Appendix B: Lower St. Croix Watershed Water Storage Analysis

Lower St. Croix River Comprehensive Watershed Management Plan

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Lower St. Croix Watershed

Water Storage Analysis

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DEPARTMENT OF NATURAL RESOURCES

Purpose:

The Lower Saint Croix River (LSCR) One Watershed One Plan (1W1P) Advisory Team has identified the need to assess water storage as a means to improve/protect watershed hydrology. Pre-settlement hydrologic conditions identified by the team as a desired future condition will likely need a set of incremental benchmark goals to meet shorter term planning goals. The purpose of this analysis is to identify storage volumes needed to reach the desired future condition or some proxy which best represents that condition as well as any possible benchmarks which would have a positive impact on watershed hydrology.

Data:

The LSCR water storage analysis will use three primary sets of information. The first data set is the historic discharge record for the Saint Croix River at the United States Geological Survey (USGS) stream gaging station at St. Croix Falls, WI (5340500). The gage has the longest data record for discharge in the watershed but is located approximately 52 miles upstream of the confluence of the Saint Croix River and the Mississippi River. A substantial portion of the LSCR watershed, 258 square miles (28%), is not capture by this gage. Additionally, a large portion of the Upper Saint Croix River's watershed discharges to this gage. The use of this data set therefore requires an assumption that the hydrologic trends identified are also representative of the LSCR watershed. A targeted approach representing the LSCR Watershed specifically will determine potential water storage volumes.

The second data set used in this analysis is watershed averaged precipitation data going back to the late 19^{th} century. The dataset utilizes gridded monthly precipitation totals averaged over major watersheds within the state and compiled by the Minnesota State Climatology Office.

The third data set consists of Soil and Water Assessment Tool (SWAT) model output runs characterizing sub-watershed runoff volumes from 1998 to 2007 obtained from the St. Croix Research Station director Jim Almendinger.

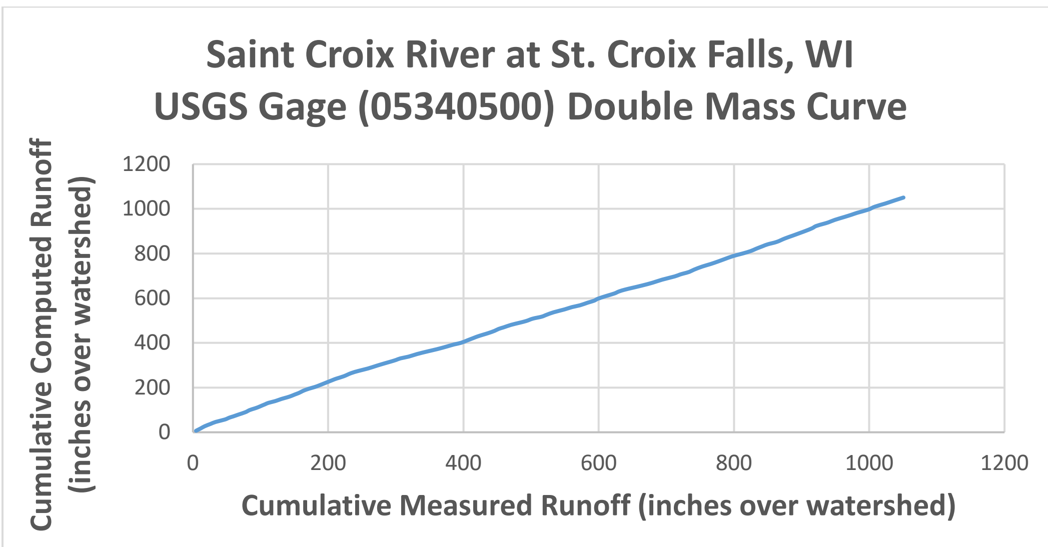
Analysis:

The approach to determining storage goals for the LSCR watershed comprises three parts. The first part uses a series of analyses to identify changes in hydrologic conditions over time and to determine succinct periods in the records where alteration has occurred. The second part utilizes the points in time established in the first part to separate historical data and look at trends before and after the periods of change. The third and final part takes those trends and attributes the larger watershed relationships to subwatersheds delineated in the SWAT model by applying runoff ratios calculated within the model. This creates targeted goals that are representative of the physical conditions driving hydrology throughout the watershed. These subwatershed goals can then be prioritized and appropriate management strategies developed.

