THE IMPORTANCE OF GEOMORPHIC CONTROLS ON HYDRAULIC PROCESSES IN NORTHERN YELLOWSTONE NATIONAL PARK

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INTRODUCTION

The greater Yellowstone ecosystem is the largest mostly intact temperate-zone ecosystem in the world (Fig 1). Within Yellowstone, riparian corridors are key zones that provide abundant water and food resources. These corridors are particularly important in the relatively dry semiarid landscape of northern Yellowstone National Park, which is characterized by sagebrush, grasslands, and scattered conifer groves (Yellowstone National Park, 1997). In the early 20th century, many streams in northern Yellowstone hosted abundant beaver and their dams created extensive wetlands along valley floors (Fig. 2, Warren, 1926). Beaver and their dams have been largely absent from Yellowstone since the mid-20th century (Jonas, 1955). The causes of beaver extirpation and associated decline of riparian habitat is a topic of scientific intrigue (National Research Council, 2002; Yellowstone National Park, 1997). According to some, the loss of beaver is the direct result of competition with elk (Chadde and Kay, 1991). In the early 20th century, elk populations increased dramatically due to the extermination of wolves. The high numbers of elk over-browsed willow and aspen outcompeting beaver and degrading riparian habitat. This sequence of events is hypothesized to be part of a trophic cascade triggered by wolf removal. Using the trophic cascade framework, some have proposed that stream incision in northern Yellowstone caused an ecosystem state switch from beaver-willow to elk-grasslands during the latter half of the 20th century (Fig. 2).

The transition from a dominantly riparian landscape to grasslands is attributed to the combined effects of the loss of beaver and intensive elk browsing that altered both the form and function of streams (Wolf et al., 2007). The loss of beaver dams increased channel gradients that triggered channel incision (Beschta and Ripple, 2018; Wolf et al., 2007). Incision disconnected channels from floodplains because high frequency flood events no longer were able to inundate floodplains. Additionally, incision effectively lowered water tables thus limiting willow and aspen recovery after wolf reintroduction (Marshall et al., 2013). The decreased riparian vegetation also caused channels to increase in width, further degrading riparian habitat (Beschta and Ripple, 2006; Chadde and Kay, 1991; Wolf et al., 2007). Regardless of changes to beaver populations and vegetation density, there are other factors that control stream dynamics and channel form.

River function and channel morphology are controlled by myriad of factors including hydraulic flow properties, bank material, subsurface conditions, and
climatic variability (Knighton, 1998). For example, in Yellowstone, sediment size is an important control on channel morphology and the frequency of floodplain inundation (Meyer, 2001). And climate variability influences surficial processes throughout the entire drainage basin (Meyer et al., 1995). Climate change can alter forest fire frequency and severity and alter sediment loads delivered to channels (e.g. Legleiter et al., 2003; Meyer et al., 1992; Meyer et al., 1995). Climate variability can also influence ecologic function such as beaver activity (Persico and Meyer, 2012) and aspen regeneration (Romme et al., 1995). Morpho-stratigraphic evidence indicates that climate variability is significant control on the long-term history of channel dynamics and that some stream incision predates the historical period on many streams in northern Yellowstone (Meyer et al., 1995; Persico and Meyer, 2009). These factors must be accounted for when assessing how streams have responded to trophic cascade events in the 20th century.

In the summer of 2019, our five-student Keck research project focused on characterizing the hydraulic characteristics and Holocene fluvial history of two streams in Northern Yellowstone. Our goal was to document underlying geomorphic controls on stream function and history. This context is vital to assess how vegetation changes affected 20th century stream behavior. The field season began on
We identified and mapped geomorphic surfaces on the valley floor including kame terraces, Holocene fluvial terraces, paleochannels, active floodplains and channels. We also described terrace deposit stratigraphy at selected locations and sampled for 14C. The 14C samples allow us to constrain the timing of channel aggradation and terrace formation. After field work, the team travelled back to Whitman College to digitize field observations, prepare samples for 14C analyses, and begin the process of creating a hydraulic flow models based on the topographic surveys.

STUDENT PROJECTS

Trent Foky (Whitman College) focused on the geomorphic history of Blacktail Deer Creek and created a surficial geologic map. Trent used field observations of geomorphic surfaces in conjunction with topographic surveys, high-resolution orthorectified aerial imagery, and 1-m lidar derived DEM (National Ecological Observatory Network, 2019) to map the extent of the different surfaces. The timing of terrace formation was constrained using 14C ages (see Chantal’s project) and a volcanic ash that we identified in terrace stratigraphy. Trent also analyzed the nature of the geomorphic surfaces and characterized the slopes of the active channel relative to the terrace surfaces. Trent’s work documents that most of the valley floor is a fill terrace that aggraded during the early and middle Holocene. The active channel and floodplain are confined to a narrowly incised corridor in this surface. This limits the total area of the valley floor that is influenced by 20th century riparian vegetation changes.

