CHANGING HISTORY AT ST. LOUIS–
ADJUSTING HISTORIC FLOWS FOR FREQUENCY ANALYSIS

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Abstract In 1997, the Corps of Engineers embarked on a major re–evaluation of flood discharge and stage frequencies along the Lower Missouri and Upper Mississippi Rivers. The first step in the overall study, to be completed in 2000, is to develop a preliminary set of peak discharge data that is relatively homogenous. This requires that the effects of known biases, like historic flood discharge over–estimates and reservoir effects, be removed. For this data set, flood peak discharges at St. Louis prior to 1931 were adjusted downward to reflect the over–estimates made throughout the period when floats were primarily used for velocity measurements. Flood peak discharges recorded after 1957 were adjusted upward to remove the partial control by flood reduction reservoirs which came on line throughout the period to the early 1980's. Preliminary evaluations were made of peak discharge frequency at St. Louis using Bulletin 17B techniques and compared to the current discharge-frequency estimate for a no reservoir condition. The results using the revised data show a varying impact, ranging from almost nothing at common frequencies to about a 10% reduction for rarer events.

INTRODUCTION

Stages have been measured continuously at St. Louis, Missouri since the Civil War. Discharge data are available through periodic measurements made during this period, but the published values are the result of a variety of measurement techniques. The Corps took most discharge measurements at St. Louis prior to 1931, after which the USGS fully took over this task. The methods that the Corps used to obtain velocity measurements varied significantly from 1861–1931. Surface floats, single and double floats, rod floats, and various meters were used. Meter measurements were taken from both floating plant, subject to water movement, and from bridges. Only after 1931, when the USGS took over discharge measurements at St. Louis bridge sites using the Price Current Meter, have homogenous and reasonable accurate flood discharge measurements been available. Published peak discharges prior to 1931 for flood events have been found to be significantly over–estimated by several past investigations..

Similarly, changes in the upstream watershed, especially the construction of dozens of flood reduction reservoirs, have also had impacts on discharges at St. Louis. The first major reservoir, Fort Peck in Montana, was completed just prior to World War II, but reservoirs did not significantly impact the record at St. Louis until the late 1950's. Reservoir construction continued until the early 1980's and the record at St. Louis during the past 40 years includes lower flood peak discharges than would have occurred prior to reservoir construction.

Impacts of the 1993 Flood The 1993 flood produced record flood levels throughout all or portions of the five Corps Districts that comprise the Upper Mississippi River and Lower Missouri River Basins. The Lower Missouri River extends from the most downstream main stem reservoir (Gavins

Point) to the mouth, while the Upper Mississippi River is the entire reach upstream from the mouth of the Ohio River. Some locations experienced flood levels exceeding the 0.2% chance stage (500–year average recurrence interval) flood. Many questions were raised as to the frequency of the 1993 event. In addition, inconsistencies were noted at some locations in comparing recent flood records over the last two decades to the calculated stages of hypothetical floods, like the 1% chance event (100–year average recurrence interval). For example, the estimated 1% chance flood at Hannibal, MO had been exceeded on three occasions from 1965-1993, a highly unlikely occurrence. The hypothetical profiles currently in force were developed generally in the 1960's and 70's based on data available at that time. With the passage of time, at least 20 years of additional data, including the 1993 flood, is now available to re–evaluate frequency profiles on both the Lower Missouri and Upper Mississippi Rivers. Congress directed the Corps to undertake this re-analysis in 1997. The initial work is aimed at developing preliminary estimates of peak discharges at all main stem gages to evaluate the appropriateness of the current Federal standard for frequency analysis: the log Pearson Type III distribution. This paper addresses the effort to determine preliminary peak discharges at St. Louis, removing the impacts of measurement errors and upstream reservoir effects.

