Slate River, Gunsight Reach

Prediction Level Assessment of River Stability and Recommendations for Alleviating Instability Consequences

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1.0 Introduction

The study area for this project is a reach of the Slate River at the Gunsight Bridge on Crested Butte Land Trust (CBLT) property (**Figure 1**).

1.1 Purpose of this Study

A geomorphic assessment was made of the Slate River Watershed in 2012, and the Gunsight Reach was identified as a potential problem area for stream instability related to anthropogenic stress. According to that study, this reach is a moderate priority in the watershed from a sediment and river stability perspective, but since it is a *"property that CBLT either owns or has a conservation easement on, and therefore it may have a higher 'standard of care' than other private or public reaches in the watershed*." In the assessment, the Gunsight reach scored high for potential instability that is primarily related to the presence of a wide, braided channel that is directly affected by human impacts including the Gunsight Pass Road (which runs along the left bank of the river and eventually crosses it on this reach), a pedestrian bridge that spans the river here, and a berm (an historic railroad grade that is now a trail) which effectively cuts off part of the floodplain.

Our recommendation at the time of this report was to "*pursue a broad-scale PLA study on this group of reaches (the Gunsight reach and its neighboring reaches up- and downstream) to determine impacts of the road and bridge, and to assess the condition of observed braided stream morphology*." This study was commissioned to assess the issues in more detail and to begin a monitoring program to inform the decision about whether corrective action is warranted or not. In an initial reconnaissance of the river during runoff in June 2013 by Mark Beardsley and Danielle Beamer of CBLT, it was decided that this study should focus on the impacts of the road and bridge. The more general question about the legitimacy and quality of a braided channel form at this location is not addressed except to say that we have no reason to believe that braided channels are not a natural, healthy, functional, and potentially stable river form in this system.

1.2 Assessment Strategy

This study utilizes the US Environmental Protection Agency (EPA) Watershed Assessment of River Stability and Sediment Supply (WARSSS) protocol for predicting stream stability and sediment load (Rosgen 2006). According to this method, the stability of a stream is a major determinant of its condition and a prerequisite for optimal functioning, and a formal definition of stability is given: "*Stream stability is morphologically defined as the ability of the stream to maintain, over time, its dimension, pattern, and profile in such a manner that it is neither aggrading nor degrading and is able to transport without adverse consequence the flows and detritus of its watershed*" (Rosgen 1996).

WARSSS is a four-phase assessment method. The first two phases, namely the Reconnaissance Level Assessment (RLA) and Rapid Resource Inventory of Sediment and Stability Consequences (RRISSC) were completed for the Upper Slate River Watershed in 2012. This study is an application of phase 3, the Prediction Level Assessment (PLA), on the Gunsight Reach specifically. PLA is essentially a set of diagnostic tools (some quantitative and some qualitative) that aid the evaluator in making informed predictions about the stability and sediment supply from a river reach using field data from hydrologic and geomorphic surveys. These surveys were set up and monumented on site so that they can be repeated as part of an ongoing monitoring strategy (phase 4) that can be used to validate or refute the predictions or to monitor changes related to future management actions.

Thus, if decision-makers are satisfied with the level of certainty in the predictions made in the PLA assessment, then specific restoration treatments can be made immediately to address identified problems and monitoring could then be directed at evaluating restoration or stabilization success. In general, though, river restoration treatments tend to be both expensive and risky in nature so it is important to be quite certain about the need to take on these activities before designing specific treatments and implementing them. Our assessment strategy therefore includes specific monitoring activities that can be completed over several years prior to any treatment. Data and observations made during this pre-project monitoring period will significantly reduce uncertainty about any of the predictions made in this report and better inform decisions about whether and what kind of intervention could be warranted.

Figure 1: Oblique View of the Gunsight Reach

2.0 Methods

This study is an application of the PLA phase of WARSSS. A detailed description of the WARSSS process and specific methodology for each of the phases are described in Rosgen (2006). The steps outlined below describe how the phases of WARSSS were used to provide the data needed to make predictive assessments of stability for the Gunsight Reach of Slate River. Fieldwork for this project was performed in 2012 by Mark Beardsley, Jessica Doran, and David Sutherland of EcoMetrics with additional support from Michael Blazewicz of Round River Design.

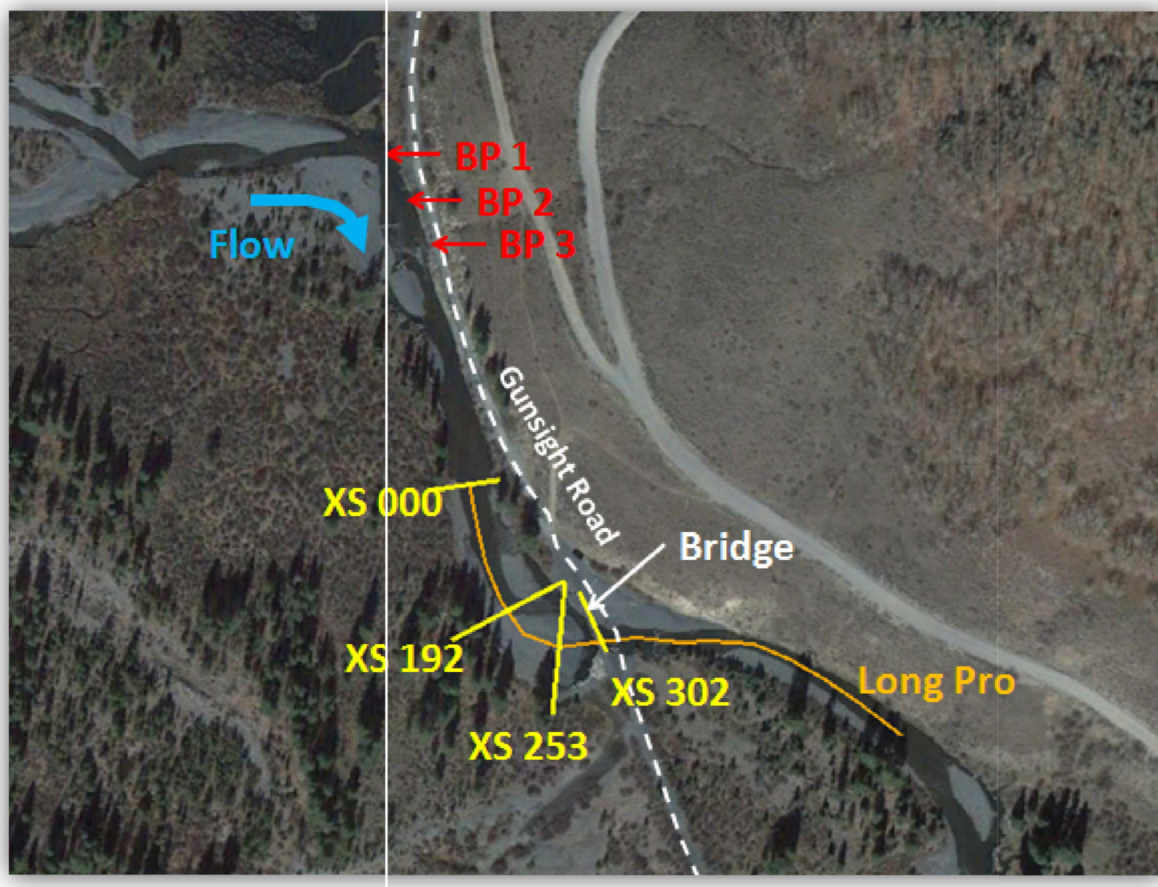
2.1 Overview

An overview was prepared using information from existing studies as well as a survey of potential stressors.

2.2 Physical Surveys

Field data were collected in September 2012. **Figure 2** is a site map showing the location of surveys and monitoring points.

Figure 2: Gunsight Reach Monitoring Site Map



2.1.1 Channel Dimension

Four physical cross-section (XS) surveys were made in the area that is directly impacted by the road and bridge, and the end points were monumented so that they can be repeated in the future. XS were surveyed by setting up tapes from the left bank end pin (0 ft) to the right bank end pin to record station. Elevation was measured with a survey rod and laser level. Points were measured at a frequency to capture all significant grade breaks that define the shape of the channel, banks, and floodplain. All surveys were tied to a benchmark elevation on the deck of the bridge which was assigned a relative elevation of 100 ft. We took photos of each XS.

2.1.2 Channel Profile

A longitudinal profile survey was completed over 700 feet of the reach. Stationing was measured as distance along the approximate center of the channel using a measuring wheel. The survey captured elevations for streambed on the thalweg, water surface, bankfull indicators, and left and right bank using a laser level and rod.

2.1.3 Channel Pattern

Plan form was assessed using the most recent aerial imagery available on Google Earth (from 2012).

2.1.4 Channel Materials

Pebble counts were made to quantify the size distribution of channel materials on relatively straight riffles at XS 0000 and XS 0192 by sampling regular intervals across the complete bankfull width of the streambed and banks on as many complete transects as it took to obtain a statistically valid sample size.

2.3 Stream Classification

Valley and stream types used in this study follow the Rosgen classification system (Rosgen 1996). An additional stream type not described by Rosgen is used, D_B , to represent natural multi-channel streams that are heavily influenced by biotic drivers such as beaver activity (Beardsley 2011).

2.4 Bankfull Discharge Estimation

Discharge on the Slate River is gauged at a point just upstream of Baxter Gulch which is some distance downstream from the study site. This presented us an opportunity for estimating bankfull discharge from historic flow frequency data. Bankfull discharge was also estimated using field indicators of bankfull elevation and calculation of discharge from hydraulic relationships based on XS area and velocity on the uppermost straight, stable cross section (XS-000). Several methods were applied to calculate velocity from channel roughness and slope including friction factor equations, the Darcy-Weisbach equation, and several different equations for calculating Manning's N. The most appropriate of these results were used to estimate bankfull discharge on the reach.

2.5 Identification of Reference Condition

The WARSSS PLA approach requires the use of a stable reference reach for an analog to make predictions of stability. For this study we used the segment of stream along the Gunsight Pass Road upstream from the direct influence of the bridge as a C4 reference. This segment is a straight riffle that appears to be stable.

2.6 Identification of Stability Indices

The following indicators of stream stability were observed and classified for individual segments along the reach according to PLA guidelines:

- Riparian vegetation condition
- Meander patterns
- Deposition patterns
- Channel blockage
- Width/depth ratio condition
- Pfankuch channel stability assessment
- Degree of channel incision
- Degree of lateral confinement

2.7 Prediction of Bank Erosion Volume

Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) values were calculated for each potentially erodible bank segment on the reach while in the field. For each bank segment scored, the mean bank height and bank segment length was also recorded. Bank erosion was calculated using the empirical model described in Rosgen (2006) for Colorado streams to predict annual bank lateral accretion from observed BEHI and NBS values. Sediment volume was calculated for each segment from lateral accretion rate, mean bank height, and segment length. Sediment volume is converted to mass using a standard conversion rate of 1.3 tons per cubic yard (cy).

2.8 Sediment Competence

WARSSS PLA procedures describe two methods for evaluating bed stability from sediment competence using dimensionless and dimensional shear stress calculations. Calculating competence using critical dimensionless shear stress requires a volumetric bedload sample taken at bankfull flow or volumetric point bar sample. Neither of these data exist for this reach, so this study uses only the dimensional shear stress method. We evaluated sediment competence following the protocols for this method on all three riffle XS on the study reach. Critical dimensional shear stress was derived from Rosgen's (2006) empirical relationship to particle size for Colorado streams. Competence was assessed by comparing predicted stable shear stress to actual shear stress values calculated on each riffle XS using the best estimate for bankfull particle size.

2.9 Stream Channel Succession

The successional status of channel type evolution was assessed across the reach and recorded by segment according to the scenarios described in Rosgen (2006).

2.10 PLA Stability Predictions

The data from all of the above parameters were compiled using PLA worksheets to make predictions of lateral stability, vertical stability, enlargement, and sediment supply.

2.11 Historic Aerial Analysis

Historical aerials are available on Google Earth Pro™ for the years 1995, 2003, 2005, 2011, and 2012. We traced bank lines on these photos and overlaid them on each other to track lateral movement of the channel over this 18-year time frame. Photo overlays were checked for alignment by tracing solid landmarks as well as bank lines to be sure that the overlays line up precisely. Estimates for channel migration distance were made using measurement features in Google Earth Pro™.

