KECK Geology Consortium
Learning Science Through Research
Published by the Keck Geology Consortium
Short Contributions
Keck Geology Consortium
Volume 33
May 2020
doi: 10.18277/AKRSG.2020.33.13

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

LYMAN PERSICO, Whitman College

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.

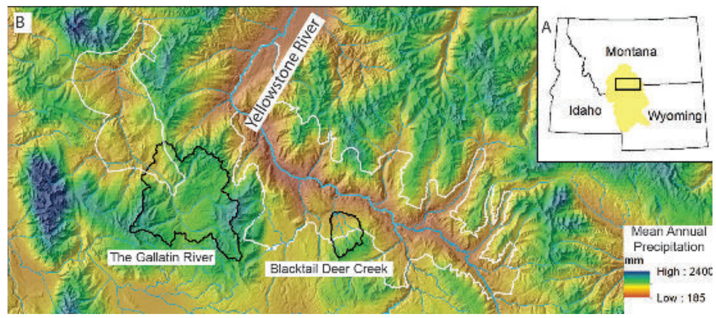

Figure 1. The Greater Yellowstone ecosystem spans across Wyoming, Idaho, and Montana (A). In northern Yellowstone (extent shown in A), low elevations are relatively dry (PRISM Climate Group, 2004) and limited snow pack creates winter foraging habitat for Elk (B). The Blacktail Deer Creek drainage basin (black line) is part of the winter range of the northern Yellowstone elk herd (white line). In Yellowstone National Park, the lower reaches of the Gallatin River drainage basin (black line) are part of the winter range of the Gallatin River elk herd (white line).

River function and channel morphology are controlled by myriad of factors including hydraulic flow properties, bank material, subsurface conditions, and

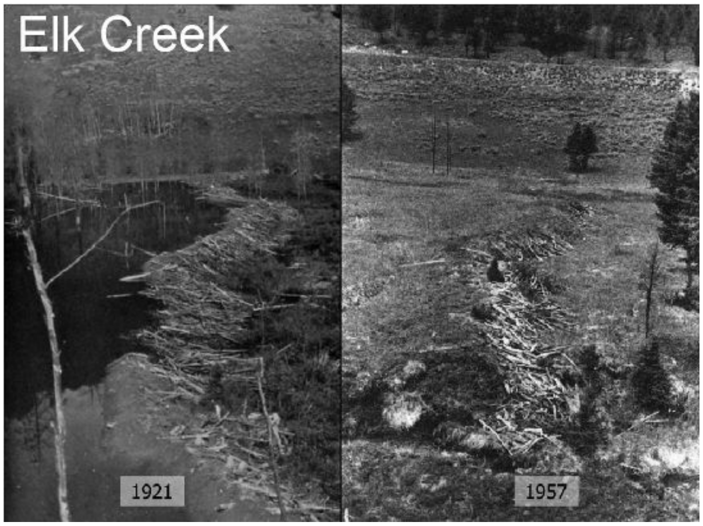

Figure 2. The Northern Range stream of Elk Creek contained many beaver dams in the 1920s that extended across much of the valley floor. Those beaver dams were abandoned by the 1950s and the stream has incised over 2 m from the top of the beaver bond sediments.

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 Blacktail Deer Creek in north central Yellowstone (Fig. 3). The stream is part of the National Ecological Observatory Network (NEON) and has experienced willow resurgence in the past two decades (Beschta and Ripple, 2007; Marshall et al., 2013). We next travelled to the Gallatin River in western Yellowstone (Fig. 4). The Gallatin River contains riparian habitat that is both in and out of elk winter range (Brazda, 1952; Peek et al., 1967). We worked collectively in the field for three weeks to collect data sets that were used independently in each student project. Along each stream reach, we characterized channel, terrace and floodplain morphology by topographic survey using RTK GPS and a total station (Fig. 5A &B). We surveyed channel cross sections and channel/water surface long profiles with cm-scale accuracy. We also characterized channel bed material by pebble counts

