Evaluation of the Hydrology of the Missouri River Below Fort Peck Dam: 1945-2009

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ABSTRACT

This report serves as a companion to two reports (Owen and Hahn 2014, Owen 2014) that evaluated changes and trends in off-channel fish habitat in the Missouri River below Fort Peck Dam. In those reports, the authors measured side-channel and backwater habitats as observed on aerial photographs. This report evaluates and compares hydrologic characteristics for the 1945-1956, 1957-1980, and 1981-2009 time periods, which are bounded by the aerial photograph dates used in the previous studies. Analysis of daily discharge data from above and below Fort Peck Reservoir shows that operation of Fort Peck Dam dramatically reduced the magnitude of high flow events during the latter two periods. Operations also consistently inverted the hydrograph during the latter two periods, with the winter releases being substantially elevated. The natural inter- and intra-annual flow variability and timing that is still present above Fort Peck, although dampened by upstream anthropogenic influence, is absent below Fort Peck.

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1.0 INTRODUCTION

Fort Peck Dam on the Missouri River was closed in 1938 and the reservoir, which first filled in 1944, holds 18.7 million acre-feet at normal full pool. Canyon Ferry Dam on the Missouri River near Helena and Tiber Dam on the Marias River, the largest tributary to the Missouri River between Canyon Ferry and Fort Peck dams, were contemporary in their completion. Canyon Ferry Dam was completed in 1954, and the reservoir stores up to 1.89 million acre-feet at normal full pool. Tiber Dam was completed in 1956, and the reservoir impounds up to 1.52 million acre-feet. Figure 1 shows the relative locations of the dams and reservoirs. This report examines the hydrologic impacts on the Missouri River due to Fort Peck Dam, with consideration to the influence of Tiber and Canyon Ferry dams.