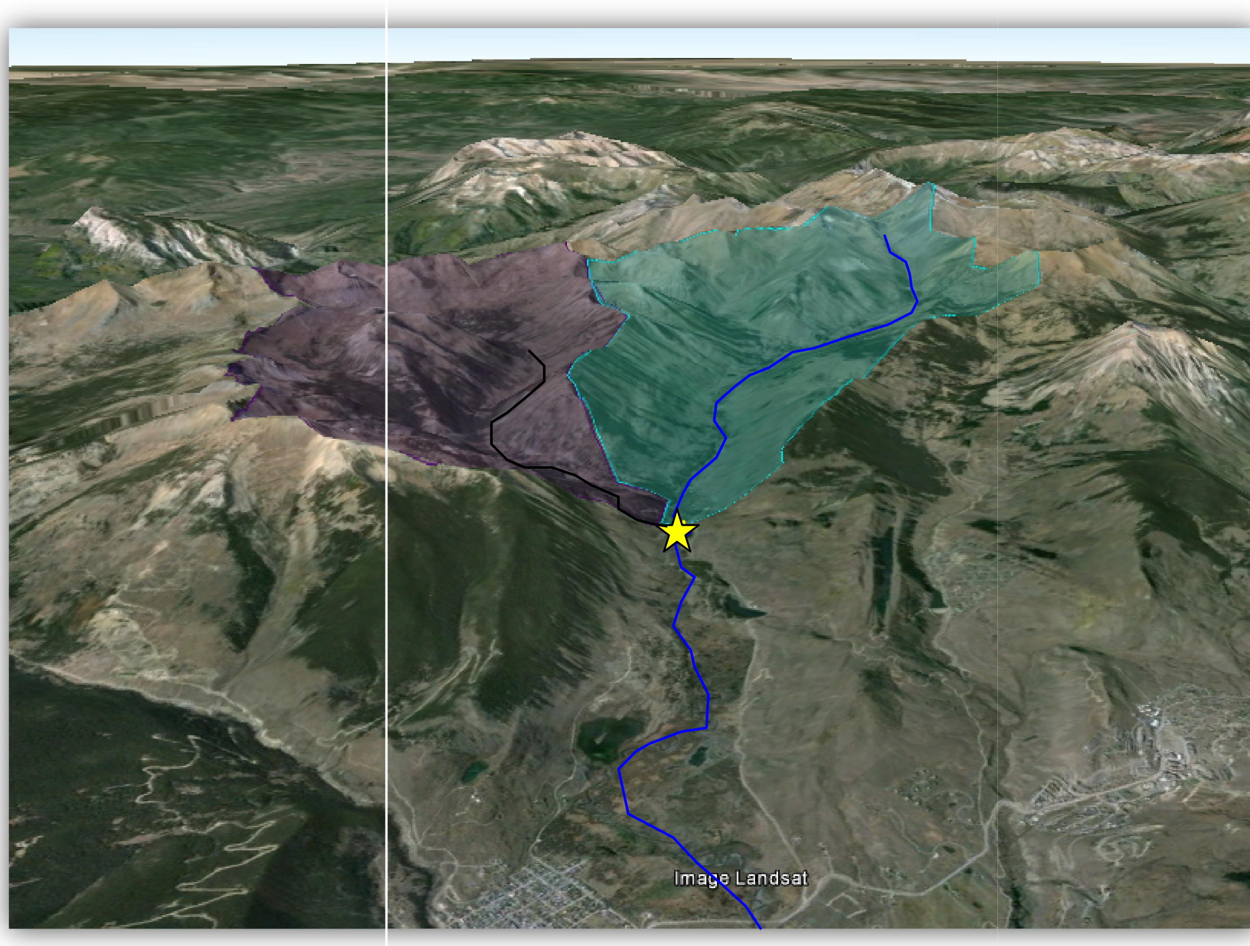
3.0 Results

3.1 Overview

3.1.1 Watershed Context

The contributing watershed for the Gunsight Reach of the Slate includes the Upper Slate (about 20.8 mi^2) and Oh-Be-Joyful (approximately 12.8 mi^2) Watersheds for a total contributing area of about 33.6 mi^2 (**Figure 3**).

Figure 3: Oblique View of the Contributing Watershed



The approximate alignment of Slate River is shown by the blue line. The Shaded areas show the contributing watersheds including the Upper Slate (light blue) and Oh-Be-Joyful (purple) which joins the slate just upstream from the Gunsight Reach (yellow star). The Town of Crested Butte is visible in the foreground.

Our 2012 report contains a detailed qualitative assessment of these watersheds which can be summarized succinctly as follows. Most of the watershed area is undeveloped public land and/or wilderness. Human stressors on hydrology or flow regime are few and mostly insignificant. The natural snowmelt-driven hydrograph dominates, and there are probably just minor impacts to peak or base flow magnitudes, duration, and timing.

The watershed areas are naturally very active from a geological perspective, with frequent avalanches, debris flows, and landslides that regularly deliver pulses of sediment, wood, and debris to the fluvial system. Upstream from the Gunsight Reach, there are few human influences affecting stream stability save some short reaches where riparian vegetation has been removed and the stream channelized near Pittsburg. There has also been extensive recent channel and bank hardening/stabilization efforts at the Oh-Be-Joyful Campground area just upstream from Gunsight. Despite the relative lack of human stress, channel instability (aggradation and degradation) is still common on the Slate due to natural geologic causes. We therefore need to be careful in making inferences that assume stream health is dependent on stability (an assumption upon which WARSSS is based). In a dynamic watershed such as the Slate, the river can be naturally healthy and functional and at the same time geologically unstable. That is, depositional reaches, as well as transitional ones may be naturally functional.

3.1.2 Reach Context

The Slate River is a braided D4 stream below Oh-Be-Joyful Campground and through the confluence of Oh-Be-Joyful Creek, and the braided condition appears to be the natural functional form. The braided stream form is very dynamic and greatly influenced by beavers, woody debris, and log jams. Below Oh-Be-Joyful Creek, the river flows diagonally across its valley in this channel form until it encounters the left edge of the valley which it hits at an almost perpendicular angle. This nearly 90-degree turn marks the upper end of the Gunsight Reach study area **(Figures 4, 5)** and the point where the channel becomes single-threaded and best described as C4.

Figure 4: Reach Context

Figure 5: Slate River at the Top of the Gunsight reach

The Slate River flows diagonally across the valley (directly towards the viewer) making a sharp 90-degree right turn where it hits the valley edge and the Gunsight Pass Road in the foreground. The oxbow is seen on the right.

This point is also the site of a relatively recent (geologically speaking) meander avulsion. The abandoned meander sits north of the channel and is now an oxbow pond that impounds groundwater and overbank flows behind beaver dams (**Figure 5**).

Downstream from the oxbow, the river flows along the left edge of the valley and parallel to it (the Gunsight Pass Road is cut into the valley flank to form the left bank of the river) for about 600 feet until it has to bend back to the left to go through the opening of the Gunsight Bridge which runs diagonally across the direction of flow of the river. The section immediately above the bridge is very wide and aggraded and best classified as a D4 channel that grades to an F4 channel where flood prone area becomes constricted by a berm (an historic elevated railroad grade) that cuts off floodplain access and ultimately forces all flows through the bridge opening. Downstream of the bridge, the river again flows alongside the steep left valley wall as a single-thread channel for about 400 feet more before finally resuming its normal braided D4 channel pattern. The 400-ft length of straight single-thread channel downstream from the bridge could be moderately incised.

The reach supports a wide riparian wetland complex that depends critically on floodplain connectivity of the Slate River. In the braided sections of river up- and downstream of the Gunsight reach, it appears that the floodplain is activated regularly each year by overbank flows, and low bank heights suggest that a very high water table and wetland hydrology is maintained across the riparian zone in these areas even during base flow. This pattern is also generally apparent throughout the Gunsight reach except perhaps on the 400-ft segment of single-thread below the bridge. There were possible indications on this segment of moderate incision and an inset floodplain that would result in decreased frequency of overbank flows and lower water table at this location. These hydrologic impacts to riparian wetlands may be exacerbated by the elevated railroad grade that partitions this section of floodplain from upstream portions.

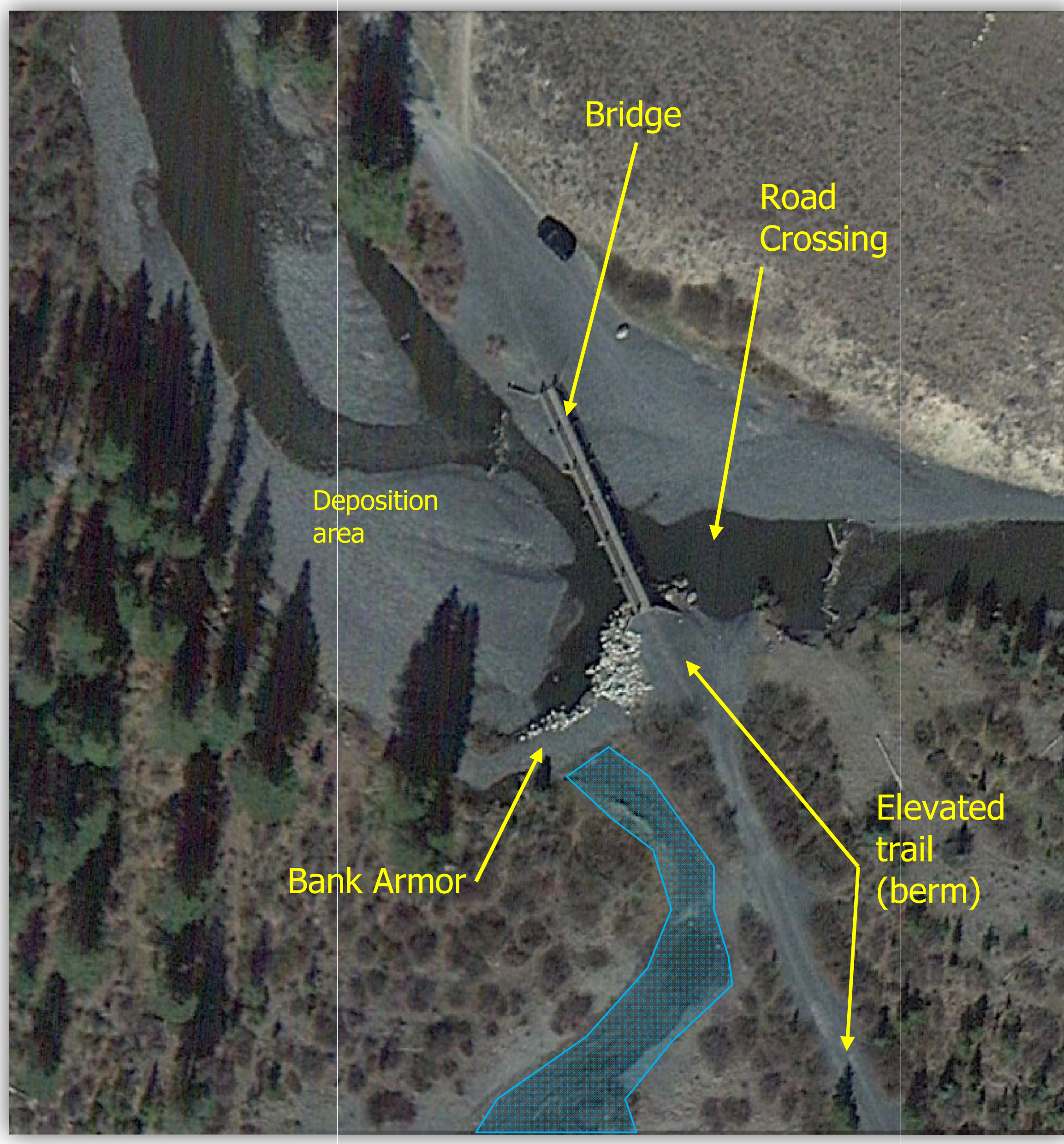
3.1.3 Stressor Identification

The Bridge and Berm: Several direct and indirect human stressors affect the Gunsight Reach of the Slate. The most obvious direct impact to the river is the bridge (**Figures 6-9**). The bridge impacts the river in several ways. Most obviously, it constrains the channel to an unnaturally narrow width and limits the ability of the river to utilize its floodplain. The bridge span is about 80 ft, but the effective channel top width through the opening is more like 45-50 ft (**appendix 1, Figure A-4**) which is much narrower than the normal bankfull width of the channel that is on the order of 80 to 160 ft. This narrowing is further exacerbated by the fact that the bridge is aligned diagonally across the river which means that the actual functional width of the channel through the bridge (which is perpendicular to the channel and not aligned with the bridge) is effectively even narrower, probably around 35-40 ft. It also means that the river must turn sharply at the bridge, which is why there is so much scour energy and erosion potential on the right bank and bridge abutment. This turn is also the reason that there is excess deposition on the left side of the channel near the bridge. This area is effectively a point bar, and deposition serves to further limit cross-sectional area of the channel at this point.

A second bridge impact is related to blockage. In addition to the abutments on either end of the span, the bridge is supported by five sets of four piers each. The piers affect hydraulics and scour, and they further decrease the effective cross-sectional area and width of the channel. But even more important, the piers serve to collect debris in the channel such as trees, logs and branches. Large woody debris and detritus is frequent and common in the Upper Slate watershed. The four piers of each set are aligned perpendicular with the bridge span, but this alignment is diagonal to the flow of the river which exposes each pier to direct flow. The bridge is a very effective rack for collecting debris. Logs and other debris move most frequently at high flows which means that the bridge must regularly clog during peak flows at runoff. In addition to being a hazardous "strainer" in this condition, the clogged bridge would essentially act like a dam, impounding water upstream. This greatly increases flood risk and damage potential and it also reduces velocity in the impounded segment which leads to sediment deposition. We suspect that debris must be removed frequently to clear the bridge, which is both expensive and dangerous.

In addition to the bridge itself, the associated berms and hardened bank lines are also notable stressors. The elevated road/trail surfaces leading up to the bridge on each side (but particularly on the right bank) effectively prevent the river from flooding onto the floodplain, and all flow is routed through the bridge opening. The berm on the right bank looks to be the historic elevated railroad grade that is now used as a trail. It is probably overtopped only during large floods or when the bridge opening becomes clogged with debris. The bridge abutments are reinforced with sheet piling and an apron of boulders which are necessary to protect the bridge; but these structures are unnatural hard scour points that alter hydraulics. Similarly, the right bank leading into the bridge from upstream was recently armored with boulder rip-rap several times between 2004 and 2010. The object of this hardening effort was surely to protect the bridge, but it also limits low flow connectivity between the river and a large backwater area upstream of the bridge. Interestingly, most of the hardened bank was mostly buried under deposited sediment in 2013.

