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POTENTIAL MECHANISMS OF GEOMORPHIC CHANGE OPERATING ON FLOODPLAIN AND CHANNEL FORM ON THE GALLATIN RIVER IN NORTHWESTERN YELLOWSTONE

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INTRODUCTION

In recent years, northern Yellowstone National Park has drawn interest from scientists interested in the region's ecology. Of particular interest to researchers is the effect of wolf extirpation on ecosystem health. After the removal of wolves in the 1920s, predation of elk dropped significantly, and consequently the elk population skyrocketed (Kay, 1997). This larger population of elk has over-grazed the willow population in some regions of Yellowstone, decreasing food sources for other animals such as beaver. Beaver are a keystone species because their dams slow down stream velocity, promoting the development of floodplains and riparian zones (Ripple and Beschta, 2012). The relationship between beaver and willow is a positive feedback loop, as drained beaver ponds provide an ideal location for willow establishment (Wolf et al., 2007). Some have hypothesized that due to beaver loss in Yellowstone, stream incision has occurred in the northern area of the park (Beschta and Ripple, 2006 and 2019). This has resulted in streams that are disconnected from their historical floodplains, thus diminishing riparian habitat.

After the reintroduction of wolves into the ecosystem in 1995, researchers became interested in whether the effects of the extirpation of wolves could be reversed, and to what degree. Wolf et al. (2007) examine the codependent nature of beavers and willows, and determine that while the reintroduction of wolves has caused a decrease in the elk population, this action alone is not sufficient to return the Yellowstone landscape to its historical state. Instead, the authors posit that the increased stream incision during the period of willow over-grazing has rendered a return to the historical state impossible. However, other research has pointed to the recovery of these riparian zones with the establishment of new inset floodplains in areas where willows have begun to recover from elk herbivory (Beschta and Ripple, 2019).

This study focuses on the geomorphology and hydraulic dynamics of the Gallatin River in northwestern Yellowstone. The goal of the research is to determine what factors influence fluvial processes and channel form to help understand the potential for trophic cascade related changes to the geomorphology. This study investigates the hydraulic processes of the river and determines whether the floodplain and terrace surfaces that border the river are inundated by 2-year, 5-year, or 10-year floods. With this data, I seek to understand potential geomorphic controls on the Gallatin River, and whether they are related to the ongoing research into the effects of trophic cascades resulting from wolf extirpation and reintroduction.

GEOLOGICAL SETTING

The Gallatin River originates in the Gallatin Range of the Rocky Mountains and flows northwest before converging with the Missouri River. The upper Gallatin Basin is located at an elevation of around 2000 meters, with prominent mountain peaks and wide valley bottoms (Beschta and Ripple, 2006). The Gallatin Range was glaciated during the last glacial maximum (LGM), and there are moraines, outwash terraces, and glacial lake sediments influencing the valley floor morphology (Pierce, 1979).

This study focuses on the section of the Gallatin River that runs through the park. Data was collected at five reaches along the river (Fig. 1). The studied section of the river runs through a valley with gradual elevation change. Reach 1 is located the farthest upstream and is typified by high sinuosity and marshland in its upper section. Reach 2 continues along the valley floor and splits into multiple channels for some sections of the reach. Both Reach 1 and Reach 2, which are separated by a small feeder creek, are located outside of elk winter range (Beschta and Ripple, 2006). Reach 3 is marked by the confluence of Fan Creek with the Gallatin River and by multiple active channels. Reach 4 and Reach 5 are located just upstream of the border between Yellowstone National Park and the Gallatin National Forest.

METHODS

We characterized channel and floodplain dimensions by surveying valley cross sections along the Gallatin River using high-resolution RTK GPS (accurate within 1-2 cm), supplemented with a total station when necessary. These data were collected in August 2019. Upon returning from the field, I created a hydraulic model of the Gallatin River using the US Army Corps of Engineers' Hydrologic Engineering Center's River Analysis System (HEC-RAS). The program requires two types of data to build the channel flow model; channel geometry/characteristics and stream discharge.

