Measuring Gravel Bar Mobility in a Large River with Tracer Gravel

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Abstract

The Bureau of Reclamation deployed 600 tracer clasts labeled with Passive Integrated Transponder (PIT) tags on gravel bars in the Methow River in the vicinity of the Sugar Levee near Twisp, WA. PIT tags equip each rock with a unique identifier that can be detected and read from a few feet away via Radio Frequency Identification (RFID) technology. The purpose of the experiment was to test a hypothesis that the Sugar Levee is disrupting sediment transport dynamics through the study reach and causing ‘excess’ deposition on a gravel bar downstream of the levee, resulting in bank erosion and property loss on the opposite bank.

The tracer rocks were installed on 4 gravel bars upstream of the levee and on 1 bar across the river from the levee in October 2018. Searches for the tracers in 2020, 2021, and 2022 recovered and surveyed the locations of 448 (75%), 356 (59%), and 413 (69%) of the 600 rocks installed. Some tracers have traveled more than a mile. An increase in bed slope at the upstream end of the levee continuing to the downstream end appears to be enhancing sediment mobility adjacent to the levee. Confinement by the levee appears to have caused the river to incise adjacent to the levee, resulting in the increased steepness.

Introduction

There is evidence in the sediment transport literature that there is a relationship between the representative travel distance of gravel clasts in rivers and the spacing of gravel bars [Hassan and Bradley, 2017; Pyrce and Ashmore, 2003a; 2003b; 2005]. This relationship makes intuitive sense although it is not easy to separate cause from effect: The gravel bars may act as traps that modulate sediment travel distance or perhaps some other factor (another aspect of river morphology, the length of a typical flood, etc.) favors a particular travel distance and sets the bar spacing.

The Sugar Levee occupies the right bank of the Methow River near Twisp, WA (Figure 1). The levee prevents the river from migrating to the south. Downstream of the levee, a growing point bar is forcing the river to the east, resulting in erosion and property loss on the opposite bank. Our hypothesis was that the levee is disrupting the typical bar-to-bar sediment transport dynamics, resulting in ‘excess’ deposition on the point bar downstream of the levee and causing erosion on the opposite bank. To test this hypothesis, we conducted a gravel tracer experiment using 600 rocks labeled with Passive Integrated Transponder (PIT) tags. The PIT tags equip each tracer clast with a unique identifier that can be detected from up to about 3 feet away using a portable radio frequency identification (RFID) system. PIT tagged gravel tracking is a well-established method for observing sediment transport in rivers [Bradley and Tucker, 2012; Olinde and Johnson, 2015; Phillips and Jerolmack, 2014; Phillips et al., 2013].

Study Area

The Methow River in north-central Washington is a tributary of the Columbia River. The Methow flows mostly south from headwaters on the east side of the North Cascade Mountains (Figure 1). The study area is centered on the Sugar Levee about 1 mile north of the town of Twisp, WA on the east side of State Route 20. The drainage area at the site is about 1074 square miles. Mean annual precipitation is 35.6 inches [USGS, 2022]. The elevation at the upstream end of the study reach is about 1605 feet dropping to 1580 feet and the downstream end. The average slope over the reach is 0.003.