ACCURACY OF HISTORIC DISCHARGES

Early Work As early as 1944, it was known that a significant difference in calculated discharge at St. Louis existed between measurements using floats and those using meters. Field tests and discharge comparisons were made in 1944 of the gaging techniques used by the U.S. Geological Survey and the Corps of Engineers at St. Louis. These joint tests were performed simultaneously between the USGS, using the Price Current Meter suspended from a bridge (still the current standard today), and the Corps, using double floats and old style meters suspended from floating plant. For the double floats, differences with USGS results ranged from about 10% at discharges of 400,000–500,000 cfs to over 15% at discharges of 700,000 cfs. Extrapolations to higher discharges found that differences would exceed 20% at flowrates greater than 850,000 cfs. In all cases, the double floats resulted in higher discharges. Although not tested, surface floats would likely exhibit even higher velocity measurements and discharges. A similar finding was made between velocity measurements using a USGS Price meter suspended from a bridge and those using Corps of Engineers old style meters suspended from floating plant. The Corps measurements were considerably higher than GS results, ranging from 4% higher at a discharge of 530,000 cfs to 15% higher at a discharge of 670,000 cfs. Extrapolations to higher flows again illustrated a continuation of this trend, with differences of 20% or more at discharges exceeding 900,000 cfs. However, the field tests made no recommendations concerning any adjustment of the historic record, which was largely the result of Corps measurements until 1931. As a reference, a flow of about 500,000 cfs is roughly the bankfull capacity, while a flow of 850,000 cfs represents about a 4% annual chance event and is about equal to the peak discharge experienced in April 1973. The stage of the 1973 event represented the flood of record at St. Louis until the 1993 flood occurred.

UMR Work The subject of the accuracy of historic flow measurements was again addressed by the University of Missouri–Rolla (UMR) in the late 1970's as a research effort funded by the St. Louis District (1). Actual measurements were taken at the Chester, Illinois gage, located 70 miles downstream of St. Louis, with a variety of historic techniques and compared to standard USGS

measurements taken from the nearby long-record gage site. While no great differences were noted for low and moderate flows within banks, important differences were found for higher in–bank flows and for one moderate flood. Measurements of high in– bank and flood discharges found that 83% of these measurements with historic methods were more than 5% higher and that 42% of the historic technique measurements were more than 10% higher (2).

Models Finally, the physical model of the Mississippi Basin constructed by the Waterways Experiment Station, Vicksburg, MS was utilized in 1986–87 to evaluate the impact of levees and reservoirs on flooding at and downstream of St. Louis (3). Part of the testing attempted to approximate the discharge of each of the two largest historic floods at St. Louis (1844 and 1903). This would be accomplished by matching about one dozen known highwater marks from each event through the St. Louis reach for the channel and overbank conditions existing at those times. The results of the testing found that highwater marks from both floods were very well matched with flows that were 33% (1844) and 23% (1903) lower than the published historic discharge estimates for the two floods (4). Neither historic flood was measured at St. Louis and published records simply represent estimates made after the 1903 flood. These findings were also confirmed through later analytic {UNET, (5)} modeling of the Mississippi River following the 1993 flood.

ADJUSTMENT OF HISTORIC FLOOD DISCHARGES

Since the comparison of USGS and Corps techniques performed by UMR generally found minor differences in discharges less than channel capacity and a conservative approach to adjusting the discharges was desired, it was assumed that flows less than the current channel capacity (approximately 500,000 cfs) did not require any modification (decrease). This decision left about one-half of the historic peak discharges prior to 1931 (after which the USGS performed discharge estimates exclusively) unchanged. The greatest historic floods prior to 1931 were the events of 1903 and 1844, neither of which were measured at St. Louis. These events were modeled with both physical and analytical techniques. All models gave similar results---the published values were too high. The three models found that discharges of 870,00-1,000,000 cfs (depending on the model used) reconstituted 1844 flood highwater marks very well, while peak discharges ranging from 790,000-875,000 cfs hit highwater marks from the 1903 event. Consequently, an initial, linear relationship between published flood peaks and adjusted flood peaks was developed and all historic flood discharges from the start of record to 1931 evaluated. This initial relationship was further simplified by reducing recorded flood discharges between 500,000-700,000 by 5% and discharges between 701,000-1,000,000 cfs by 10%. The adjustments are intended to be a conservative modification of the historic data; i.e., the adjusted value is likely to be the upper limit of the possible range of the actual value. With these guides, adjustments were made to the peak discharge in 34 of the 72 years of record prior to 1931. Table 1 illustrates some typical changes to St. Louis flows.

RESERVOIR IMPACTS

Reservoir construction that resulted in significant impacts to flood discharges on the Mississippi River at St. Louis did not really begin until well after World War II. Five of the six major reservoirs in the Upper Missouri Basin came on line in the 1950's and flood reduction reservoirs on major tributaries of the Missouri, especially the Kansas River Basin, were built in the 1950's and '60's.