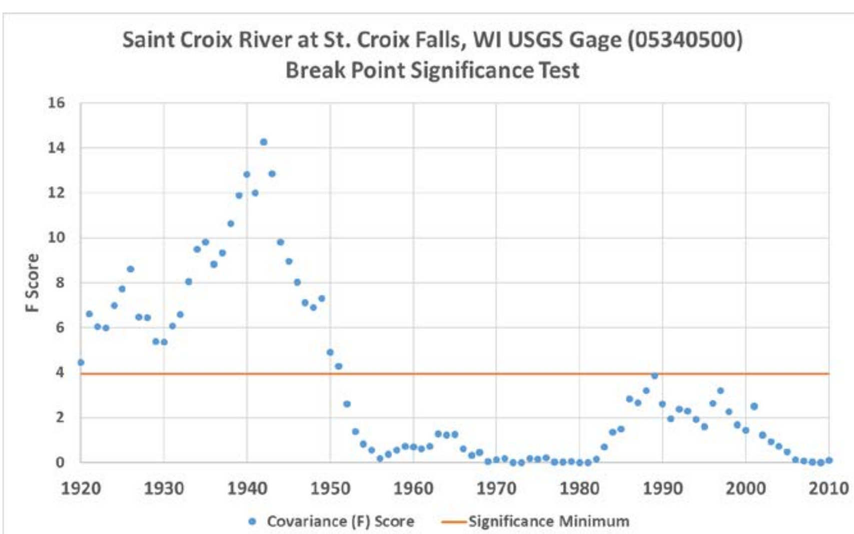
Part 1:
The first analysis in this part utilizes methods in the USGS Manual of Hydrology: Part 1 (Searcy J.K and Hardison C.H., 1960) to calculate a double mass curve comparing the relationship between the annual mean discharges from the USGS stream gage with a computed annual mean discharge dataset. The

computed discharge dataset derived from the relationship between effective annual precipitation and measured annual discharge removes the non-linear relationship between precipitation and discharge, as it would otherwise violate the premise of the double mass curve. Effective precipitation consists of a percentage of both past and current year's precipitation, which produces the current year's annual discharge, and compensates for the lag seen from groundwater storage and other factors.

The results from the double mass curve do not show a visual break in the relationship through the period of record (a). A covariance test determining the variance around a line of regression calculates the degree of significance that two data sets do not represent a consistent record. Assessment of the two variables in the double mass curve using each year of the period of record as a separation point for a pre and post data sets excluded the first and last decades. The strongest significant breaking point (95% significance) located at the year 1942, had the highest F value (b).

