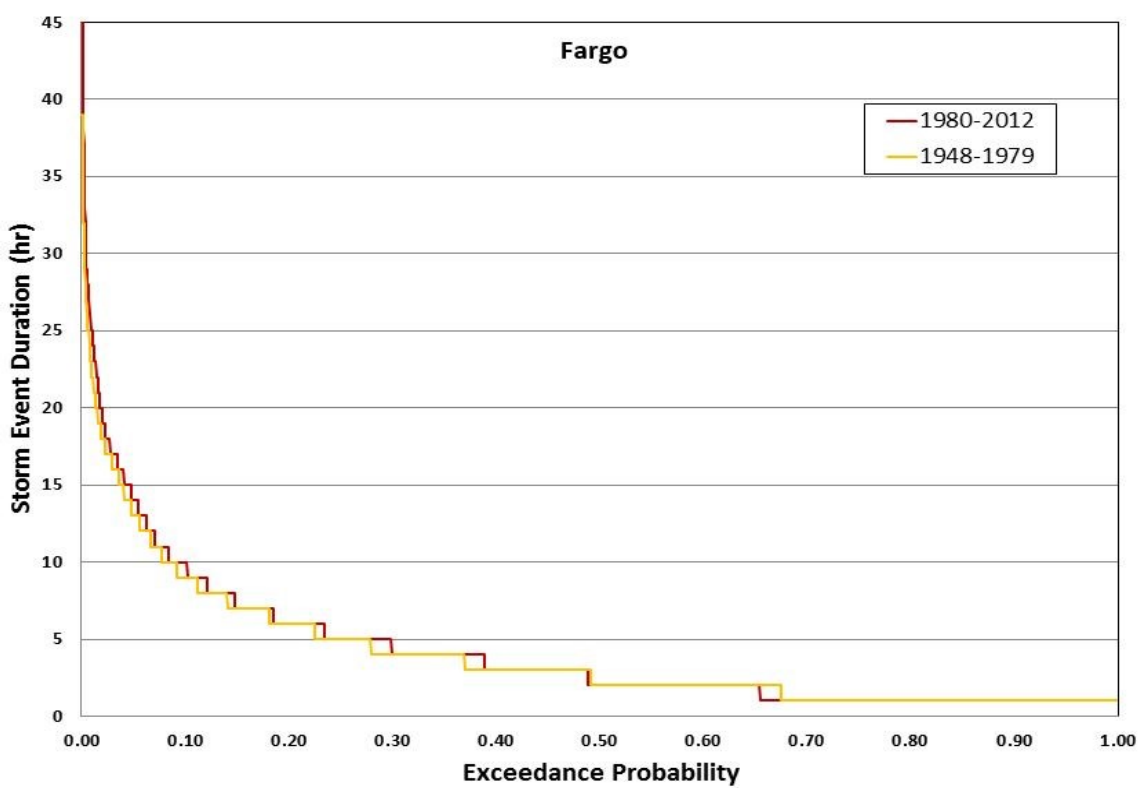

Bismarck
Storm Event Duration (hr)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
60
55
50
45
40
35
30
25
20
15
10
5
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

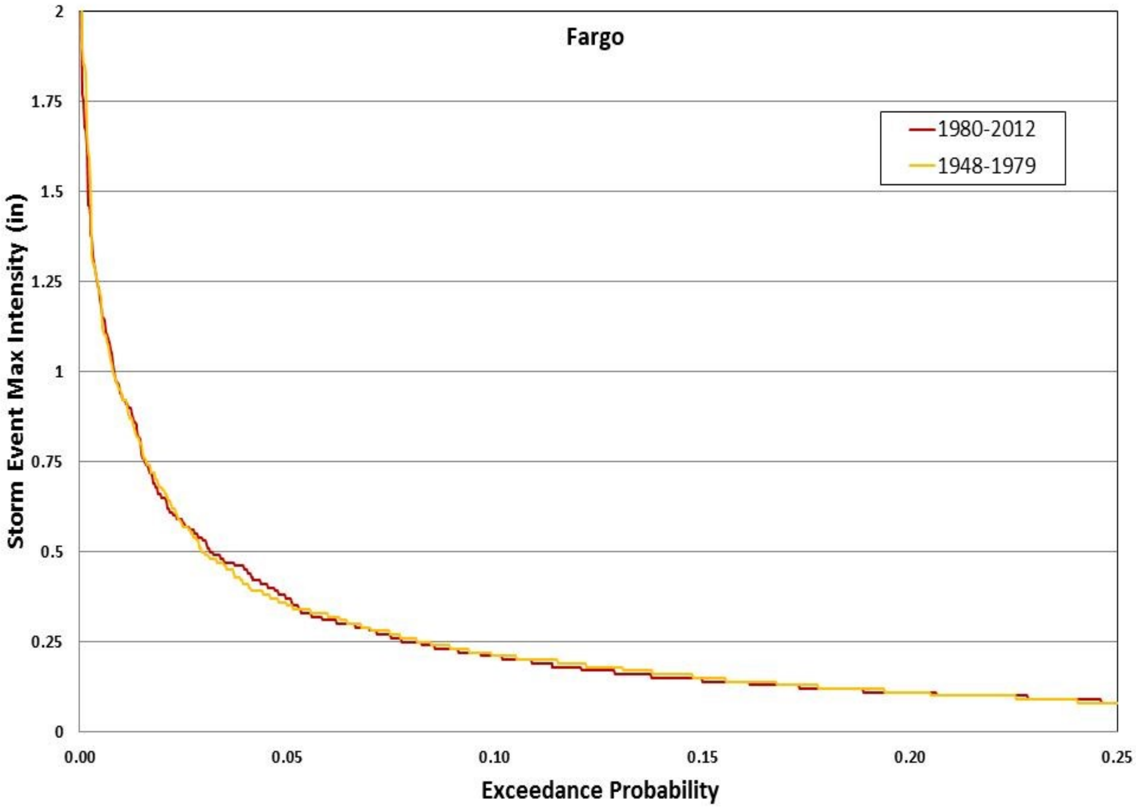

Bismarck
Storm Event Max Intensity (in)
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s

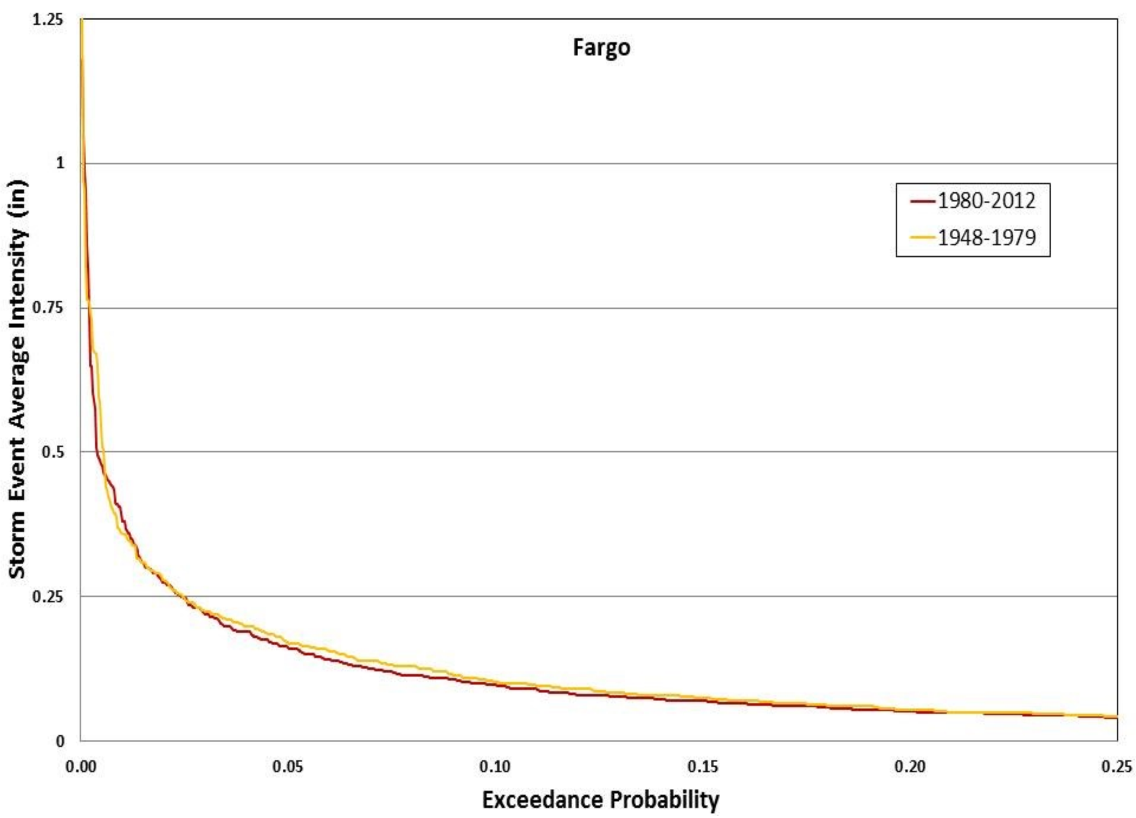

Bismarck
Storm Event Average Intensity (in)
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s

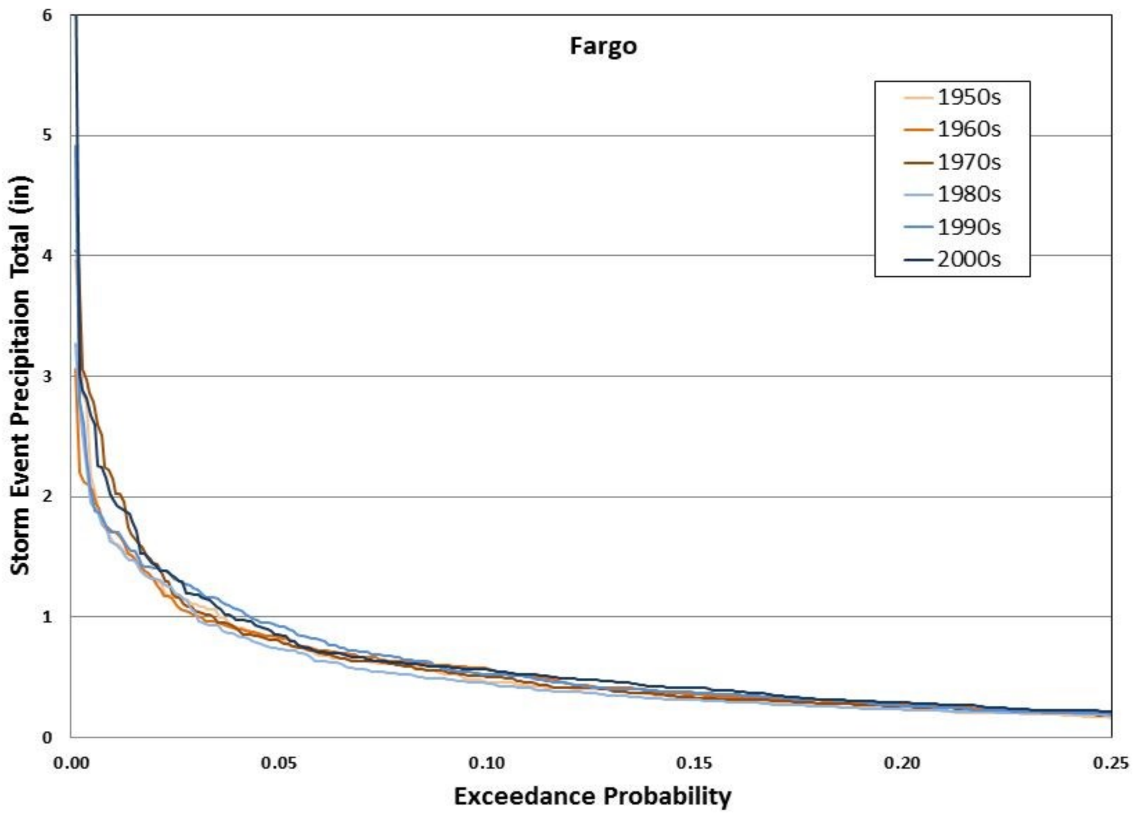
Appendix C-15. Exceedance probabilities of the characteristics of rainfall in Fargo.

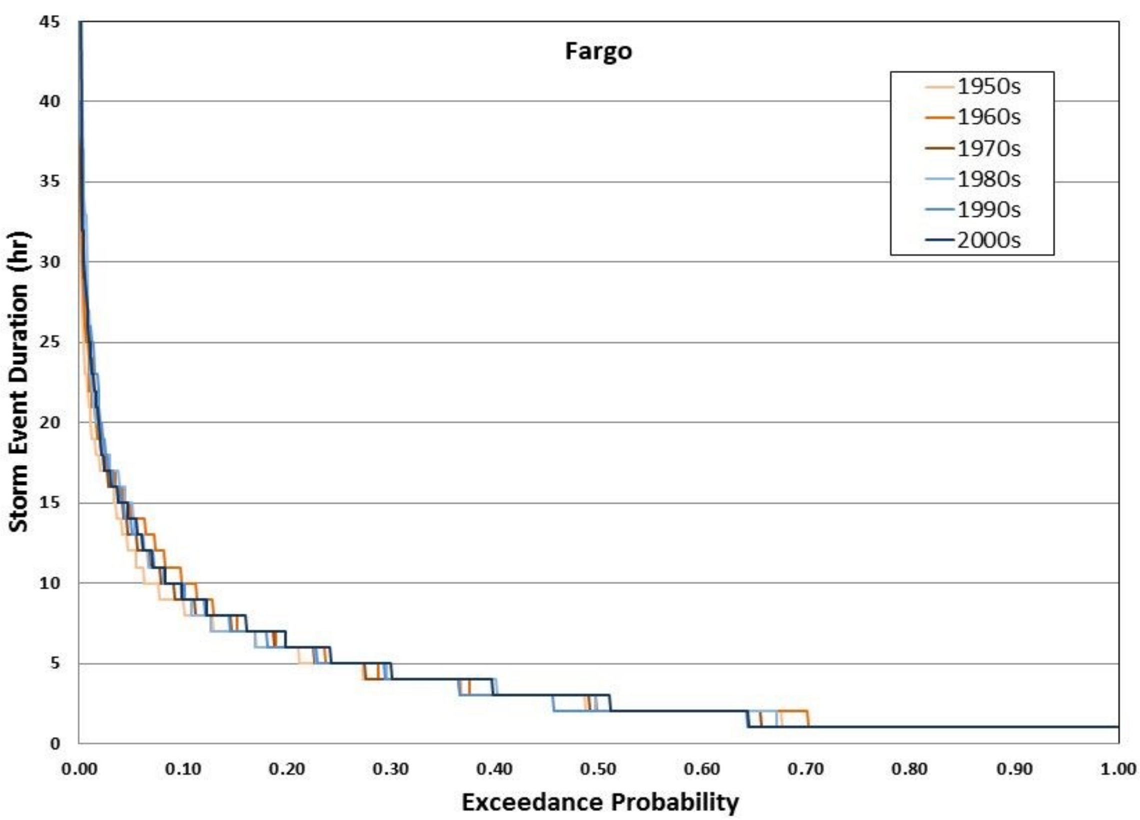


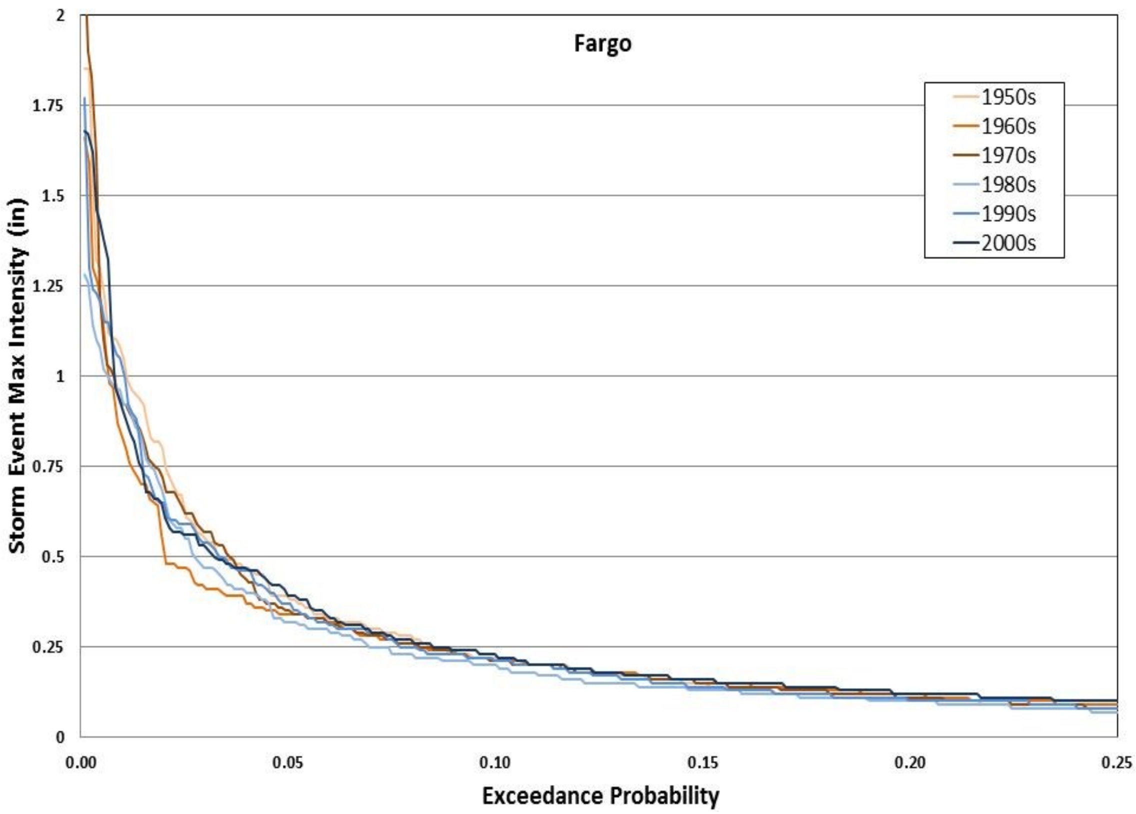



Fargo
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

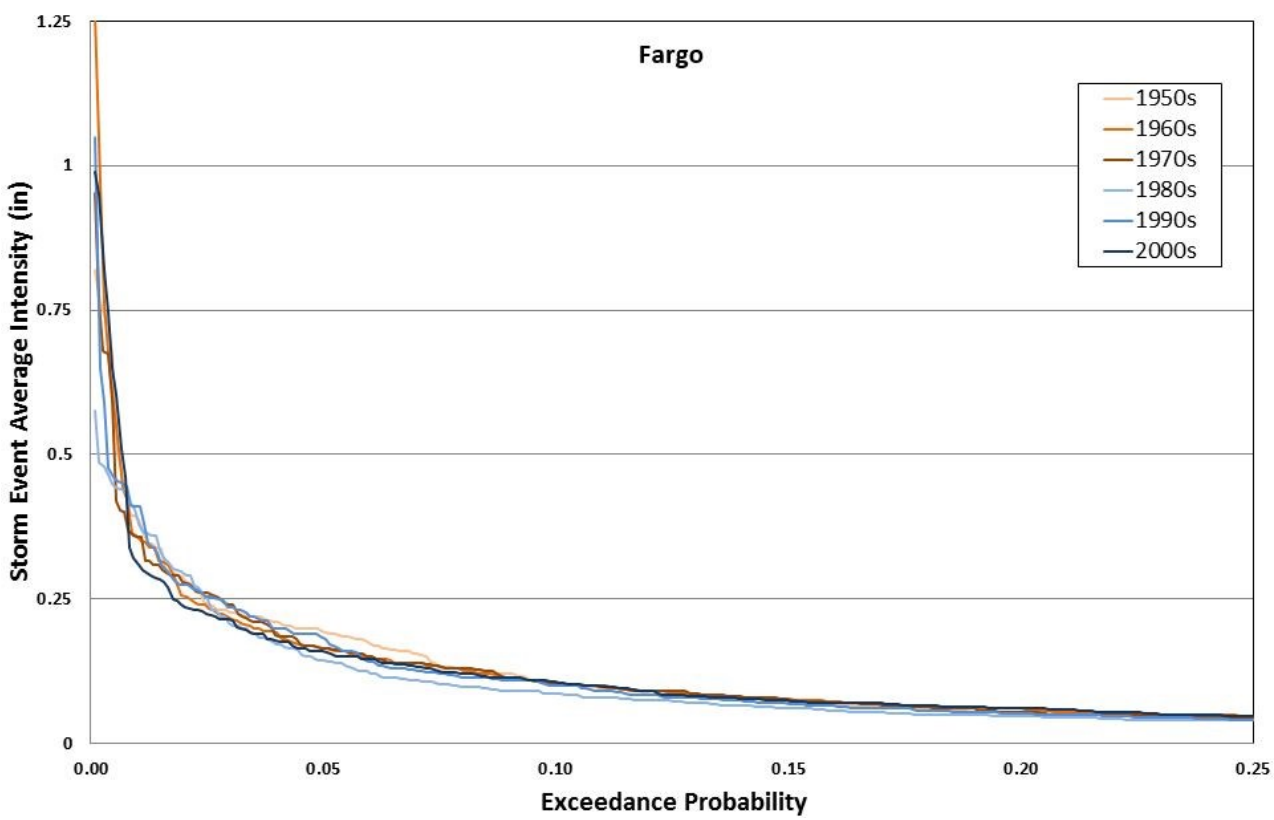

Fargo
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25


Fargo
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
1
2
3
4
5
6
0.00
0.05
0.10
0.15
0.20
0.25


Fargo
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

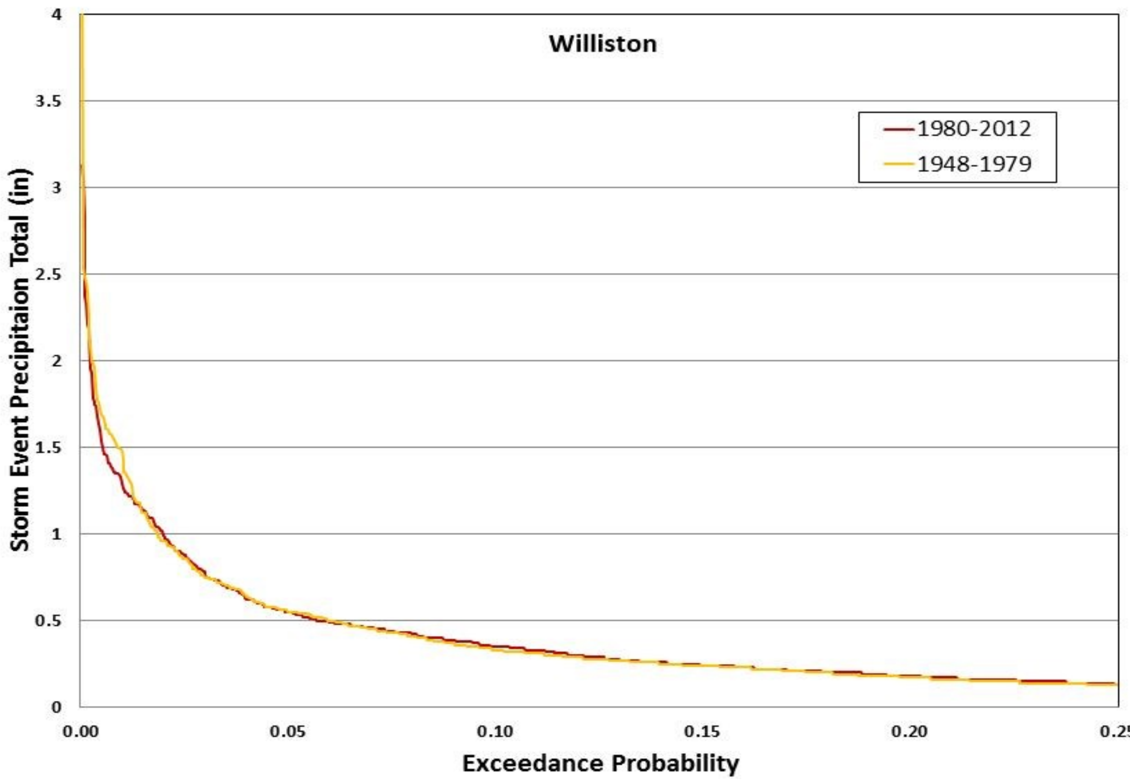


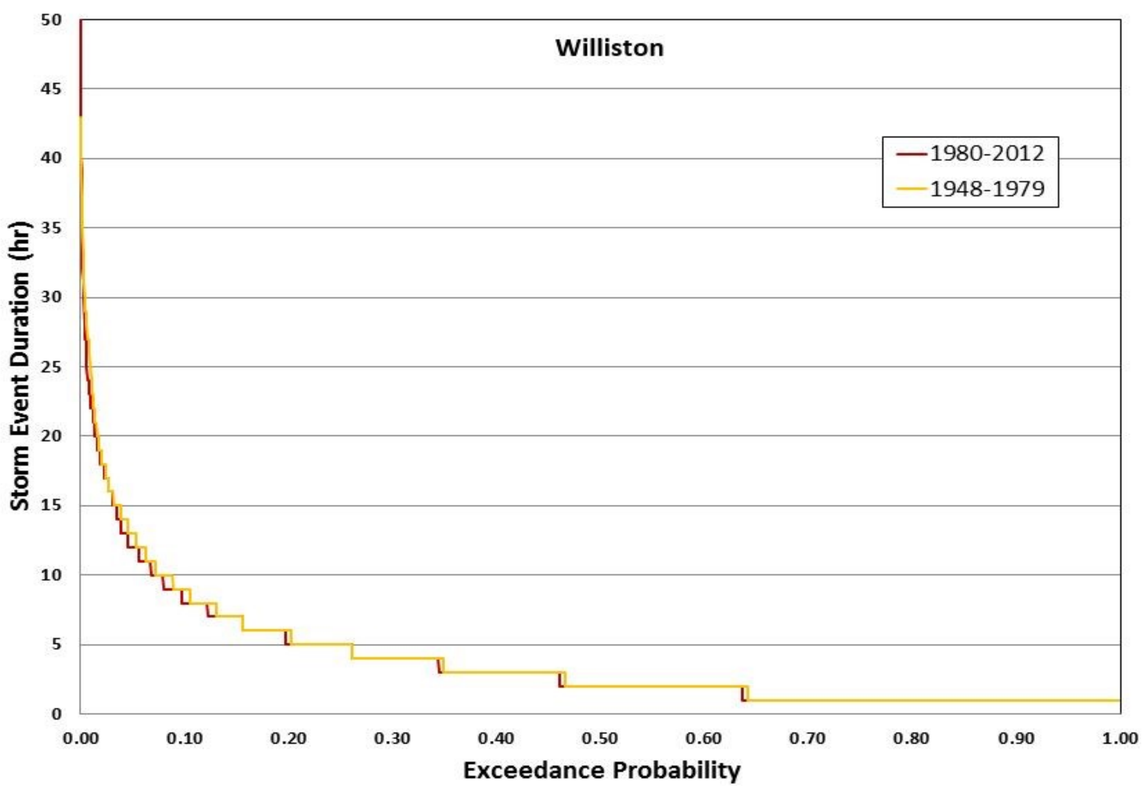
Fargo
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Max Intensity (in)
Exceedance Probability
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

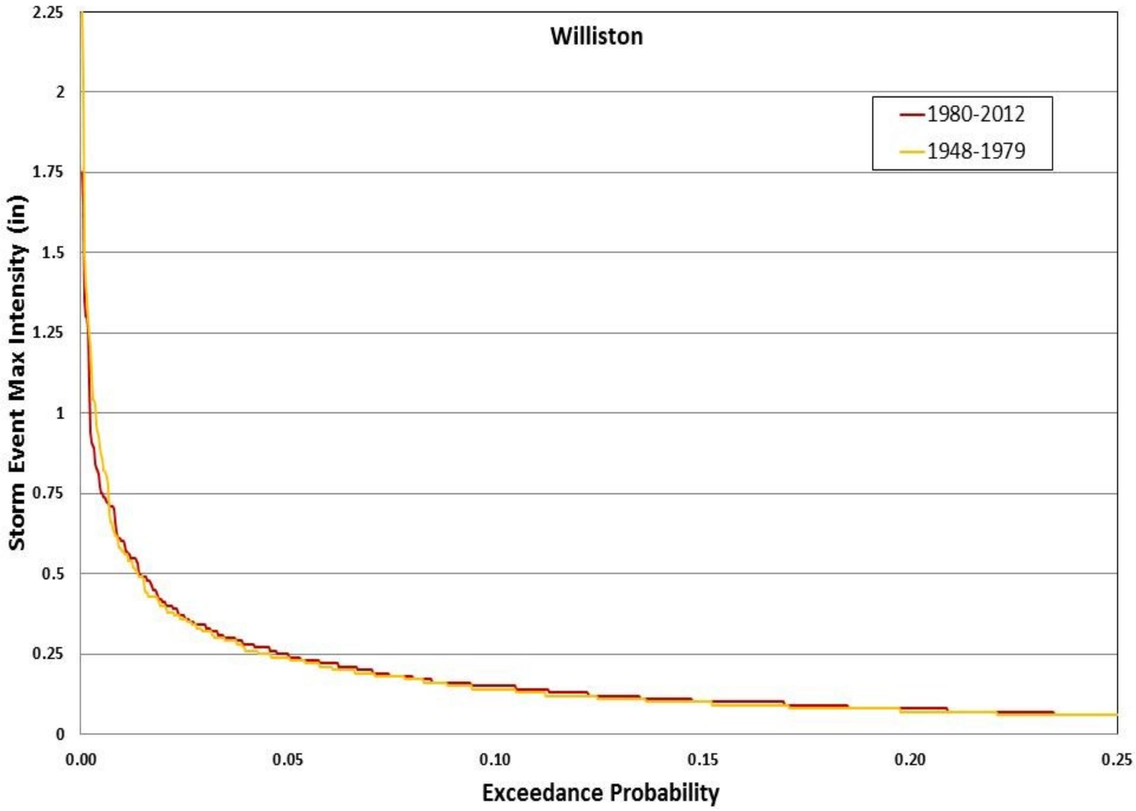


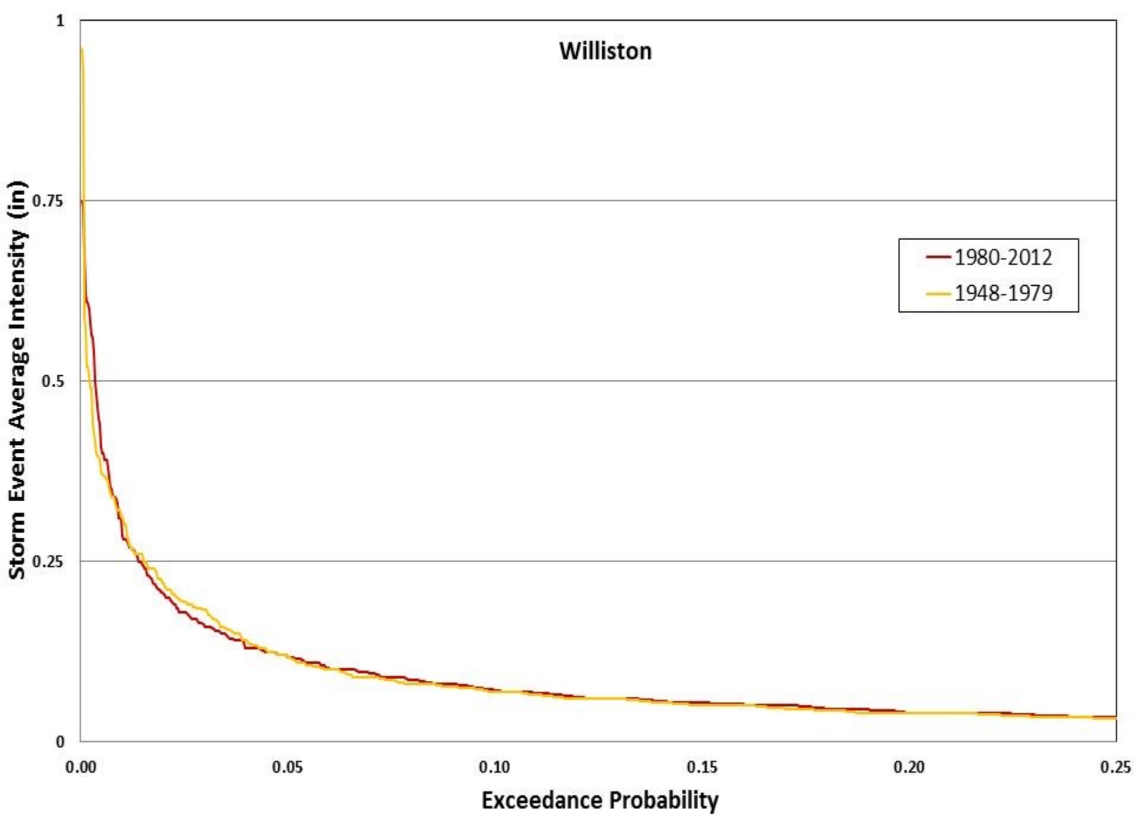
Fargo
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Average Intensity (in)
Exceedance Probability
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

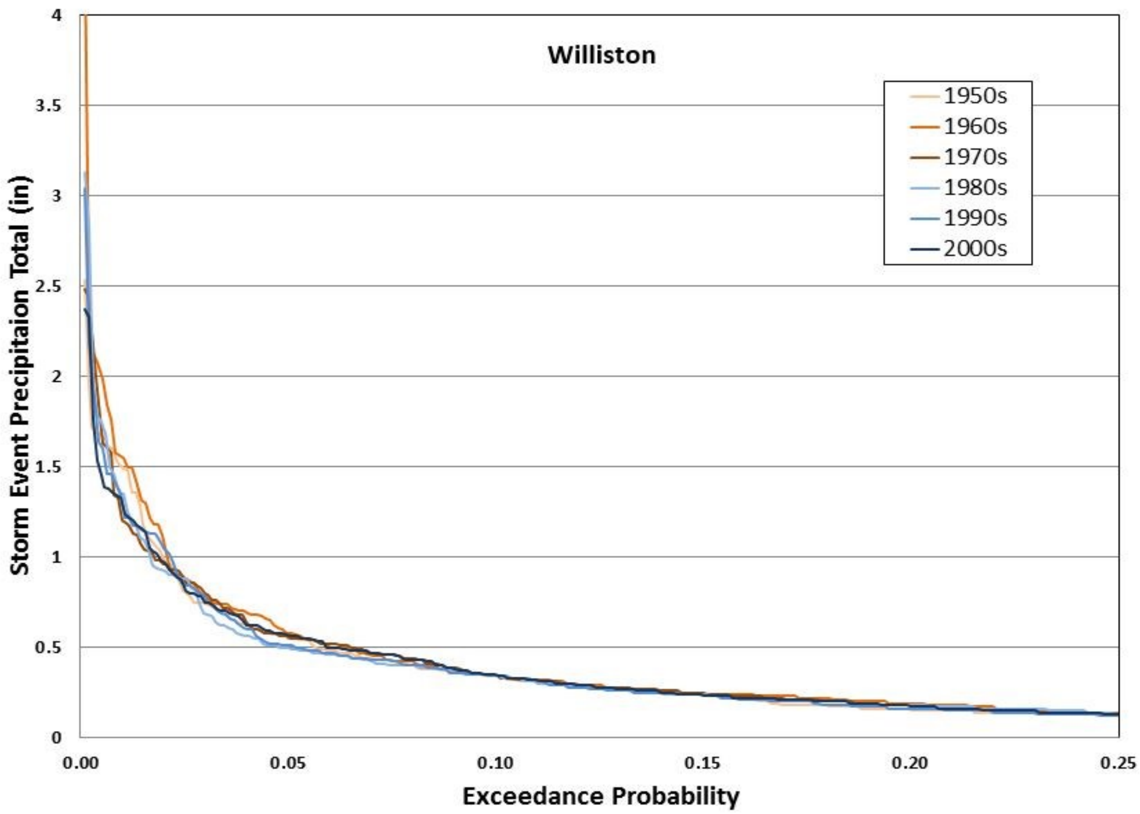
Appendix C-16. Exceedance probabilities of the characteristics of rainfall in Williston.

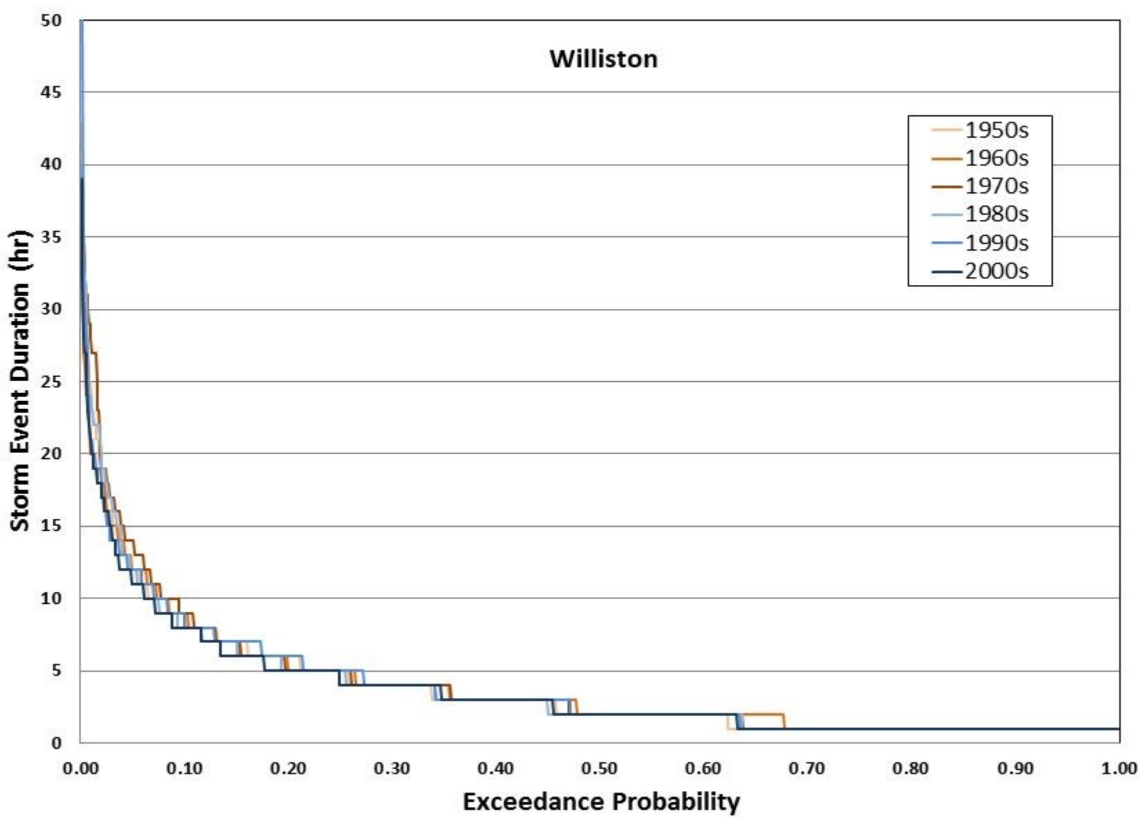


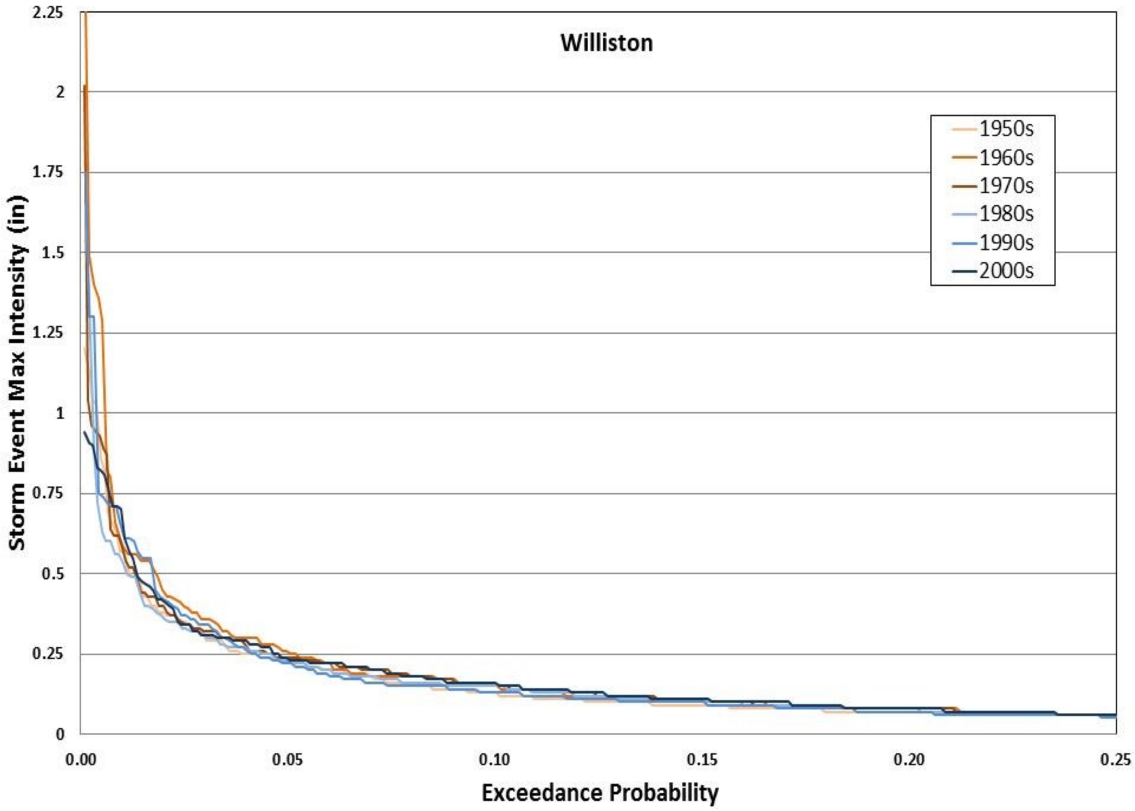


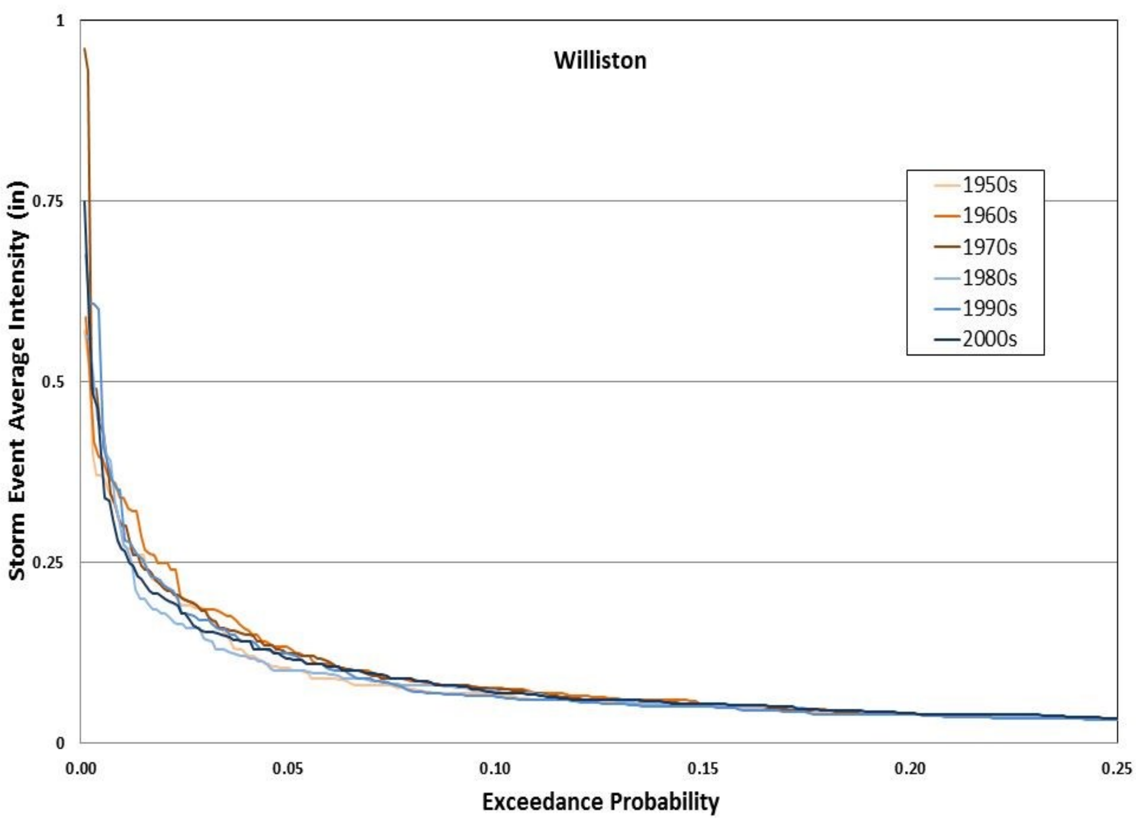

Williston
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25


Williston
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

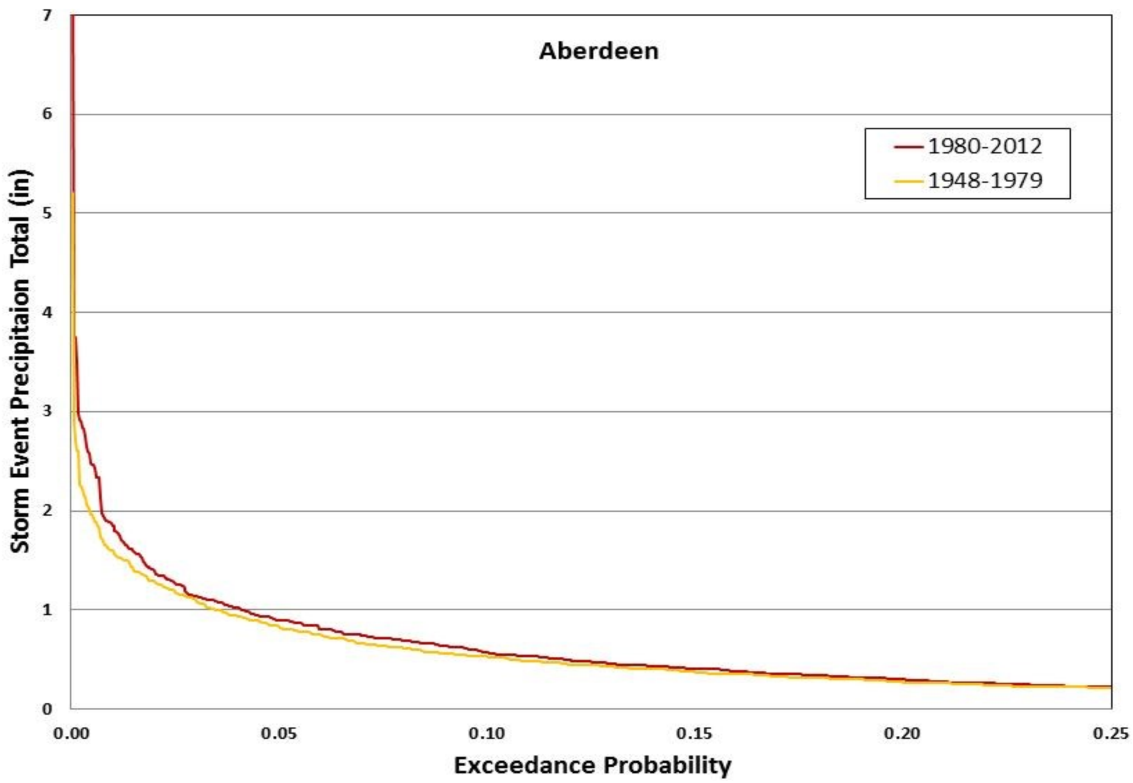

Williston
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
0.00
0.05
0.10
0.15
0.20
0.25

