Water Quality of the Lower Missouri River, 1970-2001

By John Ford, Environmental Specialist, Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, MO 65102-0176 573-751-7024 john.ford@dnr.mo.us

I. Introduction

Three great rivers dominate the hydrology of the central United States, the Missouri, the Mississippi and the Ohio. The State of Missouri is particularly blessed with large rivers. The former two flow for large distances within or bordering the State of Missouri and the latter joins the Mississippi along the southeastern edge of the state. The size of these great rivers provides aquatic resources scarce or absent in smaller rivers. These rivers are focal points for electrical power production, commercial navigation and they provide drinking water supplies for several large population centers. They are home to many aquatic animals rarely found in smaller river and thus provide critical habitat for these animals.

The great rivers have been much altered by man. Stream channels and flow patterns have been altered by control structures and dams. Along most of their length, levees separate these rivers from their floodplains. And these rivers receive much of the wastes from a highly industrialized and consumer-oriented society. Hundreds of millions of gallons of treated sewage and industrial wastewater flow into these rivers daily. Surface runoff from rainfall and snow melt carries to them, large amounts of fertilizer, animal manure, sediment, and a wide variety of man-made chemicals.

We are now trying to both fully understand what damage we have done and to provide for some restoration of these rivers. This report on the recent water quality of the Lower Missouri River is offered to assist in putting water quality in its proper context in a total great river restoration strategy.

II. History of Water Quality on the Lower Missouri

Human disease (predominately typhoid fever) and the safety of drinking water dominated water quality concerns from the 1830s through the 1940s. In 1946, the US Public Health Service published a manual of water treatment and disinfection practices that introduced effective chlorine disinfection. Use of this new and highly effective method was adopted rapidly and bacterial and viral waterborne disease was no longer a concern for public water suppliers along the river.

However, treatment of sewage and disposal of garbage and industrial waste was still substandard. Poor water quality continued to threaten fish and other aquatic life in the river through the 1960s. In May 1964, a rapid rise in flow in the Missouri produced a fish kill in a 120-mile segment of the river from Leavenworth, Kansas to Waverly, Missouri. Monitoring of dissolved oxygen just after the kill indicated levels in some areas were less than 2.0 mg/l and may have been even lower on the days the kill occurred. Inflow of organic pollutants from surface runoff and resuspension of organic bottom deposits were the suspected cause.

Plans to improve wastewater treatment along the Missouri were begun by the Federal Water Pollution Control Administration in the late 1960s and continued in the early 1970s with the replacement of that agency by the US Environmental Protection Agency and the passage of the Federal Water Pollution Control Act. This act and subsequent federal acts regulating the disposal of garbage and other solid and hazardous wastes greatly improved the appearance, odor and general water quality of the river.

Today a few of the traditional water quality variables are still of some concern. Periodic high flow events still cause occasional low levels of dissolved oxygen, and elevated nitrogen levels in rivers throughout the Midwest are known to contribute to hypoxia problems in the Gulf of Mexico. A significant drop in suspended sediment in the lower river has occurred due to the construction of the main stem reservoirs. Some fishes native to the lower Missouri may be adversely affected by these lower levels of suspended solids. Newer water quality concerns on the lower Missouri River are related to trace chemicals or microorganisms and human health. These concerns include the bioaccumulation of mercury, PCBs and chlordane in fish tissue, and the levels of herbicides and parasitic protozoans in drinking water supplies.

III. Diel Variation in Water Quality

Streams typically show a daily trend of increasing water temperature and percent dissolved oxygen (DO) saturation from early morning through at least mid-afternoon. Data from continuous monitors that would show daily variation have not been used to any extent on the Lower Missouri. A summary of grab samples by the US Geological Survey from 1969 through 2001for two locations on the Missouri and four interior rivers is shown in Table One. The interior rivers all show statistically significant increases in percent DO saturation between mornings and afternoons during the warm weather season, indicating the influence of photosynthesis on dissolved oxygen levels. Summer water temperatures also appear to increase during the day on these rivers, but the increase is statistically significant in only two of these streams.

Because of its large size, depth and turbidity, water quality in the Lower Missouri responds very little to the daily cycle of solar insolation and darkness, nor to the corresponding biological cycle of photosynthesis and respiration. The Missouri at Hermann shows increasing water temperatures during the day in summer. The Missouri at St. Joseph shows a downward trend in DO saturation during the day. Better information on this subject will come from the future use of continuous water quality metering devices.

Table One. Comparison of Average Morning and Afternoon Water Temperature And Percent Dissolved Oxygen Saturation, Missouri River 1969-2001

Location	Season	Time of Day	Avg. Temp	N	Student's t Prob. >t	Avg. % DO Saturation	N	Student's t Prob. >t
Missouri R. St. Joseph	June-September	6:45-10:30	24.2	87	0.010 0.992	76.4	86	1.111 0.273
		12:30-17:00	24.2	24		73.1	24	
	Dec.-March	6:45-10:30	2.4	90	0.892 0.377	**90.5**	87	**3.231** **0.002**
		12:30-17:00	2.0	29		**80.7**	28	
Missouri R. Hermann	June-September	6:45-10:30	**24.6**	40	**-2.909** **0.005**	77.8	39	-1.545 0.131
		12:30-17:00	**26.5**	21		83.6	21	
	Dec.-March	6:45-10:30	4.2	33	-0.330 0.743	88.2	32	-1.133 0.264
		12:30-17:00	4.5	21		92.8	21	
Grand River	June-September	6:45-10:30	**24.2**	48	**-3.105** **0.003**	**78.6**	48	**-2.963** **0.004**
		12:30-17:00	**26.4**	50		**90.4**	50	
	Dec.-March	6:45-10:30	2.56	63	-0.033 0.973	85.6	60	1.054 0.295
		12:30-17:00	2.59	38		82	38	
South Fabius River	June-September	6:45-10:30	23.7	17	-1.393 0.176	**80.4**	16	**-5.627** **0.000**
		12:30-17:00	25.3	17		**105.7**	15	
	Dec.-March	6:45-10:30	3.4	15	0.817 0.422	101.1	13	-0.331 0.743
		12:30-17:00	2.4	18		102.4	17	
Meramec River	June-September	6:45-10:30	23.3	31	-0.997 0.322	**86.2**	31	**-4.714** **0.000**
		12:30-17:00	23.9	61		**96.4**	60	
	Dec.-March	6:45-10:30	5.6	39	-0.781 0.437	**91.6**	39	**-3.257** **0.002**
		12:30-17:00	6.1	60		**97.3**	60	
Current River	June-September	6:45-10:30	**21.3**	23	**-3.499** **0.001**	**88.6**	23	**-2.002** **0.050**
		12:30-17:00	**23.5**	42		**95.6**	45	
	Dec.-March	6:45-10:30	**7.8**	27	**-2.403**	89.7	27	-1.564

		12:30-17:00	**9.1**	45	**0.021**	94.9	44	0.126

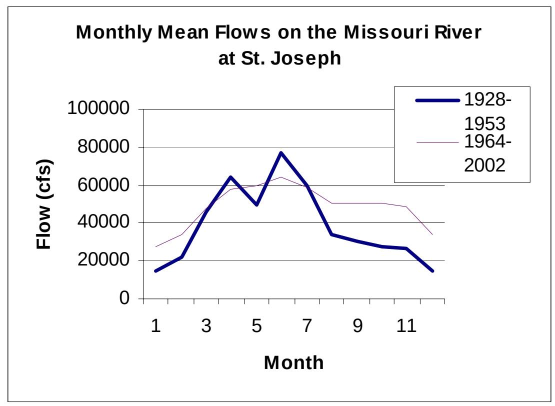
Note: Pairs of AM/PM data in bold print indicate a significant difference based on a one-tailed t test assuming unequal variances and the probability of a greater "t" value due to chance of 0.10 or less.

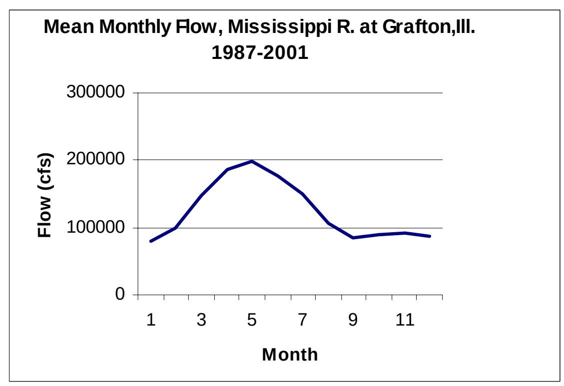
IV. Seasonal Variation in Water Quality

Lying in the North Temperate Zone, the Missouri River and its watershed are subject to large seasonal variations in air temperature that affect water temperature and the rivers ability to hold dissolved gases. In addition, the division of the year into two distinct periods when terrestrial plants are either active or dormant can affect both water and nutrient cycling in the watershed. Agricultural cropping cycles also have strong seasonal components, particularly for such practices as tillage and application of fertilizer or herbicides.