Alice Hinzmann (Carleton College) studied the hydraulic characteristics of the Gallatin River. She used four reference stream reaches to study how potential geomorphic and trophic cascade-related processes have influenced the flooding behavior of the river. She estimated the discharge for 2, 5, and 10-year recurrence interval floods using multiple regression of known gauge stations with basin area and elevation (Johnson and Parrett, 2004). Alice used the surveyed cross sections to create a hydraulic model using HEC-RAS software. With this model Alice predicted the size of flood necessary to inundate floodplain and terrace surfaces. Alice’s modeling shows that floodplain surfaces are not inundated during high frequency low magnitude flood events, even sites that are outside of elk winter range. Additionally, some reach gradients are controlled by local base level constraints that produced channel that fill more frequently (Fig 5). Alice’s results are important as...
they highlight how deceptively simple concepts like floodplain, terrace, and bankfull recurrence interval and controlled by site-specific geomorphic characteristics related to the Quaternary geomorphic history of the drainage basin.

**Chantal Iosso** (Washington and Lee College) focused on advancing our understanding of the timing of fluvial depositional events on both Blacktail Deer Creek and the Gallatin River. Chantal identified exposed sections of terrace and floodplain deposits where she described the stratigraphy and soil morphology. She tediously picked through the exposed sediments looking for charcoal, twigs, or pinecones for 14C age analyses. Chantal cleaned the samples of modern organic material. Chantal calibrated the 14C ages and compared them to other records of fluvial processes in Yellowstone. Chantal also identified an ash in stratigraphy of the widespread terrace on the east fork of Blacktail Deer Creek. The ash was deposited during an eruption for Glacier Peak at 11.2 ka. Chantal also documented floodplain sediments that are inset within the widespread 1.5 m terrace that date to late Holocene. These dates combined with the geomorphic mapping indicate that the Blacktail Deer Creek aggraded during the early and middle Holocene and was followed by a period of late Holocene incision.

**April Phinney** (Wheaton College) focused on the hydraulic characteristics of the east and west forks of Blacktail Deer Creek. Similar to Alice’s project, April estimated discharges at the ungauged study reaches using multiple regression analyses (Miller, 2003). April then produced a hydraulic model using surveyed topographic cross sections in HEC-RAS. April mapped inundation extent of various flood magnitudes on the high-resolution LiDAR-derived DEM (National Ecological Observatory Network, 2019). Both the east and west forks of Blacktail are in elk winter range and have experienced over-browsing of riparian vegetation in the 20th century and recent increase in willow. April’s modeling indicates that despite these similarities, the east and west forks respond very differently to flooding. Along the west fork, even high magnitude (100-yr) floods are confined to a narrow incised channel. The east fork, however, has overbank flooding during low magnitude floods. These results indicate that geomorphic factors like basin area and stream power are important controls on the amount of flood plain inundation during flood events.

**Eliza Van Wetter** (Whitman College) explored historical changes to channel patterns and also analyzed the magnitude of discharges required to activate the channel bed material along Blacktail Deer Creek. Eliza compared high-altitude aerial imagery from the middle 20th century with recent high-resolution orthographic imagery using GIS. This analysis shows that streams have mostly remained stable during the past 60 years. The only differences are where there have been stream avulsions and creation of new channels and abandonment of older channels. Eliza’s work helps to explain the various paleochannels that Trent mapped on both the east and west fork of Blacktail Deer Creek. Eliza determined the shear stresses required to initiate sediment movement in channels and compared that to shear stress during flood events that April estimated using HEC-RAS. These analyses indicate that even during large floods a significant portion of the bed material is immobile due to its large size. This large sediment is likely relict Pleistocene glacial outwash that underlies the Holocene stream deposits. This suggests that incision is limited by local base level control created by the underlying glacial sediments. This work is important to understanding the Holocene evolution of Blacktail Deer Creek and persistent controls of geomorphic history on modern process.

**SUMMARY**

Collectively, the five student projects provide a nuanced analysis of fluvial processes and geomorphic history of both Blacktail Deer Creek and the Gallatin River. The results of these analyses indicate that geomorphic history has persistent and widespread control on modern channel geometry and hydraulic processes. Along Blacktail Deer Creek, the valley floor aggraded during the early and middle Holocene and has incised in the late Holocene, prior to the historical period (Fig 5C). The magnitude of incision is controlled by local base level related to glacial deposits. Additionally, stream power is important because the larger west fork can effectively incise through fine-grained Holocene terrace deposits. Along
the Gallatin River, channel stability and form are controlled by the extent and type of late Pleistocene deposits. The upper reaches are more stable due to limited ability to incise into recessional moraine deposits. The lower reaches are less stable as the river has incised into thick outwash gravels and alluvium during the Holocene.

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