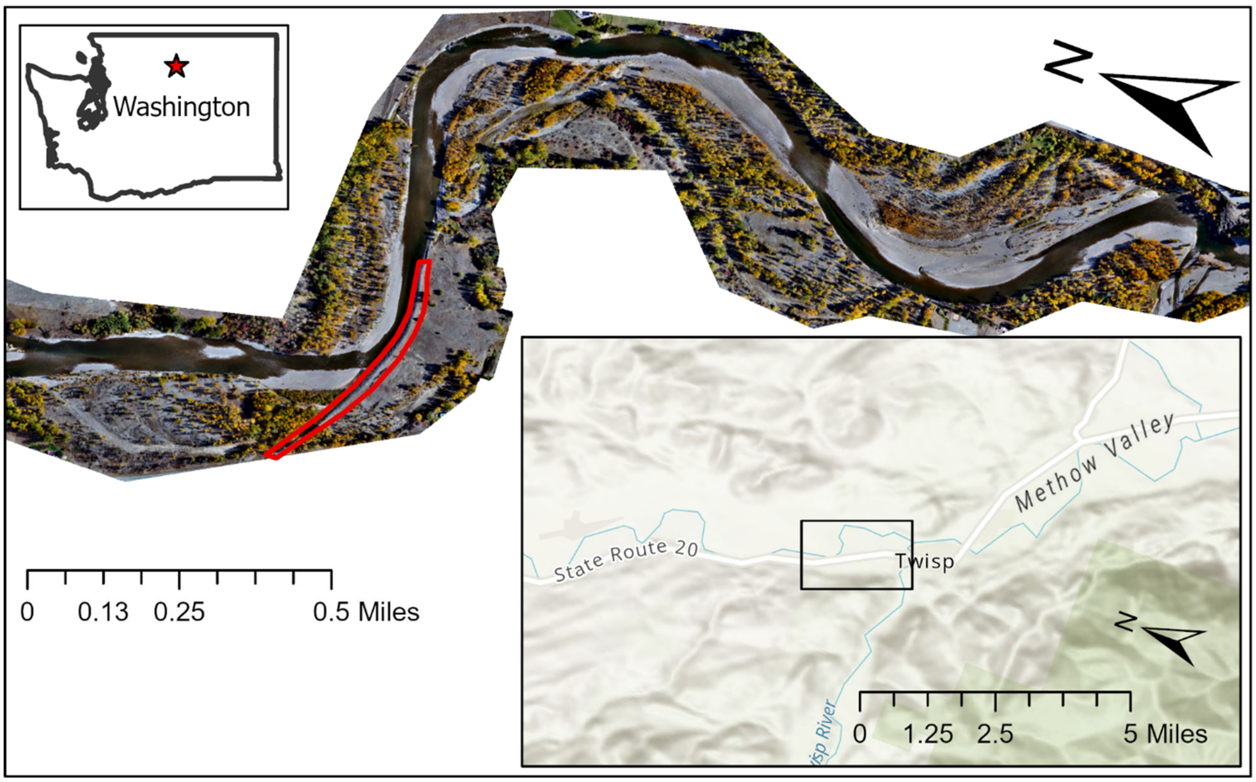

Figure 1. The Methow River study area in north-central Washington. The Sugar Levee is outlined in red.

High flows capable of mobilizing sediment have occurred only during snowmelt in the late spring over the duration of the study. The hydrograph from the USGS gage at Winthrop, WA (USGS 12448500) for water years (WY) 2019-2022 is shown in Figure 2. The Winthrop gage is upstream of the study area and is representative of the flow at the site. Flows during WY 2020-2022 peaked in mid-May to early June at 7220 cubic feet per second (cfs), 9760 cfs, 7900 cfs, and 10,300 cfs, respectively. The highest flow was in 2022, peaking at 10,300 cfs on June 2, slightly higher than the expected 2-year peak flow (9860 cfs) [*Byrne and Bountry*, 2021]. The lowest peak flow during the study period, 7220 cfs, occurred on May 17, 2019. It was thought that this flow was too low to mobilize the tracers, so no recovery was performed in 2019.