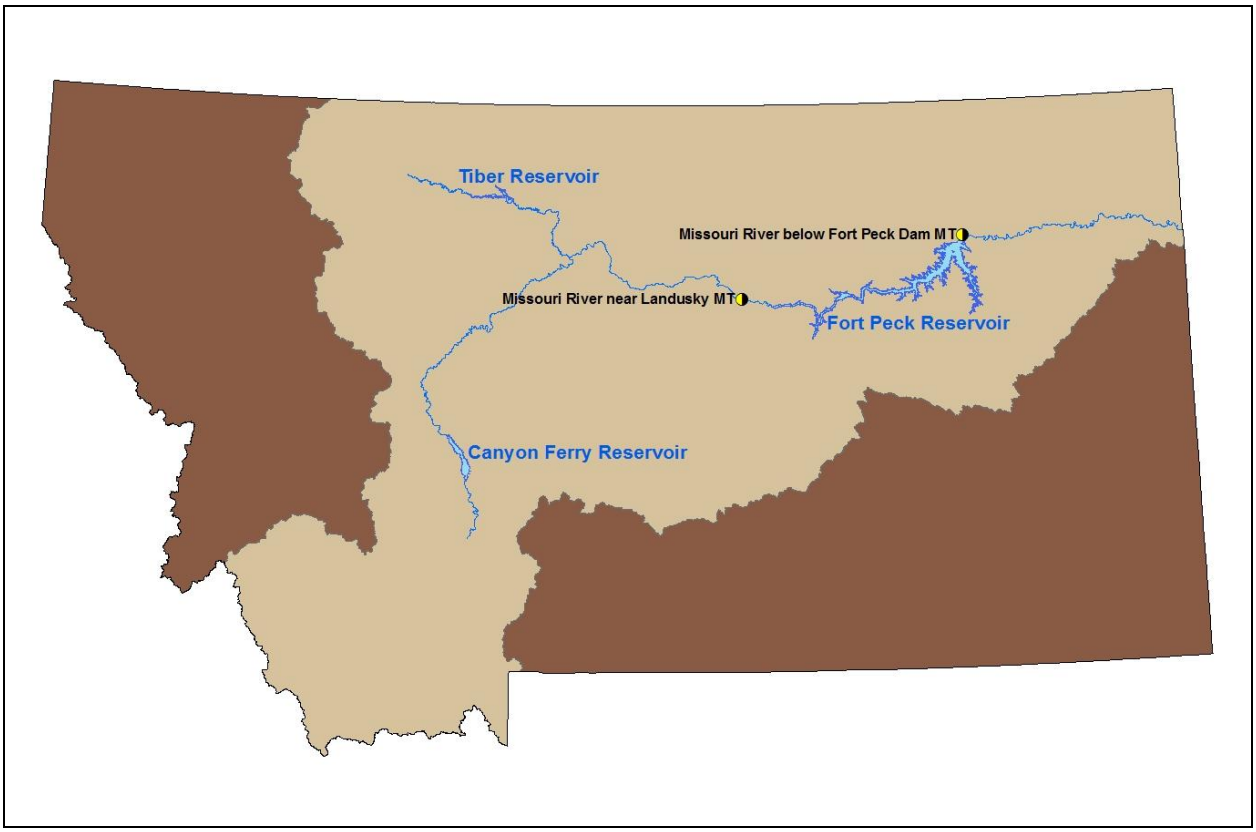

Figure 1. Relative location of reservoirs, rivers and USGS stream gages.

This report serves as a companion to two reports (Owen and Hahn 2014, Owen 2014) that evaluated changes and trends in off-channel fish habitat in the reach of the Missouri River between Fort Peck Dam and the North Dakota border. In those reports, the authors measured side-channel and backwater habitats as observed on aerial photos dating from 1956-57, 1980, 2009, 2011 and 2013. These years were selected (with the exception of 2011) due to the availability of aerial photographs on dates of similar discharge in the Missouri River. This report evaluates and compares hydrologic characteristics for the 1945-1956, 1957-1980 and 1981-2009 time periods. The largest flood event below Fort Peck Dam since its construction occurred in 2011 and appears to have impacted the size and occurrence of side-channel and backwater habitats. The hydrologic records after 2009 are not of sufficient length to

provide a meaningful comparison to the preceding periods and, therefore, are not evaluated in this report. This report focuses on the three time periods after Fort Peck Reservoir filled which also corresponds to the period between aerial photograph dates.

2.0 METHODS

2.1 *Study Area*

The study area includes the Missouri River above and below Fort Peck Reservoir. Data analyzed comprises daily mean discharge data from U.S. Geologic Survey (USGS) stream flow gages *Missouri River near Landusky, MT* No. 06115200 (located above Fort Peck Reservoir) and *Missouri River below Fort Peck Dam, MT* No. 06132000. Figure 1 depicts the relative locations of the two USGS gages.

2.2 *Time Periods Evaluated*

From 1945-1956, Fort Peck Dam was the only major dam on the Missouri River and was relied upon to supply the full supplemental navigational needs of the lower Missouri River. Also, at the end of this period Canyon Ferry and Tiber Dams became operational, impacting inflows into Fort Peck Reservoir. The end of this period corresponds well with the first series of aerial photographs previously analyzed from 1956 and 1957 (Owen and Hahn 2014 , Owen 2014).

The second time period evaluated (1957-1980) ends with the second series of aerial photographs from 1980 that were previously evaluated. The third time period (1981-2009) ends with the third series of aerial photographs previously evaluated (Owen and Hahn 2014, Owen 2014). The largest flood event below Fort Peck Dam since its construction occurred in 2011 and may have scoured and degraded the channel, thereby impacting the size and occurrence of side-channel and backwater habitats (Owen, 2014). The hydrologic records after 2009 are not of sufficient length to provide a meaningful comparison to the preceding periods and, therefore, are not evaluated in this report.

2.3 *Data Analysis*

The daily mean discharge data for the *Missouri River near Landusky, MT* and the *Missouri River below Fort Peck Dam, MT* were obtained from the USGS National Water Information System Web Interface. The analysis is calendar-year based as opposed to water-year. Statistical calculations were made using Streamflow Analysis and Assessment Software (Metcalfe and Schmidt 2014).