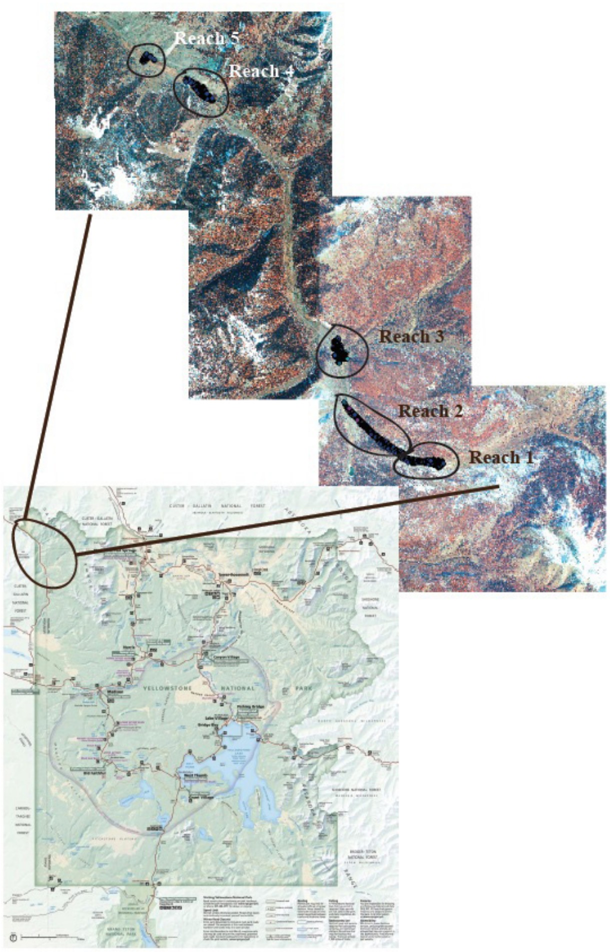

Figure 1. Map of the study area, including cross section locations.

To generate the channel geometry for each reach, I implemented the GPS and total station data that were collected in the field. I then input Manning's roughness values for the channel and the banks of 0.03 and 0.15, respectively. These values were selected based off of roughness values from Arcement and Schneider (1989). In order to represent the singular channel flow that defines most of the study area, I applied the HEC-RAS levee marker on reaches where the model inaccurately predicted multi-channel flow.

To estimate discharge during flooding events I used multiple regression methods to estimate discharge on the Gallatin River, which is not gauged in our study area. I was able to determine discharges for the 2-year, 5-year, and 10-year floods based off of the following United States Geological Survey (USGS) formula for calculating discharge for ungauged sites on a gauged stream (Parrett and Johnson, 2004):

$$Q_{T,U} = Q_{T,G}\left(\frac{DA_U}{DA_G}\right)^{exp_r}$$

In this equation, $Q_{T,U}$ and $Q_{T,G}$ are the peak flows in cubic feet per second for the T-year flood at the ungauged and gauged site, respectively. DA_U and DA_G are the drainage areas in square miles for the ungauged site and the gauged site, respectively, and exp_r is the regression coefficient that corresponds to the T-year flood.

I generated a plot of typical discharge for the 2-year, 5-year, and 10-year floods on the Gallatin Gateway stream gauge using the USGS PeakFQ program. The drainage area of the Gallatin River at the Gallatin Gateway gauge station is 1318 km2 per the USGS Water Data site, and I determined the drainage areas for each of the five reaches using topographic maps and Google Earth. The values I used for expAEP in the study area are listed in the USGS report on estimating flood frequency in Montana through water year 1998 (Parrett and Johnson, 2004). For the Gallatin River, which falls within the Upper Yellowstone-Central Mountain Region, these values were 0.877, 0.768, and 0.712 for the 2-year, 5-year, and 10-year floods respectively.

After calculating the discharge values, I entered them into steady flow data along with the slope of each reach, which I calculated using the measurement tools in the HEC-RAS program. With these data, I ran a total of 15 steady flow analyses – three simulations per reach.

RESULTS

For each reach in the study area, I determined whether the floodplains were consistently inundated across the entire reach at the 2-year, 5-year, and 10-year floods. I considered a reach's floodplains to be consistently inundated when the water level achieved bankfull stage in at least half (≥ 50%) of the cross sections for that reach. A summary of my findings can be found in Figure 2. During the 2-year flood, the floodplains for 0 out of 5 reaches are consistently inundated. For the 5-year flood, 2 out of 5 reaches—reaches 3 and 4—have floodplains that are consistently inundated. During the 10-year flood, the floodplains are consistently inundated in 5 out of 5 reaches.

