DEPARTMENT OF NATURAL RESOURCES

Appendix A: Case Studies of Streamflow

Appendix to the Water Availability and Assessment Report

09/15/2020

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Appendix A: Case Studies of Streamflow

From a statewide perspective, conditions continue to get wetter (see climate section). For the 10-year period of water year 2010 through water year 2019, watersheds across Minnesota rank in the normal (20), above normal (60), and high flow (1) category (Figure A-1). This is similar to the previous 10-year period of water year 2000 through water year 2009, the major difference being a shift to a wetter period for a greater portion of the state, with more watersheds in the above-normal/high flow versus normal flow rank. The percentage of watersheds in the above normal or high flow ranking increased from 54% to 75% between these two 10-year periods.

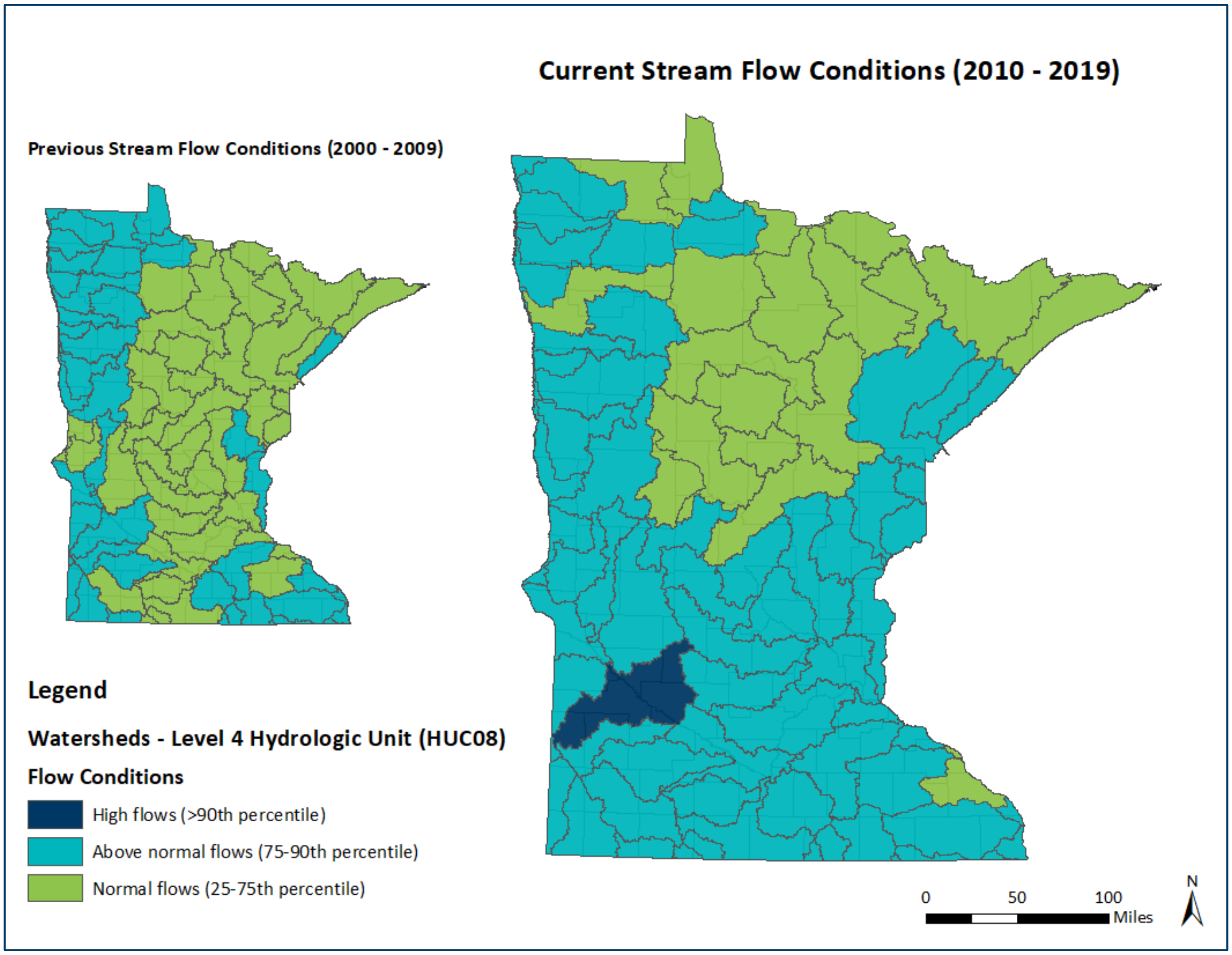

Figure A-1. Streamflow conditions from 2010 through 2019

Streamflow Changes – Select Watersheds

The DNR examined four streams, representing four major basins across the state, to further assess streamflow conditions in Minnesota (Figure A-2). These streams were chosen to further investigate conditions for a portion of the Upper Mississippi River, a Minnesota River watershed, a Red River watershed, and a large portion of the Rainy River basin.