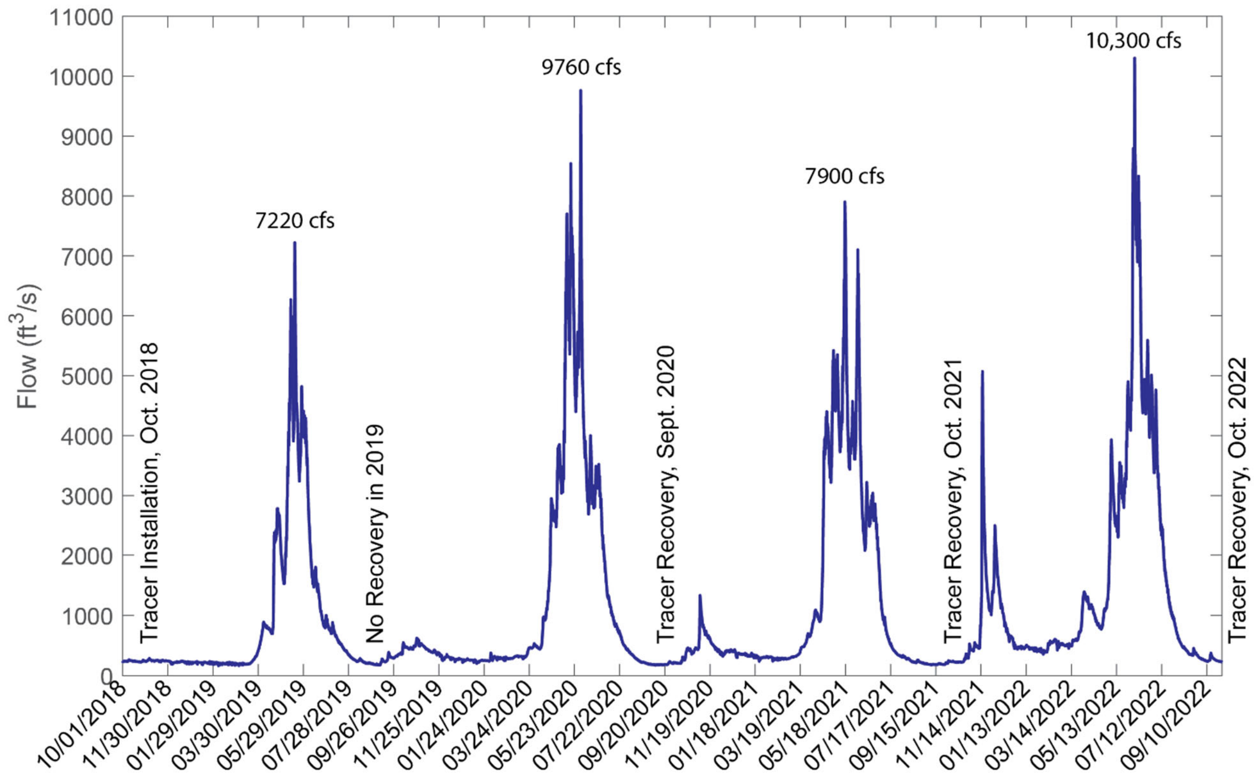

Figure 2. The Methow River hydrograph at Winthrop, WA (USGS 12448500) for water years 2019 to 2022.

Methods

Tracer Preparation

I prepared tracer clasts using coarse gravel and cobbles obtained from a landscape supply yard near Golden, CO. The material was mostly granitic, with some schist and gneiss, similar to the composition of the native material in the study area. The size of clasts selected for tracer preparation was guided by the average of five grain size distributions derived from Wolman pebble counts [*Wolman*, 1954] conducted along the Methow River from about 1.5 miles upstream of the Sugar Levee to about 2 miles downstream. Rocks were secured in a custom-built drilling rig based on a design developed by *Slaven et al*. [*2014*] and drilled using a hammer drill and a 5/32" carbide drill bit. After drilling, I inserted a 32 mm PIT tag into each rock and sealed the hole with waterproof marine epoxy putty. I weighed the rocks, measured the a, b, and c-axes with calipers, scanned the RFID (the unique identifier stored on the PIT tag), and recorded the data. I prepared six hundred rocks, totaling more than 1690 pounds. The median grain size (D_{50}) of the tracers was about 84 mm, slightly finer than the 90 mm D_{50} of the averaged measured grain size distributions. The overall size distribution of the tracer population was narrower than the measured distributions, with both the fine and coarse tails underrepresented.

