An Assessment of Kootenai River Channel Migration and Associated Encroachment of Riparian Habitat

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Abstract

The lower reach of the Kootenai River in northern Idaho is dominated by large and actively migrating meander bends. Flow conditions, altered by both upstream flow reductions and by downstream backwater effects, are believed to be important geomorphological drivers throughout the reach. For example, Trout Creek Peninsula, located in an area of active meander migration, is undergoing continued bank erosion that has the potential to capture South Fork Trout Creek and result in an alteration of the Kootenai River active channel. Although chute-cutoffs are natural and common in meandering channels and can increase habitat diversity, avulsion events on regulated rivers with heavily used floodplains can also lead to loss of land and habitat. A chute-cutoff at Trout Creek Peninsula would create an island and potentially result in large volumes of erosion and deposition on private and tribal land. This could result in decreased riparian habitat and private land access along Trout Creek. To address landowner risk we refine estimates of bank erosion rates and the potential timeline for the capture of Trout Creek to inform stakeholder decisions about monitoring or managing bank erosion processes. Historical imagery, airborne and boat-mounted light detection and ranging (LiDAR), and repeat bathymetric surveys suggest that localized areas of high short-term bank erosion rates have increased to about 15 ft/yr near South Fork Trout Creek and the possibility of a chute cutoff event by 2043. Changes in bank erosion rates over time were compared to flow records to better understand how the complex flow regulation in this reach might be impacting geomorphic processes.

Introduction

The meander reach of the Kootenai River in northern Idaho is characterized by a large and active meandering channel that flows through a wide, agriculturally dominated valley (Figure 1). Beginning in the late 19th century, dikes were constructed using instream sediments to raise the elevation of naturally occurring levees to minimize the effects of flooding and protect nearby agriculture (Turney-High 1969; Boundary County Historical Society 1987; Redwing Naturalists 1996). Multiple dams were built throughout the basin during the 1900s including Upper and Lower Bonnington Falls Dam (1907 and 1925, respectively) and Corra Linn Dam (1931) on Kootenay Lake in British Columbia, Canada and Libby Dam (1972) on the Kootenai River upstream of Libby, Montana, United States forming Lake Koocanusa. The variable flow flood control operations at Libby Dam have reduced the peak flows in the Kootenai River during the spring for flood control and reservoir filling and increased flows during the winter months to increase storage space within Lake Koocanusa (Figure 2; McGrane 1998). Corra Linn Dam allows Kootenay Lake water surface elevations to be managed up to six feet higher than levels before the dam was built. Historically, Kootenay Lake has created backwater conditions within the meander reach, but Corra Linn Dam operations have increased the year-around backwater conditions (International Joint Commission 1935).

Flow regulation and disconnection with the floodplain impacts natural geomorphic processes throughout the Kootenai River Basin resulting in negative consequences for sensitive flora and fauna (Paragamian et al. 2001; Barton et al. 2005; Benjankar 2009; Benjankar et al. 2012; Fosness 2013; Fosness et al. 2021). In particular, the Kootenai River Habitat Restoration Program (KRHRP) summarized numerous studies that identified bank erosion in the meander reach as a driver of land loss and a significant source of fine sediment loading that has negative impacts on aquatic habitat (Kootenai Tribe of Idaho 2009). Previous bank erosion analysis using the Bank Assessment for Non-Point source Consequences of Sediment model suggests that bank erosion accounts for 15 to 30% of the total annual bedload supply (Rosgen 2006; Kootenai Tribe of Idaho 2009).

One area of particular concern for bank erosion is Trout Creek Peninsula (TCP), located at river mile 135 and owned by the Kootenai Tribe of Idaho. TCP is formed by a series of tight meander bends that have nearly doubled back on themselves, resulting in among the highest sinuosity and bank curvature values in the meander reach (Figure 3). Continued bank erosion at TCP has the potential to intersect South Fork Trout Creek (SFTC) and initiate the formation of a chute cutoff channel across the peninsula. At present, the minimum distance between the Kootenai River and SFTC is approximately 30 ft. The bank that forms the upstream side of TCP is approximately 20 ft tall during baseflow conditions, nearly vertical, composed primarily of silty lacustrine sediment, and largely unvegetated. Typical of the meander reach, the channel bed at TCP is sand dominated with migrating dune bedforms. Lacustrine clay that is common in the Kootenai River Valley forms shelf-like features within the active channel that tend to be more resistant to erosion and deposition (Barton 2004; Berenbrock and Bennett 2005; McDonald et al. 2006; Barton et al. 2012). Though a common event in meandering rivers, chute cutoff formation at TCP has the potential to result in habitat loss within SFTC, substantial loss of private land, and loss of access to the peninsula, which Kootenai Tribe of Idaho has considered for future restoration projects.