Flow

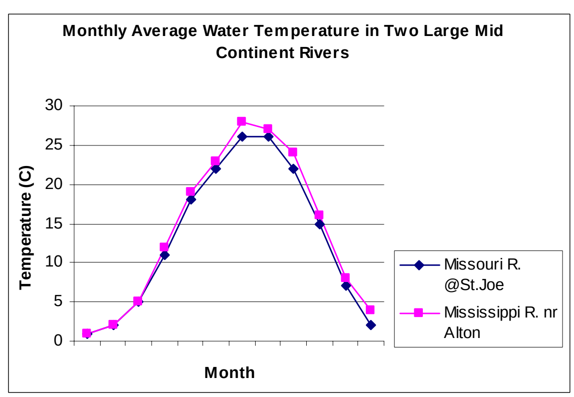
Prior to construction of the main stem reservoirs between 1953 and 1964, the Missouri had a seasonal flow pattern with separate peak flow periods in April and June. This pattern was the result of an approximate two-month interval between the period of maximum snowmelt on the Great Plains and in the Rocky Mountains. Flows declined rapidly through July and were relatively low for the remainder of the year. The main stem reservoirs are now used to help control the flows in the Lower Missouri River. Spring flows are now lower and summer, autumn and winter flows higher than the natural seasonal flow pattern. The seasonal flow pattern of the Mississippi River at Grafton, Illinois, just upstream of the mouth of the Missouri, shows a single peak monthly flow in June. Otherwise the shape of the annual hydrograph of this river appears to lie about halfway between that of the original and present annual hydrographs of the Lower Missouri.





Water Temperature

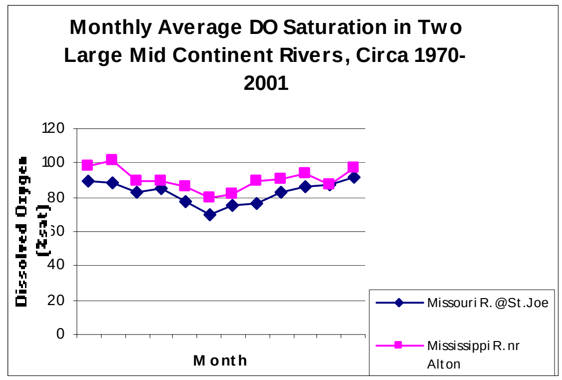
Mean monthly water temperatures on the Missouri at St. Joseph are less than 1 C in January and reach a high of 26 C in July and August. The summer monthly mean temperatures are slightly lower than on the Mississippi at Alton, probably due to the cooler deep water discharged from the main stem reservoirs into the lower Missouri.



Dissolved Oxygen

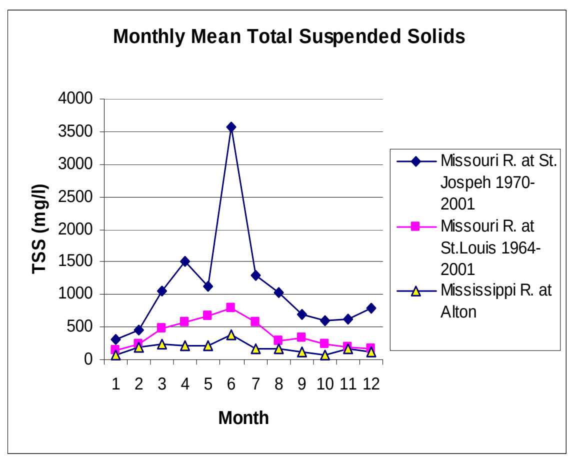
The amount of dissolved oxygen in natural waters is influenced by a number of factors. Water temperature greatly influences gas solubility, with winter temperatures on the Lower Missouri having the potential to hold nearly twice as much oxygen dissolved in the water as summer water

temperatures.
When a river contains all of the dissolved oxygen its water temperature allows, it is said to be at 100% saturation. The reaeration rate of a river is a measure of how well gas is exchanged between the water and the atmosphere. While the Lower Missouri does not have the waterfalls or rapids responsible for very high reaeration rates, the river is turbulent, with bottom and top water being continually interchanged and reasonably good reaeration maintained.



As the graph of dissolved oxygen saturation on the Missouri and Mississippi rivers shows, saturation values are almost always somewhat less than 100 % saturation. The main reason for levels of dissolved oxygen below 100% saturation is the oxygen demand created by the oxidation of organic matter by bacteria. The general seasonal trend is for a lower percent saturation in the warmer months. Since the oxidation of organic matter by bacteria is a biological process that increases in rate with water temperature, it explains the general shape of the graph. However, water temperature does not explain all the variation in DO saturation. The lowest monthly mean DO saturation on the Missouri (and the Mississippi as well) occurs in June rather than in July or August which have higher water temperatures. Suspended solids, organic nitrogen (not shown on graph) and total nitrogen levels on the Missouri peak in June suggesting that an increased amount of organic matter entering the river from surface runoff in that month, exerts a greater influence on dissolved oxygen values than does water temperature.

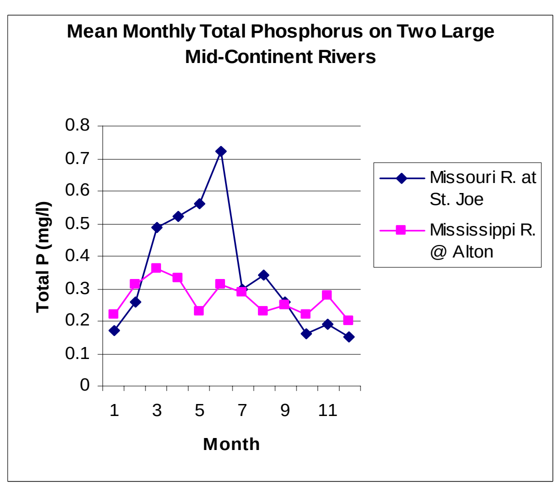
Suspended Solids



Suspended solids in the Missouri and Mississippi rivers contain some suspended organic matter in the form of planktonic plants and animals and plant detritus, but by far the vast majority of suspended material is inorganic or mineral solids. These mineral solids come primarily from erosion of the land surface and most enter rivers with the surface runoff accompanying rainfall.

In the watershed of the Lower Missouri, monthly rainfall is similar in April, May and June. The increasing level of Total Suspended Solids in the river through those months suggests that the pattern of rainfall changes to shorter duration and higher intensity rainstorms in June that produce more soil erosion.

Total Phosphorus

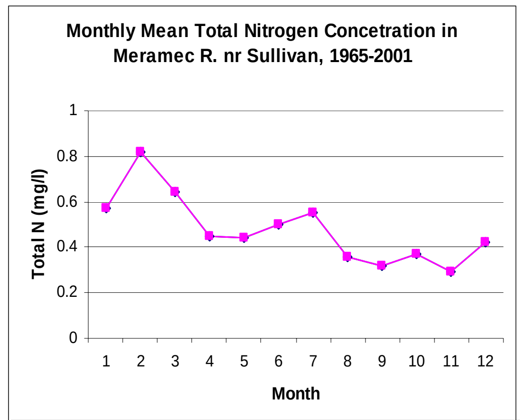


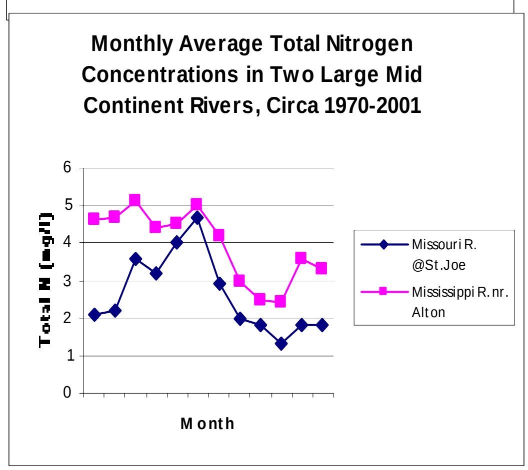
Phosphorus concentrations, and often nitrogen as well, are of concern in waters where nutrients can stimulate excessive growth of algae or aquatic macrophytes. On the Missouri River, turbidity, velocity of flow and fluctuating water levels rather than plant nutrients limit the growth of aquatic plants, so that phosphorus and nitrogen levels have little if any biological impact on the river. The nutrient load of the Missouri does become biologically significant when it reaches tidal estuaries and the open waters of the Gulf of Mexico. In these quieter areas where the water becomes clearer, these nutrients produce large quantities of algae which subsequently die and exert a substantial oxygen demand and a resulting hypoxia in these coastal waters.

