SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

Feasibility Report

October 15, 2015

Prepared for:
Scott County, MN
Watershed Management Organization

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Scott

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Prepared by

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Table of Contents

INTRODUCTION

Sand Creek flows north through Minnesota's Le Sueur, Rice, and Scott counties before discharging into Louisville Swamp and the Minnesota River, near Jordan, Minnesota (Figure 1). The middle reach of Sand Creek flows through the knick zone, or bluff zone, which delineates the remnant valley walls of glacial River Warren (e.g., Gran, 2009, 2013). The bluff zone consists of a relatively sharp break in slope from low gradient farm land in the uplands, to steep, sandy hillsides dropping to the Minnesota River floodplain below. Channels cutting through the bluffs contribute a disproportionate volume of sediment to their mainstem streams and the Minnesota River (Engstrom et al., 2009, Kelley and Nater, 2000). For example, suspended sediment yields from the middle reach of Sand Creek range from 5 to 10 times larger than the yields from reaches outside of the bluff zone (Scott County WMO, 2010). The relatively large sediment production impacts riverine habitat and water quality, including Sand Creek and Porter Creek being impaired for aquatic life due to turbidity (i.e. sediment/total suspended solids). Near bank erosion and subsequent sediment transport also increase risks to landowners adjacent to eroding bluffs or near downstream depositional areas.

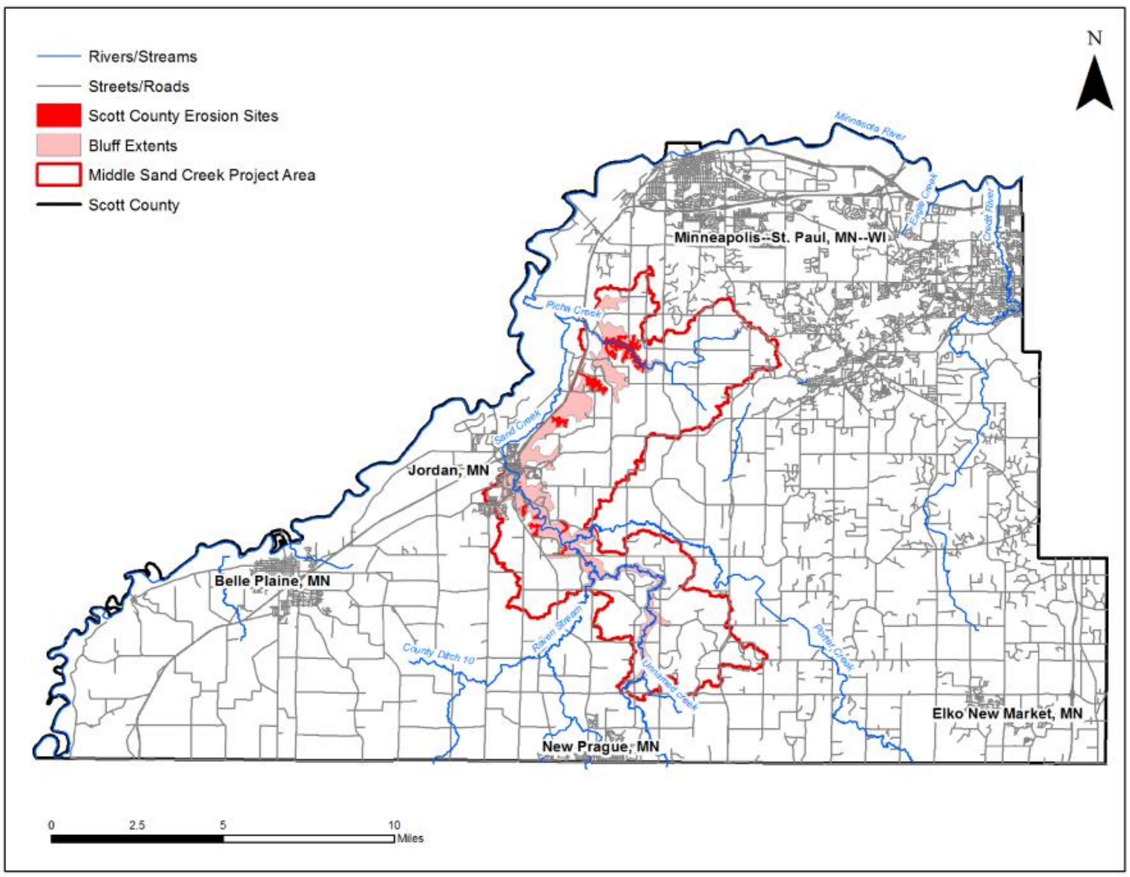

Figure 1. Map of the Middle Sand Creek-Picha Creek Study Area, Scott County, MN.