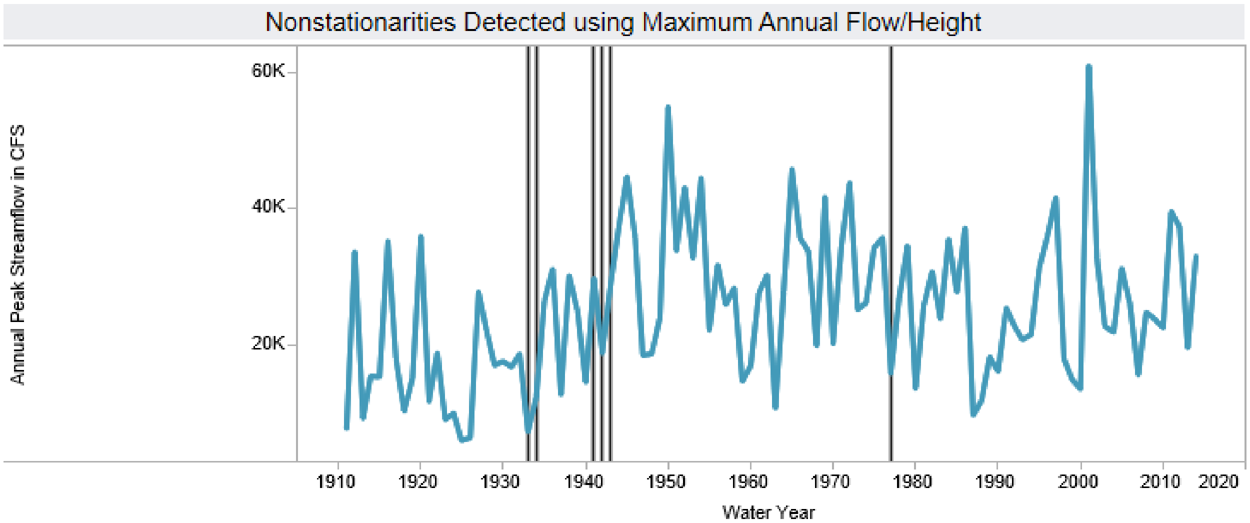


a. Double Mass Curve



b. Covariance Analysis Results

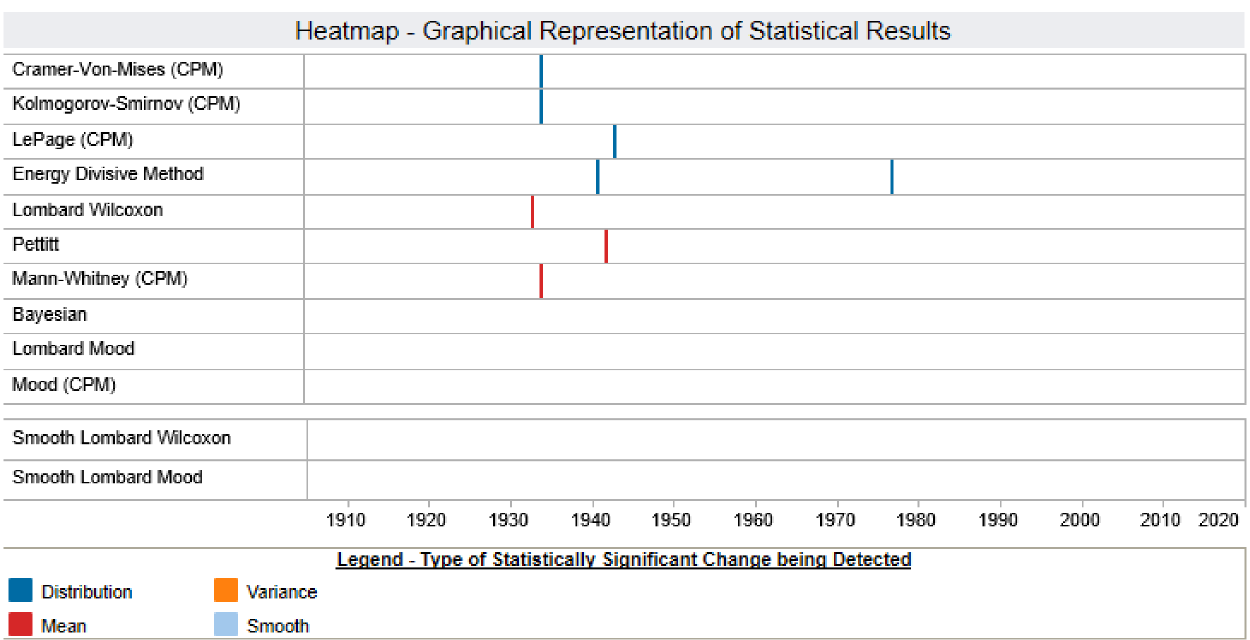
The next analysis utilizes the United States Army Corps of Engineers (USACE) Nonstationarity Detection Tool (Friedman D., 2018). The tool runs multiple statistical tests on annual peak data at the St. Croix Falls USGS gage to determine breaks in stationarity in the hydrologic record (c). Identified breaks in both distribution and mean identified around 1934 and 1941 indicate possible hydrologic alteration.



This gage has a drainage area of 6,240 square miles.

The USGS streamflow gage sites available for assessment within this application include locations where there are discontinuities in USGS peak flow data collection throughout the period of record and gages with short records. Engineering judgment should be exercised when carrying out analysis where there are significant data gaps.

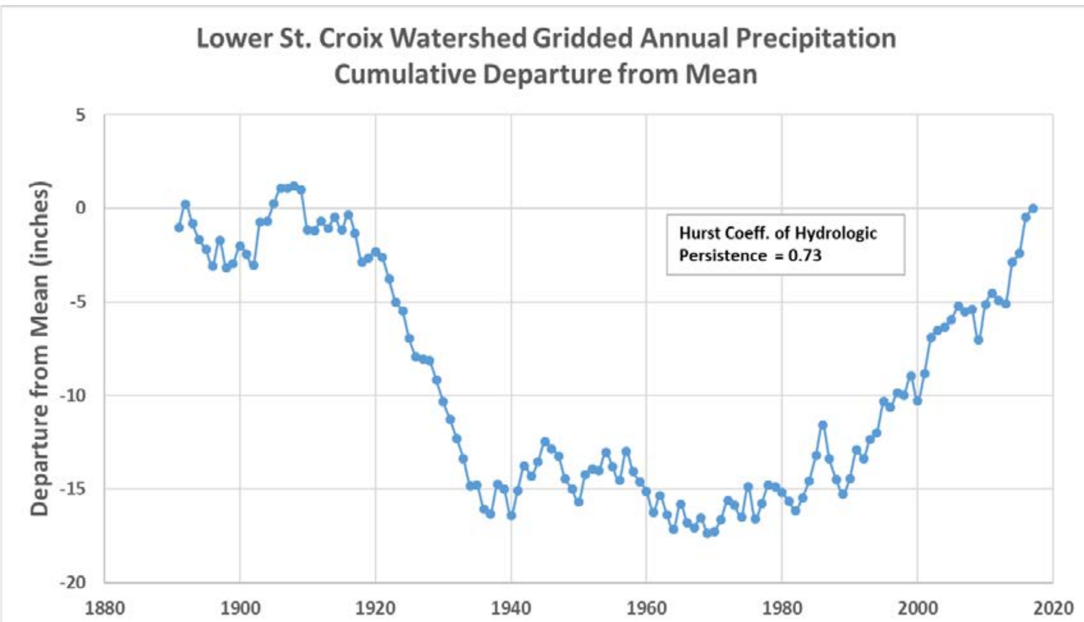
In general, a minimum of 30 years of continuous streamflow measurements must be available before this application should be used to detect nonstationarities in flow records.