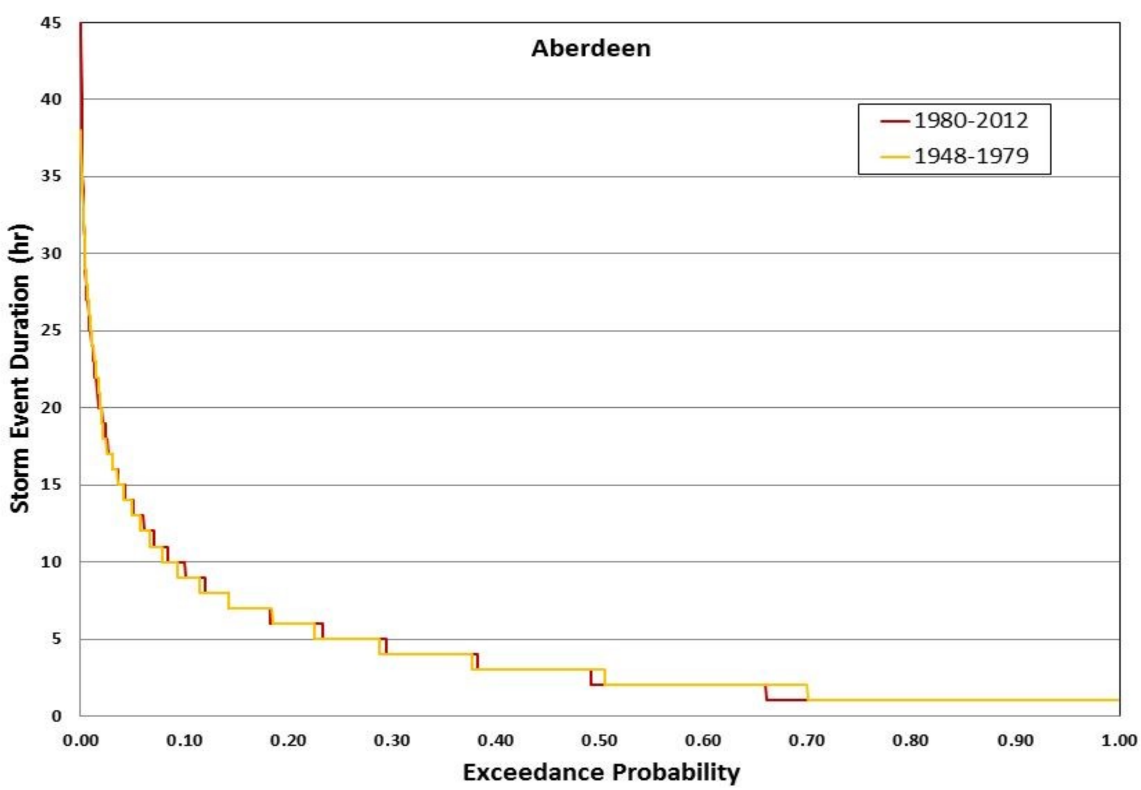

Williston
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

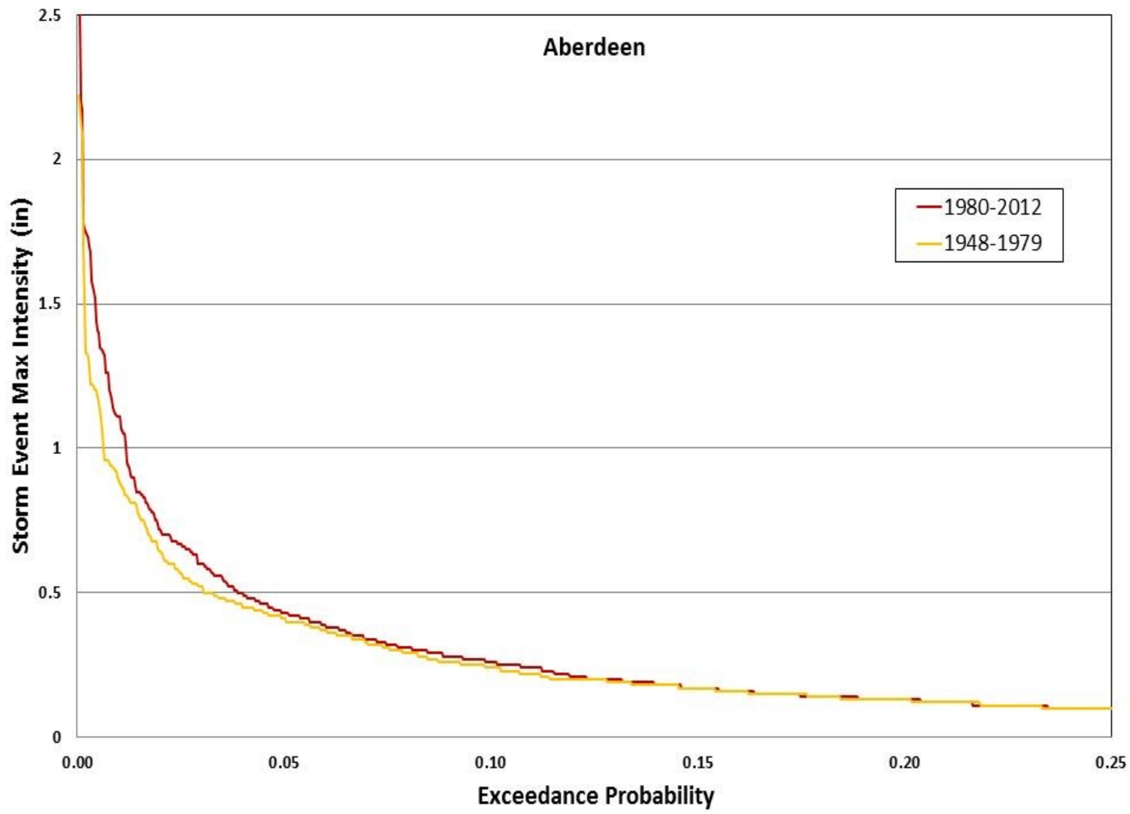

Williston
Storm Event Max Intensity (in)
Exceedance Probability
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

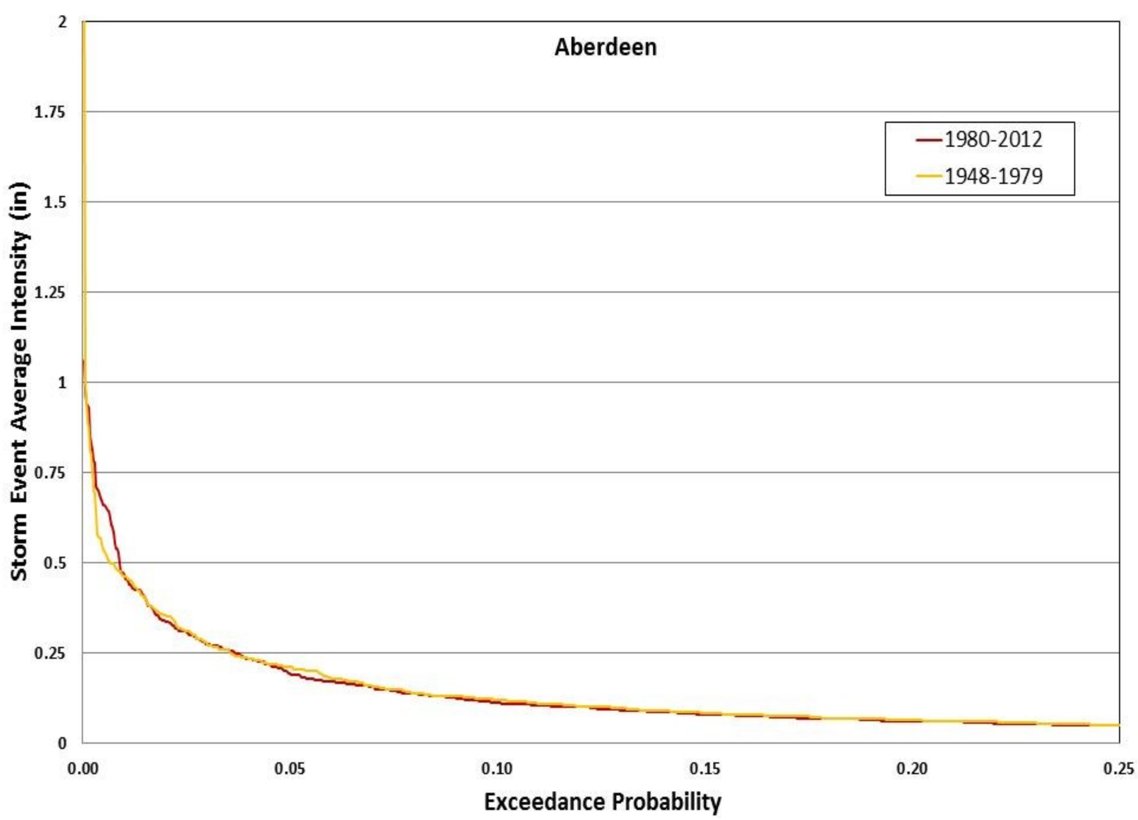

Williston
Storm Event Average Intensity (in)
Exceedance Probability
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

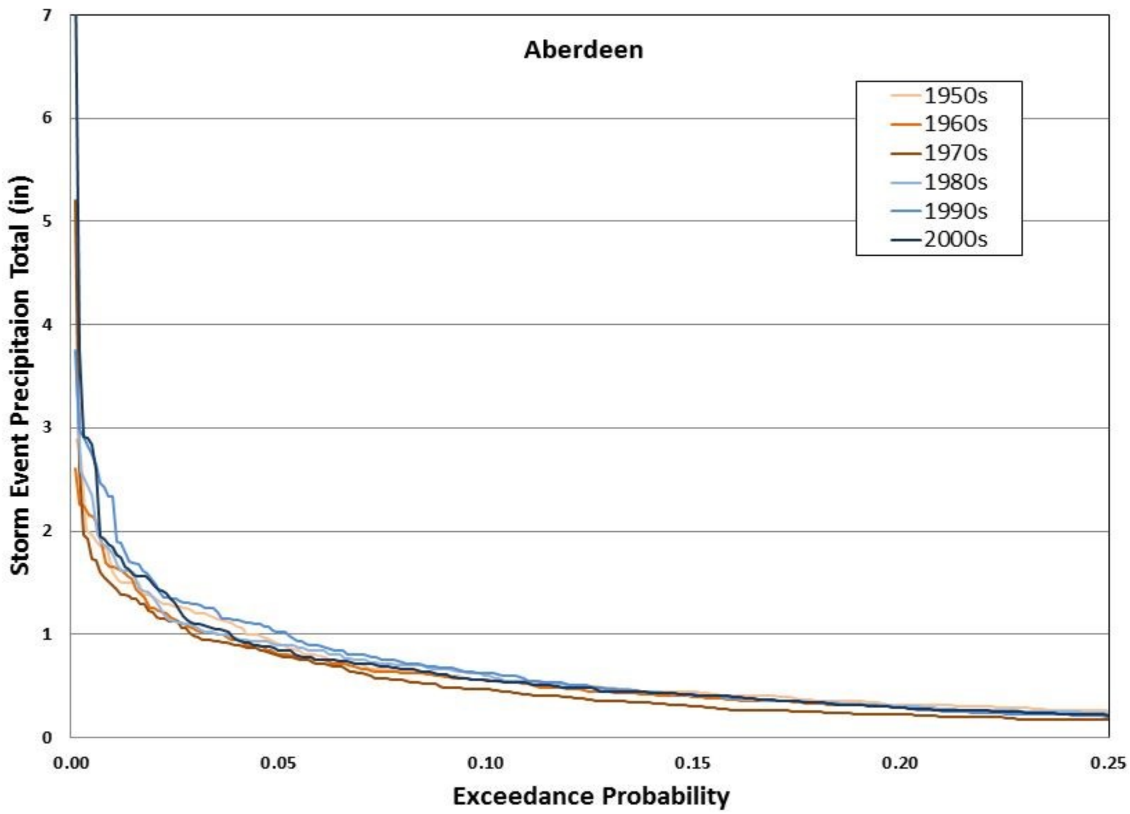
Appendix C-17. Exceedance probabilities of the characteristics of rainfall in Aberdeen.

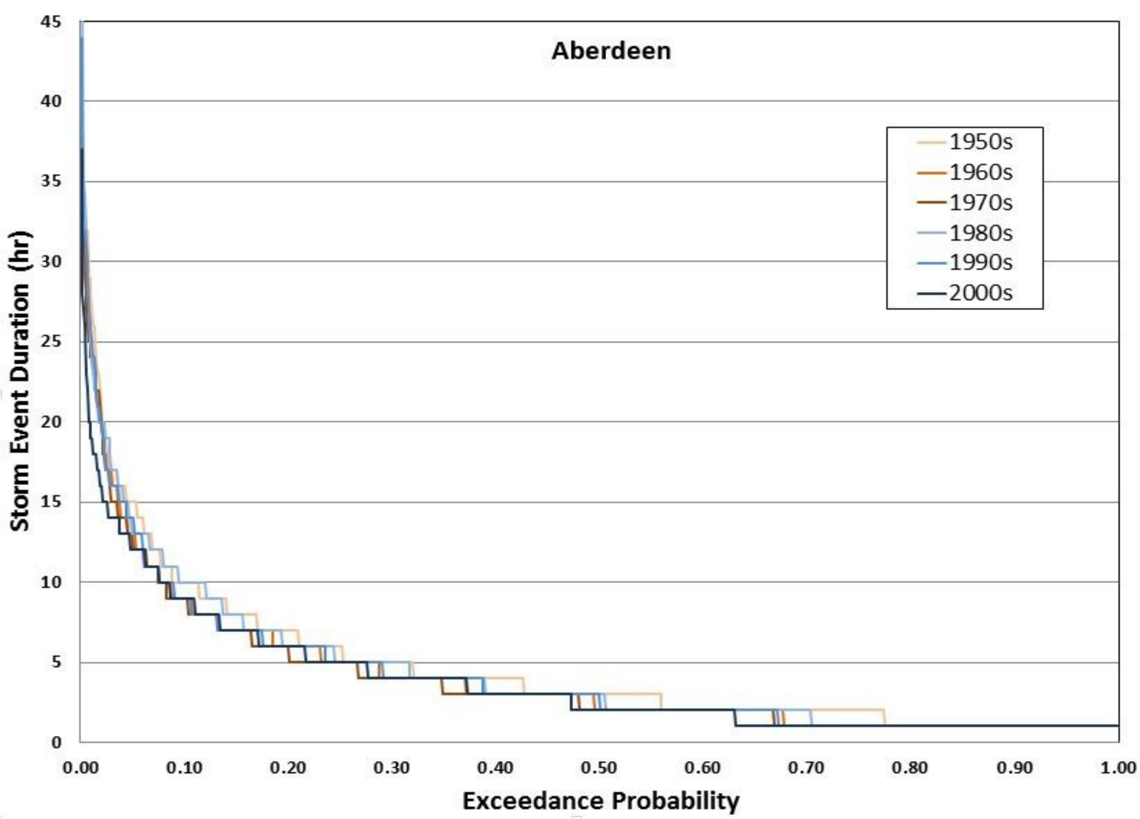


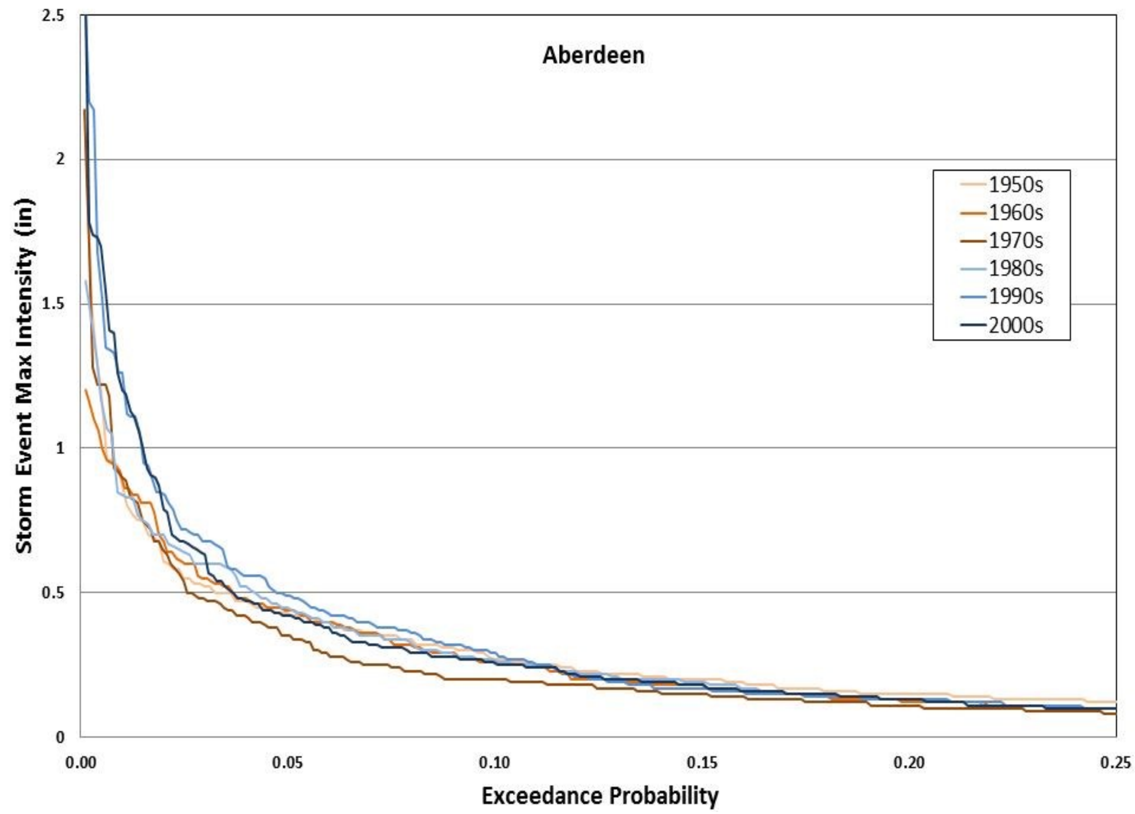


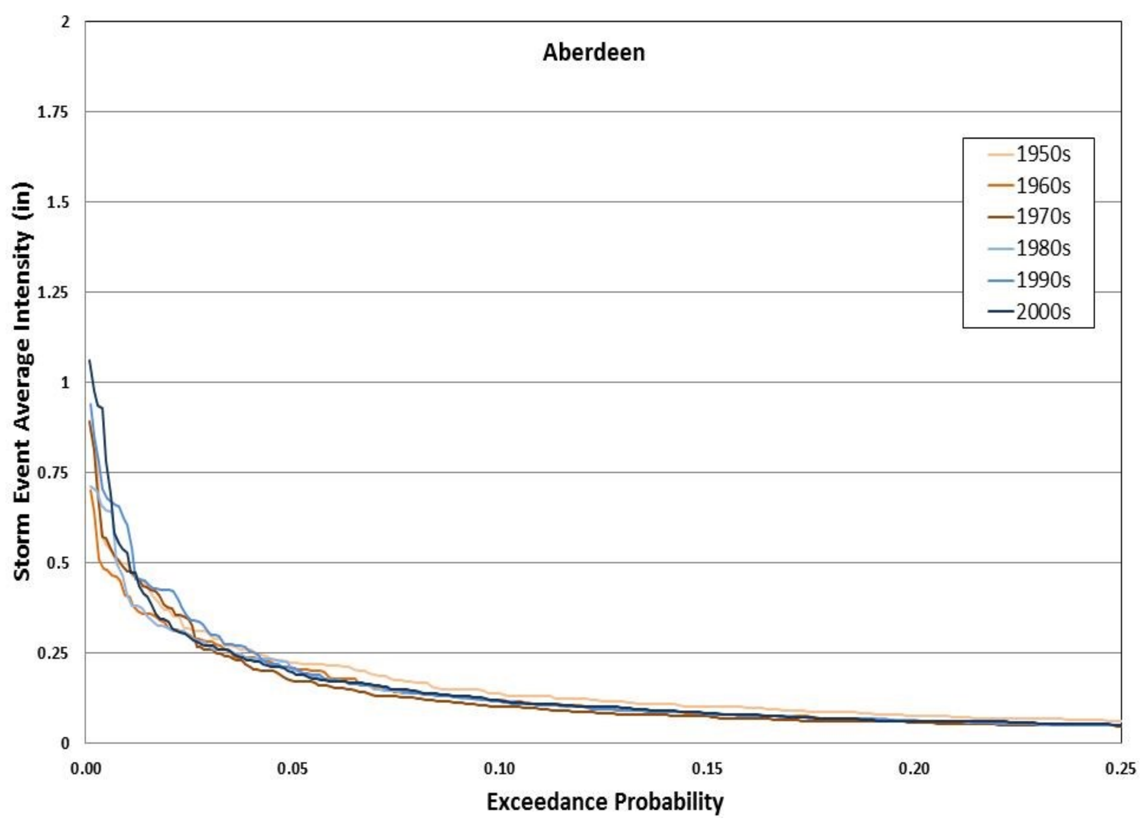

Aberdeen
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25


Aberdeen
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

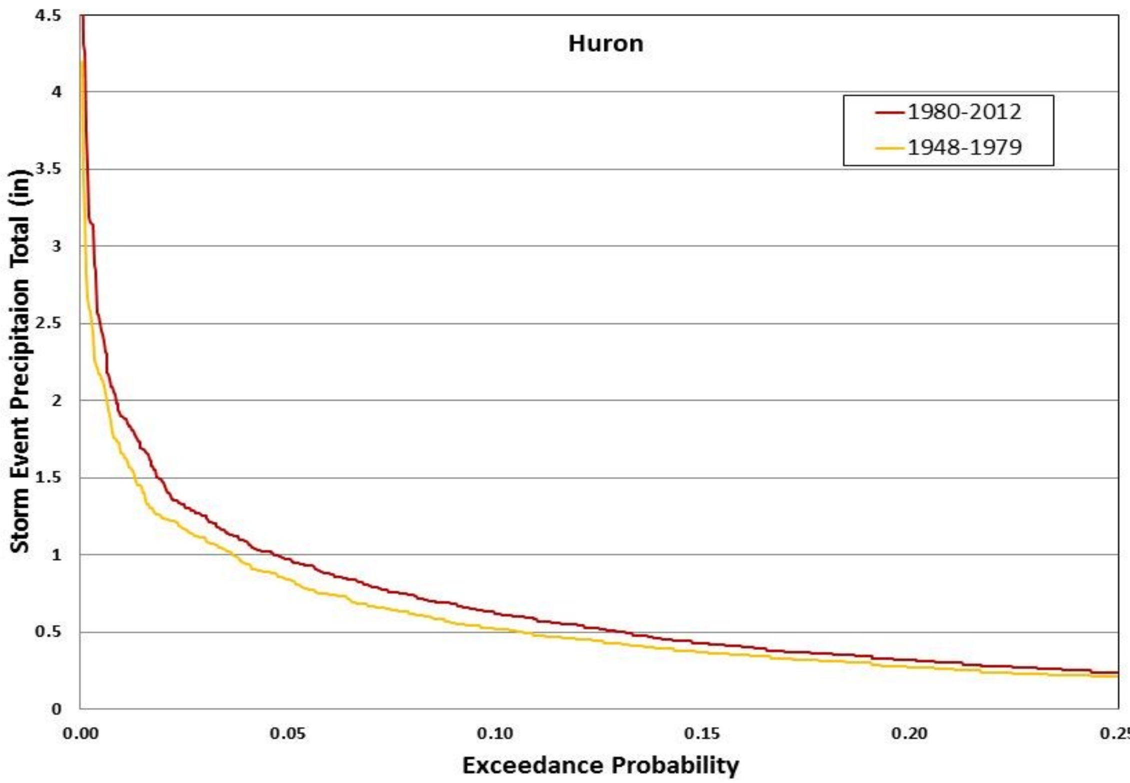

Aberdeen
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
1
2
3
4
5
6
7
0.00
0.05
0.10
0.15
0.20
0.25

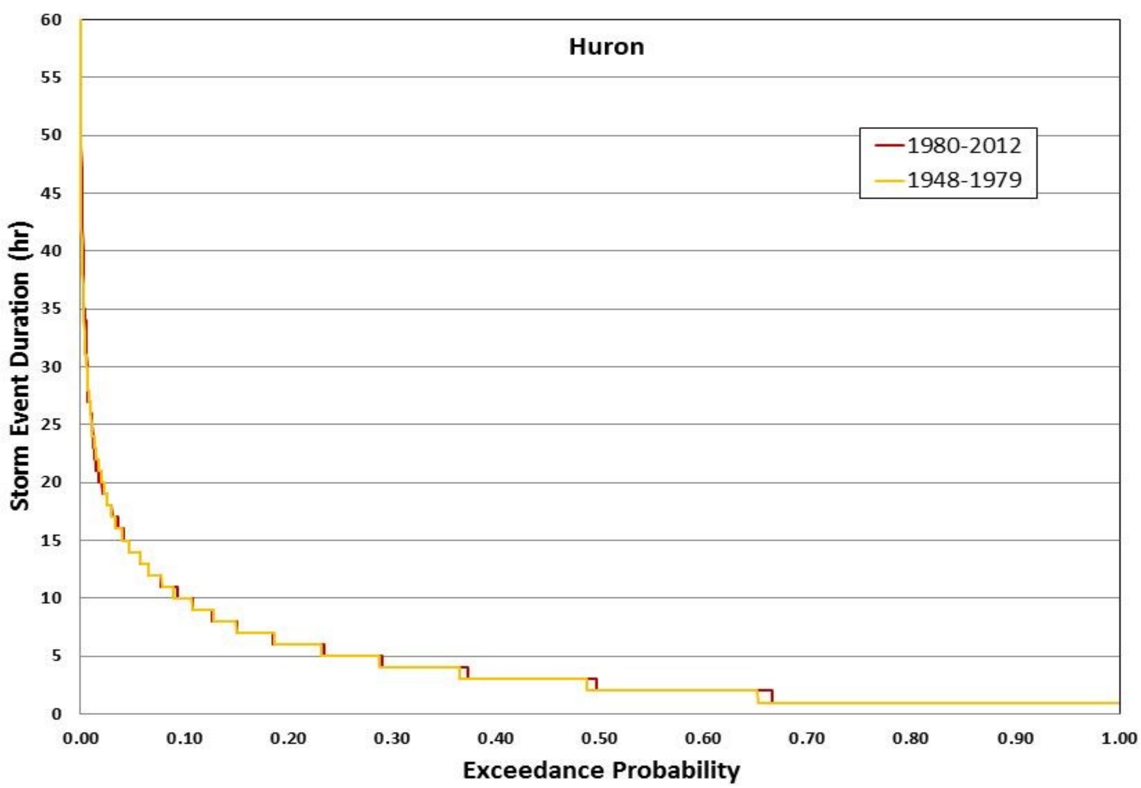

Aberdeen
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

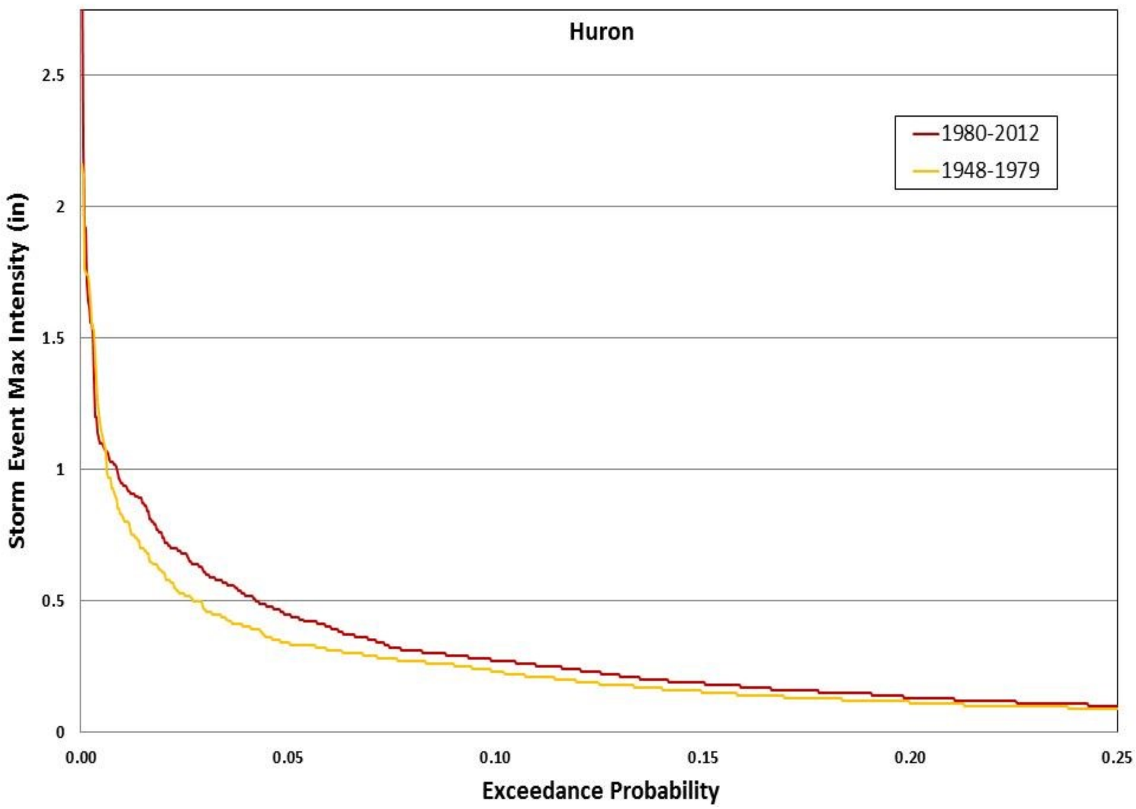

Aberdeen
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

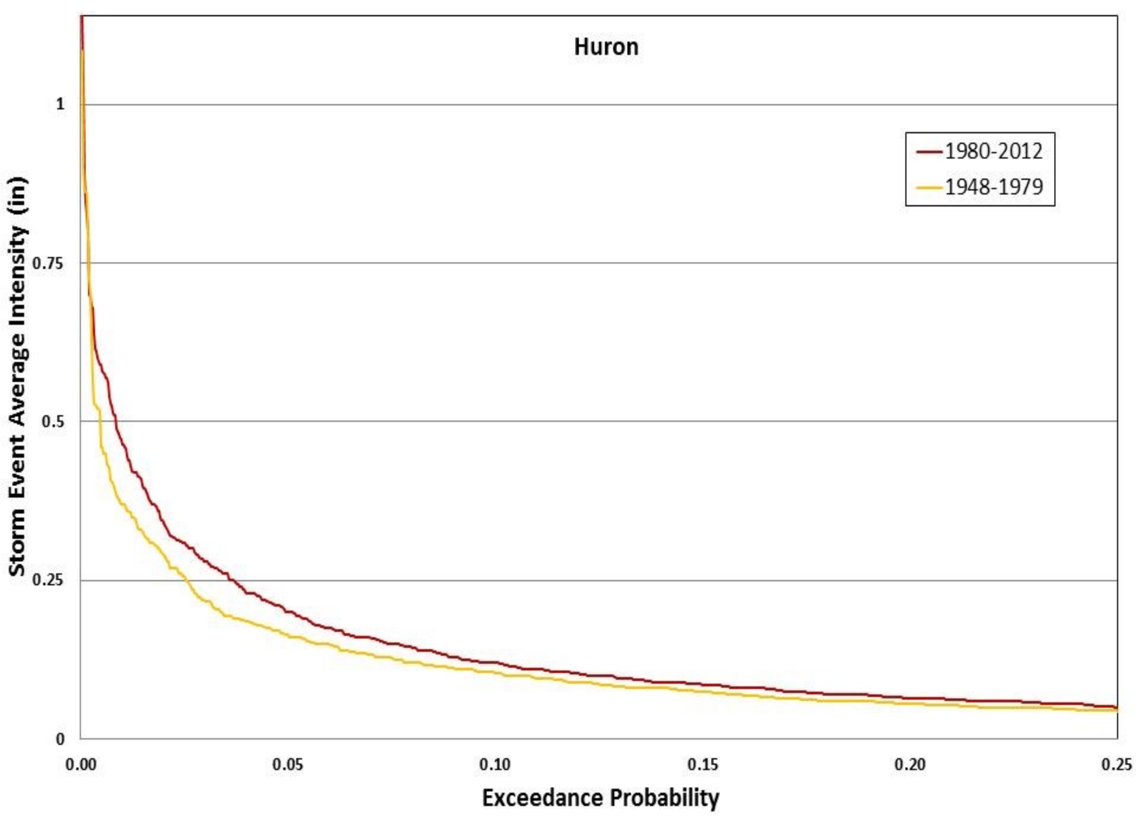

Aberdeen
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

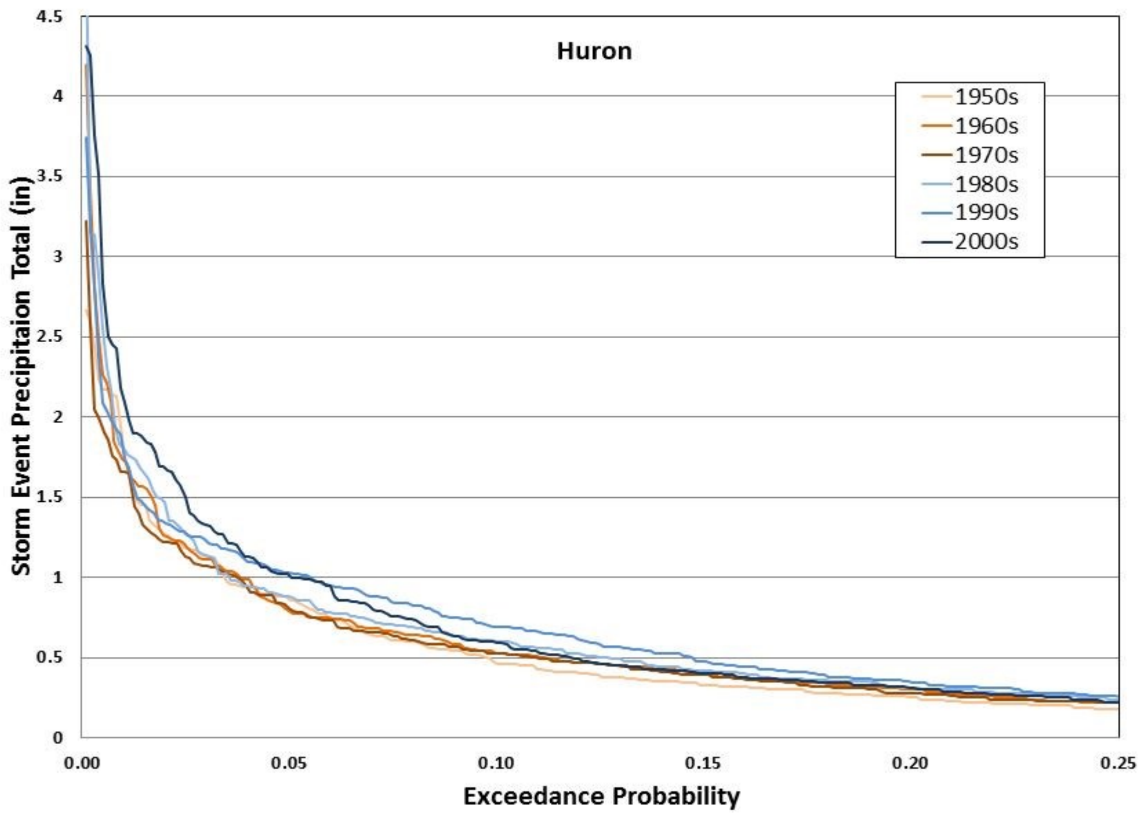
Appendix C-18. Exceedance probabilities of the characteristics of rainfall in Huron.



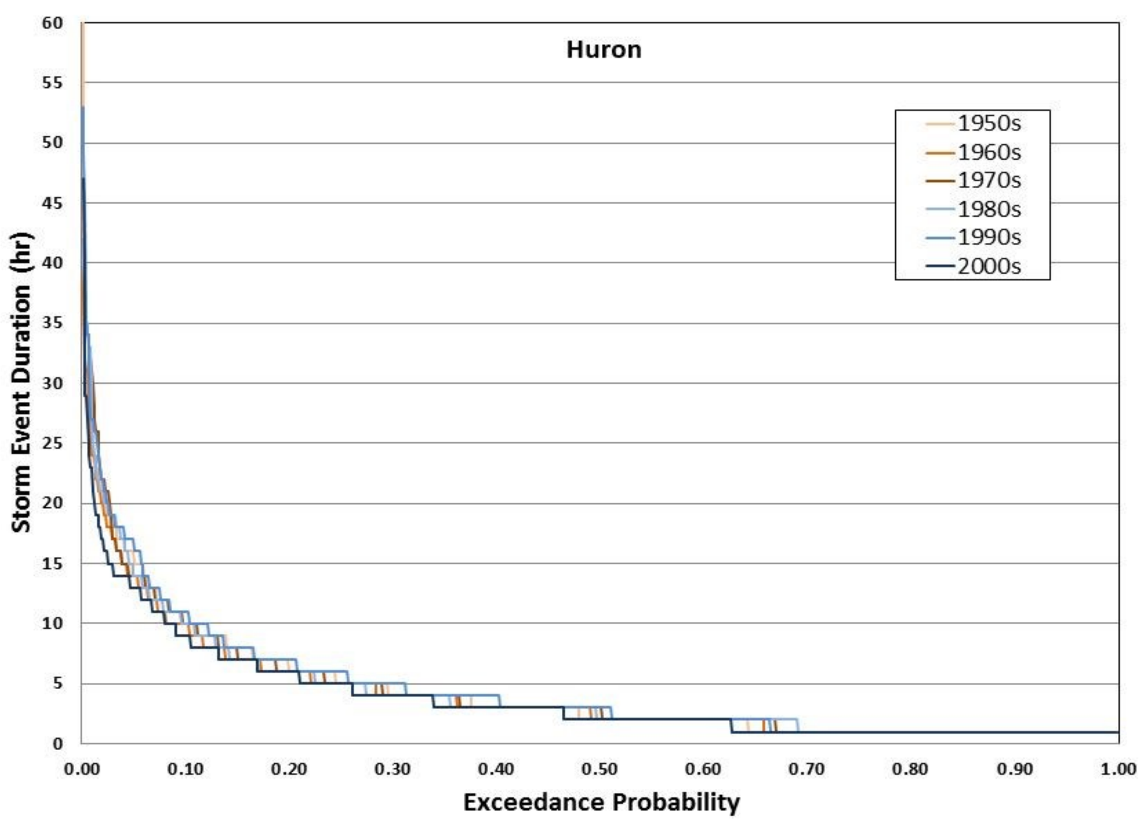



Huron
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
0.00
0.05
0.10
0.15
0.20
0.25

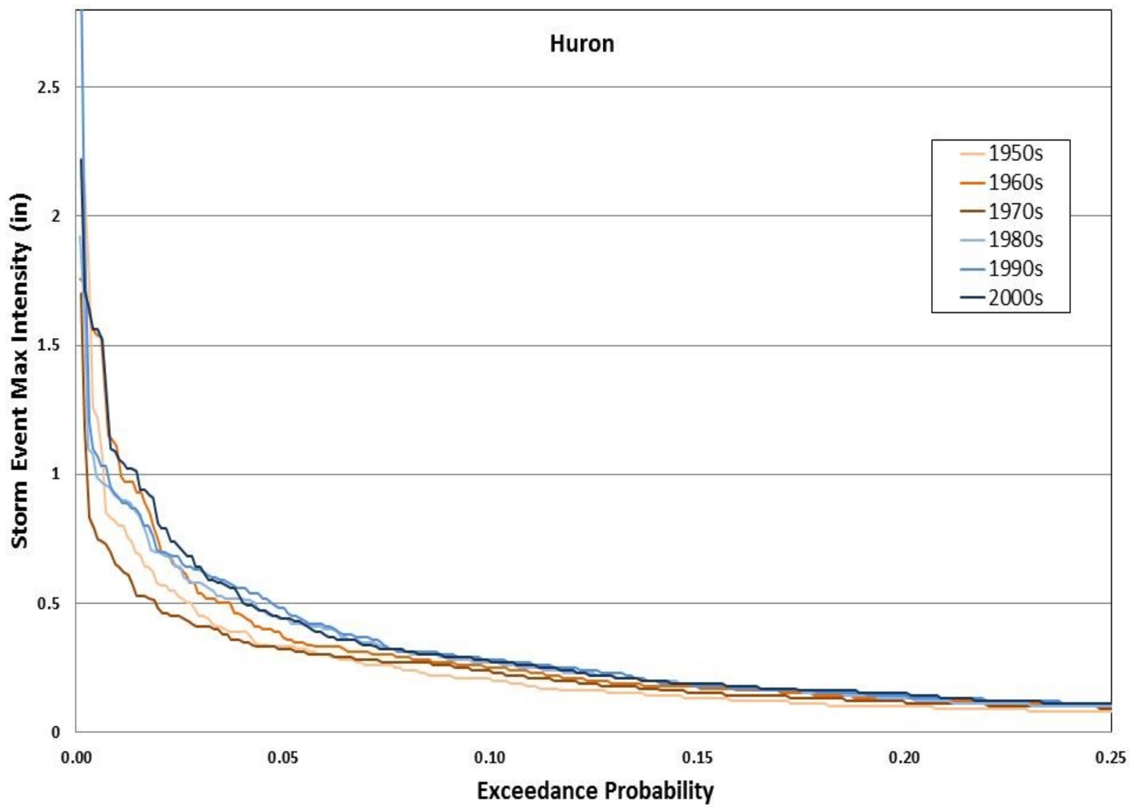

Huron
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
0.00
0.05
0.10
0.15
0.20
0.25