The average annual discharge from both gage stations was compared to determine the influence of inflow to Fort Peck Reservoir from other tributary sources, such as the Musselshell River and Big Dry Creek, as well as the influence of reservoir evaporation. Median daily discharge for the respective periods was developed to examine the influence of Fort Peck Dam operation.

Peak discharge events were evaluated on a 1.5-year return interval, the generally accepted surrogate for bankfull discharge, which is the discharge at which sediments are mobile and channel maintenance is occurring (Leopold, et al. 1964, Williams 1978, Dunne and Leopold 1978, Rosgen 1996). Both the number of events meeting or exceeding the 1.5-year return interval and the duration exceedances were calculated for each period.

Seasonal discharge exceedances by period were determined. Table 1 shows the time periods assigned to each season.

Season	Period
Winter	January 1 to February 28
Spring	March 1 to July 31
Summer	August 1 to September 30
Autumn	October 1 to December 31

Table 1. Seasonal periods used in hydrologic analysis.

The seasonal periods were selected to include the normal highest natural flows during the "spring". The natural hydrograph of the Missouri River shows (in some years) an early March or April peak corresponding to plains snowmelt, which this period includes. The typical high flow driven by higher elevation mountain snowmelt and spring precipitation occurs in late May or June. The natural summer low-flow period of August through September was incorporated into the "summer" period. December was also included in "autumn" for ease of calculation by keeping all the periods within a single calendar year, matching the data used.

3.0 RESULTS AND DISCUSSION

Figure 2 shows the mean annual flow by period, including the full 1945-2009 period.

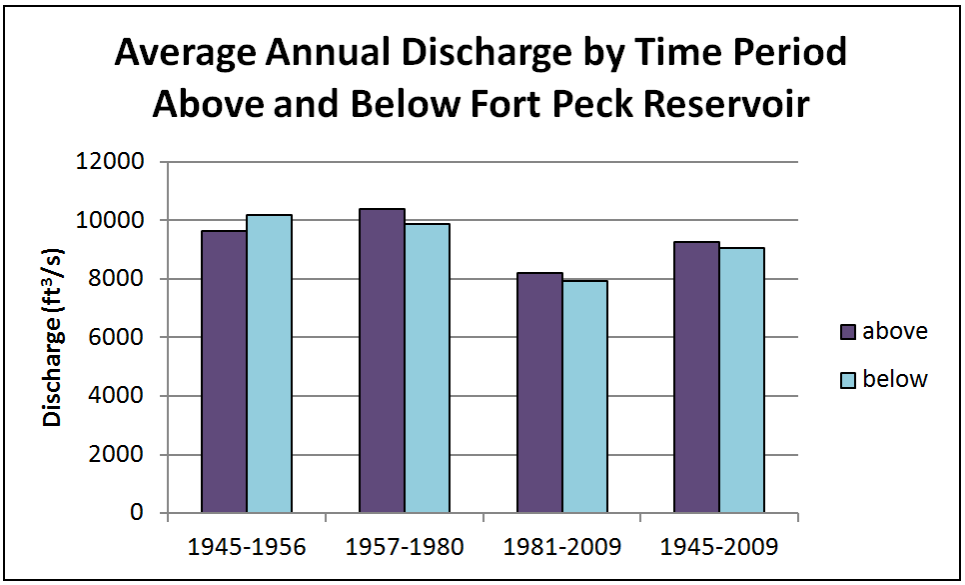

Figure 2. Comparison of average annual discharge by period.