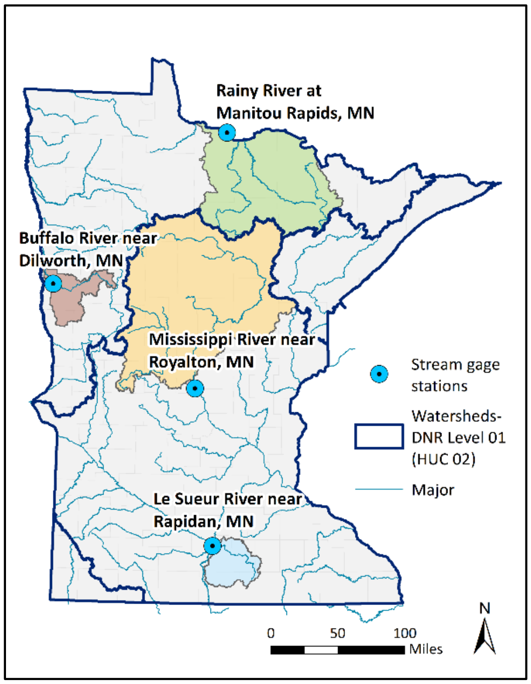

Figure A-2. Streamflow case study locations

Mean Annual Precipitation and Mean Annual Streamflow

Precipitation and streamflow have increased over the period of record for all streams examined (Figure A-2). To evaluate the patterns of change, precipitation (mean annual, inches) and streamflow (mean annual, cfs) were plotted for each site, and mathematically derived 'breakpoints' were calculated. Presence of a significant breakpoint indicates a shift in either the mean value or variance or both. For the break point analysis only, the time-series was converted to a trend-free, filtered series. The serial correlation was removed from the data series while leaving the trend intact using the technique described in Yue et al. Break points were determined using the e.divisive function in the ecp R package. All other statistics were based on raw data.

At all sites, the mean annual values and the corresponding 95% confidence interval (CI) show significant change after the identified breakpoint. Break point changes occurred in 3 of the 4 sites examined at 1940.

The breakpoints compute a statistically significant point of change (mean or standard deviation) in the dataset – but they do not tell us why the change occurred. Timing and the degree of breakpoint alignment between plots of precipitation and streamflows can help indicate whether the change resulted from climate or land use changes, or a combination.

- The Buffalo River at Dilworth (Figure A-3) had a break point in the early 1990s, though it was somewhat disconnected to the precipitation break point, which was closer to 2000. As the streamflow change preceded the precipitation change, this suggests a land use impact may have affected this watershed prior to climate change impacts.

- The absence of the 1940 break point for the LeSueur River (Figure A-4) likely reflects the lack of data during this period for discharge. However, the precipitation pattern did not change significantly during this same time. For the LeSueur River, both precipitation and streamflow breakpoints occurred around 1990, when mean annual values increased significantly. The close alignment of the Le Sueur River precipitation and streamflow breakpoints suggest that climate change (increasing precipitation) plays a major role in the increasing flows seen at this site. The magnitude of mean annual flow changed substantially in 1990, from previous decades and to a greater extent than precipitation, suggesting additional influence of land use in the change. Based on this assessment, it appears that both climate and land use changes have influenced mean annual flow changes in the LeSueur River.
- The Mississippi River at Royalton (Figure A-5) and the Rainy River at Manitou Rapids (Figure A-6) had a singular break point at 1940.

Mean Seasonal Precipitation and Streamflow

Seasonal flows are important to the ecology of river systems. Aquatic life in rivers has adapted to all parts of the hydrologic regime. Winter flows, which can be among the lowest of the year, provide refugia. Spring flows impart dispersal and reproductive triggers and provide access to floodplains and from headwaters to the river mouth. Summer flows supply conditions favorable for growth and recruitment. Fall flows establish connectivity to stable, predictable habitat conditions.

Mean annual flow potentially masks seasonal variations in flow. Huge variations, like severe drought and major flooding, may occur in the same year but are not revealed by the mean. To examine seasonality of flow and its relationship to rainfall over time, we plotted mean seasonal precipitation (inches) and mean seasonal discharge (cfs) for each of the sites. As plotted, *fall* months included October, November, and December; *winter* months included January, February, and March; *spring* months included April, May, and June values; and *summer* months were July, August, and September. Two of the sites were in agricultural areas of the state, the Buffalo River (Figure A-7) and the Le Sueur River (Figure A-8). These show marked increases in spring flows - greater than expected - relative to the precipitation increase in the same season. This likely reflects increases in runoff from drainage and a shift from perennial vegetation to row crops. For the Upper Mississippi River (Figure A-9) and the Rainy River (Figure A-10), the pattern of precipitation and flows match more closely for all seasons.