Figure 6: Aerial View of the Gunsight Bridge



The Gunsight Bridge is aligned diagonally across the Slate River. Bank armor, road crossing, and the berm are identified, as is the deposition area upstream of the bridge. The blue shaded area is backwater habitat. The floodplain area right of the channel (below it on the photo) is wetland upstream of the berm, but much drier upland where it is cut off from overbank flows downstream of the berm.

Figure 7: The Gunsight Bridge

The narrow opening, diagonal alignment, and flow interference of the piers are evident on these photos of the Gunsight Bridge

Figure 8: Deposition Area Upstream of the Gunsight Bridge

The river upstream of the bridge is a deposition area. The hard armored right bank and elevated berm are visible in the foreground.

Figure 9: Debris Jams are Common at the Gunsight Bridge

Large woody debris like this dead tree are common in the Upper Slate Watershed, but this bridge does not accommodate transport of this material. Debris jams that clog the bridge during high flows cause impoundment, flooding, and sediment deposition.

The Road: The Gunsight Pass Road (**Figures 10-11**) is another stressor with direct impact on the river. The road is a hard compacted dirt surface that obviously prohibits the growth of normal bank side riparian vegetation. This would be a much greater stress on the system were it not for the position of the road cut into a steep valley side slope. Vegetation is less important in this condition than it would be on a floodplain setting, though it is still an issue. The most significant impact from the road is probably the need to maintain it. Rivers like the Slate on this reach are mobile. Migration and bank erosion are natural processes that can either be accommodated or artificially arrested. The position of the road adjacent to the active river means that active management is probably necessary to prevent the road from being washed out. It is inevitable that fill or engineered stabilization will have to be added or installed to protect the road at this location if erosion is actively occurring.

The road is also a point source of fine sediment to the river. Every time it rains, the bare dirt surface creates fine sediment that goes directly into the river with no opportunity for buffering. The actual volume of sediment introduced by this mechanism is not known, but it is at least enough to affect water quality, if not geomorphology. Below the road, the river becomes very turbid during and after each significant rain or runoff event.

Figure 10: Gunsight Pass Road on the Bank of the River

The road is on the left bank of the river. Active maintenance is probably necessary to combat erosion and to maintain it in this position. Fine sediment from the road and traffic enters the river directly, making the water turbid during and after each significant rain event.

Figure 11: Gunsight Pass Road on the Bank of the River

The eroding left bank of the river is adjacent to the road.

3.1.4 Rapid Qualitative Assessment

The WARSS phase 2 RRISSC assessment was made during the 2012 watershed assessment of the Slate, and the results are summarized in **Table 1**.

Hillslope and hydrologic processes score low in RRISSC for this reach with the exception of sediment contribution from roads. The Gunsight Pass Road is an unimproved dirt road that is directly adjacent to the river, so sediment from road runoff, erosion, and maintenance go directly into the river. The overall RRISSC rating of 4 (high) is a result of the way scoring is affected by direct impacts to channel processes, primarily the road and bridge. The direct channel impact of Gunsight Pass Road adjacent to the channel is significant enough to drive both the *direct channel impacts* and *degradation* variables to the 5 (very high) risk category. The *stream bank erosion* variable scores 4 (high), and the primary contributing factor is the position of the road alongside a very tight outside meander bend. *Aggradation* risk is 4 (high), largely due to the impounding effect of the Gunsight Bridge and associated berms in addition to the observation of obvious excess deposition and extensive mid-channel bar formation upstream from the bridge. *Degradation* risk scored 5 (very high) due to the combination of direct channel impacts from the road and bridge plus observed pier and constriction scour at the bridge.

WARSSS RRISSC rating scores for the Gunsight Reach of Slate River			
Variable		**RRISSC rating**	
Hillslope Processes			
1	Mass erosion risk	**1**	very low
2	Sediment from roads	**4**	high
3	Surface erosion	**2**	low
Hydrologic Processes			
4	Streamflow change	**1**	low
Channel Processes			
5	Streambank erosion	**4**	high
6	In-channel mining	**1**	very low
7	Direct impacts	**5**	very high
8	Channel enlargement	**3**	moderate
9	Aggradation	**4**	high
10	Channel evolution	**2**	low
11	Degradation	**5**	very high
Overall Rating			
Overall RRISSC score		**4**	high

Table 1: Summary of RRISSC Scores From the Original 2012 Assessment

3.2 Physical Surveys

3.3.1 Channel Dimension

Plots of channel XS surveys, photos and relevant bankfull channel dimension data are shown in **Appendix 1, Figures A1-A4**.

3.3.2 Channel Profile

Results of the longitudinal profile survey are displayed in **Appendix 1, Figure A5**. Channel slope, a measure of stream gradient, averaged over the length of the reach is 0.51 percent, meaning that water elevation at bankfull stage drops an average of 0.51 ft per 100 ft of stream length. However, the Bridge constriction restricts flow to the point that effective bankfull slope is diminished to an estimated 0.14% gradient upstream. The flattened slope caused by bridge constriction has significant consequences for sediment transport and deposition.

3.3.3 Channel Pattern

The channel through the reach is essentially straight except for two sharp bends (one where the channel hits the edge of the valley at the top of the reach, and the other where it turns to go through the bridge). These bends are a result of hard constraints to flow rather than meandering plan form dynamics. The effective sinuosity of the reach is 1.0-1.1.

3.3.4 Channel Materials

Pebble count surveys at XS-000 and XS-192 are plotted in **Appendix 1, Figures A6-A7**. It is noteworthy that the channel materials are quite similar on these two segments even though the upper XS is assumed to be effectively transferring sediment and the lower is apparently a depositional area. D_{50} (the median particle size making up the bed material) is 19-20 mm, and D_{84} is 40-41 mm. The distribution of bed materials appears to be more or less consistent throughout the reach except at the scour point through the bridge opening.

3.3 Stream Classification

The Slate River enters the reach as a D4 (wide, braided, multi-channel) stream. From the point where the stream hits the valley edge and turns right to parallel it through XS-0000, it classifies as a single-thread C4 channel with a width-depth ratio (W/d) about 52. The segment below this including XS-0192 is almost doubly wide and shallower with a W/d of about 113. Deposition bars in this segment are as even taller than the banks (and therefore bankfull stage) to create a braided multi-channel form that classifies as D4. The very wide braided condition continues through XS-0253 to the bridge, but this segment classifies as F4. The reason for the F4 designation is that floodprone area is artificially constrained by the berm and bridge opening which makes the river effectively cut off from floodplain access, if not actually "entrenched". Classification data for each of these segments are summarized in **Table 2**. Downstream of the bridge, the river appears to be a single-thread C4 stream for about 400 ft before reverting back to a D4 downstream, but detailed classification data was not collected on this segment. The valley type is best described as Type V, a moderately steep "U" shaped glacial trough.

3.4 Bankfull Discharge Estimation

Bankfull discharge is estimated to be approximately 500 cubic feet per second (CFS). This value was obtained by two methods. First, historic data from the USGS gauge above Baxter Gulch indicates a fairly consistent regular annual peak flow on the order of 1100 CFS (**Figure 12**). We did not see the need to calculate return intervals for this small data set, knowing that the level of precision would not be improved much over the simple observation that, aside from the two most recent drought years, peak flows during runoff were consistently in the range of 1200-1400 CFS. The average over all six years of record is approximately 1100 CFS which is probably close to a 1.5-year return interval and a reasonable approximation of bankfull discharge at that location. Drainage area at the gauge site is 73.4 mi^2, and if we assume a constant relationship of bankfull discharge per unit of drainage area for the contributing watershed, then bankfull discharge at the study site can be calculated from drainage area at that site which is 33.6 mi^2. This calculation results in a bankfull discharge estimate of about 500 CFS at the Gunsight Reach.

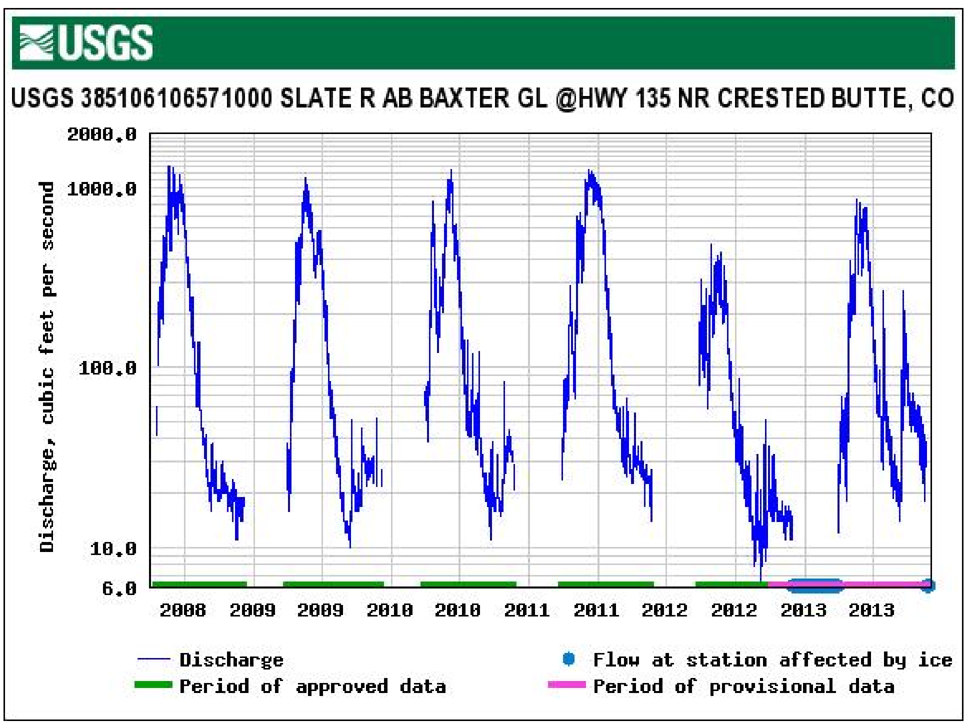
Table 2: Stream Classification Data

Slate River, Gunsight Reach XS 0000 Channel Data		
Valley Type	Valley	V
Bankfull Width	W	76 ft
Mean Depth	d	1.5 ft
Bankfull XS Area	A	111 ft^2
Width/Depth Ratio	W/d	52
Max depth	d_{max}	1.9 ft
Width Floodprone	W_{fpa}	~500 ft
Entrenchment Ratio	ER	>2.2
Channel Materials	D_{50}	20 mm
Slope	S	0.51%
Sinuosity	K	1.1
Stream Type		**C4**

Slate River, Gunsight Reach XS 0192 Channel Data		
Valley Type	Valley	V
Bankfull Width	W	128 ft
Mean Depth	d	1.1 ft
Bankfull XS Area	A	146 ft^2
Width/Depth Ratio	W/d	113
Max depth	d_{max}	2.7 ft
Width Floodprone	W_{fpa}	~300 ft
Entrenchment Ratio	ER	2.3
Channel Materials	D_{50}	19 mm
Slope	S	0.40%
Sinuosity	K	1.1
Stream Type		**C4/D4**

Slate River, Gunsight Reach XS 0253 Channel Data		
Valley Type	Valley	V
Bankfull Width	W	143 ft
Mean Depth	d	1.5 ft
Bankfull XS Area	A	211 ft^2
Width/Depth Ratio	W/d	97
Max depth	d_{max}	2.9 ft
Width Floodprone	W_{fpa}	~180 ft
Entrenchment Ratio	ER	1.4
Channel Materials	D_{50}	19 mm
Slope	S	0.14%
Sinuosity	K	1.1
Stream Type		**F4**

Figure 12: USGS Gauge Data for Slate River Above Baxter Gulch



Gauge data from the Slate River above Baxter Gulch indicates regular peak flows in the range of 1200-1400 CFS at that location with a mean of about 1100 CFS. These data can be extrapolated to estimate peak flows at the study site using a constant drainage area relationship.

The second method for estimating bankfull discharge uses a combination of field indicators and hydraulic calculations at XS-000, which is a straight and apparently stable riffle. We calculated velocity for bankfull stage (determined from field indicators) using a variety of hydraulic equations that relate hydraulic radius, bankfull slope, roughness, and cross-sectional area of the channel. This is possible because clear field-identifiable indicators of bankfull stage are present at this location. The results again yielded a bankfull estimate of about 500 CFS. All of these results are summarized in **Table 3**.

Table 3: Results for Calculation of Bankfull Discharge

Gunsight Reach. Velocity and discharge estimates for stage that matches field bankfull indicators on XS-0000	Velocity		Discharge	
Friction Factor/Relative Roughness u = [2.83 + 5.66 Log (R/D84)]U*	4.30	ft/s	503	CFS
Roughness Coefficient: Mannings n from R/D84 (Limerino's curve) Manning's n = 0.028 $u = (1.4895*R^{.667}*S^{.5})/n$	4.93	ft/s	577	CFS
Roughness Coefficient: Mannings n from R/D84 (Rosgen West curve) Manning's n = 0.032 $u = (1.4895*R^{.667}*S^{.5})/n$	4.32	ft/s	505	CFS
Roughness Coefficient: Mannings n from Jarrett $n = 0.39*S^{.38}*R^{-.16}$ Manning's n = 0.049 $u = (1.4895*R^{.667}*S^{.5})/n$	2.80	ft/s	328	CFS
Darcy-Weisbach Factor f from R/D84 f = 0.103 $u = \sqrt{(8gRS/f)}$	4.34	ft/s	508	CFS
Gauge Analysis DA= 33.6 Q_{BKF} @ Gauge 1100 DA @ Gauge 73.4	4.30	ft/s	504	CFS

Chosen estimation method	Gauge, D/W, Rosgen West, friction factor
Reason	Values agree Q_{BKF} is approximately 500 cfs.