TABLE 1
Comparison of Selected Historic Flood Discharges

Year	Published Value (cfs)	Adjusted Value (cfs)
1844	1,300,000	1,000,000
1903	1,019,000	875,000
1892	926,500	833,900
1908	850,000	765,000
1884	543,600	516,400

However, these reservoirs are several hundred miles upstream from St. Louis and large uncontrolled watersheds enter the Missouri River downstream of the reservoirs. Estimates of reservoir impacts at St. Louis from these reservoirs were generally a foot or less for most floods prior to 1978. The structures having the most impact on flood levels at St. Louis are the Truman Dam (completed in 1978) on the Osage River in west central Missouri and the Cannon Dam (completed in 1984) on the Salt River in northeast Missouri. Cannon Dam is one of four significant flood reduction structures on tributaries of the Upper Mississippi River and these came on line during the period from the late 1950's to the early 1980's. Again, the other three reservoirs, in east central Iowa, have little impact on Mississippi flows at St. Louis compared to Cannon Dam. Due to reservoir construction at the time, any given flood discharge throughout the period from the mid-1950's through the mid 1980's can show varying impacts from upstream flood reduction reservoirs. Only since about 1984 have records reflected a relatively homogenous period of reservoir effects. Precise knowledge of reservoir impacts is further complicated by a lack of adequate hydrologic models to firmly establish exact effects of the reservoirs at downstream points. Reservoir effects can only be estimated based on the results of limited Missouri River modeling, limited modeling of tributary reservoirs of the Mississippi and Missouri, and a maximum of engineering judgement. Estimates of the reservoir effects at St. Louis have been made for every significant flood since 1973, but detailed modeling has not been performed for any flood except 1993. Detailed hydrologic and hydraulic modeling of a no reservoir scenario was featured as part of the Flood Plain Management Assessment Study (6) performed after the 1993 flood, and these results were used as a basis for estimating the impacts of other events between the mid-1950's and today. Again, no adjustments were made for peak discharges less than channel capacity at St. Louis (approximately 500,000 cfs), assuming that locally heavy rainfall downstream of existing reservoirs could cause flows of this magnitude. This resulted in upward adjustments to 19 events from 1958-96. A simple linear relationship between channel capacity and the 1993 flood peak discharge was developed for existing vs. no reservoir conditions. An initial estimate of reservoir impacts for each flood from 1958 through 1996 was obtained from this relationship and then further adjusted, based on the knowledge of which reservoirs were on line during that specific flood year. These adjustments resulted in a no reservoir flow that was typically 2-15% greater than actual, except for 1993 which reflected a 20% increase. As with the previous adjustments for gaging techniques, these adjustments are intended to be conservative. Selected recorded and adjusted flows at St. Louis are shown in TABLE II.

Variations of adjusted flow for some events differ from later floods having a similar discharge, due to the presence of certain reservoirs which were built after the earlier flood. The detailed hydrologic and hydraulic modeling effort scheduled for the 1998-2000 time frame will greatly improve the estimates of reservoir effects on peak discharges. The figures in Table II should be viewed as an initial estimate for the evaluation of selected frequency distributions.

TABLE II
Comparison of Selected Flood Discharges for Reservoir Impacts

Year	Recorded Discharge (cfs)	Adjusted Discharge (cfs)
1995	800,000	925,000
1993	1,070,000	1,285,000
1979	694,000	755,000
1973	852,000	875,000
1969	618,000	650,000

PRELIMINARY ANALYSIS OF ADJUSTED DISCHARGES

These adjusted peak annual discharges are part of a set of similar discharges from all long-record stations on both the Missouri and Upper Mississippi Rivers that will be statistically evaluated during 1998. About 25-30 stations will be analyzed using at least four different statistical distributions to determine if one is superior for the evaluation of large river systems (over 5000 square miles). A recommendation will not be forthcoming until late in 1998. However, a statistical analysis of the adjusted St. Louis discharge data was performed using Bulletin 17B procedures (7). The Log Pearson Type III distribution was applied to the 136 years of record, including the adjusted data at St. Louis, and compared to previous estimates of discharge-frequency under no reservoir conditions. The analysis showed little change at the common flood frequencies (50%, 20% chance), however, estimates of rare floods like the 1% chance were considerably lower (about 10%) than the earlier estimates . Although this evaluation is for a no reservoir condition, presumably a with reservoir condition might be expected to show a similar result. If so, discharge and stage for a given frequency at St. Louis may be reduced when the overall re-evaluation of the hydrology and hydraulics of the Mississippi-Missouri Rivers is completed late in the year 2000.

SUMMARY

This effort was intended to provide a preliminary set of adjusted discharges at St. Louis for use in statistical analysis testing a variety of distributions. Final discharge estimates will be obtained through major, detailed hydrologic studies now underway. Annual peak discharges at St. Louis for floods were decreased prior to 1931 to reflect gaging over-estimates, while annual flood peak

discharges after 1957 were increased to remove reservoir impacts. Preliminary analysis suggests that current estimates of discharge for rarer floods may be conservative.

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