This study quantified bank erosion rates for the entire upstream bank of TCP and where ongoing bank erosion is likely to intersect SFTC to inform landowners of the timing of potential consequences associated with bank erosion to their property. Additionally, bank erosion rates were estimated for pre and post Libby Dam flow regimes, and over multiple short-term periods to determine if bank erosion rates are changing. Erosion rates were estimated through comparison of historical imagery, repeat LiDAR topographic datasets, and multibeam bathymetric datasets (Fosness and Dudunake 2019; National Oceanic and Atmospheric Administration 2022; U.S. Geological Survey 2022b). The potential impact of flow regulation on bank erosion at TCP was also investigated by comparing discharge and stage records with periods of more rapid short-term erosion, and through two-dimensional (2D) hydraulic modeling for two different hydrologic scenarios.

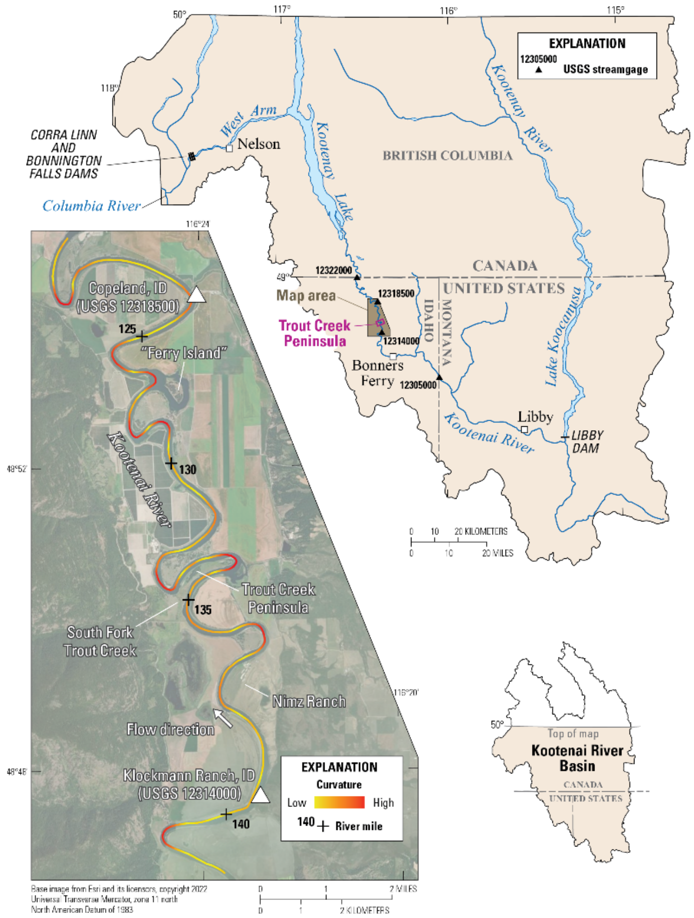

Figure 1. Location of Trout Creek Peninsula in the meander reach of the Kootenai River near Bonners Ferry, Idaho (U.S. Geological Survey 2022a)