Tracer Installation

Reclamation staff installed tracers on five gravel bars in the vicinity of the Sugar Levee during October 2-4, 2018 (
Figure 3). The bar furthest upstream, assigned the label Bar 0, is a left bank bar about 2000 ft upstream of the Sugar Levee. Bar 1 is a low bar on the right bank. Bar 2 is a low mid-channel bar. Bar 3 is a right bank bar that terminates against the upstream end of the Sugar Levee. Bar 4 is across from the levee on the left bank. On each bar, we installed groups of 3 tracers spaced 10 feet apart along lines running perpendicular to the direction of flow. In an attempt to place the tracer in a natural position, a rock of similar size was removed and replaced with a tracer. The lines were spaced 20 feet apart in the flow parallel direction on all bars except Bar 3, where the lines were 25 feet apart. After placing the tracers, the RFIDs were recorded, and center of the cluster was surveyed with a high precision Global Positioning System (GPS).

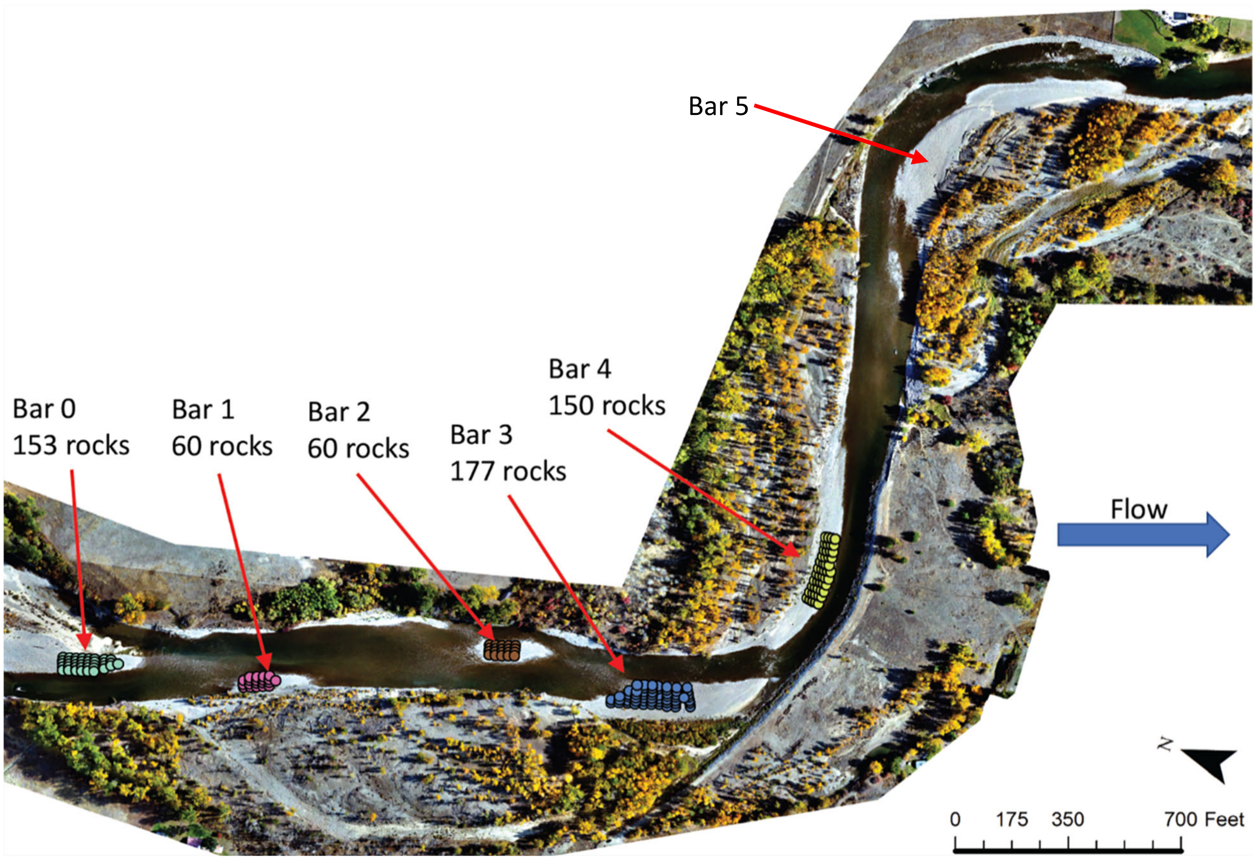

Figure 3. The locations of 600 tracers installed in October 2018. Each colored circle represents 3 tracers.

