2.6 TEMPERATURE, PRECIPITATION, AND STREAMFLOW TRENDS IN THE MISSOURI BASIN, 1895 TO 2001

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1. INTRODUCTION

The flow of a river, especially a major river, is a wonderful integrator of all the physical process in that river basin. Changes in temperature, precipitation, flow, and land use; agriculture, flood prevention activities, reservoir operations, etc. are all eventually reflected in the flow pattern of the river. The Missouri River is one such major river and at 3727 kilometers, is the second longest river in the conterminous United States (USA), as well as draining 1.37 million square kilometers, which is 17.5% of the conterminous USA. The Missouri River drains all or parts of nine states (MT, WY, CO, ND, SD, NE, KS, MO and IA). Surface temperature and precipitation data are available for these states from 1895 to 2001 (NOAA, 1995). Discharge (flow) data for the Missouri River from 1929 to 2000 is also available (USGS, 2002). The temperature, precipitation, and discharge data are examined for long term trends and compared for relative statistical significance. Potential trends (e.g., climate change) are identified and possible causes discussed. Possible trends in temperature, precipitation, and flow in the Missouri Basin are important as they represent a large part of the conterminous USA and would be useful in decisions concerning future water use and water management.

2. PROCEDURES AND DATA

The U.S. Geological Survey (USGS) provides mean annual streamflow data for many locations across the U.S. The gaging site selected for this study was Hermann, Missouri (USGS 06934500) for its location, length of record, and quality of data. Hermann, located in east central Missouri, is the USGS gaging station nearest the mouth of the Missouri River. As such, the flow at Hermann represents nearly all the flow out of the Missouri Basin. The drainage area above the gage is 1.36 million square kilometers or 99.3 % of the total basin drainage. In effect, all the flow out of the Missouri Basin must go by the Hermann gage. Streamflow data is available for Hermann from 1929 through 2001. Statewide monthly precipitation and monthly average temperatures are available from 1895 through 1999 from the National Climate Data Center (NCDC), a part of NOAA.

Streamflow data, for the period of record, was analyzed for mean annual flow, standard deviation of mean annual flow, maximum and minimum annual flows, and slope or trend of the best fit line of a time series plot. The regression coefficient, sometimes called the slope or trend of the best fit line, indicates the long term trend of the data. A zero regression coefficient would indicate no identifiable trend; a positive coefficient would indicate increasing values while a negative coefficient would indicate decreasing values for that data with time.

Similar analysis was done for temperature and precipitation data. In the case of temperatures, the state monthly mean temperatures were averaged to produce a mean annual temperature for each year of record for each state which contributes flow to the Missouri River. The state annual mean temperatures for CO, IA, KS, MO, MT, NE, ND, SD, and WY were then averaged to produce a basinwide mean annual temperature for the entire Missouri Basin. A similar process was repeated for precipitation data except the value used was the annual mean precipitation value for each state. This resulted in a mean annual precipitation value for each year for the entire Missouri Basin. Thus it was possible to compare the mean annual streamflow of the Missouri River at Hermann with the mean annual precipitation and mean annual temperature for the entire basin in a time series format. Also, the time series format presented an opportunity to look at long term trends in flow, temperature, and precipitation for the Missouri Basin.

3. RESULTS

3.1 *Temperature Analysis*

Table 1 presents the results of the temperature analysis for all states which contribute flow to the Missouri Basin, as well as average temperatures for the entire basin. The most interesting results are those in the column labeled “slope.” As discussed previously, the slope of the best fit line or regression line indicates the long term trend of that data. Some of the states (IA, KS, MO, and NE) have trend lines with values less than 0.005 degrees Centigrade per year indicating little if any observable trend, either increasing or decreasing, in the average annual temperatures. Other states (CO, MT, SD, WY) have higher trends (0.006 to 0.008 degrees Centigrade per year). ND has the largest single increase in average annual temperatures as indicated by a trend of +0.016 degrees Centigrade per year. The average annual increase in temperature for the entire Missouri

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basin, as indicated by the best fit trend line, is +0.006 degrees Centigrade per year.