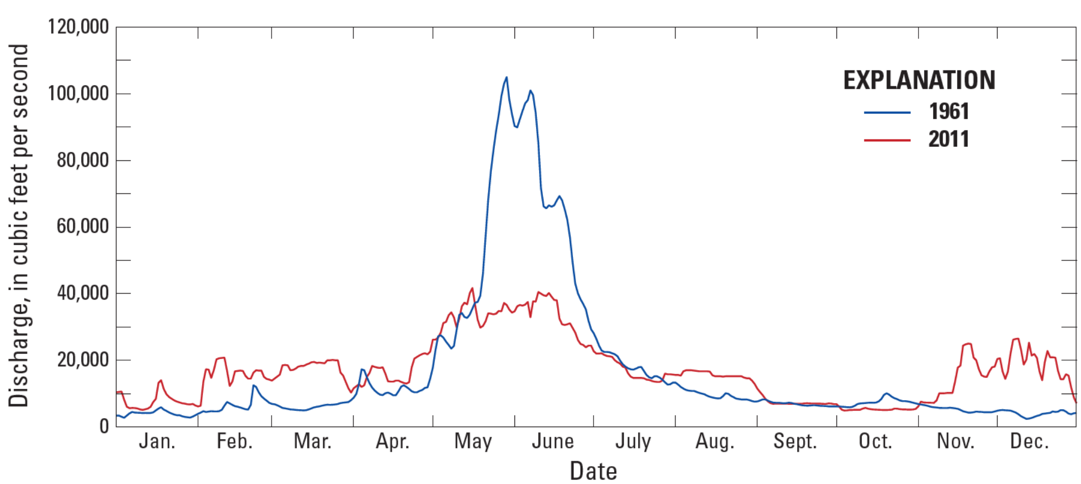

Figure 2. Daily mean discharge at Kootenai River at Leonia, ID (USGS 12305000) during pre-Libby Dam (1961) and Libby Dam era (2011) flow regimes (U.S. Geological Survey 2022a)

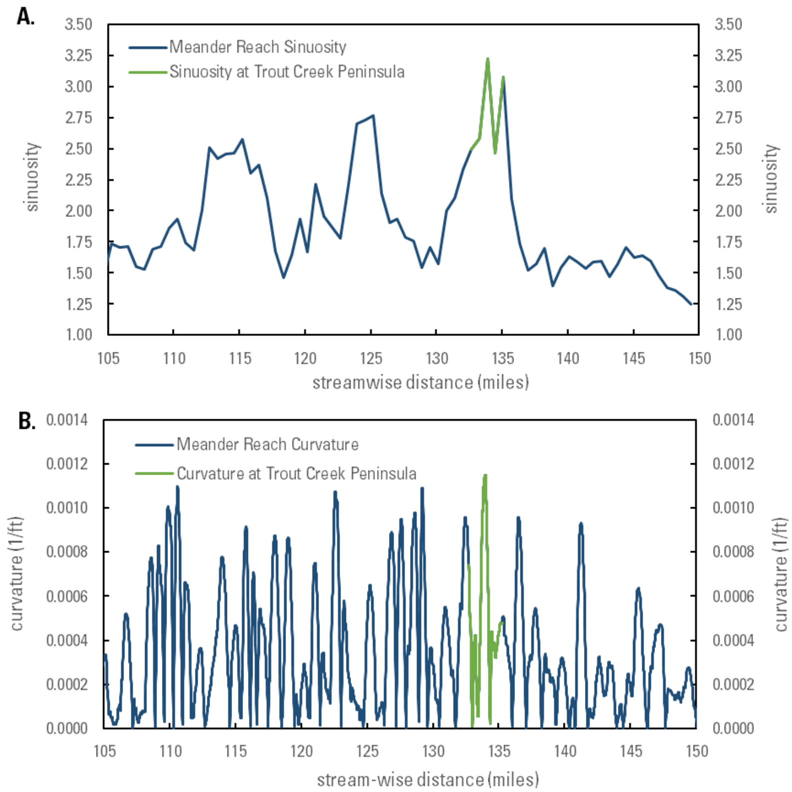

Figure 3. (A) Sinuosity and (B) curvature of the Kootenai River meander reach from Porthill, ID (river mile 105) to Ambush Rock (river mile 152)

Methods

Bank Erosion Rates

To compute historical changes in bank erosion rates, publicly available software and datasets were used to observe short-term and long-term bank erosion rates. The Digital Shoreline Analysis System (DSAS) software is used to compute rate-of-change statistics between bankline vector data (Himmelstoss et al. 2018). Banklines were digitized from georeferenced scanned historical photography, orthorectified aerial imagery, and LiDAR datasets collected between 1928 and 2019 to compute long-term and short-term net bankline movement and bank erosion rates for the length of TCP. All imagery and LiDAR data used to generate hand-digitized banklines were accessed from the U.S. Geological Survey Earth Resources Observation and Science Center (EROS) EarthExplorer web application (U.S. Geological Survey 2022b) and National Oceanic and Atmospheric Administration (NOAA) Data Access Viewer (National Oceanic and Atmospheric Administration 2022). Imagery resolution was between 1.6 ft and 10.2 ft whereas LiDAR resolution was between 1.6 ft and 3.3 ft. The net bankline movement was calculated by determining the distance between the oldest and youngest bankline along a series of transects for the period of interest. The DSAS software uses the net bankline movement and the time elapsed between the oldest and youngest bankline to determine a bank erosion rate for each transect.

Long-term bank erosion rates along TCP were computed for 1928-1963, representing the pre-Libby Dam flow regime, and for 1975-2019, representing the Libby Dam era flow regime.