To improve general stream habitat impairment and meet water quality standards, Scott County is addressing sediment loading from direct bluff and ravine erosion in the Middle Sand Creek and Picha Creek watersheds. Inter-Fluve, Inc. conducted a desktop geomorphic investigation aimed at identifying eroding bluffs or ravines that contribute large amount of sediment to Sand Creek. A rubric was constructed to prioritize sites based on erosion and sediment yield, project cost and complexity, and infrastructure risk. This document specifies the desktop and field based site selection process, and describes conceptual treatments at six sites prioritized for potential pilot projects. Several sites will be slated for implementation by the Scott WMO. Funding for this Feasibility Study as well as the construction of the improvements is provided with a Targeted Watershed Grant from the Minnesota Clean Water, Land, and Legacy Amendment Funds appropriated by the Board of Water and Soil Resources and granted to the Scott County Watershed Management Organization.

GENERAL GEOMORPHOLOGY OF RAVINES AND BLUFFS

Over time, river and stream channels adjust their gradient, dimensions, and sediment characteristics to most efficiently pass the sediment and water delivered them from upstream. When energy associated with the flow volume and channel slope balances the sediment load and bed material size, the channel is considered stable and in equilibrium (Figure 2; Lane 1955). Large or consistent changes in flood flow energy related to climate or land management will likely result in a change in channel dimensions to accommodate the new conditions. Increases in flow typically lead to erosion and a larger channel, and diminished flows typically result in deposition and a smaller channel. Similarly, increases in sediment delivery will usually result in channel deposition, and a decrease in sediment delivery often results in erosion along the bed and banks (Figure 2).

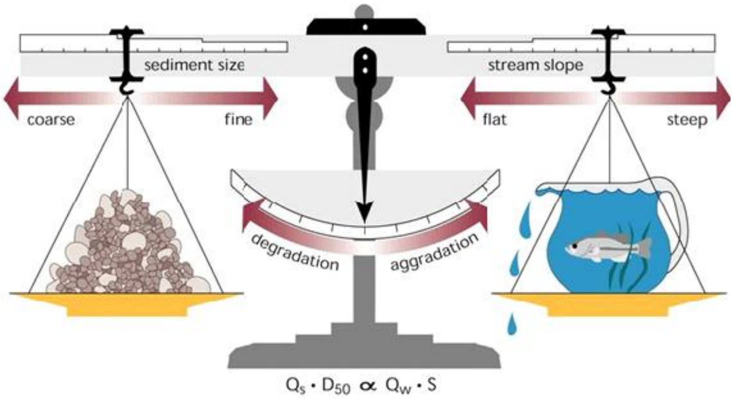

Figure 2. Lane's Balance – Channels in equilibrium balance their slope and flow capacity with their sediment load and sediment size (Lane, 1955).

Ravines

Scott County's ravines are ephemeral drainages in which active channel evolution processes are occurring. Ravines are erosional features characterized by steep, often entrenched channels within a narrow valley with steep valley walls. They often develop where elevated runoff and decreased sediment input to channels, especially those with steep slopes, trigger a sequence of in-channel change. The channel will likely initiate in a swale or small gully, and then rapidly incise or degrade (Figure 3, Step II). This stage is commonly seen in the upper parts of Scott County ravines, but incision can occure at multiple nick points or headcuts along the profile.

Incision migrates its way upstream during runoff events until bank heights become unstable or the bed material limits further incision via coarsening or contact with bedrock or clay (Figure 3; Steps III and IV). Because more flow is concentrated in the deep, narrow gully than the initial channel, sediment production from bank erosion can be rapid. Additionally, mass wasting of unstable valley slopes into the stream also contribute to high sediment loss to the channel.

