GEOMORPHIC ADJUSTMENTS ON THE UPPER MISSOURI RIVER IN RESPONSE TO DAM MANAGEMENT AND FLOODING

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ABSTRACT

The Missouri River has had a long history of anthropogenic modification with considerable impacts on riparian ecology, form, and function. During the 19th and 20th century, the Missouri River basin experienced several massive dam-building efforts for irrigation, flood control and the generation of hydroelectric power. The river today has over 1/3 of its length inundated by reservoirs, and another 1/3 channelized with the flow managed for recreational use, fisheries, and habitat maintenance. In this study we examine how massive flooding in 2011 affected the geomorphic adjustments related to river management.

Our study is conducted along the 70-mile free flowing Upper Missouri River reach bounded upstream by the Garrison Dam (1953) and downstream by Lake Oahe Reservoir (1959) around the City of Bismarck ND. The Upper Missouri River has had its hydroperiod greatly reduced and stabilized by the presence of these dams. Typical discharges prior to the dam ranged from 10,000- 100,000 cubic feet per second (cfs) and fell to 30,000-45,000 cfs afterwards. In response, sedimentation rates and patterns along the river have had over 50 yrs to adjust to this new regime. The largest flood since dam regulation occurred in 2011 following an abnormally high snow pack season and a week-long rain event in the headwaters. Flood releases from the Garrison Dam began in May 2011 and peaked in June with a flow of approximately 150,000 cfs, more than triple that of normal peak loads for two weeks. The 2011 flood has highlighted the critical need for quantifying the complex interaction between the regional geomorphology and human activities.

The dam releases have had a discernible impact on the Missouri River throughout this section, such as reduction in sediment loads and channel bed degradation. A quantitative investigation of the historical impacts of the dams on channel planform, morphology, and sediment dynamics is necessary to provide a baseline to assess the impact of the 2011 flood. We have created a spatial-temporal conceptual model of the governing fluvial and deltaic processes for the reach. Ecological and geomorphic effects of dams and reservoirs have been well documented at specific sites, however relatively little attention has been paid to their interaction along a river corridor. We examine the morphological and sedimentation changes in the Upper Missouri River between the Garrison Dam and Oahe Dam. Through the use of historical aerial photography, stream gauge data, and cross sectional surveys we demonstrate that the impacts of the upstream dam do not completely attenuate to natural conditions before the backwater effects of the downstream

reservoir begin. Analysis of historic cross-sections and channel planform resulted in a series of geomorphic classifications along river.

The segment between the Garrison and Oahe dams was divided into five geomorphic reaches termed: *Dam Proximal, Dam-Attenuating, River-Dominated Interaction, Reservoir-Dominated Interaction, and Reservoir*. The Dam Proximal reach of the river is located immediately downstream of the dam and extends 50 km downstream and contained 22 cross-section sites. The cross-sectional data and aerial images suggest that the Dam Proximal reach of the river is eroding the bed, banks, and islands. All sites experienced an increase in cross-sectional area. The areal extent of islands in the Dam Proximal Reach in 1999 was 43% of what is was in 1950. The Dam-Attenuating reach extends from 50 to 100 km downstream of the dam and contained 14 cross-section sites. The islands in this reach are essentially metastable (adjusting spatially but with little net increase or decrease in areal extent). The reach itself has experienced net erosion with respect to the bed and banks, but to a lesser extent than the Dam Proximal reach. Twelve cross sections in the Dam-Attenuating reach show an increase in cross-sectional area. The reach gained 16% in island area from 1950 to 1999. All major islands present in 1950 were still present in 1999 with mostly similar geometries and distribution. The River-Dominated Interaction reach extends from 100 to 140 km downstream of the dam and contains 11 cross-sections. This reach is characterized by an increase in islands and sand bars and minimal change in channel cross-sectional area. Four of the sites have erosion and 5 of the sites are depositional (2 show no change). The areal extent of island area in this reach in 1999 was 150% greater in 1950. The Reservoir-Dominated Interaction reach is located 140– 190 km downstream from the Garrison Dam and contains 11 cross-sections. Reservoir effects vary both annually and seasonally due to changing reservoir levels creating a recognizable deltaic morphology. The Reservoir- Dominated Interaction reach is characterized by aggrading islands, sand bars, and the flooded meander bends (former meanders that have been flooded by the reservoir). Nine sites indicate deposition. The active extent of this reach can migrate drastically from year to year depending on the reservoir level. The Reservoir reach (Lake Oahe) is depositional but the channel morphology is stable. This reach extends from approximately 190 km to just upstream of the Oahe Dam; 512 km downstream from Garrison Dam. Cross-sections in this section extend into the first 100 km into this reach. All 12 cross sections in the Oahe reach shows deposition. It should be noted that because the lower floodplain is impounded (unlike other sections of the river), the deposition that occurs is spread out laterally rather than vertically. Thus, even though the cross-sectional area for the surveyed sample transect in this reach has changed, the overall change in channel capacity is only 2.5%. General channel morphology remains stable and all pre-dam islands in this reach are submerged under several meters of water.