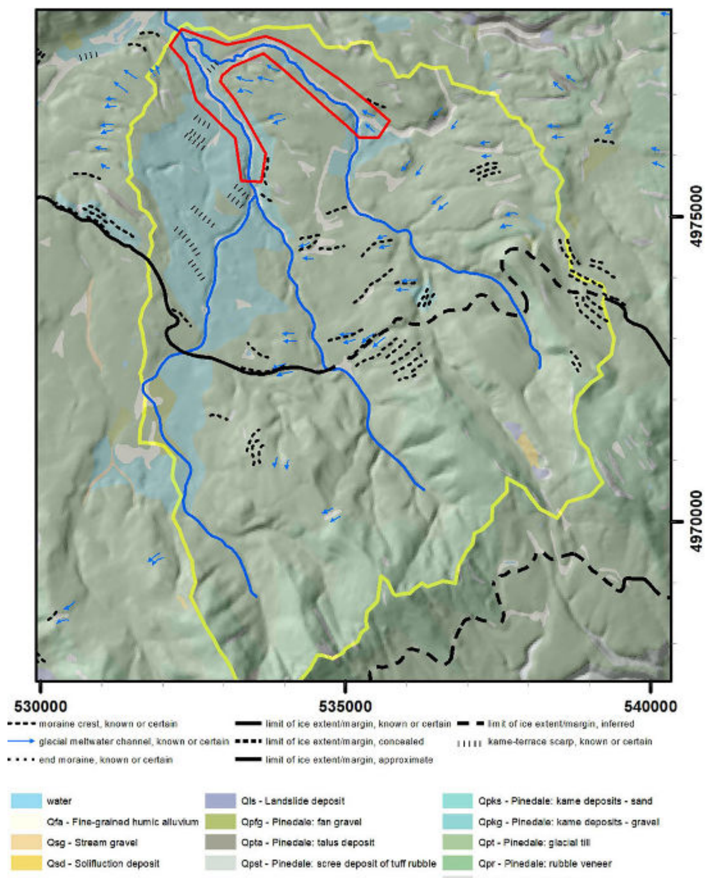

Figure 3. Blacktail Deer Creek drainage basin (yellow line) drains the northern flank of the Washburn Range. The range was entirely glaciated by the Yellowstone Ice Cap during the LGM (Pierce, 1979). The Blacktail Deer Creek drainage network is heavily influenced by meltwater channels (blue arrows) and kame deposits associated with the recission of the northern Yellowstone outlet glacier (Pierce, 1973a). Redline indicates the extent of the 2019 field season surveys.

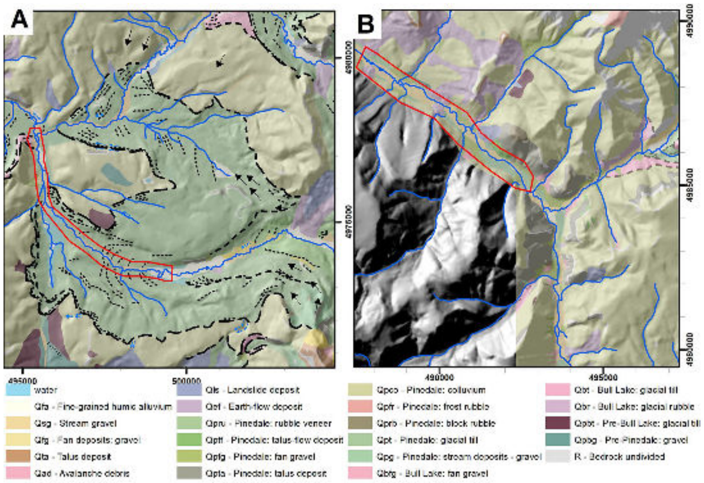

Figure 4. The Gallatin River drains the western flank of the Gallatin Range. The upper portions of the watershed were glaciated during the LGM (Pierce, 1973b) and the slope of the stream is controlled by recessional moraines (A, line symbology explained in Fig. 3). The lower reach of the river was not glaciated at the LGM and the valley floor contains glacial outwash and alluvial fan deposits (B). Redline indicates the extent of the 2019 field season surveys.

(Fig. 5C). 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

Figure 4. The 2019 Keck Yellowstone Research team surveyed channel geometry using RTK GPS and a total station. The upper reaches of the Gallatin River (A) are relatively low gradient because of local base level control set by recessional moraines (Fig. 3A). Overbank flooding occurs with higher frequency relative to the lower reaches where the river has incised into late Pleistocene outwash deposits (B). The research team characterized bed material using gravelometers and zig-zag pebble counts. Blacktail Deer Creek (C) aggraded during the early and middle Holocene and incised during the late Holocene prior to the historical period.

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 though 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.

ACKNOWLEDGEMENTS

This material is based upon work supported by the Keck Geology Consortium and the National Science Foundation under Grant No. 1659322. Further financial and laboratory support was provided by Whitman College. We thank Roy Renken, Annie Carlson and Beth Horton of the National Park Service for their support.

REFERENCES

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, no. 12, p. 1525-1539.

Beschta, R. L., and Ripple, W. J., 2007, Increased willow heights along northern Yellowstone's Blacktail Deer Creek following wolf reintroduction: Western North American Naturalist, v. 67, no. 4, p. 613-617.

Beschta, R. L., and Ripple, W. J., 2018, Can large carnivores change streams via a trophic cascade?: Ecohydrology, v. 0, no. 0, p. e2048.