Despite the drainage area's increasing by 16,600 mi^2 or about 40%, the water yield is very similar above and below Fort Peck Reservoir. Over one half of the increased drainage area (9,471 mi^2) between the two gage sites lies within the Musselshell River basin. While the Musselshell Basin represents a 23% increase in drainage area over that above the Landusky USGS station, the average annual 1945-2009 discharge of the Musselshell River at Mosby (near the bottom of the basin) is only 257 cfs or 2.7% of the

Landusky measurement. This small contribution from the Musselshell Drainage is despite its headwaters having mountainous areas over 8,000 feet in elevation. The remainder of the additional drainage area outside of the Musselshell Basin is lower elevation with a relatively smaller water yield per area than the Missouri Basin above Landusky. Figure 2 demonstrates that the 1945-2009 average annual discharge at Landusky above Fort Peck Reservoir is actually slightly higher than below the dam, despite the additional tributary inflow. It appears that evaporative losses from Fort Peck Reservoir consume slightly more than the tributary inflow contributes. Given the similarity in average annual discharge between the two gage sites, direct comparisons between them are reasonable.

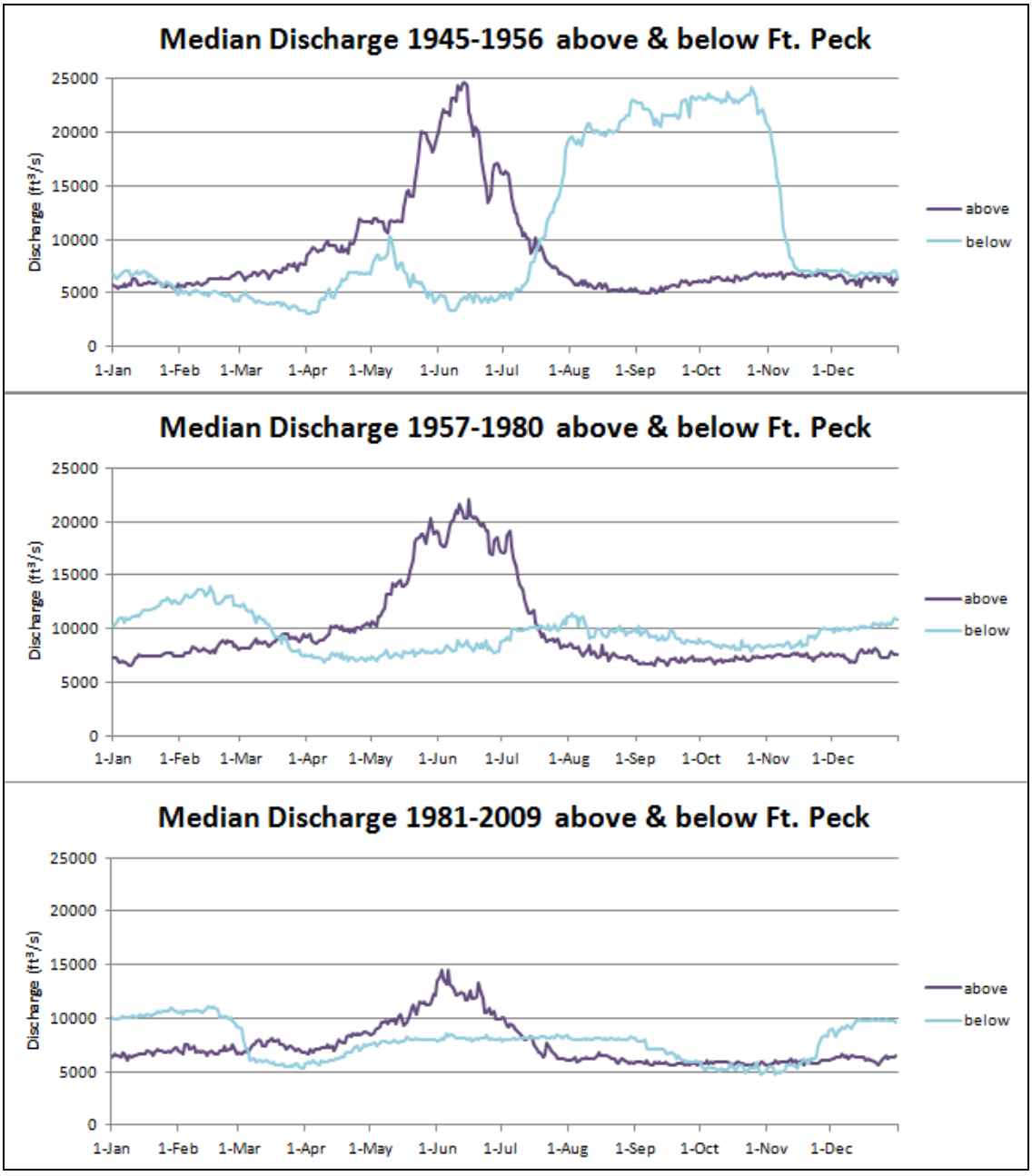

Figure 3. Median daily discharge by period above and below Fort Peck Reservoir.

Figure 3 displays the daily median hydrographs for the three respective periods. The median daily discharge for 1945-1956 shows similar peak values both above and below Fort Peck Dam, however the timing and duration of the high flows is considerably different.

Figure 4 shows the 1.5-year return interval peak discharge for the three periods. Through the early period (1945-1956) the 1.5-year return peak discharge (28,370 ft ^{3}/s) is about 11% higher above when compared to below Fort Peck (25,521 ft ^{3}/s). The number of events was higher below (24) than above (11), an indicator of relatively high sustained releases. The median duration is considerably higher above (8 days compared to 3 days).

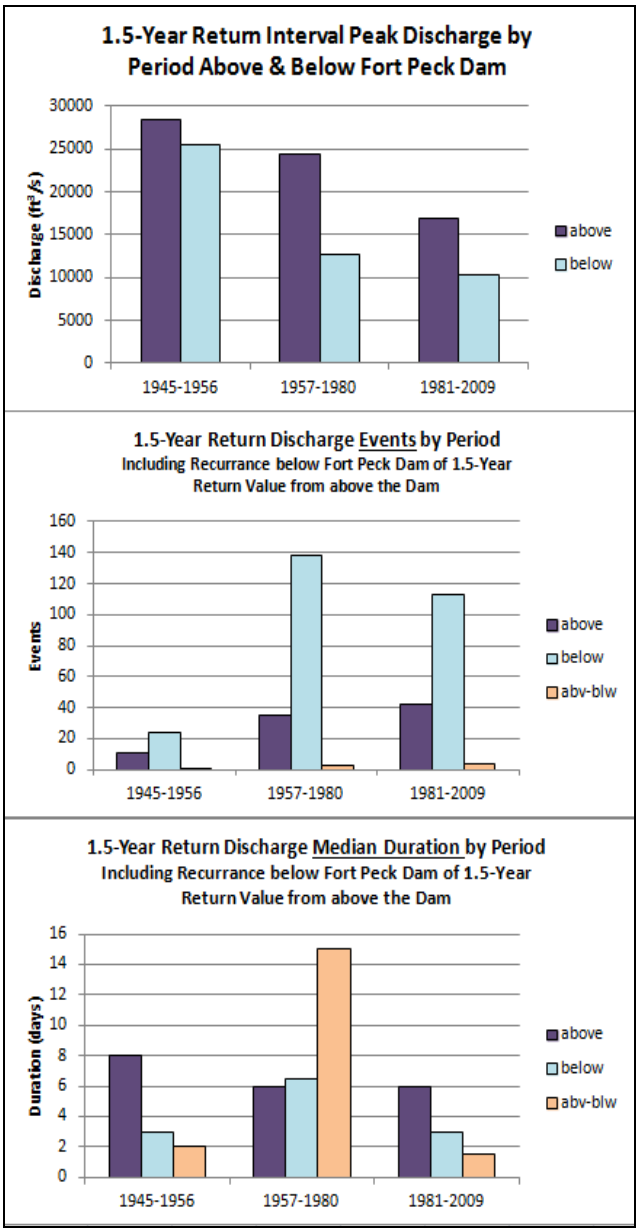

Figure 4. 1.5-year return discharge.