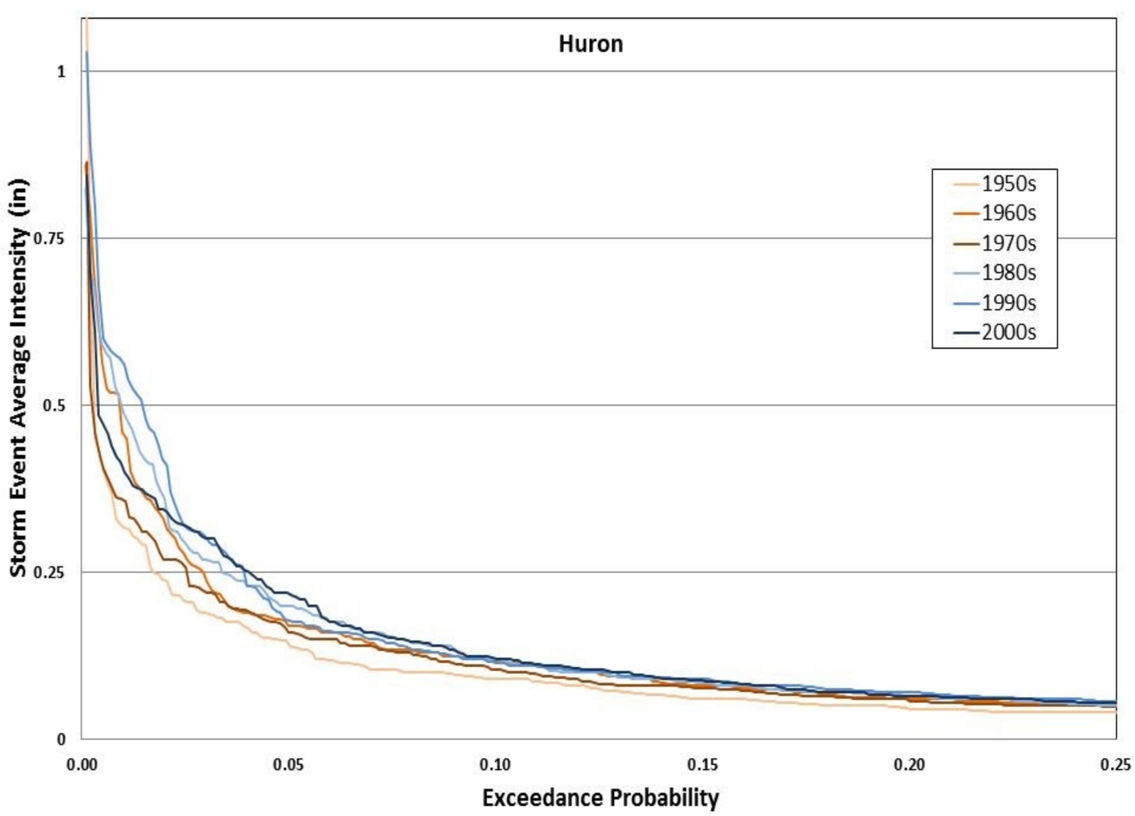


Huron
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

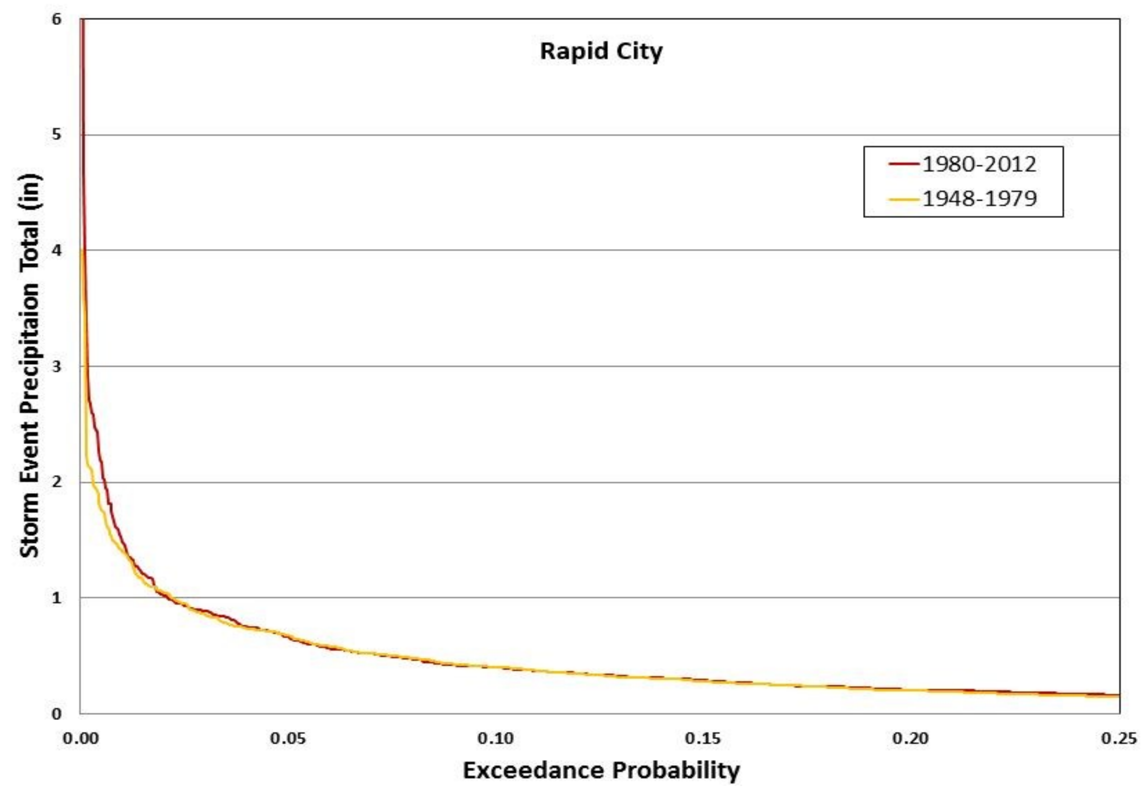


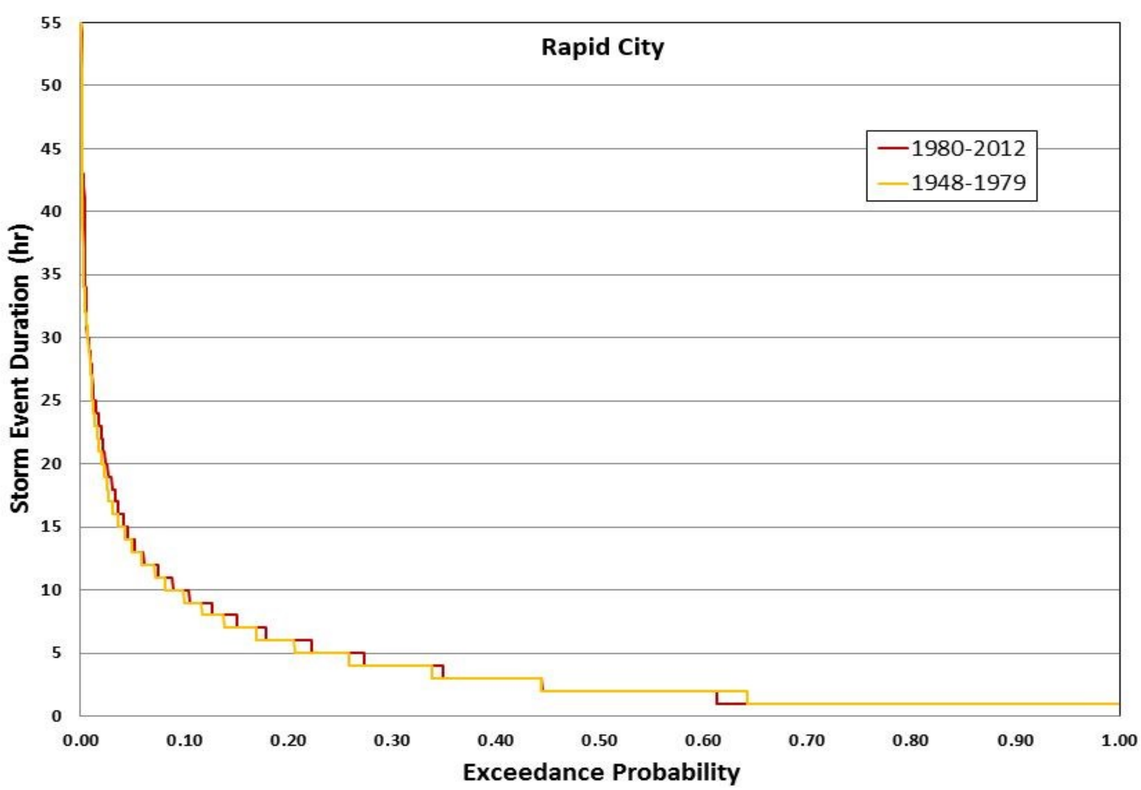
Huron
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
60
55
50
45
40
35
30
25
20
15
10
5
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

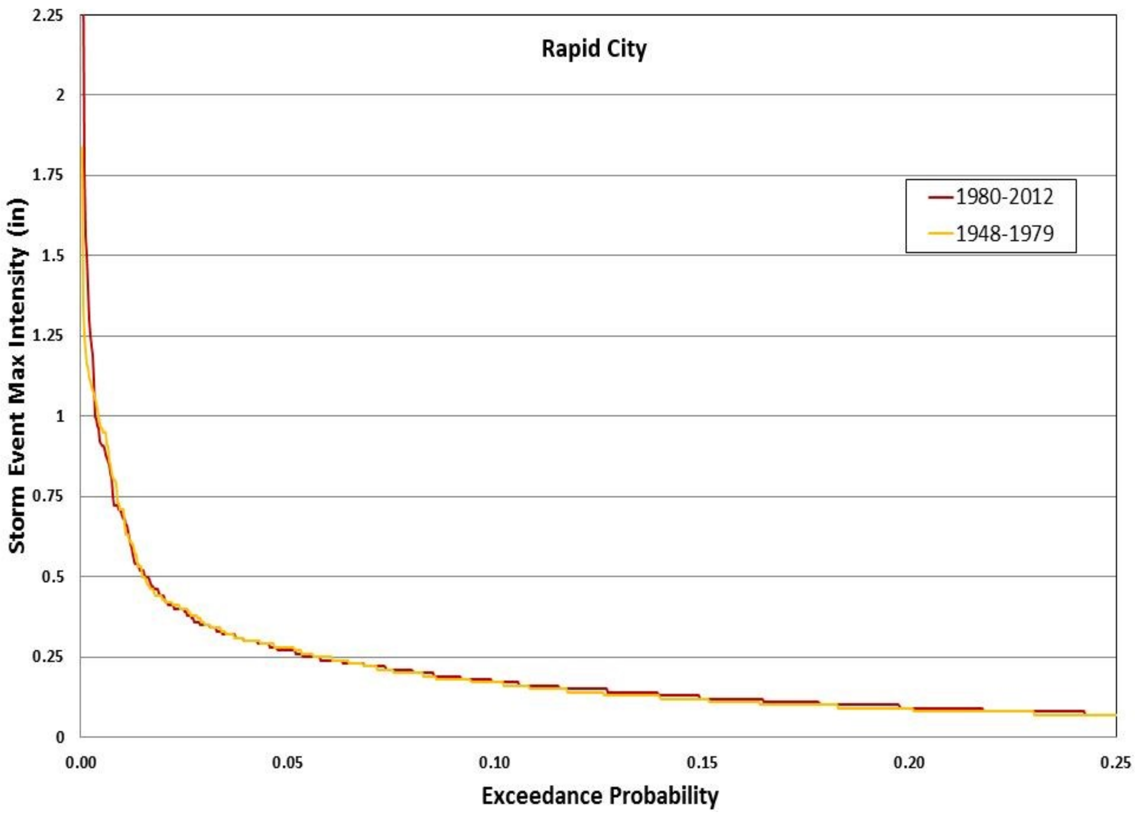

Huron
2.5
2
1.5
1
0.5
0
Storm Event Max Intensity (in)
1950s
1960s
1970s
1980s
1990s
2000s
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

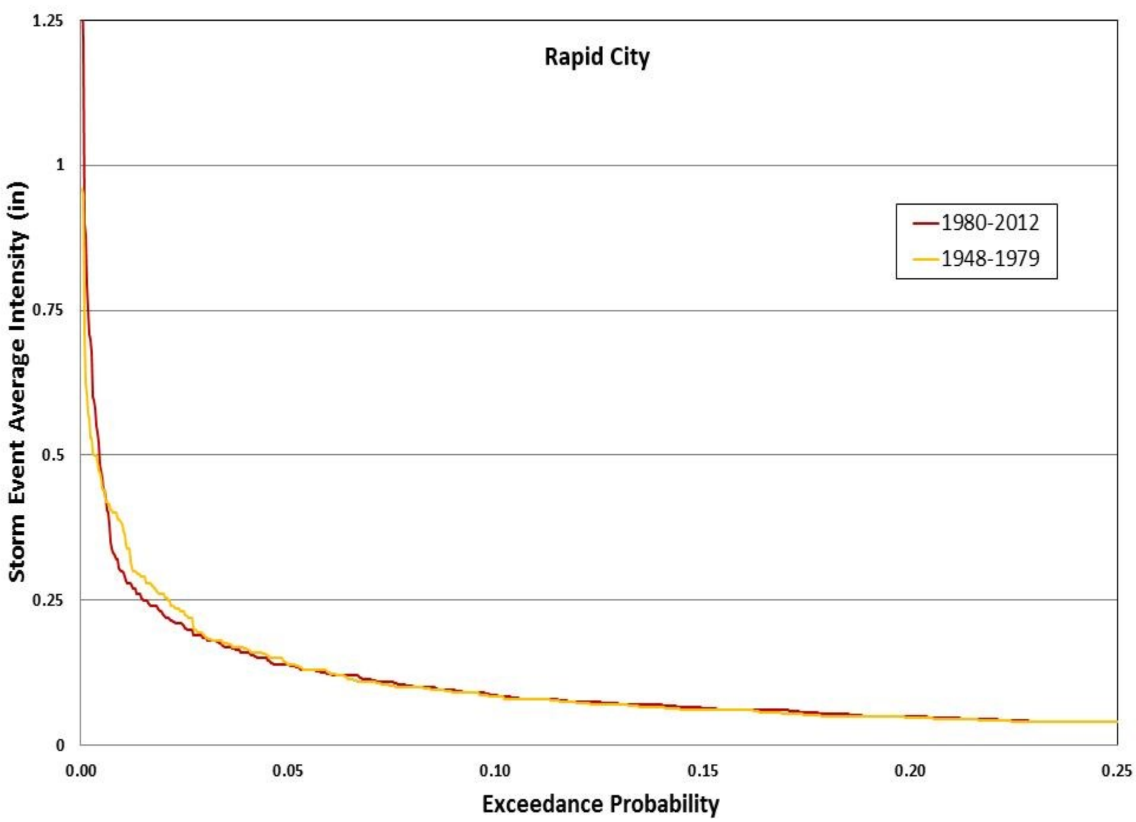

Huron
1
0.75
0.5
0.25
0
Storm Event Average Intensity (in)
1950s
1960s
1970s
1980s
1990s
2000s
0.00
0.05
0.10
0.15
0.20
0.25
Exceedance Probability

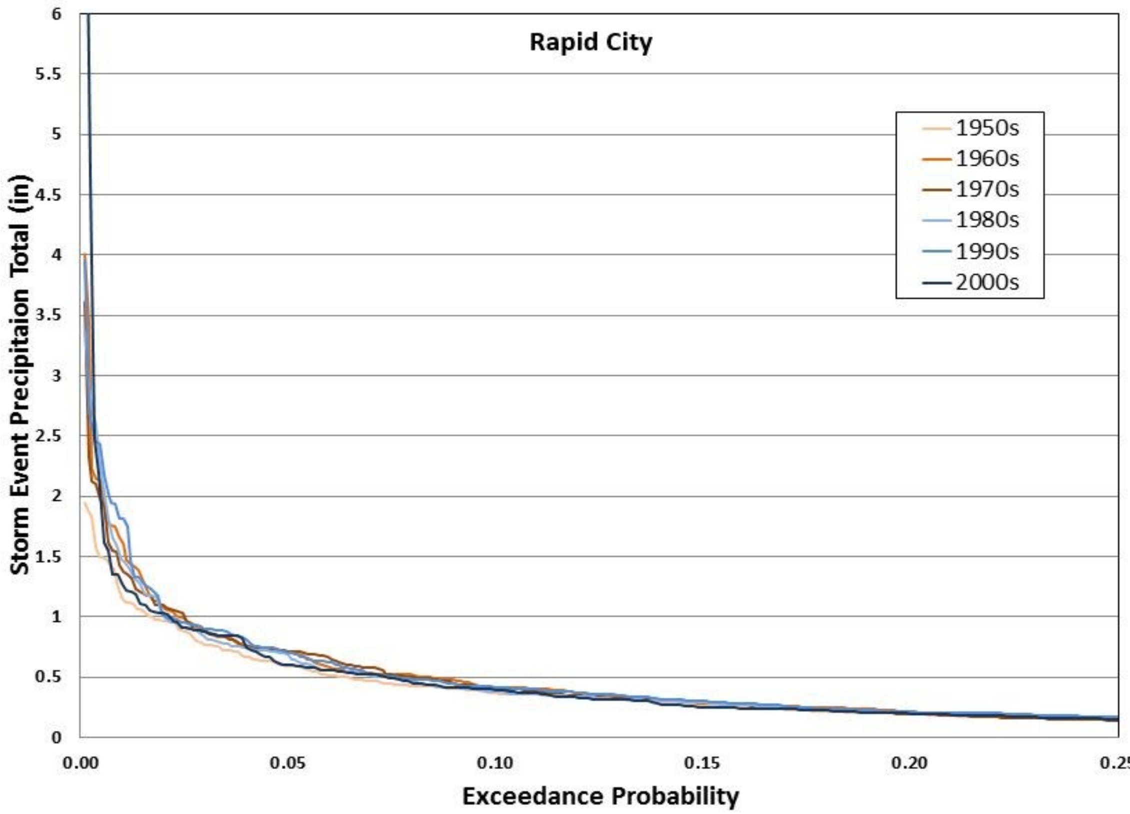
Appendix C-19. Exceedance probabilities of the characteristics of rainfall in Rapid City.

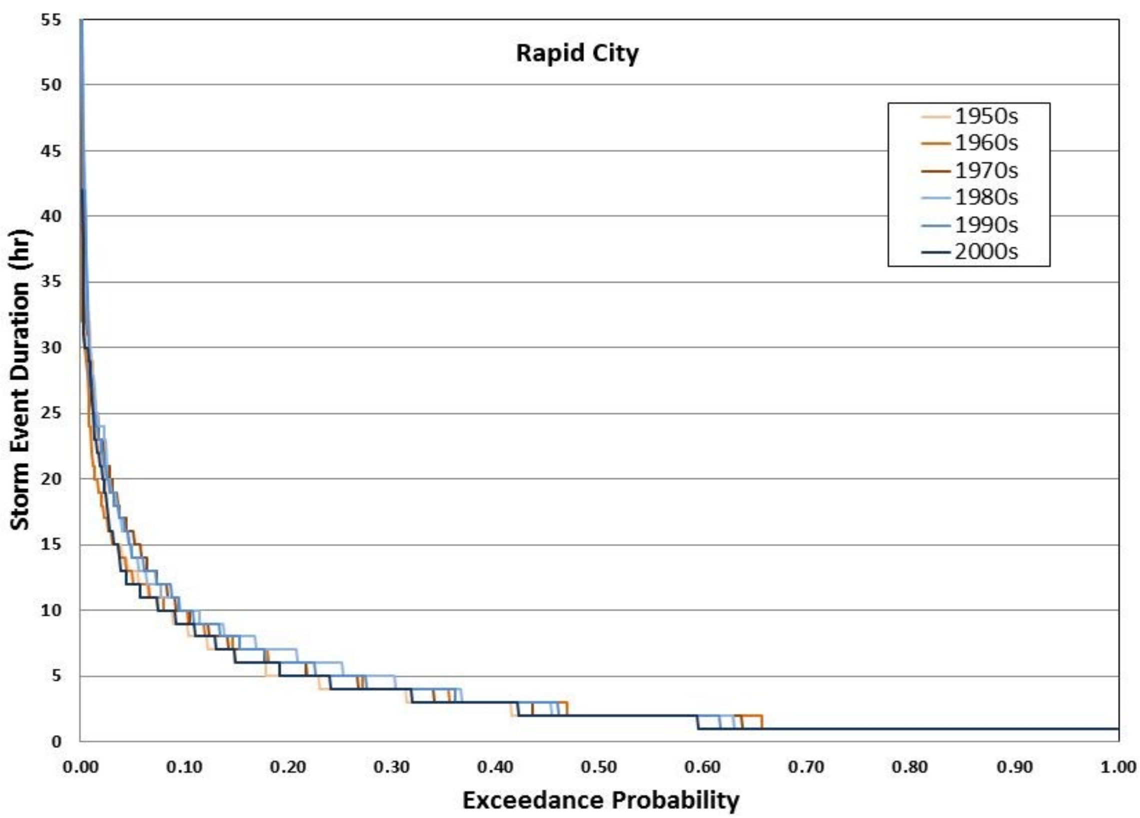


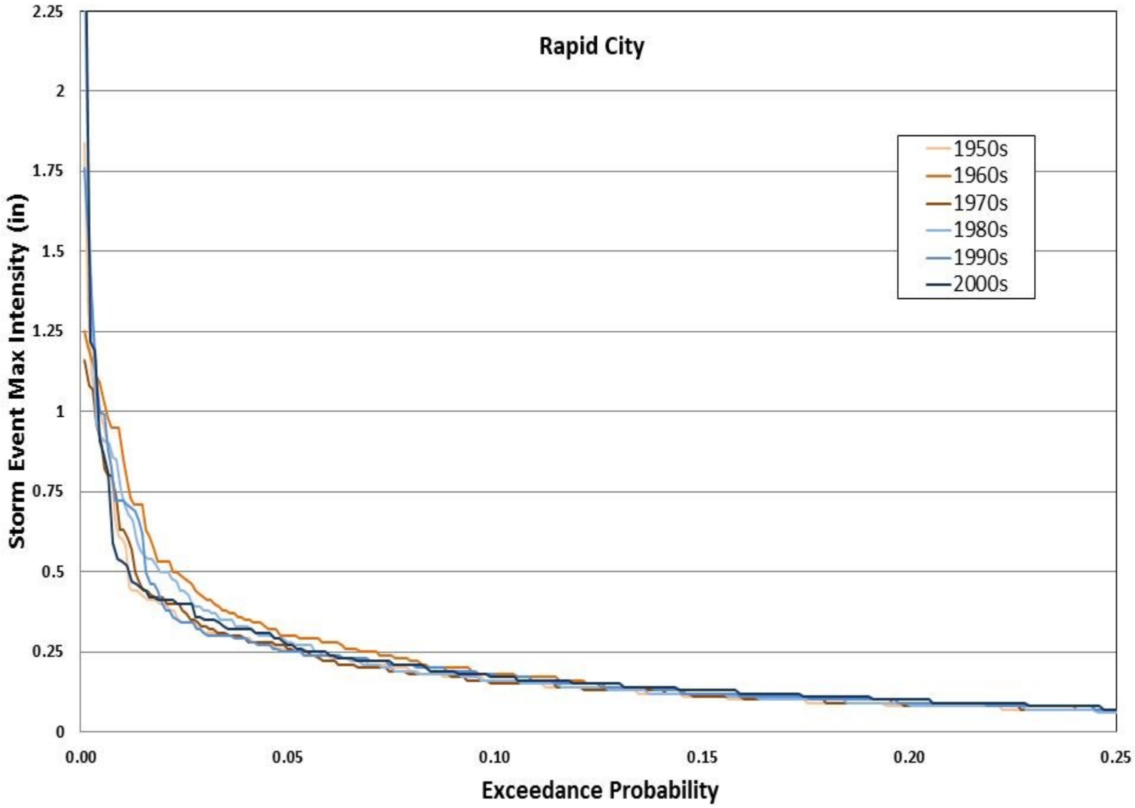


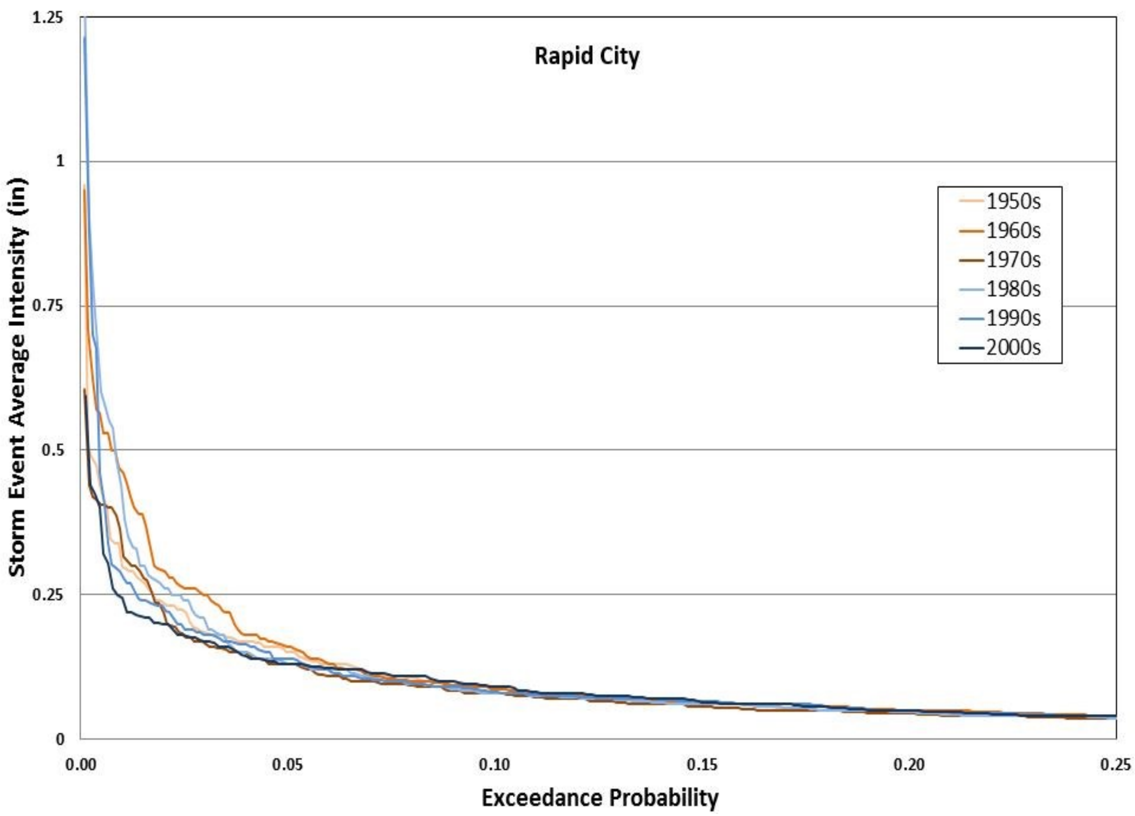

Rapid City
Storm Event Max Intensity (in)
Exceedance Probability
1980-2012
1948-1979
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25


Rapid City
Storm Event Average Intensity (in)
Exceedance Probability
1980-2012
1948-1979
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

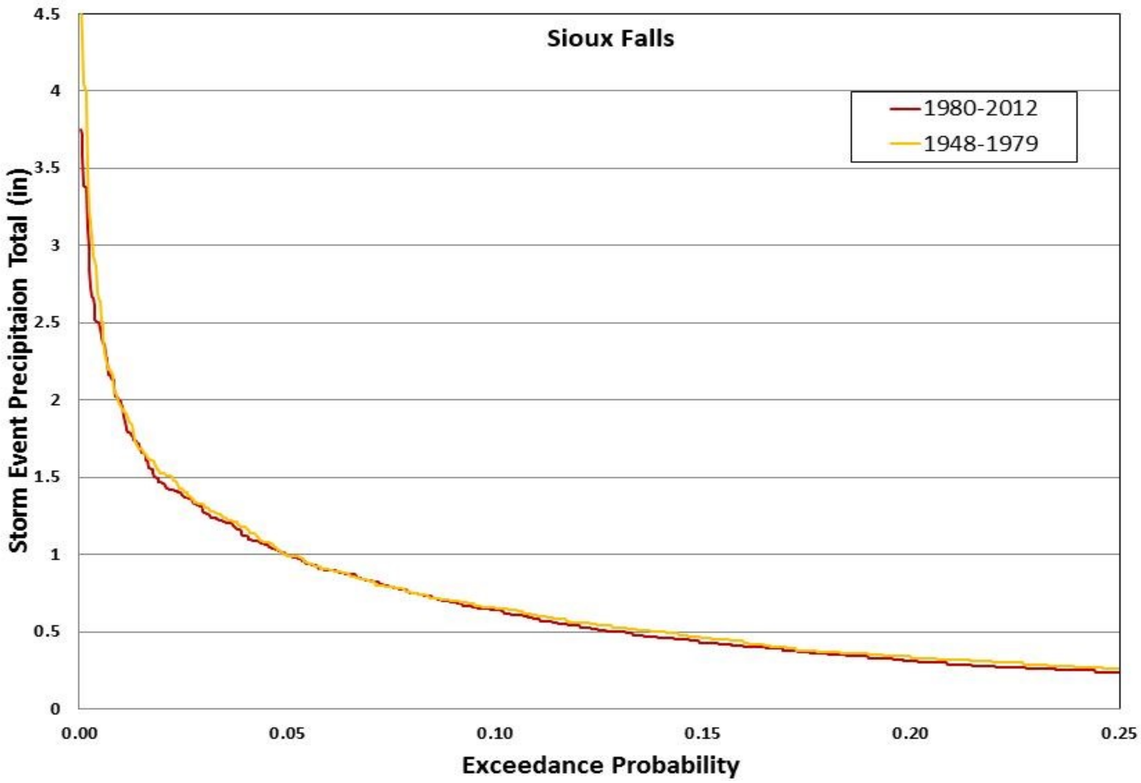

Rapid City
Storm Event Precipitaion Total (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
0.00
0.05
0.10
0.15
0.20
0.25

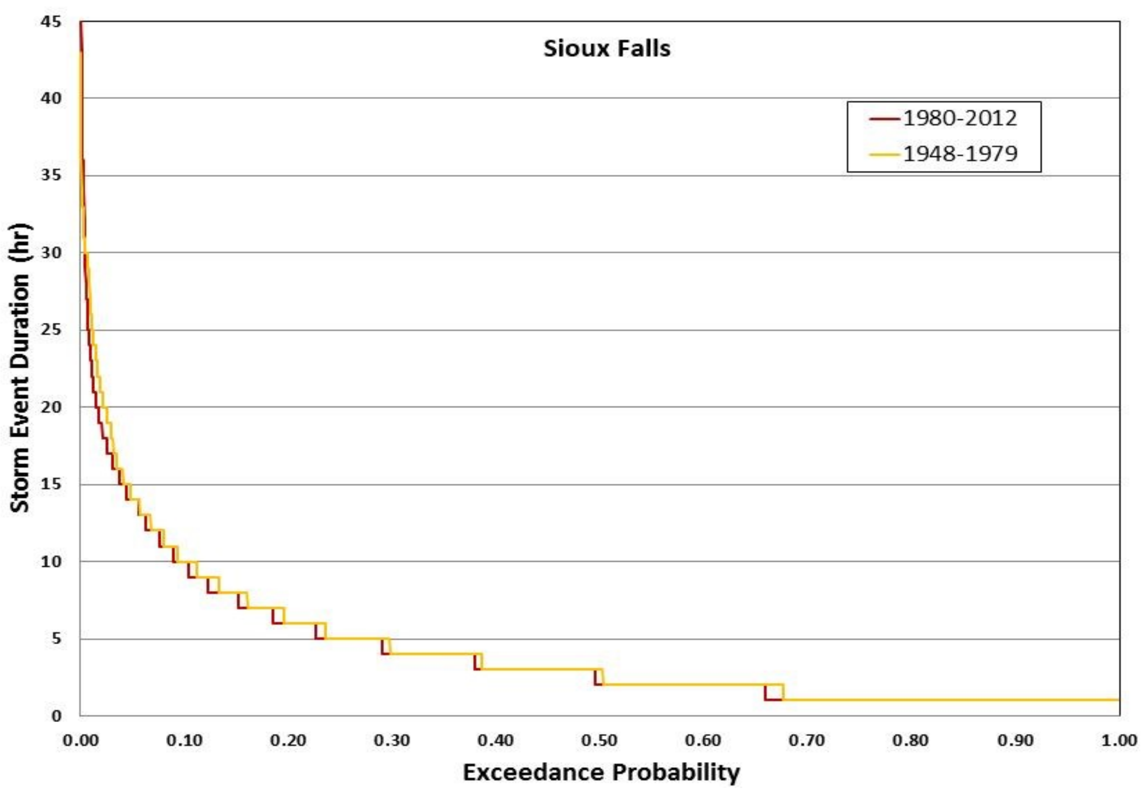

Rapid City
Storm Event Duration (hr)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
0
5
10
15
20
25
30
35
40
45
50
55
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

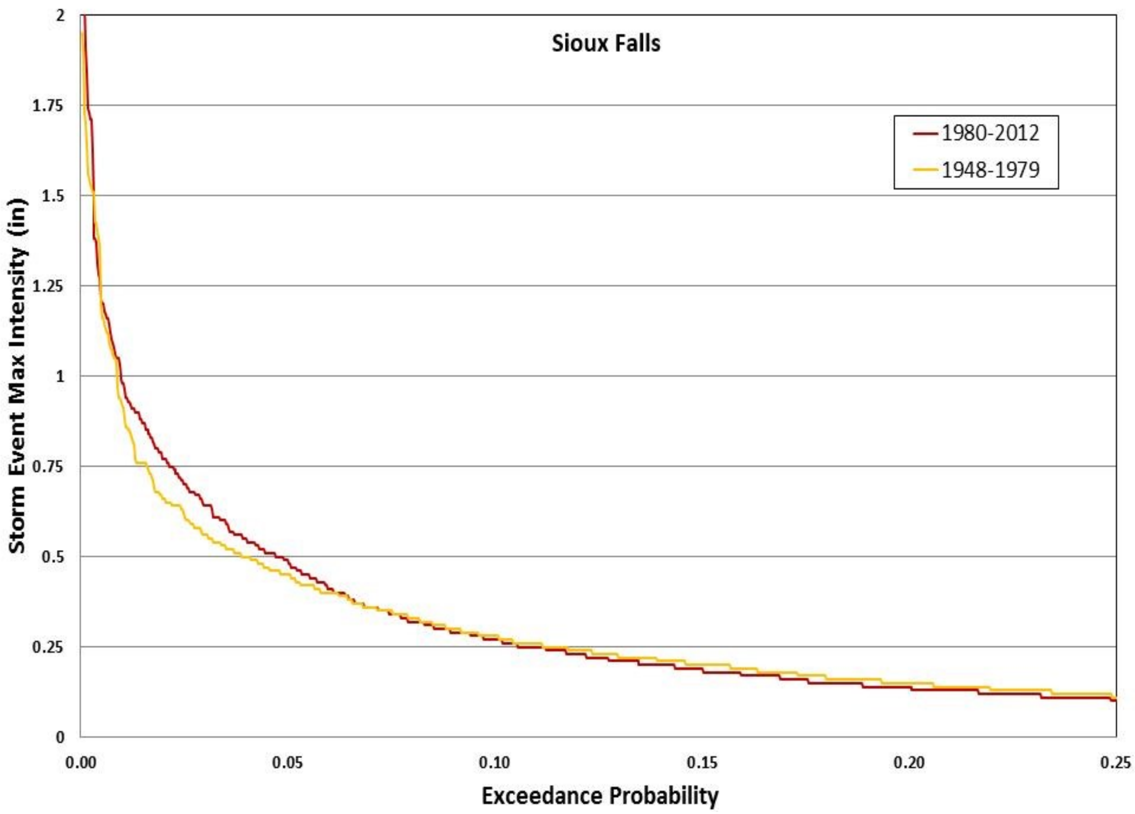

Rapid City
Storm Event Max Intensity (in)
Exceedance Probability
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s


Rapid City
Storm Event Average Intensity (in)
Exceedance Probability
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

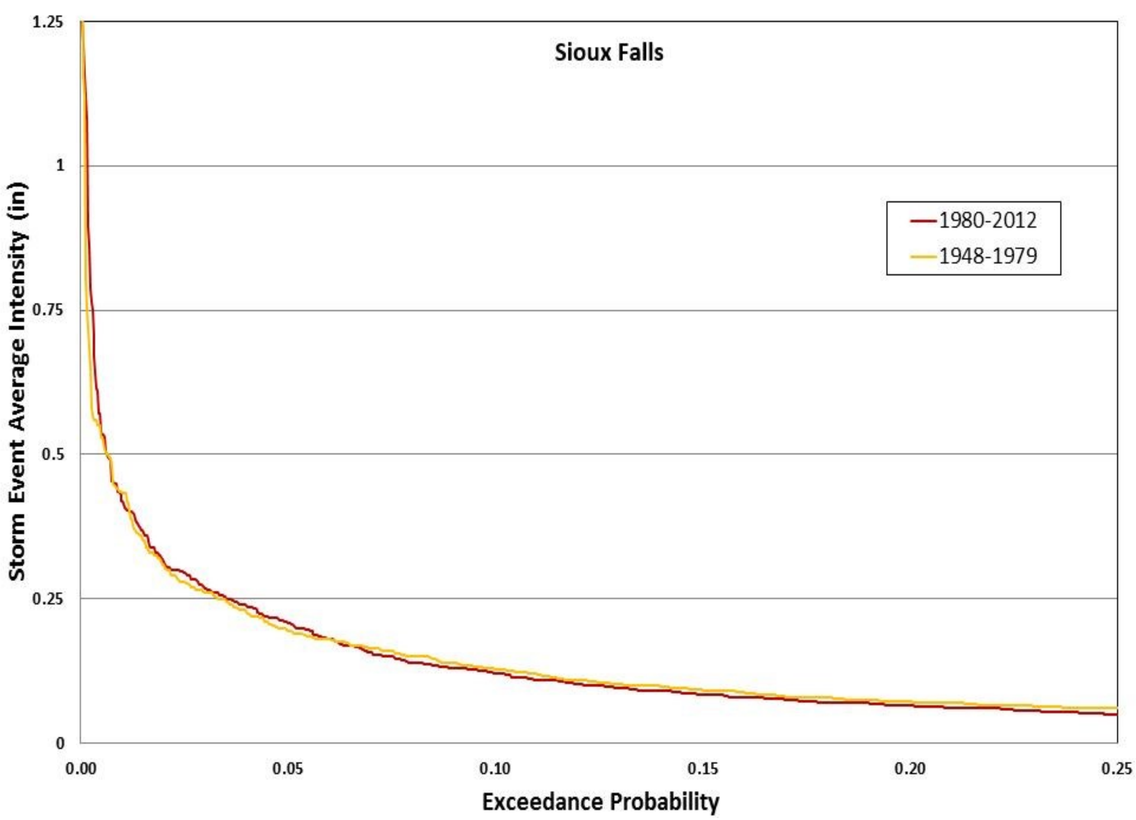
Appendix C-20. Exceedance probabilities of the characteristics of rainfall in Sioux Falls.



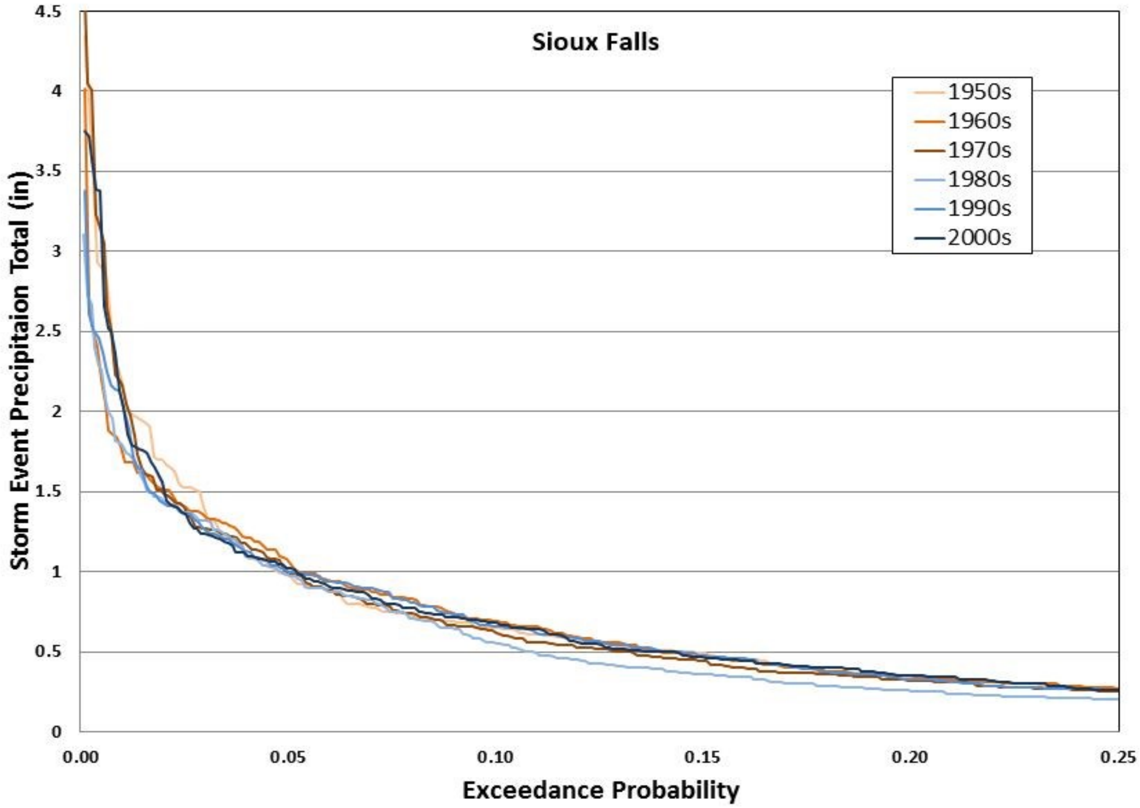


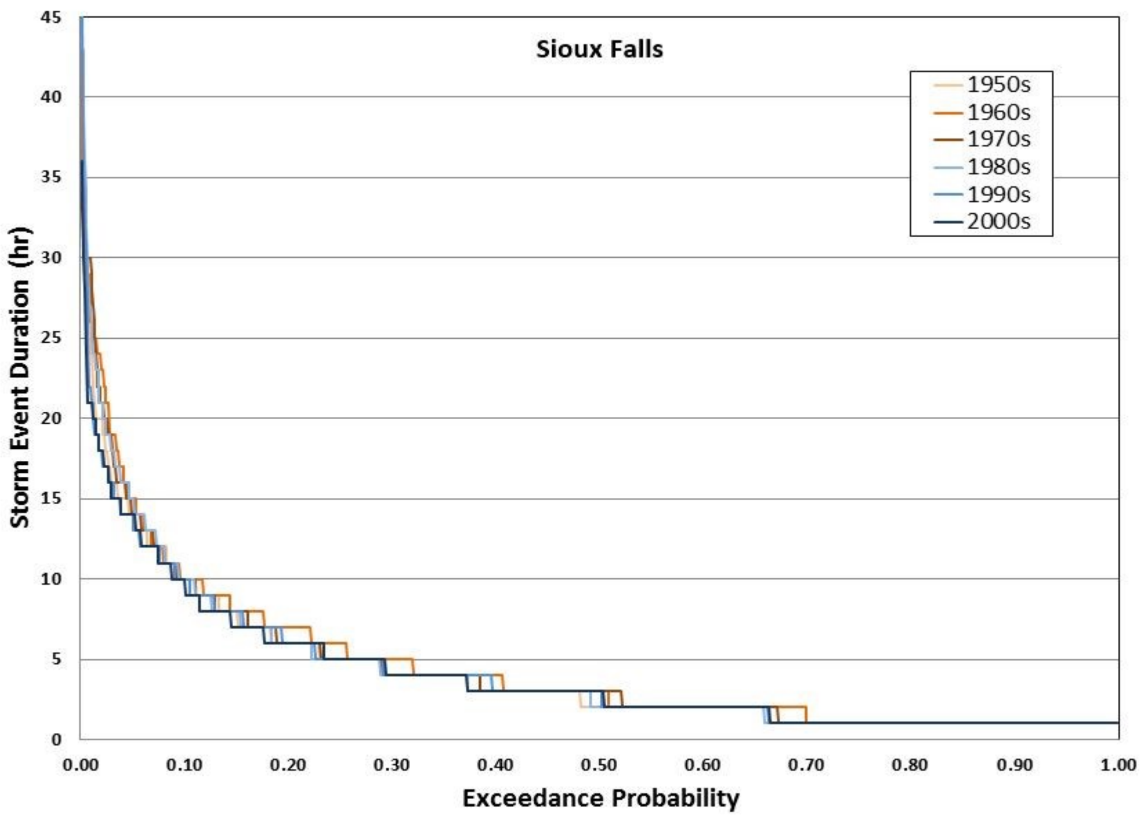


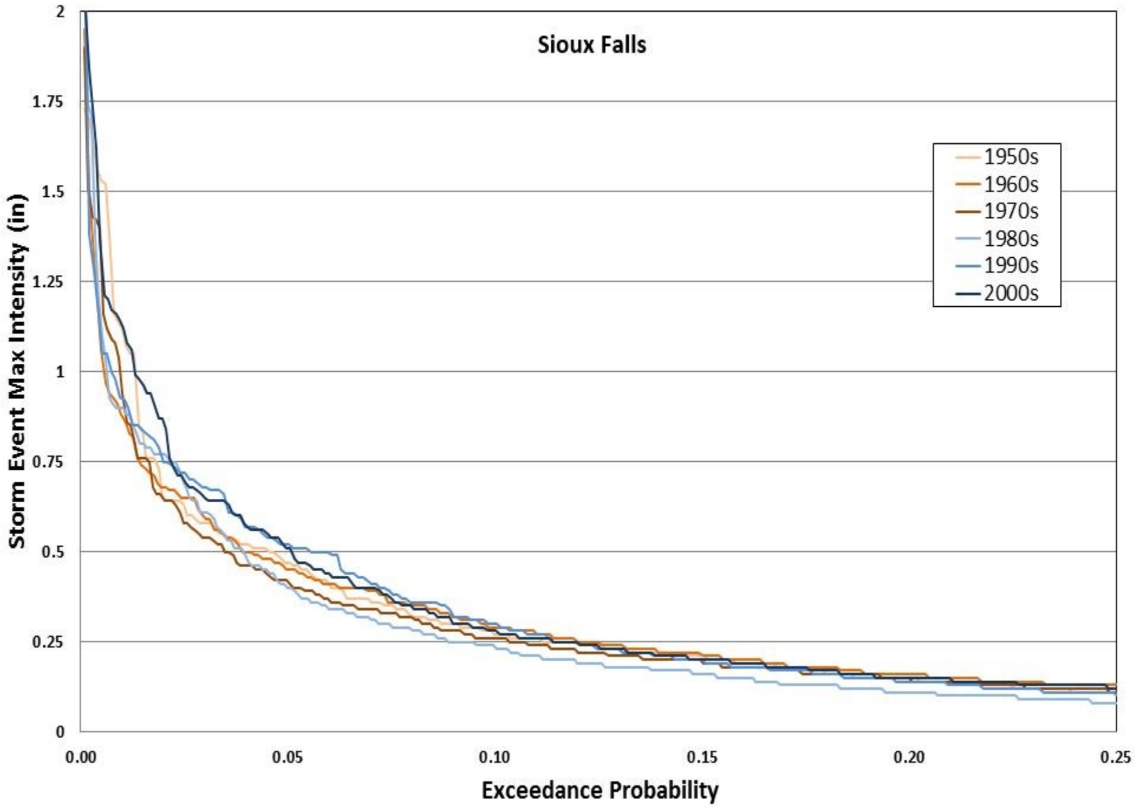
Sioux Falls
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