Annual Peak Flows for the 25-year Recurrence Interval (RI)

High flows represent disturbance but are essential elements of river hydrology. They maintain the balance of species in stream and riparian communities, sort coarse substrates, providing habitat in the channel, shape the physical habitat of the floodplain, flush organic material (food) and woody debris (habitat structure) into the channel, disperse seeds and fruits of riparian plants, and drive lateral movement of the river channel, forming new habitats.

Flood flows were examined for the 25-year Recurrence Interval (RI). Flood frequency analysis was performed using the USGS program PeakFQ version 7.3. The Bulletin 17B method was used for the analysis of the Le Sueur River while the more recent method Expected Moments Algorithm (EMA) was used on the other rivers. Additionally, the map-based weighted regional skew was used, and historic peaks were not considered. The mean discharge break point was used for the peaks.

- Buffalo River flood flows (mean 25-year RI) increased after each break point (1940, 1994), but were accompanied by large increases in variability (Figure A-11). Land use changes in this watershed may be adding to the hydrologic alteration due to climate change.
- For the Le Sueur River (Figure A-12), the mean 25-year peak flow increased after the break point at about 1990, along with the variability of these events, as evidenced by comparison of the 90% CI lines before and after the break point. The increases seen here are likely resulting from climate change. Land use is generally not seen as an important influence for high flow events, as the magnitude overwhelms the landscape's ability to absorb the water, regardless of vegetative cover.
- The Mississippi River (Figure A-13) had a significant increase in the mean 25-year flood flow after 1940.
- The increase in average 25-year flood flows for the Rainy River (Figure A-14) was minimal after the 1940 break point, and variability of flood flows decreased dramatically – likely the result of hydropower operations upstream at International Falls, MN.

August Baseflows

Low flows in river systems provide refugia for aquatic organisms, maintain suitable temperatures, DO, and water chemistry, during summer months enable fish to move to feeding and spawning areas, and suspend fish and amphibian eggs, protecting their viability.

The bf_eckhardt function available in the FlowScreen R package was used for the separation of baseflow (the same as the default in the WHAT web-based hydrograph analysis tool). The mean discharge break point was used for the baseflow analysis.

- The baseflow increase in the Buffalo River (Figure A-11) was consistently positive after 1990, providing the clearest pattern of change in this parameter for the sites examined.
- An increase in mean August baseflow was noted after the 1990 break point for the Le Sueur River (Figure A-12). Percent change in August baseflow for each decade revealed that the baseflow increase was fairly rare for this site, occurring in only three of the eight decades with data, and not entirely consistent. After increasing to the maximum value in 1990, the decadal mean fell below the grand mean for the 2000 decade and increased again during the 2010 decade. Also, examination of the annual August baseflow values show that a few very high flows in August are responsible for these increased decadal means.
- Significant baseflow increases occurred after the 1940 break point for the Mississippi River (Figure A-13) and the Rainy River (Figure A-14), but the pattern of change (increasing) was not entirely consistent, from decade to decade.

Number of Days at the Bankfull Flow (1.5 year RI)

Bankfull flow is used as an index for all the flows that form river channels. It ranges between the 1.1 and 2-year event and is most commonly equated with a 1.5-year RI, especially in cases where field measurements are not available. Bankfull flows move the most sediment over time, and therefore shape and maintain the channel and the habitat within it. As such, bankfull flows are geomorphologically and ecologically important.

We investigated changes to bankfull flows by looking at the number of days the 1.5-year RI was equaled or exceeded for each decade in the period of record. The distribution of these values for each decade within the period of record is presented in Figure A-15, Figure A-16, Figure A-17, and Figure A-18.

An increase in variability for the number of days bankfull flow was reached or exceeded is apparent after 1950. The most recent decade, 2010–2019, showed the greatest variability and highest median value: 50% of bankfull flows occurred for 20 days or more. This represents a doubling of the mean number of days at bankfull for 50% of the time. The increase in days at or above the bankfull flow was consistent after 1990, and grew in magnitude, from 31% increase above the mean value (9.8 days) for the 1990 decade to 128% of the overall mean for the 2010 decade.