Phosphorus levels on the lower Missouri in winter correlate well with indicators of surface runoff such as increasing levels of nitrogen and decreased levels of dissolved major ions. In spring and summer when the ground is not frozen and is more susceptible to soil erosion, phosphorus levels correlate well with both suspended solids and nitrogen. Correlations of phosphorus with other water quality variables are weaker on the Mississippi River than on the Missouri, but the strongest correlation is with indicators of higher flow conditions and surface runoff. There are significantly higher concentrations of phosphorus in the Missouri River during spring and summer than in the Mississippi. This occurs despite its much lower density of people and industry and this also suggests that nonpoint source runoff rather than point sources provide the greatest source of phosphorus to the river.

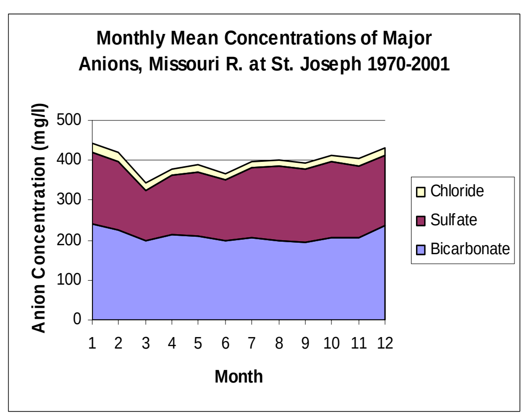
Total Nitrogen

The main natural source of nitrogen to the Missouri River watershed is precipitation. Ammonium and nitrate ions in rainfall in the upper Midwest provide a total of about 0.4-0.5 mg/l nitrogen. While much of this nitrogen entering the basin in a given year would be sequestered in terrestrial plants, a long term equilibrium should result in an export of almost all nitrogen via streams and a small amount to the atmosphere via denitrification. Thus, a long-term average nitrogen level in a stream draining a watershed with little or no cultural inputs of nitrogen might be expected to be around 0.4 or 0.5 mg/l. The Meramec River at Sullivan has a watershed dominated by forest and receives little commercial fertilizer additions. Thirty-five years of water quality data shows an average total nitrogen concentration of 0.48 mg/l for this stream with a seasonal pattern showing the highest levels in winter through mid-summer and the lowest levels in late summer and autumn.

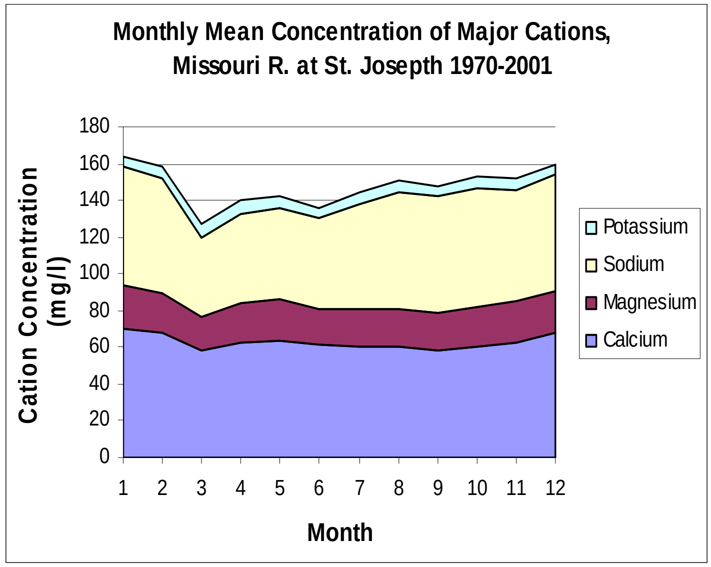




By contrast the Missouri River at St. Joseph has an average nitrogen level of about 2.6 mg/l and the Mississippi at Alton, 4 mg/l, reflecting the large amount of nitrogen, predominantly commercial fertilizers, that are released into these watersheds. The seasonal pattern for the Missouri closely follows that of suspended solids suggesting that stormwater runoff events are the major sources of nitrogen to the river. Sharp declines in monthly mean nitrogen after June might be explained as the result of gradual flushing of spring applications of nitrogen fertilizers from the watershed. This explanation is probably partially correct, but does not account for the rebound in nitrogen concentrations in late fall and early winter. Uptake of nitrogen by crops and other terrestrial vegetation throughout summer and the end of plant uptake with plant senescence or the initiation of dormancy, would explain this seasonal pattern and

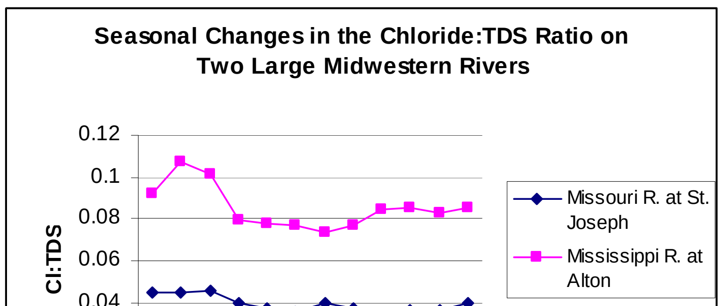


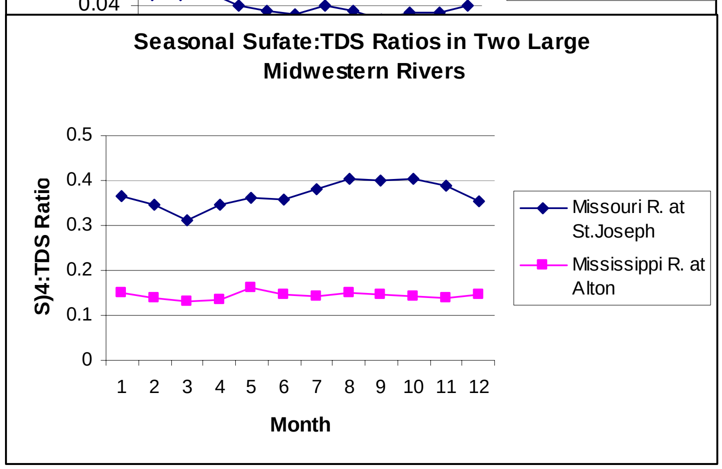
gives evidence that terrestrial plants exert a strong seasonal effect on nitrogen levels in the river.



Major Ions

There are no strong seasonal trends in the relative amounts of the major dissolved substances in the Missouri river. Total dissolved solids (TDS) concentrations in the river tend to be somewhat lower in spring and early summer and are probably related to the diluting effect of rainfall runoff during this period. Otherwise, the most discernable seasonal trend is associated with changes in the relative proportions of water from the western portions of the watershed (flows released from the main stem reservoirs) and inflow from the tributaries in the eastern portion of the basin which have relatively less sodium and sulfate. From mid-summer through fall, when tributary inflow is low, flows necessary to maintain commerical navigation are sustained by releasing more flow from the main stem reservoirs. Thus summer and fall flows on the river have somewhat higher relative proportions of sodium and sulfate than other times of the year.





A plot of seasonal ratios of sulfate to total dissolved solids (TDS) for the Missouri at St. Joseph and the Mississippi at Alton clearly shows the Mississippi has no such seasonal pattern for sulfate. A plot of seasonal chloride to TDS ratios for these two rivers shows a fairly strong late winter-early spring rise in the relative proportion of chloride in the Mississippi River and a less obvious rise during the same period on the Missouri. This seasonal pattern is probably related to the timing of thaw and the flushing of road salt with late winter snowmelt and early spring rains. Since the watershed of the Upper Mississippi River is more densely populated and has a greater density of roads than the watershed of the Missouri, the seasonal chloride pattern would be expected to be more pronounced in the Mississippi River.

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V. Variation in Water Quality Due to Hydrographic Events

A hydrographic event is a relatively rapid increase in stream flow followed by a somewhat less rapid decline in flow until normal flow levels are reached. Diel variations in water quality on the Lower Missouri are very slight and seasonal variations change slowly. In contrast, hydrographic events, typically those related to rainfall and surface runoff, can cause both rapid and substantial changes in water quality. Table 2 below shows the average difference in water quality for three general types of hydrographic periods.