Additionally, the net bankline movement and bank erosion rates were summarized for transects immediately adjacent to SFTC to estimate short-term and long-term localized bank erosion rates most relevant to potential chute-cutoff channel formation. Future bankline locations were also forecasted using the computed bank erosion rates. The additional analyses for calculating short-term erosion rates near SFTC used each year that imagery and LiDAR datasets were available for digitizing banklines (1975, 1992, 2004, 2005, 2006, 2009, 2010, 2012, 2013, 2015, 2017, 2019). The calculated short-term bank erosion rates depended on the temporal resolution of the available imagery and LiDAR data. In total, eleven distinct time intervals were used to calculate short-term bank erosion rates during the Libby Dam era flow regime. The DSAS software forecasting capability uses the Kalman filter to combine observed banklines with linear-regression model derived positions to forecast a future position (Himmelstoss et al. 2018). Forecasted banklines were estimated using historical retreat rates and predictions may not be valid if there are changes in hydrology, upstream sediment supply, or physical bank properties.

Geomorphic Change Detection

To determine the volumetric changes in bank sediment along TCP since 2011, two digital elevation models (DEMs) were generated to represent 2010 and 2022, respectively. These DEMs (1 foot cell resolution) are an integration of LiDAR data (National Oceanic and Atmospheric Administration 2022) and high-resolution bathymetry data (Fosness and Dudunake 2019) that represent the best available continuous surface for those two years. Areas that were too shallow to collect bathymetric data or where the LiDAR data were missing were interpolated and merged with the surface to remove any void areas. The Geomorphic Change Detection software was used to generate a DEM of difference for determining areas of erosion or deposition along TCP and to compute volumetric changes between 2010 and 2022 (Riverscapes Consortium 2022). An uncertainty analysis of these surfaces was not performed as part of the DEM of difference generation.

Hydraulic Modeling

Hydraulic conditions for two different flow conditions at TCP were simulated using the International River Cooperative (iRIC) Flow and Sediment Transport Model with Morphological Evolution of Channels (FaSTMECH) two-dimensional hydraulic flow model (Nelson et al. 2003). The simulated flow conditions were selected to investigate how annual changes in backwater conditions at TCP and hydrologic changes from regulation upstream might influence bank erosion rates. The first condition was high flow (31,850 ft^3/s on June 17, 2022) with high backwater conditions, which is typical during the spring snowmelt when Kootenay Lake is filling and reaching its highest stage. The second condition was also a high flow (33,026 ft^3/s on December 3, 2021) with diminished backwater conditions at TCP, which can occur during winter dam operations. The downstream extent of the hydraulic model was the USGS streamgage at Copeland, ID (USGS 12318500) and the upstream extent was the streamgage at Klockmann Ranch (USGS 12314000); however, the streamflow boundary condition originated from a USGS streamgage downstream, Kootenai River at Porthill, ID (USGS 12322000), because the streamgages at Copeland, ID (USGS 12318500) and Klockmann Ranch (USGS 12314000) did not record discharge during the period of the model simulations. Discharges were not adjusted for drainage area because tributaries between the model domain and the streamgage at Porthill, ID (USGS 12322000) are relatively minor. All USGS streamgage data are published in the National Water Information System (U.S. Geological Survey 2022a). The model grid was extended upstream by approximately 6,500 feet to allow more suitable flow alignment within the study reach. Hydraulics were simulated with a 16 ft by 16 ft computational grid.

Model topography was derived from high resolution LiDAR and bathymetry data (Dudunake and Fosness 2019). Model calibration included adjusting the roughness coefficient until the modeled water surface elevation agreed with observed water surface elevations at the upstream gage at Klockmann Ranch (USGS 12314000). One additional flow condition (37,400 ft^3/s on June 4, 2020) was also simulated to help calibrate the model because depth averaged velocity data (Elliott et al. 2021) were available for this date near Nimz Ranch located upstream of TCP but within the model domain. Model outputs of interest for this study were depth averaged velocity (ft/s) and shear stress (Pa). To better compare the potential impacts of flow hydraulics for these two scenarios on bank erosion at TCP, results were cropped to a smaller region near SFTC.

Results

Bank Erosion Rates and Change Detection

The geomorphology throughout the meander reach is important for understanding the effects of channel migration and the resulting bank erosion in the study area. The DSAS and Geomorphic Change Detection software provided a quantitative approach for assessing recent and historical changes in bank erosion rates and volumetric changes along TCP and near SFTC.