Eventually, the ravine cross section becomes large enough where sediment is no longer easily entrained, and sediment deposits in an inset floodplain (Step IV). The channel begins to establish a new stable configuration a this lower elevation (Step V). This process tends to translate from downstream to upstream over time, with the downstream end revegetating and becoming stable. Changes in flow rate and volume, or a drop in the base elevation of receiving streams can result in further downcutting in tributary ravines, thus restarting the process. Minnesota River ravines appear to experience gullying cycles roughly every 800 years. Modern agriculture, and possibly climate shifts, have augmented the current gullying cycle.

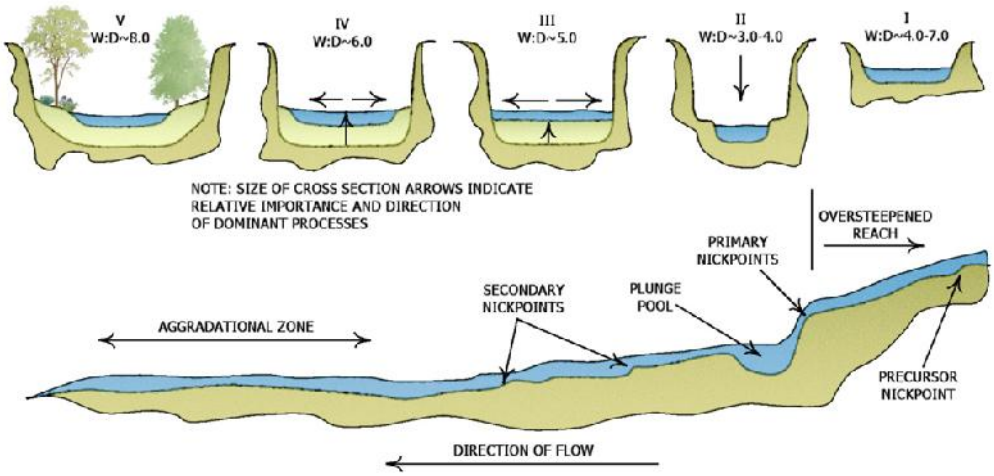

Figure 3. Schumm channel evolution model showing spatial substitution for temporal changes in stream bed elevation. Stages in the upper row correspond to the long profile directly below.

Bluffs

Bluffs form where a stream channel abuts a valley or terrace wall at the edge of its floodplain. They usually form, and are maintained, by erosion at the toe of the bluff (Figure 4), which removes material helping to hold the bank in place and increases the slope along the bluff face. Regionally, high (>50 ft), unvegetated bluffs are common along Minnesota River tributaries due to incision through the glacial sands and clays along the bluff zone. Scott County bluff erosion sites are formed and maintained by erosion at the toe of the slope, often where groundwater seepage creates easily erodible and unstable soil at the water interface (Figure 4). Erosion occurs via fluvial erosion at the toe, dry granular sand flow and sheet and rill erosion on the bluff face, and mass wasting through slab and rotational failure. Once mass wasting has occurred, the deposited materials are often more easily eroded by fluvial entrainment.