State/ Basin	Mean	Std Dev	Max	Min	Slope
CO	7.12	0.67	9.38	5.33	0.006
IA	8.65	0.85	11.14	6.49	0.003
KS	12.39	0.81	14.96	11.02	0.004
MO	12.56	0.74	14.22	10.94	0.002
MT	5.64	0.94	9.34	3.39	0.007
NE	9.25	0.80	11.32	7.77	0.004
ND	4.08	1.18	7.21	-0.77	0.016
SD	7.12	0.93	9.44	5.08	0.007
WY	5.30	0.77	7.24	3.24	0.008
Basin	8.01	0.71	9.88	6.47	0.006

Table 1. Temperature Data (Centigrade)
Missouri Basin 1895-1999

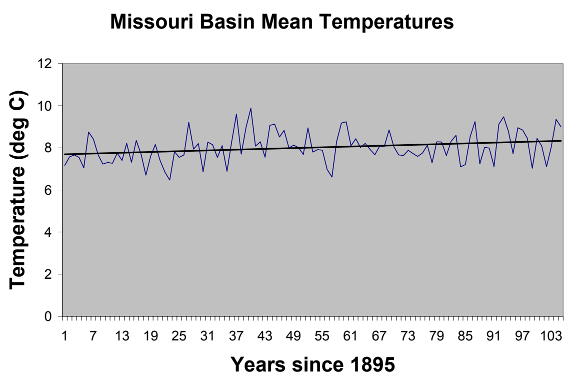

Figure 1. Temperature trend (1895-1999)

3.2 *Precipitation Analysis*

Table 2 presents the precipitation data for the Missouri Basin. Mean annual precipitation is shown for each state which contributes to the flow of the Missouri River. Also shown are maximum and minimum annual precipitation values as well as the standard deviation. The slope or regression coefficient of the best fit trend line is shown in the last column. The mountain states (CO, MT, WY) all show minor negative slopes (-0.238 to –0.138 millimeters per year). The plains states, except for ND, all show minor increase in annual precipitation with trends ranging from 0.218 to 1.225 millimeters per year. ND, which showed the largest annual increase in temperature, showed a regression coefficient of only 0.037 millimeters per year for precipitation. SD, which showed the largest annual precipitation increase at 1.225 millimeters per year, had a moderate temperature increase of 0.007 degrees Centigrade per year. The mean annual precipitation for the entire Missouri Basin was 574.02 millimeters per year with a slope of the best fit trend line of +0.306 millimeters per year.

State/ Basin	Mean	Std Dev	Max	Min	Slope
CO	404.46	61.54	557.78	265.18	-0.138
IA	814.77	131.75	1225.30	505.97	0.844
KS	697.64	130.87	1054.61	390.14	0.637
MO	1037.89	159.51	1444.75	643.13	0.403
MT	390.29	61.01	551.69	252.98	-0.232
NE	578.28	97.40	911.35	368.81	0.218
ND	441.47	71.70	591.31	219.46	0.037
SD	464.72	86.30	658.37	277.37	1.225
WY	336.67	54.48	466.34	216.41	-0.238
Basin	574.02	70.10	771.48	415.88	0.306

Table 2. Precipitation Data (mm)
Missouri Basin 1895-1999

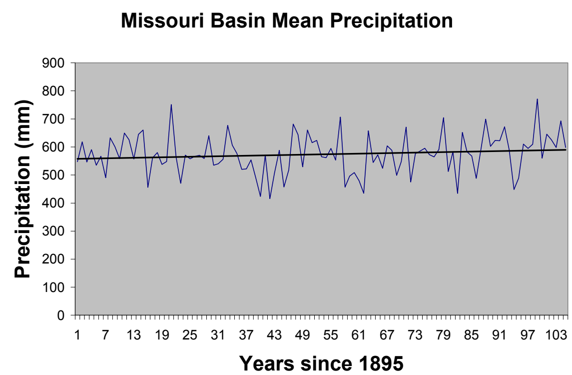

Figure 2. Precipitation trend (1895-1999)

3.3 *Streamflow Analysis*

Table 3 shows the results of the streamflow analysis for the Missouri River at Hermann, Missouri. Again, the slope or regression coefficient of the best fit trend line is interesting. The slope is +16.76 $m^3 s^{-1}$ increase per year (about 0.7% of the mean annual flow). This indicates a positive increase in annual flow out of the basin.