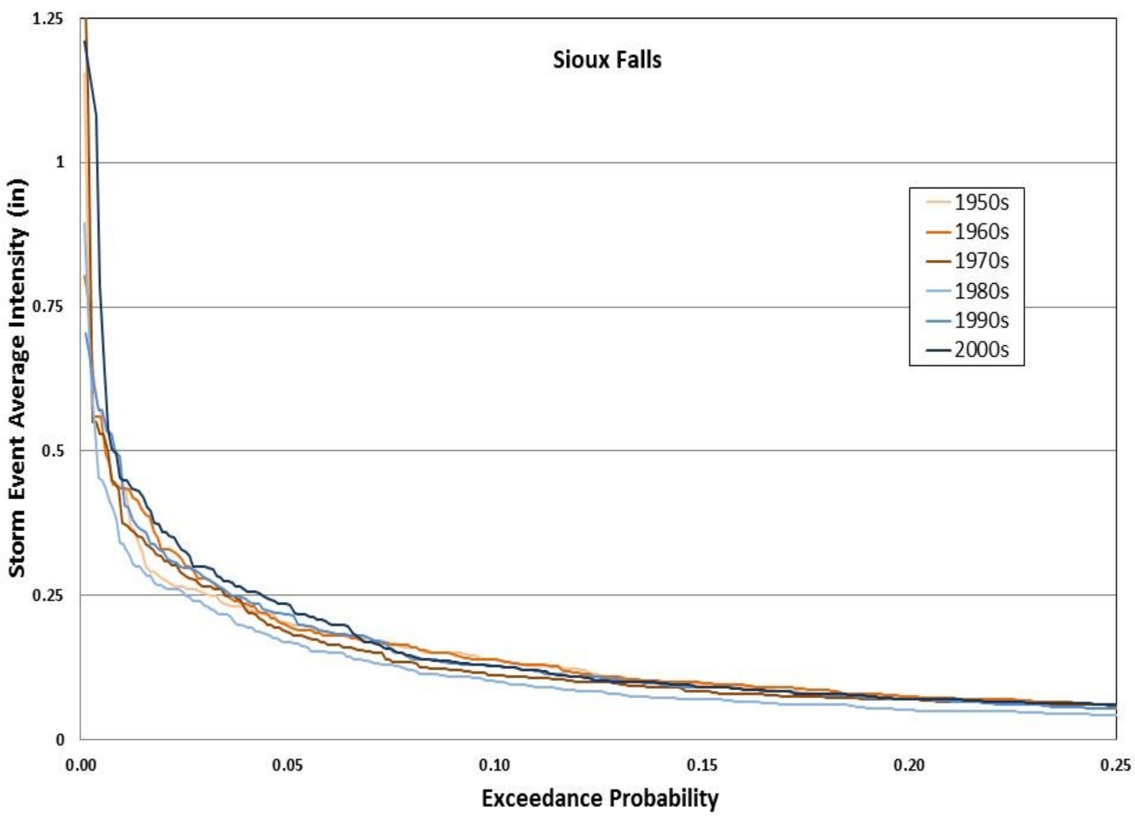


Sioux Falls
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

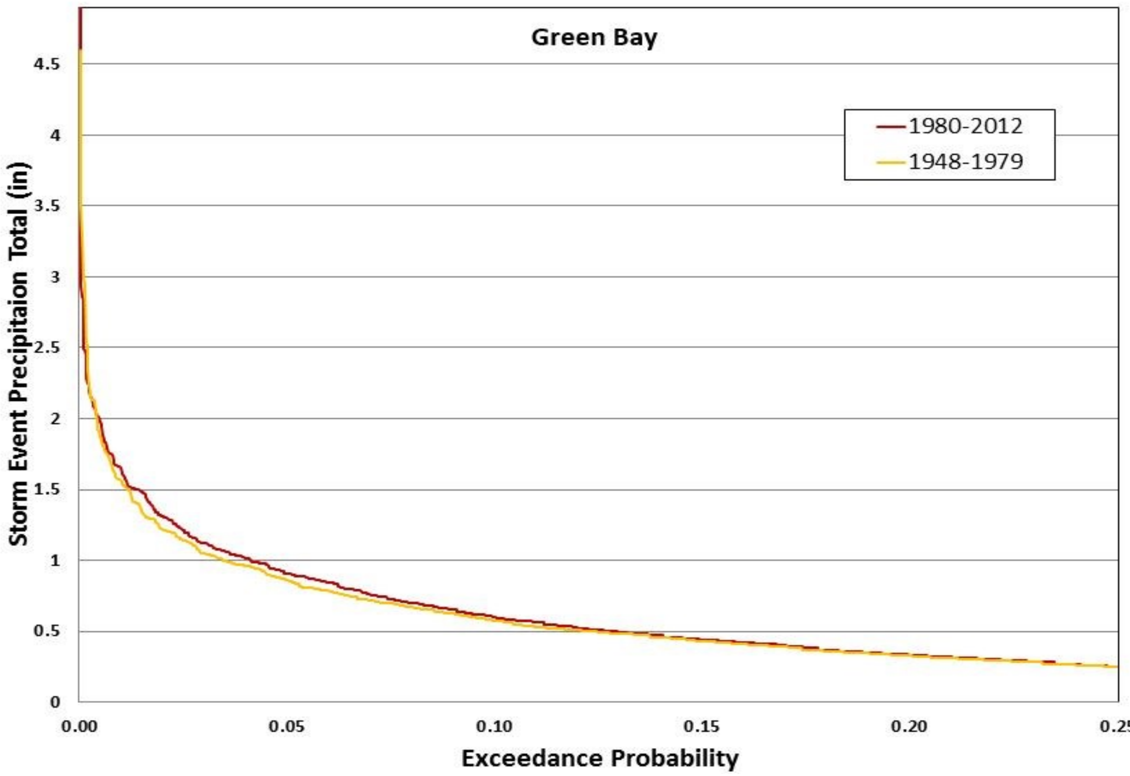

Sioux Falls
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

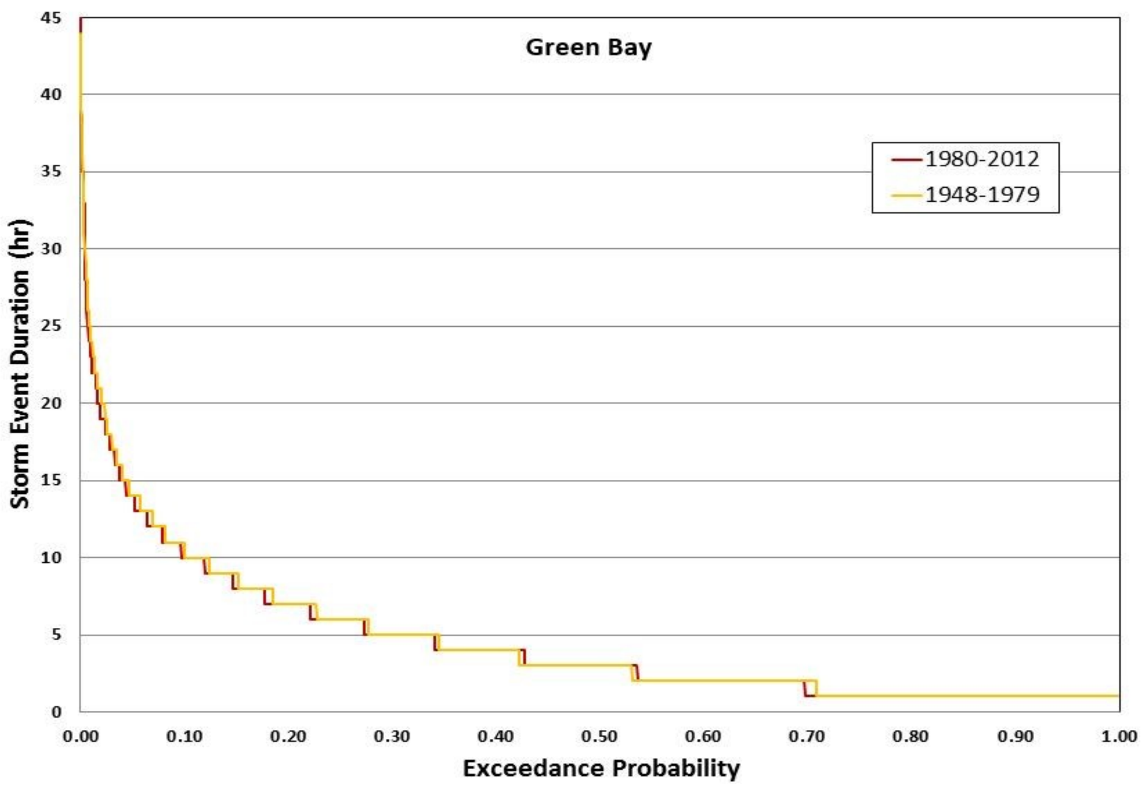

Sioux Falls
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
45
40
35
30
25
20
15
10
5
0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

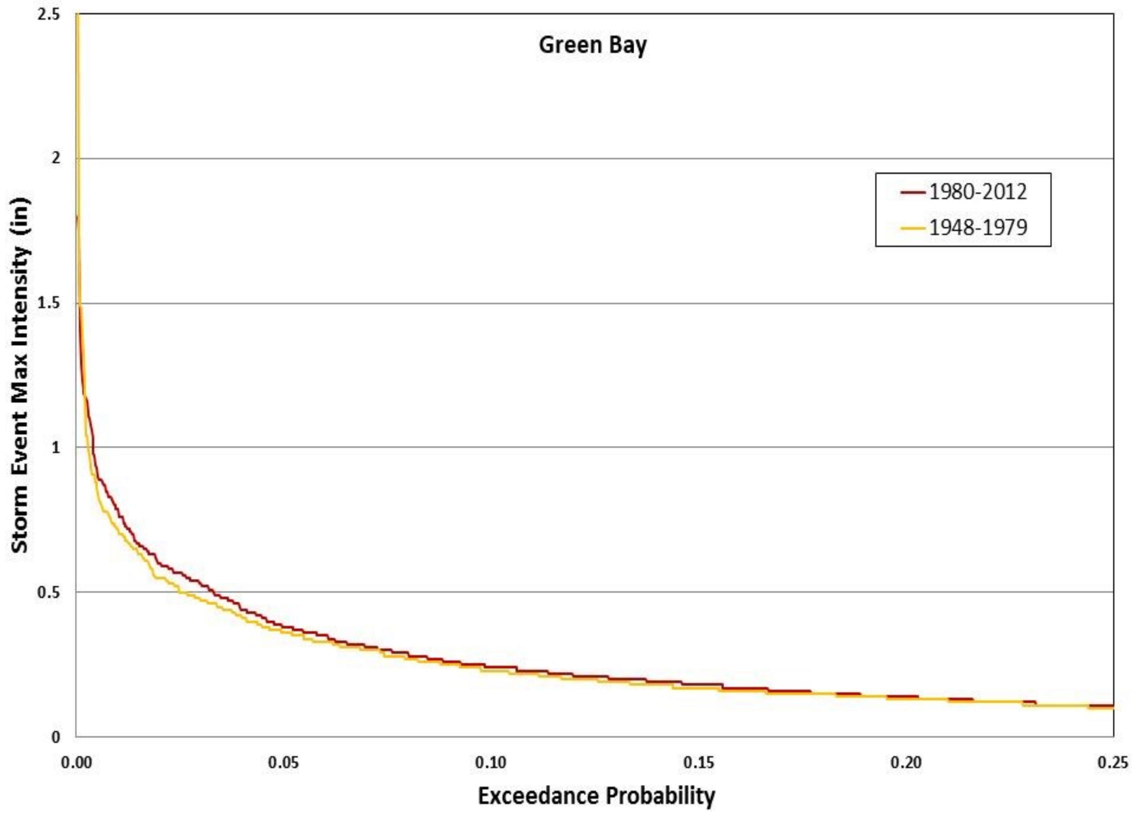

Sioux Falls
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

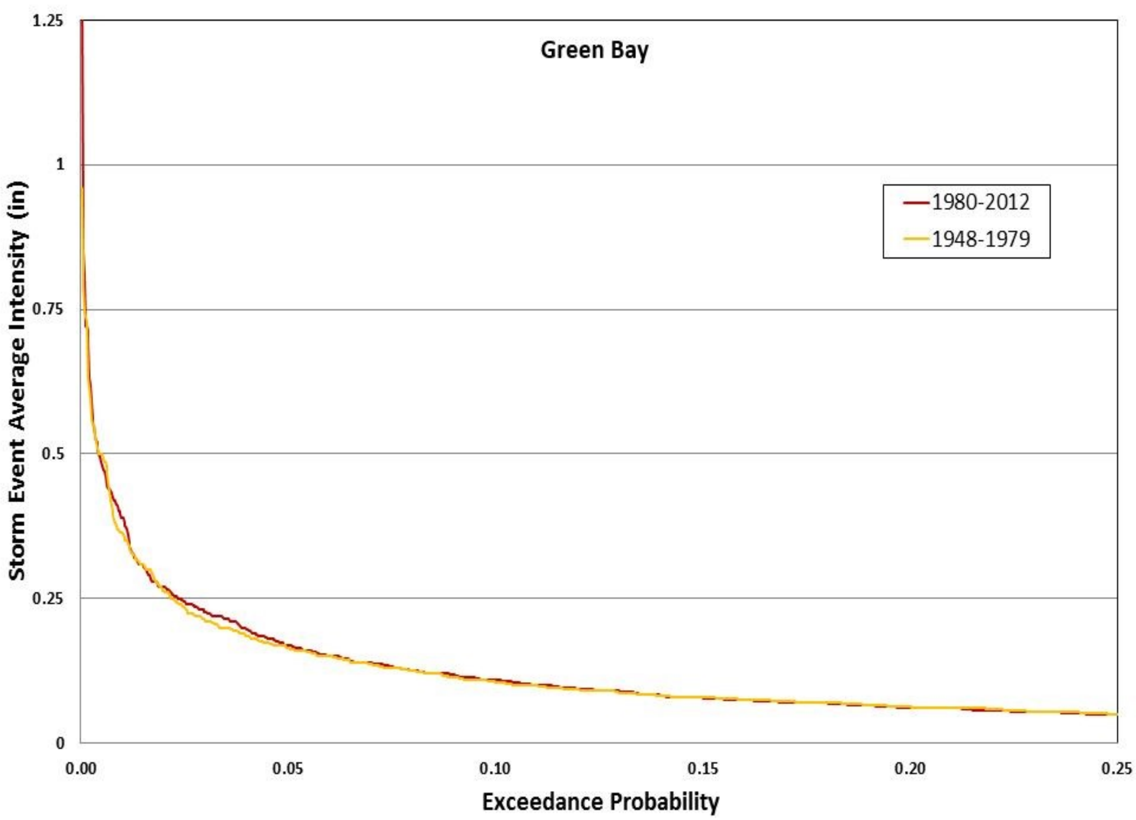

Sioux Falls
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

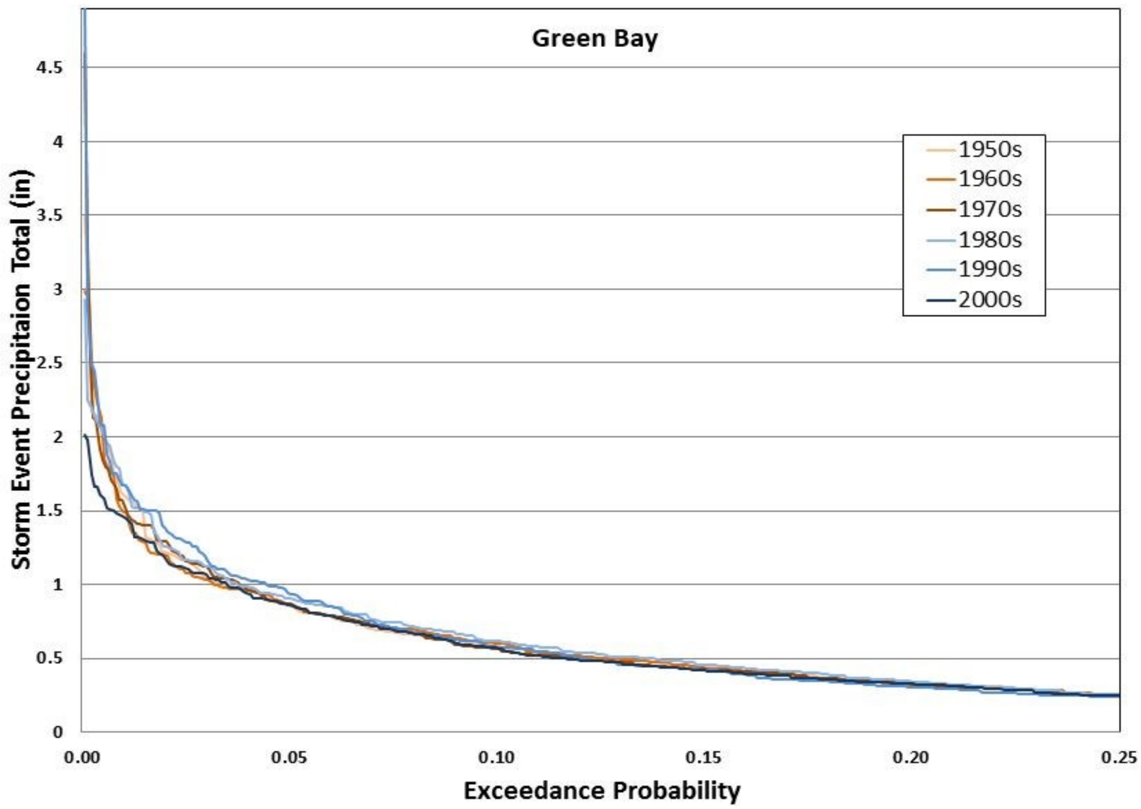
Appendix C-21. Exceedance probabilities of the characteristics of rainfall in Green Bay.



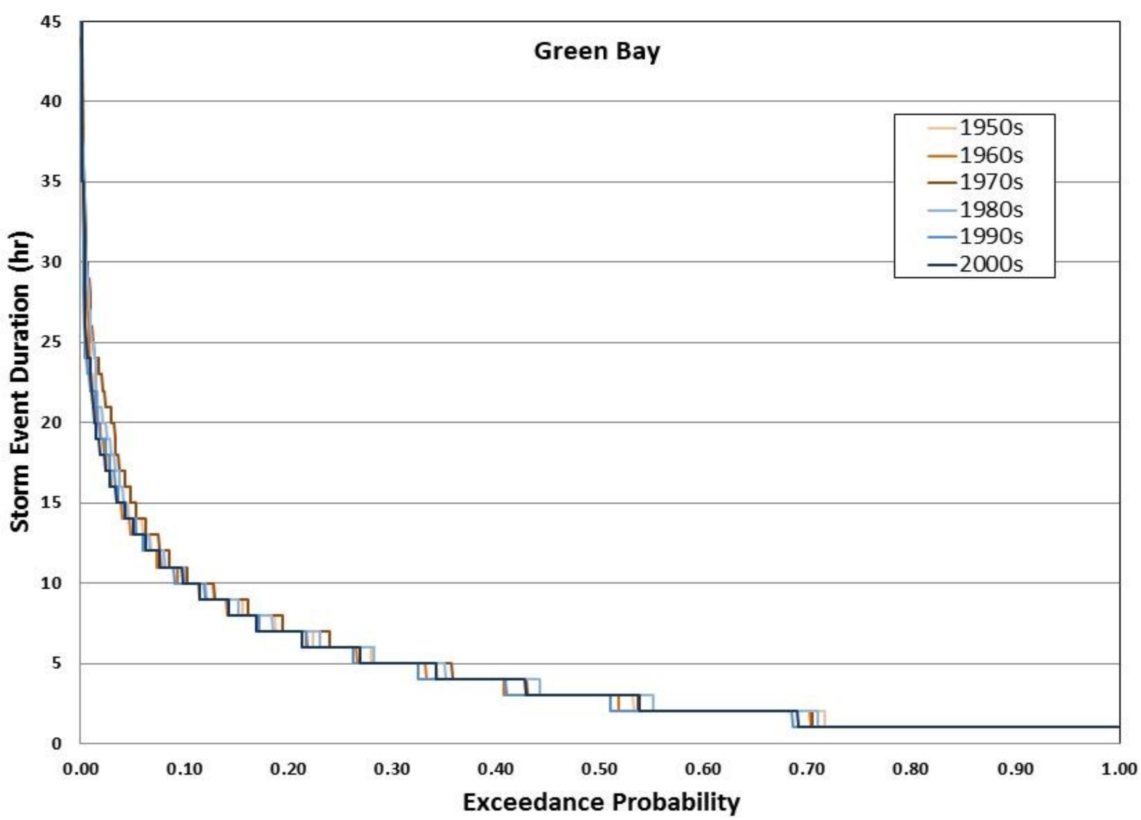



Green Bay
Storm Event Max Intensity (in)
Exceedance Probability
1980-2012
1948-1979
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

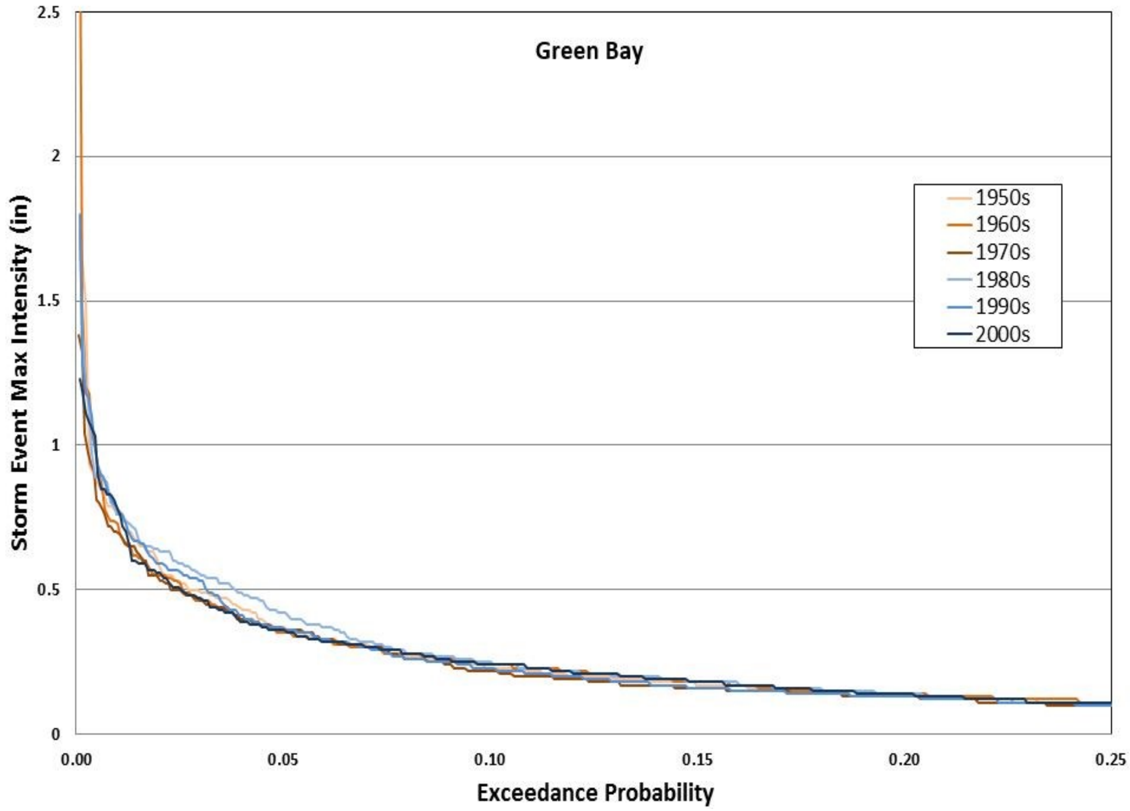

Green Bay
Storm Event Average Intensity (in)
Exceedance Probability
1980-2012
1948-1979
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

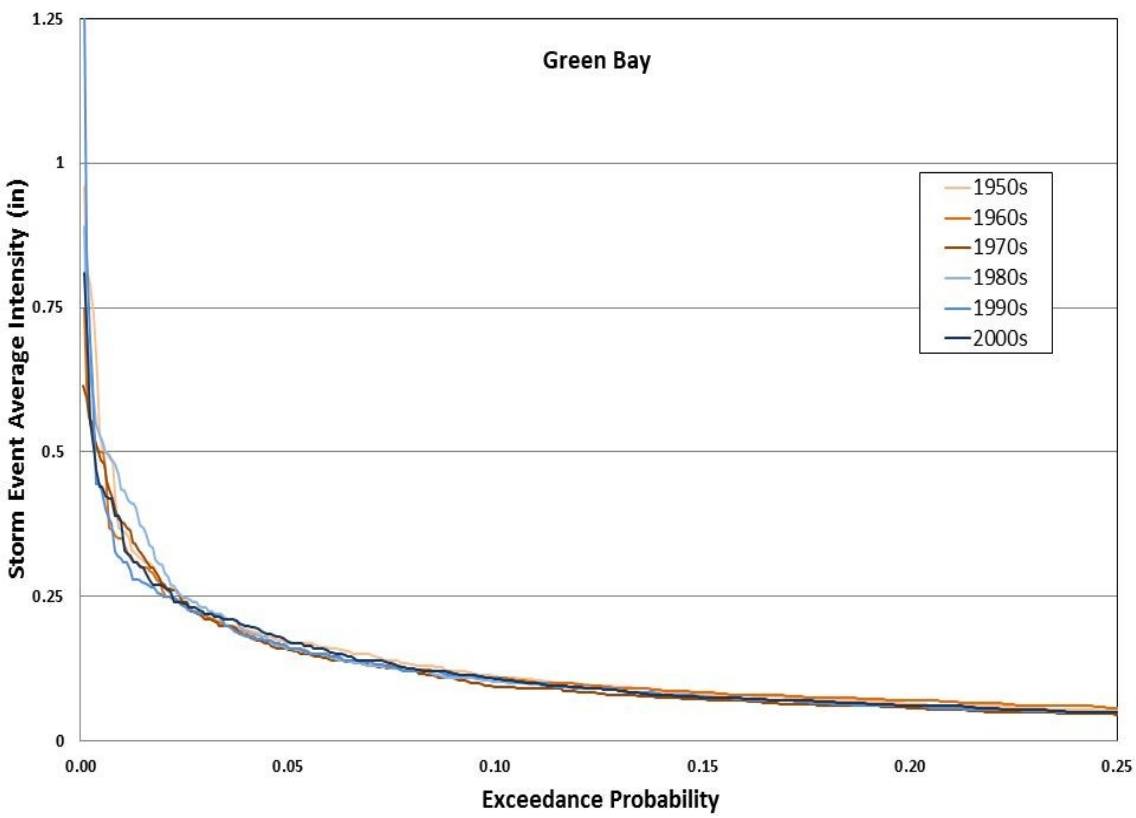


Green Bay
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0.00
0.05
0.10
0.15
0.20
0.25

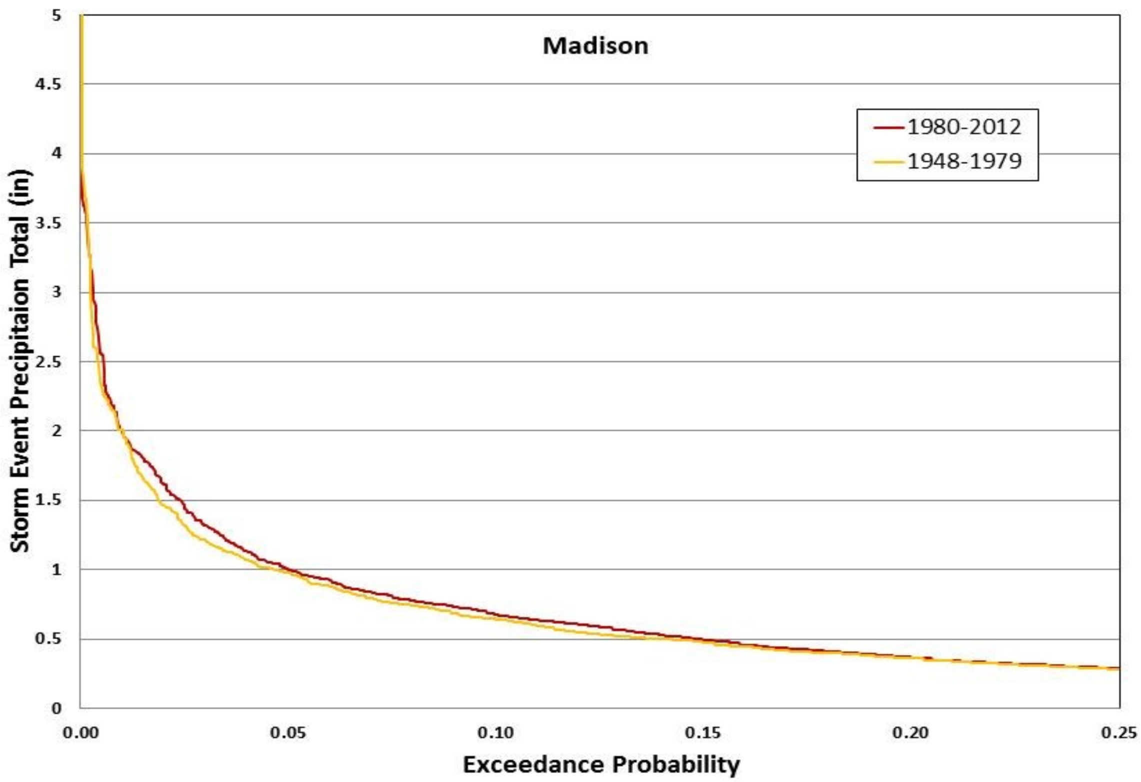


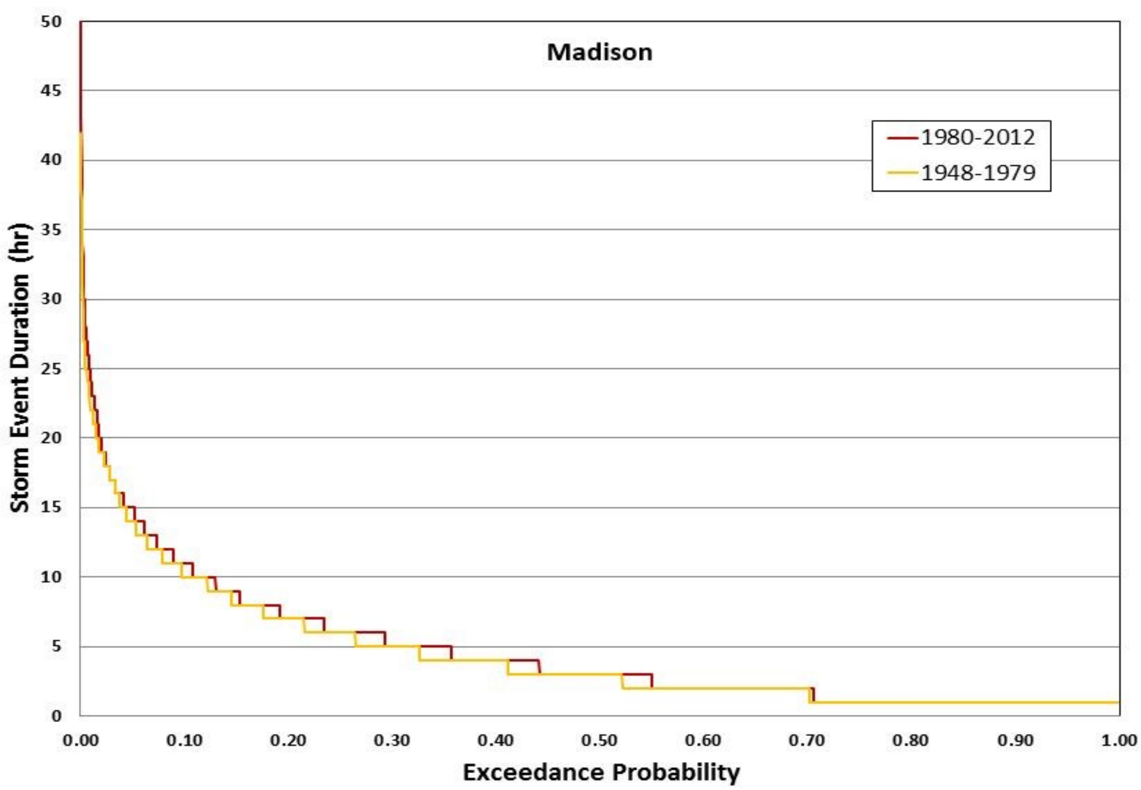
Green Bay
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

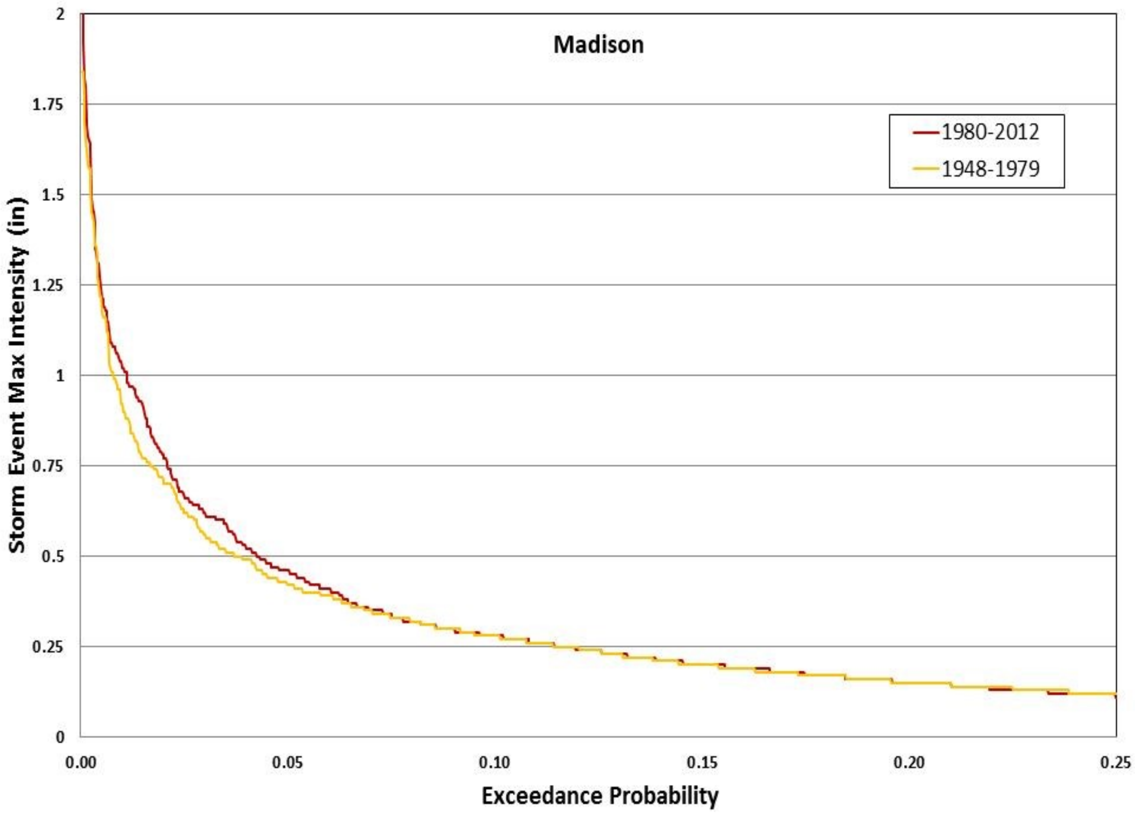

Green Bay
Storm Event Max Intensity (in)
Exceedance Probability
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s


Green Bay
Storm Event Average Intensity (in)
Exceedance Probability
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

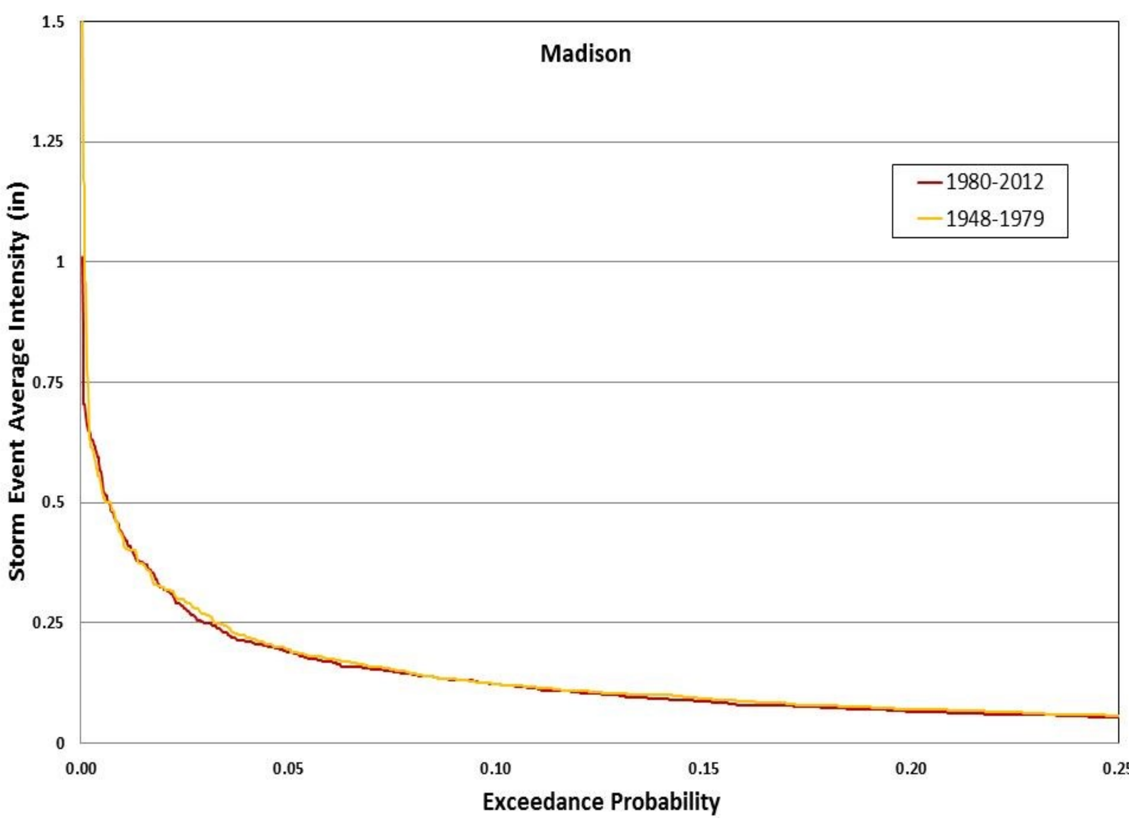
Appendix C-22. Exceedance probabilities of the characteristics of rainfall in Madison.



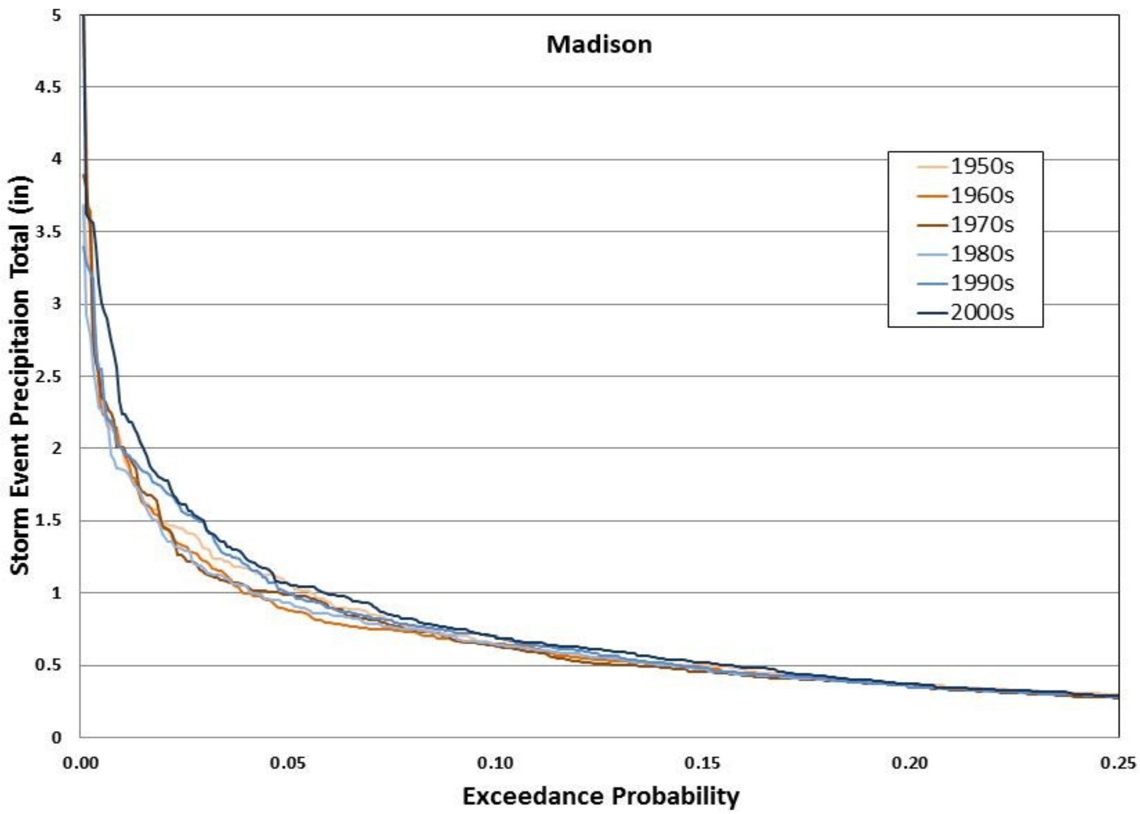




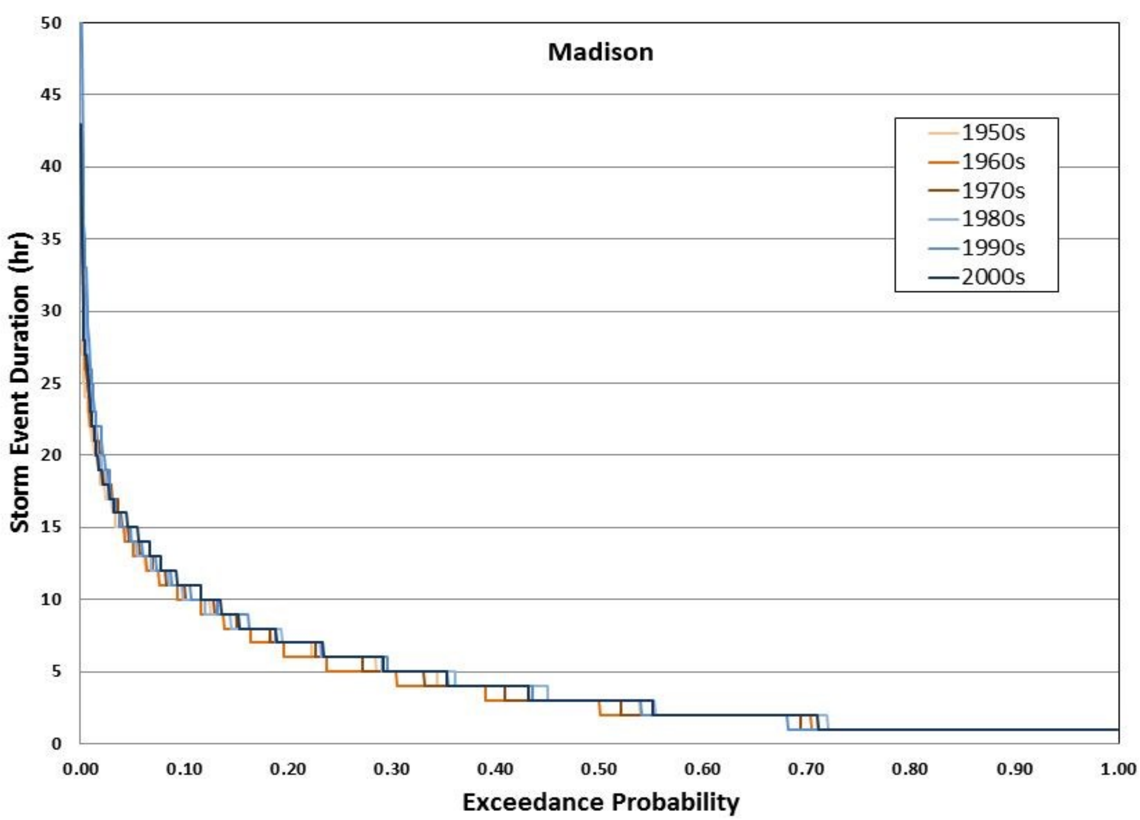
Madison
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25



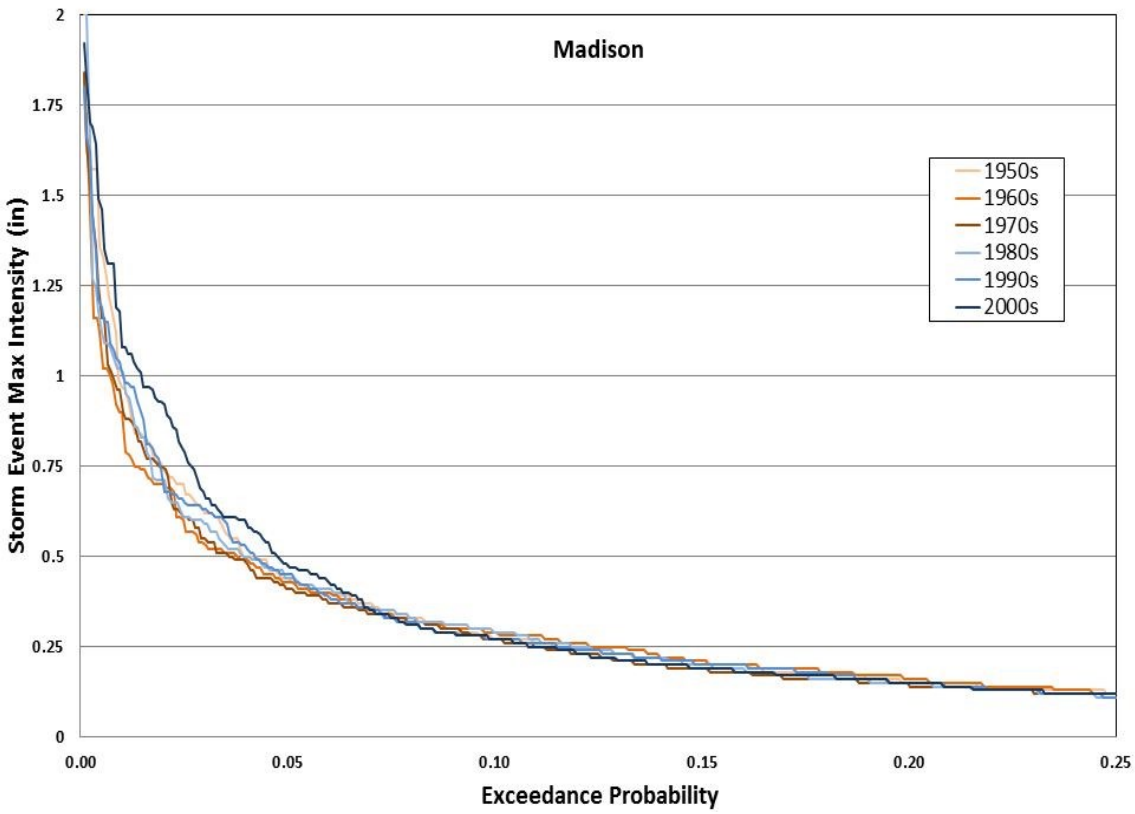
Madison
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25