Summary of Streamflow Changes

Overall, streamflow changes occurred at all the sites examined. Conditions are wetter across all the sites. Seasonal changes in spring flows were greatest for sites in watersheds with predominantly agricultural land use. Peak flows (25 year RI) increased at all sites after the break points, but were greatest on the Mississippi River. Increased variability (width of the 90% CI) was noted for the agricultural watersheds and may reflect additive change from land use. Increases in the August baseflows after the break point were also noted for all watersheds, but the pattern of increasing baseflow was not entirely consistent from decade to decade for all sites except the Buffalo River, which consistently saw increased baseflows after 1990. The duration of days of bankfull events, when examined for each decade, has increased substantially for all sites after the break points. The most consistent changes were noted after the 1990 break point for the Le Sueur River, and for the Buffalo River site, though less markedly. The bankfull duration for the Mississippi River site increased notably during the last decade.

Overall, the changes noted likely reflect a combination of climate change and land use impacts, with the relative contribution of these factors determined by the type and intensity of human activity in a particular watershed.

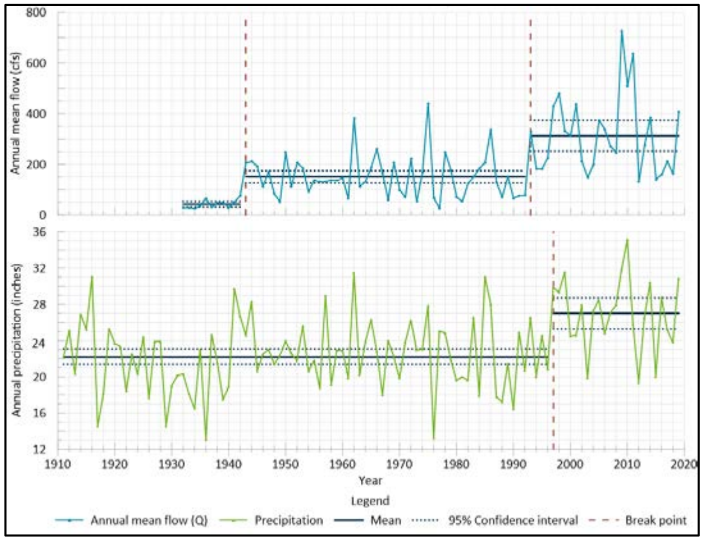

Figure A-3. Mean annual precipitation and streamflow on the Buffalo River near Dilworth (1910-2019)

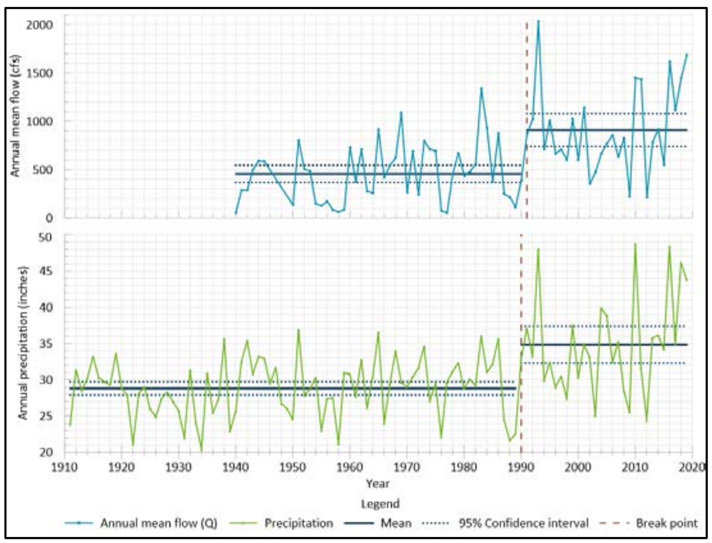

Figure A-4. Mean annual precipitation and streamflow on the Le Sueur River near Rapidan (1910-2019)

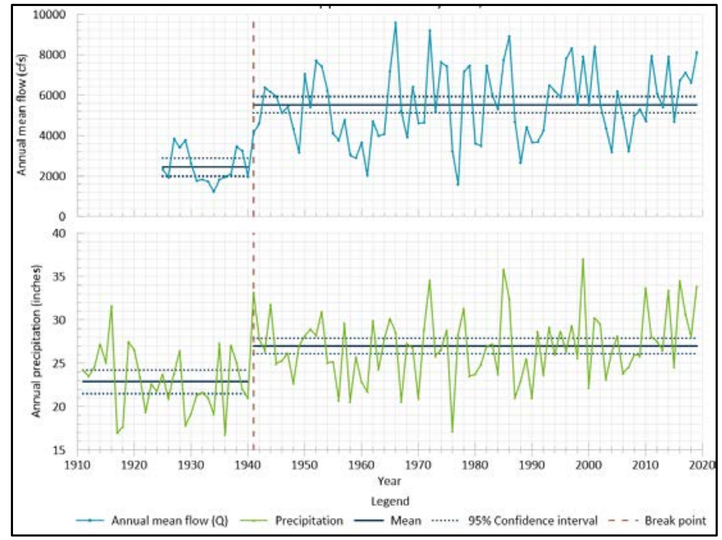

Figure A-5. Mean annual precipitation and streamflow on the Mississippi River near Royalton (1910 - 2019)