Table 2. Mean Water Quality in the Missouri R. at St.Joseph, March-November 1970-2001 For Three Hydrographic Conditions

	Hydrographic Event on the Missouri R.[1]	High Stable Flows on the Missouri R.[2]	Low to Normal Stable Flows on Missouri R.
DO Saturation (%)	70	81	85
Organic N (mg/l)	3.2	1.3	1.0
NO2+NO3-N (mg/l)	1.83	1.23	0.93
Ammonia N (mg/l)	0.15	0.07	0.07
Total Phosphorus (mg/l)	0.82	0.32	0.22
Total Susp. Solids (mg/l)	2,286	1,053	641
Fecal Coliform (#/100ml)	15,466	5,714	2,569
Fecal Strep (#/100ml)	24,862	4,842	1,350
Total Diss.Solids (mg/l)	400	458	464
Calcium (mg/l)	56	63	60
Magnesium (mg/l)	18	22	21
Sodium (mg/l)	44	58	61
Potassium (mg/l)	6.8	6.2	6.0
Bicarbonate (mg/l)	192	208	202
Sulfate (mg/l)	135	177	178
Chloride (mg/l)	16	16	19

Table Two clearly shows that hydrographic events on the Missouri bring with them reductions in the amount of dissolved oxygen in the river and substantial increases in the concentration of suspended solids, nitrogen, phosphorus, and bacteria. Since during hydrographic events the river contains more rainwater, which is relatively dilute in terms of dissolved substances, levels of dissolved substances in the river decline. For the data in the first column of Table 2, Hydrographic Events on the Missouri, water quality data was also evaluated based upon whether the flow at the time of sample collection was on the rising, peak or the falling portion of the hydrograph. This information is presented in Table 3.

[1] For the purposes of this report, a hydrographic event was defined as a percent change in flow in the 48 hours preceding sample collection. If the flow at time of sample collection was greater than the median flow, the percent difference in flow during that 48 hours had to be greater than 10%, if the flow was between the median flow and the flow exceeded 90% of the time, the percent difference had to be greater than 15%, and if the flow was less than the flow exceeded 90% of the time, the percent difference had to be greater than 20%.

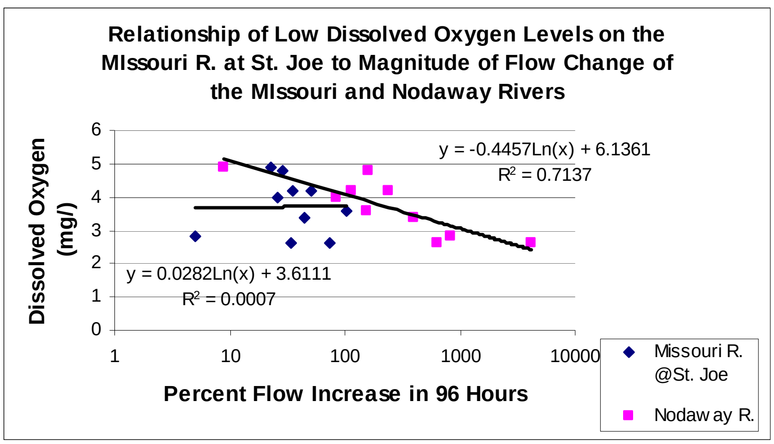
[2] These conditions are presumed to occur when tributaries are providing higher than normal but stable flows to the Missouri and these flows include some stormwater runoff. The breakpoint separating this category from the normal to low stable flows is the median flow of the river at St. Joseph, 42,300 cfs.

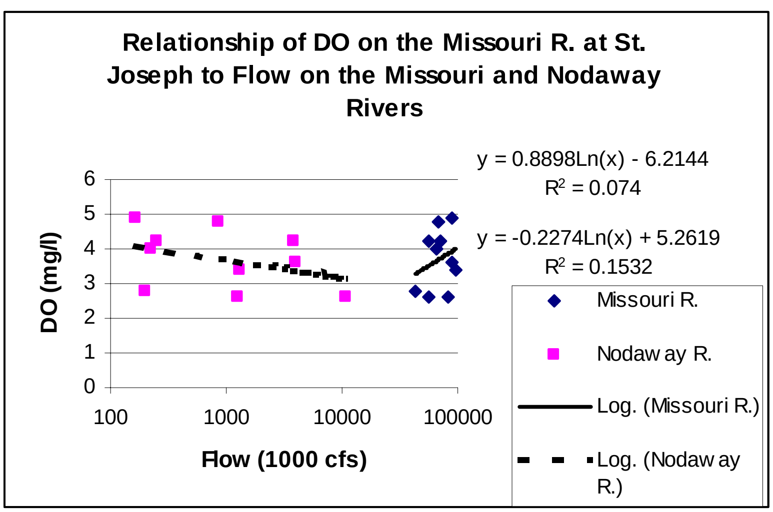
Table 3. Mean Water Quality in the Missouri R. at St. Joseph, March-November 1970-2001 for Three Positions on the Stream Hydrograph (in mg/l unless otherwise noted)									
Hydrograph Condition	No. of Obs.	DO Sat. (%)	Org. N	NO2+ NO3 N	NH3 N	Total Phosphorus	Total Susp. Solids	Fecal Coliform (#/100ml)	Total Diss. Solids
Rising	19	71	3.0	1.66	0.17	0.85	1,723	13,586	422
Peak	9	56	5.3	2.31	0.20	1.17	4,833	31,867	348
Falling	34	73	2.8	1.79	0.13	.70	1,793	12,175	401

Table 3 indicates the greatest impact on water quality on the Missouri occurs at peak flows. Smaller watersheds often show a "first flush" effect where the first part of the storm water runoff carries the greatest concentration of pollutants and can have the poorest water quality. This effect is probably rare on the Missouri because large watersheds are unlikely to have all their tributaries delivering "first flush" runoff to the same portion of the Missouri at the same time.

Review of Hydrographic Events Causing Low Levels of Dissolved Oxygen in the Lower Missouri

Dissolved oxygen levels on the Lower Missouri typically meet state water quality standards requiring a minimum of 5 mg/l. Substantially lower DO levels that do not meet this standard have been documented in several studies going back as far as 1913 and pose a threat to fish and other aquatic animals. These low DO episodes occur during high flow periods on the Missouri and in May, 1964, one was severe enough to cause a fish kill in a 120 mile segment of the river from Leavenworth, Kansas to Waverly, Missouri. Nonpoint source runoff from rural lands was known to be a contributor to the problem. However, up to this time, treatment of sewage and meatpacking house wastes was poor in the cities along the Missouri (Sioux City, Omaha, St. Joseph and Kansas City). Thus, untreated wastes from urban areas that would settle to the streambed and then resuspend during higher flow conditions was also thought to contribute to the problem.





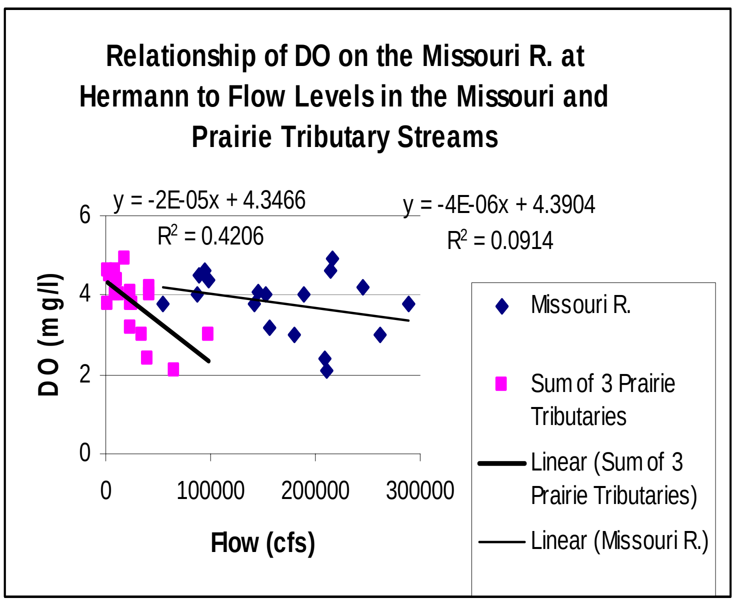
Since 1970, the US Geological Survey monitoring point on the Missouri River at St. Joseph has recorded ten observations of dissolved oxygen less than the 5 mg/l standard the State of Missouri sets for the river. For these ten occasions, the antecedent flow conditions on both the Missouri River at St. Joseph and the Nodaway River, which enters the Missouri about 18 miles upstream of St. Joseph, were plotted against the dissolved oxygen level in the Missouri.

Two flow variables were plotted. The first was the percent increase in flow over the 96 hours preceding the most recent hydrographic peak, which is an indicator of stormwater runoff intensity. The second variable was the volume of streamflow. Although dissolved oxygen values on the Missouri are clearly lower during hydrographic events, neither the size nor the rate of rise in the hydrograph on the Missouri correlated well with dissolved oxygen during these low DO episodes. However, there was somewhat better correlation of Missouri River low DO events with flow of the Nodaway River and a strong correlation with the rate of rise of hydrographs on the Nodaway River.