Tracer Recovery

Tracer recovery consisted of walking along gravel bars and wading the channel with a backpack-mounted RFID reader system. The system energizes an antenna to generate a magnetic field that induces a current in any PIT tags within about 3 feet of the antenna. The induced current charges a capacitor in the PIT tag and the tag transmits a unique identifier to the reader when the capacitor discharges. When a tag is detected, the reader sounds an audible alarm and records the detection in an internal database. The RFID reader systems used in the 2022 recovery also recorded the position using an internal GPS receiver. In the 2020 and 2021 recoveries, the position of each tracer was measured with an external GPS system.

The study area is large, so we had to prioritize areas where tracers are most likely to be found. The highest priority search areas were the installation gravel bars. Many tracers did not move far or did not move at all, so a large fraction of the tracer population remained on the installation bars. It was expected that tracers at the upstream end of the study reach (Bars 0 through 3) would tend to move to the next bar downstream, so searching the installation bars would also recover tracers from upstream. The submerged transverse bars that connect Bar 0 to Bar 1, Bar 1 to Bar 2 and Bar 2 to Bar 3 (visible as lighter colored, shallower areas in Figure 2) were also a priority. Other priority search areas included the shallow submerged area upstream of the point bar labeled Bar 5 in Figure 3 and the lower surfaces of that point bar. The 2020 recovery included only the area shown in
Figure 3. The 2021 and 2022 recoveries extended downstream another 3600 feet (shown in the next section).

Results

We performed tracer recoveries in September 2020, October 2021, and October 2022. We thought that the 2019 flood was too small to mobilize tracers and we did not do a recovery following that flood. In light of the tracer motion observed in the 2021 flood, that was probably a mistake and some tracer motion probably occurred in 2019. Tracer recovery rates were 75%, 59%, and 69% in 2020, 2021 and 2022. The tracer positions in October 2022 are shown in

Figure 4. Most tracers remain on the bar where they were installed, but a few tracers have traveled more than a mile. The most tracer accumulation is on and immediately upstream of Bar 5 at the center of

Figure 4. Tracers from Bars 3 and 4 are disproportionately represented on this bar and on a bar further downstream. This is supported by Figure 5. More than 60% of the tracers installed on the upstream bars (Bars 0-2) remain in place, while only 32% of the tracers installed on Bar 3 and 9% of the tracers installed on Bar 4 remain there. 137 out of 150 Bar 4 tracers have been eroded and they are not being replaced by tracers from upstream. Bar 4 had accumulated only 18 tracers from upstream by 2022. Bar 3 had accumulated only 1 tracer from upstream.