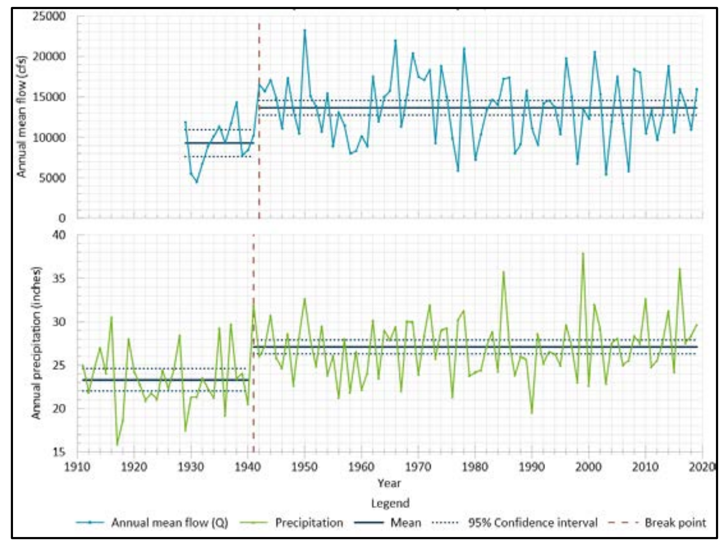

Figure A-6. Mean annual precipitation and streamflow on the Rainy River near Manitou Rapids (1910-2019)

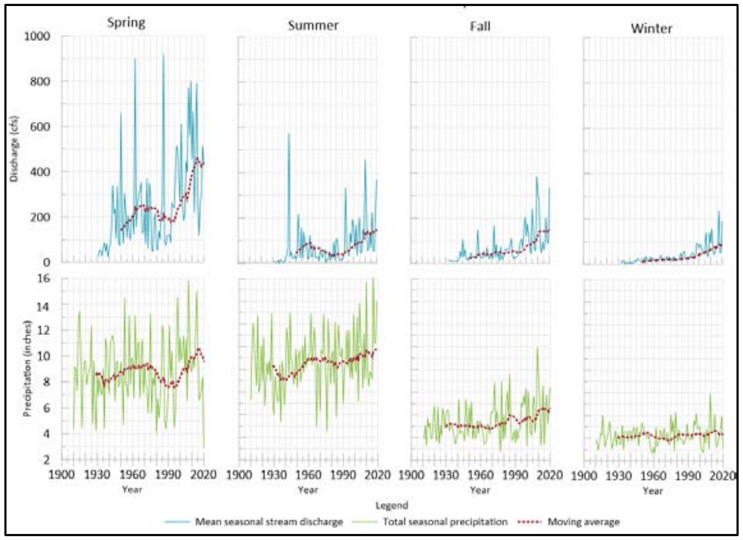

Figure A-7. Seasonal discharge and precipitation on the Buffalo River near Dilworth (1910-2020)

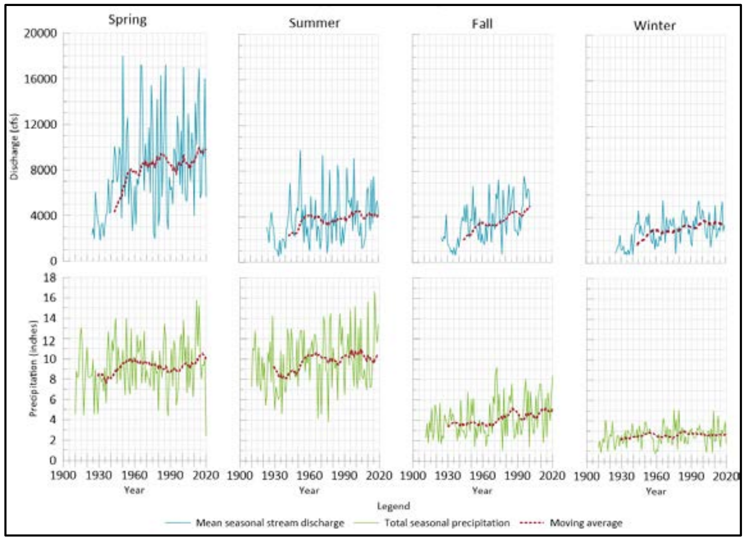

Figure A-9. Seasonal discharge and precipitation on the Mississippi River near Royalton (1910-2020)