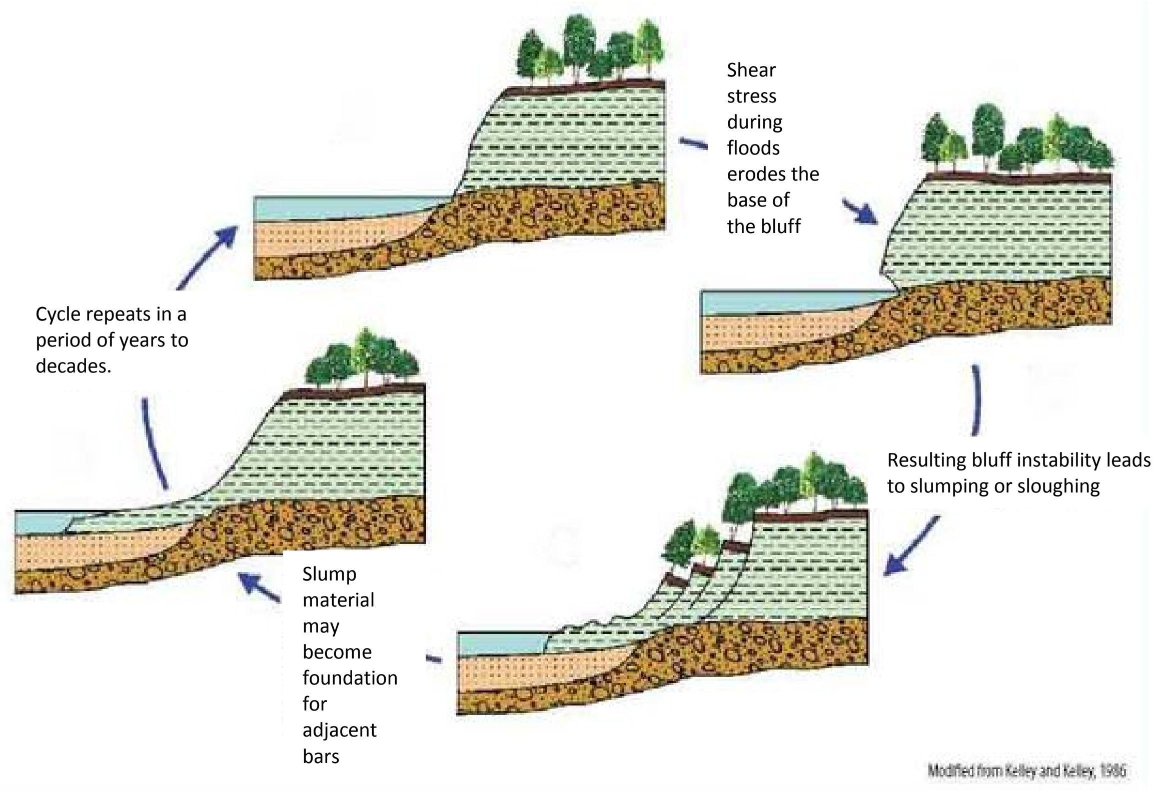

Figure 4. Bluff erosion cycle showing bluff toe erosion, followed by rotational failure/slumping, bar formation and transport, and back to bluff toe erosion.

METHODS

Desktop Analysis

The primary goal of the desktop assessment was to identify candidate sites where channel, ravine, and/or bluff toe stabilization will significantly reduce erosion and therefore, reduce sediment loads to Sand and Picha Creeks. The identified sites would later be ranked, largely based on estimated sediment production, and used to prioritize field assessment activities and project planning. Previously, the Scott County Soil and Water Conservation District (SWCD) estimated erosion rates along Sand Creek ravines by comparing LiDAR elevation data collected in 2003 and 2010. Inter-Fluve expanded this analysis to all channel segments (between confluences) with watershed areas larger than 2500 ft^2, as delimited using ArcHydro tools in ArcGIS 10.1 (Figure 5). Geomorphic change was calculated by subtracting the 3 ft DEM representing the 2010 LiDAR data from the 3 ft DEM representing the 2003 LiDAR data using Geomorphic Change Detection software within the GIS. The GCD software runs the subtraction analysis, but also accounts for error within the data. Although the GCD software adjusted for a generalized error of about 0.4 ft, the original LiDAR data did not include enough information (i.e., flight information, return errors, etc.) to perform a detailed error analysis. Change within Sand Creek and lower Picha Creek bankfull channels, as delineated from 2013 air photos, were ignored (set to 0 ft difference), as LiDAR does not penetrate water well and flows were different during the 2003 and 2010 surveys. The final geomorphic change values were summarized within channel segment areas delineated by 80 ft offsets from tributary lines and 200 ft offsets from the mainstem centerline (i.e., 160 ft and 400 ft wide buffer areas, respectively).

In addition to the LiDAR data analysis, historic air photos from 1937, 1958, 1966, 1998, and 2010 were used to estimate average bank and bluff retreat rates over the period of record at potential project sites. In most cases, especially along ravine sites, photo resolution, tree cover, and general photographic quality prohibited a quantitative analysis of channel change. However, general trends could be observed at some sites and migration was quantified at larger bluff exposures.