Results show that the 512 km between the Garrison and Oahe Dam is not enough distance to isolate their influence on the river and therefore requires that they are not considered separately in impact investigations. The conditions which created the current morphology of the Upper Missouri river are likely found in many other rivers across the US. Most major rivers in the US have dams which are proximal longitudinally and are likely interacting in a similar way as the Garrison and Oahe Dams. In a GIS analysis of 66 major rivers within the contiguous United States, 73% of 404 dams surveyed are separated by less than 100 km. Dams were identified using USACE National Inventory. For each river, only the main river stem was considered and river distance was delineated in ArcGIS to the nearest km. We propose a conceptual model of how a sequence of interacting dams might impact river geomorphology (Figure 1) based on our

results. We call this morphologic sequence the Inter-Dam Sequence, and we present a simplified model based on the Upper Missouri River that could be easily adapted to other river reaches. Although the morphologic sequence is a useful conceptualization, there are clear limitations to these results. This model likely only applies to large dams on alluvial rivers. Dams on rivers that are controlled by bedrock or where morphologic adjustment is limited by vegetation or cohesive banks may respond differently than the model presented here. Similarly, the downstream effects of small dams will likely attenuate over much shorter distances. However, this framework is a helpful advancement in our understanding of longitudinal responses to multiple dams.

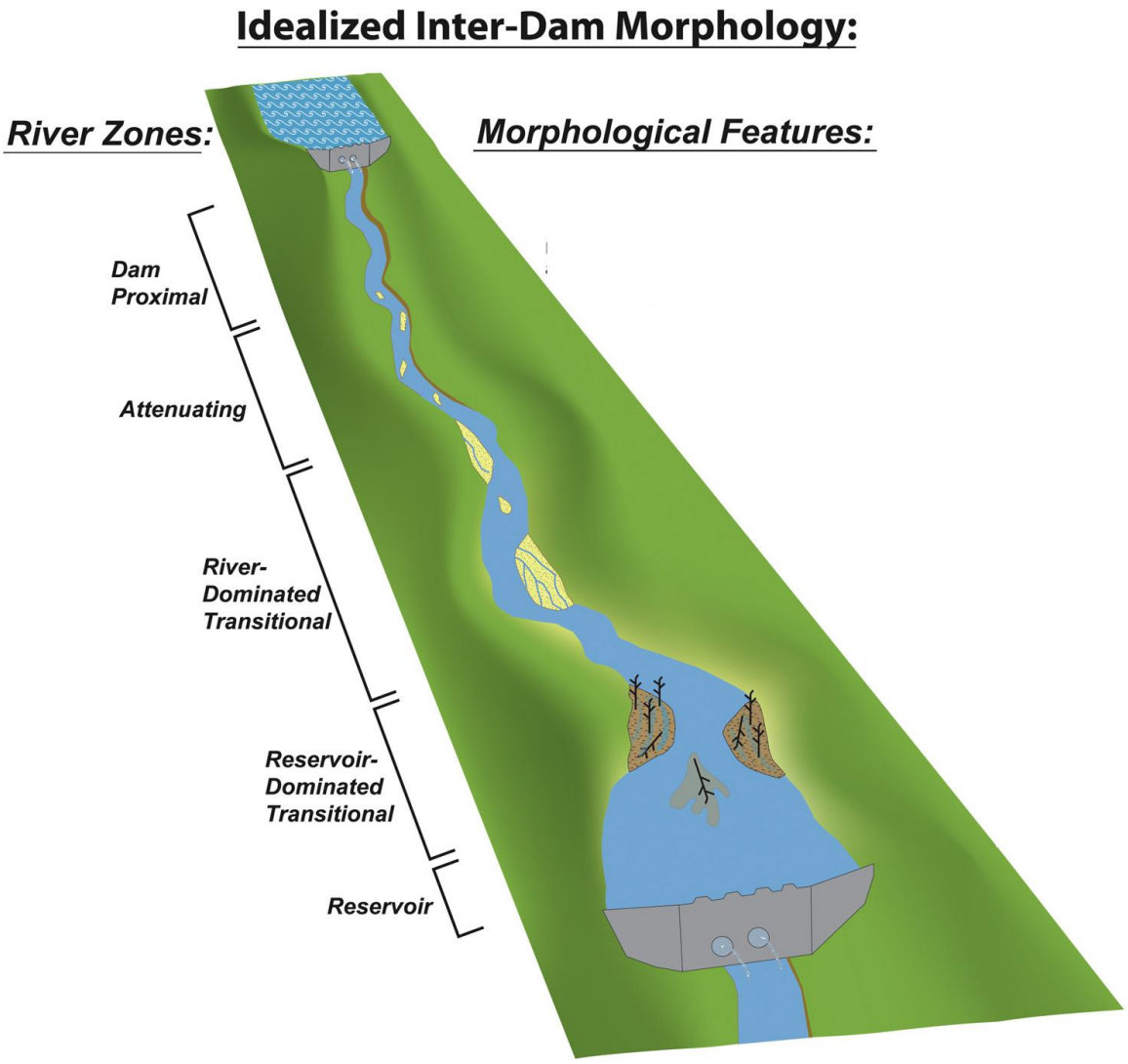

Figure 1 Idealized inter-dam morphology based on the geomorphic classification of the Missouri River.