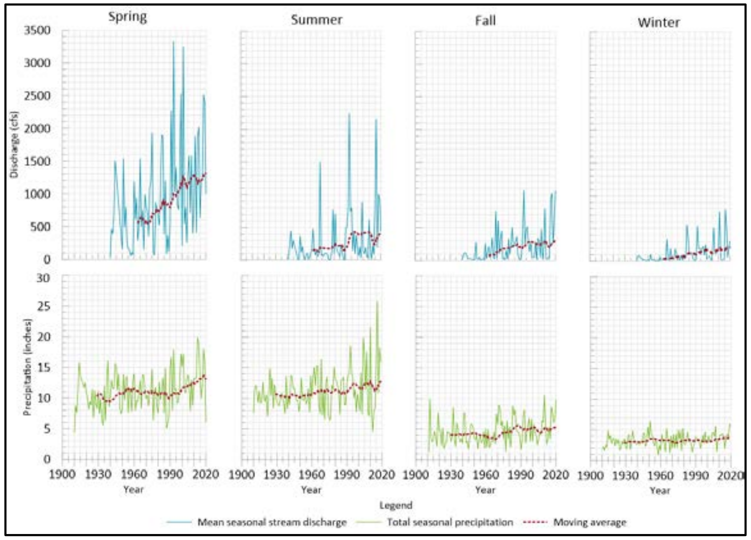

Figure A-8. Seasonal discharge and precipitation on the Le Sueur River near Rapidan (1910-2020)

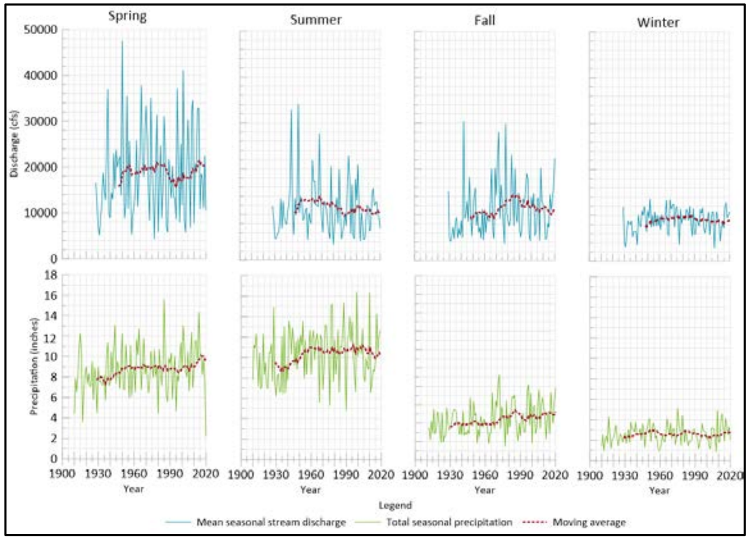

Figure A-10. Seasonal discharge and precipitation on the Rainy River near Manitou Rapids (1910-2020)

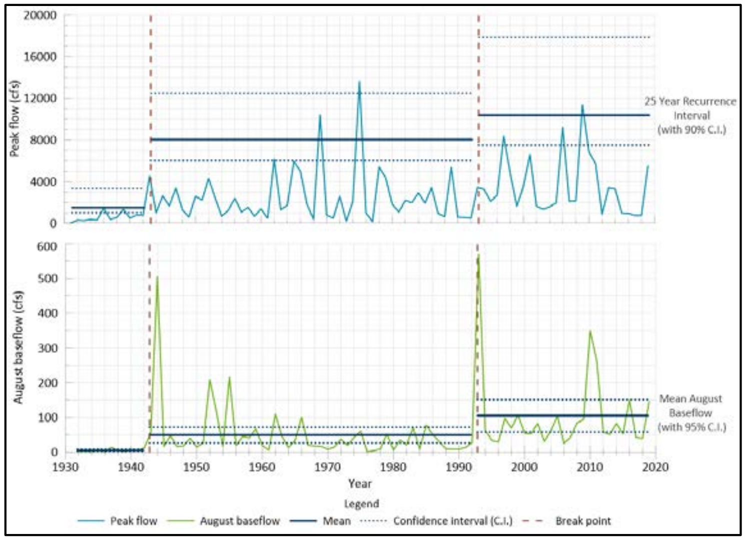

Figure A-11. Peak flow with 25-year recurrence interval and August baseflow on the Buffalo River near Dilworth (1931-2019)