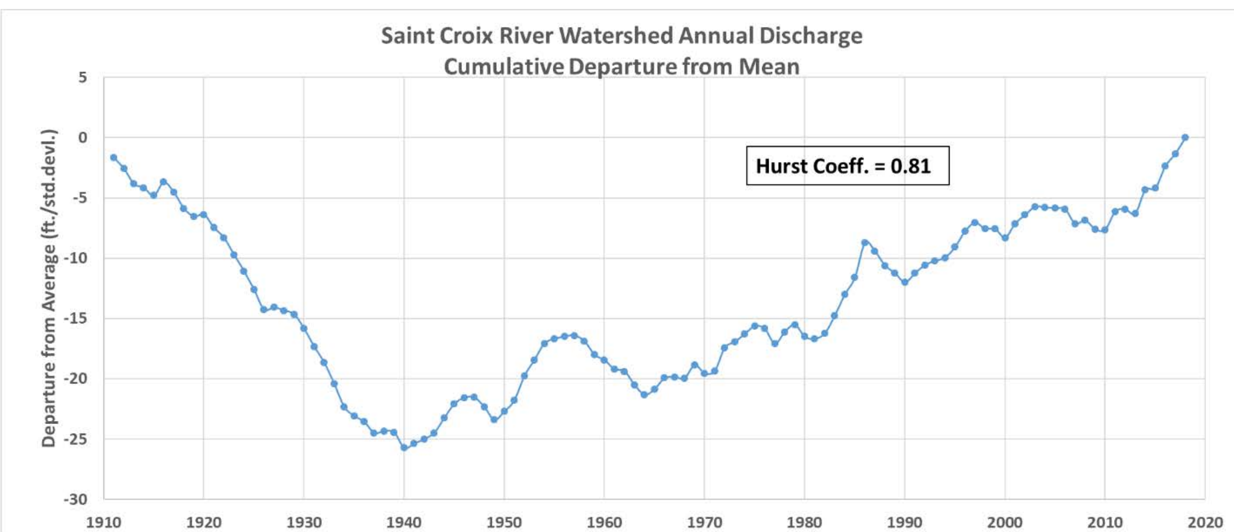
c. USACE Nonstationarity Detection Tool

The third analysis calculates the HURST coefficient and identifies the persistence of a record to behave in a non-random manner (Hurst H.E., 1951). Values from one-half moving towards one indicate a more strongly persistent data set where increasing values are more likely to follow increasing values and decreasing values following decreasing values.

The HURST coefficients from both the precipitation and discharge records were computed (0.73 and 0.81 respectively) and the annual cumulative departure from the mean for those records were graphed by dividing by the standard deviation to normalize the data (d,e). The negative slopes in both graphs from around 1910 to 1940 indicate annual values consistently below the mean value of the overall record, indicative of a period of drought. From 1937 to 1940, both data sets show a break in slope and generally increase to the end of the record.