A similar analysis was done for 18 DO values less than 5 mg/l on the Missouri further downstream at Hermann. Table 4 shows the correlation between low DO episodes on the Missouri at Hermann with flows and rates of hydrograph rise on the Missouri and each of five tributary streams. Results showed that lowered DO levels in the Missouri correlated more strongly with higher flows and more rapid hydrographic rises on tributaries from prairie rivers such as the Grand and Chariton than on the Missouri itself. Hydrographic events from the Ozark Plateau tributaries actually had a slight correlation with higher dissolved oxygen levels on the Missouri.

Table 4. Pearson Correlation Coefficients for Relationship of Dissolved Oxygen Levels on the Missouri R. at Hermann with Flow and 96 Hour Percent Hydrograph Rise on the Missouri River and Five Tributaries

River	Flow	96 Hour Percent Hydrographic Rise
Missouri	-0.3023	-0.2622
Gasconade	+0.1628	+0.1066
Osage	+0.4355	+0.1191
Lamine	-0.2365	-0.2016
Chariton	-0.4707	-0.5682
Grand	-0.6869	-0.2907
Osage+Gasconade	+0.4291	+0.091
Grand+Chariton+Lamine	-0.6485	-0.2107



The data at St. Joseph and Hermann provide contradictory evidence on the relative importance of flow and percent hydrographic rise in lowering dissolved oxygen levels in the Missouri River. Their relative importance aside, it is clear that stormwater runoff from the major prairie tributaries is primarily responsible for low DO episodes on the Lower Missouri. The weaker correlation of low DO with elevated flows on the Missouri River itself is evidence that resuspension of oxygen-demanding bottom sediments in the Missouri is much less important in determining DO levels in the river.

VI. Water Quality Changes Over Time

Several water quality variables were analyzed for time trends[3]. Tables Five and Six show the results of these statistical analyses for water quality on the Missouri at St. Joseph and Hermann, respectively.

Table Five. Time Trend Analysis of Selected Water Quality Variables on the Missouri River at St. Joseph, 1970-2001.

Variable	Regression Statistics		
	Slope of Regression Line	Student's " t" statistic	Probability of a Greater value of "t" if Slope is Actually Zero
Dissolved Oxygen (DO)	0.063	3.851	**0.000**
DO % Saturation	0.634	8.414	**0.000**
Log Nitrate Nitrogen	0.026	5.058	**0.000**
Log Total Nitrogen	0.033	3.303	**0.001**
Log Total Phosphorus	-0.001	-0.475	0.635
Cube of TDS	0.600	1.270	0.205
Log Fecal Coliform	-0.029	-7.263	**0.000**
Log Fecal Strep	-0.030	-5.708	**0.000**
Log Total Susp. Solids	-0.030	-6.473	**0.000**

Table Six. Time Trend Analysis of Selected Water Quality Variables on the Missouri River at Hermann, 1970-2001.

Variable	Regression Statistics		
	Slope of Regression Line	Student's " t" statistic	Probability of a Greater value of "t" if Slope is Actually Zero
Dissolved Oxygen (DO)	0.034	2.217	**0.027**
DO % Saturation	0.466	5.571	**0.000**
Nitrate Nitrogen	0.013	3.591	**0.000**
Log Total Nitrogen	0.001	0.499	0.618
Log Total Phosphorus	0.002	1.220	0.223
Log Fecal Coliform	-0.022	-6.645	**0.000**
Log Fecal Strep	-0.022	-4.422	**0.000**
Log Total Susp. Solids	-0.001	-0.443	0.658

The data shows a clear and significant trend of higher levels of dissolved oxygen and nitrate nitrogen and lower levels of bacteria over time. There does not appear to be a significant trend for phosphorus or for total dissolved solids (TDS). Dissolved oxygen levels show an apparent increase and bacteria and suspended sediment concentrations an apparent decrease over time. At St. Joseph, total nitrogen and total suspended solids showed a significant increasing trend over time, but this trend was not apparent at Hermann. Neither total phosphorus nor total dissolved solids showed a significant time trend on the Lower Missouri.

[3] Statistical method used was linear regression of a water quality variable against year. Histograms and probability plots were used to assess normality and, where needed variables were transformed to improve the similarity of the variable distribution to a normal distribution.

Declines in suspended sediment and bacteria levels and increases in dissolved oxygen suggest improvements in storm water runoff quality. Declines in bacteria levels at St. Joseph may also be related, at least in part, to improvements in wastewater collection and treatment that occurred in the Omaha area during the 1970s and 1980s. Nitrogen levels in the river appear to be increasing over time and are probably a reflection of crop production trends[4]. The thirty year trend for flows on the Nodaway River corresponding to the times of water quality sampling on the Missouri at St. Joseph shows somewhat higher flows in the later years than the earlier years. This suggests that the declines in suspended solids and increasing levels of dissolved oxygen are not an artifact of sampling dates.

Dissolved Oxygen

The time trend analysis showed significant and substantial increase in dissolved oxygen levels in the Missouri River at both St. Joseph and Hermann.

To further assess if these trends were real, the relationship between dissolved oxygen saturation values and time of day, and the changes in the time of day samples were taken over the 30-year interval were assessed[i]. These calculations resulted in estimates that only 14% and less than 1% of the 30-year increase in DO saturation on the Missouri at St. Joseph and Hermann, respectively, were due to time-of-day sampling bias.

To see if there may have been other types of sampling bias due to sampling procedures or analytical method changes during that 30 years, time trend regression and this same time-of-day sampling bias analysis were also done for three interior rivers of Missouri (the Grand River near Sumner, the Meramec near Sullivan and the Current at Doniphan). These streams have similar periods of water quality data collection as the two stations on the Missouri River. The latter two rivers and their watersheds are still relatively pristine and dissolved oxygen levels should have changed very little over this 30-year period. Corrected for time-of-day bias, there were 30-year increases in DO saturation on the Meramec and Current of 3.7 and 6.2% respectively. This suggests that there is some form of bias that is responsible for an approximate 4-6% increase in average DO saturation over the last 30 years.

Correcting for time-of-day bias, the 30-year DO saturation increase was 16.3% at St. Joseph and 13.9% at Hermann. Even if we reduce these values by 4-6% to account for other sampling bias, it appears there is still an approximate 10% increase in DO saturation in the lower Missouri in the last 30 years.

Fecal Coliform Bacteria

Data from both St. Joseph and Hermann suggested highly significant changes in fecal coliform levels in the Missouri River over time. While improvements in disinfection of wastewaters in the Omaha area may have contributed to declines of bacteria in the river at St. Joseph, the declines as Hermann cannot be attributed to this reason. Since bacteria levels are greatly influenced by storm water runoff, improvements in storm water runoff quality in the Lower Missouri basin may account for the observed declines. To see if declines might also be due to some bias in measurement, fecal coliform time trends for eight interior rivers of Missouri were evaluated.

The results of these analyses are given in Table Seven. Three prairie rivers, the Grand, Chariton and South Fabius all showed statistically significant declines[5] in fecal coliform levels over time, but improved soil conservation practices and improved storm water quality could also be a factor in these watersheds. Four Ozark plateau rivers, the upper Meramec, Current, Black and Eleven Point have relatively pristine

[4] Grain production in the midwest continues to increase slowly despite reductions in cropland acres. Missouri, Kansas, Nebraska and Iowa had a combined loss of 7.4 million acres of cropland (9%) between 1982 and 1997 (National Resource Inventory, NRCS)

[5] Log mean fecal coliform concentrations for various time periods were evaluated using two sample "t" tests. Significant differences in means were defined as those where the probability of a greater "t" value due to chance was <0.20.

watersheds. The Lower Osage carries mostly water that is discharged from Lake of the Ozarks where bacterial levels are low.

Table 7. Geometric Mean Fecal Coliform Levels by Time Period and Percent Change by Time Period									
Location	1968-85	1986-01	Percent Change	1968-76	1977-88	Percent Change	1977-88	1989-01	Percent Change
Missouri R. @ St. Jos.	3555	886	-75	3415	3152	-8	3152	727	-77
Missouri R. @ Hermann	1307	497	-62	1832	785	-57	785	496	-37
Grand R. nr. Sumner	1001	400	**-60**	1081	873	-19	873	340	**-61**
South Fabius nr. Taylor	575	178	**-69**	760	278	**-63**	278	167	-40
Chariton R. nr. Prairie Hill	459	241	**-48**	547	388	-29	388	237	-39
Osage R. @ St. Thomas	32	27	-16	37	27	-27	27	27	0
Meramec R. nr. Sullivan	29	16	**-55**	29.5	27.5	-7	27.5	14.5	**-47**
Current R. nr. Doniphan	14.5	14.7	+1	18.5	11.6	-37	11.6	16	+38
Black R. nr. Annapolis				165	68	**-59**			
Eleven Point R. nr Bardley							23	19	-39

Note: Percent Change values in oversize bold print indicate the difference in the geometric means for the two time periods had a Student's "t" value that had less than a 0.2 probability of being due to chance.