A list of sites to undergo further review was prepared based on comparisons of the erosion/sediment yield data, stakeholder complaints, ravines identified by the SWCD, project sites noted in the 2008 Sand Creek Geomorphic Study, and an initial review of historic air photos.

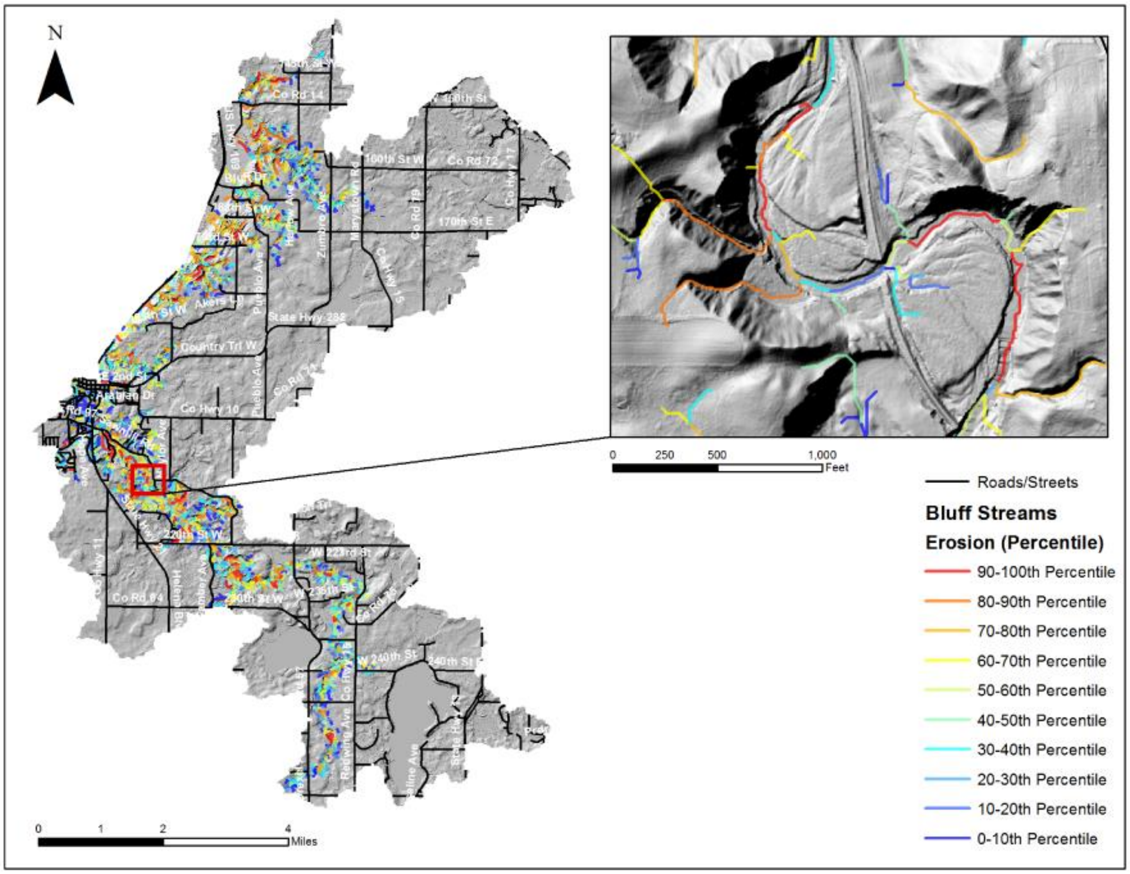

Figure 5. Example of identification of high sediment yield reach identification along the middle reach of Sand Creek.

Field Reconnaissance (Ground-Truthing)

A subset of the initially identified high sediment yield sites was chosen to qualitatively verify the results of the desktop assessment and ground-truth erosion rates based on field clues. General erosion rates were evaluated in the field based on root structure and exposure, observed mass wasting, positions of outfall and other structures to the channel bed, valley wall composition, vegetation cover, and seepage locations. Risks of ongoing or imminent mass wasting or instability were also noted, such as tension cracks, small slope failures, local aggradation, and head cut locations along ravines and tributaries. In most cases, recent erosion was evident at the visited sites, and additional knowledge concerning the processes and stages of failure was also gained. At the Naylor-Sawmill, Ridgeview Circle, and Highway 169 - South Sites, the tributary channels appear to be relatively stable with limited hillslope activity and small bluff erosion sites only at the outside of some meander bends.