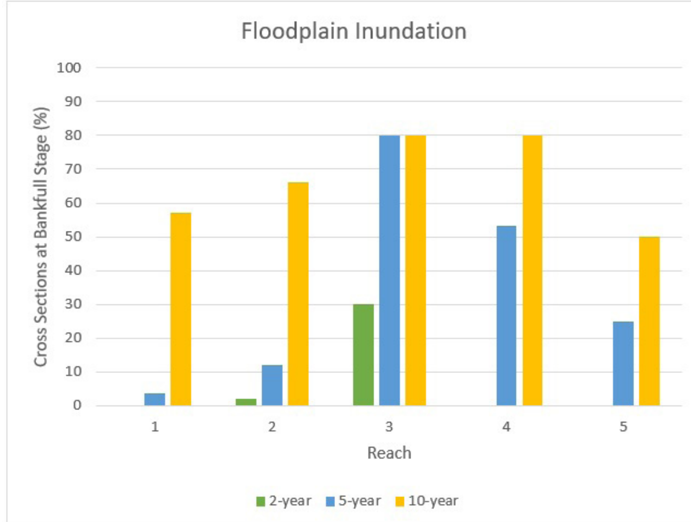

Figure 2. A summary of the HEC-RAS simulations displaying the percentage of inundated cross sections per flood for each cross section.

DISCUSSION

As indicated by the results, the majority of the reaches in this study require at least a 10-year flood in order for their floodplains to be consistently inundated. In a typical stream, a flood with a recurrence interval of 4 years will produce a bankfull flow and affect the channel (Leopold et al., 1964). Thus, it seems unlikely that a large flood is required for the floodplains on the Gallatin River to be inundated. This clear separation between the Gallatin River and its floodplains indicates that the stream has incised over time.

Channel incision on the Gallatin River may be due to the loss of beaver and willow populations from the park after wolf extirpation. However, it is also important to consider other possible geomorphic controls acting on the Gallatin River and how they may affect channel morphology.

Wolf Extirpation and Riparian Vegetation Loss

One possible explanation for the current morphology of the Gallatin River is channel incision as a result of losing riparian vegetation. Beschta and Ripple lay out such a hypothesis in their 2006 paper, where they claim that a trophic cascade driven by the extirpation of wolves from Yellowstone was the cause of this vegetation loss.

As described by Kay (1997), wolf extirpation was directly responsible for an elk population boom, which in turn has led to overbrowsing of willows and a decrease in their population. Willows are considered riparian vegetation, which means that they contribute to the development of effective floodplains. Riparian vegetation is effective in maintaining bank stability and preventing excessive channel erosion. When this vegetation is removed, banks can become unstable and a greater degree of channel erosion may occur. This increased channel erosion leads to separation of a river from its floodplains, as the channel continues to incise to a point where the original floodplain can no longer be inundated. This may be the case along the Gallatin River in several places. In Reach 5, such channel incision is clearly evident (Fig. 3). The water level achieves bankfull stage in 2 out of 4 cross sections during the 10-year flood, but it is clear from the cross

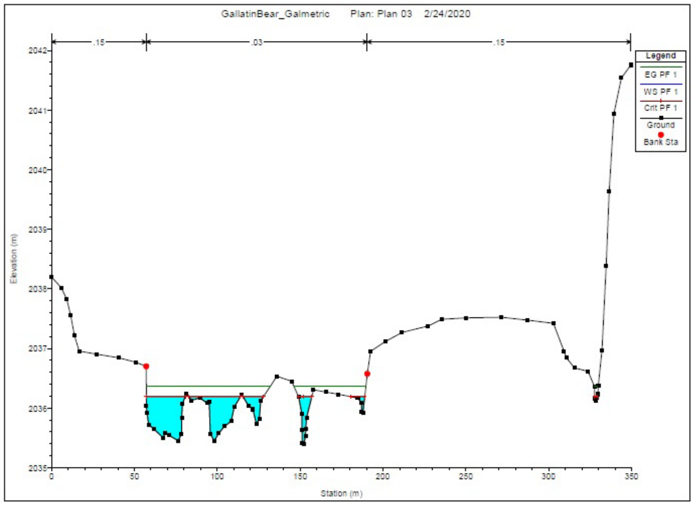

Figure 3. HEC-RAS output for Reach 5, cross section 1 during the 10-year flood.