There should be little reason for changes in bacterial levels in these rivers over time other than measurement bias. Two of these rivers, the upper Meramec and the Black showed statistically significant declining trends in fecal coliform levels over time. The Osage and the Eleven Point showed trends of declining fecal coliform which were smaller and not statistically significant. No trend was observed on the Current River. During this time period, none of these interior rivers had a long term trend of increasing flows on dates when water samples were taken.

Thus, it appears that there has been some measurement bias that has produced at least part of these trends of declining fecal coliform levels over time. However, the fact that percent reductions in fecal coliform concentrations appears to be greater in prairie streams than on the Ozark plateau, also suggests some of this time trend is real and does represent some improvement in the quality of storm water runoff.

Total Suspended Solids

While data indicated a significant trend of declining TSS levels in the Missouri at St. Joseph over time, this trend was not seen on the Missouri at Hermann. Five interior rivers had a sufficient number of measurements of total suspended solids for time trend analysis. The summary of these analyses are shown in Table Eight. All three prairie rivers, the Grand, Chariton and the South Fabius, showed a statistically significant declining trend in total suspended solids over time. Of the two Ozark plateau rivers, the Current showed a slight downward trend and the upper Meramec showed no time trend for TSS. Again, during this time period, none of these interior rivers had a long term trend of increasing flows on dates when water samples were taken.

Table 8. Time Trend Statistics for Log Total Suspended Solids on Five Missouri Rivers.					
Stream	1969-1985 vs 1986-2001				Linear Regression 1969-2001, Probability that slope is due to chance
	1969-1985 Log Mean [GeoMean]	1986-2001 Log Mean [GeoMean]	Students t	Prob. >t due to chance	
Grand R.	2.431 [270]	2.09 [122]	2.896	0.005	0.000
Chariton R.	2.449 [281]	2.078 [120]	2.664	0.009	0.001
S. Fabius R.	1.641 [44]	1.428 [26]	1.251	0.221	0.093

Meramec R.	0.725 [5.3]	0.759 [5.7]	-0.374	0.771	0.835
Current R.	0.667 [4.6]	0.427 [2.7]	1.96	0.052	0.584

The lack of strong trends on the two Ozark Plateau rivers suggests there is little or no measurement bias associated with time. Thus at least some of the observed declines in total suspended solids in the Missouri at St. Joseph and on the interior prairie rivers appear to represent a real trend in declining levels of suspended solids over time.

Nitrogen

Tables 9 and 10 show time trend statistics for nitrate-nitrogen and total nitrogen in six interior rivers of Missouri. The three prairie rivers show statistically significant declines in nitrogen over time, with the exception of nitrate-nitrogen on the Grand River, which showed no time trend. Of the two Ozark Plateau rivers, the Current showed no time trend for nitrogen and the upper Meramec showed slight trends of increasing nitrogen over time but these trends were generally not statistically significant.

Table 9. Time Trend Statistics for Nitrate Nitrogen on Six Missouri Rivers.

Stream	1969-1985 vs 1986-2001				Linear Regression 1969-2001, Probability that slope is due to chance
	1969-1985 Log Mean [GeoMean]	1986-2001 Log Mean [GeoMean]	Students t	Prob. >t due to chance	
Grand R.	-0.515 [0.31]	-0.555 [0.28]	0.463	0.643	0.580
Chariton R.	-0.396 [0.40]	-.0.560 [0.27]	1.761	0.080	0.158
S. Fabius R.	-0.264 [0.54]	-0.740 [0.18]	4.029	0.000	0.000
Meramec R.	-0.820 [0.15]	-0.808 [0.16]	-0.214	0.831	0.068
Current R.	-0.641 [0.23]	-0.633 [0.235]	-0.184	0.854	0.189
Osage R.	-0.583 [0.26]	-0.743 [0.18]	2.64	0.009	0.014

Table 10. Time Trend Statistics for Total Nitrogen on Six Missouri Rivers.

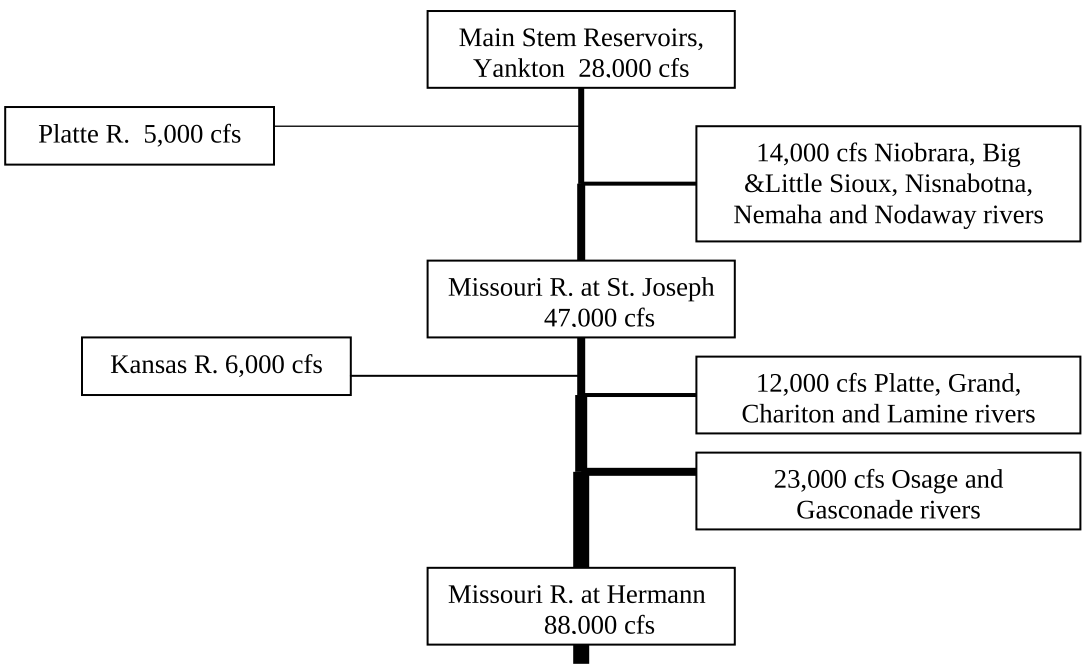
Stream	1969-1985 vs 1986-2001				Linear Regression 1969-2001, Probability that slope is due to chance
	1969-1985 Log Mean [GeoMean]	1986-2001 Log Mean [GeoMean]	Students t	Prob. >t due to chance	
Grand R.	0.262 [1.8]	0.156 [1.4]	2.685	0.008	0.053
Chariton R.	0.243 [1.7]	0.125 [1.3]	2.804	0.006	0.033
S. Fabius R.	0.255 [1.8]	0.048 [1.1]	2.752	0.016	0.009
Meramec R.	-0.415 [0.38]	-0.456 [0.35]	-1.400	0.164	0.245
Current R.	-0.499 [0.32]	-0.484 [0.33]	-0.433	0.666	0.328
Osage R.	-0.071 [0.85]	-0.176 [0.67]	3.155	0.002	0.025

Conclusion

In general, the Lower Missouri River and it prairie tributaries show 30 year time trends of increasing dissolved oxygen levels and declining levels of fecal coliform bacteria and total suspended solids. These trends suggest that the amounts of sediment and organic matter in storm water runoff, from this principally rural watershed, is declining over time. While nitrogen levels on the Missouri, particularly at St. Joseph show an increasing trend over time, the interior prairie rivers of Missouri show either a declining trend or no trend at all. This suggests the tributary rivers upstream of St. Joseph, the Nodaway, Nishnabotna, Big and Little Sioux and the Platte, may still have increasing nitrate levels while those rivers further down in the watershed within Missouri do not.

VII. Spatial Changes in Water Quality

The mean annual flow of the Missouri triples between Yankton, South Dakota (28,000 cfs) and Hermann, Missouri (88,000 cfs). Of this 60,000 cfs increase in mean annual flow, 18 percent comes from the Platte and Kansas rivers that drain the high plains of Colorado, Kansas, southern Wyoming and western Nebraska. Another 43 percent comes from rivers draining the till plains of eastern Nebraska, western Iowa and northern Missouri. The remaining 39% comes from impounded waters of the Osage River of eastern Kansas and west central Missouri and the Gasconade River which drains a portion the Ozark Plateau.