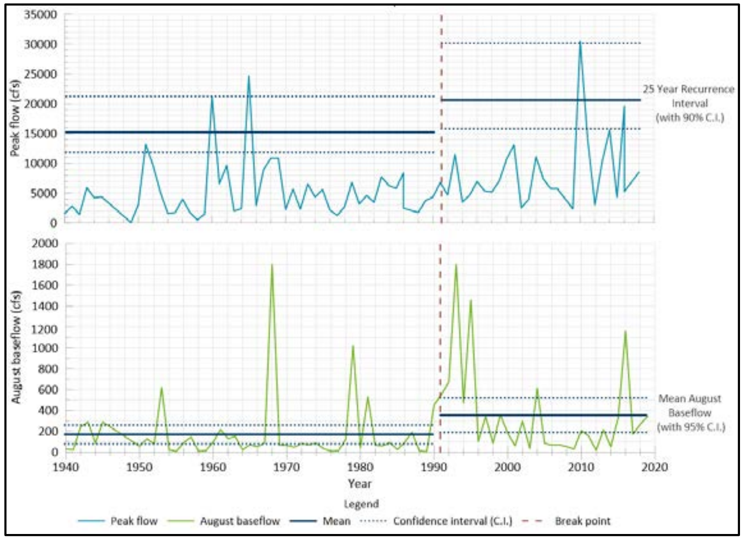

Figure A-12. Peak flow with 25-year recurrence interval and August baseflow on the Le Sueur River (1940-2019)

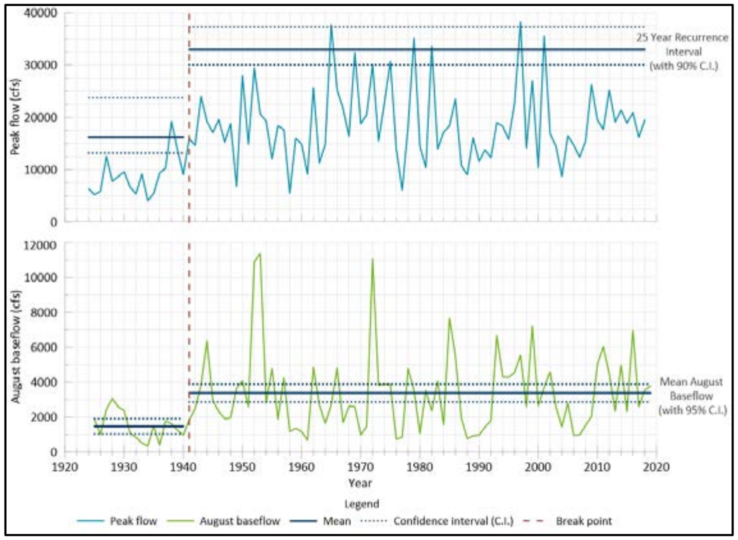

Figure A-13. Peak flow with 25-year recurrence interval and August baseflow on the Mississippi River (1924-2019)

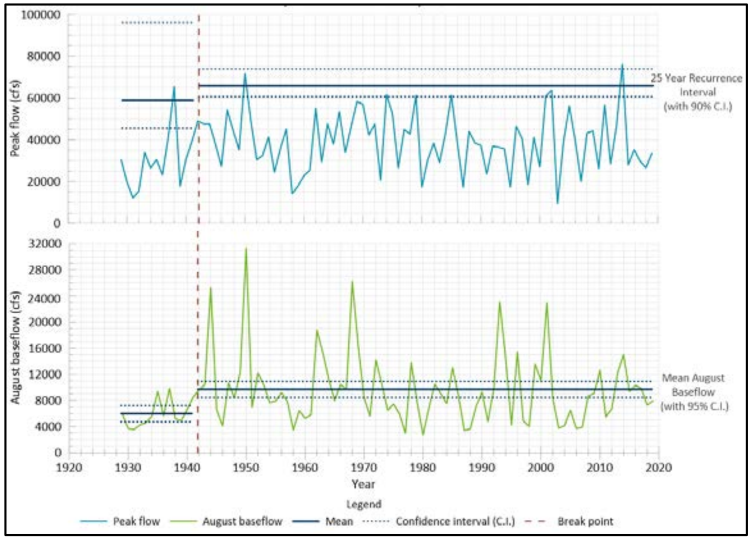

Figure A-14 Peak flow with 25-year recurrence interval and August baseflow on the Rainy River (1929-2019)