Rows highlighted in bright yellow indicate methods that provided similar estimates of bankfull discharge.

Results from the three most reliable equations for this stream type are in excellent agreement (Friction factor, Manning's N derived from R/D_{84} using "Rosgen's West" curve, and the Darcy Weisbach method). The Jarrett method is not a good estimate of velocity for low-gradient streams, and the derivation of Manning's N directly from stream type is also often very unreliable, so we are justified in eliminating results from these equations from consideration for the estimate of bankfull velocity and discharge on this reach. The results corroborate well with bankfull estimation made using the gauge data and drainage area relationship.

3.5 Identification of Reference Condition

Channel form of the Slate River at this position in the watershed is complex. In most reaches where the river flows through an unconfined glacial valley, it is a braided D-type channel. However, on the Gunsight reach where the channel is confined on the left side by a steep valley wall, the channel is single-threaded. The straight segment upstream from the influence of the bridge appears to be stable and was therefore used as a reference analog. Stability of this segment is apparent on historical aerial analysis (see section 3.12) but has not been verified through long term monitoring. For the purpose of the WARSSS stability departure analysis, we used channel dimensions of this segment as reference.

3.5 Identification of Stream Stability Indices

Slate River on this reach is a 4th order stream with bankfull width ranging from 30 to 65 feet. Results for the rest of the PLA stability indices are summarized in Table 4.

Table 4: Results for the Stream Stability Indices

Stability indicator	Slate River Gunsight Reach
Riparian vegetation	High stability vegetation (dense shrub/grass mix with carex) right bank. Left bank is mostly weak upland veg.
Meander patterns	M4 - Truncated meanders
Deposition patterns	B5, B7 - Diagonal bars, side bars, and mid-channel bars
Debris/ blockage	D4, D7, D10 - LWD numerous, beaver dams present, artifical blockage = bridge pilings/strainer
W/D ratio state	Unstable $W/D : W/D_{REF} \geq 1.6$
Pfankuch	129 - Poor = Very unstable for C4
Degree of incision	Stable BHR = 1.0 - 1.1
Degree of confinement	Confined by levees, road and bridge constriction

WARSSS uses special rating system to evaluate the potential impact of bridges and culverts. Table 5 is a summary of the way the Gunsight Bridge is scored. The instability risk rating associated with the bridge based on these scores is high.

Table 5: Results of Scoring the Risk Rating for Gunsight Bridge

Slate River Gunsight Reach Bridge Evaluation		
Parameter	Score	Criteria
Percent reduction of sinuousity (insert numeric rating)	2	(1) = No change
Stream crossing structure (insert numeric rating)	1	(1) = Bridge
Subtotal S[(2)+(3)]	2	Sum
Increase in energy slope (use (4) points and insert numeric rating)	1	VL (1) = 2
Ratio of a decrease in w/d ratio to existing reference w/d ratio (insert numeric rating)	3	M (3) = 0.41–0.60
Backwater potential above structure (insert numeric rating)	5	VH (5) = Backwater at bankfull discharge
Presence of floodplain drains (through fills)	5	VH (5) = Backwater at bankfull discharge
Subtotal S[(5)+(6)+(7)+(8)]	14	Sum
Overall risk rating: culverts or bridges	**4**	**H (4) = 13–16**

3.7 Prediction of Bank Erosion Volume

Stream bank and channel parameters were measured along the length of the reach to calculate BEHI and NBS, and these values were used to predict annual bank erosion rates and to calculate a predicted annual volume of sediment produced from bank erosion on the reach. The only segments where significant bank erosion is predicted are along the upper end of the straight reach, adjacent to the Gunsight Pass Road. **Table 6** summarizes the results of the BANCS model and the computation of estimated annual sediment volume produced by bank erosion. Over the entire reach, an estimated 834 cubic feet (ft^3) or about 40 tons of sediment is produced annually from bank erosion.

3.8 Sediment Competence

Sediment competence was estimated using calculations of dimensional shear stress for each riffle XS. For each XS, we calculated the maximum particle size that would be entrained using Rosgen's simple empirical relationship between shear stress and particle size for Colorado streams. Our best approximation of upper size range for incoming bedload material comes from particles observed on side bars which occasionally measured 60-80 mm. Extrapolating from this, we can then predict sediment competence of the segment represented by each XS. Results are shown in **Table 7**.

Table 6: Results from Stream bank Erosion Estimates Using the BANCS Model

bank ID	BEHI	NBS	rate (ft/yr)	bank ht (ft)	length (ft)	erosion (ft^3/yr)
1	VH	EX	1.80	3.5	40	252
2	H	EX	1.20	4	30	144
3	H	EX	1.20	4	30	144
4	H	VH	0.70	7	60	294
					total erosion (ft^3/yr)	834
					Total erosion (yd^3/yr)	30.9
					Total erosion (tons/yr)*	40.2
					Mean erosion rate (tons/ft/yr)*	0.057

Table 7: Results of Sediment Entrainment Calculations for Riffle XS

Gunsight Reach competence sediment entrainment			
Segment	**XS-000**	**XS-192**	**XS-253**
Actual calculated shear stress (Tc) (lb/ft^2)	0.46	0.30	0.13
Max particle size entrained (Rosgen's Empirical Colorado curve) (mm)	86	60	34
Competence prediction (assuming bedload in the 60-80 mmm range)	**Competent**	**Threshold**	**Incompetent**

These results indicate that the channel becomes increasingly incompetent at moving incoming sediment as it approaches the bridge. This is caused by the combination of a decreased effective slope due to backwater effects from the bridge constriction (and blockage that occurs when debris catches on the bridge) and increasing width/depth ratio due to aggradation and widening of the channel.

3.9 Stream Channel Succession

Above the bridge, the channel appears to be aggrading and perhaps slowly widening which is evidence of the C4→D4 channel type succession. At the bridge, the floodprone area width is artificially confined, making it an F4 channel which would also likely be aggrading and widening were it not for the artificial confinement. At the bridge, there is significant scour and localized incision, but the bed rises quickly downstream and the channel rapidly regains its floodplain below the bridge to become wide C4 channel again. It is possible that this segment is slightly incised but there is no indication that active channel evolution is taking place.

3.10 PLA Stability Predictions

At this stage, all of the available data from the observations, measurements, and models from previous steps in the PLA process are compiled using analytical worksheets to make predictions about lateral stability, vertical stability, the potential for channel enlargement, and overall sediment production.

Lateral stability predictions: PLA uses a scoring procedure to evaluate five primary parameters in and prediction of lateral stability. The conditions and corresponding scores for each parameter are summarized in **Table 8**. According to PLA guidelines, the prediction of lateral stability can be made directly from the total points from each of the five parameters as follows: <8 (stable), 8-12 (moderately unstable), 13-21 (unstable), >21 (highly unstable). By these criteria, the score of 20 leads to a prediction of **lateral instability** for the reach.

Table 8: Parameters Used to Predict Lateral Stability

Slate River Gunsight Reach Lateral Stability Analysis										
Lateral Stability Assessment Parameters										Total points
W/d / W/d_{ref}		Deposition pattern		Meander pattern		Dominant BEHI/NBS		Confinement MWR / MWR_{ref}		
points	condition	points	condition	points	condition	points	condition	points	condition	
8	> 1.6	4	B5, B7	1	M4	4	mostly low	3	0.3 - 0.1	20

Vertical stability predictions: The PLA procedure for predicting vertical stability requires the evaluator to score each of nine parameters as either an indicator of stability, aggradation (excess deposition) or degradation (excess scour). If bankfull sediment and hydrology data are available, a tenth parameter for modeled sediment capacity may be added to the analysis, but neither of these types of data are available on this site.

The parameters are listed in order of relative importance, and the evaluator makes a final prediction of vertical stability based on the distribution of indicators among the different parameters with those near the top of the list receiving greater weight. A summary of the scoring table is provided in **Table 9** with the conditions for the study reach highlighted in yellow. The results yield a prediction of **aggradation or excess deposition** on the reach upstream from the bridge.

Table 9: Parameters Used to Predict Overall Vertical Stability

Stability Category	Stable	Aggradation (or excess deposition)	Degradation (or excess scour)
Critical Dimensionless Shear Stress	Sufficient depth and/or slope	Insufficient depth and/or slope	Excess depth and/or slope
Critical shear stress	Sufficient shear stress	Insufficient shear stress	Excess shear stress
Degree of Incision (BHR)	< 1.1	N/A	> 1.1
W/d Ratio State	< 1.6	> 1.6	< 0.8 and BHR > 1.1
Stream Successional State	Stream type = potential stable type	(C→D), (C→C_{wide})	(C→G), (E→G), (B→G)
Depositional Patterns	B1, B2, B4, B8	B3, B5, B6, B7 (or coarse deposit on floodplain)	N/A
Meander Patterns	M1, M2, M3	M5, M6, M8	M5 or M6 with conversion of floodplain to terrace
Entrenchment Ratio	> 2.2 for E or C types 1.6 to 2.2 for B types	N/A	< 1.2 for E or C types < 1.1 for B types
Confinement	1.0 - 0.3	N/A	< 0.1

A summary of parameter conditions and associated indications for vertical stability, aggradation, and degradation for determination of an overall prediction of vertical stability on the segments of the Gunsight Reach. For each parameter, we highlighted the relevant condition (observation) obtained from the results of surveys and the appropriate stability indication from PLA guidelines. Aggradation or excess deposition is indicated by this method.

Potential for channel enlargement: The prediction for channel enlargement is made directly by applying numerical scores to each of the previous stability predictions (lateral and vertical) combined with a score for channel successional stage. According to PLA guidelines, the prediction of channel enlargement can be made directly from the total points from each of the three parameters as follows: 6 (stable), 7-12 (slight increase), 13-18 (moderate increase), >18 (extensive). The results of these scoring procedures are summarized in **Table 10**. With a score of 18, these criteria yield a prediction of **extensive channel enlargement** for the study reach.

Table 10: Parameters Used to Predict Channel Enlargement

Gunsight Reach Potential for Enlargement Analysis							
Enlargement Assessment Parameters						Total points	Prediction
Lateral Stability		Vertical Stability		Successional stage			
points	condition	points	condition	points	condition		
6	Unstable	6	High Excess Deposition	6	(C→D) (F→D)	18	**Extensive**

Overall sediment production: PLA also includes a prediction for the relative amount of sediment contributed by the study segments as a way to prioritize restoration efforts in watersheds that have systemic sediment problems. These predictions, once again, are based on a scoring system that based on the previous stability and enlargement predictions. It also adds in an additional parameter score for the Pfankuch stability index (see Section 3.6). A summary of the scoring for the sediment production is provided in **Table 11** which results in a prediction of **very high sediment production** for this reach.

Table 11: Parameters Used to Predict Sediment Production

Slate River Gunsight Reach Sediment Supply Analysis									
Sediment Supply Parameters								Total points	Sediment Supply Rating
Lateral Stability		Vertical Stability		Channel Enlargement		Pfankuch Assessment			
points	condition	points	condition	points	condition	points	condition		
3	Unstable	3	Aggrading	3	High Risk	4	Very Poor	13	**Very High**