d. Annual precipitation cumulative departure from mean

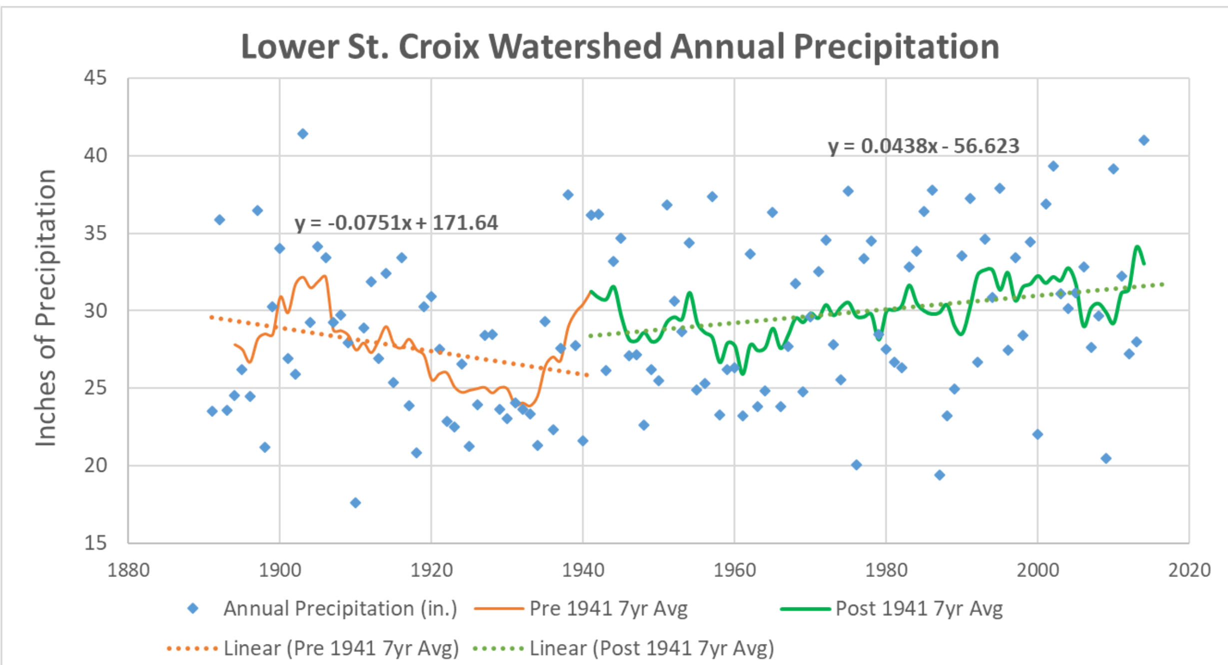


e. Annual discharge cumulative departure from mean

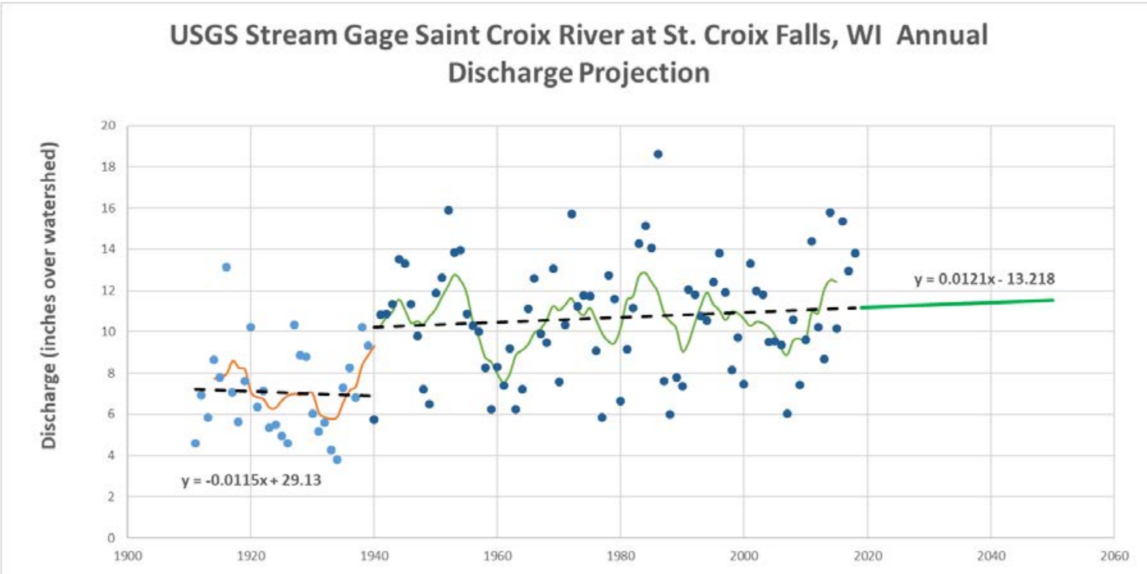
The Double Mass Curve analysis, the Nonstationarity Detection tool, and both cumulative departure analysis' of precipitation and discharge identified points between 1940 to 1942 as the most likely change period in the historical record. The middle of this period at 1941 is therefore determined to be the best representative breaking point to separate current hydrologic function with historic hydrologic conditions.

Part 2:

The precipitation and discharge records are separated into two time-periods to determine trends (beginning of record – 1941 and 1941 to present). Linear equations based on a 7 year running average of the data for each record are computed pre and post 1941 and the equation for the post break point data set forecasted forward to 2050 represents future conditions. 2050 was chosen as the target year as it is often an output for forecasted climate models and runs approximately 30 years from the implementation start of the 1W1P for the LSCR (f,g).



f. Annual Precipitation with 1941 Change Point



g. Annual Discharge with 1941 Change Point

Part 3:

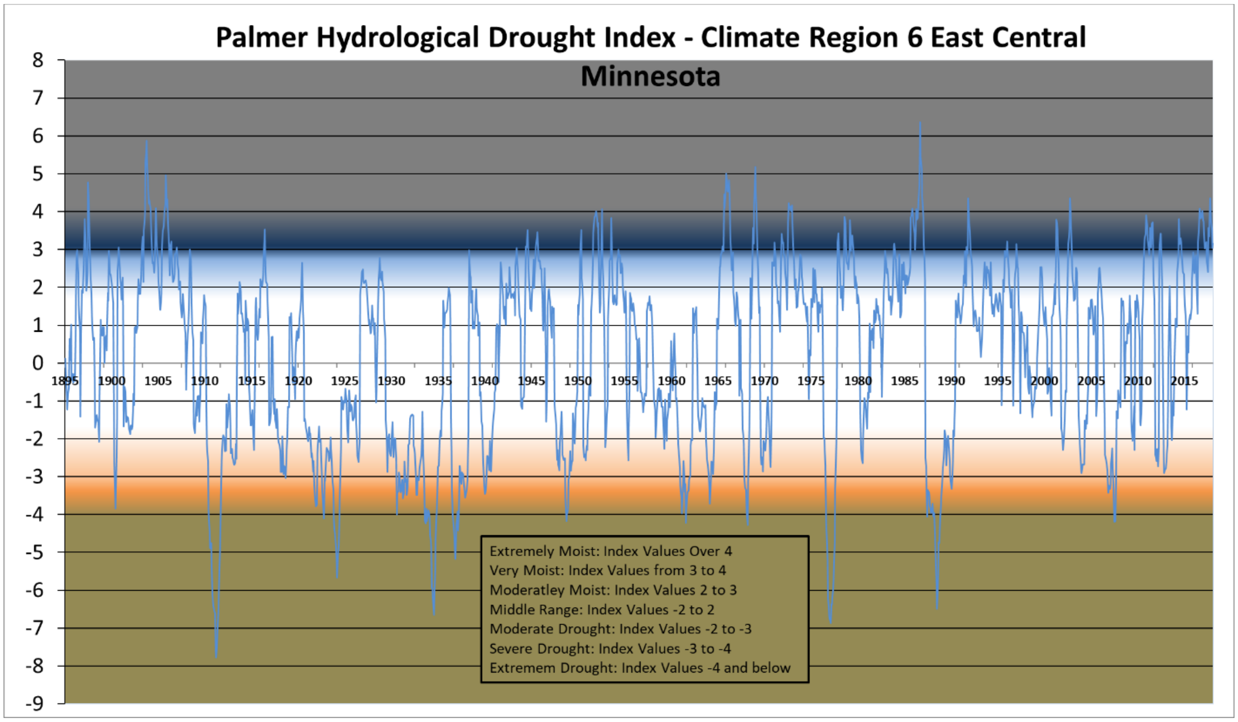
The final step of the analysis computes the changes in runoff for the LSCR and its subwatersheds based on two distinct periods. The first period begins at the point of hydrologic change at 1941 and ends at the most current year of data at 2018. The second period begins at 2018 and goes forward to 2050. Runoff volumes computed at the three years of 1941, 2018, and 2050 for each sub-basin allowed the calculation of runoff reduction goals on a future and past basis.

SWAT model outputs of average annual runoff divided by basin averaged annual precipitation for the model period (1998-2007) create modern runoff ratios per subwatershed to attribute changes at the subwatershed scale.

The modern modeled runoff ratios multiplied by the projected 2050 annual precipitation amount, derived from the post 1941 equation from graph f, created the projected runoff estimates per subwatershed under the assumption that the relationship between precipitation and discharge would remain constant.

The model runoff ratios for each subwatershed multiplied by the 7-year average precipitation from 1941 (f) created runoff estimates per subwatershed reflecting runoff representing 1941 hydrologic conditions.

A pre-1941 runoff ratio adjustment was not computed to adjust the modeled outputs due to the considerable drought persisting through most of the discharge records in the period prior to 1941 (h). Doing so would have estimated much less runoff and would not reflect pre-settlement discharge volumes accurately prior to the drought period.