Channel sinuosity, the ratio of channel length and the valley length, has been shown to influence bank erosion rates in similar river systems (Elliott 2011; Coles and Klingeman 2014). One example of this is demonstrated through comparison of historical imagery and LiDAR data downstream of the TCP study area at Ferry Island, the location of a chute cutoff event that occurred between 1963 and 1975 (figure 1). Sinuosity and curvature at Ferry Island were comparable to TCP suggesting that chute cutoff events are possible throughout the meander reach during the Libby Dam era. Unlike other locations in the meander reach where sinuosity and curvature are lower, the high sinuosity and curvature of the Kootenai River at TCP appear to contribute to increased erosion rates similar to Ferry Island and other studies that investigated similar dynamics between curvature and erosion rates (Sylvester et al. 2019).

Average DSAS bank erosion rates varied depending on the temporal and spatial characteristics of the analysis. The DSAS bank erosion rate along TCP during the pre-Libby Dam (1928 to 1963) flow regime was 5.3 ft/yr while the Libby Dam era (1975 to 2019) flow regime bank erosion rate was about 1.5 ft/yr. The large difference in the long-term bank erosion rates is likely attributed to substantial bank erosion at the end of TCP prior to 1975. This reduction in long-term bank erosion rates suggest that flow regulation may have slowed overall meander migration processes at TCP. To avoid biased erosion rates near SFTC, long-term erosion rates were calculated for 20 transects near SFTC. The average long-term bank erosion rates during pre-Libby Dam and Libby Dam era flow regimes near SFTC were 2.3 ft/yr and 2.4 ft/yr (figure 4), respectively.

These short-term bank erosion rates near SFTC varied from a minimum of 0.97 ft/year to a maximum of 14.9 ft/year. When compared to the discharge record downstream at Porthill, ID (USGS 12322000), intervals with high bank erosion rates did not correlate with the annual peak discharge suggesting other drivers may exist for the high bank erosion rates. For example, the highest bank erosion rate (figure 5) near SFTC occurred between 2009 and 2010 when the annual peak discharges were 36,800 ft^3/s and 47,800 ft^3/s, respectively. Conversely, the lowest bank erosion rate occurred between 2010 and 2012, a period of relatively high annual peak discharges (figure 5). Errors associated with imagery resolution, poorly georeferenced imagery, and the resulting digitized banklines were apparent with some calculated short-term erosion rates. For example, the positive bank erosion rate between 2006 and 2009 suggested accretion of bank material which is unlikely given the location along TCP (figure 5) suggesting possible errors in georeferenced imagery.

These observations suggest that discharge alone may not be a significant driver of bank erosion rates for the transects immediately adjacent to SFTC. Additionally, there was no clear relationship between periods of high bank erosion and various flow runoff characteristics such as annual cumulative flow volume near SFTC or winter operations at Libby Dam. This suggests that bank erosion adjacent to SFTC may be the result of numerous drivers such as longer-term meander migration, bank geometry and sediment characteristics, vegetation density, and other flow characteristics not considered here (e.g. duration of various flow conditions).

Using the long-term bank erosion rates near SFTC, a 10-year and 20-year bankline was forecasted using the DSAS software near SFTC and suggest that a chute-cutoff event could occur between 2033 and 2043 (figure 4) resulting in up to 20 acres of land loss and the potential for the reconfiguration of TCP into an island. However, the stochastic nature of short-term bank erosion suggests the capture of SFTC has the potential to occur sooner than predicted. Implications of this potential for chute-cutoff include the increase of fine sediment loading into the Kootenai River that may lead to loss of spawning material due to the increased embeddedness of coarse sediments preferred for spawning habitat of various fish species.

While erosion rates were variable during the Libby Dam era flow regime, an analysis of the volumetric change shows large amounts of sediment eroded from the bank along TCP between 2010 and 2022. Approximately 330,000 yd^3 of bank and channel sediments were eroded resulting in a lowered surface while 116,741 yd^3 of sediment was deposited resulting in a net volume of cut of 213,000 yd^3 at Trout Creek Peninsula (figure 6). The largest volume of sediment was removed near SFTC immediately downstream of where the highest bank erosion rates were calculated. Localized areas near SFTC lowered by 37 feet between 2010 and 2020, approximately equal to the water surface elevation during baseflow streamflow conditions (1,745 ft).