Brazda, A. R., 1952, Elk migration patterns, and some of the factors affecting movements in the Gallatin River drainage, Montana [M.S.: Montana State University.

Chadde, S. W., and Kay, C. E., 1991, Tall-willow communities on Yellowstone's Northern Range: A test of the "natural-regulation" paradigm, in Keiter, R. B., and Boyce, M. S., eds., The Greater Yellowstone Ecosystem: Binghamton, Yale University Press, p. 231-263.

Johnson, D. R., and Parrett, C., 2004, Methods for estimating flood frequency in Montana based on data through water year 1998: Water-Resources Investigations - U. S. Geological Survey.

Jonas, R. J., 1955, A population and ecological study of the beaver (Castor canadensis) of Yellowstone National ParkM.S.]: University of Idaho, 193 p.

Knighton, D., 1998, Fluvial Forms and Processes A New Perspective, New York, Oxford University Press.

Legleiter, C., Lawrence, R., Fonstad, M., Marcus, W., and Aspinall, R., 2003, Fluvial response a decade after wildfire in the northern Yellowstone ecosystem: a spatially explicit analysis: Geomorphology, v. 54, no. 3-4, p. 119-136.

Marshall, K. N., Hobbs, N. T., and Cooper, D. J., 2013, Stream hydrology limits recovery of riparian ecosystems after wolf reintroduction: Proceedings of the Royal Society B-Biological Sciences, v. 280, no. 1756.

Meyer, G. A., 2001, Recent large-magnitude floods and their impact on valley-floor environments of northeastern Yellowstone: Geomorphology, v. 40, no. 3-4, p. 271-290.

Meyer, G. A., Wells, S. G., Balling, R. C., and Jull, A. J. T., 1992, Response of alluvial systems to fire and climate change in Yellowstone-National-Park: Nature, v. 357, no. 6374, p. 147.

Meyer, G. A., Wells, S. G., and Jull, A. J. T., 1995, Fire and alluvial chronology in Yellowstone National Park: Climatic and intrinsic controls on Holocene geomorphic processes: Geological Society of America Bulletin, v. 107, no. 10, p. 1211-1230.

Miller, K. A., 2003, Peak-flow characteristics of Wyoming streams: Water-Resources Investigations - U. S. Geological Survey.

National Ecological Observatory Network, 2019, High-resolution orthorectified RGB camera imagery and mosaics, Elevation - Lidar: Provisional data downloaded from http://data.neonscience.org on 9/1/19., Batelle, Boulder, CO, USA.

National Research Council, 2002, Ecological Dynamics on Yellowstone's Northern Range, Washington DC, National Academy Press.

Peek, J. M., Lovaas, A. L., and Rouse, R. A., 1967, Population Changes within the Gallatin Elk Herd, 1932-1965: The Journal of Wildlife Management, v. 31, no. 2, p. 304-316.

Persico, L., and Meyer, G., 2009, Holocene beaver damming, fluvial geomorphology, and climate in Yellowstone National Park, Wyoming:

Quaternary Research, v. 71, no. 3, p. 340-353.

Persico, L., and Meyer, G., 2012, Natural and historical variability in fluvial processes, beaver activity, and climate in the Greater Yellowstone Ecosystem: Earth Surface Processes and Landforms, v. 38, no. 7, p. 728-750.

Pierce, K. L., 1973a, Surficial geologic map of Mammoth Quadrangle and part of the Gardiner Quadrangle, Yellowstone National Park, Wyoming and Montana: Miscellaneous Geologic Investigations Map.

Pierce, K. L., 1973b, Surficial geologic map of the Mount Holmes Quadrangle and parts of the Tepee Creek, Crown Butte, and Miner quadrangles, Yellowstone National Park, Wyoming and Montana: Miscellaneous Geologic Investigations Map.

Pierce, K. L., 1979, History and dynamics of glaciation in the northern Yellowstone National Park area, 729F.

PRISM Climate Group, O. S. U., 2004, 30-yr Normal Annual Precipitation: http://prism.oregonstate.edu.

Romme, W. H., Turner, M. G., Wallace, L. L., and Walker, J. S., 1995, Aspen, elk, and fire in northern Yellowstone National Park: Ecology, v. 76, no. 7, p. 2097-2106.

Warren, E. R., 1926, A study of the beaver in the Yancey region of Yellowstone National Park, Syracuse, Roosevelt Wildlife Annals 1.

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, no. 6, p. 1572-1587.

Yellowstone National Park, 1997, Yellowstone's Northern Range: Complexity and Change in a Wildland Ecosystem, Mammoth Hot Springs, National Park Service, 148 p.