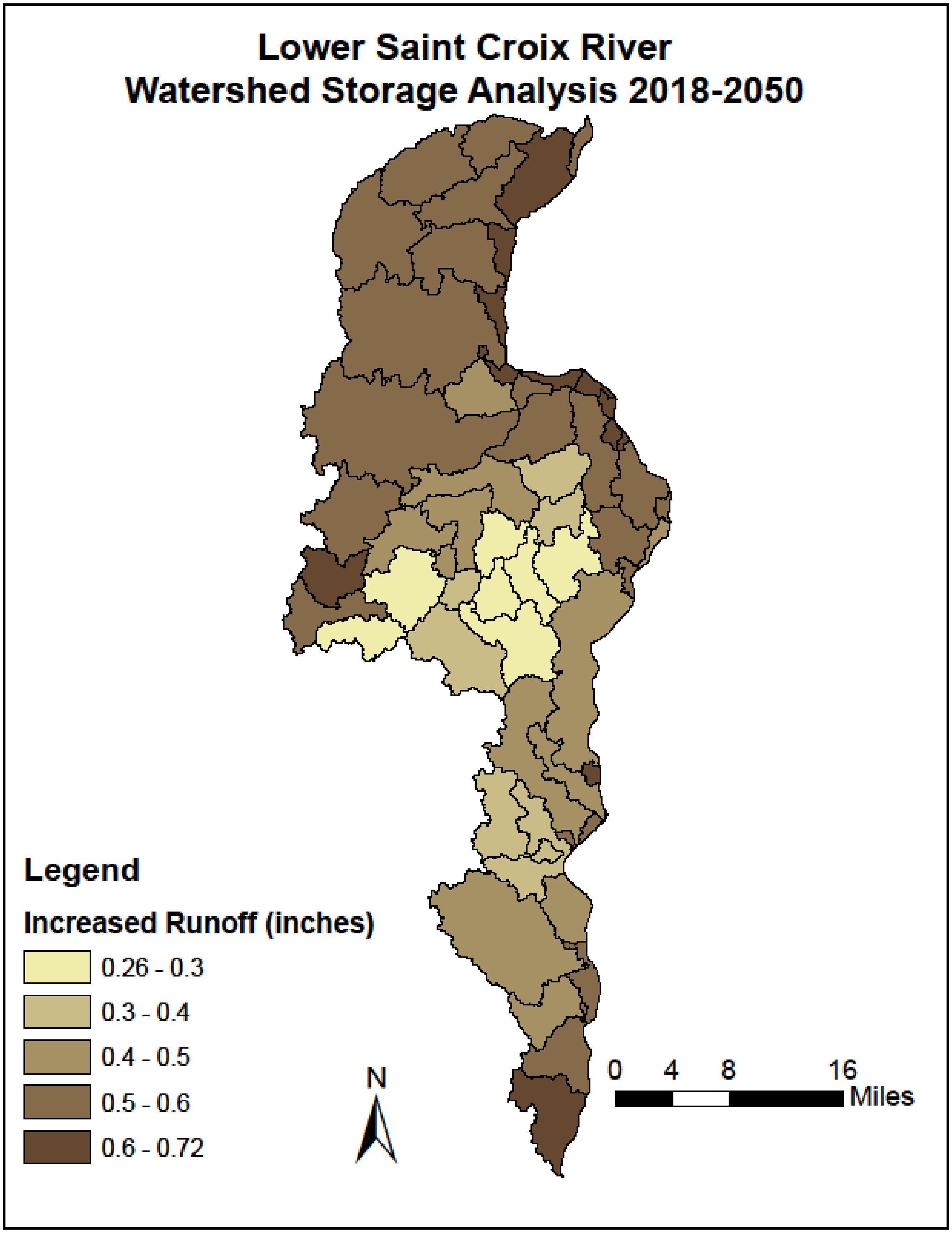
h. Palmer Hydrologic Drought Index

Calculation of the difference in subwatershed runoff volumes for the two periods created two separate runoff volumes to use as water storage goals.

