Examining the Hydrologic Properties of the Missouri River Basin

https://github.com/cwatson1013/Hydrologic_Data_Analysis_Final_Proj

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Abstract

The Missouri River provides critical water resources that drives the region's agriculture, industry, and ecosystems. This is a region that experiences surface water variability, characterized by damaging floods and severe droughts, greatly impacting the agricultural production of the area. It is reported that a serious flood disaster occurred in the lower Missouri River in the spring of 2019 and the Missouri River experienced severe drought in 2012-2013. This project highlights the changes in stream flow and water quality over time, and identifies key characteristics of the river. Twenty two sites across the lower Missouri River Basin were examined in order to get a fuller picture of the Missouri River and its tributaries over time. By analyzing the trend of the Missouri River discharge, we can predict future changes in the Missouri River flow to provide a reference for water resources management. In addition, we focus on the stream flow and water quality of Missouri River during March to July, 2019 to see how discharge influence the water quality and what can be done to keep the water in the Missouri River in good quality.

Contents

List of Tables

List of Figures

1 Research Question and Rationale

The Missouri River is the largest river in North America (2,540 miles) and has the second largest watershed (529,000 mi^2/339 acres, U.S.-Canada). Its watershed covers portions of ten states, which account for approximately one-sixth of the continental United States, as well as a small part of Canada. The headwater is located in the Bitterroot Mountains River of northwestern Wyoming and southwestern Montana. The watershed is home to around 12 million people in 1990, and has been inhabited by indigenous people for millennia. Demands for managing the river for the benefit of human livelihood has resulted in drastic modification in the river and the floodplains. Numerous reservoirs and dams have been constructed, of which six major dams were built on the mainstream, following the Pick-Sloan Plan in 1944. Now, the river is used intensively in multiple ways, including municipal, agricultural, hydropower, recreation, flood control etc.

Within the 328 million acres of the basin's total area in the United States, 95% is related to agricultural uses, while the rest dedicated for recreation, fish and wildlife, and urban. More than half of the total is pasture and range grassland primarily for grazing, and cropland consists of almost 104 million acres, which is 32% of the whole basin. Irrigated land comprises 7.4 million acres, and 6.9 million acres are intensively cropped. Water bodies, on the other hand, cover 3.9 million acres. In spite of the low proportion of water areas (1.2%), they are the pivotal foundation for agricultural or other usages, and thus critical to the whole region's economy.

Along with the agricultural, urban, and industrial development in the region is nutrient loading and enrichment in water bodies, especially for nitrogen (N) and phosphorus (P). Unlike other regions, agricultural input through fertilizer is the predominant anthropogenic source for nutrient in water bodies in the whole basin. Regardless of the major anthropogenic source, nutrient enrichment is considered nationally as one of the leading factors for water quality impairment. According to USEPA 303(d) lists, more than 160 stream reaches, lakes, or reservoirs were reported by USEPA to suffer nutrient-related impairment in 2006.

In addition to change in nutrient concentration, discharge appears to be highly variable in the basin, and both severe drought and flooding events occurred in the basin in the past. For example, in the spring and summer of 2011, an unprecedented flooding event caused over $2 billion damage FEMA disaster declaration was made in all states along the Missouri River. Subsequently, in 2012, a drought even struck the Central Great Plain, including the basin, and inflicted at least $12 billion of loss before July, 2012. Recently, another flooding event occurred in the spring of 2019.

Given all the background information above, we would like to know the current state of Missouri River and its tributaries, with a focus on the changing pattern in discharge and nutrient. Since regions along the downstream are more likely to be impaired by nutrient loaded and accumulating upstream, in this project study sites were concentrated in the southeast of the whole basin (Figure 1). We are interested in how the dramatic change in discharge (i.e. water quantity) could potentially interact with nutrient enrichment (i.e. water quality). Also, we examined a few specific flooding events, during which changes in both water quality and quantity were well recorded, so that we could make concrete inference on the interplay between quantity and quality. Finally, based on the pattern in the past and the best model we could fit, we attempted to predict the likely future conditions and trends in the Missouri River Basin.

«««< HEAD Given the interesting hydrologic history of this region, we are interested in the past, present, and future conditions of the Missouri River and its tributaries. Our research questions and acccompanying hypotheses are below:

1.How have changes in discharge (i.e. water quantity) interacted with nutrient enrichment (i.e. water quality) in the Missouri River Basin?

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a) Nutrient levels have increased over time
b) Discharge has become more variable over time
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2. What effects do specific flood and drought events have on the water quality and quantity of rivers in the Missouri River Basin areas of interest?
    a) Rivers will exhibit a flushing behavior due to the land use and type of flow during storms
    b) Discharge will decrease during drought, causing nutrient levels to also decrease due to decreased overland flow.
3. Given past and current data, what can we predict about the future state of water in the Missouri River Basin?
    a) Total flow in the Missouri River Basin is decreasing (non-stationary) over time
    b) The future situation of the river basin will see the continuation of current trends of decreasing overall volume of flow.