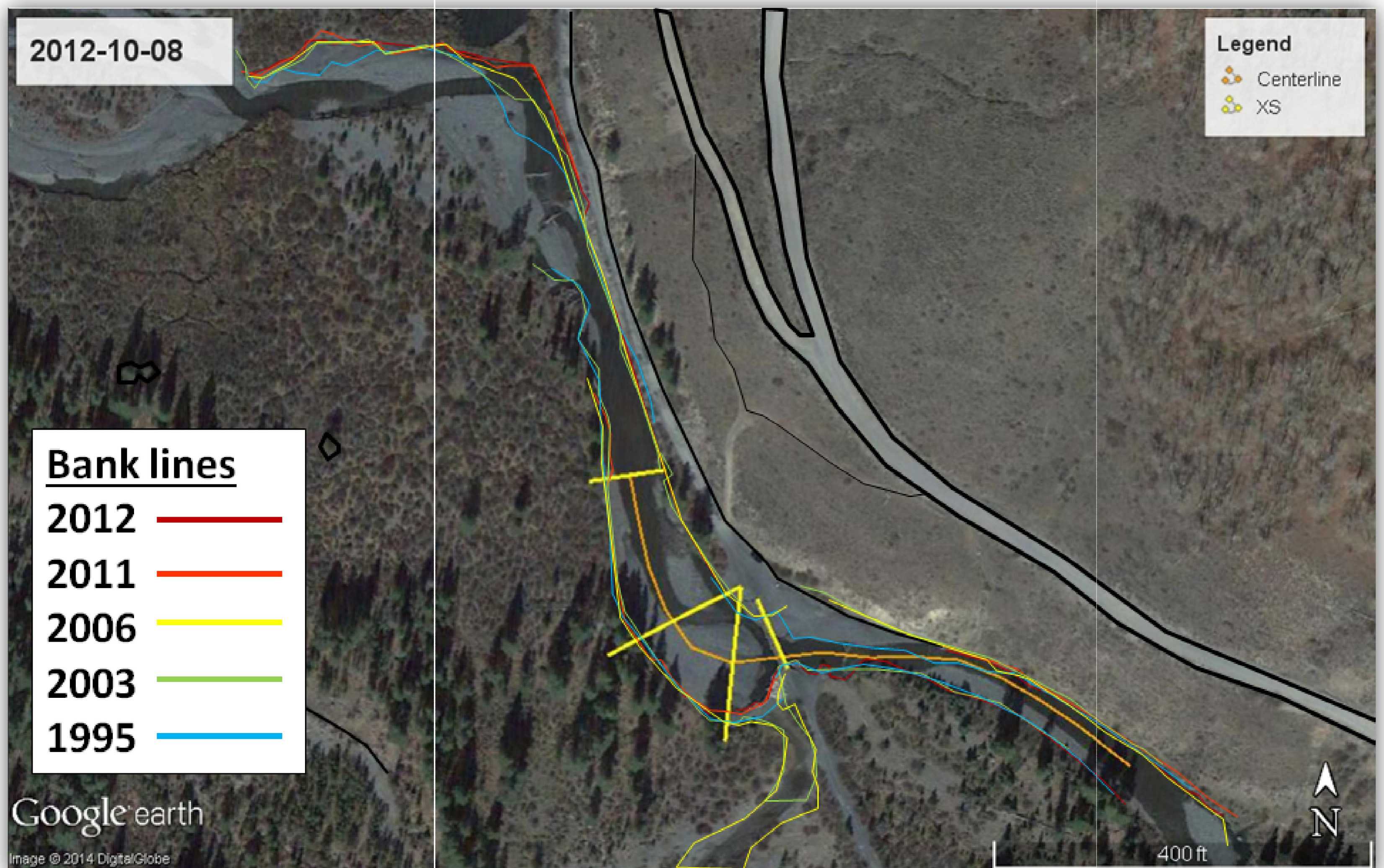
3.11 Historical Aerial Analysis

Channel migration and morphology changes over the past 18 years were documented by analyzing historical aerial photos going back to 1995. The analysis was performed on both the study reach and the braided reach upstream. **Figure 13** shows results for the study reach, and **Figure 14** shows the reach upstream. The level of precision of this method is not great, but locations with significant bank erosion, channel migration, and morphological changes are identifiable. On the study reach, there are two locations where such changes are detectable. The upper portion of the reach, where the river makes a sharp right turn just before meeting the Gunsight Pass Road is the site of significant migration and bank erosion (**Figure 15)**. The left bank appears to have moved about 42 ft to the left over 18 years, with a mean migration rate of 2.3 ft/yr. This observed rate is similar but slightly greater than predicted rates of bank erosion made using the BANCS model in section 3.7 which were on the order of 1.2 to 1.8 ft/yr for these segments.

The segment near the bridge also shows some significant changes to plan view of the river **(Figure 16)**. Most notably, the right bank upstream from the bridge was moved inward and lined with rip-rap in 2004-05 and again in 2010. There is also significant bank erosion just downstream of the bridge on the right. The apparent migration on the left bank below the bridge may be real or it may be an error in interpreting bank lines from the 1995 aerial photo, which was not clear at this location.

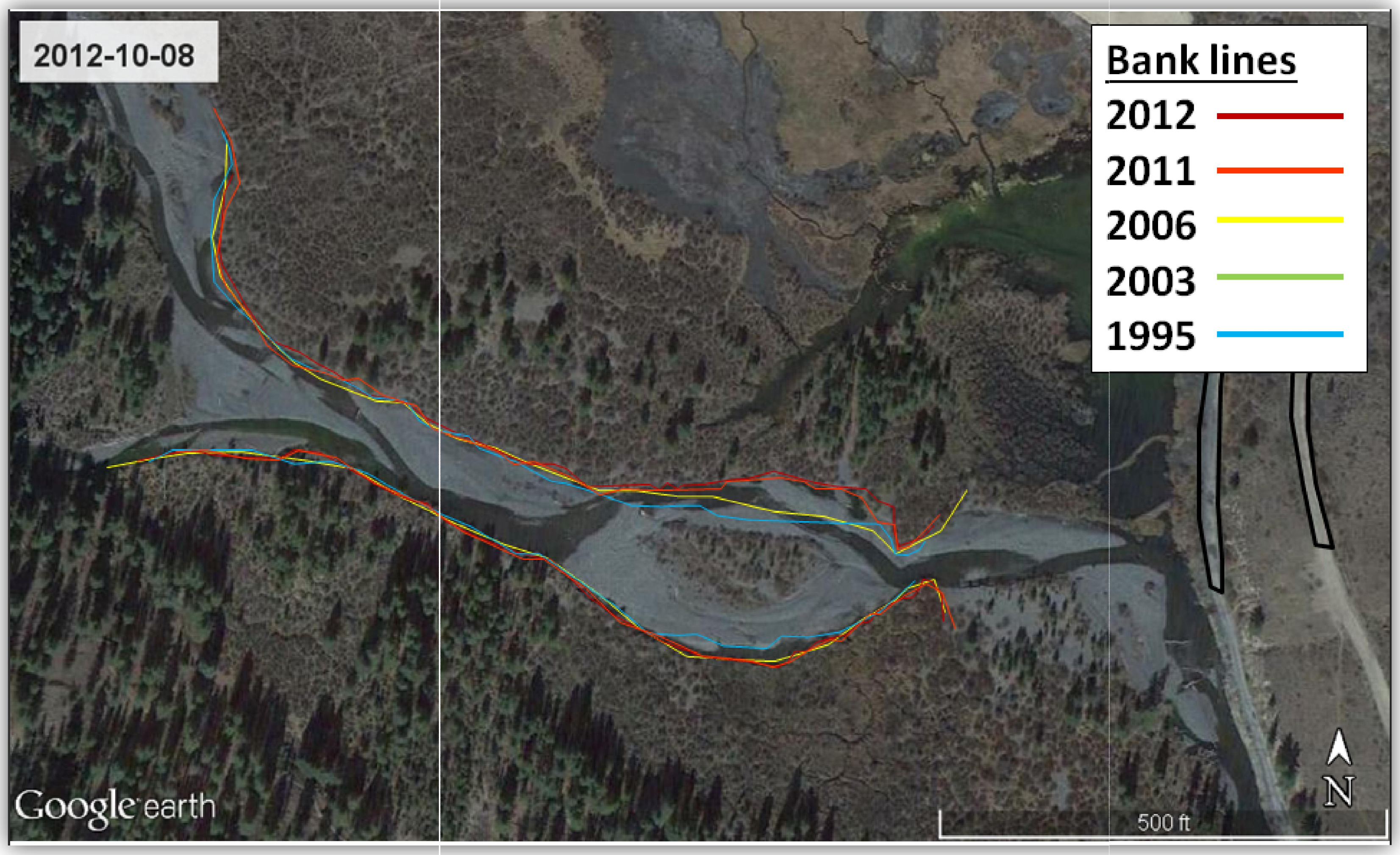
Channel migration and bank erosion is common on wide braided rivers like the Slate. On the reach upstream from the Gunsight, migration rates of 20-50 feet over 18 years (1.1-2.8 ft/yr) were observed (**Figure 17**).

Figure 13: Historic Bank Lines for the Gunsight Reach



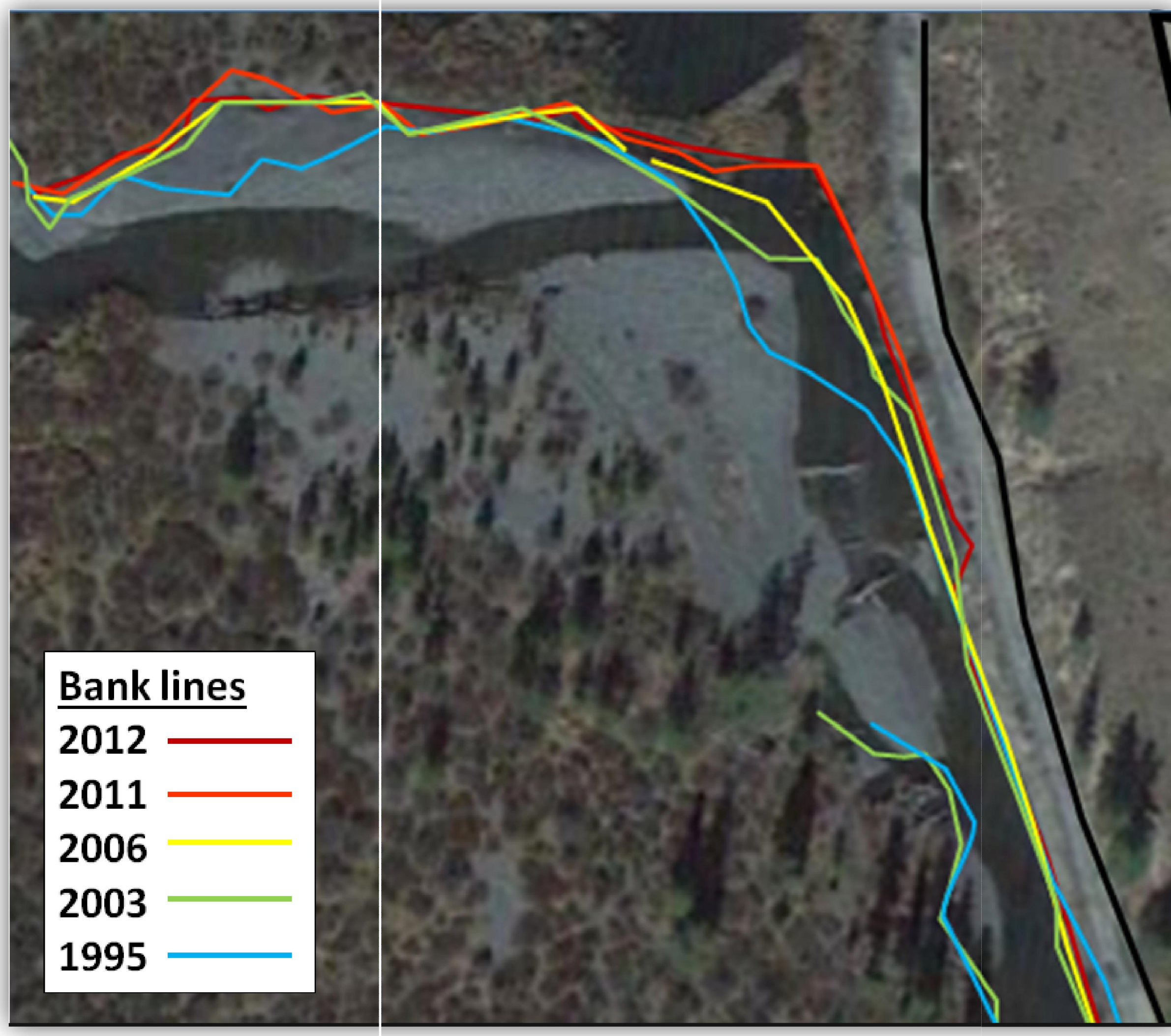
Historic bank lines are shown on the most recent imagery from 2012.

Figure 14: Historic Bank Lines for the Reach Above Gunsight



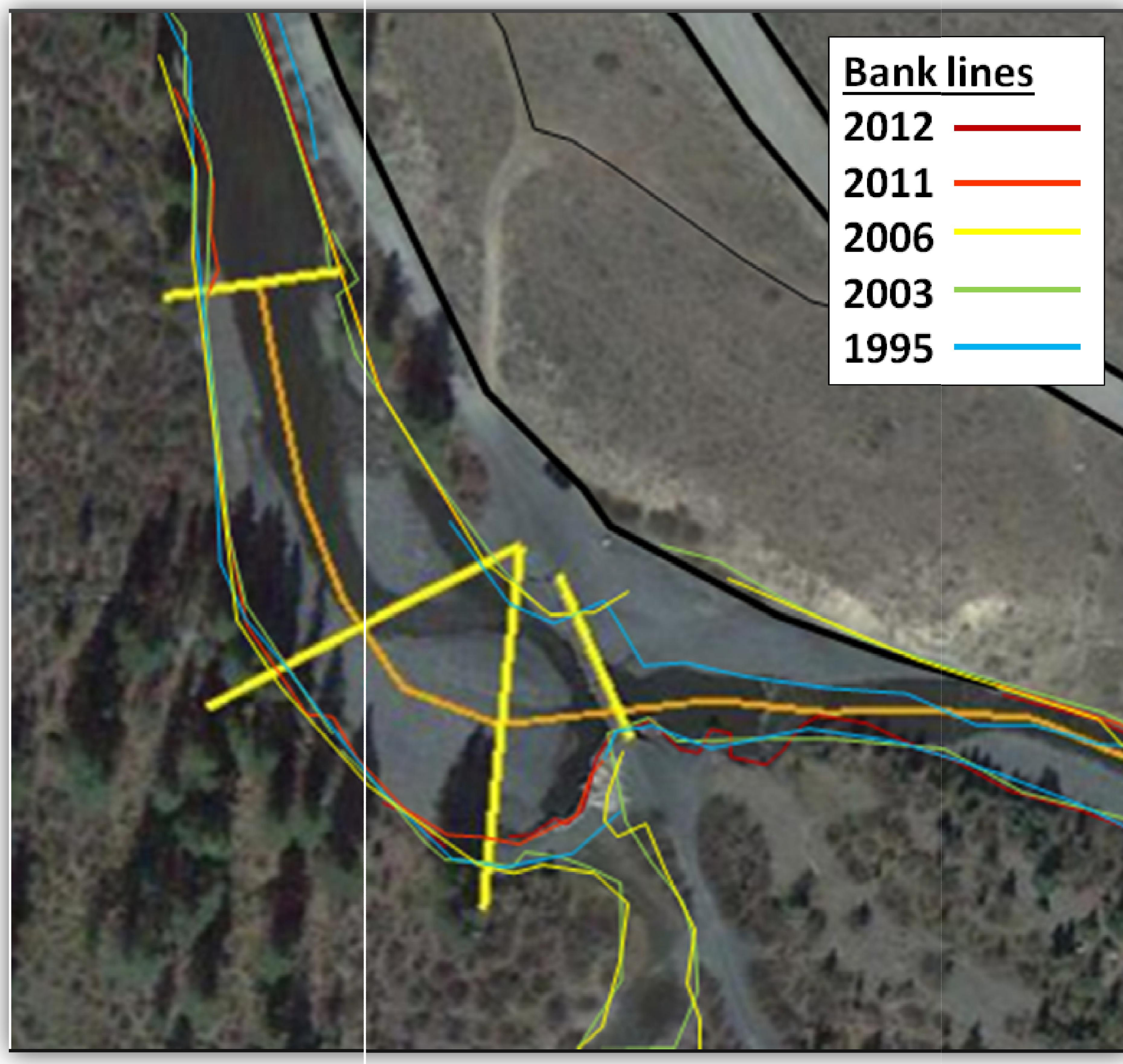
Historic bank lines are shown on the most recent imagery from 2012.