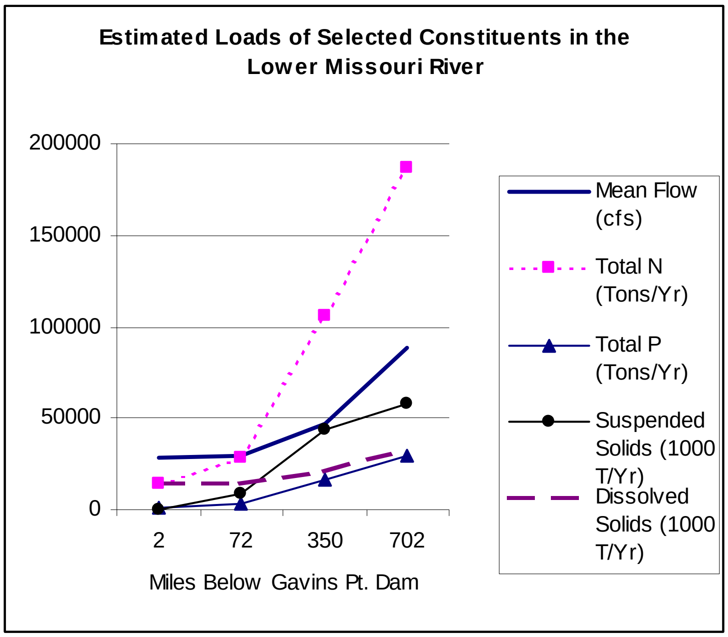


Between Yankton, South Dakota and Hermann, Missouri, the water quality of the Missouri River changes substantially. The very upper parts of the river are heavily influenced by the discharge of the waters impounded behind Gavins Point Dam. These impounded waters have relatively low levels of nitrogen and phosphorus due to nutrient uptake by phytoplankton and relatively low levels of suspended solids due to the absence of current and the long periods of time available for particle settling in the reservoirs. As the river moves downstream, the average concentration of these three constituents increase significantly due to inflow of relatively nutrient and sediment rich tributaries. Levels of sulfate and total dissolved solids however are less in the tributaries than in the main stem reservoirs, and so the levels of these constituents in the Missouri decline in the downstream direction.

These downstream trends are changed somewhat by the inflow of the Osage and Gasconade rivers which have relatively low levels of nutrients and suspended solids and represent a significant portion of the total annual mean flow at Hermann. Table 11 summarizes some of the spatial water quality trends of the Lower Missouri.

Table 11. Spatial Water Quality Trends on the Lower Missouri River								
Location	Mean Concentration (mg/l unless otherwise noted)							
	Water Temp C	NO3N	TN	TP	DO % Sat.	TSS	TDS	SO4
Yankton, SD	11.5	0.21	0.58	0.05	93	12	520	219
Sioux City, Ia	12	0.27	1.12	0.10	95	296	512	226
St. Joseph, Mo.	13	1.26	2.65	0.34	83	955	460	169
Hermann, Mo.	15	1.13	2.20	0.34	83	672	378	122

Note: Most data at Yankton and Sioux City based on 20-70 observations. Most data at St. Joseph and Hermann based on 150-350 observations.



Using annual mean flow and mean concentration levels, rough estimates were made of loads for total nitrogen, total phosphorus, sulfate and suspended solids. These estimates show that the percent of the Missouri River annual load at Hermann that comes is discharged from Gavins Point Dam is only seven percent for total nitrogen, three percent for total phosphorus and less than one percent for total suspended solids. However the discharge from Gavins Point makes up 44 percent of the total dissolved solids load and 52 percent of the total sulfate load of the river.

VIII.   Trace Substances in Water

Substances typically found in natural waters at a concentration less than 1 mg/L are often referred to as “trace substances”. Of particular interest are those whose presence in water can cause water quality problems even at low concentrations.

Heavy Metals

Several heavy metals when present in the water in sufficient amounts, can be harmful to aquatic life and to humans or other animals using the water as a drinking water supply. In natural waters most metals tend to be sorbed tightly to suspended soil or other particles and therefore are not available to aquatic life and are thus considered to be generally non-toxic. Metals in solution and not sorbed to suspended particles are considered to be in the “dissolved” form and are considered to be available to aquatic life and therefore toxic. In the laboratory two separate analyses are commonly used for metals, “total metals” which includes both sorbed and dissolved metal, and “dissolved” metal.

Both dissolved and total metal concentrations tend to increase with suspended solids as the graphic shows for iron. However, in the relatively high suspended solids environment of the Missouri River, 90 to 99 percent of total iron is sorbed to suspended sediments.

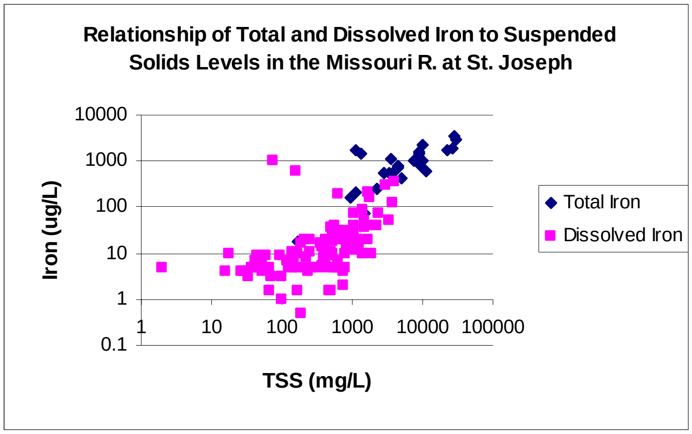


Table 12 shows the mean concentration of selected dissolved heavy metals and compares them to the state water quality standards for protection of aquatic life and for drinking water source waters.

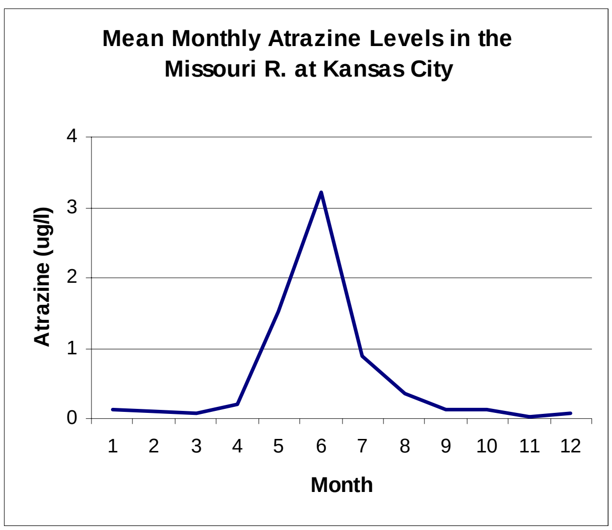
Table 12. Mean Levels of Dissolved Heavy Metals in the Missouri R. at St. Joseph, 1975-2001

Metal	Mean Concentration (ug/L)	Water Quality Standard for Protection of Aquatic Life (ug/L)	Water Quality Standard for Protection of Human Health-Drinking Water Supply Source (ug/L)
Aluminum	27	750	none
Arsenic	3	20	50
Cadmium	1.7	15.5	5
Chromium	2.1	42	100
Copper	4.3	36	1300
Iron	49.5	1000	300
Lead	7.1	23	15
Nickel	17.6	650	100
Zinc	18.6	433	5000

The values for cadmium, chromium and lead should be considered only estimates since much of the data for these metals indicate the amounts present were reported by the laboratory as "less than" the detection level. In recent years the US Geological Survey has also noted that contamination of heavy metals samples can easily occur during the sample collection and handling process. Thus it is likely that some of the heavy metal values obtained for the Missouri River may be too high due to sample contamination. However as Table 12 indicates, heavy metals are not a threat to aquatic life in the river, nor do they pose a threat to those that use the river as a drinking water supply source.

Pesticides in Water

The most heavily used pesticide currently in Missouri is Atrazine, a broadleaf herbicide used to control weeds in corn and grain sorghum. Atrazine is applied primarily in the spring and a small percent typically leaves the application site during stormwater runoff and enters streams.



Atrazine has been monitored frequently in the Missouri River for several years. Concentrations in the Missouri are strongly related to season of the year, with maximum concentrations occurring in late spring. Table 13 shows the average concentration in the Missouri River at Kansas City of some of the most commonly used pesticides.

Table 13. Average Pesticide Concentration in the Missouri River at Kansas City, 1989-2000 and Allowable Pesticide Concentration in Drinking Water Supply Source Waters.