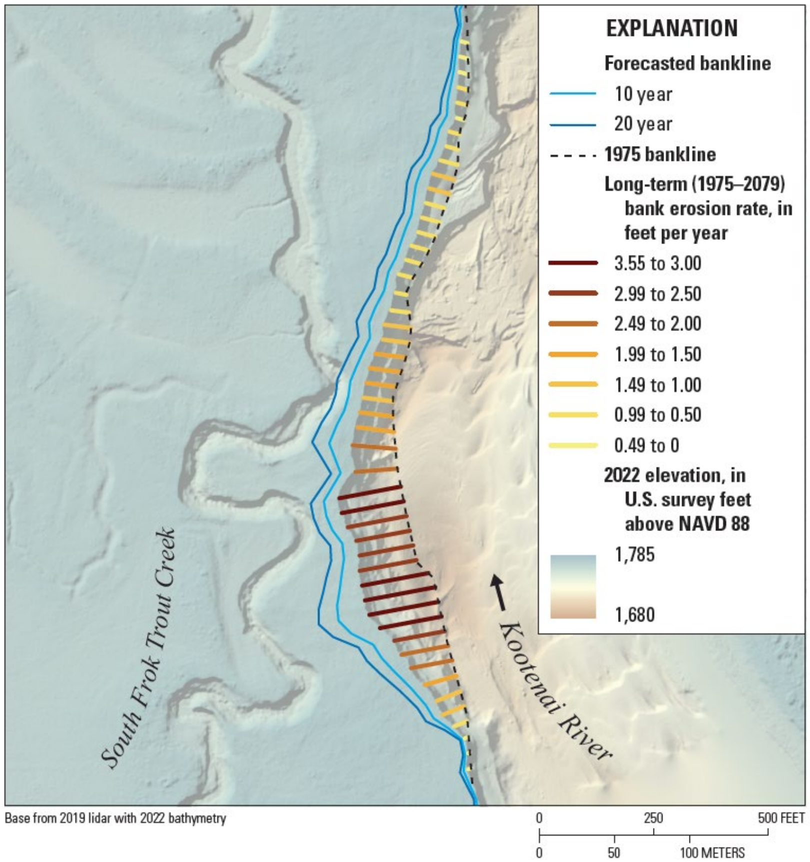

Figure 4. 10-year and 20-year forecasted banklines and long-term bank erosion rates near South Fork Trout Creek at Trout Creek Peninsula on the Kootenai River near Bonners Ferry, ID computed from 1975 to 2019 average bank erosion rates

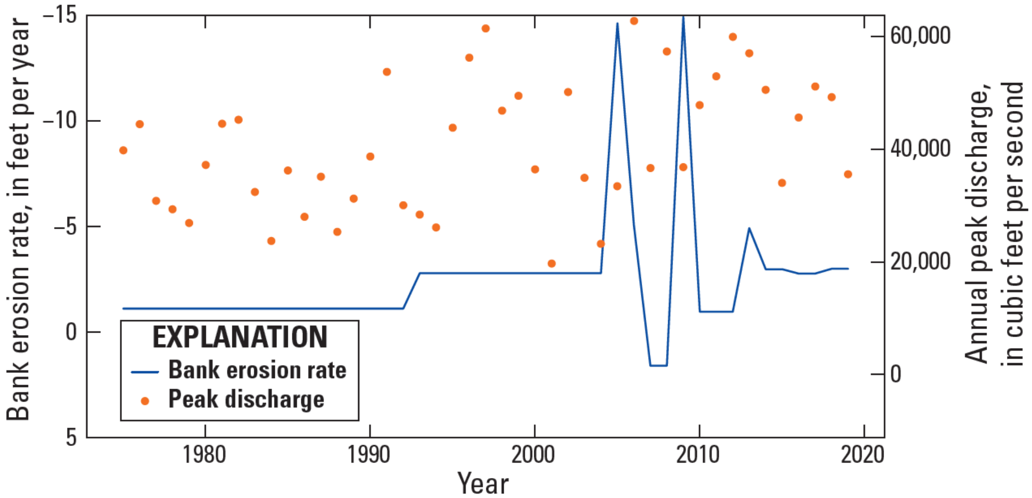

Figure 5. Short-term bank erosion rates near South Fork Trout Creek at Trout Creek Peninsula on the Kootenai River near Bonners Ferry, ID computed during the Libby Dam era flow regime