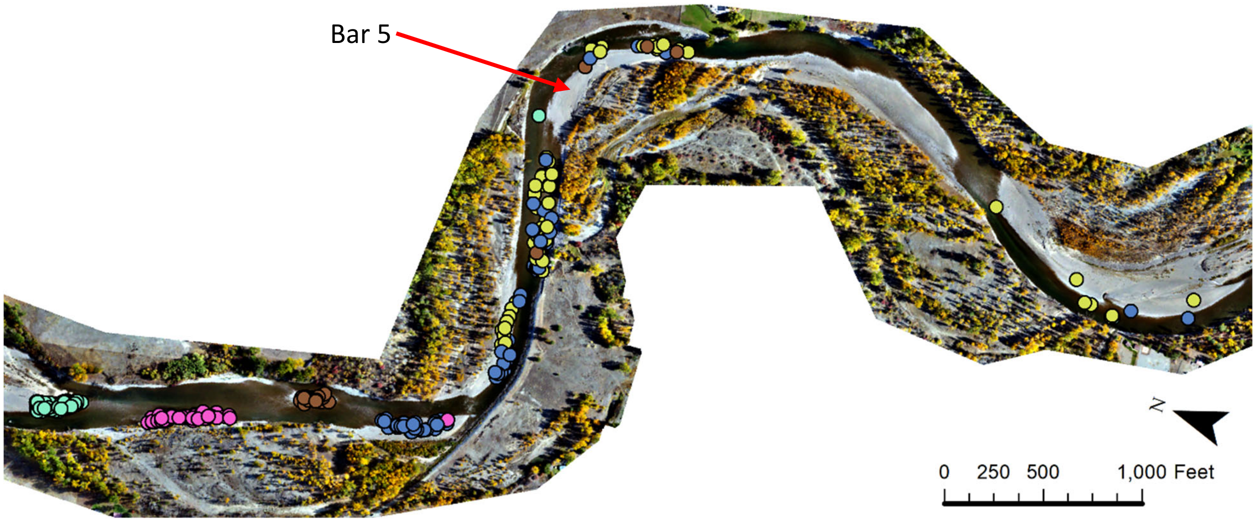

Figure 4. The tracer position in October 2022. Each circle represents one tracer. The circles are colored according to the installation bar of the tracer.

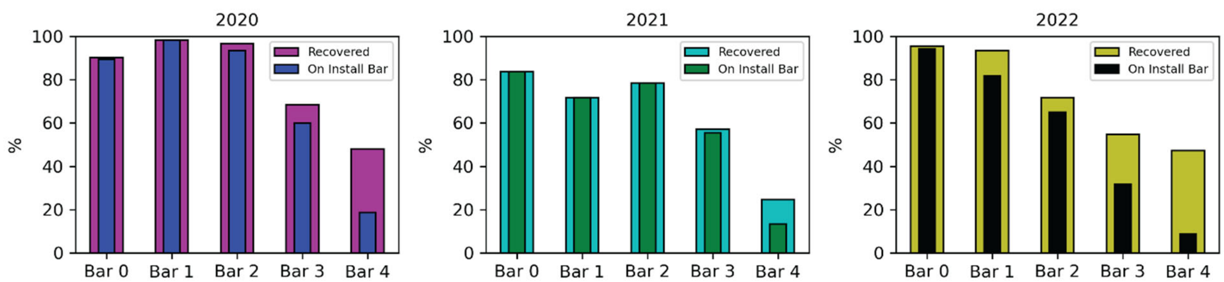

Figure 5. The percentage of tracers from each installation bar that were recovered in each year and the percentage that remained on the installation bar.

Discussion

Tracer accumulation on and upstream of the point bar downstream of the Sugar Levee (Bar 5) is consistent with the hypothesis that deposition on this bar is driving bank erosion on the opposite bank. The enhanced mobility of tracers from Bar 4 (Figure 5) and the lack of deposition of tracers from upstream on Bar 4 are also consistent with the hypothesis that the levee is disrupting sediment dynamics by constraining the growth of Bar 4. However, tracers from Bar 3 also exhibit enhanced mobility and there is almost no deposition of tracers from upstream on Bar 3. Bar 3 is upstream of the Sugar Levee, suggesting that a lack of accommodation space for deposition is not the only mechanism for enhancing sediment mobility in the vicinity of the levee.