Figure 15: Historic Bank Lines on for the Gunsight Reach (Upper)



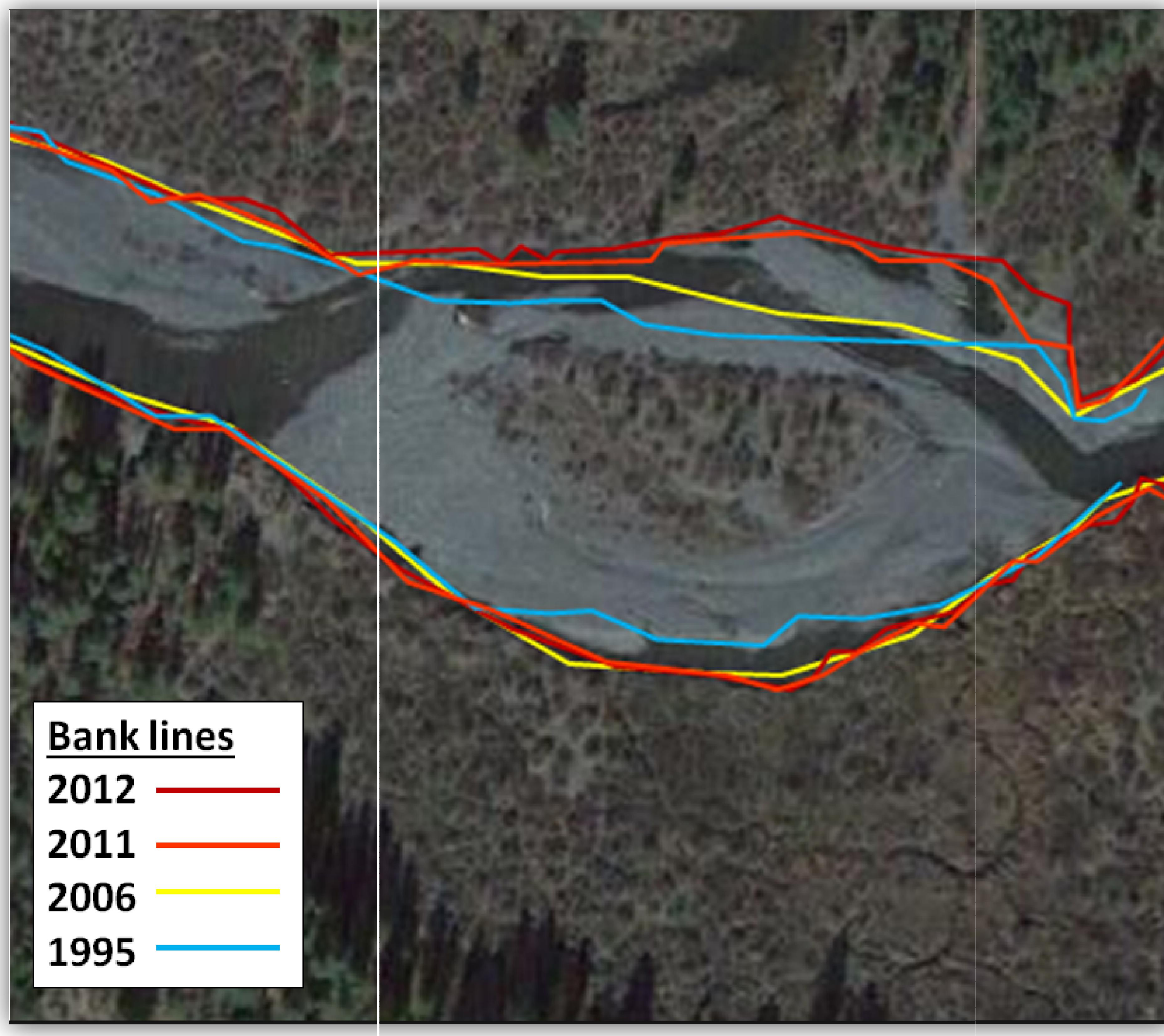
Historic bank lines indicate channel migration towards the road at a rate of approximately 2.3 ft/yr from 1995 to 2012.

Figure 16: Historic Bank Lines for the Gunsight Reach (Bridge Area)



Historic bank lines show channel changes near the bridge from 1995 to 2012. Most notable is the construction of a right bank and armoring that occurred in 2010 just upstream of the bridge.

Figure 17: Historic Bank Lines for the Reach Above Gunsight



Historic bank lines on the braided reach upstream of Gunsight show rates of bank erosion on the order of 1-3 ft/yr.

4.0 Discussion

The bridge, berm, and road are obvious problems with straightforward impacts on the river system. The bridge is undersized, poorly aligned, and constructed in a way that debris cannot pass. It is a major impediment to flow, especially when it clogs with debris, and this has very clear ramifications for sediment transport and channel instability. Equally obvious is the fact that the berm (old railroad grade) south of the bridge inhibits the ability of the floodplain to disperse high flows. The predictable effect of these factors is a raised flood stage upstream of the bridge and berm and dried riparian area downstream. Likewise, it should be obvious that maintaining a road alongside a fluvially active river channel will be a constant battle, and that fine sediment from the unimproved dirt road at this location will be a constant point source of turbidity. We now have quantitative data to justify our conclusion and some monitoring sites in place to test these predictions as hypotheses in the future.

It is not surprising, looking back, that the WARSSS diagnostic tools we applied in this study yield predictions of instability at every turn. The conclusion, officially stated using the language of WARSSS, is that the Gunsight Reach of the Slate River is at a high risk of being unable "*to maintain, over time, its dimension, pattern, and profile in such a manner that it is neither aggrading nor degrading,"* and unable *"to transport without adverse consequence the flows and detritus of its watershed."* In other words, we predict that the reach will and has changed morphological character as a result of the stresses on it, and this causes it to function differently from the way it would in its native condition. The study predicts aggradation to occur upstream of the bridge, and indeed the signs of aggradation are obvious: mid-channel bars have grown to heights that are actually taller than the banks. Channel capacity is diminished, flood stage is elevated, and lateral instability is high. This much has been made clear.

The underlying purpose of this study is to inform the decision about whether corrective action is warranted on the reach. So perhaps the more relevant question, then, is related to the consequences of instability, given that we know the reach is unstable. Let's begin by considering the bridge. In its present state, the bridge will continue to restrict flows, and aggradation will occur upstream. The consequences of this are a wide and shallow stream with a poorly defined channel and banks for several hundred feet upstream of the bridge, and this has some implications for habitat diversity and quality. That said, most of the Slate River in this area is wide and shallow with poorly defined channel and banks, so it would appear that physical in-stream habitat loss is not great compared to reference conditions on neighboring braided reaches.

A second habitat-related consequence is increased frequency of flooding for land adjacent to the river that is caused by impoundment behind the bridge and by an elevated channel bed. This also may not be major issue, since the native wetland plants making up the riparian community in this area can likely tolerate this "augmented" hydrology. The exception might be the conifer stand growing on the floodplain right of the channel. There is a real risk that the elevated water table and increased frequency and duration of flooding could exceed the tolerance of these trees and cause them to die.

A more pragmatic risk related to the bridge is the risk of avulsion that comes with the elevated flood stage. Should flows greatly exceed the capacity of the bridge opening (or more likely if the bridge becomes severely clogged with debris) the stage of water upstream could easily elevate above the height of the road and berm which would cause a breach. If the condition lasted long enough (days perhaps), then a new channel could feasibly form by eroding around the bridge altogether. This risk is quite real; a similar avulsion scenario recently played out just upstream at the Oh-Be-Joyful campground, and that episode took place even without the exacerbating factors related to an undersized bridge. The costs related to this are tangible since an avulsion would likely damage infrastructure including the road, trails, and bridge, but additional habitat loss is also a concern should this event occur.

The solid berm further exacerbates these problems, particularly the issue of elevated flood stage, by preventing the floodplain from draining. It also introduces a new habitat consequence that is the unnaturally dry riparian area downstream from the bridge. The berm effectively prevents floodplain flows from reaching these riparian areas and they present as unnaturally dry. The plant community reflects this condition with fewer wetland species present, and it is probable that some of this area is no longer wetland.

When considering consequences related to the road, we must think of impacts caused by the road on the river as well as risks to the road from the river. The primary impact that the road has on river function is that it is a constant source of fine sediment and turbidity. The volume of sediment from this source is not so great to cause excess deposition, embeddedness, or other impairments to the physical habitat structure, but it is a significant water quality concern. Turbidity is a water quality impairment that may affect macroinvertebrates, fish, and other aquatic life. It is also an aesthetic concern as well as a concern for downstream water treatment efforts. Another impact the road has is the lack of riparian vegetation. At points where the road is alongside the stream bank, only sparse bank side vegetation exists. This is both a habitat impairment and a stability issue since diminished bank vegetation means less root mass to stabilize bank soils.

The river is also a threat to the road. The wide, shallow and typically braided stream type present on this reach is laterally active by nature. This reach is especially prone to lateral migration and bank erosion due to aggradation and excess deposition that forms diagonal bars, side bars, and mid-channel bars. During moderate to high flows, these bars increase the erosive force on banks by directing flow velocity towards them. Over the past 18 years, the upper portion of the reach has migrated towards the road, meaning a greater length of the road is now adjacent to the bank with no riparian buffer in between. The river will continue eroding the road, and maintaining it in this position will require constant maintenance that will probably involve hardening the bank or continuing to add fill to build the road up as it erodes. Adding fill into a *Water of the US* is a federally regulated activity that requires a permit and, in some circumstances, mitigation. That is, maintaining the road by adding fill to the river is illegal except as permitted by the Army Corps of Engineers.

We need to point out, that all of these consequences need to be evaluated as risks as well as direct losses or costs. Some of the consequences we described above are ongoing losses such as the impaired habitat conditions, water quality (turbidity) impairment, and regular maintenance costs for clearing the bridge and protecting the road. Other consequences are best understood as risks, or the probability that something bad could happen. These include the risk of major damage to the road and bridge at their present locations as well as the risk of catastrophic river change or avulsion related to instability. Assessing the probability of one of these catastrophic events occurring is difficult. While it seems inevitable that an avulsion will occur and that the road and bridge will be washed out one day, it is difficult to say when that day will come. The road and bridge are indeed very old structures, and these risks have been in play for decades, so an assessment of risk should take these facts into consideration.

The simplest recommendation we could make would be to remove the bridge, berm, and road altogether, and thereby alleviate all the major sources of anthropogenic stress on the system. But this is obviously not feasible since we know that the community values this infrastructure, and a cost-benefit analysis would probably indicate that the amenities these structures provide to society outweighs the cost and risks associated with their impacts to the river. Our recommendation is therefore to find ways of alleviating stress without giving them up.

We begin with some simple solutions. First, we recommend creating openings in the berm so that flood flows can have access to a wider floodplain and not be as drastically impounded behind the bridge. This should be done whether the bridge is replaced or not. It would be a simple task to survey the berm to determine the degree to which it does function as a barrier and then to alleviate this by designing openings of a proper size to provide adequate flow-through. The openings could either be portions of the berm that are removed to the floodplain elevation or culverted drains that are bored through the base of the berm, depending on the desires of stakeholders. This activity may also provide an opportunity for wetlands restoration by allowing flows to reach the apparently dewatered wetland areas downstream of the berm.