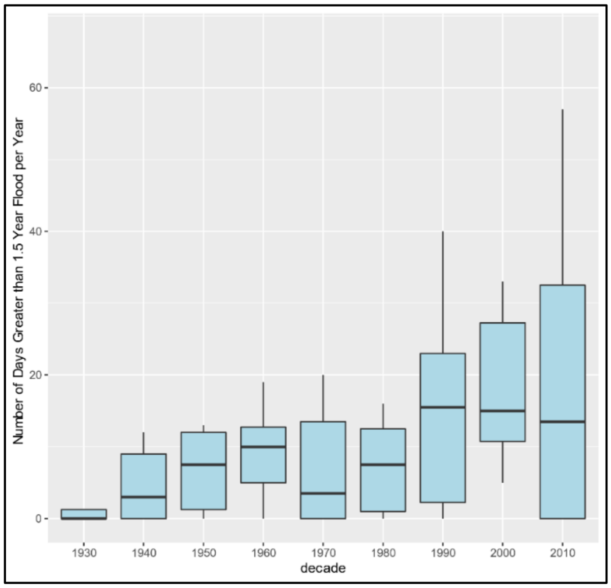

Figure A-15. Number of days the 1.5-year event is equaled or exceed during each decade on the Buffalo River near Dilworth

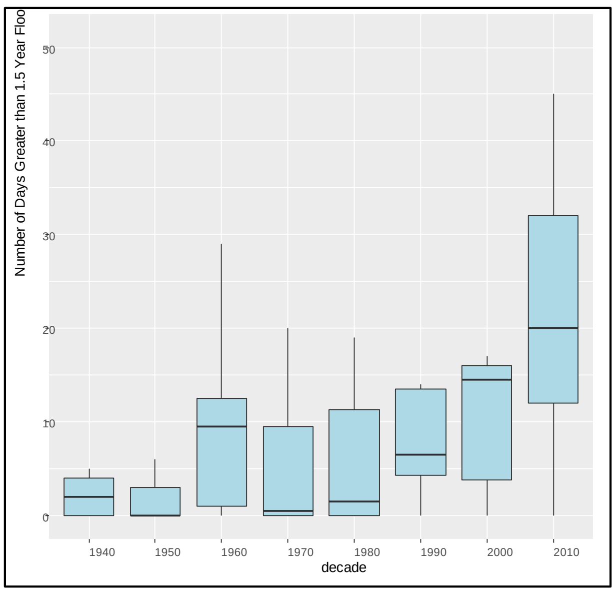

Figure A-16. Number of days the 1.5-year event is equaled or exceed during each decade on the Le Sueur River near Rapidan

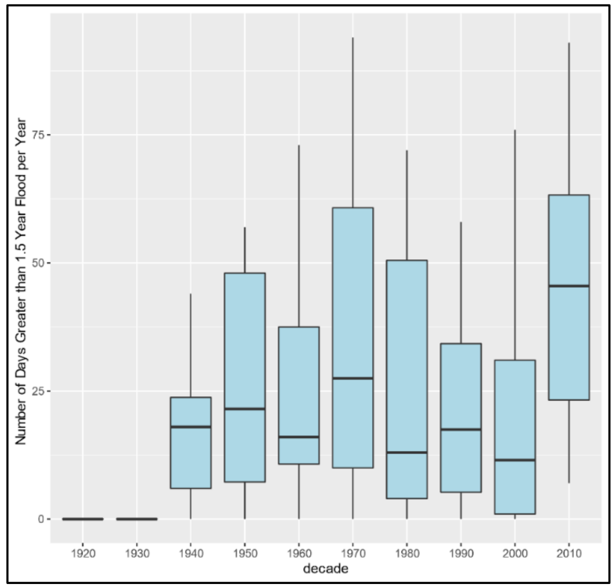

Figure A-17. Number of days the 1.5-year event is equaled or exceed during each decade on the Mississippi River near Royalton

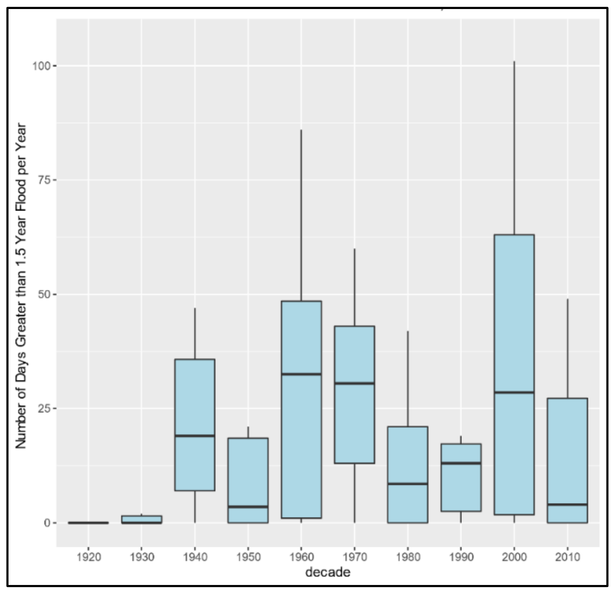

Figure A-18. Number of days the 1.5-year event is equaled or exceed during each decade on the Rainy River near Manitour Rapid