Prioritization

When dealing with multiple unstable channel sites throughout a reach or watershed, it is important to have some way of prioritizing these sites. For the 2008 geomorphic assessment of Sand Creek (Inter-Fluve, 2008), priority ranking criteria (metrics) were used to rank overall projects. For this study, Inter-Fluve worked with the WMO to modify the 2008 matrix to specifically address sediment loading sites within the area of interest (Middle Sand and Picha Creek Watersheds). In order to prioritize these projects for funding allocation, a ranking system of potential restoration projects was developed which scores potential stream project sites based on 5 metrics (Table 1). For each metric, each site is assigned a value of 1 through 7 based on existing site conditions, and the total of all of the metrics is the potential project score. The delimited sites were prioritized by scoring each site using the modified rubric, which was weighted to reflect the priority of reducing sediment production at each site, but also included other factors included, such as project cost and complexity and infrastructure risk. Some sites received lower prioritization scores due to lack of landowner permissions, field assessments indicated the channel was stabilizing (e.g., Naylor-Sawmill, Ridgeview Circle), presence of existing projects (e.g., Delmar – Highway 121, Highway 169 – North), or the ravine was disconnected from Sand Creek, keeping sediment out of the channel (e.g., Green Ash Court). In most of these cases, sediment production and yield to mainstem channels was likely significantly reduced relative to the desktop analysis results. Once scored, the sites were narrowed down to the top six sites having the highest potential for pilot projects.

Table 1. Prioritization Matrix

Parameter	Weight	1	3	5	7
Sediment/nutrient loading (Sand and Picha Creeks)	2	No significant load reduction to Sand or Picha Creek	Minor reduction in sediment loading (0-250 CY/YR); sediment is managed or deposited before reaching Sand or Picha Creeks	Moderate reduction in sediment yield to Sand or Picha Creeks (250-500 CY/YR), reduced yields to perennial tributaries	Significant reduction in sediment yield to Sand and Picha Creeks and perennial tributaries (>500 CY/YR)
Erosion/Channel Stability	1.5	Minimal improvement to erosion and stability	Low to moderate improvement (<25 CF/FT/YR)	Moderate improvement (<40 CF/FT/YR)	Significant improvement to overall stream stability and function; (> 50 CF/FT/YR)
Project cost	1	> $300K	$200 - $300K	$50 -$200K	$0 - $50K
Project complexity	1	Geotechnical considerations, specialty design services required, difficult access, heavy oversight, major earthwork, EAW/EIS permitting	Geotechnical consideratoins, difficult access, engineering plans required, earthwork, significant permitting	Moderately complex, no specialty engineering required, some access issues, minor earthwork, basic permitting	Elementary solution, shelf design, volunteer and hand labor implementation, no permits
Infrastructure risk	0.5	No risk to infrastructure with no action, or no infrastructure present	Low to moderate infrastructure risk and minimal risk to public safety with no action (100-150 ft from eroding bluff or bank face), or infrastructure value <$100,000	Infrastructure at moderate but not immediate risk, moderate public safety risk, (50-100 ft from eroding bluff or bank face) or infrastructure value <$200,000	Infrastructure at high or immenent risk of failure with no action. Public safety at risk. (<50 ft from eroding bluff or bank face) or infrastructure value >$200,000

RESULTS AND DISCUSSION

Overall Channel Condition

Novotny and Stefan (2007) assessed stream flows from 36 USGS monitoring stations across Minnesota with periods of record between 10 to 90 years. They discovered the magnitude and duration of peak flows associated with summer rainstorms increased over that time, as did summer and winter base flows. Increases in annual precipitation volume, the number of intense precipitation events, and the number of days with precipitation appear to drive the increased flows (Novotny and Stefan, 2007). However, alterations in land use and land management have also likely contributed to increasing flow rates. Prior to logging in the 1850s, most of the Sand Creek watershed was part of the Big Woods ecosystem, consisting primarily of maple-basswood forest with oak savanna in the uplands. The forests were cleared for agriculture and farmers used tiles to drain water from their fields faster. Schottler et al. (2013) found that shifts from forested to agricultural watersheds often increased seasonal and annual water yields due to loss of natural storage and drainage modifications. Shifts to flashier flood pulses and higher flows likely caused some instability in the Sand Creek system, thereby triggering erosion in the channel and associated tributary streams and ravines, as well as accelerating hillslope failure processes by increasing the amount of water stored in the sediments.