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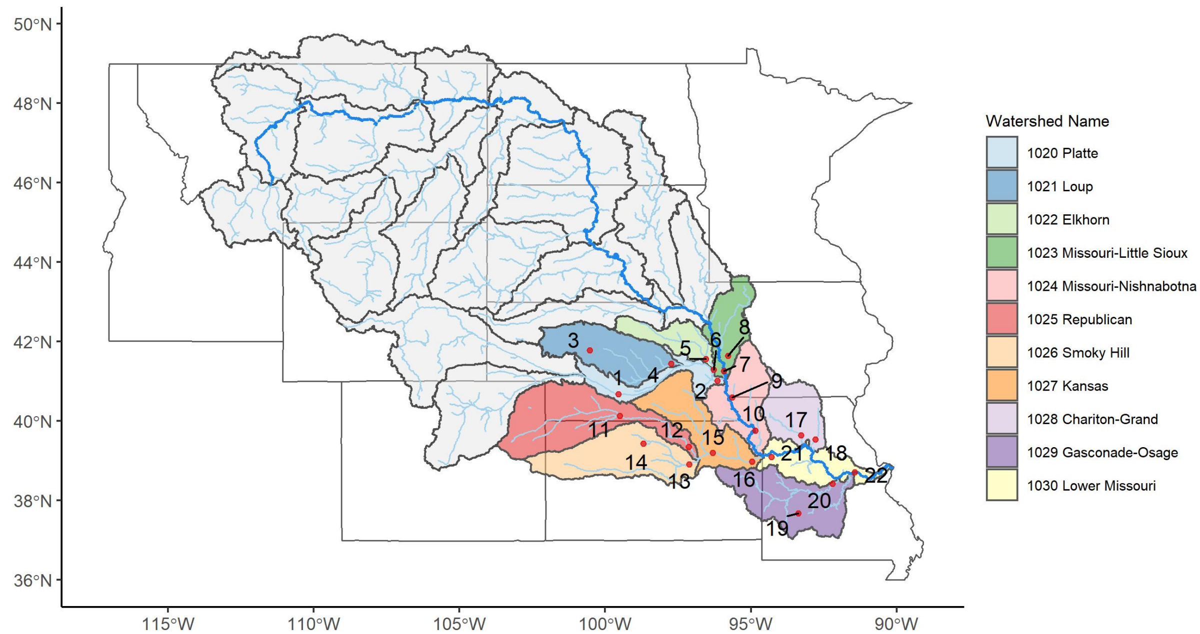

Figure 1: Map of USGS sites used for long term analysis.

2 Dataset Information

The data we are analyzing comes from the United States Geological Survey (USGS) database called the National Water Information System interface, or NWIS. We pulled data from the interface using the R package `dataRetrieval`. Because we are interested in the lower Missouri River basin, we pulled sites from each HUC4 subbasin from 1020 to 1030 (see Figure below). We chose these subbasins because they had a variety of tributaries that all flowed into the Missouri River, representing a variety of river sizes and lengths. We filtered these subbasin queries to only show us sites that had discharge, nitrogen, and phosphorus data. Once we found the sites with all of this data, we chose 2 sites from each HUC sub basin as our 22 "best sites". Our best sites had the overall best time period range for all of our "must have" variables. We retrieved data on water quantity, water quality (N, P concentrations), pH, and coliform concentrations. @ref{tab:table} illustrates the variables we examined and the number of sites in our area of interest that had quality data for each.

Only seven sites within our HUC subbasin boundary contained any high frequency discharge and nitrogen data. Therefore, we also looked at these 7 sites in order to do analyses and answer our research question about flooding.

After doing initial data wrangling and analysis on our 22 "best sites", we decided to pare it down further and only do subsequent analyses on **10** sites. While we initially wanted to look at many sites that were varied in size and location, we determined that it was too many to look at and draw relevant conclusions from.

We have three main datasets:

- The daily values dataset with our 22 "best sites"
- The water quality dataset with our 22 "best sites", with only six sites that had total coliform data.
- The high freqency dataset with 7 sites that contain both high frequency discharge and high frequency nitrogen data.

Variables	Units	NumOfSites
discharge	cfs or m3/s	22
time	UTC	22
nitrogen	mg/L	22 daily values, 7 high frequency
pH	1	22
total coliform	cfu/100mL	6
phosphorus	mg/L	22