Over the last 73 years, many changes have occurred in the Missouri Basin which have the potential to affect runoff and flow. Numerous reservoirs have been constructed, some of them very large. The river has been channeled for navigation, and flows altered to ensure sufficient flow for barge traffic as well as for flood control. Levees have been built and wetlands diminished. Agriculture has flourished which has included various types of irrigation. Evapotranspiration has no doubt been altered because of wetland effects as well as agriculture and irrigation practices. Population has increased and urban areas expanded. Trends for precipitation and temperature are both positive. One would suspect that some of these changes could increase flow and runoff while others would diminish it. What is interesting is that the combined effect of these changes has resulted in some increase to the total annual runoff from the basin as measured at Hermann, MO.

Mean Flow ($m^3\ s^{-1}$)	2299
Std Dev	873
Max (Year) ($m^3\ s^{-1}$)	5301 (1993)
Min (Year) ($m^3\ s^{-1}$)	890 (1940)
Slope	16.76

Table 3. Annual Mean Streamflow Statistics of the Missouri River at Hermann, Missouri (1929-2001)

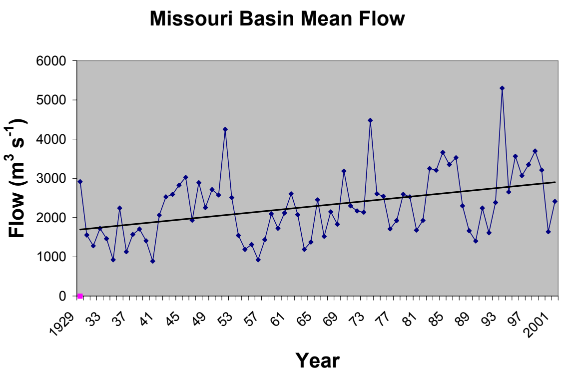

Figure 3. Streamflow trend (1929-2001)

4. TEST FOR SIGNIFICANCE

The data trends were then analyzed to determine if the rate of change over the years was significant using the null hypothesis that the slope, β, of each regression line was equal to zero. The following equations from Johnson (1994) were used:

$$t = (b - \beta)\, s_e^{-1} * \ S_{xx}^{-1/2} \tag{1}$$

and

$$S_{xx} = \Sigma x_i^2 - [(\Sigma x_i)^2 * n^{-1}] \tag{2}$$

where b is the calculated slope of the regression line and s_e is the standard error of estimate.

Using a level of significance of 0.05, the null hypothesis would be rejected if $t < -1.96$ or $t > 1.96$. Values of t for flow, temperature, and precipitation were 3.87, 2.70 and 1.38, respectively. Therefore, trends in flow and temperature were found to be statistically significant (i.e. the null hypothesis was rejected) whereas the trend in precipitation was found to be not statistically significant (the null hypothesis could not be rejected).

5. DISCUSSION and CONCLUSIONS

Based on the analysis and data presented herein, average annual precipitation in the Missouri River basin is increasing slightly at about 3.06 millimeters per decade. Statistically this is not significant. The null hypothesis that the slope of the best fit trend line was in fact zero could not be rejected at the .05 level of significance. The same was not true for average annual temperature. The best fit trend line shows an average increase of .06 degrees Centigrade per decade, which was found to be statistically significant. Average annual flow of the Missouri River at Hermann shows an upward trend also. The slope of the best fit trend line is +16.76 $m^3\ s^{-1}\ y^{-1}$ (annual average flow at Hermann is 2299 $m^3\ s^{-1}$) and again, statistically, this was found to be significant.