The third column (beige) in the lower two charts of Figure 4 reflect the number of events and median duration that the 1.5-year return discharge from above Fort Peck also occurred below the dam. This comparison gives a better sense of how the reservoir operations have changed the flow regime. During 1945-1956, only one event greater than or equal to the 1.5-year return discharge above Fort Peck occurred below it (lasting for only 2 days), compared to 11 events with an 8-day median above the dam. However, this flow regime impact may not be as significant as these data may suggest, but rather a matter of flow being regulated at levels just below the 1.5-year return discharge.

Moving into the 1957-1980 period, the 1.5-year return peak discharge (24,402 ft ^{3}/s) is about 92% higher above when compared to below Fort Peck (12,739 ft ^{3}/s). The number of events was higher below (138) than above (35), again an indicator of relatively higher sustained releases. The median duration is similar above and below (6 days compared to 6.5 days, respectively). The 1.5-year return peak discharge above Fort Peck occurred only three times below (compared to 35 above), but with a median duration of 15 days (2.5 times more than the 6 days above).

During the 1981-2009 period, the 1.5-year return peak discharge (16,851 ft ^{3}/s) is about 62% higher above when compared to below Fort Peck (10,388 ft ^{3}/s). The number of events was again higher below (113) than above (42) indicating relatively higher sustained releases. The median duration is twice as long above as below (3 days compared to 1.5 days, respectively). The 1.5-year return peak discharge above Fort Peck occurred only 4 times below (compared to 42 above), but with a median duration of 15 days (compared to 6 days above).

Peak flow magnitudes were similar above and below Fort Peck Reservoir and Dam during 1945-1956. Higher flows were sustained for longer periods below. While the peak flow magnitudes were similar above and below Fort Peck during 1945-1956, the timing was considerably different. Above Fort Peck, peak flow occurred during May and June (with June being the modal month), whereas below it, the peak flow occurred during August and September (equal number of events in each month), typically the lowest flow months above the dam. The peak flow above Fort Peck trends downward over the three periods due to the influence of Canyon Ferry and Tiber dams operating during the latter two periods, with the downward trend steepening into the last period due to persistent drought.

As previously noted, the peak flow magnitudes were quite different above and below Fort Peck during both the 1957-1980 and 1981-2009 periods. Further, the timing changed considerably, with the highest flow period below Fort Peck shifting to the winter months. Figures 5 and 6 show the percentile exceedance discharges above and below Fort Peck, respectively.

Comparing Figures 5 and 6 from left to right by season gives a sense of the seasonal impacts of Fort Peck Dam operation on the Missouri River hydrograph. These figures show the flow met or exceeded 10, 40, 50, 60 and 90 percent of the days in each season for the respective period of record. During the winter period above and below Fort Peck Dam and across all three time periods, the exceedances are relatively flat, which is not unexpected during the winter base-flow period. However, the magnitude of the winter discharge is substantially greater below Fort Peck Dam during the 1957-1980 and 1981-2009 periods, showing the aforementioned shift to higher winter releases. The influence of Canyon Ferry and Tiber dams operating during the latter two periods caused a shift to somewhat elevated winter discharge values above Fort Peck during the latter two periods across all exceedances.

During spring, the exceedance discharge above Fort Peck is substantially higher than below it across all percentiles, with the most marked differences at the lower percentiles. During the latter two periods, spring discharge below Fort Peck Dam was higher than during 1945-1956, but still lagged behind that above the reservoir considerably.

Summer exceedance discharge was more similar above and below Fort Peck during the latter two periods, although somewhat elevated below. Above the reservoir, the summer discharge is most likely elevated because of addition flows from Canyon Ferry and Tiber reservoirs, as is true during the winter. The drastic increase in summer discharge below Fort Peck observed during 1945-1956 no longer occurs

as the other main-stem Missouri Reservoirs now also help support navigation on the lower Missouri River.