An ideal solution for the bridge would be to rebuild it with a design that has a more appropriately sized opening, better alignment with the channel, and floodplain drains. At the same time the bridge is replaced, the aggraded channel should be restored to form a multi-stage channel dimension that can effectively transport sediment through the site. A full span bridge rather than one supported by piers would alleviate the clogging issue if large woody debris is able to pass through unobstructed; a full-span design would also be much safer for boaters. A suspension bridge might be the best way to meet these conditions in an affordable way. Whether the replacement bridge is a full-span or a modified pier design, it is worthwhile to consider alternate locations for the bridge. For instance, moving the bridge just downstream would make it easier to align it perpendicular to the river and the floodplain. The alternative is to keep the existing bridge as it is. If this is the chosen course of action, then stakeholders should be prepared to clear debris from it regularly and we can continue monitoring effects on the channel.

Solutions for the road are more difficult. Ideally the road would be moved away from the river, but there does not appear to be an alternative road alignment that is practical. Given these constraints, our best recommendation at this time is to live with the road in its present alignment but to seek management strategies that minimize its negative effects. Stakeholders should investigate alternative road surfaces or maintenance strategies for the riverside portions of the road to reduce sediment runoff. Regarding road stability in the face of bank erosion, it would be worthwhile for stakeholders to evaluate what is presently being done to maintain the road. Maintenance records or interviews with staff may be enough to determine how much effort is required to keep the road protected and what types of treatments have been made in the past. It is especially important to determine if fill is ever placed on the bank to rebuild washed-out sections of road. If this is the case, then it may be more cost efficient and less environmentally damaging to consider engineered stabilization of banks along the road. Another benefit of this approach would be that these could be designed to create a strip of native riparian vegetation along the river in addition to stabilizing the road.

The Gunsight Reach of the Slate River presents a classic problem of ecological stress related to human infrastructure, but in an otherwise fairly wild setting. The bridge, berm, and road are stressors with direct impacts on river stability that have consequences that include ongoing habitat loss, water quality degradation, and risk of avulsion. These consequences can be minimized by considering the several simple solutions recommended in this report. We also recommend continued monitoring to test the predictions laid forth in this report and, ultimately, to document the effectiveness of whatever mitigation measures are taken.

5.0 Literature Cited

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The Slate River at the downstream end of the Gunsight Reach where it transforms back to a braided channel form.

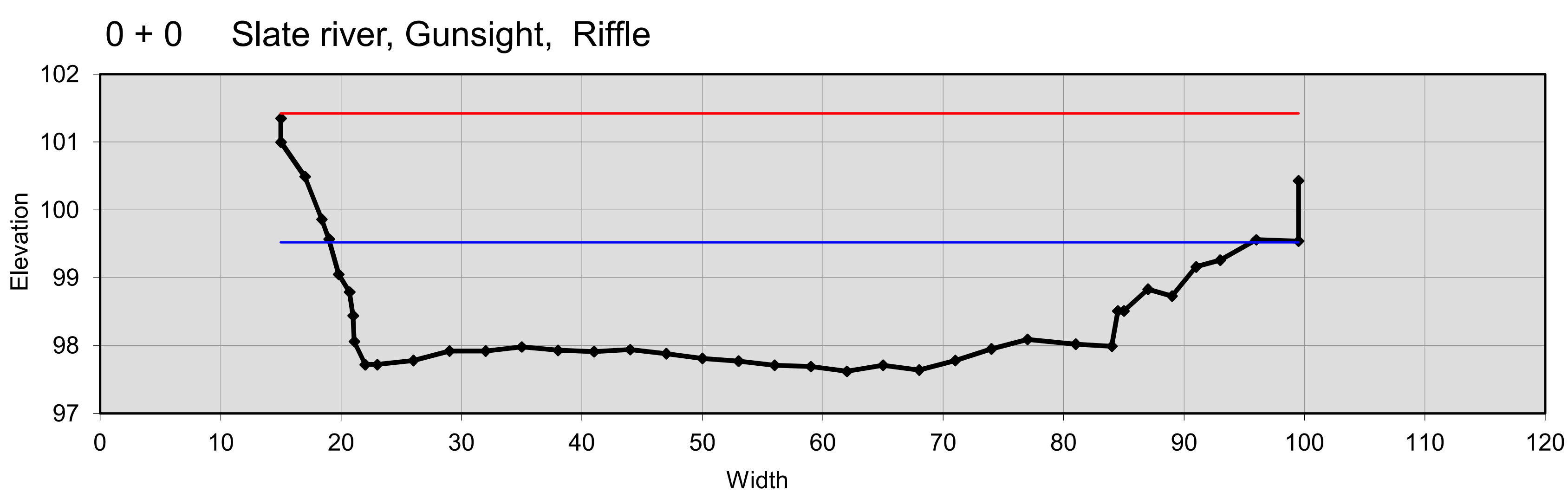
Appendix 1: Channel Surveys

Figure A-1: XS-000

Slate River Gunsight Reach 2013

XS ID:	XS-000	Facet type:	Riffle
Station:	0	Class:	C4
Area (ft_2)	117	BHR	1.0
Width (ft)	76	D_{max}/D	1.3
Depth (ft)	1.5	Slope %	0.51%
Max. depth	1.9	V (ft/s)	4.4
W/D	52	T (lb/ft^2)	0.46

Note: This XS is across the straight single-thread channel that parallels the Gunsight Road. It is presumably upstream of the influence from the slope change caused by bridge constriction.



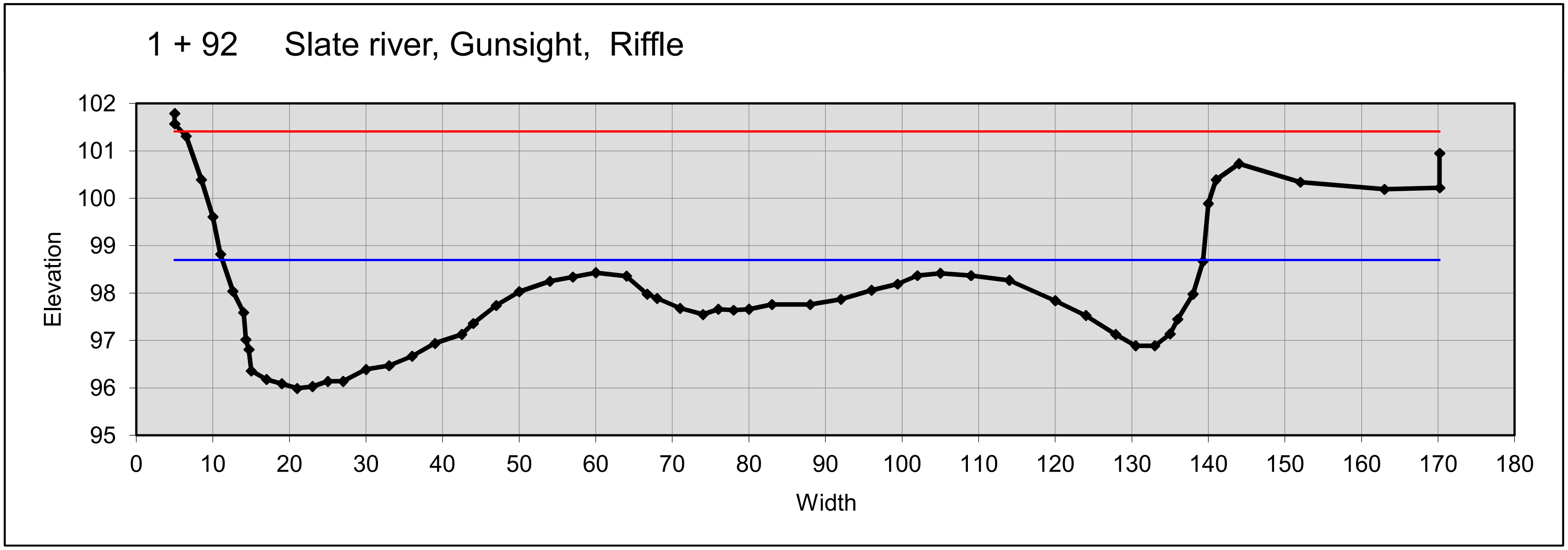
Appendix 1: Channel Surveys

Figure A-2: XS-192

<u>Slate River Gunsight Reach 2013</u>

XS ID:	XS-192	Facet type:	Riffle
Station:	192	Class:	C4/D4
Area (ft_2)	146	BHR	1.0
Width (ft)	128	D_{max}/D	2.5
Depth (ft)	1.1	Slope %	0.40%
Max. depth	2.7	V (ft/s)	3.4
W/D	113	T (lb/ft^2)	0.28

Note: This XS is across the upper end of the deposition area upstream of the bridge.



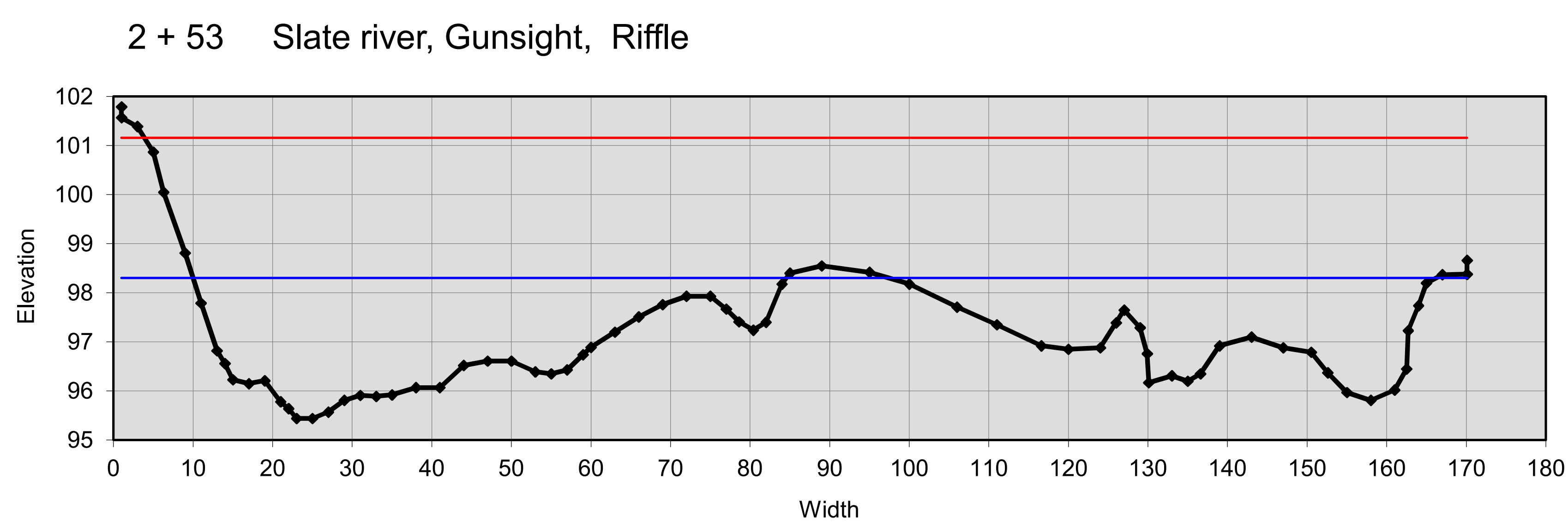
Appendix 1: Channel Surveys

Figure A-3: XS-253

Slate River Gunsight Reach 2013

XS ID:	XS-253	Facet type:	Riffle
Station:	253	Segment:	F4
Area (ft$_2$)	211	BHR	1.0
Width (ft)	143	D_{max}/D	1.9
Depth (ft)	1.5	Slope %	0.14%
Max. depth	2.9	V (ft/s)	2.4
W/D	97	T (lb/ft^2)	0.13

Note: This XS is across the main deposition area upstream of the bridge where the channel is turning to the left to go through the bridge .