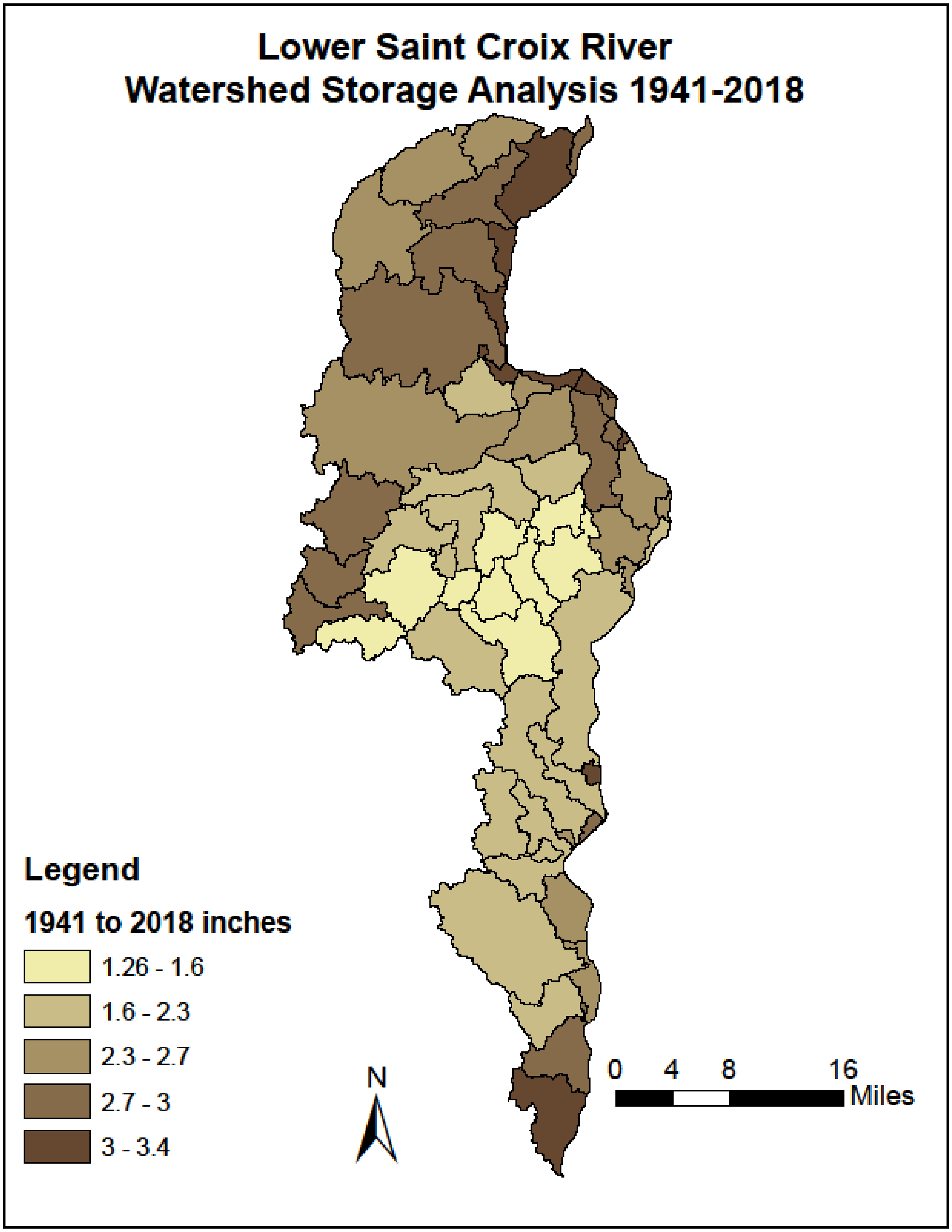
RESULTS:

The two potential basin wide storage goals based on this analysis represent the difference in runoff between the two periods of 1941 to 2018 as well as 2018 to 2050. The subwatershed goals for each period when mapped in geographic information system software provide visual context (i, j). Total watershed reduction volumes calculated by multiplying inches of runoff and area in acres and then converting to feet for each subwatershed create potential watershed wide volume reduction goals in acre-feet.

The 1941 to 2018 water storage goal would equal 2.3 inches over the entire watershed or 113,800 acre-feet of storage (i). The 2018 to 2050 water storage goal would equal 0.48 inches over the entire watershed or a total of 23,600 acre-feet of storage (j).



i. SWAT Modeling Runoff Subwatershed Storage Goal 2018-2050



j. SWAT Modeling Runoff Subwatershed Storage Goal 1941-2018

CONCLUSIONS:

The LSCR watershed is projected to have additional precipitation of 6.34 inches annually by 2050 when compared to pre-1941 averages. Estimates are that 2.78 inches of that additional water will make it into rivers and out of the watershed as discharge. While the volume may seem like a large amount, breaking it into two separate periods provides the possibility for setting long term and shorter-term storage goals.

Considering the watershed as functioning in a stable manner may also be desired since the change in the hydrologic record occurred 78 years in the past. Addressing future water inputs from increased precipitation in this instance may be the most desirable goal.

Either way the SWAT model results enable the prioritization of subwatersheds throughout the LSCB and give light to potential management strategies based on the volume reduction and the location within the watershed.

One example of this might be where a high contributing subwatershed is located along steep blufflands along the river. Finding available areas suitable for water storage may not be possible, but identifying the need to maintain perennial cover to increase interception would be a viable option. Another example would be prioritizing high contributing inland watersheds, which may have degrading wetland complexes that could be restored to increase storage capacity. A third example might be where there is a watershed that has substantial forested acreage requiring protection from clear cutting to prevent increases in runoff while also preventing loss of habitat for wildlife.

Citations

Friedman, D., J. Schechter, Sant-Miller, A.M., C. Mueller, G. Villarini, K.D. White, and B. Baker. (2018), US Army Corps of Engineers Nonstationarity Detection Tool User Guide. US Army Corps of Engineers: Washington, DC.

Hurst, H.E. (1951). "Long-term storage capacity of reservoirs". Transactions of American Society of Civil Engineers. 116: 770.

Searcy J.K and Hardison C.H., “Double Mass Curves. Manual of hydrology: Part 1. General Surface Water Techniques,” US Geological Survey, Water-Supply Paper 1541-B., 1960.