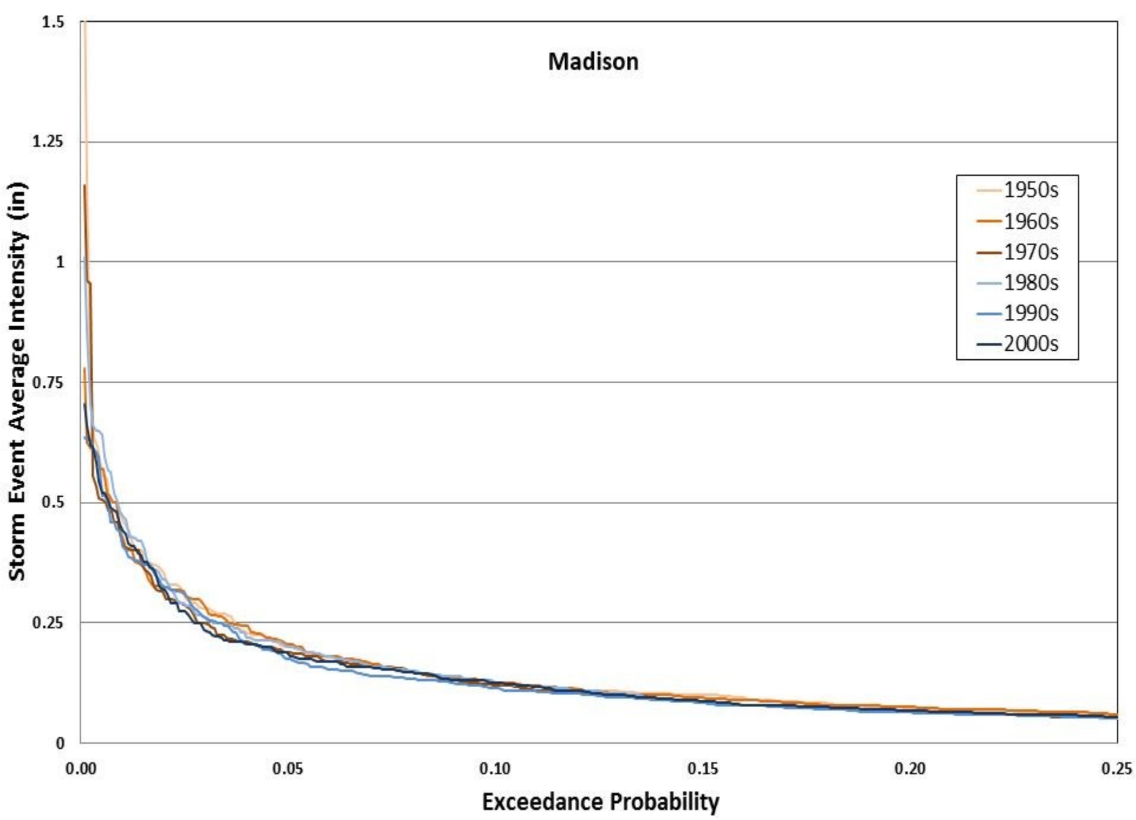
Madison
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.00
0.05
0.10
0.15
0.20
0.25



Madison
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
45
50
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

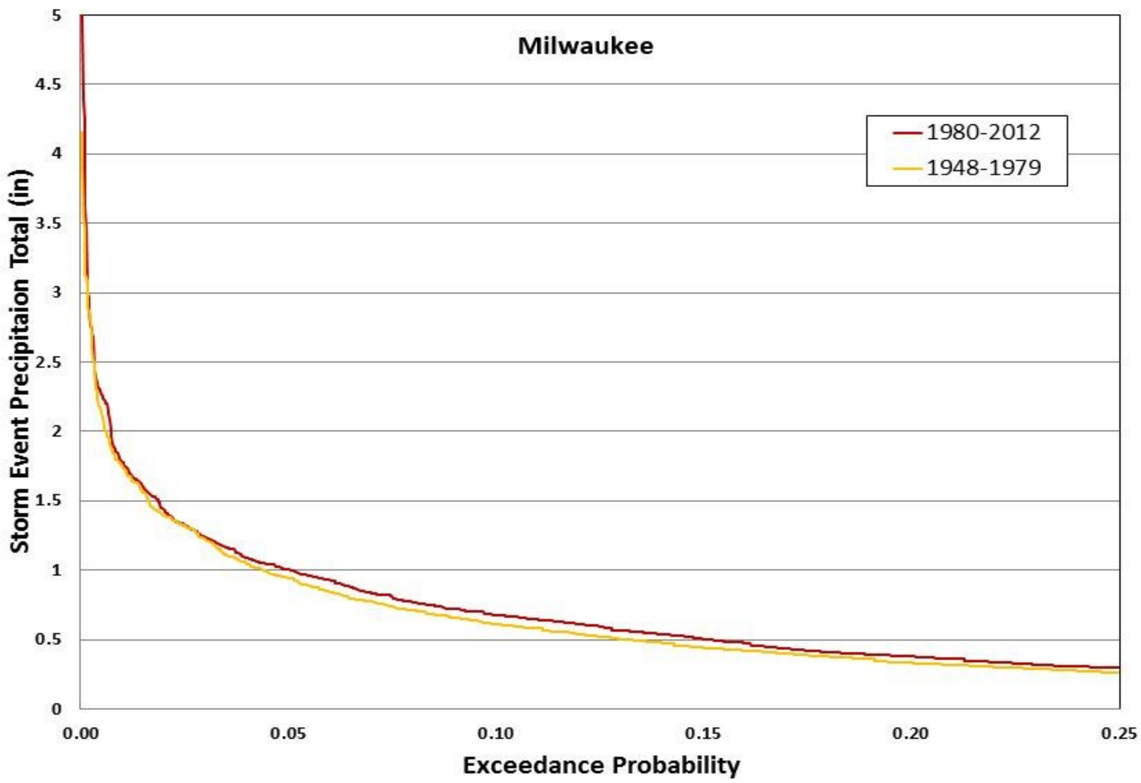


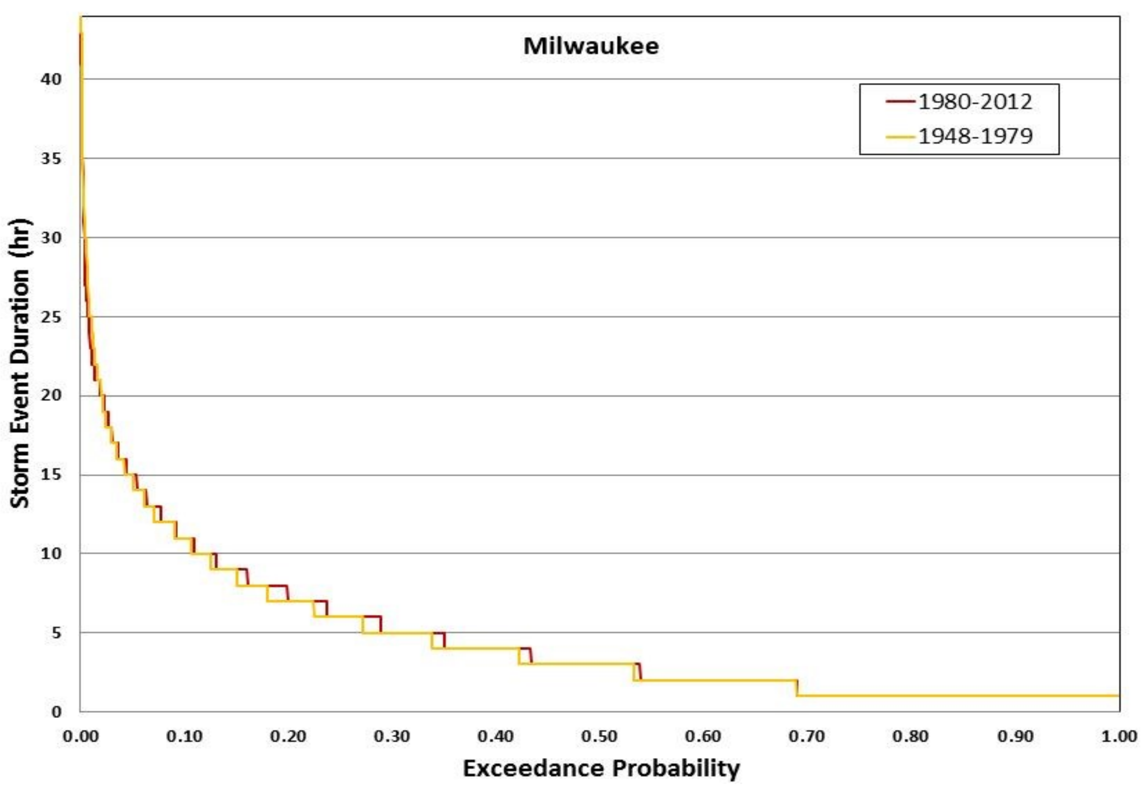
Madison
Storm Event Max Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

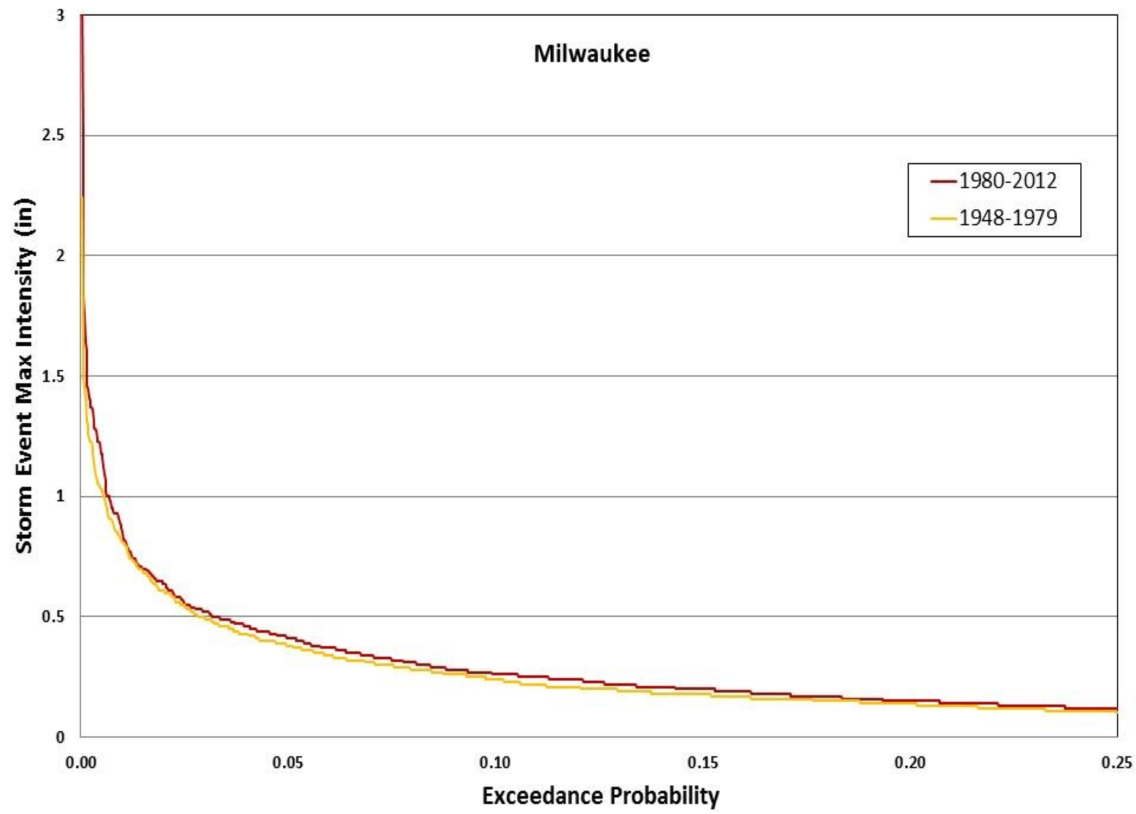


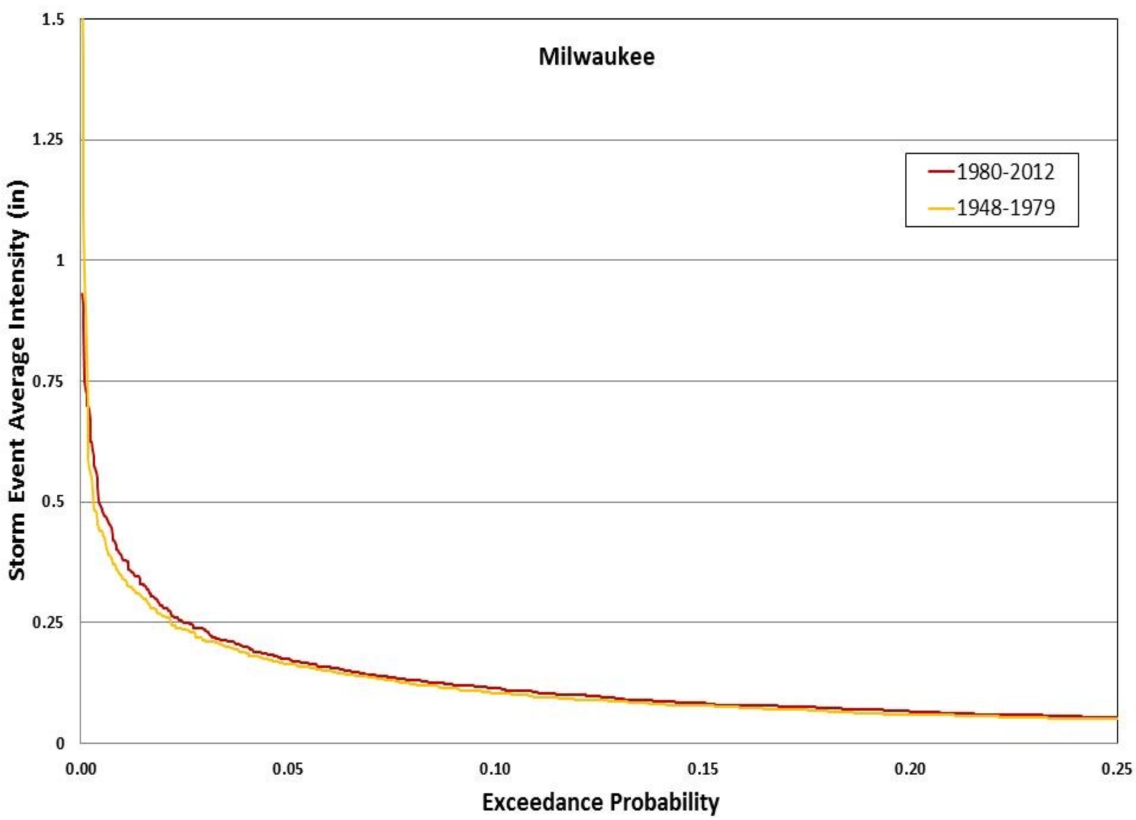
Madison
Storm Event Average Intensity (in)
Exceedance Probability
0
0.25
0.5
0.75
1
1.25
1.5
0.00
0.05
0.10
0.15
0.20
0.25
1950s
1960s
1970s
1980s
1990s
2000s

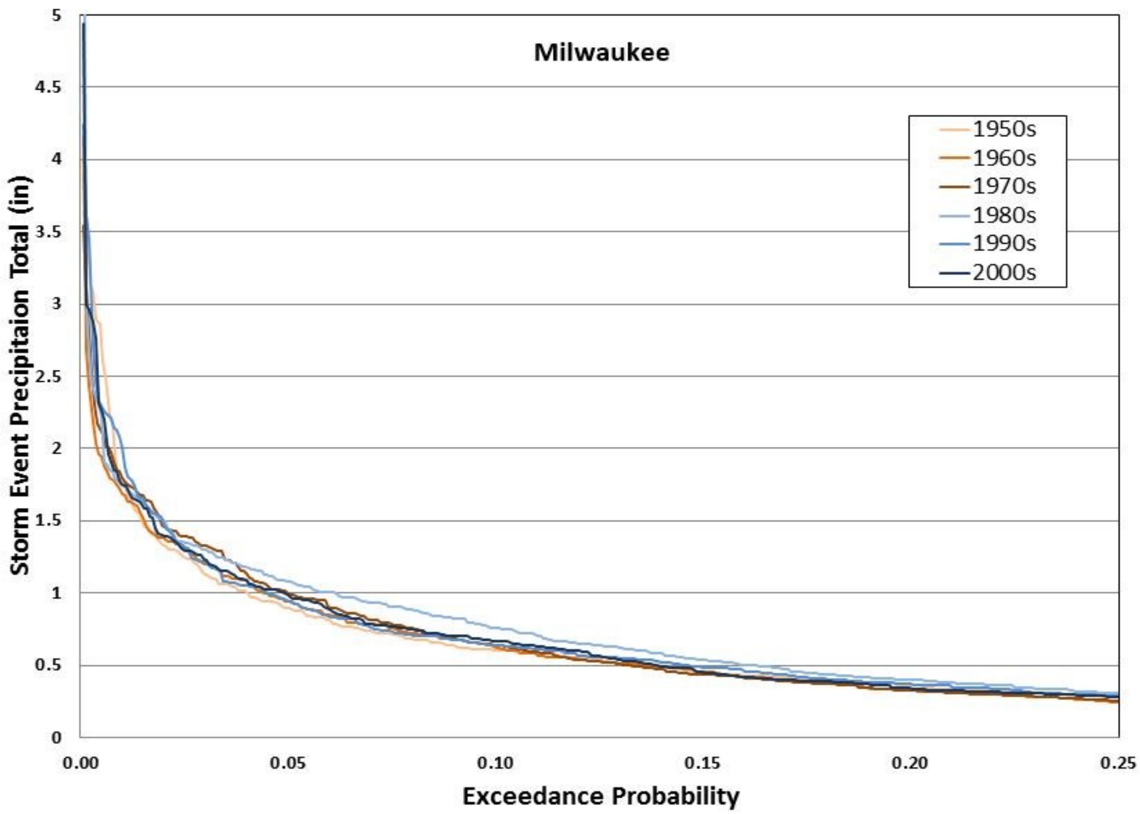
Appendix C-23. Exceedance probabilities of the characteristics of rainfall in Milwaukee.

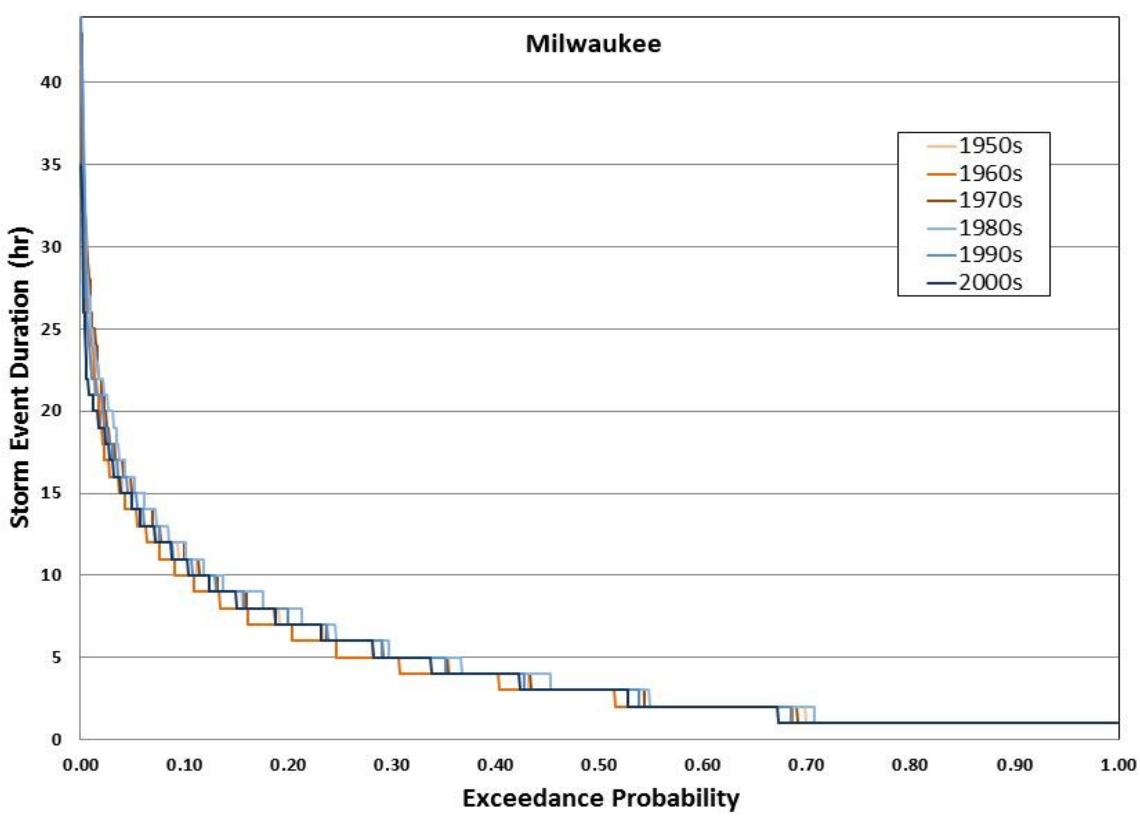


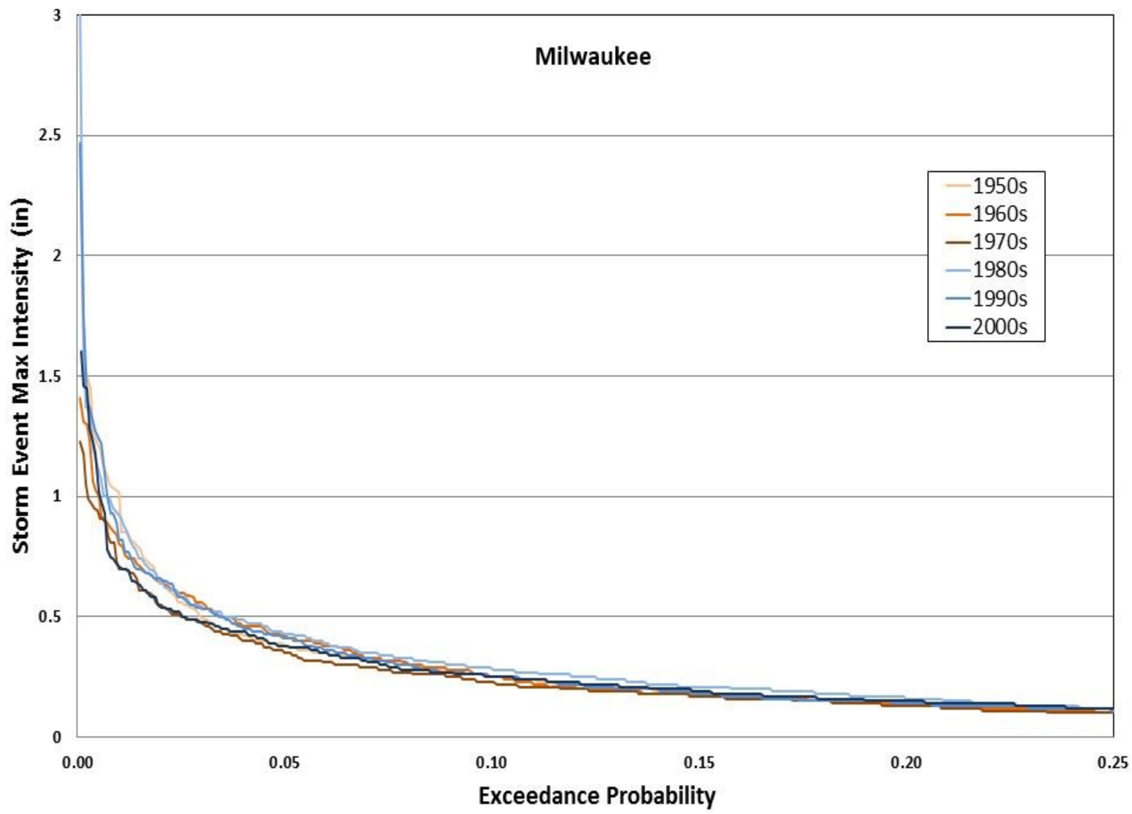



Milwaukee
1980-2012
1948-1979
Storm Event Max Intensity (in)
Exceedance Probability
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25

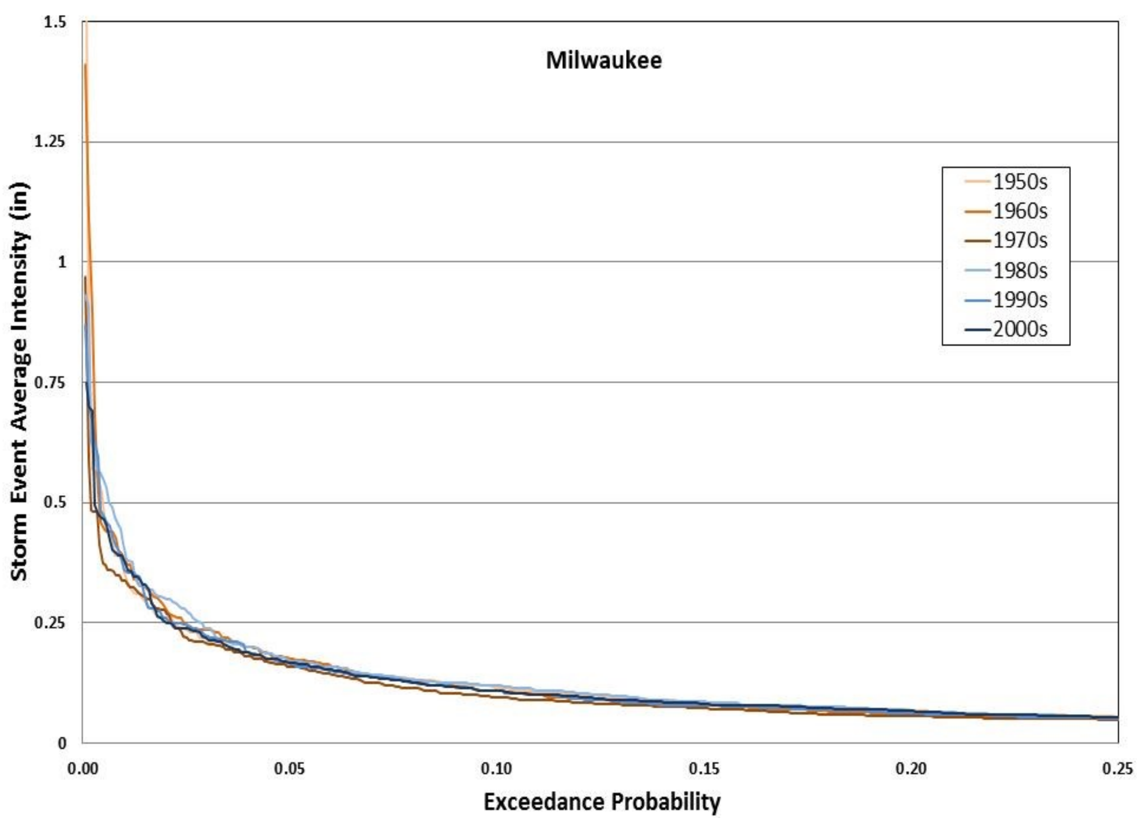

Milwaukee
1980-2012
1948-1979
Storm Event Average Intensity (in)
Exceedance Probability
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25


Milwaukee
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Precipitaion Total (in)
Exceedance Probability
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.00
0.05
0.10
0.15
0.20
0.25


Milwaukee
1950s
1960s
1970s
1980s
1990s
2000s
Storm Event Duration (hr)
Exceedance Probability
0
5
10
15
20
25
30
35
40
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00



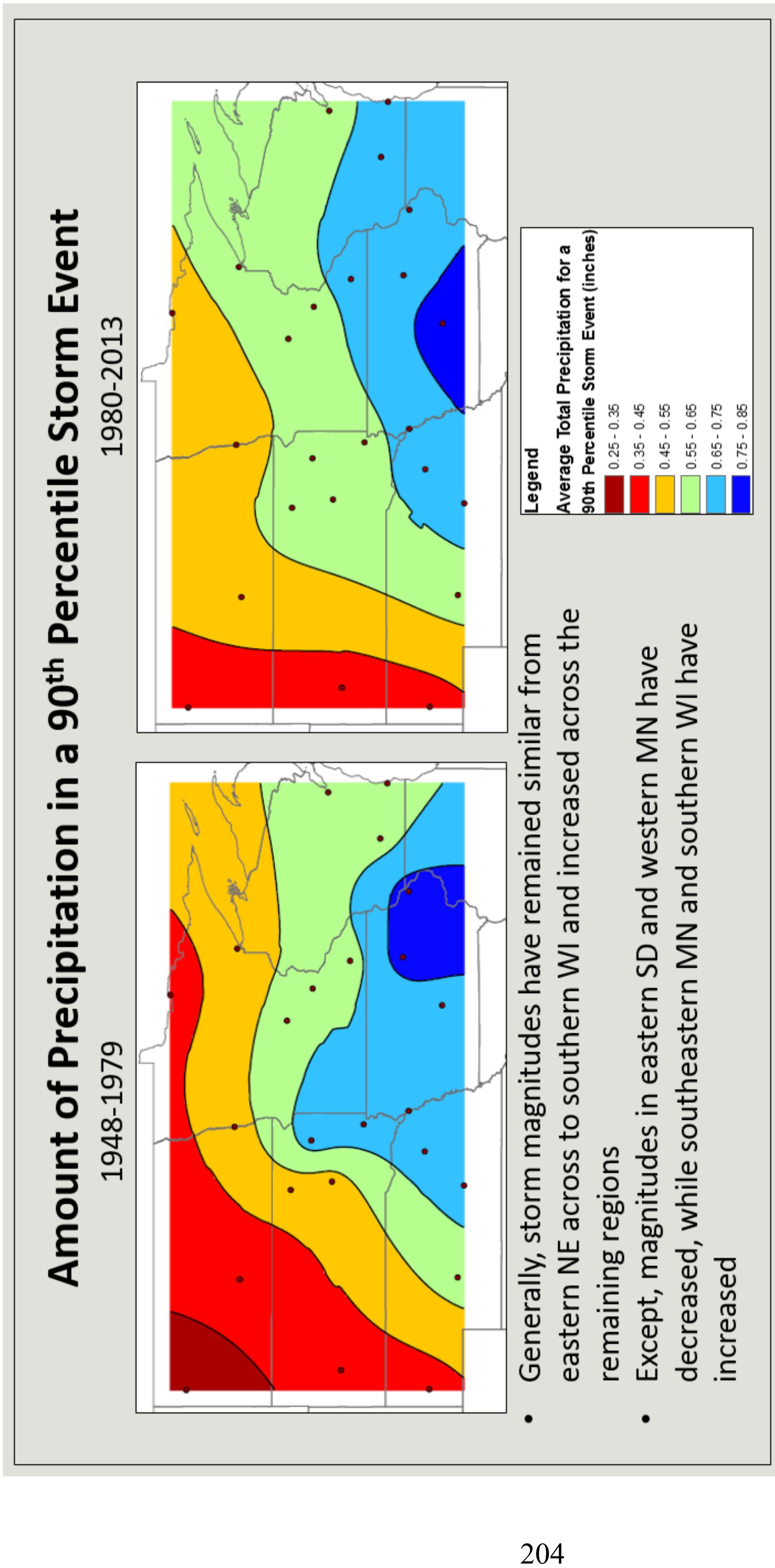
Milwaukee
Storm Event Max Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
3
2.5
2
1.5
1
0.5
0
0.00
0.05
0.10
0.15
0.20
0.25



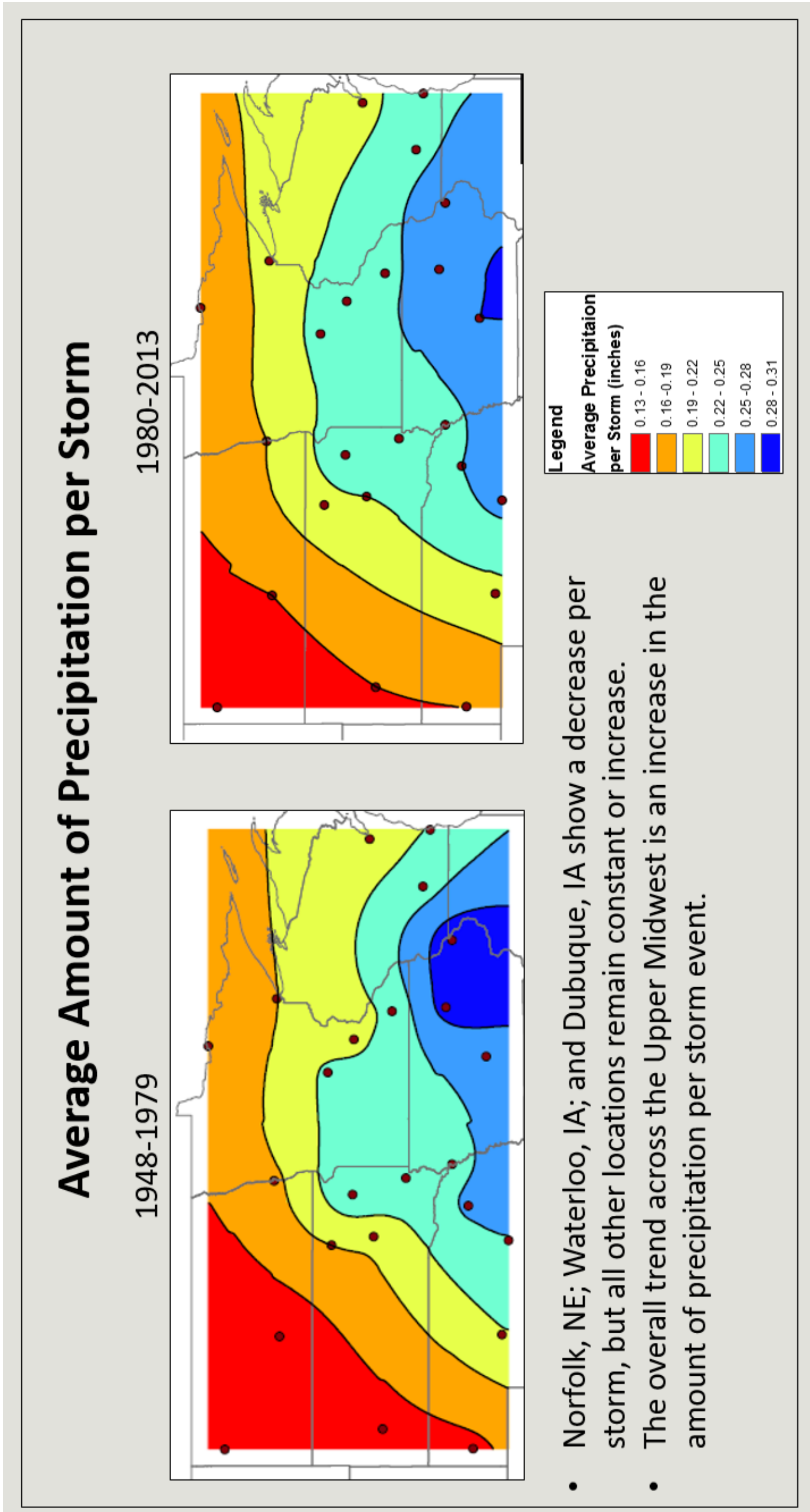
Milwaukee
Storm Event Average Intensity (in)
Exceedance Probability
1950s
1960s
1970s
1980s
1990s
2000s
1.5
1.25
1
0.75
0.5
0.25
0
0.00
0.05
0.10
0.15
0.20
0.25

Appendix D: Maps of precipitation characteristics and associated changes

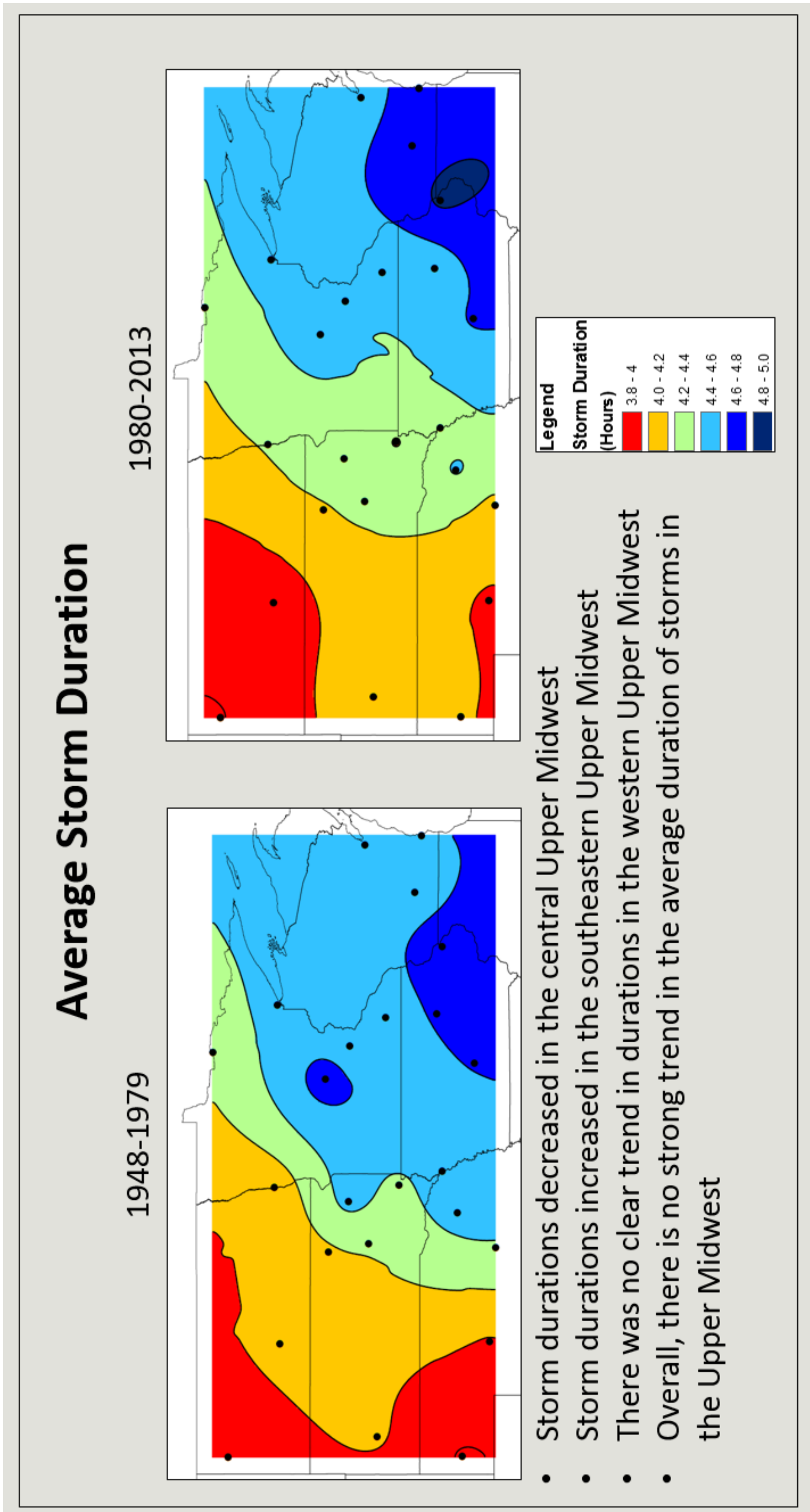
Appendix D-1. Highlights shifts in the amount of rainfall in 90th percentile storm events.



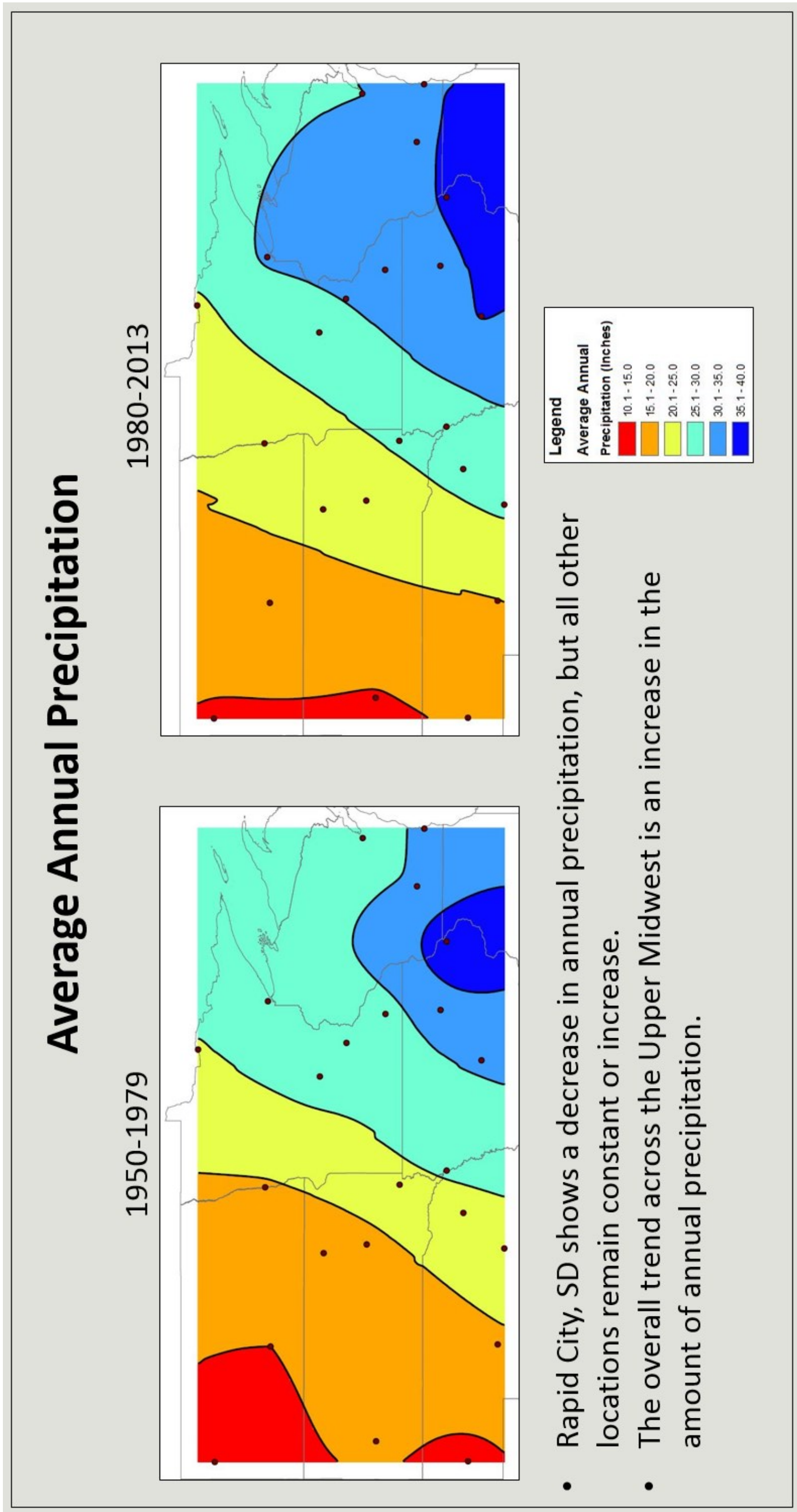
Appendix D-2. Highlights shifts in the average amount of rainfall per storm event.



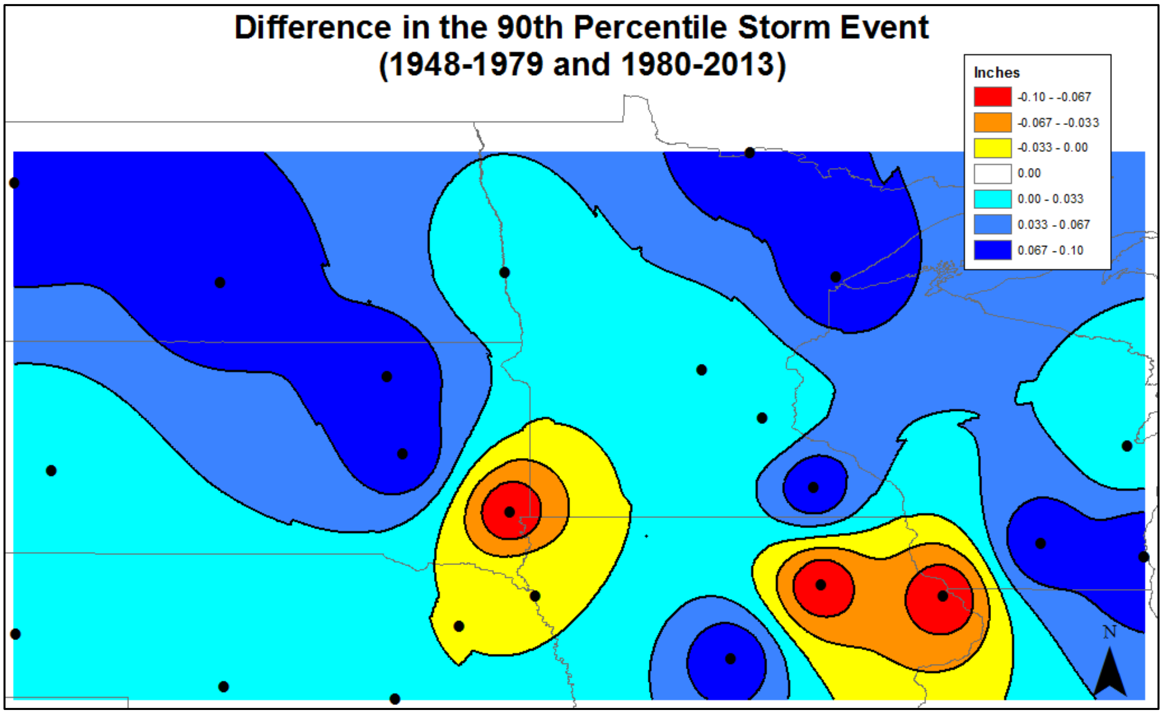
Appendix D-3. Highlights shifts in the average duration of storm events.



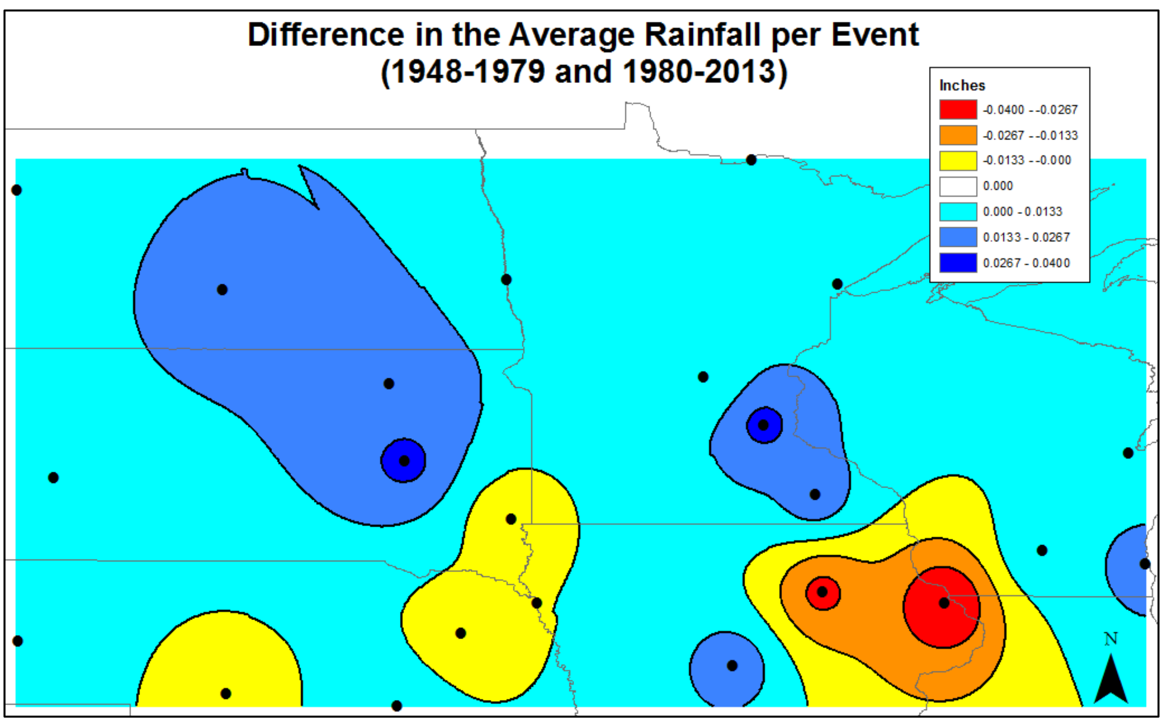
Appendix D-4. Highlights shifts in the average annual precipitation amounts.