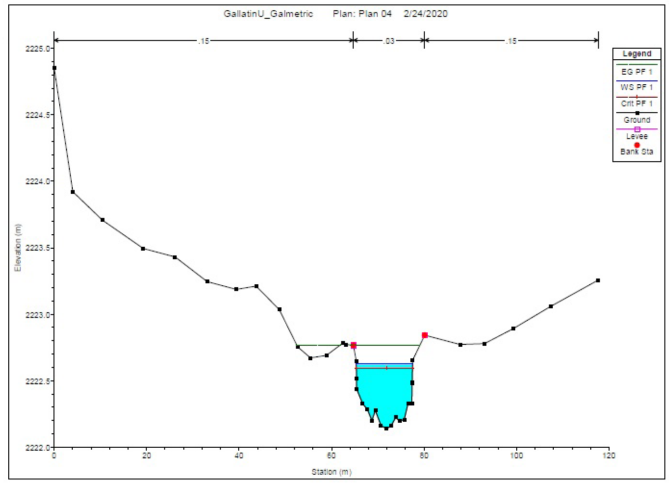

Figure 4. HEC-RAS output for Reach 1, cross section 6 during the 10-year flood.

sections that the stream has incised through a surface 0.5-1.0 m above the current channel. Instead, when Reach 5 is inundated by a 10-year flood, the bankfull stage achieved by the water level is at the elevation of what appears to be an inset floodplain. As proposed by Beschta and Ripple (2019), inset floodplains indicate that a channel is recovering from a period of high incision. If it is the case that these inset floodplains started forming after the reintroduction of wolves, then they would be evidence in favor of the theory that wolf extirpation led to channel incision.

Other Potential Geomorphic Controls

A loss of riparian vegetation due to elk herbivory is not a sufficient explanation for the apparent channel incision that has occurred along the entire study area. As previously mentioned, both Reach 1 and Reach 2 are located outside of elk winter range. Therefore, these areas have not been subject to intensive elk herbivory. If elk herbivory were the dominant control on channel form, then there would be more floodplain inundation in the upper reaches than the downstream reaches. This is not the case, as there are several cross sections in reaches 1 and 2 where the water level does not achieve bankfull stage even during the 10-year flood, much like in Reach 5 (Fig. 4). Elk herbivory may be exerting an influence over channel morphology in the lower reaches, but it does not do so for the upper reaches. Thus, an alternate explanation is needed.

Much of the Gallatin River runs over glacial till and outwash gravels (REF). There are sections throughout where the channel base contains several pebbles wider than 180 cm, and few pebbles of sand size or smaller. The presence of pebbles of this size indicates that the high discharge of the Gallatin River has removed the smaller size fractions from the channel base. Further channel incision in these areas would require the removal of glacial till, which is not possible for a river the size of the Gallatin. Thus, when discharge is high, such as in a flood event, the channel incises outward instead of down. Channel expansion also accounts for the infrequent inundation of floodplains on reaches 1 and 2 during the 2-year and 5-year floods. As the channel expands, more water is required to achieve bankfull stage. In the upper reaches of the Gallatin River where the stream discharge is lower, a larger flood is required in order to fill the channel and inundate the floodplain.

Another potential geomorphic control on the Gallatin River is channel slope. The water surface profiles for most of the study area exhibit slope values between 0.01 and 0.013. However, in the upstream section of Reach 1, the slope is 0.0015 (Fig. 5). Additionally, cross sections located in the flat portion of Reach 1 exhibit more floodplain inundation than the cross sections located in the steeper portion of Reach 1. Reaches 1, 2, and 3 are located on a recessional moraine from the LGM, which influences the flat topography in this area. This section is also unique among the study area in terms of the channel bed.

