Characterizing the Natural Flow Regime of the Missouri River Using Historical Variability in Hydrology

David L. Galat
U. S. Geological Survey, Biological Resources Division
Missouri Cooperative Fish and Wildlife Research Unit
302 Anheuser-Busch Natural Resources Building
University of Missouri, Columbia, Missouri 65211-7240

and

Robin Lipkin
The School of Natural Resources
302 Anheuser-Busch Natural Resources Building
University of Missouri, Columbia, Missouri 65211-7240

January 1999

TABLE OF CONTENTS

List of Tables ii

List of Figures iii

Summary iv

Introduction 1

Missouri River Hydrosystem 3

Range of Variation Approach 8

Methods 10

- Indicators of hydrologic alteration calculations 15
- Range of variability calculations 17

Results 19

- Magnitude of monthly discharge 23
- Magnitude and duration of discharge extremes 28
- Timing of annual discharge extremes 33
- Frequency and duration of high- and low-flow pulses 36
- Rate and frequency of change in discharge 42
- Basin wide summary 45

Discussion 47

- Alterations in seasonal flow patterns and ecological effects 47
- Natural factors contribute to spatio-temporal variability in river flows ... 53
- Preliminary flow recommendations within an adaptive management framework 56

Acknowledgments 58

References 59

Appendix A 68

Appendix B 78

LIST OF TABLES

Table

1 Characteristics of Missouri River mainstem reservoirs 6

2 Summary of the 32 hydrologic parameters and their characteristics used in the Indicators of Hydrologic Alteration method for the Missouri and lower Yellowstone rivers 9

3 Location, drainage area, pre- and post-flow regulation mean annual discharge, and percent change in mean annual discharge from pre- to post-flow regulation at two stations on the Missouri and lower Yellowstone rivers upstream from large mainstem reservoirs, three stations immediately below dams or between reservoirs, and six stations downstream from reservoirs in the channelized river 13

4 Mean annual coefficient of variation, predictability, constancy, and contingency for pre- and post-flow regulation discharge at two stations on the Missouri and lower Yellowstone rivers upstream from large meinstem reservoirs, three stations immediately below dams or between reservoirs, and six stations downstream from reservoirs in the channelized river 22

5 Percent change in median, coefficient of dispersion, and hydrologic alteration of monthly discharge between pre- and post-flow regulation periods along the Missouri and lower Yellowstone rivers 26

6 Percent change in nonparametric and parametric statistics, and hydrologic alteration for five groups of hydrologic variables between pre- and post-flow regulation period along the Missouri and lower Yellowstone rivers 29

7 Summary of flow alterations between pre- and post-regulation intervals for five groups of hydrologic variables at 11 stations along the Missouri and lower Yellowstone rivers 46

8 Summary of fishes and birds that reproduce in or along the mainstem Missouri and lower Yellowstone rivers that were federally listed as candidate, threatened, or endangered as of 1995 51

LIST OF FIGURES

Figure

1 Map of the Missouri River basin, the Missouri River and its major tributaries, mainstem reservoirs, and locations of gaging stations where historical flow records were analyzed 4

2 Mean annual discharge, ±1 standard error, for 11 stations along the Missouri and lower Yellowstone rivers for water years 1929 through 1996 20

3 Mean monthly discharge before and after flow regulation along the mainstem Missouri and lower Yellowstone rivers 24

4 June median discharge at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 27

5 Annual maximum 7-day median discharge at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 31

6 Annual minimum 7-day median discharge at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 32

7 Timing of each annual 1-day maximum discharge at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation . . . 35

8 Timing of each March-October 1-day minimum discharge at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 37

9 Annual number of high-flow pulses at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 39

10 Annual number of low-flow pulses at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 41

11 Annual mean rate of discharge rise to five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 43

12 Annual mean number of flow reversals at five stations along the Missouri and lower Yellowstone rivers before and after flow regulation 44

13 Mean of ranked percentages of hydrologic alteration for the 1967-1996 post-regulation period across five groups of hydrologic indicators for 11 stations along the Missouri and lower Yellowstone rivers 48

Summary

Restoring the ecological integrity of regulated large rivers necessitates characterizing the "natural" flow regime. Historical flow data often provide the only opportunity to estimate natural or reference conditions because few naturally-flowing large rivers exist. We applied the Range of Variation Approach (RVA) to assess the natural range of variation of the Missouri River's flow regime at 11 locations before (1929-1948) and after (1967–1996) mainstem impoundment. The 3768 km long Missouri River was divided into three sections: upper basin least-impacted, including the lower Yellowstone River; middle basin inter-reservoir, where the river is impounded by six large mainstem dams; and lower basin channelized, where flows are regulated by upstream dams and the river has been channelized for navigation, its banks stabilized, and flood-control levees are present.

Mean annual discharge for all stations ranged from 8 to 42% higher, inter-annual flow variability was lower, and flow predictability was higher in the post- than pre-regulation period. Flow regulation was associated with a reduction in magnitude and duration of the annual flood pulse, an increase in magnitude and duration of annual discharge minima, a reduction in frequency of annual low-flow pulses, earlier timing of March-October low-flow pulses, and a general increase in frequency of flow reversals with a reduction in the rate of change in river flows. These hydrologic alterations were smallest at two least-impacted upper-basin sites and most frequent and severe in inter-reservoir and upper-channelized river sections. The influence of reservoir operations on depressing the annual flood pulse was partially offset by tributary inflow in the lower 600 km of river, but the increase in low-flow discharge was not. Intra- and inter-annual Missouri River flow patterns were complex due to geographic and climatic factors. Geographically distant sites on the mainstem upper Missouri or lower Yellowstone rivers did not

provide suitable references for lower-basin stations, and differing precipitation between the two time intervals affected applicability of historical flows to assess contemporary reservoir operations.

Reservoir operations could be modified to more closely approximate the 1929-1948 flow regime of the Missouri River if a management goal is to establish a simulated natural riverine ecosystem. Ecological structure and function of the inter-reservoir and upper channelized river sections would benefit by controlled flooding through managed reservoir releases during June and July of some years, as well as by increasing the frequency and duration of annual high-flow pulses, and the annual rate of hydrograph rises and falls. All of the regulated Missouri River would receive ecological benefits from reducing reservoir discharges in most, if not all, years from August through February, modifying the timing of releases and reducing the annual number of hydrograph reversals. Assessment of ecological responses to a reregulation of river flows that more closely approximates the natural flow regime should then be used in an adaptive fashion to further adjust reservoir operations.

Aspects of these ecologically based flow-management guidelines conflict with contemporary Missouri River management objectives of maximizing mid-summer power production in the inter-reservoir section and providing flow releases for navigation in the channelized river. We hope that consideration of the range of flow variability approach will stimulate discussion among the various beneficiaries within and outside the Missouri River basin to reconcile these differences.