The following table, Table 4, shows correlation coefficients between flow, temperature, and precipitation. Since precipitation is the driving force for all flow in the basin (Linsley, et al, 1982), one would expect a high positive correlation coefficient between precipitation and flow. Indeed it is relatively high at 0.75. The correlation of flow with temperature is not as clear. One would expect that with high temperatures, evapotranspiration would increase thus reducing streamflows. On the other hand, increasing temperatures could increase atmospheric water vapor thus producing conditions conducive for increased rainfall. As it turns out, for the data presented herein, the correlation coefficient between flow and temperature is negative and relatively low (-0.42). This would indicate that as temperatures increase, flow tends to decrease, which is typical of summertime flows. This is, however, counter to what was observed in the Missouri Basin since an increase in basin temperature was observed along with an increase in flow. The correlation between precipitation and temperature is even weaker at -0.23. One possible explanation is various seasonal trends tend to cancel each other out. For example, synoptic scale high pressure systems in the summer typically produce dry, warm weather while similar systems in the winter produce dry, cool conditions. (See figures 4 and 5)

The increase in streamflow is interesting and was shown to be statistically significant. The slight increase in average annual flow (+16.76 $m^3\ s^{-1}$) could be due to a combination of various factors. There does seem to be a slight increase in average precipitation, which would increase flow. Flood protection through building levees over the past 50 years, has decreased flood plain area thus decreasing the opportunity for flood flows to percolate into the lower soil mantels. Urban areas have expanded thus increasing the amount of impermeable area and increasing runoff.

	Flow	Temperature	Precipitation
Flow	1.00	-0.42	0.75
Temperature	-0.42	1.00	-0.23
Precipitation	0.75	-0.23	1.00

Table 4. Correlation Coefficients

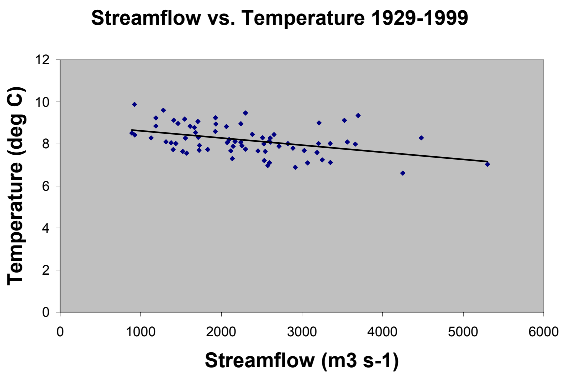

Figure 4. Streamflow vs. Temperature

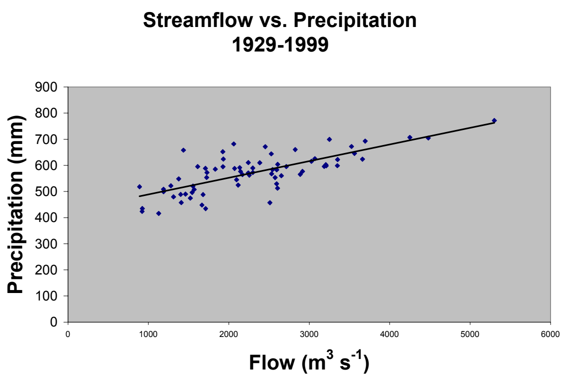

Figure 5. Streamflow vs. Precipitation

Navigation concerns have prompted continuous dredging, channeling and straightening of the Missouri River over the past decades. These changes could all contribute to the observed increase in annual flows measured at Hermann. On the other hand, agriculture and population (i.e., consumptive use) have increased which, one would suspect, would decrease the flows at Hermann. Also, the construction of numerous reservoirs, both large and small, while providing a constant and reliable flow for navigation purposes as well as reducing peak flows during flood events, retain the water longer in the basin. Their large surface areas increase evaporation losses. But, whatever the combination of situations and factors, the average annual flow of the Missouri River at Hermann, MO does seem to be increasing.

In summary, after examining 105 years of precipitation and temperature data and 73 years of streamflow data, some statistically significant trends were identified. There are slight increases in all three variables (streamflow, precipitation, temperature) in the Missouri River basin, but only upward trends in temperature and streamflow were found to be statistically significant.

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