Autumn exhibits a similar scenario as the summer period, with relatively flat discharge above and below Fort Peck Reservoir and Dam during the latter two periods, while exhibiting considerably more variability during the 1945-1956 period. This increased variability is due to higher flows extending past September in some years while in most years were considerably lower.

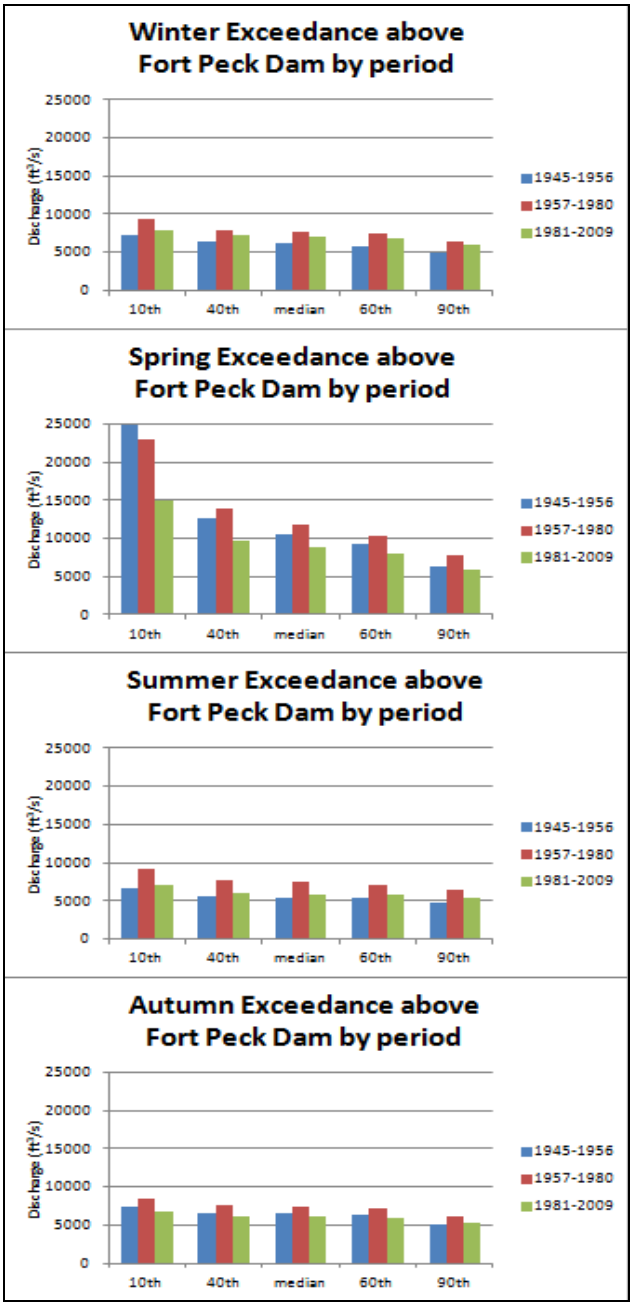

Figure 5. Seasonal exceedances above Fort Peck Dam.