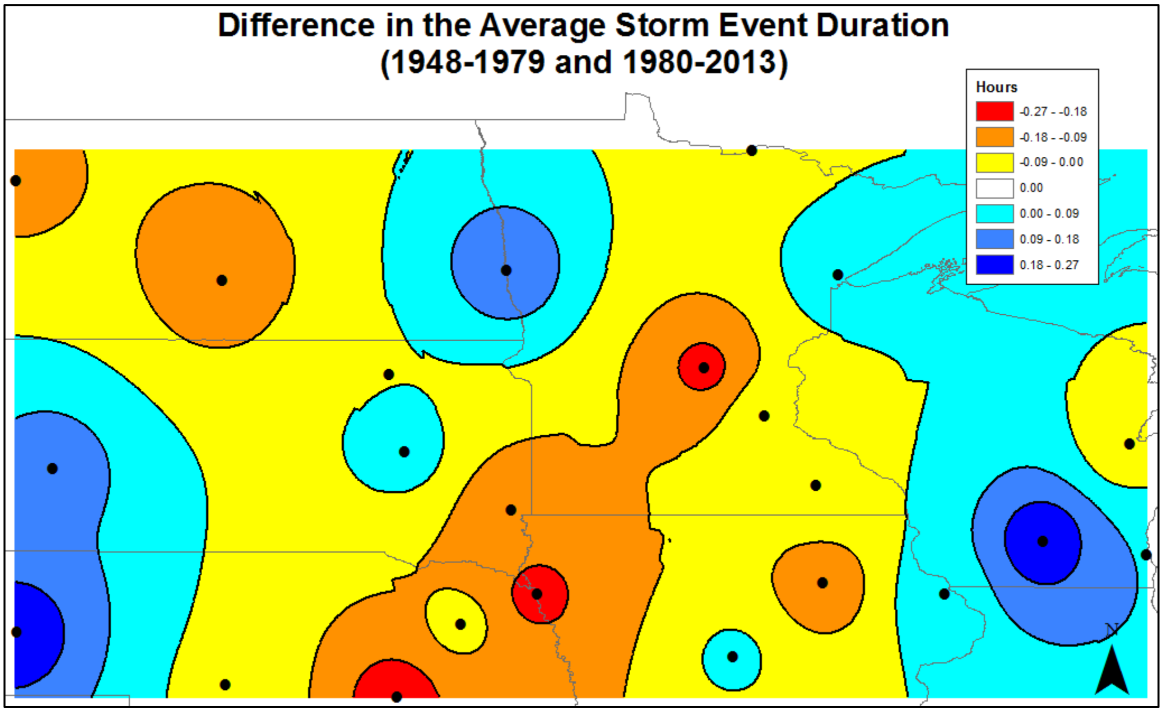
Appendix D-5. Highlights differences in the amount of rainfall in 90th percentile event.



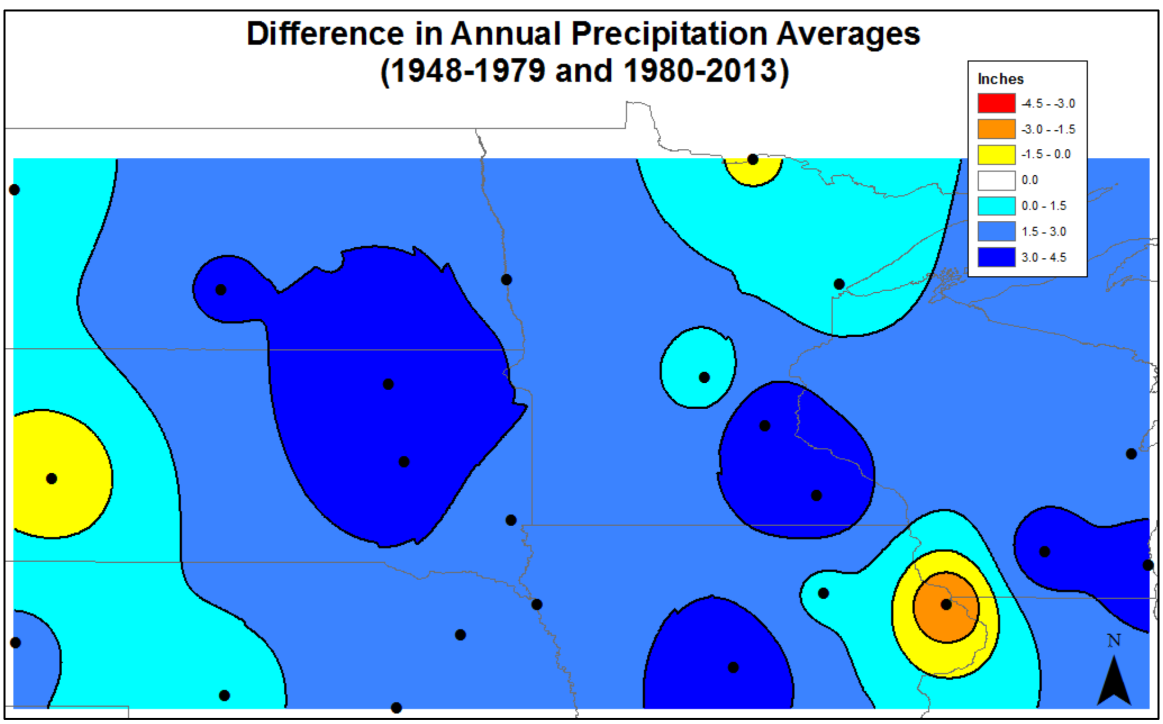
Appendix D-6. Highlights differences in the average amount of rainfall per storm event.



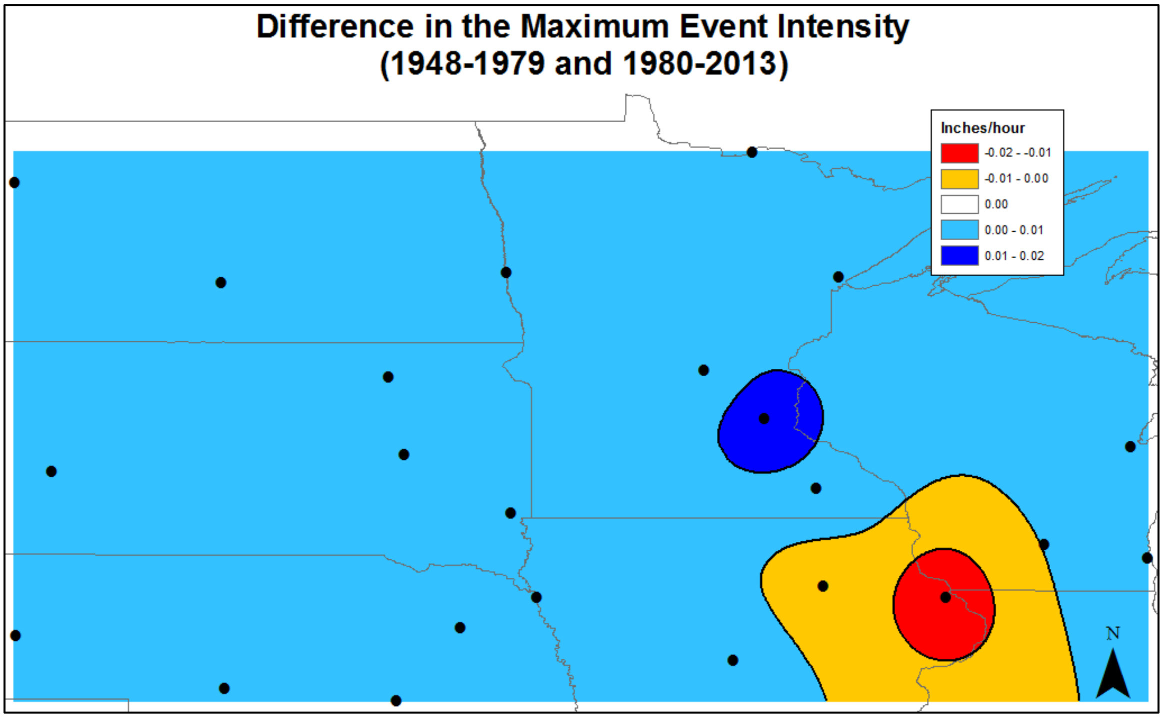
Appendix D-7. Highlights differences in the average duration of storm events.



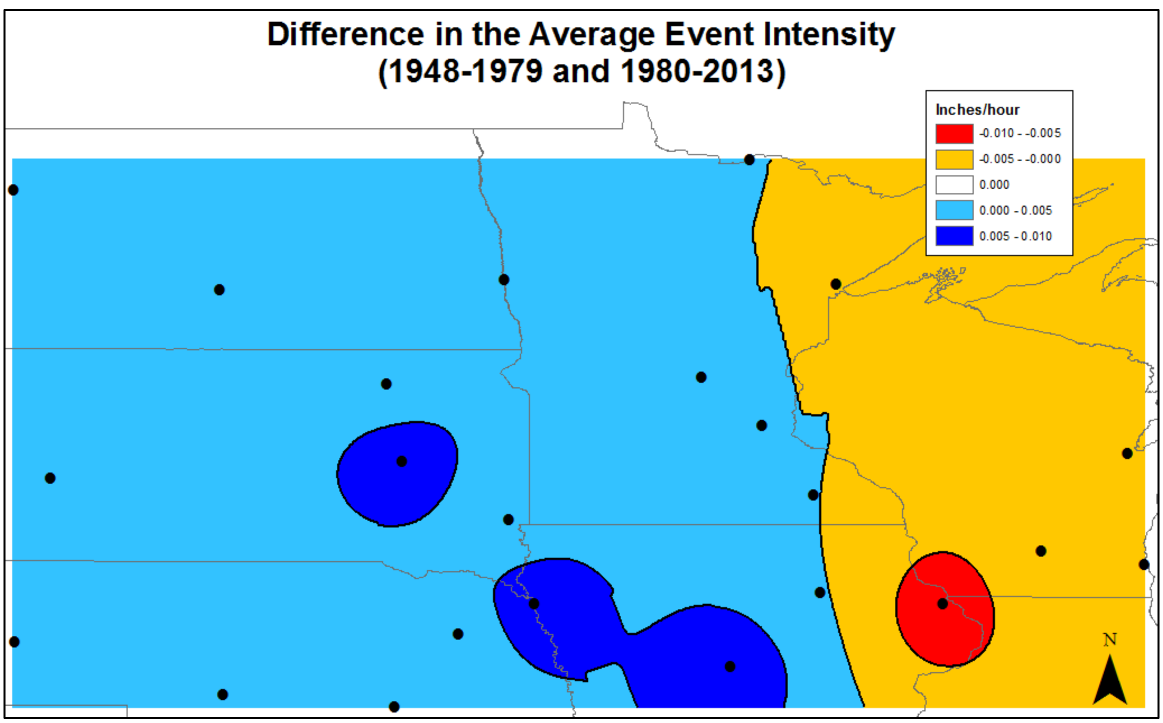
Appendix D-8. Highlights differences in the average annual precipitation amounts.



Appendix D-9. Highlights differences in the maximum event intensity.



Appendix D-10. Highlights differences in the average event intensity



Appendix E: Discharge and precipitation volume tables

Appendix E-1. Des Moines River Basin at Tracy, IA precipitation and flow volumes

Precipitation Volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.941	1.115	0.763	-0.352	-31.54%
Feb	0.972	0.880	1.067	0.187	21.23%
Mar	1.775	1.747	1.803	0.056	3.23%
Apr	2.851	2.790	2.912	0.122	4.38%
May	3.492	3.460	3.524	0.064	1.85%
Jun	3.708	3.752	3.662	-0.090	-2.41%
Jul	3.232	3.171	3.294	0.123	3.87%
Aug	3.229	2.857	3.610	0.753	26.35%
Sep	2.746	2.847	2.642	-0.205	-7.19%
Oct	1.987	1.888	2.088	0.201	10.63%
Nov	1.685	1.567	1.806	0.239	15.27%
Dec	1.071	1.063	1.080	0.018	1.68%
Annual	27.688	27.137	28.253	1.116	4.11%

Flow volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.159	0.133	0.186	0.054	40.30%
Feb	0.238	0.227	0.249	0.022	9.71%
Mar	0.622	0.624	0.620	-0.004	-0.68%
Apr	0.809	0.701	0.919	0.218	31.10%
May	0.794	0.639	0.953	0.314	49.10%
Jun	0.967	0.797	1.142	0.346	43.38%
Jul	0.813	0.467	1.169	0.702	150.22%
Aug	0.483	0.285	0.685	0.400	140.11%
Sep	0.287	0.210	0.366	0.156	74.35%
Oct	0.229	0.191	0.267	0.075	39.38%
Nov	0.242	0.184	0.301	0.118	64.04%
Dec	0.200	0.116	0.288	0.172	148.74%
Annual	5.843	4.573	7.144	2.571	56.22%

Appendix E-2. Root River Basin at Houston, MN precipitation and flow volumes

Precipitation Volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.080	0.079	0.082	0.003	3.53%
Feb	0.080	0.079	0.082	0.003	4.19%
Mar	0.161	0.162	0.160	-0.002	-1.05%
Apr	0.264	0.224	0.304	0.081	35.99%
May	0.323	0.319	0.328	0.009	2.96%
Jun	0.372	0.372	0.373	0.001	0.33%
Jul	0.308	0.293	0.324	0.031	10.60%
Aug	0.348	0.309	0.389	0.080	25.84%
Sep	0.295	0.296	0.295	-0.001	-0.39%
Oct	0.198	0.187	0.208	0.021	11.06%
Nov	0.149	0.133	0.166	0.032	24.17%
Dec	0.097	0.090	0.103	0.013	13.96%
Annual	2.677	2.543	2.814	0.271	10.66%

Flow volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.031	0.028	0.037	0.009	33.37%
Feb	0.035	0.029	0.045	0.016	54.49%
Mar	0.110	0.113	0.106	-0.008	-6.76%
Apr	0.097	0.083	0.120	0.037	44.31%
May	0.073	0.056	0.101	0.045	81.01%
Jun	0.081	0.063	0.109	0.046	72.14%
Jul	0.067	0.051	0.093	0.041	80.79%
Aug	0.057	0.044	0.079	0.035	80.03%
Sep	0.048	0.039	0.063	0.024	62.25%
Oct	0.043	0.036	0.056	0.020	55.56%
Nov	0.040	0.033	0.052	0.019	56.72%
Dec	0.034	0.028	0.046	0.018	66.02%
Annual	0.698	0.603	0.871	0.268	44.52%

Appendix E-3. North Loup River Basin at Taylor, NE precipitation and flow volumes

Precipitation Volume (km^3)

	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.085	0.083	0.087	0.005	5.69%
Feb	0.111	0.100	0.122	0.022	22.11%
Mar	0.222	0.183	0.261	0.078	42.67%
Apr	0.408	0.344	0.473	0.129	37.34%
May	0.572	0.538	0.606	0.068	12.70%
Jun	0.598	0.609	0.586	-0.023	-3.76%
Jul	0.410	0.393	0.428	0.034	8.74%
Aug	0.429	0.389	0.471	0.082	20.97%
Sep	0.318	0.324	0.312	-0.013	-3.87%
Oct	0.249	0.198	0.302	0.104	52.52%
Nov	0.134	0.095	0.173	0.078	81.92%
Dec	0.095	0.087	0.102	0.015	17.33%
Annual	3.630	3.344	3.923	0.579	17.33%

Flow volume (km^3)

	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.038	0.036	0.040	0.005	12.95%
Feb	0.039	0.037	0.042	0.005	14.33%
Mar	0.048	0.046	0.050	0.004	9.41%
Apr	0.045	0.042	0.048	0.005	12.64%
May	0.043	0.039	0.047	0.008	20.36%
Jun	0.037	0.034	0.040	0.006	17.20%
Jul	0.027	0.024	0.030	0.006	26.60%
Aug	0.023	0.021	0.025	0.004	19.15%
Sep	0.029	0.027	0.031	0.004	12.92%
Oct	0.038	0.034	0.041	0.007	20.28%
Nov	0.038	0.036	0.041	0.005	13.51%
Dec	0.038	0.035	0.040	0.006	16.44%
Annual	0.443	0.410	0.475	0.065	15.75%

Appendix E-4. Cannonball River Basin at Breien, ND precipitation and flow volumes

Precipitation Volume (km^3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.101	0.105	0.097	-0.008	-7.22%
Feb	0.107	0.103	0.111	0.007	6.92%
Mar	0.176	0.158	0.195	0.036	23.00%
Apr	0.389	0.395	0.384	-0.012	-2.95%
May	0.667	0.631	0.704	0.073	11.58%
Jun	0.922	0.971	0.870	-0.101	-10.40%
Jul	0.718	0.656	0.780	0.124	18.86%
Aug	0.480	0.484	0.476	-0.008	-1.61%
Sep	0.379	0.357	0.401	0.044	12.28%
Oct	0.280	0.220	0.341	0.122	55.42%
Nov	0.135	0.126	0.144	0.019	15.04%
Dec	0.095	0.083	0.108	0.025	30.33%
Annual	4.449	4.290	4.612	0.322	7.51%

Flow volume (km3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.0012	0.0012	0.0013	0.0002	13.42%
Feb	0.0047	0.0034	0.0061	0.0027	79.52%
Mar	0.0588	0.0609	0.0567	-0.0043	-6.99%
Apr	0.0679	0.0676	0.0682	0.0006	0.86%
May	0.0314	0.0225	0.0405	0.0180	80.15%
Jun	0.0277	0.0333	0.0220	-0.0113	-34.02%
Jul	0.0144	0.0158	0.0129	-0.0028	-17.89%
Aug	0.0058	0.0042	0.0073	0.0031	74.09%
Sep	0.0025	0.0022	0.0028	0.0006	29.26%
Oct	0.0036	0.0015	0.0057	0.0043	289.14%
Nov	0.0023	0.0015	0.0031	0.0016	106.27%
Dec	0.0015	0.0009	0.0021	0.0012	132.14%
Annual	0.2217	0.2149	0.2287	0.0138	6.43%

Appendix E-5. Missouri River Basin at Bismarck, ND precipitation and flow volumes

Precipitation Volume (km3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	5.16	5.31	5.00	-0.31	-5.78%
Feb	5.33	5.39	5.26	-0.13	-2.49%
Mar	8.74	8.24	9.26	1.02	12.33%
Apr	17.41	18.18	16.61	-1.57	-8.62%
May	29.39	28.07	30.75	2.68	9.54%
Jun	41.12	43.57	38.62	-4.95	-11.37%
Jul	32.71	29.11	36.41	7.30	25.08%
Aug	25.37	23.85	26.94	3.09	12.96%
Sep	18.77	17.38	20.20	2.82	16.21%
Oct	13.90	10.73	17.15	6.42	59.81%
Nov	7.11	6.74	7.49	0.75	11.19%
Dec	5.32	4.66	6.01	1.35	28.94%
Annual	210.35	201.23	219.69	18.46	9.18%

Flow volume (km3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	1.38	1.16	1.66	0.50	42.67%
Feb	1.33	1.13	1.58	0.45	39.53%
Mar	1.56	1.58	1.52	-0.06	-3.81%
Apr	1.74	2.00	1.42	-0.58	-28.97%
May	1.73	1.81	1.63	-0.18	-9.96%
Jun	2.27	2.56	1.90	-0.67	-25.98%
Jul	2.18	2.16	2.20	0.04	1.79%
Aug	1.90	1.74	2.10	0.36	20.48%
Sep	1.65	1.58	1.73	0.15	9.33%
Oct	1.60	1.69	1.48	-0.21	-12.70%
Nov	1.41	1.38	1.45	0.07	4.86%
Dec	1.30	1.14	1.50	0.35	30.87%
Annual	19.95	19.95	19.96	0.02	0.09%

Appendix E-6. White River Basin at Oacoma, SD precipitation and flow volumes

Precipitation Volume (km3)

	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.30	0.30	0.31	0.01	4.65%
Feb	0.38	0.39	0.38	-0.01	-3.07%
Mar	0.76	0.65	0.87	0.22	33.05%
Apr	1.50	1.45	1.55	0.10	6.74%
May	1.98	1.92	2.03	0.11	5.61%
Jun	2.37	2.39	2.34	-0.06	-2.49%
Jul	1.53	1.42	1.64	0.22	15.49%
Aug	1.40	1.33	1.48	0.14	10.53%
Sep	1.11	1.01	1.21	0.20	19.83%
Oct	0.91	0.74	1.08	0.35	46.71%
Nov	0.44	0.41	0.47	0.05	13.33%
Dec	0.29	0.29	0.29	0.00	-1.47%
Annual	12.98	12.33	13.65	1.32	10.72%

Flow volume (km3)

	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.0066	0.0046	0.0087	0.0041	89.78%
Feb	0.0210	0.0127	0.0296	0.0169	133.94%
Mar	0.1016	0.1018	0.1015	-0.0004	-0.36%
Apr	0.0826	0.0721	0.0934	0.0214	29.67%
May	0.1031	0.0950	0.1114	0.0164	17.25%
Jun	0.0987	0.1015	0.0958	-0.0056	-5.56%
Jul	0.0435	0.0401	0.0471	0.0070	17.45%
Aug	0.0245	0.0204	0.0286	0.0082	40.32%
Sep	0.0148	0.0140	0.0157	0.0017	12.41%
Oct	0.0163	0.0108	0.0220	0.0113	104.29%
Nov	0.0129	0.0091	0.0169	0.0078	85.98%
Dec	0.0077	0.0053	0.0101	0.0048	88.95%
Annual	0.5335	0.4873	0.5809	0.0936	19.21%

Appendix E-7. Baraboo River Basin at Baraboo, WI precipitation and flow volumes

Precipitation Volume (km3)

	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.047	0.048	0.046	-0.002	-4.64%
Feb	0.046	0.044	0.048	0.003	7.49%
Mar	0.080	0.077	0.083	0.007	8.78%
Apr	0.131	0.118	0.145	0.027	22.70%
May	0.144	0.138	0.149	0.011	7.97%
Jun	0.182	0.176	0.188	0.012	6.92%
Jul	0.152	0.139	0.166	0.026	18.87%
Aug	0.155	0.144	0.167	0.024	16.64%
Sep	0.142	0.149	0.134	-0.016	-10.46%
Oct	0.093	0.089	0.097	0.008	8.91%
Nov	0.084	0.076	0.091	0.015	19.54%
Dec	0.056	0.055	0.057	0.001	2.64%
Annual	1.311	1.254	1.370	0.117	9.30%

Flow volume (km3)

	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.020	0.018	0.022	0.004	20.63%
Feb	0.023	0.019	0.026	0.007	34.61%
Mar	0.057	0.061	0.053	-0.008	-12.95%
Apr	0.056	0.054	0.058	0.005	8.55%
May	0.036	0.029	0.042	0.012	41.60%
Jun	0.035	0.029	0.041	0.012	42.89%
Jul	0.028	0.021	0.033	0.012	57.50%
Aug	0.023	0.016	0.028	0.012	75.51%
Sep	0.024	0.019	0.028	0.008	43.09%
Oct	0.022	0.020	0.024	0.004	22.20%
Nov	0.024	0.021	0.027	0.006	30.24%
Dec	0.020	0.015	0.024	0.009	59.41%
Annual	0.368	0.322	0.406	0.084	26.07%

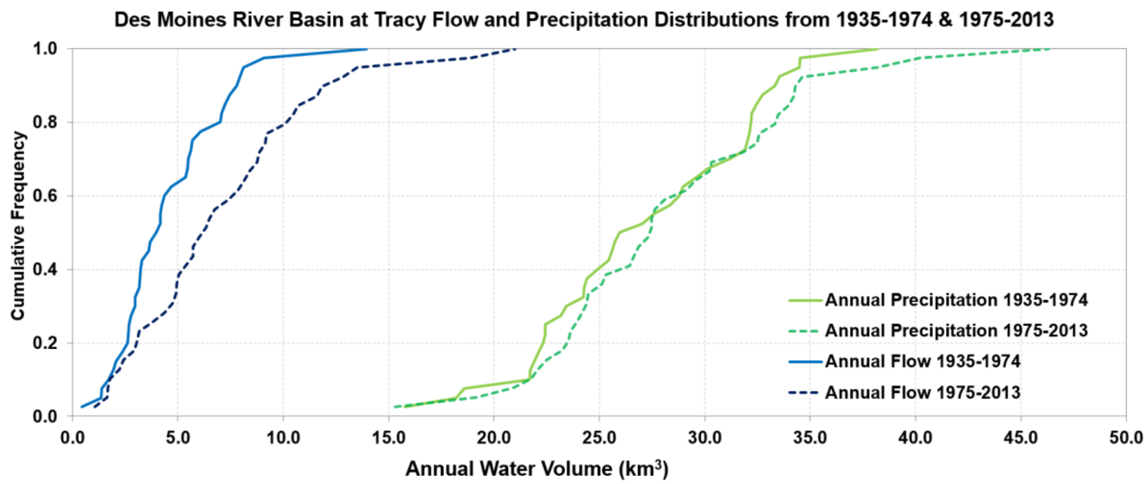
Appendix E-8. Chippewa River Basin at Durand, WI precipitation and flow volumes

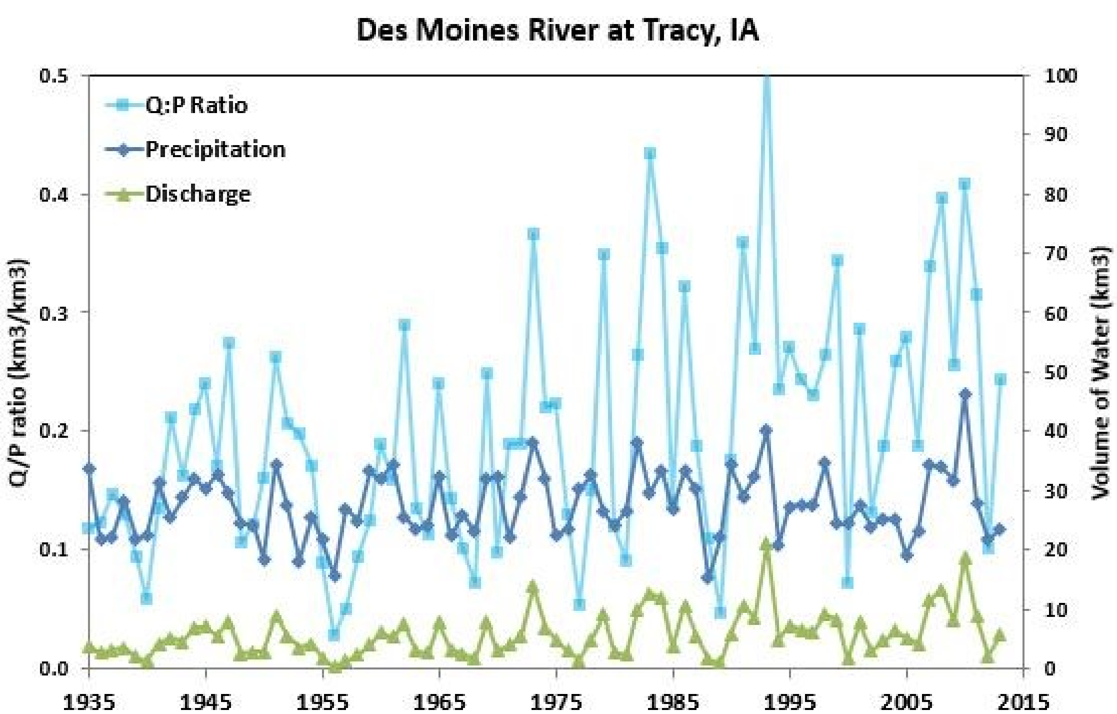
Precipitation Volume (km3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.62	0.61	0.63	0.02	3.54%
Feb	0.54	0.53	0.54	0.01	1.30%
Mar	1.03	0.98	1.08	0.10	10.17%
Apr	1.56	1.48	1.65	0.18	12.03%
May	2.20	2.34	2.05	-0.29	-12.28%
Jun	2.65	2.76	2.55	-0.21	-7.72%
Jul	2.35	2.34	2.36	0.02	0.80%
Aug	2.48	2.48	2.49	0.00	0.09%
Sep	2.22	2.15	2.29	0.14	6.51%
Oct	1.53	1.35	1.71	0.36	26.95%
Nov	1.08	1.03	1.14	0.12	11.25%
Dec	0.71	0.70	0.73	0.03	3.64%
Annual	18.98	18.75	19.22	0.47	2.51%

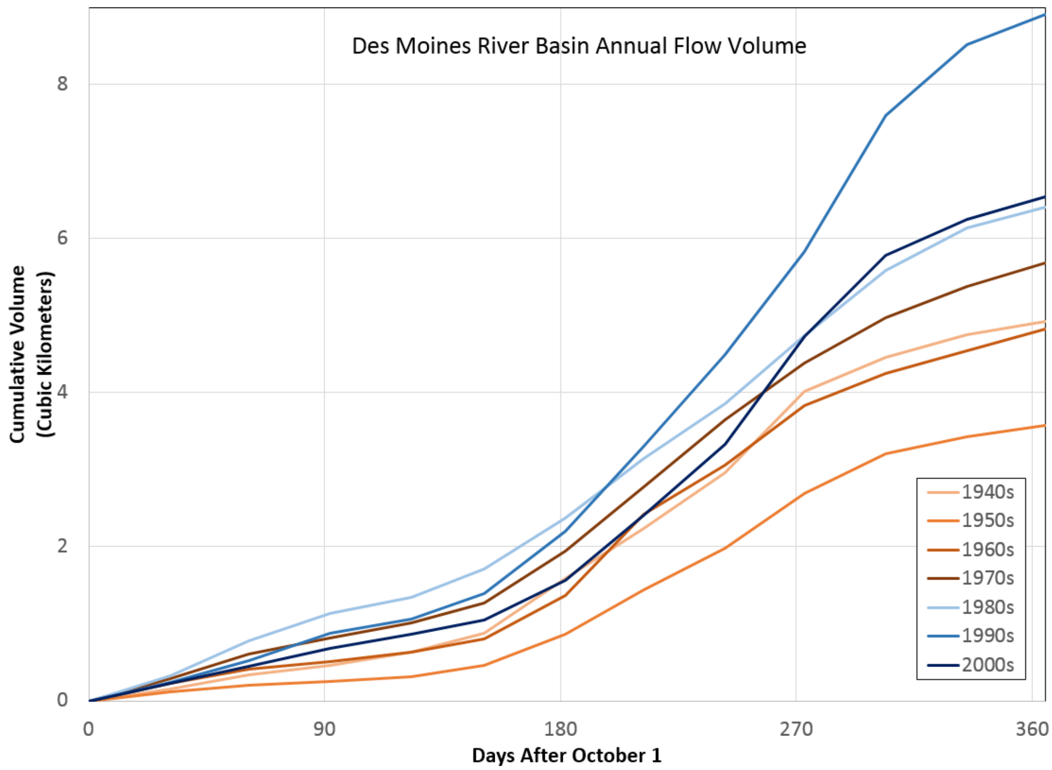
Flow volume (km3)					
	1935-2013 Average	1935-1974 Average	1975-2013 Average	Difference	% Change
Jan	0.36	0.35	0.36	0.01	2.87%
Feb	0.34	0.33	0.35	0.01	3.45%
Mar	0.72	0.74	0.70	-0.04	-5.21%
Apr	1.20	1.18	1.22	0.04	3.68%
May	0.83	0.87	0.80	-0.08	-8.64%
Jun	0.70	0.78	0.63	-0.15	-19.42%
Jul	0.48	0.51	0.46	-0.05	-9.73%
Aug	0.41	0.38	0.43	0.05	13.31%
Sep	0.51	0.50	0.52	0.01	2.58%
Oct	0.50	0.45	0.56	0.11	25.11%
Nov	0.49	0.47	0.51	0.04	8.67%
Dec	0.40	0.39	0.42	0.03	8.06%
Annual	6.96	6.96	6.96	0.00	0.00%

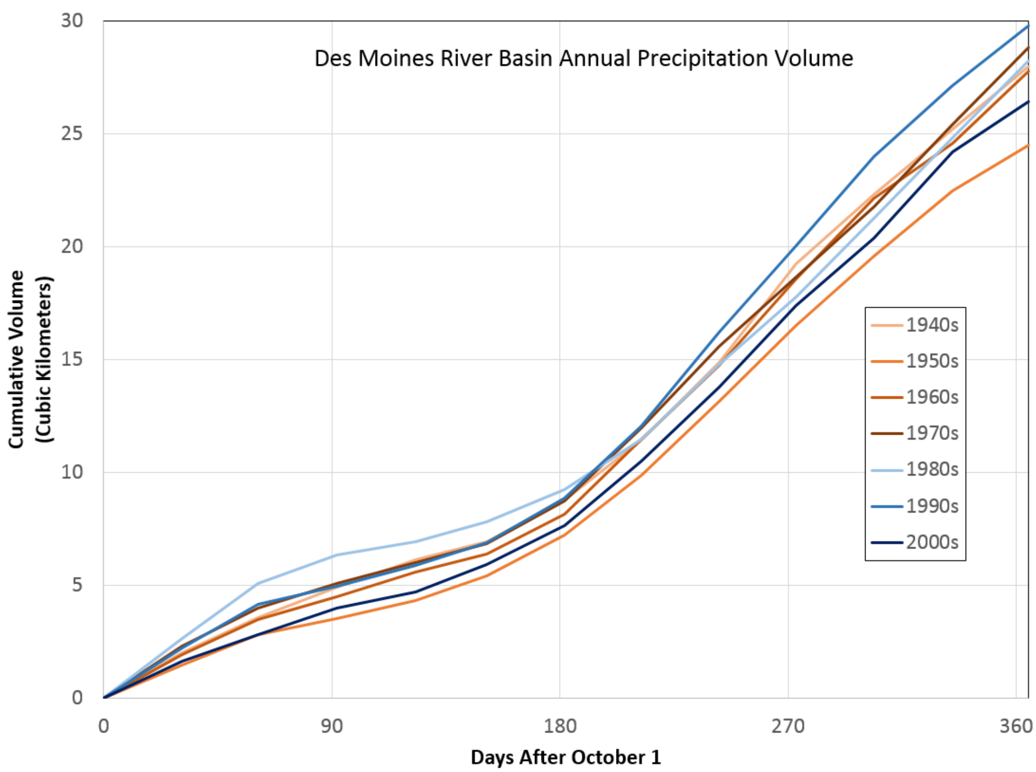
Appendix F: Precipitation and discharge trends for analyzed basins

Appendix F-1. Highlights the differences in annual flow and precipitation volumes for the Des Moines River near Tracy, Iowa. These figures indicate that both precipitation and flow volumes are increasing in the Des Moines River basin. However, it appears that increases in flow rates are outpacing the precipitation increasing. This indicates that other factors in the basin may be having a greater effect on flow in the basin.

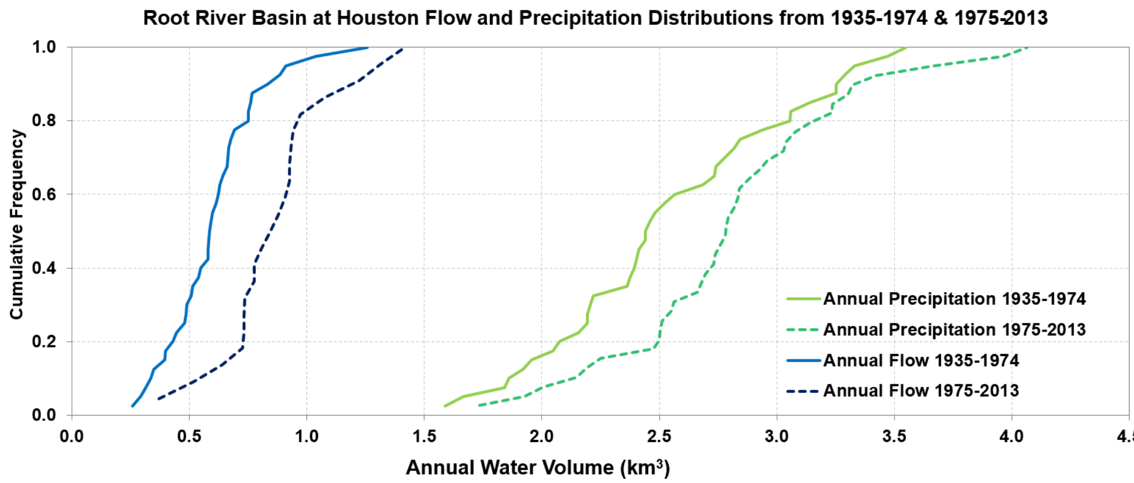


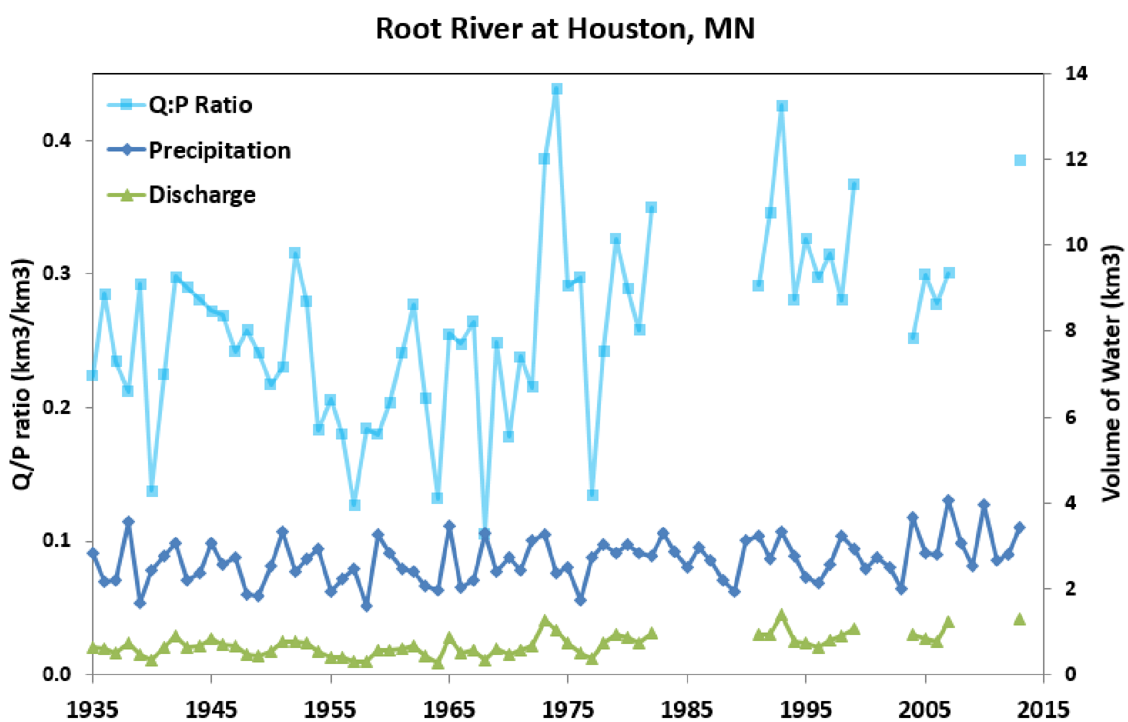


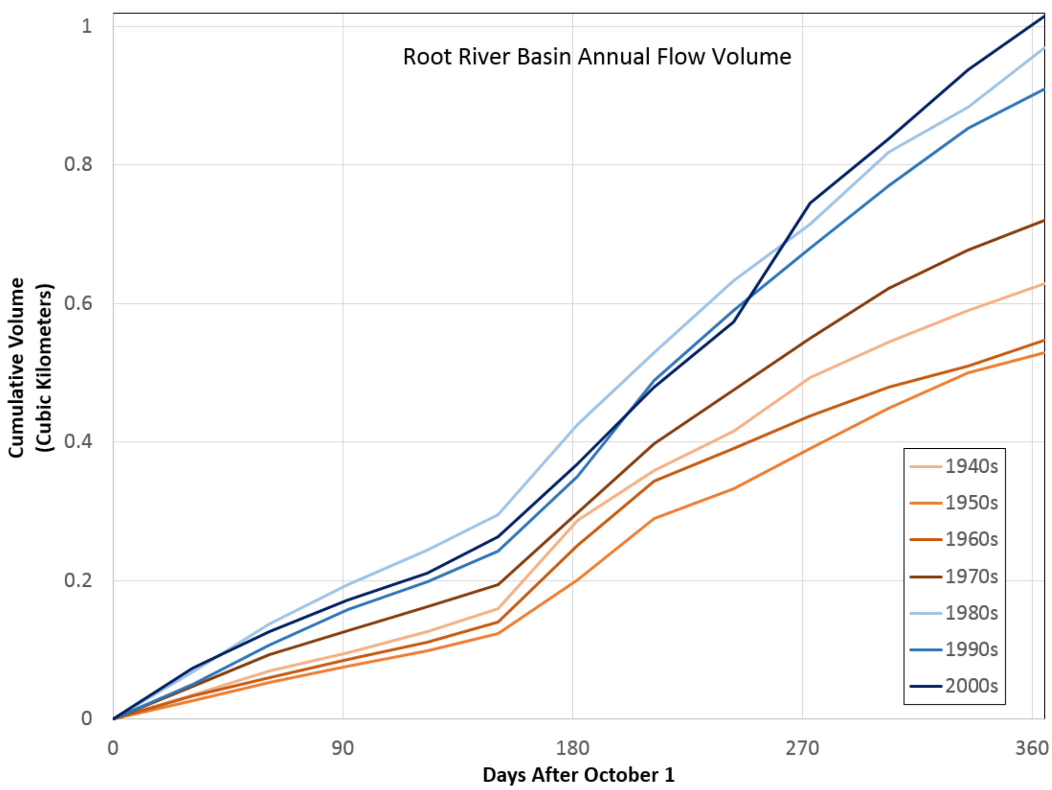

Des Moines River Basin Annual Flow Volume
Cumulative Volume (Cubic Kilometers)
0
2
4
6
8
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

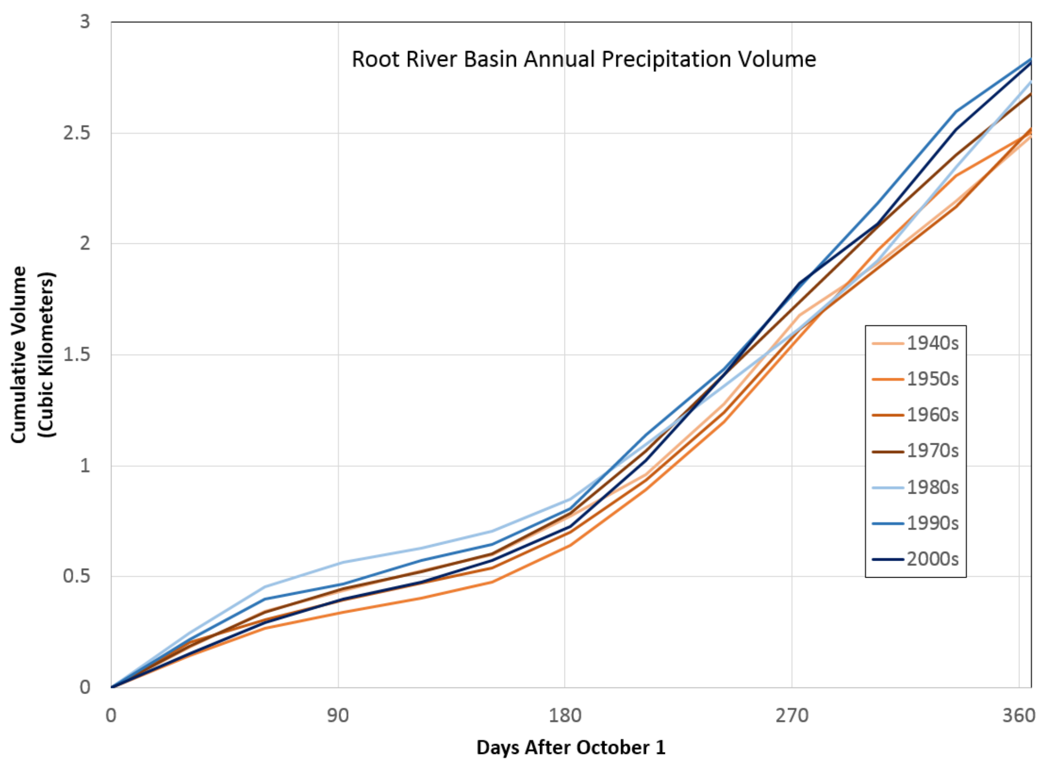

Des Moines River Basin Annual Precipitation Volume
Cumulative Volume (Cubic Kilometers)
0
5
10
15
20
25
30
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-2. Highlights the differences in annual flow and precipitation volumes for the Root River near Houston, Minnesota. This indicates that both precipitation and flow volumes are increasing in the Root River basin. However, it appears that increases in flow rates are slightly outpacing the precipitation increasing. This indicates that other factors in the basin may be having a greater effect on flow in the basin.