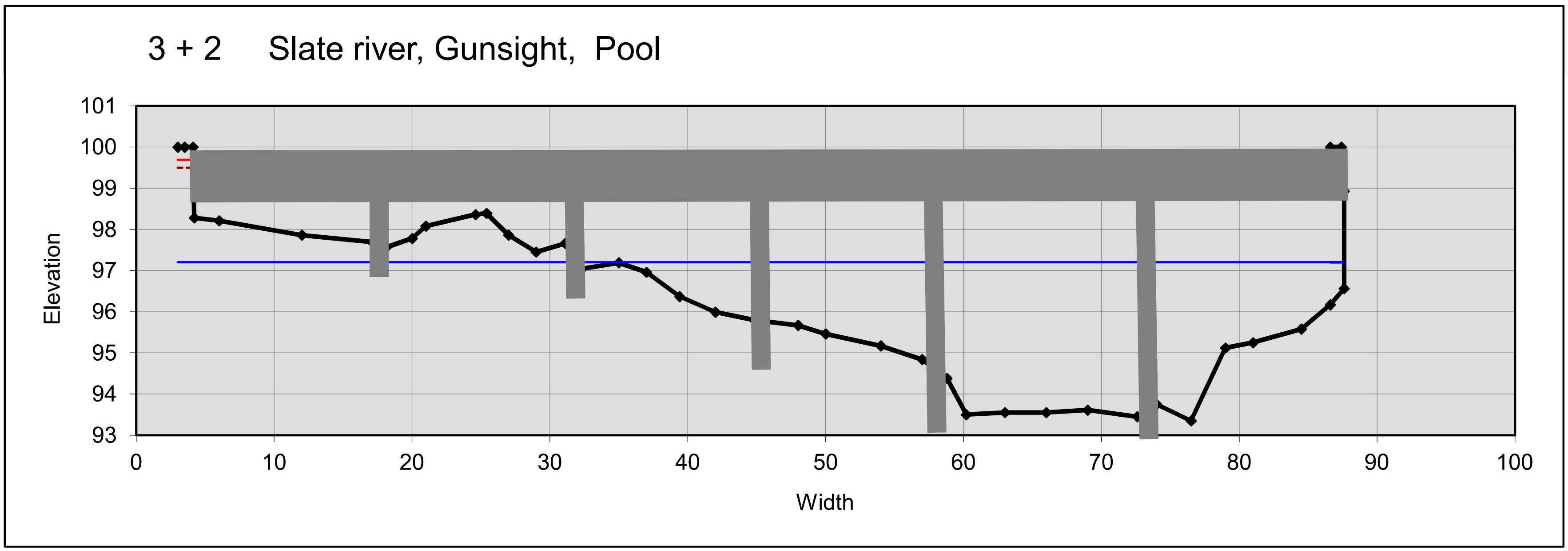
Appendix 1: Channel Surveys

Figure A-4: XS-302

Slate River Gunsight Reach 2013

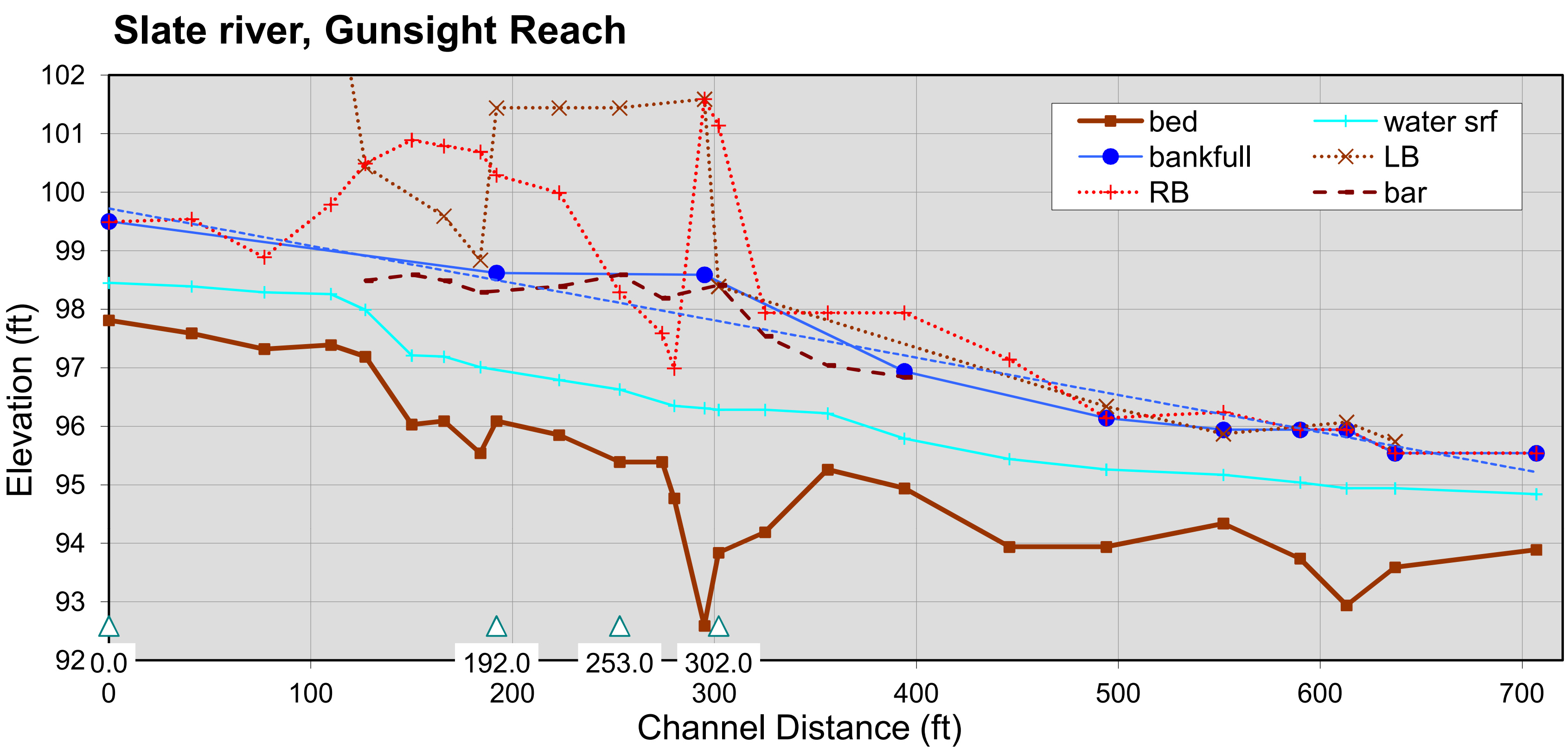
XS ID:	XS-302	Facet type:	Pool
Station:	302	Segment:	F4
Area (ft_2)	120	BHR	1.6
Width (ft)	56	D_{max}/D	2.0
Depth (ft)	2.2	Slope %	N/A
Max. depth	4.3	V (ft/s)	N/A
W/D	26	T (lb/ft^2)	N/A

Note: This XS is along the downstream edge of the bridge. Bridge structure is depicted in the plot below. The road on the left bank and a berm on the right bank confine flood flows to the bridge span.



Appendix 1: Channel Surveys

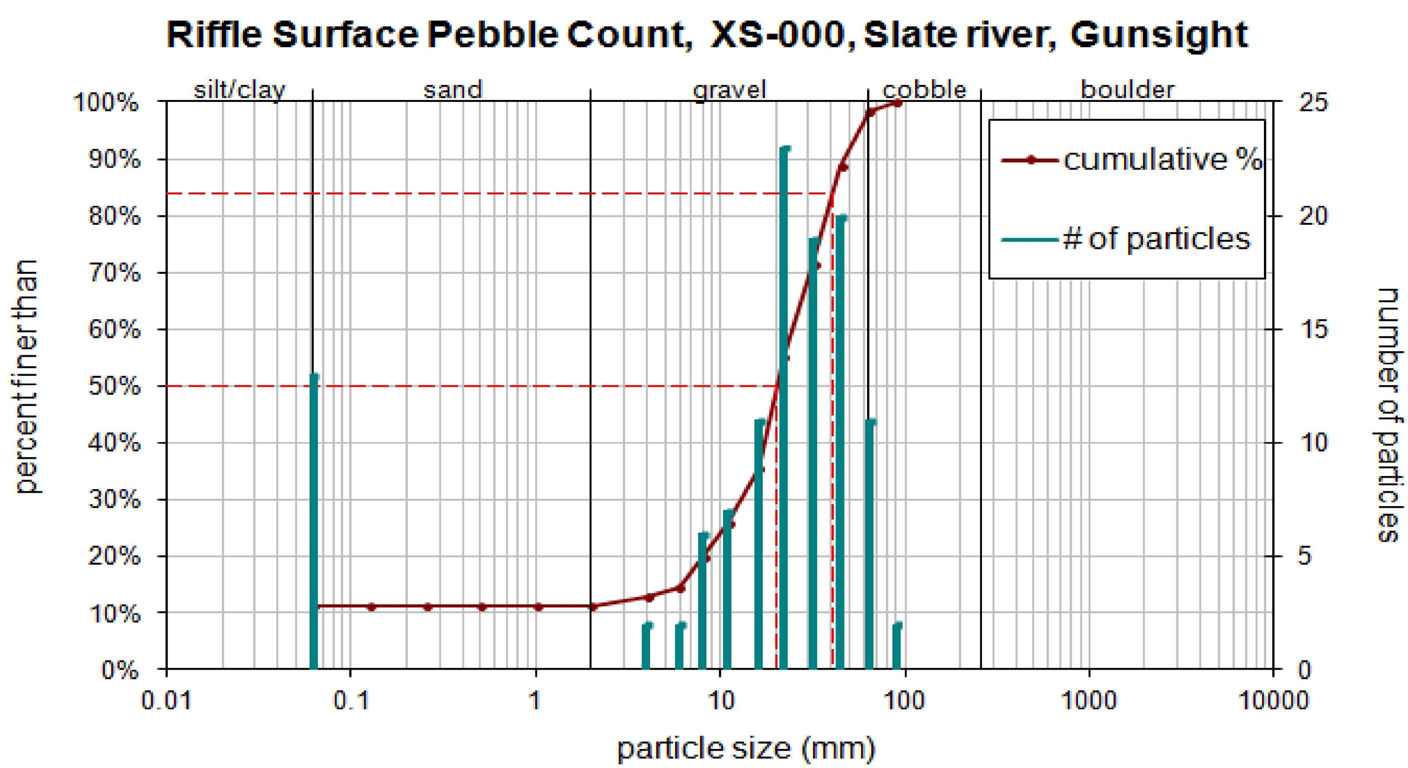
Figure A-5: Longitudinal Profile



Longitudinal profile shows measured data points for bed, top of bars, water surface, and left and right bank. Banks were measured as the elevation at which water would flood out onto a wider floodplain. Bankfull indicators are also shown. These were typically the height of lowest bank or tops of depositional features. Bankfull stage elevations were cross checked using hydraulic calculations at relevant XS. The locations of XS are also shown.

Appendix 1: Channel Surveys

Figure A-6: Channel Materials at XS-000



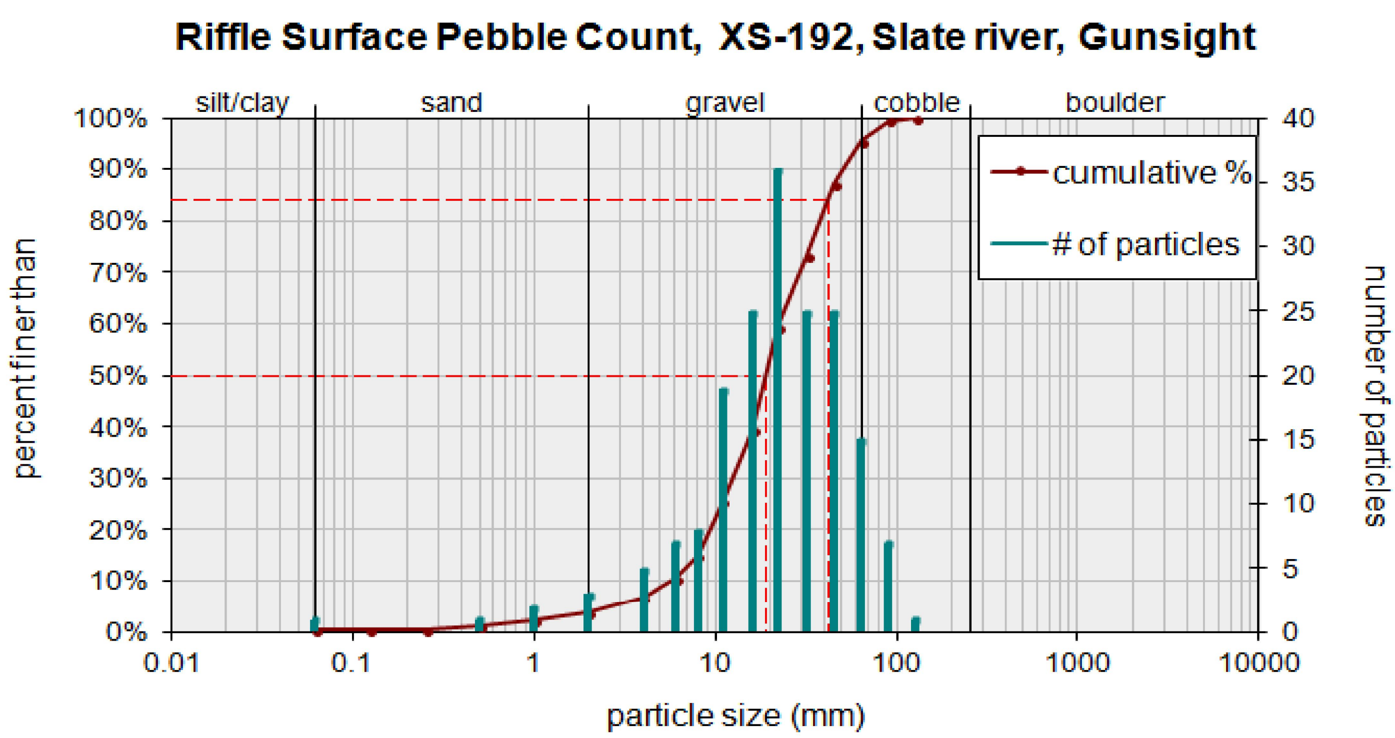
Size (mm)	
D16	6.5
D35	16
D50	20
D65	28
D84	41
D95	57

Size Distribution	
mean	16.3
dispersion	2.6
skewness	-0.10

Type	
silt/clay	11%
sand	0%
gravel	87%
cobble	2%
boulder	0%

Appendix 1: Channel Surveys

Figure A-7: Channel Materials at XS-192



Size (mm)		
D16	8.2	3.4
D35	14	12
D50	19	17
D65	26	20
D84	42	29
D95	63	39

Size Distribution	
mean	18.6
dispersion	2.3
skewness	-0.01

Type	
silt/clay	1%
sand	3%
gravel	92%
cobble	4%
boulder	0%