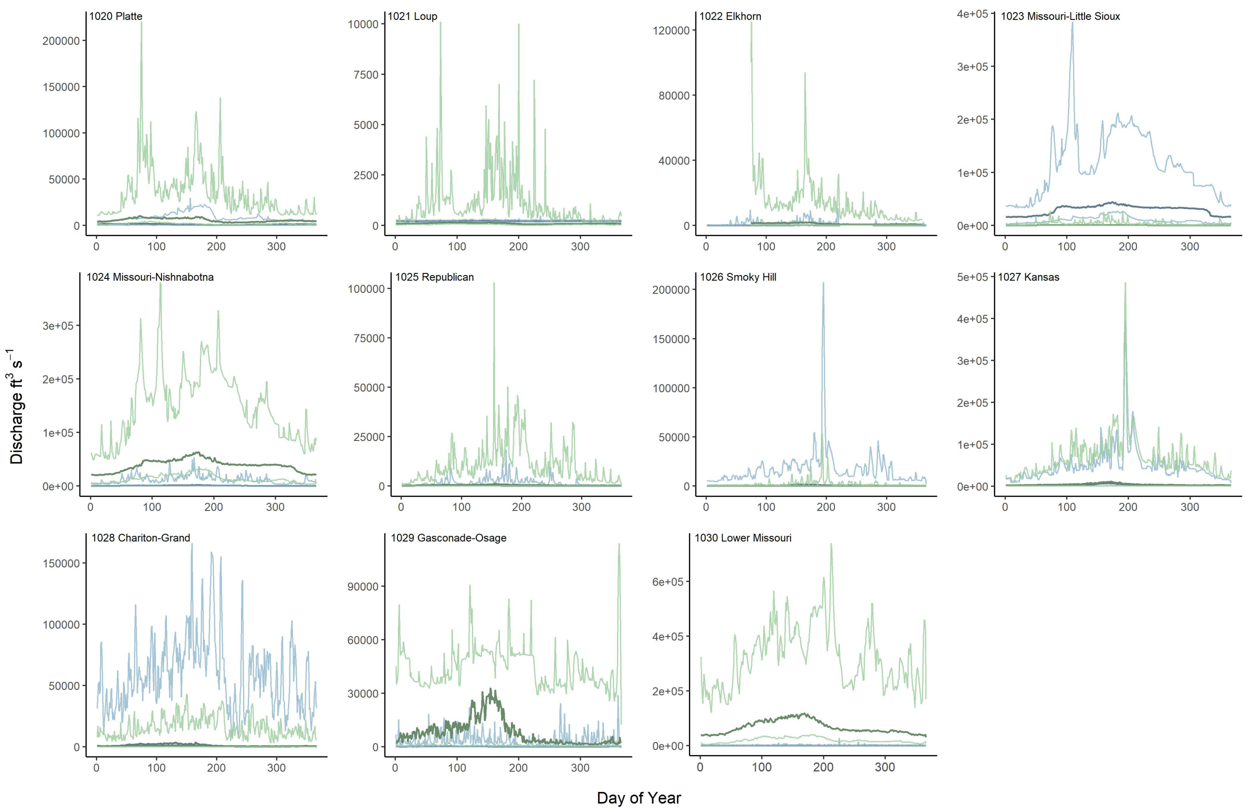

Figure 2: Yearly discharge pattern for 11 HUC4 watersheds. Thick, dark lines are the median of all discharge records on a day of year, while light, thin lines are the maximum and minimum discharge on that day.

3 Exploratory Data Analysis and Wrangling

3.1 Yearly Discharge Pattern

Typical discharge patterns within a year for each HUC4 watershed from 1020 to 1030 were generated by compiling all available discharge data at each USGS site, and two sites in the same HUC4 watershed were plotted in the same panel with different colors (Figure 2). Generally, discharge reaches its peak during the summer and falls to minima during the winter. Most of basins exhibit rather high variations across years, as indicated the large difference between the medians and maxima or minima. Furthermore, highest variations in discharge appear to occur in the summer, whereas discharge in the winter varies less across years.

Table 1: Slopes of linear regression between year and standard deviation of discharge at 22 sites.

	Site Name	HUC4	β_1	P
1	Platte River near Overton, Nebr.	1020	-0.805	0.83

	Site Name	HUC4	β_1	P
2	Platte River at Louisville, Nebr.	1020	33.6	0.145
3	Dismal River near Thedford, Nebr.	1021	0.047	0.196
4	Beaver Creek at Genoa, Nebr.	1021	0.168	0.812
5	Maple Creek near Nickerson, Nebr.	1022	1.1	0.314
6	**Elkhorn River at Waterloo, Nebr.**	**1022**	**11.7**	**0.009**
7	**Missouri River at Omaha, NE**	**1023**	**-95.2**	**0.0093**
8	Boyer River at Logan, IA	1023	2.4	0.134
9	**Nishnabotna River above Hamburg, IA**	**1024**	**13**	**0.0018**
10	Missouri River at St. Joseph, MO	1024	-32.1	0.452
11	**Republican River near Orleans, Nebr.**	**1025**	**-5.86**	**1e-04**
12	REPUBLICAN R AT CLAY CENTER, KS	1025	-5.58	0.157
13	SMOKY HILL R AT ENTERPRISE, KS	1026	-12.9	0.226
14	SF SOLOMON R AT OSBORNE, KS	1026	-5.27	0.0716
15	KANSAS R AT WAMEGO, KS	1027	-6.68	0.714
16	KANSAS R AT DESOTO, KS	1027	2.56	0.91
17	**Grand River near Sumner, MO**	**1028**	**40.4**	**0.0264**
18	**Chariton River near Prairie Hill, MO**	**1028**	**11.9**	**0.0199**
19	Pomme de Terre River near Polk, MO	1029	1.39	0.704
20	Osage River below St. Thomas, MO	1029	138	0.311
21	Little Blue River near Lake City, MO	1030	2.1	0.141
22	Missouri River at Hermann, MO	1030	0.657	0.994