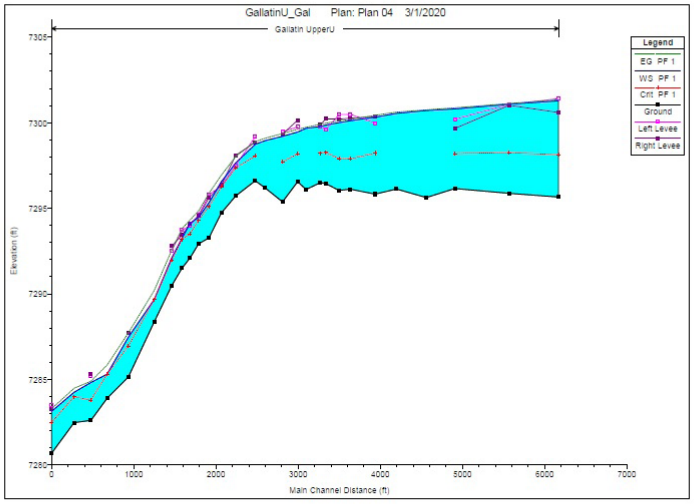

Figure 5. HEC-RAS output of the water surface profile for Reach 1 during the 10-year flood.

While much of the study area is characterized by larger pebble size fractions, the upstream section of Reach 1 contains a much larger percentage of pebbles 2 mm and smaller.

The makeup of the channel bed in the upper section of Reach 1 may indicate that the water velocity in that section is too low to move most pebble sizes. In such a case, it is unlikely that channel incision has occurred on a measurable scale. If the difference between a reach where only glacial till remains and a reach where there are pebbles of all size fractions is the slope, then it must play an important role in stream morphology along the Gallatin River.

CONCLUSION

On the Gallatin River, a 10-year flood is required to consistently inundate the floodplain in each of the studied reaches. This result indicates that the river is currently separated from a well-defined surface 0.5-1.0m above the channel. The reasons for this separation may be complicated, as the underlying geomorphology of the Gallatin River is not consistent along the stream. It is likely that the upstream reaches and the downstream reaches are acted upon by different processes that have caused the separation. In the downstream reaches, channel incision appears to be the main mechanism of separation, and may also be responsible for promoting the development of an inset floodplain. In the upstream reaches, channel bed material and channel slope exhibit a more drastic influence on overall channel morphology.

It is possible that the extirpation and subsequent reintegration of wolves in Yellowstone have had effects on the geomorphology of the Gallatin River in the lower reaches of the study area. However, the channel morphology of the upper reaches cannot be explained by the same mechanism. In fact, channel incision appears unable to affect the upper reaches. More research should be conducted on these upper reaches in order to better understand the morphology that governs them.

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REFERENCES

Arcement, G. J., Jr., and Schneider, V. R., 1989, Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains: U.S. Geological Survey Water-Supply Paper 2339, 38 p.

Beschta, R. L., and Ripple, W. J., 2006, River channel dynamics following extirpation of wolves in northwestern Yellowstone National Park, USA: Earth Surface Processes and Landforms, v. 31, p. 1525-1539.

Beschta, R. L., and Ripple, W. J., 2019, Can large carnivores change streams via a trophic cascade?: Ecohydrology, v. 12, doi: 10.1002/eco.2048

Kay, C. E., 1997, Viewpoint: Ungulate herbivory, willows, and political ecology in Yellowstone: Journal of Range Management, v. 50, p. 139-145.

Leopold, L. B., Wolman, M. G., and Miller, J. P. (1964). Fluvial processes in geomorphology: W. H. Freeman and Company, San Francisco, California.

Parrett, C., and Johnson, D. R., 2004, Methods for Estimating Flood Frequency in Montana Based on Data through Water Year 1998: U.S. Geological Survey Water-Resources Investigation Report 03-4308, 99 p.

Pierce, K. L. (1979). History and dynamics of glaciation in the northern Yellowstone National Park area. Professional Paper.

Ripple, W. J., and Beschta, R. L., 2012, Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction: Biological Conservation, v. 145, p. 205-213.

Wolf, E. C., Cooper, D. J., and Hobbs, N. T., 2007, Hydrologic regime and herbivory stabilize an alternative state in Yellowstone National Park: Ecological Applications, v. 17, p. 1572-1587.