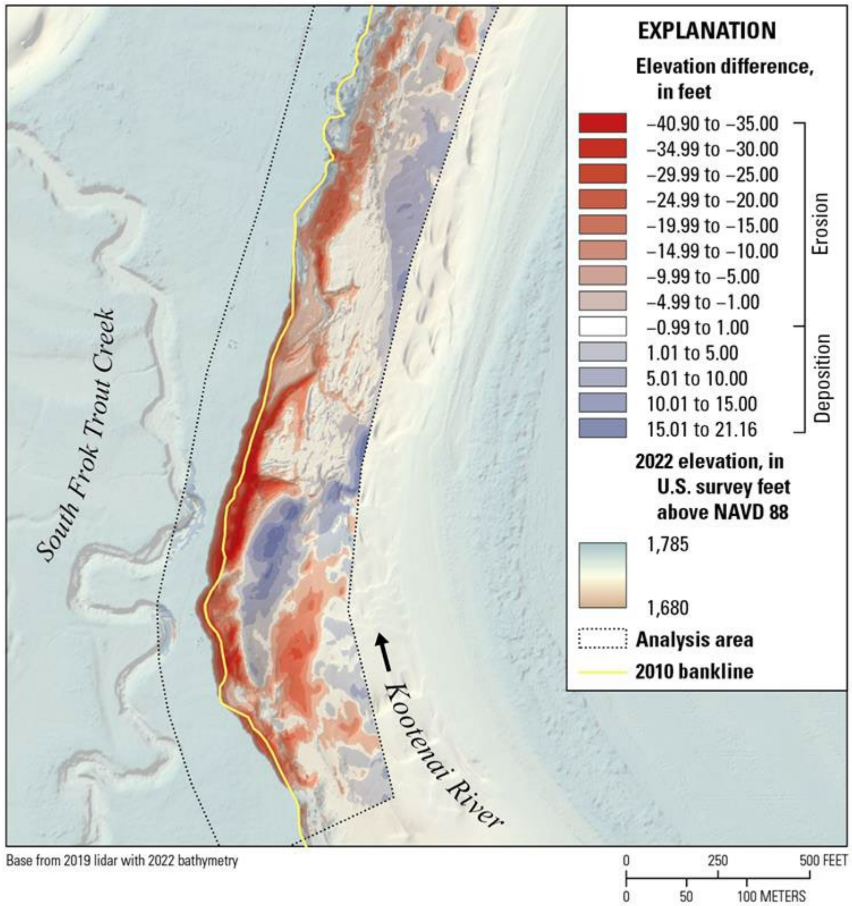

Figure 6. Digital elevation model (DEM) of difference between 2010 and 2022 showing areas of erosion and deposition near South Fork Trout Creek. Negative values (warmer colors) represent erosion and positive values (cooler colors) represent deposition

Hydraulic and Hydrologic Assessment

Simulation of two flow conditions at TCP indicate that for similar discharges (31,850 ft^3/s and 33,026 ft^3/s), estimated depth-averaged velocities and shear stresses are larger when the water surface elevation at Kootenay Lake is low and the backwater effect at TCP is lower. The mean depth-averaged velocities for the low and high backwater conditions in the near bank zone were 2.1-ft/s and 1.7-ft/s, and maximum depth-averaged velocities were 3.4 ft/s and 3.1 ft/s, respectively. Similarly, the mean estimated shear stress in the near bank zone was 0.39-Pa and 0.27-Pascals (Pa) for the low and high backwater conditions, respectively (Figure 7). The differences in estimated velocity and shear stress for each condition are likely driven by the impact of backwater conditions on water surface slope near TCP. Modeled scenarios suggest that water surface slope at TCP is higher when backwater conditions are lower but declines as the backwater conditions increase. Reach average slopes estimated from measured mean daily water surface elevations at the two USGS streamgages in the study reach illustrate this, with slopes of approximately 3×10^{-5} ft/ft and 1.6×10^{-5}-ft/ft for the low and high backwater conditions, respectively.