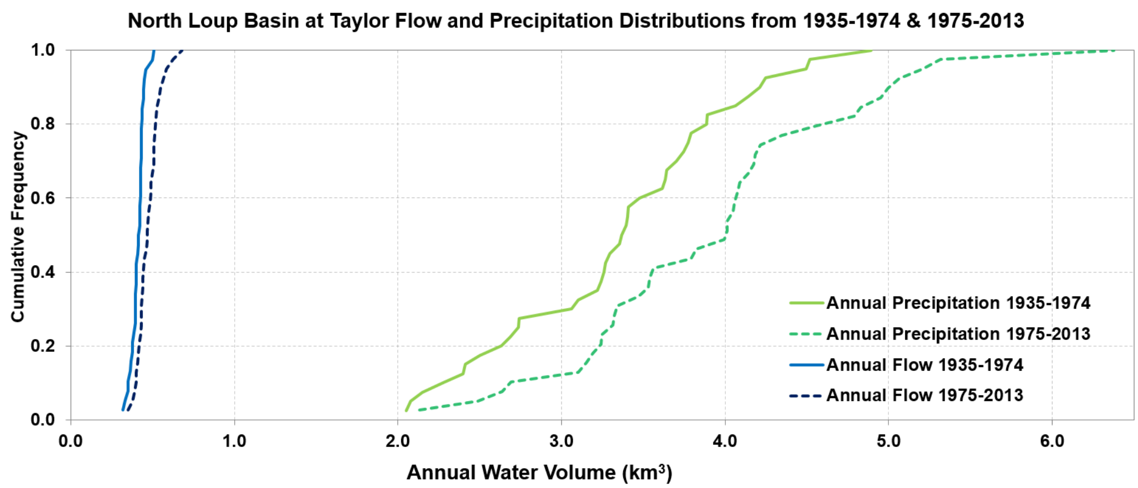


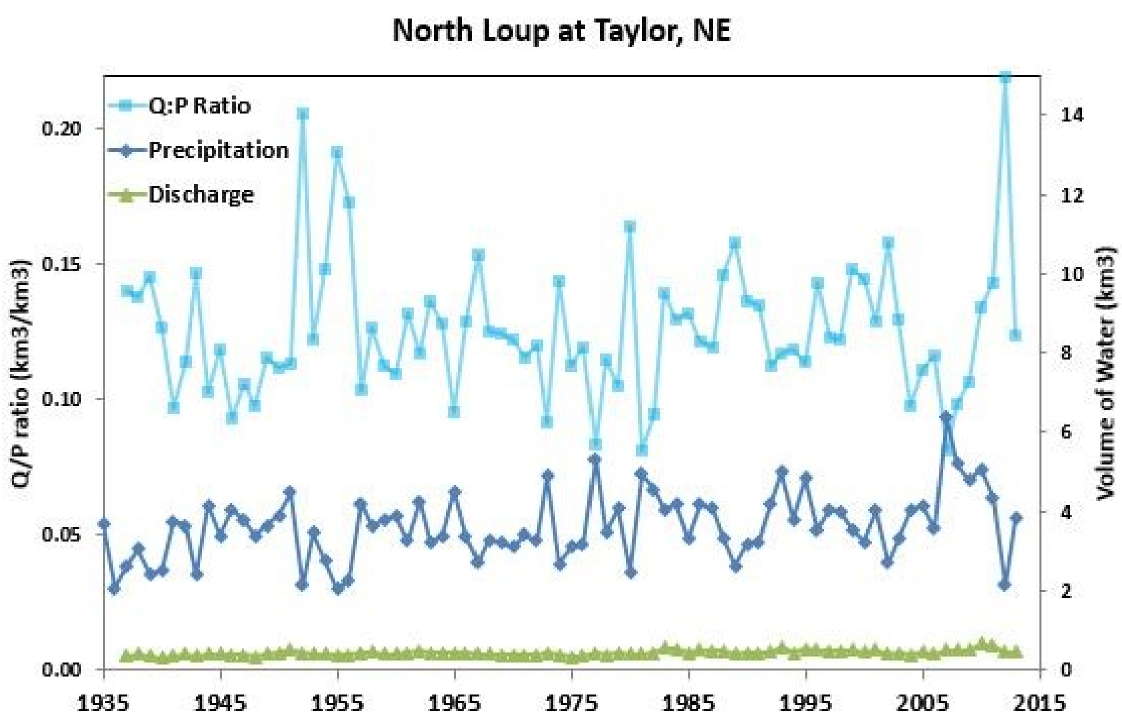


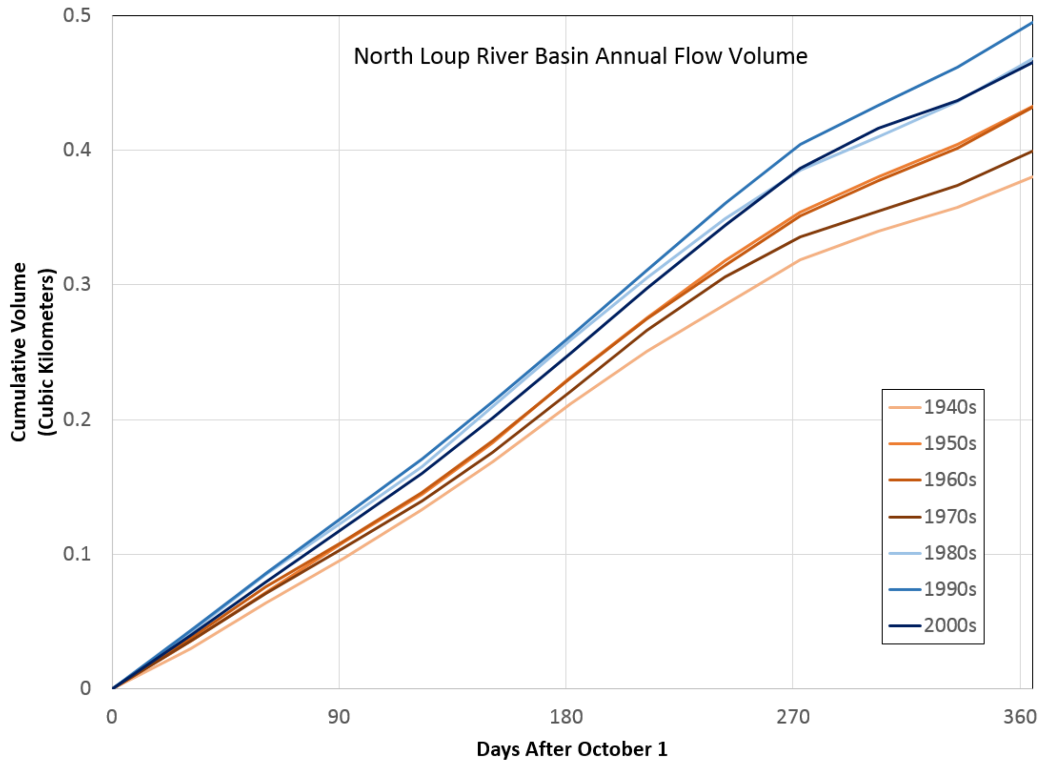

Root River Basin Annual Flow Volume
Cumulative Volume (Cubic Kilometers)
1
0.8
0.6
0.4
0.2
0
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

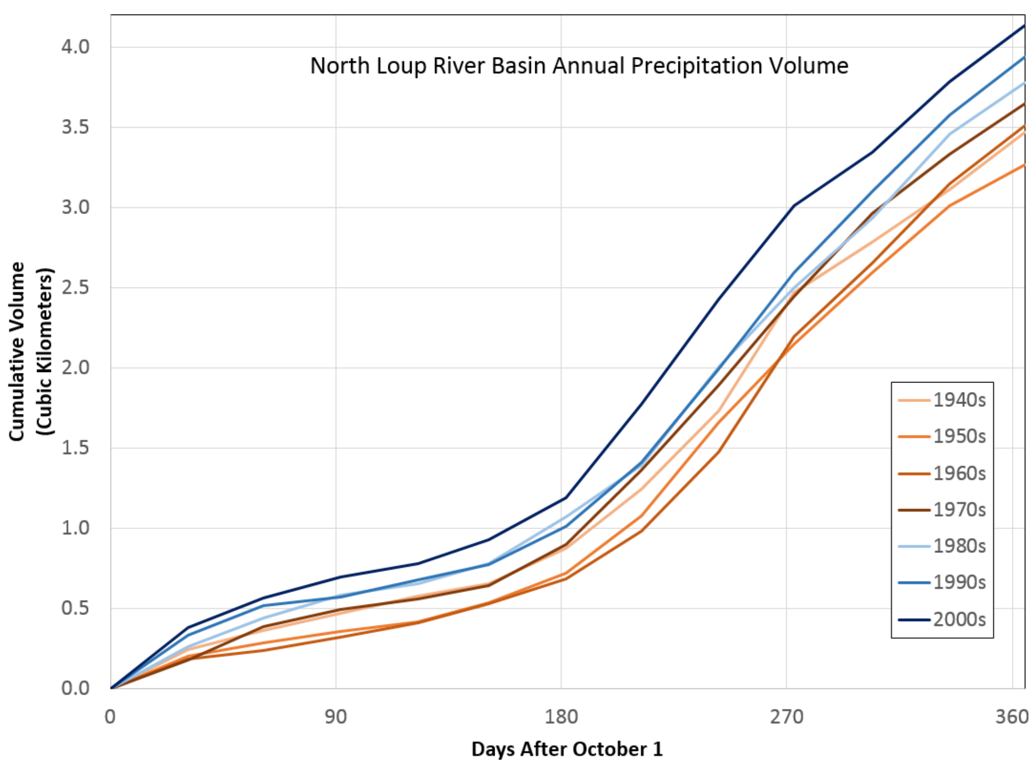

Root River Basin Annual Precipitation Volume
Cumulative Volume (Cubic Kilometers)
3
2.5
2
1.5
1
0.5
0
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-3. Highlights the differences in annual flow and precipitation volumes for the North Loup River near Taylor, Nebraska. This indicates that both precipitation and flow volumes are increasing in the North Loup River basin. However, it appears that increases in flow rates are increasing at a much slower rate than the precipitation is increasing. This indicates that flow is likely being heavily effected by water usage and evapotranspiration in the basin.

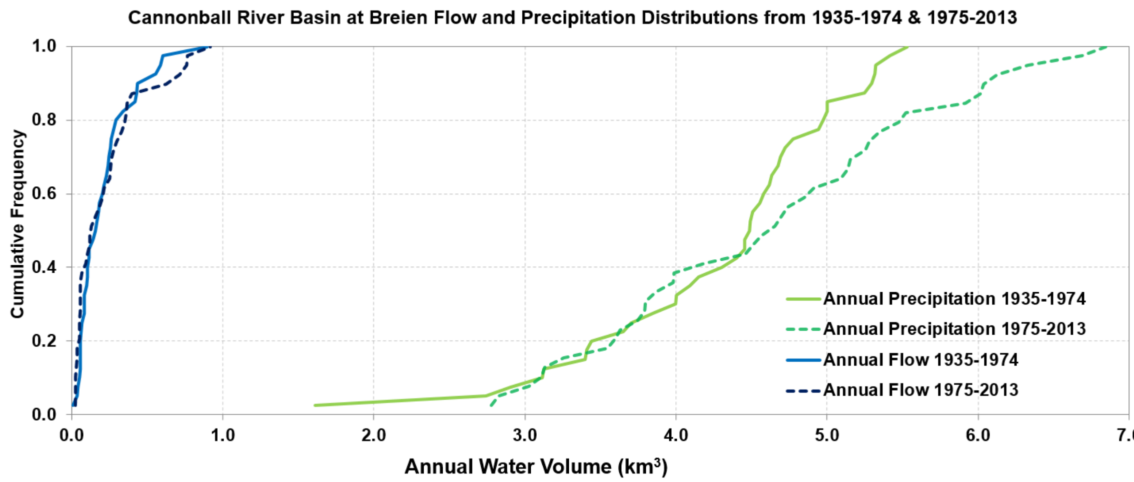


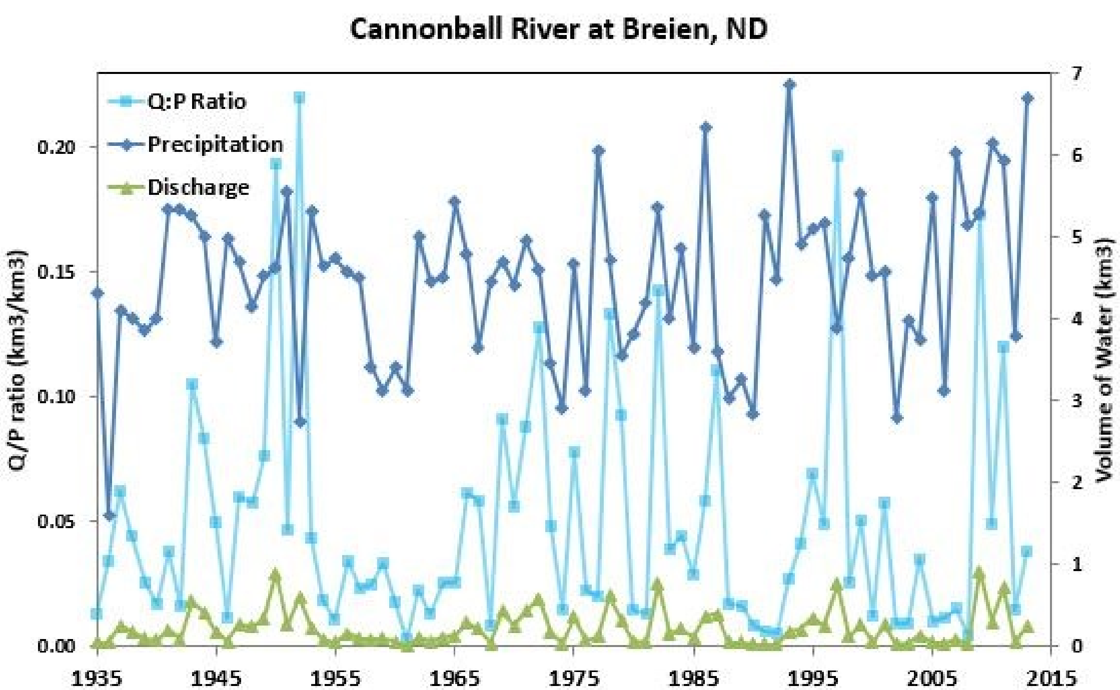


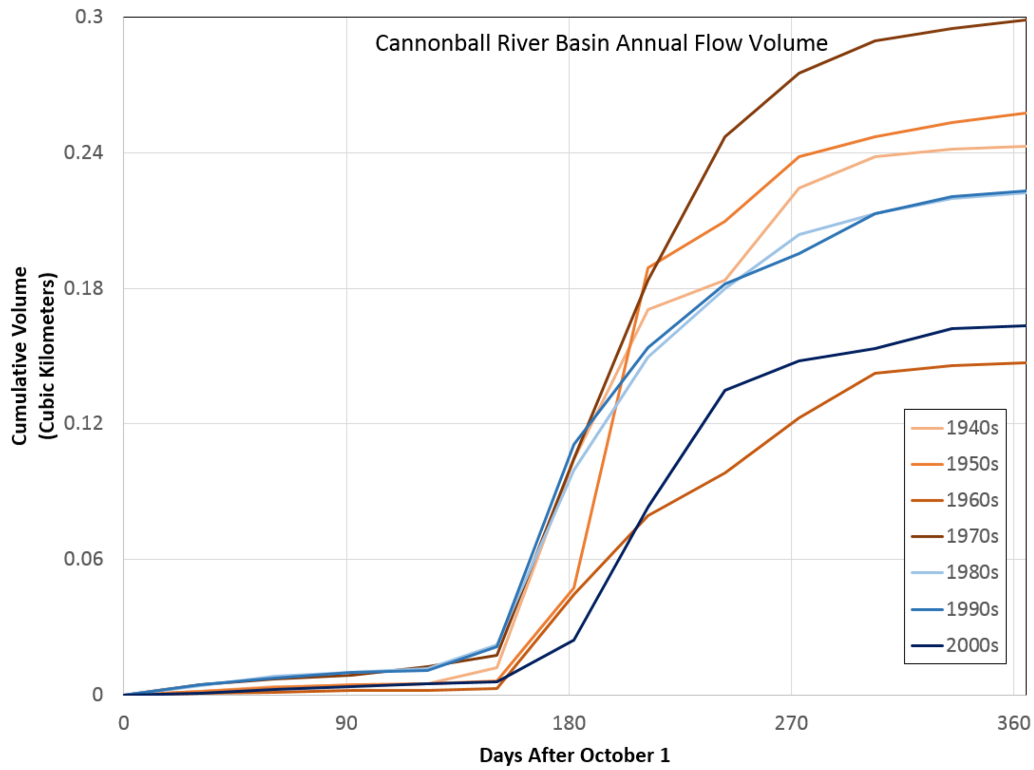

North Loup River Basin Annual Flow Volume
Cumulative Volume (Cubic Kilometers)
0.5
0.4
0.3
0.2
0.1
0
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

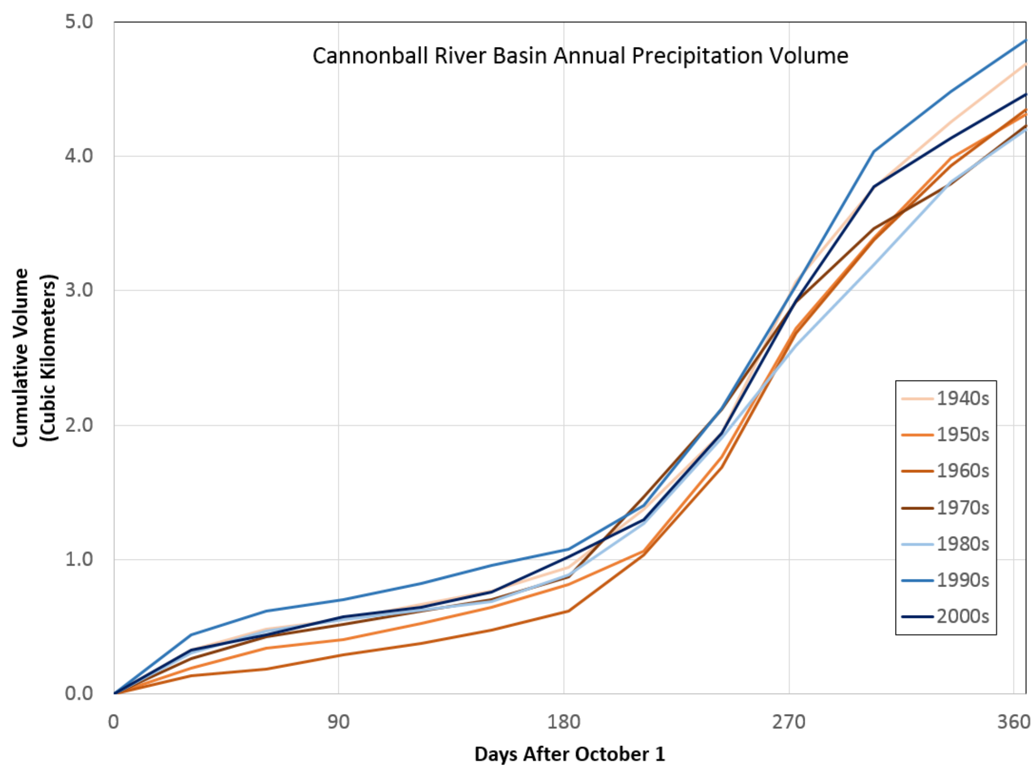

North Loup River Basin Annual Precipitation Volume
Cumulative Volume (Cubic Kilometers)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-4. Highlights the differences in annual flow and precipitation volumes for the Cannonball River near Breien, North Dakota. This indicates that the annual volume of precipitation is increasing in the Cannonball River basin. However, it appears that flow rates have remained largely unchanged between the two time periods. This indicates that flow is likely being effected by water usage and evapotranspiration in the basin.

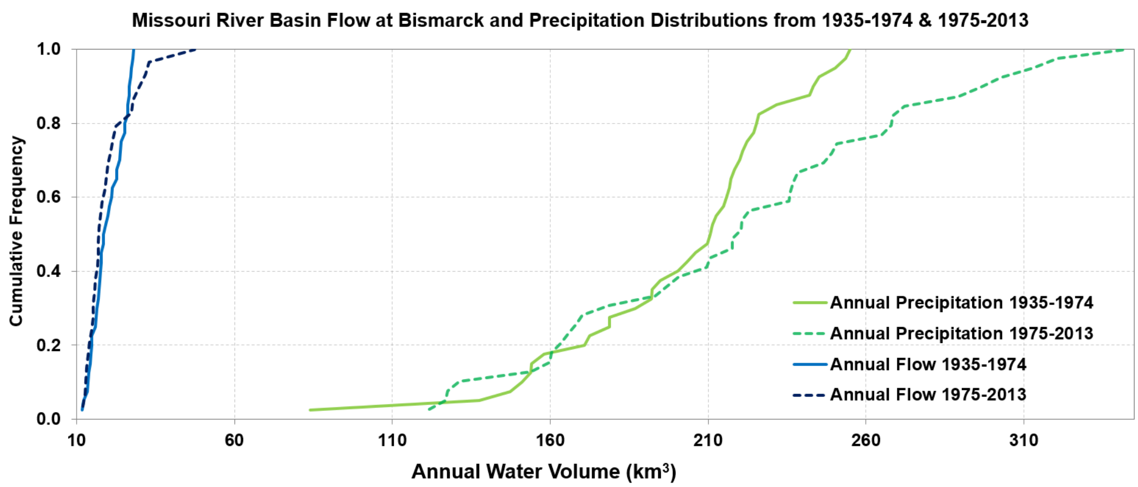


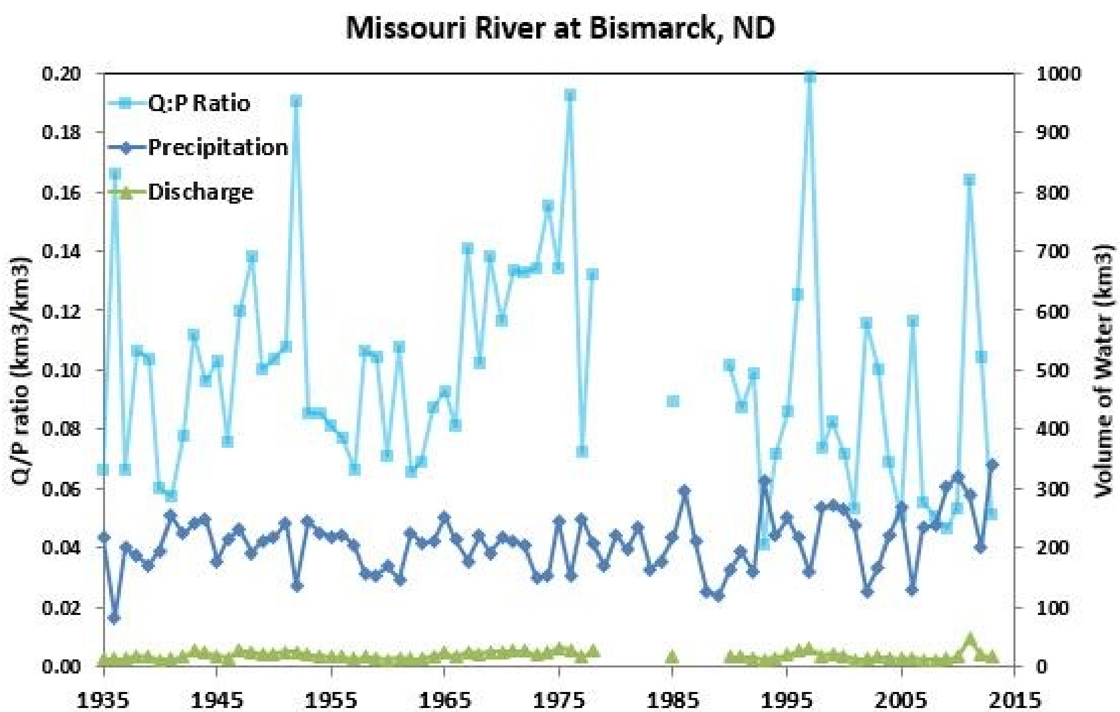


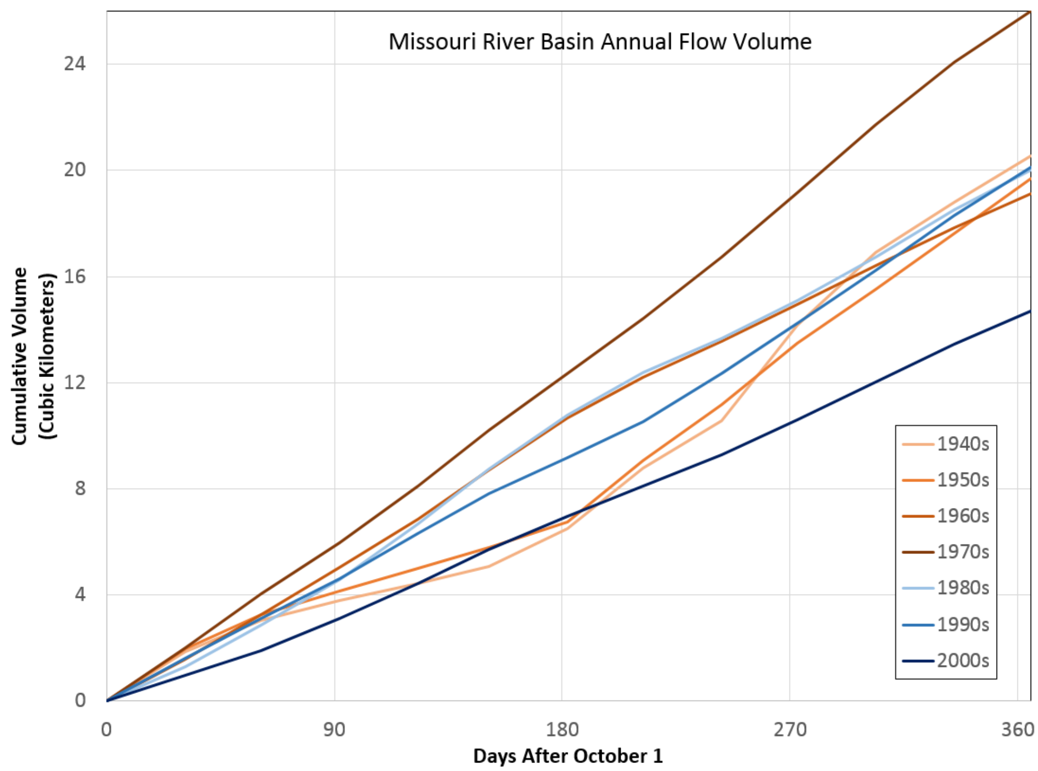

Cannonball River Basin Annual Flow Volume
Cumulative Volume (Cubic Kilometers)
0.3
0.24
0.18
0.12
0.06
0
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

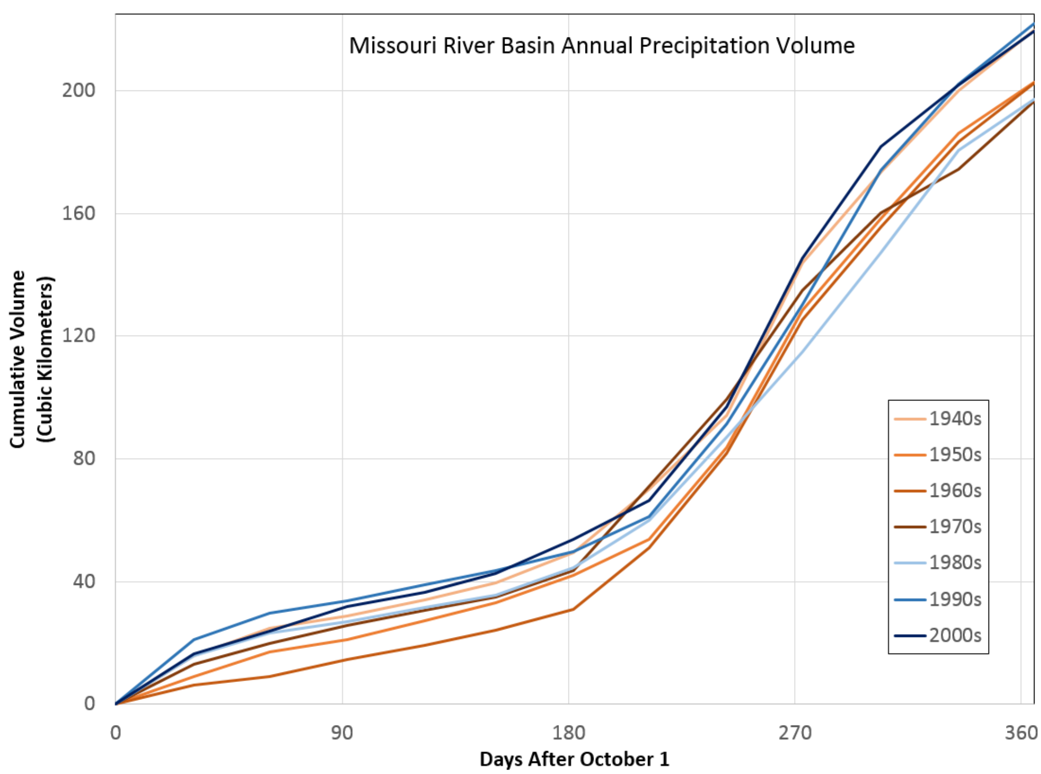

Cannonball River Basin Annual Precipitation Volume
Cumulative Volume (Cubic Kilometers)
5.0
4.0
3.0
2.0
1.0
0.0
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-5. Highlights the differences in annual flow and precipitation volumes for the Missouri River near Bismarck, North Dakota. This indicates that the annual volume of precipitation is increasing in the Missouri River basin. However, it appears that flow rates have remained largely unchanged between the two time periods, with the exception of the top 10% of annual water volumes. This indicates that flow is likely being effected by water usage and evapotranspiration in the basin.

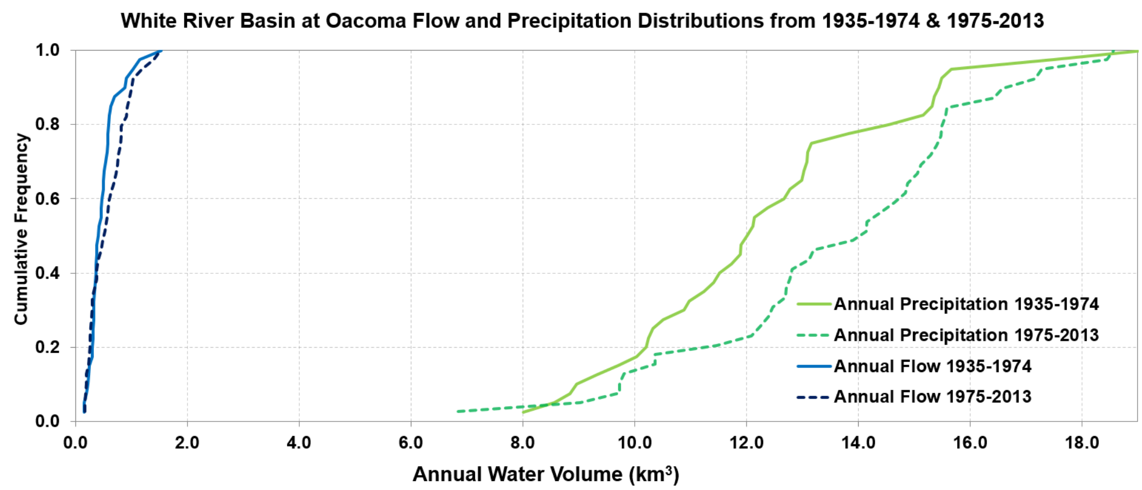


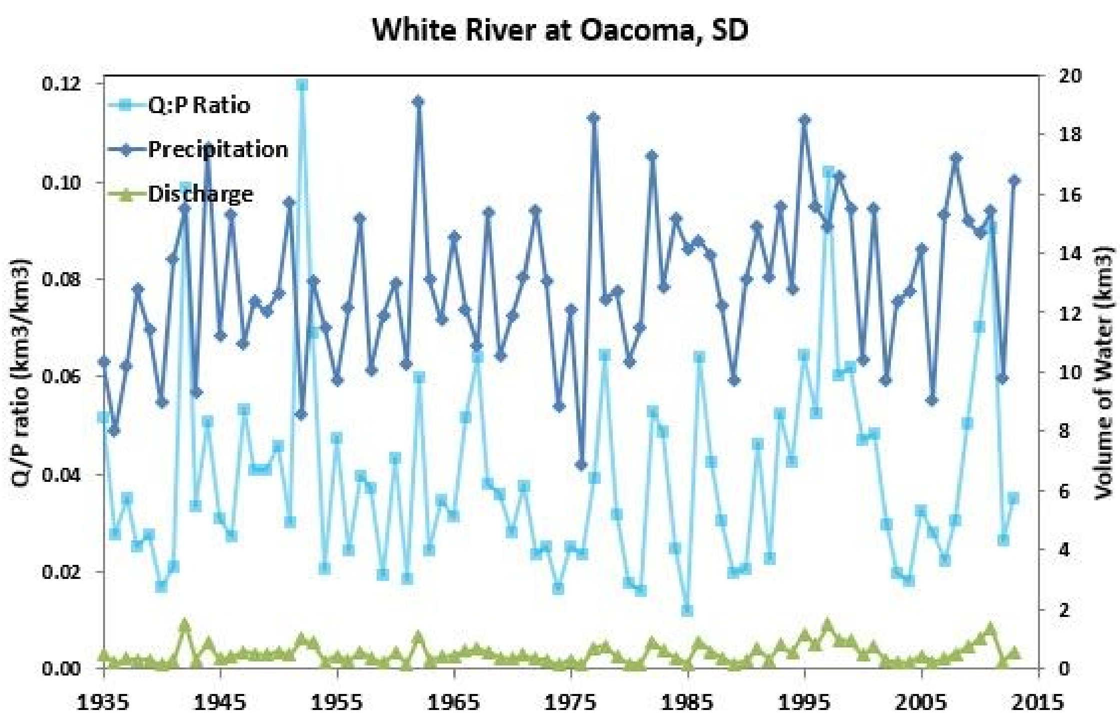


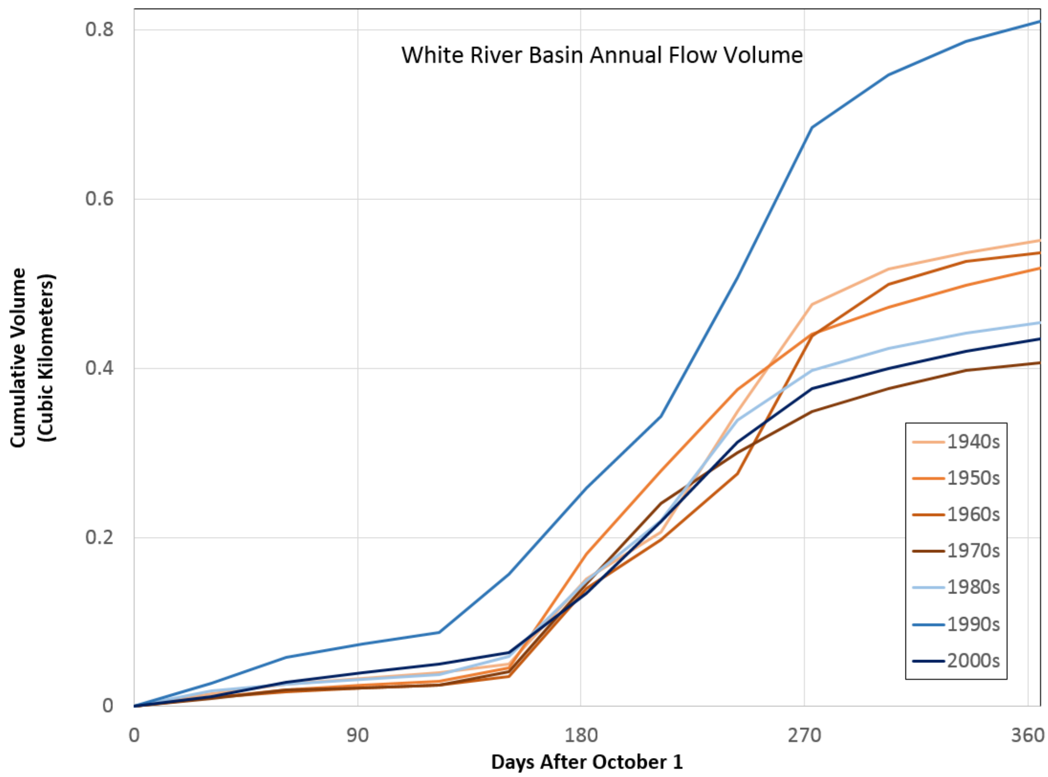

Missouri River Basin Annual Flow Volume
Cumulative Volume
(Cubic Kilometers)
0
4
8
12
16
20
24
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

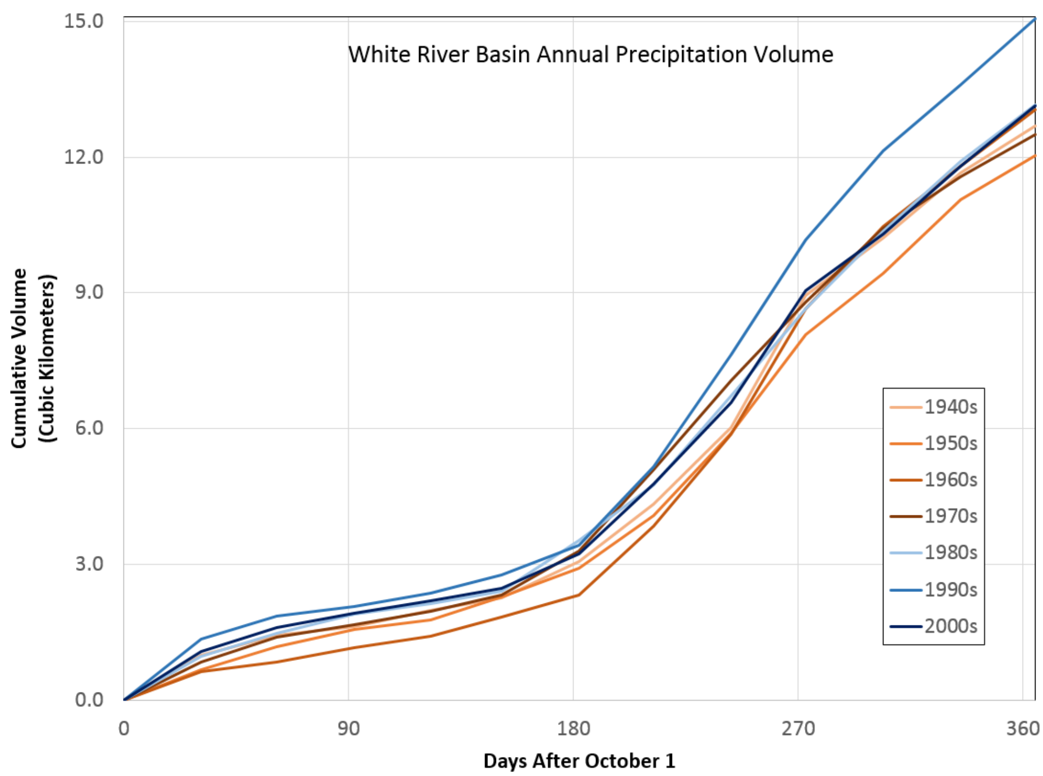

Missouri River Basin Annual Precipitation Volume
Cumulative Volume
(Cubic Kilometers)
0
40
80
120
160
200
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-6. Highlights the differences in annual flow and precipitation volumes for the White River near Oacoma, South Dakota. This indicates that the annual volume of precipitation is increasing in the White River basin. Flow volumes have slightly increased in the most recent time period, but not in a significant way. This indicates that flow volumes are likely being effected more by water usage and evapotranspiration than precipitation in the basin.

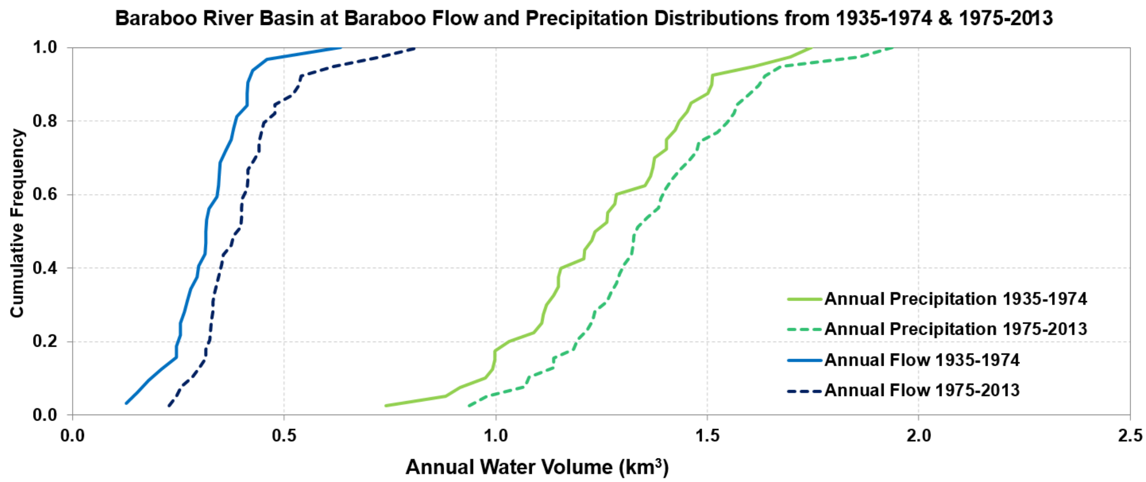


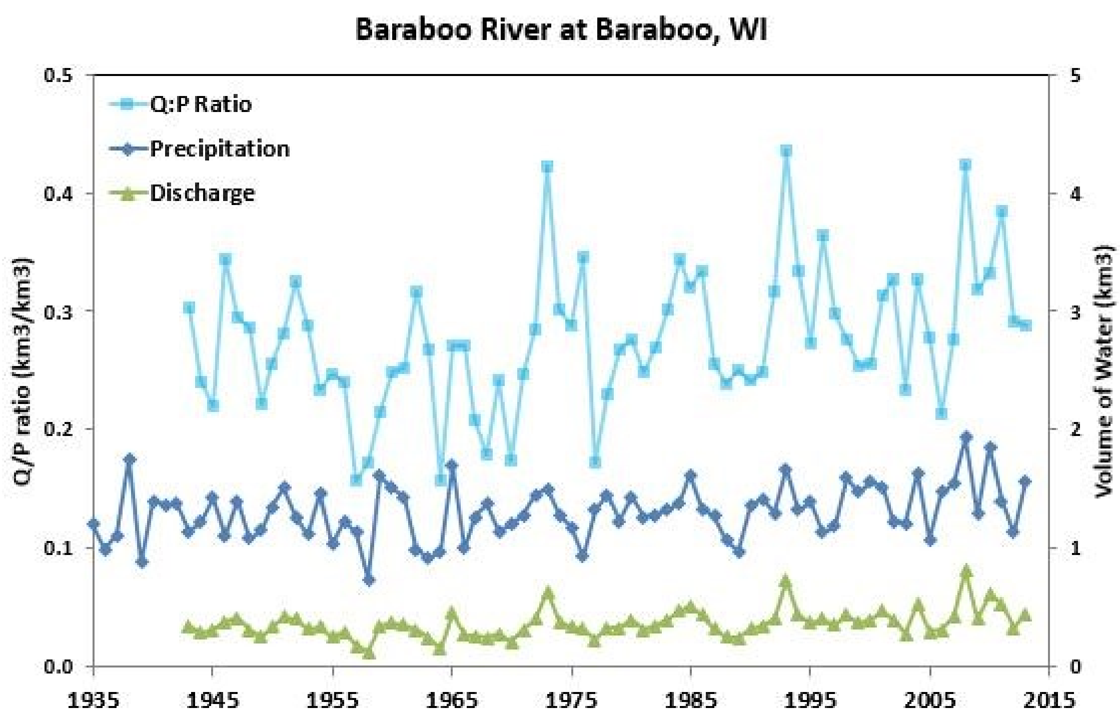


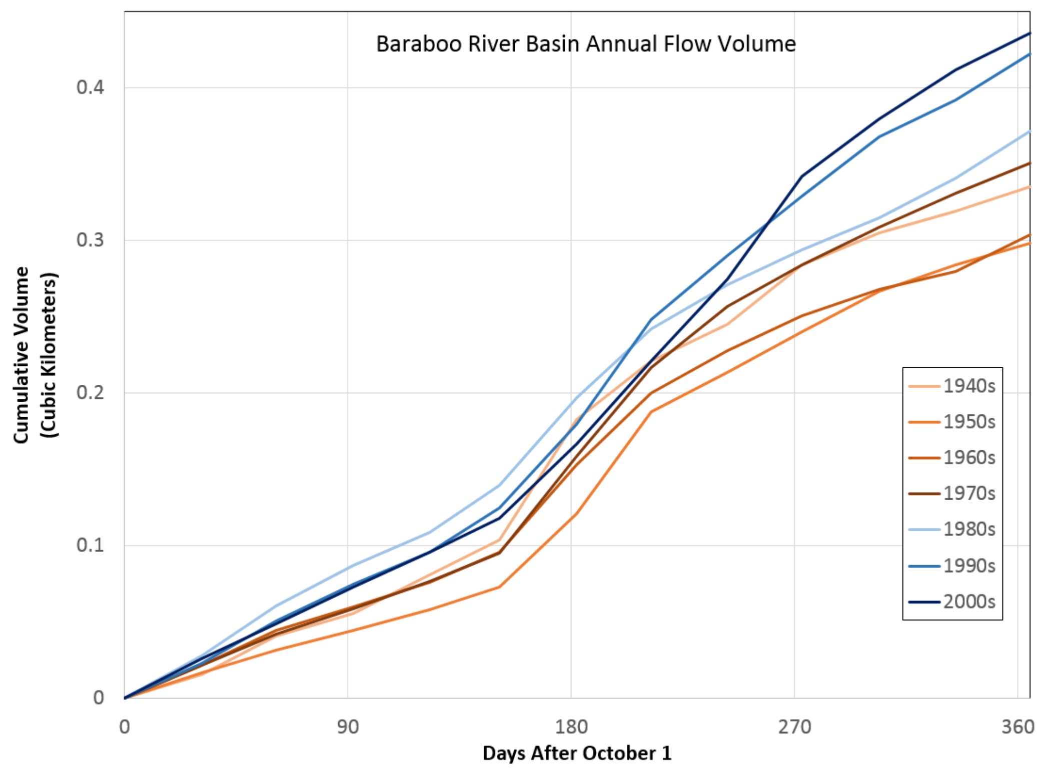

White River Basin Annual Flow Volume
Cumulative Volume (Cubic Kilometers)
Days After October 1
0.8
0.6
0.4
0.2
0
0
90
180
270
360
1940s
1950s
1960s
1970s
1980s
1990s
2000s

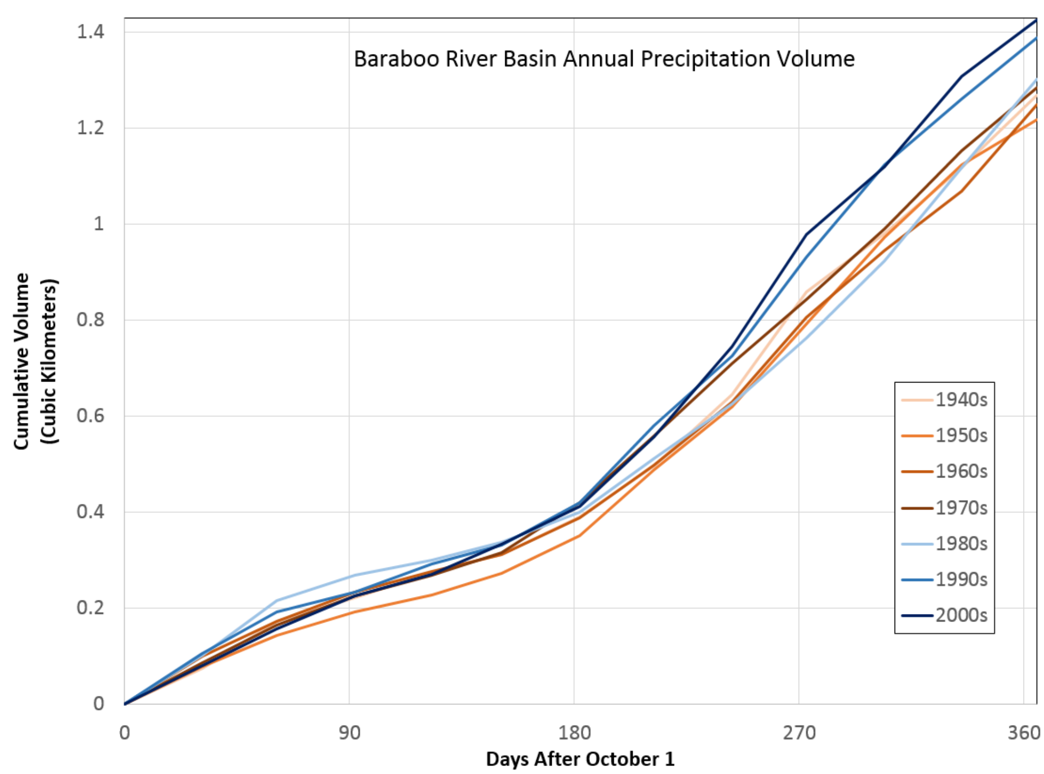

White River Basin Annual Precipitation Volume
Cumulative Volume (Cubic Kilometers)
Days After October 1
15.0
12.0
9.0
6.0
3.0
0.0
0
90
180
270
360
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-7. Highlights the differences in annual flow and precipitation volumes for the Baraboo River near Baraboo, Wisconsin. This indicates that both precipitation and flow volumes are increasing in the Baraboo River basin. Increases in flow rates are very similar to the precipitation increase. This indicates that increased precipitation could be the main cause of the flow increase.