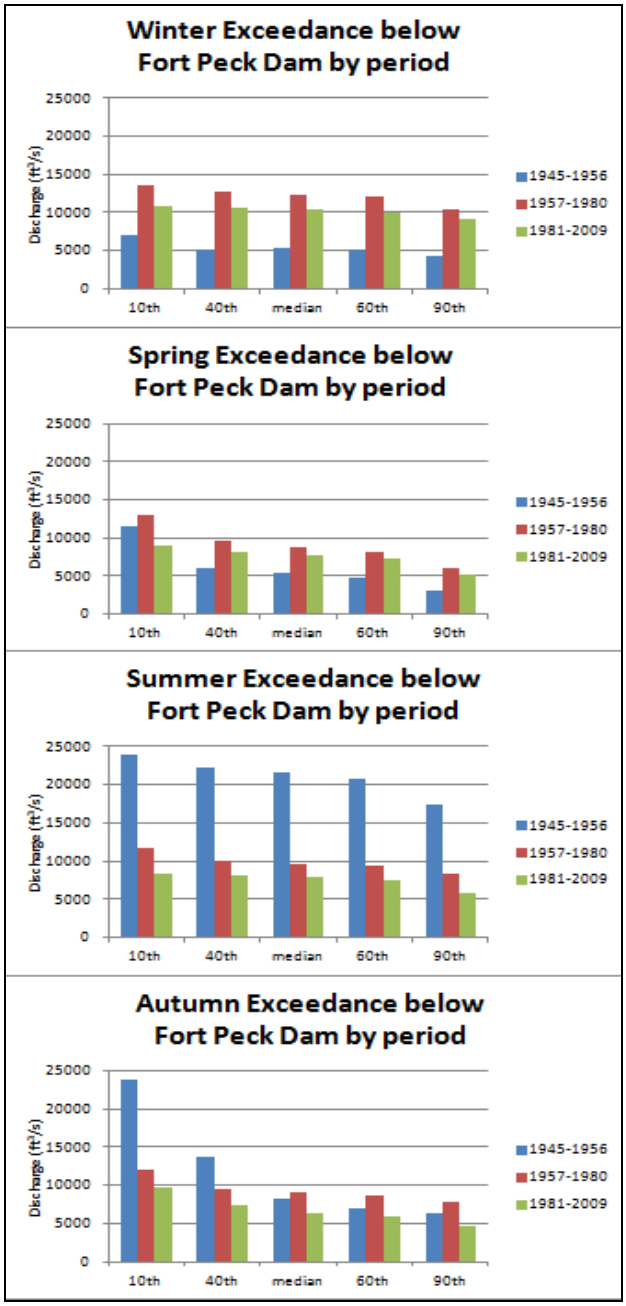

Figure 6. Seasonal exceedances below Fort Peck Dam.

4.0 CONCLUSION

The operation of Canyon Ferry and Tiber dams reduced peak discharges observed above Fort Peck Reservoir during the 1957-1980 and subsequent periods. Even with this reduction, the 1.5-year return-interval discharge magnitude above Fort Peck during this period was nearly double (or 92%) higher than below . Water yield in the Missouri River basin during the 1981-2009 was considerably lower due to significant droughts during the first and last decades of the period. Drought coupled with the operation of Canyon Ferry and Tiber dams further reduced peak discharges observed above Fort Peck. Despite these reductions, the 1.5-year return-interval discharge above Fort Peck during this period was still 62% higher than below, showing the dramatic impact the operation of the dam has on the Missouri River.

During the 1945-1956 period, the channel-forming processes normally associated with the 1.5-year peak flow (bankfull discharge) likely continued below Fort Peck Dam, as it would have if the dam were not present, due to similar magnitude peaks. Scouring and degradation may have been more common due to the longer flow duration and lower sediment load. The timing of these discharges during the 1945-1956 period was considerably later than upstream, with the peak discharges below Fort Peck Dam occurring in August and September, the pre-dam, low-flow period.

Fort Peck Dam operation substantially reduces intra- and inter-annual variability of the Missouri River below it. The period 1957-1980 shows somewhat more variability in flow than 1981-2009, with neither period showing the variability observed above Fort Peck during all periods. This lack of variability is evident even though the operations of Canyon Ferry and Tiber dams dampen the variability above Fort Peck. While Canyon Ferry and Tiber dam operations have reduced natural intra- and inter-annual variability of the Missouri River, Fort Peck Dam operation has nearly eliminated it.

Comparison of discharges above and below Fort Peck Reservoir and Dam demonstrate that operation of the dam consistently inverted the hydrograph below it during the latter two periods analyzed. Spring discharge is substantially reduced, while summer and winter discharges are substantially elevated.

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