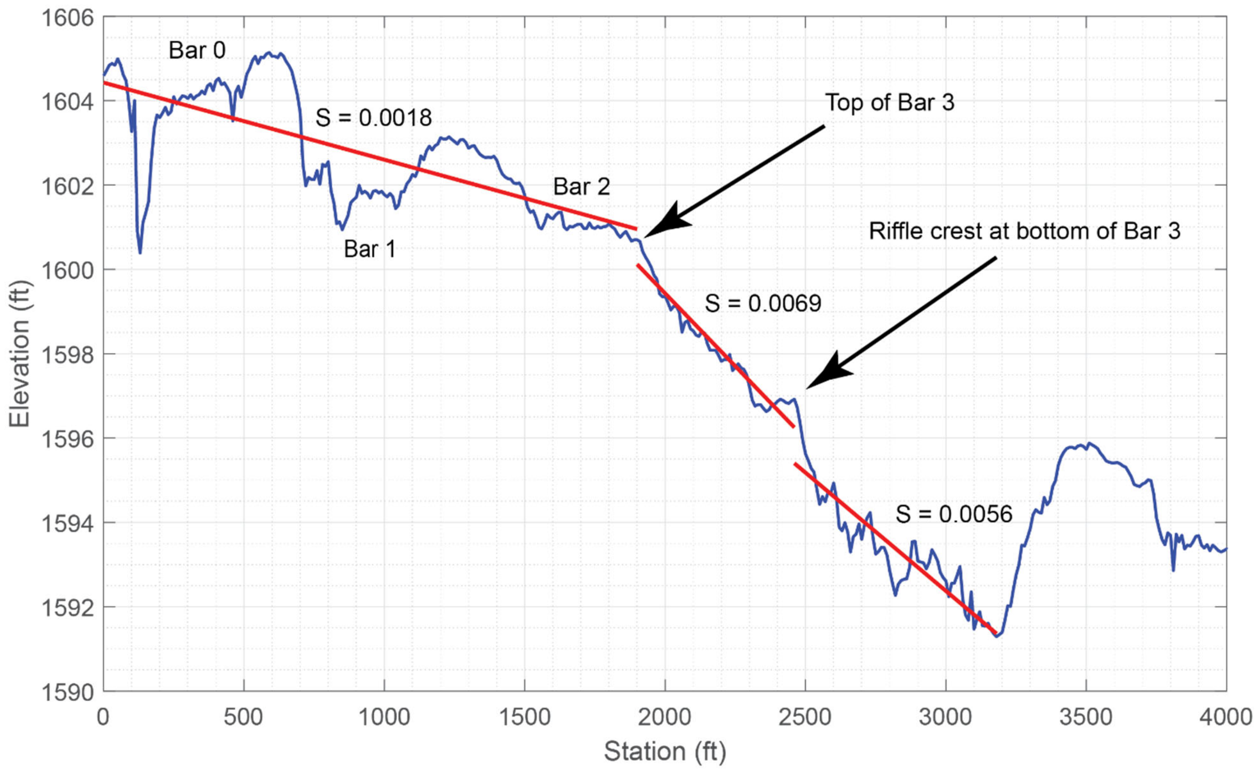

Figure 6. The bed profile through the upstream part of the study reach. The profile is derived from a 2020 bathymetric survey. The Sugar Levee extends from approximately station 2500 to 3200.

Figure 6 shows the bed profile from the upstream end of the study reach to the area of tracer accumulation downstream of the Sugar Levee. The channel slope increases substantially at the upstream end of Bar 3 (at station 1900). The steepened section continues to the downstream end of the levee at approximately station 3200. The bulge in the bed profile centered on station 3500 corresponds to the area of tracer accumulation upstream of Bar 5. The increase in channel slope is likely responsible for increase in tracer mobility in the vicinity of the levee.

Conclusions

Enhanced tracer erosion from Bar 4 relative to the upstream bars supports the hypothesis that the Sugar Levee is disrupting sediment transport dynamics. However, the mechanism appears to be different from the original hypothesis. Rather than constraining accommodation space for deposition on Bar 4, it appears that the levee has caused channel incision in the vicinity of the levee. The incision kicked off upstream propagation of a knick zone that has increased the steepness of the river from the upstream end of Bar 3 to the downstream end of the levee. The increased steepness seems to account for the enhanced erosion of tracers from Bar 3. This is consistent with observations that the bed coarsens significantly about midway down Bar 3 and is very coarse and deep adjacent to the levee.

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