Pesticide	Average Concentation (ug/L)	Allowable DW Standard (ug/L)	Pesticide	Average Concentation (ug/L)	Allowable DW Standard (ug/L)
Acetochlor	0.02		Metolachlor	0.26	70
Alachlor	0.06	2	Metribuzin	0	100
Atrazine	0.58	3	Propachlor	0.01	90
Butylate	0	350	Simazine	0	4
Cyanazine[6]	0.31	1	Trifluralin	0.04	5
Diazinon	0.01	0.6	2,4 D	0.16	70

The pesticides with the greatest concentration in the Missouri River are atrazine, cyanazine and metolachlor, three common agricultural herbicides. 2,4D is commonly used as a “brush killer” along right-of-ways for roads, railroads, power lines, fence lines and pipelines. Diazinon is an insecticide often found in over the counter products sold for household, lawn and garden use. None of these pesticides closely approach the allowable maximum levels for drinking water supply source waters.

Pesticides and Other Trace Substances in Fish

Contaminants in water and river sediments are often transferred to aquatic plants and animals. Tissues of various species of fish are often analyzed for trace toxic compounds both to assess their potential impact on aquatic ecosystems and the threat to the health of people that consume those species of fish. Tables 14 and 15 below give levels of selected toxicants in Carp fillets and in whole Carp for urban and rural segments of the Missouri River within and bordering the state of Missouri. The tables also note some tissue criteria used to judge human and ecosystem health. Carp data are used in these tables because they are a commonly analyzed species. Some fish species can have a special affinity for certain pollutants. Pollutants such as chlordane, dieldrin, DDT and PCBs have a high affinity for fatty tissues. As a result, fish species with typically high levels of fat, such as sturgeon, tend to accumulate more of these contaminants than fish species with less fat. Both the Missouri and Mississippi Rivers within the state of

Table 14. Concentrations of Selected Trace Toxicants in Carp Fillets in Urban and Rural Sections of the Lower Missouri River, and Human Health Criteria for Consumption of Fish (mg/kg)

Missouri R.	chlordane	dieldrin	DDT and metabolites	PCBs	Lead	Mercury
Rural Portions	0.146	0.014	0.020	0.058	0.01	0.10
Urban Portions	**0.334**	0.006	0.025	0.078	0.01	0.05
Human Health Criteria	chlordane +dieldrin 0.300[7]		5.000	0.097[8]	0.300[9]	0.3[10]

[6] Cyanazine use is no longer allowed in the United States.
[7] The dieldrin, chlordane and DDT criteria are FDA Action Levels for Interstate shipment of food for human consumption.
[8] EPA recommended level above which no fish should be consumed.
[9] World Health Organization recommended level. The US does not have a recommended level. Most countries with lead criteria are higher than the WHO criterion.

Missouri have an advisory against the consumption of sturgeon due to PCB and chlordane levels in the tissue and eggs of this species. Affinity for certain toxicants is also a function of position in the food web.

Table 15. Concentrations of Selected Trace Toxicants in Whole Carp in Urban and Rural Sections of the Lower Missouri River, and Ecosystem Health Criteria (mg/kg)						
Missouri R.	chlordane	dieldrin	DDT and metabolites	PCBs	Lead	Mercury
Rural Portions	**0.247**	**0.094**	0.083	0.190	0.01	0.05
Urban Portions	**0.997**	**0.088**	0.218	2.269	0.06	0.07
Ecosystem Health Criteria	chlordane +dieldrin 0.100[11]		1.000			

Fish at the highest level of the food web, those that eat other fish, are more likely to have larger amounts of Mercury. In many of the smaller rivers in Missouri as well as in reservoirs, older individuals of such species as Largemouth and Smallmouth Bass and Walleye often exceed the 0.3 mg/kg limit set for human health. Missouri currently has an advisory against consumption of Largemouth Bass over 15 inches in length in any waters of the state for women that are or may become pregnant and children 12 years of age and younger.

Use of chlordane, dieldrin and DDT have been banned in the United States for many years. The use of PCBs is now greatly restricted and stringent rules now cover the disposal of these chemicals. Elimination of leaded gasoline has caused a significant reduction in the amount of lead released to aquatic environments. From the six fish tissue contaminants listed in Tables 14 and 15 which are presently among the most important, only mercury appears to be increasing over time. Since both anthropogenic and tectonic sources (vulcanism) can be important, it is unclear if this trend for mercury in fish tissue is due to mercury pollution by humans or to the changes in activity of volcanos and hot springs over time.

IX. Sediment Quality

The sediment in the main channel of the Missouri River is predominantly sand. Behind wing dikes and in other backwater areas silt-sized and finer particles are commonly deposited. The results of sediment sampling done behind wing dikes and other depositional area by the Department of Natural Resources is shown in Table 16. These samples were taken from approximately twenty locations beginning upstream of the Iowa-Missouri border and ending at St. Charles near the confluence with the Mississippi River.

Most heavy metals analyzed for in Missouri River sediments had lower concentrations in those sediments than the levels found in typical Missouri agricultural soils, suggesting anthropogenic sources of these metals were not influencing sediment chemistry in the river. Copper, manganese, nickel and zinc showed slightly higher levels in river sediment than typical agricultural soils. Mean levels of metals in eleven samples from the Missouri River upstream of Kansas City were compared to seven samples collected in the first 120 miles downstream from Kansas City. These results however, shown in Table 17, indicate that almost all metals were found at somewhat higher concentrations downstream of Kansas City and suggest that the KC metro area is measurably increasing metals levels in Missouri River sediments.

[10] Criterion currently used by the State of Missouri and many other states to issue fish consumption advisories.
[11] NAS/NAE recommended level for protection of fish-eating birds. The DDT criterion is also from this group and is also for protection of fish-eating birds.

Table 16. Mean Levels of Selected Heavy Metals in Lower Missouri River Sediments and in Missouri Agricultural Soils (mg/kg)		
Metal	Mean Concentation in River Sediment	Mean Concentration in Missouri Agricultural Soils[12]
Aluminum	15,400	42,000
Arsenic	7.96	8.9
Barium	208	650
Cadmium	0.46	<1
Carbon	8,900	12,000
Chromium	21.1	60
Cobalt	8.59	10
Iron	18,700	20,000
Lead	15.5	20
Manganese	**869**	**700**
Mercury	0.022	0.038
Nickel	**19.7**	**15**
Selenium	<5	0.35
Thallium	<5	-
Zinc	**65.2**	**50**

Table 17. Mean Levels of Heavy Metals in Sediments of Two Segments of the Lower Missouri River and Results of Two Sample "t" Tests for Significant Difference in Means				
Metal	Mean Sediment Concentration (mg/kg)		t Statistic[13]	Probability of a greater "t" value due to chance[14]
	Upstream of Kansas City	Downstream of Kansas City		
Aluminum	12,600	15,400	-0.776	0.22
Arsenic	7.19	8.94	-1.394	0.094
Barium	193	199	-0.408	0.344
Cadmium	**0.395**	**0.575**	**-1.924**	**0.039**
Chromium	17.9	20.3	-0.587	0.283
Cobalt	7.81	9.35	-1.511	0.085
Copper	15.4	19.7	-1.283	0.120
Iron	**16,100**	**20,200**	**-1.626**	**0.066**
Lead	**12.8**	**20.6**	**-1.894**	**0.050**
Manganese	808	835	-0.307	0.382
Mercury	0.023	0.022	0.302	0.383
Nickel	18.1	21.2	-1.477	0.085
Zinc	**55.8**	**81.7**	**-1.795**	**0.058**

These sediment samples were also analyzed for several polynuclear aromatic hydrocarbons (PAHs), phthalates, phenol, dieldrin, chlordane, DDE (the most commonly found metabolite of DDT), chlorpyrifos

[12] from Tidball, 1984, Geography of Soil Geochemistry and Classification by Factor Analysis of Missouri Agricultural Soils, USGS Professional Paper 954-H,I.
[13] One-tailed Two sample t test . Alternative hypothesis is that metals levels are higher downstream of KC. Assumes unequal sample variances.
[14] Maximum probability due to chance for a one-tailed test is 0.500.

(now used commonly for termite protection) and diazinon, a commonly used over-the-counter insecticide. Only three of twenty samples had detectable levels of PAHs or phthalates (in the range of 100-200 ug/kg) and none had detectable levels phenols or any of the pesticides.

End Notes

[i] The following is a calculation of percent change in DO saturation over a 30 year period due to bias induced by changes in time-of-day samples were taken. Slope is the slope of the regression line.

Station	Slope DOSat/Hr	Slope Hr/Yr	Annual Bias	30 Yr Bias	Total 30 Yr DO Sat Change	Est. 30 Yr DO Sat Change w/o Bias
Mo. St.Joe	-0.9	-0.1	.09	+2.70	+19.0	+16.3
Mo. Hermann	1.0	0.004	.004	+0.12	+14.0	+13.9
Grand R.	0.7	-0.06	-.04	-1.26	+10.2	+11.5
Meramec R.	1.5	-0.08	-.12	-3.60	+ 0.1	+3.7
Current R.	0.8	-0.018	-.014	-0.43	+5.8	+6.2