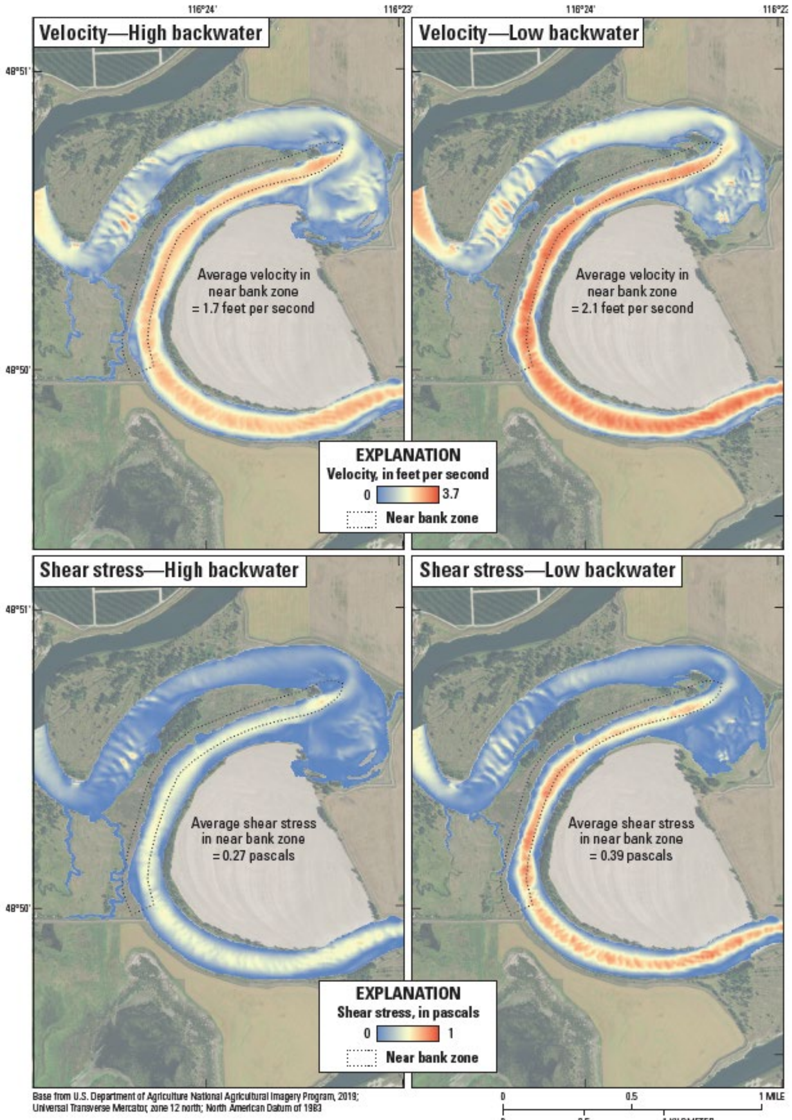

Figure 7. Simulated shear stress and depth averaged velocity at Trout Creek Peninsula for high flow conditions with significant backwater from Kootenay Lake (31,850 ft^3/s on June 17, 2022) and high flow conditions with less backwater influence from Kootenay Lake (33,026 ft^3/s on December 3, 2021)

Although the highest annual flows on the Kootenai River typically occur during the spring snowmelt, backwater conditions are also increasing as Kootenay Lake fills. Results from the 2D model suggest that the capacity of the spring peak to directly drive high bank erosion rates may be diminished by the high backwater at this time. In contrast, high flow conditions that occur throughout the winter months happen when Kootenay Lakes levels are nearly at their lowest. The greater estimated velocities and shear stresses for this condition suggest that the repeated winter peaks generated by flood control flows at Libby Dam have the potential to contribute to bank erosion rates at TCP. However, observed short-term intervals of high bank erosion did not consistently relate to years of higher winter flood control releases from Libby Dam. Coupled with the short-term bank erosion rates described above, the continued migration of the Kootenai River channel towards SFTC demonstrated by DEM of difference analysis, and the modeled shear stresses described below supports the hypothesis of a chute-cutoff event by 2043.

Conclusion

Channel migration in the meander reach of the Kootenai River has resulted in variable long and short-term bank erosion rates. While the specific drivers of increased or decreased bank erosion rates are poorly understood in this study, the localized short-term erosion rates suggest that a chute-cutoff event may occur by 2043 resulting in SFTC being captured by the Kootenai River despite relatively stable long-term bank erosion rates. This is apparent by the short-term bank erosion rates that occurred near SFTC between 2009 and 2010 resulting in large erosion events as demonstrated by volume of sediment removed from the bank through the DEM of Difference. With minimal changes in long-term bank erosion rates and no apparent relationship between annual hydrograph characteristics and intervals of higher bank erosion rates, this analysis suggests other drivers of bank erosion are dominant at this location (e.g. bank sediment characteristics, bank geometry, vegetation). A potential for land loss, diminished quality of downstream aquatic habitat from fine sediment loading, and degraded ecological function from decreased channel complexity may be the result from current bank erosion rates near TCP. A larger spatial analysis of short-term and long-term bank erosion in the meander reach may improve understanding of how the meander migration processes correlates with the current hydrologic regime.

Results from hydraulic modeling and an assessment of hydrologic processes that occur near TCP suggest that additional monitoring and analyses could support improved understanding of the dynamics affecting the short-term erosion rates. Without higher temporal resolution imagery or topographic data, it is difficult to determine if anthropogenic changes to the hydrology such as winter dam operations at Libby Dam play a role in increasing or decreasing the short-term bank erosion rates. Furthermore, studying these processes may provide further insight on the dynamics of bank erosion in regulated systems.

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