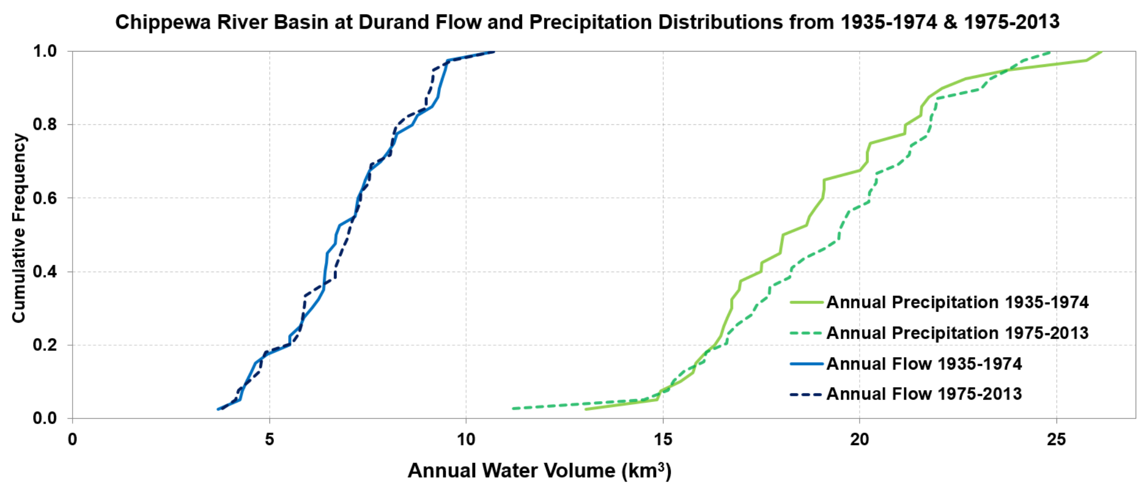


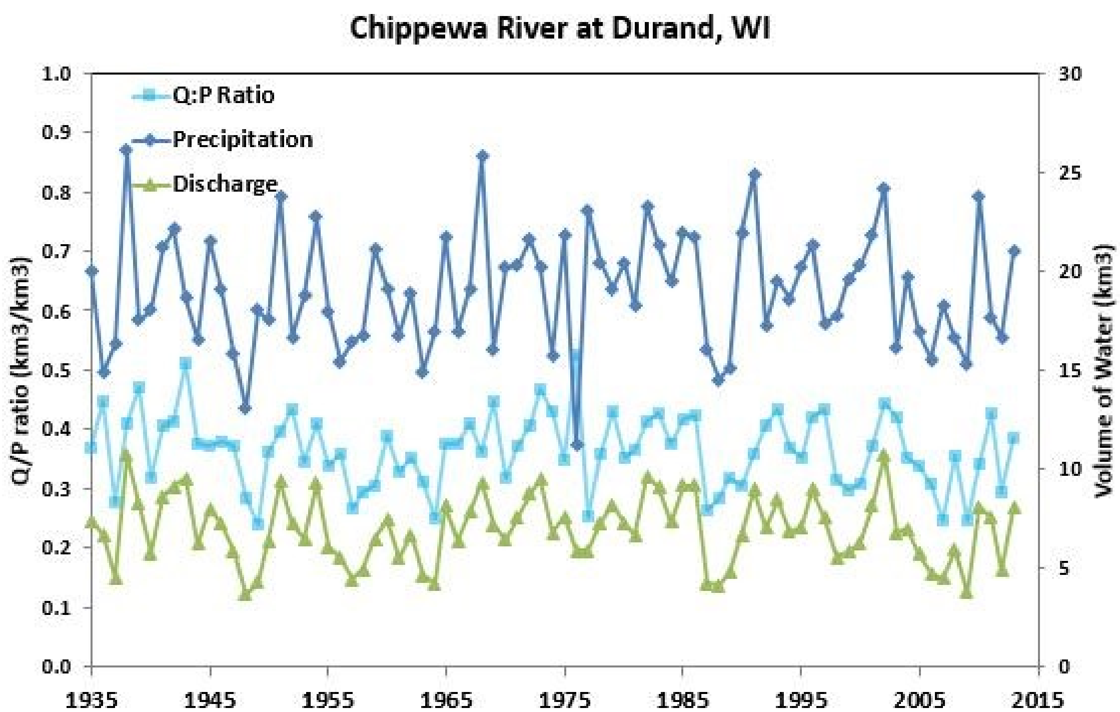


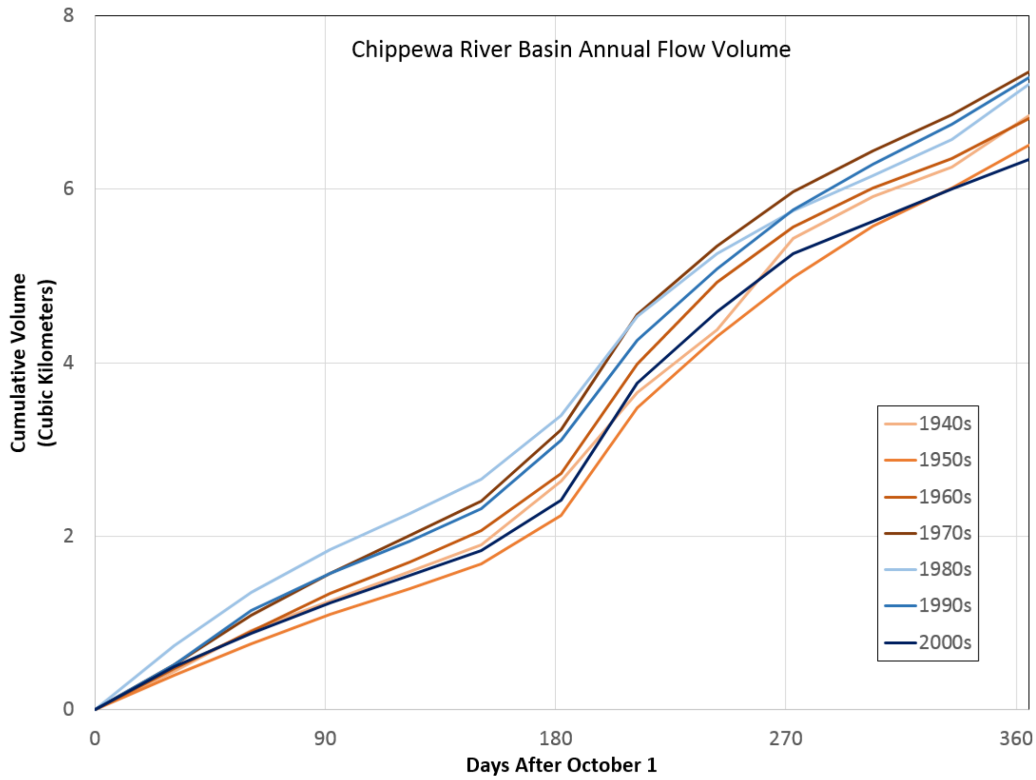

Baraboo River Basin Annual Flow Volume
Cumulative Volume (Cubic Kilometers)
0
0.1
0.2
0.3
0.4
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

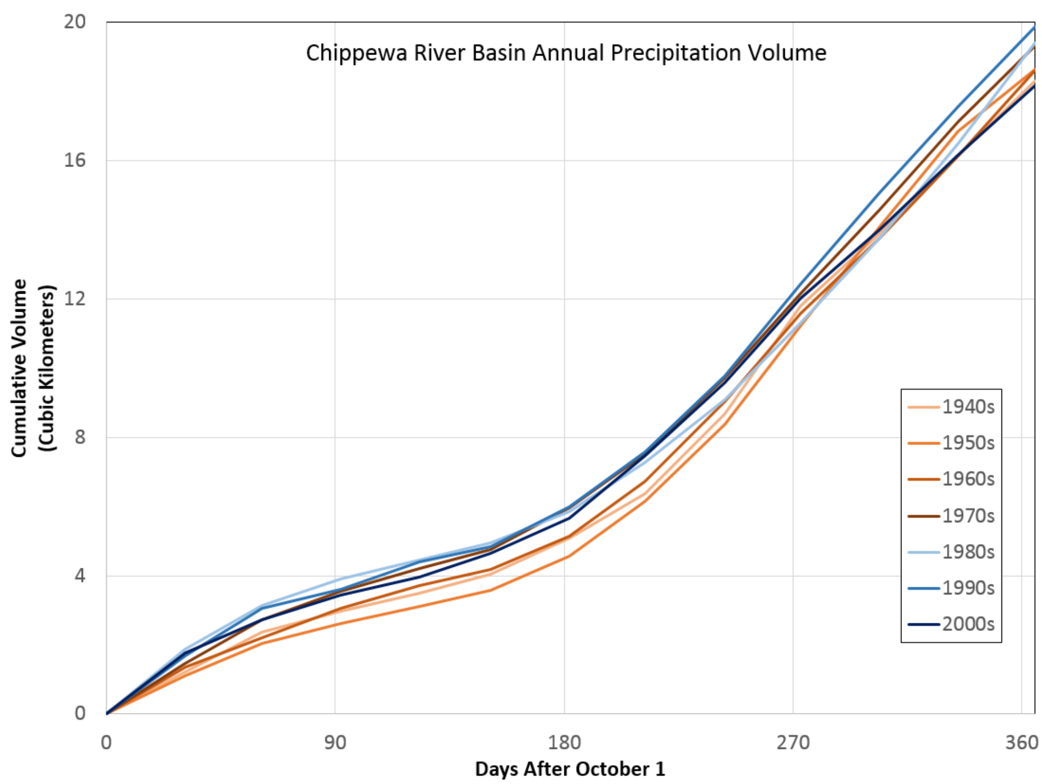

Baraboo River Basin Annual Precipitation Volume
Cumulative Volume (Cubic Kilometers)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
90
180
270
360
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s

Appendix F-8. Highlights the differences in annual flow and precipitation volumes for the Chippewa River near Durand, Wisconsin. This indicates that both precipitation and flow volumes have remained relatively stable in the Chippewa River basin. Some increases in precipitation have occurred between the 25th and 75th percentile, but are offset by the top and bottom 25 percentile.



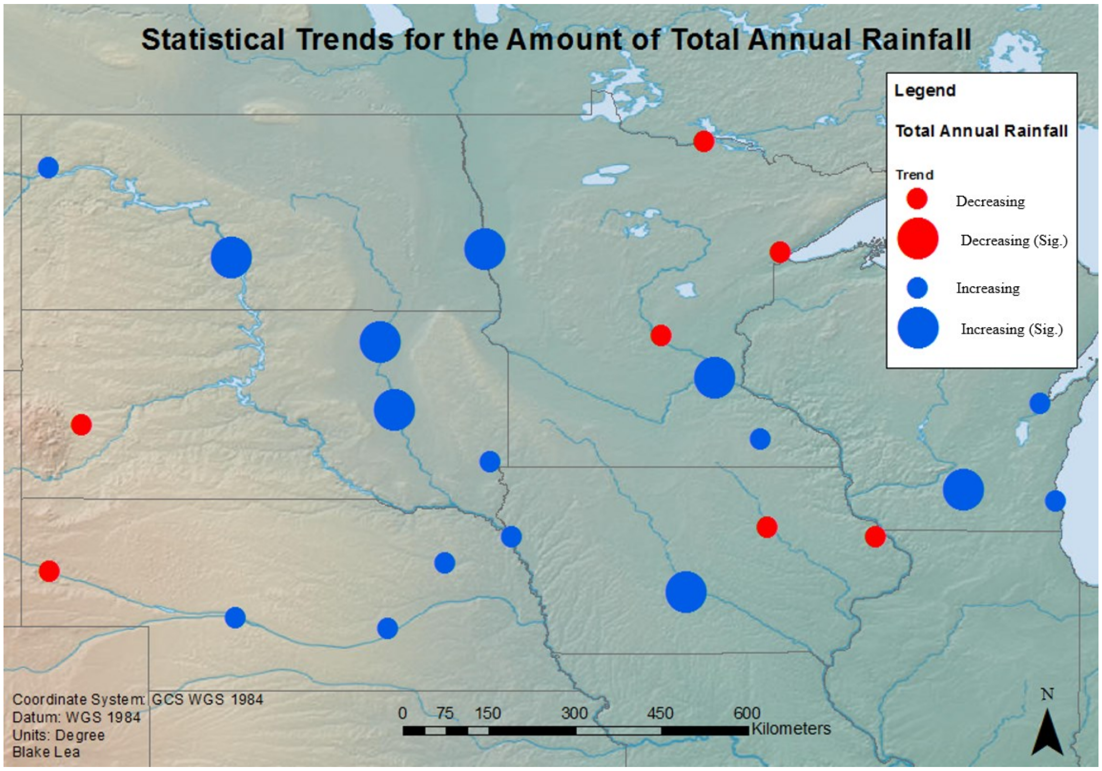



Chippewa River Basin Annual Flow Volume
Cumulative Volume
(Cubic Kilometers)
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s
0
2
4
6
8
0
90
180
270
360

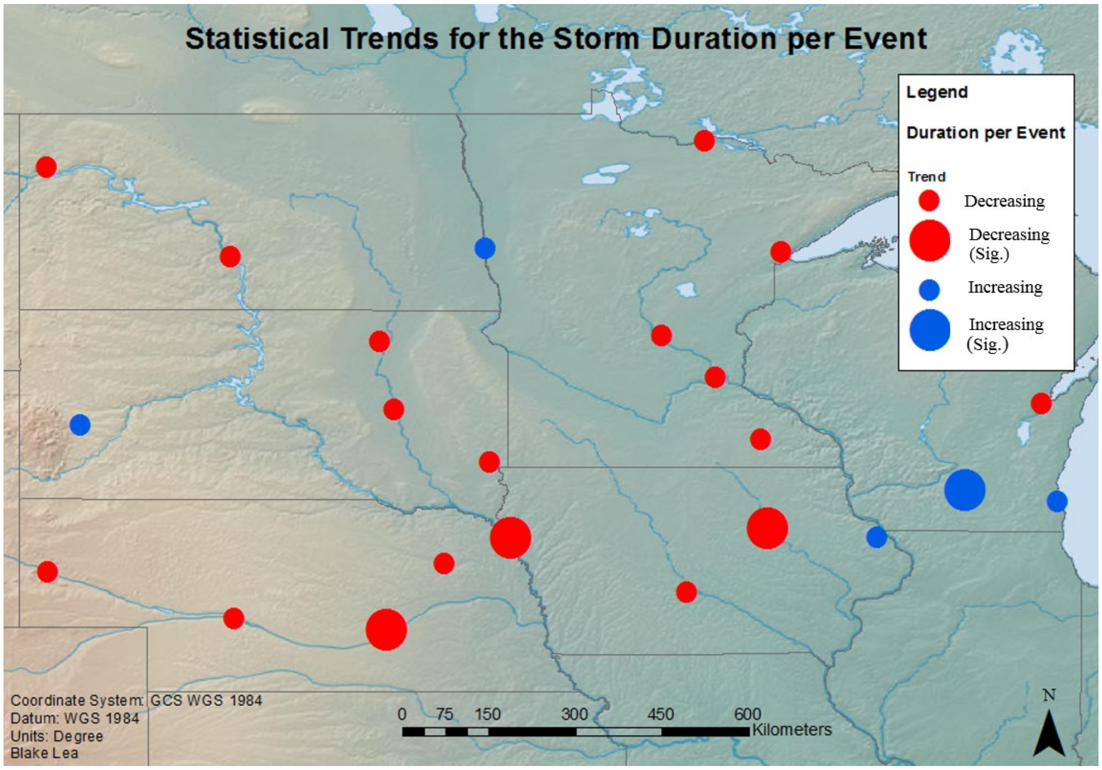

Chippewa River Basin Annual Precipitation Volume
Cumulative Volume
(Cubic Kilometers)
Days After October 1
1940s
1950s
1960s
1970s
1980s
1990s
2000s
0
4
8
12
16
20
0
90
180
270
360

Appendix G: Precipitation trend maps

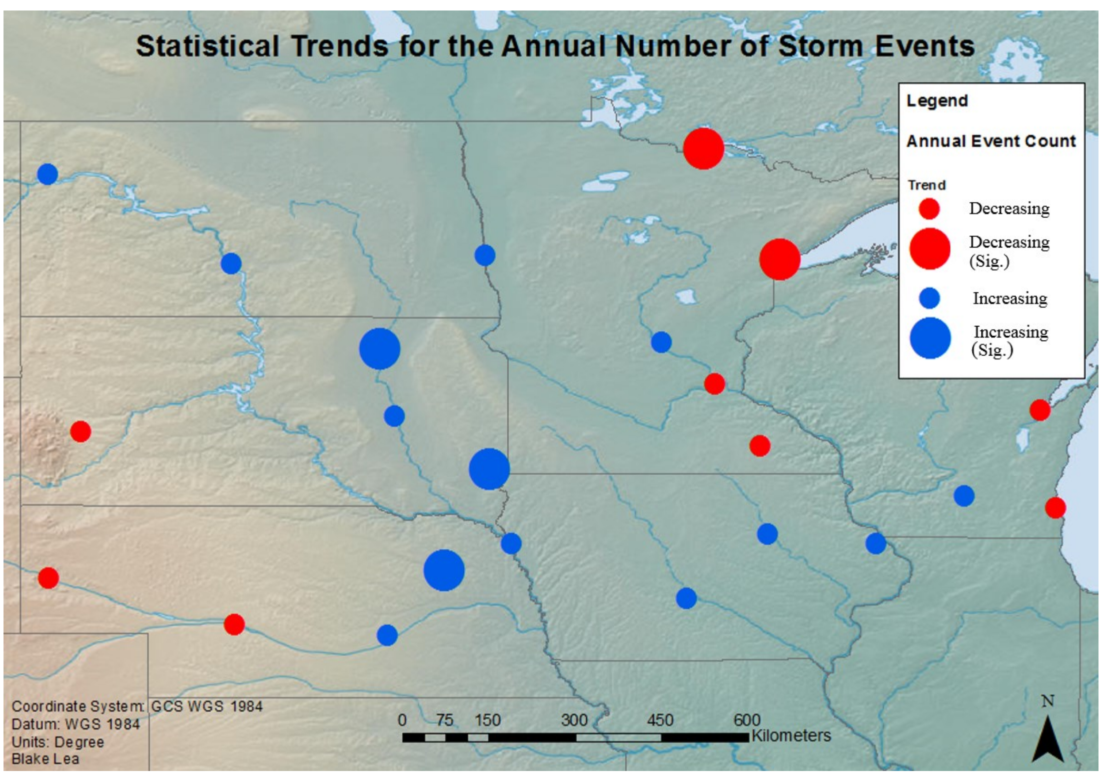
Appendix G-1. Regional trends for the amount of total annual rainfall.



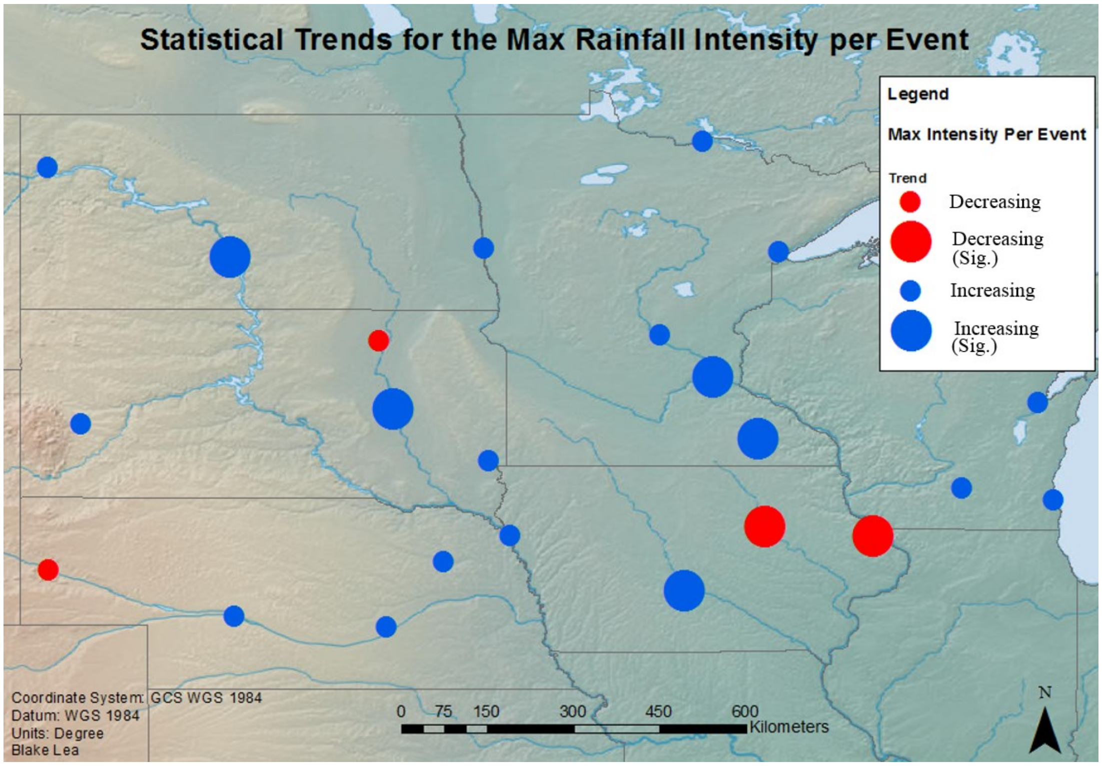
Appendix G-2. Regional trends for the duration of storm events.



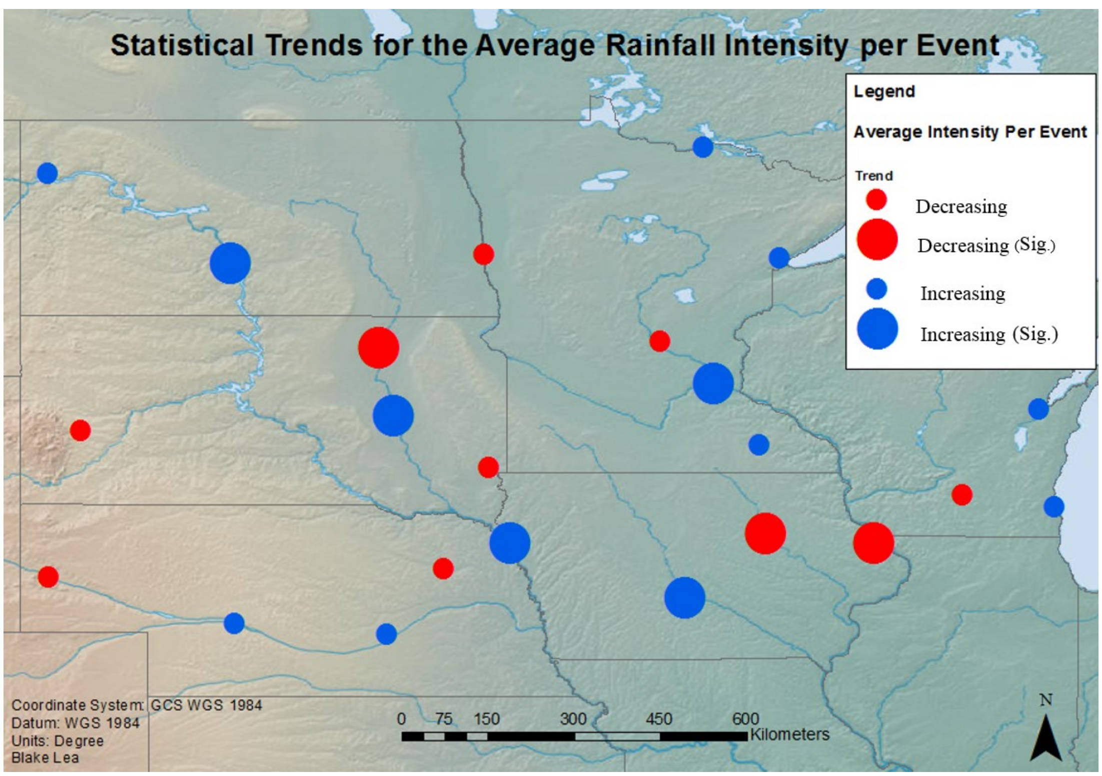
Appendix G-3. Regional trends for the annual number of storm events.



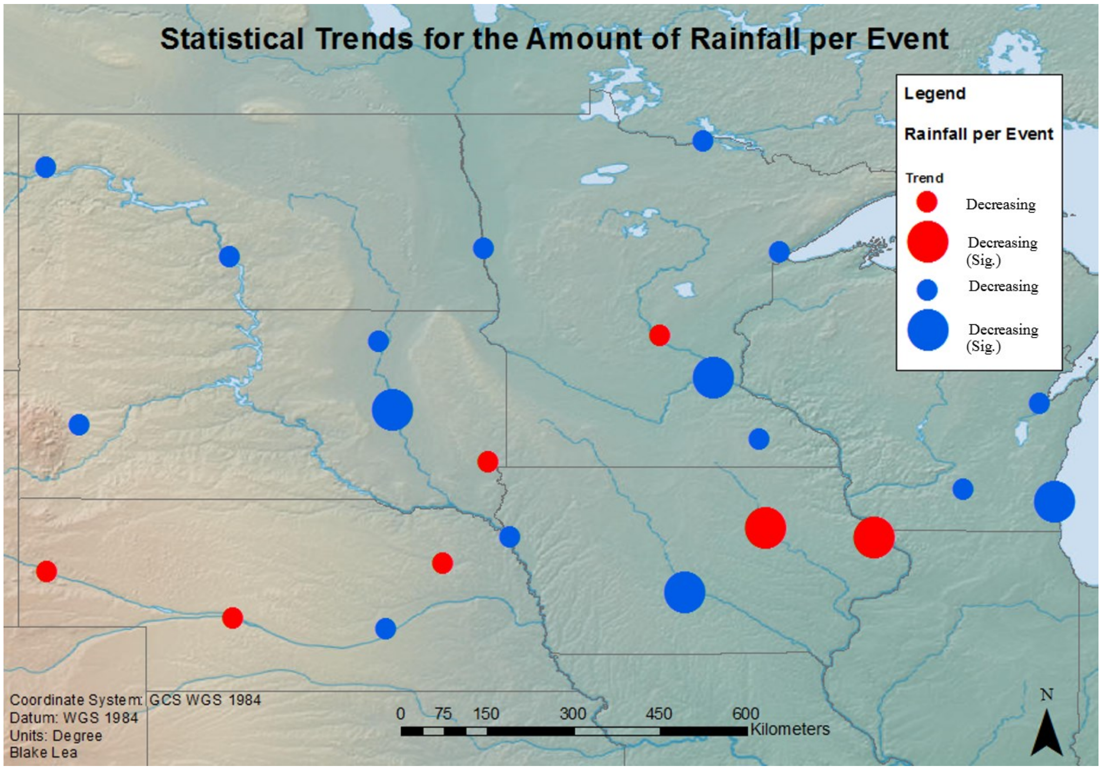
Appendix G-4. Regional trends for the maximum intensity per storm event.



Appendix G-5. Regional trends for the average intensity per storm event.

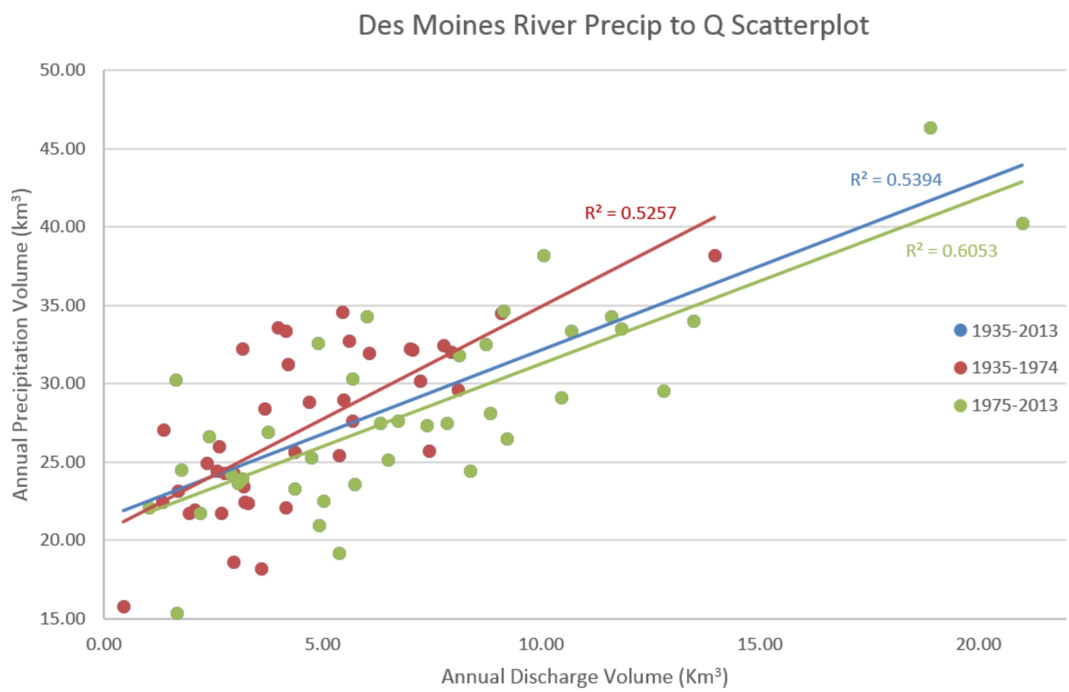


Appendix G-6. Regional trends for the average rainfall per storm event.

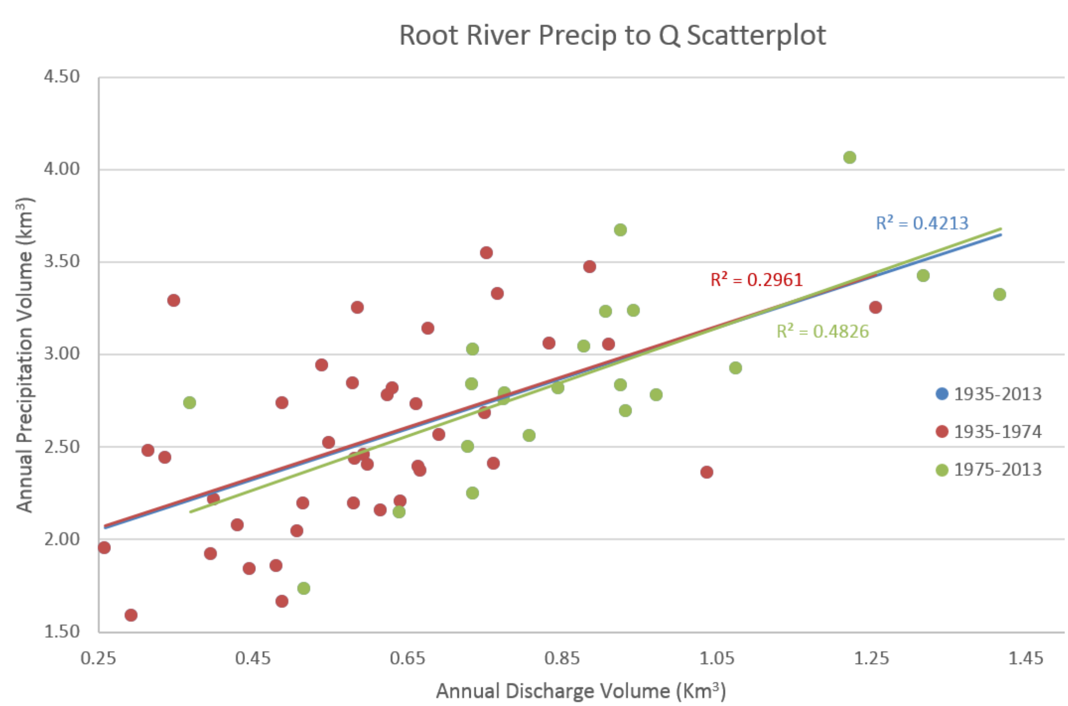


Appendix H: Precipitation to discharge correlations

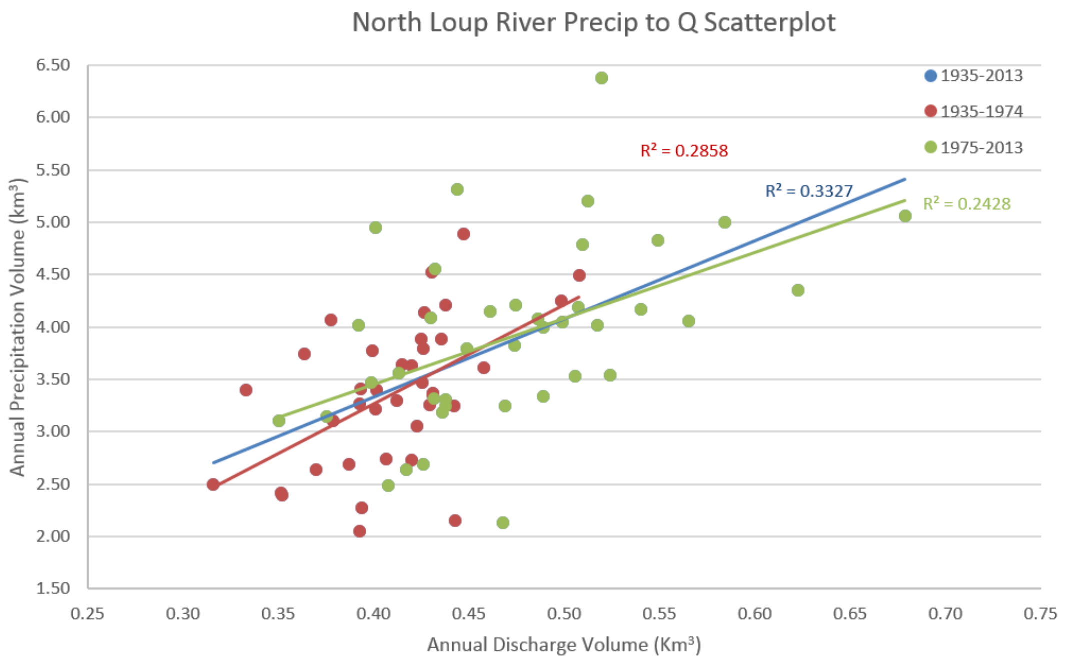
Appendix H-1. Precipitation to discharge correlation for the Des Moines River basin.



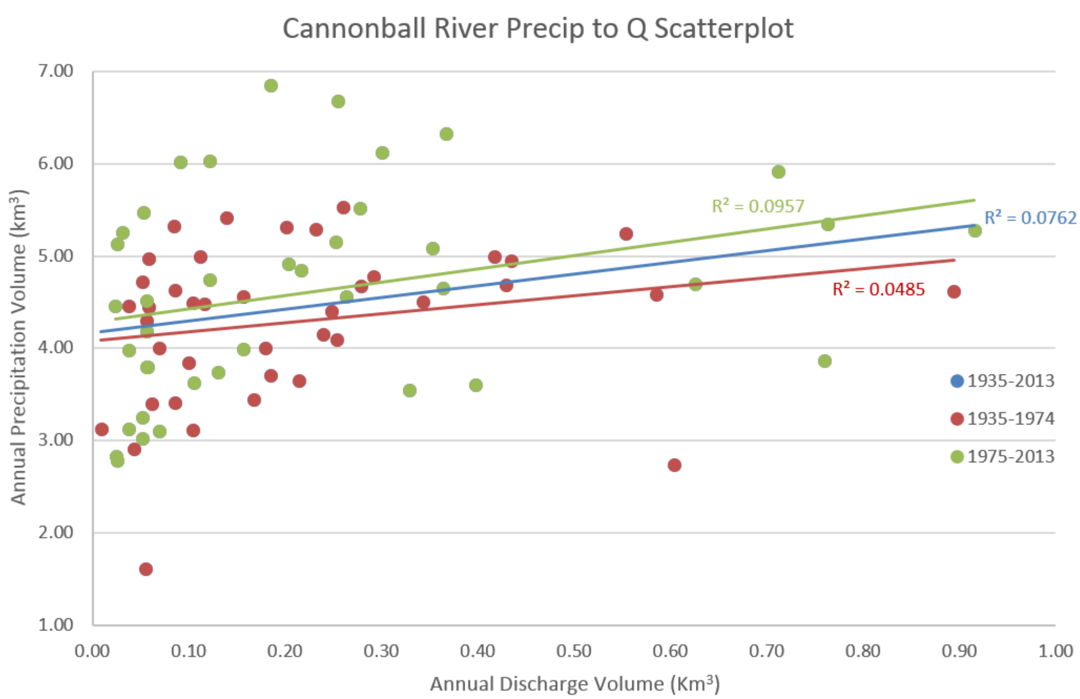
Appendix H-2. Precipitation to discharge correlation for the Root River basin.



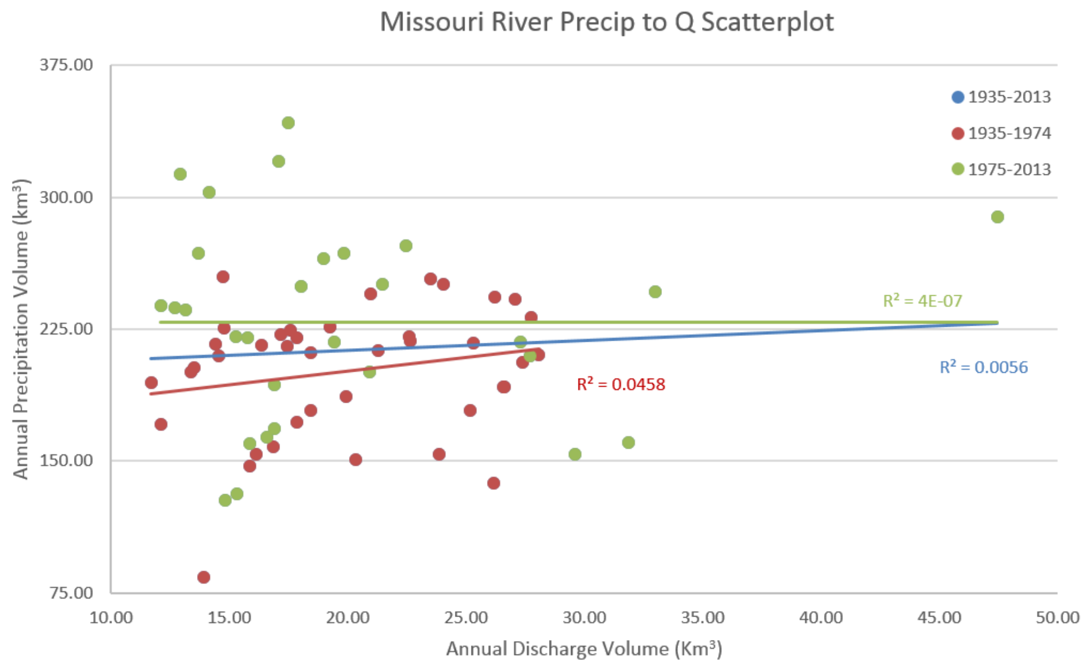
Appendix H-3. Precipitation to discharge correlation for the North Loup River basin.



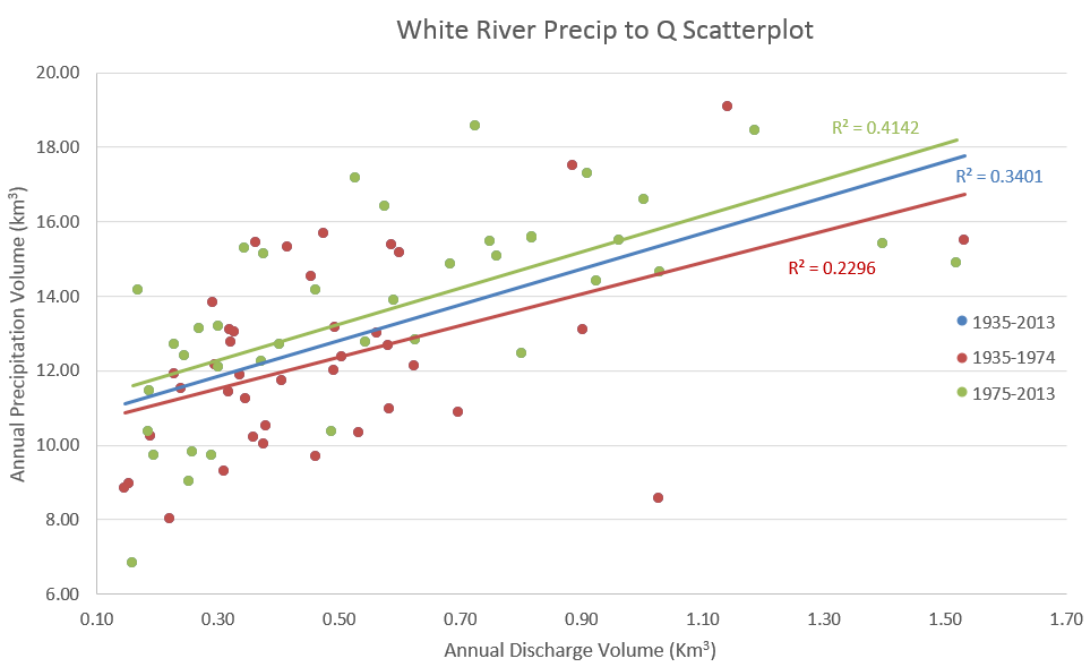
Appendix H-4. Precipitation to discharge correlation for the Cannonball River basin.



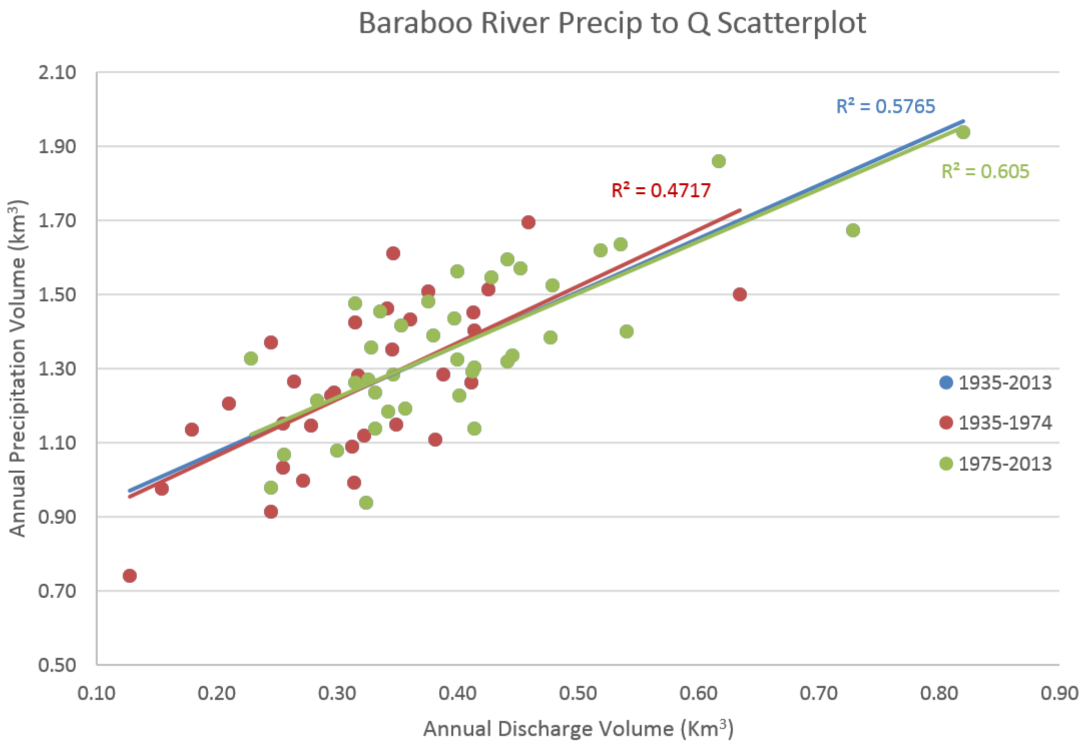
Appendix H-5. Precipitation to discharge correlation for the Missouri River basin.



Appendix H-6. Precipitation to discharge correlation for the White River basin.



Appendix H-7. Precipitation to discharge correlation for the Baraboo River basin.



Appendix H-8. Precipitation to discharge correlation for the Chippewa River basin.