In the case of Middle Sand Creek, the system likely experienced a change in flow and sediment supply related to both climate and landuse change over the last few decades, but the watershed is also experiencing a change in slope associated with longer term geological adjustment. Sand Creek's watershed topography is relatively flat above (east) the Minnesota River bluff zone, but within the zone, elevations steeply drop to the Minnesota River floodplain. The floodplain occupies the incised valley eroded by glacial River Warren. Since the glacial river receded, its former channel has been filling with sediment from tributary streams to the Minnesota River, including Sand Creek. The transported sediment is supplied from the upward migration of knickpoints traversing the channels and ravines located at the edge of the bluff zone (Jennings, 2010). Knickpoint migration, which essentially creates shifting areas of increased slope along each channel (i.e., increased stream energy), makes tributaries susceptible to increased sediment production and transport.

Previous studies (Scott County, 2010) indicate that total suspended solid concentrations in Sand Creek are dominated by sediment associated with knickpoint migration in the Minnesota River bluff zone (Jennings, 2010). Increased stream flow, whether from increased density of agricultural drain tiles, loss of upland storage, or from increased precipitation due to climate change, likely worsens knickpoint migration through streambank, gully, and ravine erosion in the Sand Creek Watershed, and the combination of these factors heightens total suspended solid (TSS) loads and concentrations in the streams.

According to Inter-Fluve's 2008 assessment, Sand Creek is fairly stable, though it is degrading slightly. Overall, minor degradation should be expected due to the aforementioned changes. The *Sand Creek Near Channel Sediment Reduction* study focused on the middle reaches of Sand Creek, which are characterized by a meandering channel flowing through steep bluffs, with tributary ravines incised into adjacent slopes. The bankfull width of Sand Creek in this reach varies from 40 to 70 feet, and the floodplains are often limited by geologic features (e.g., bedrock outcrops, bluff edges) or manmade obstacles, such as railroad berms. Bedrock is exposed along the bed in some sections and other reaches feature alternating cobble-gravel riffles and pools comprising sand and cobbles. These scour and depositional features provide most of the habitat opportunities for aquatic organisms. Large wood, boulders, and undercut banks are present but rare. Floodplain vegetation primarily includes eastern cottonwood, black locust, black willow, box elder, silver maple, green ash, and silver maple. Dominant invasive plants in the riparian zone include reed canarygrass, giant reed grass, buckthorn, and garlic mustard. The dominant floodplain soils of the study areas are sandy loam with evidence of overbank sediment deposition within areas of 1-3 year frequency of inundation. Woody species and thicker understory clearly demarcate less frequently inundated segments. Evidence of large floods is present in large bar deposits, recently moved cobble-boulder lag material, and elevated flood debris and wood jams.

Near Channel Sediment Production

Figure 6 and Figure 7 depict the high volume sediment erosion areas delineated by the LiDAR analysis (2003 -2010). Major areas of erosion include the upper reaches and side channels of ravines along Highway 169, north of 180th St West, and ravines between Jordan and County Highway 8, south of town. Erosion along middle Sand Creek is high at bluff sites throughout the reach, as well as at the outside of bends at non-bluff sites. Highly eroding subreaches were reviewed with respect to previously identified problem areas and relationships/distances to Sand Creek or its major tributaries (e.g., Porter Creek, Picha Creek), and a list of sites suitable for further investigation was developed (Table 2). Sites that did not make this list included ravines with large areas for sediment storage between their mouths and primary channels, sites where air photos and LiDAR suggested major work had been completed (e.g., lower Picha Creek), or sites where normal channel adjustments were occurring within the floodplain (i.e., sites without bluffs or ravines). Additionally, WMO staff, through previous field reconnaissance, had identified about a dozen sites that were given special attention.

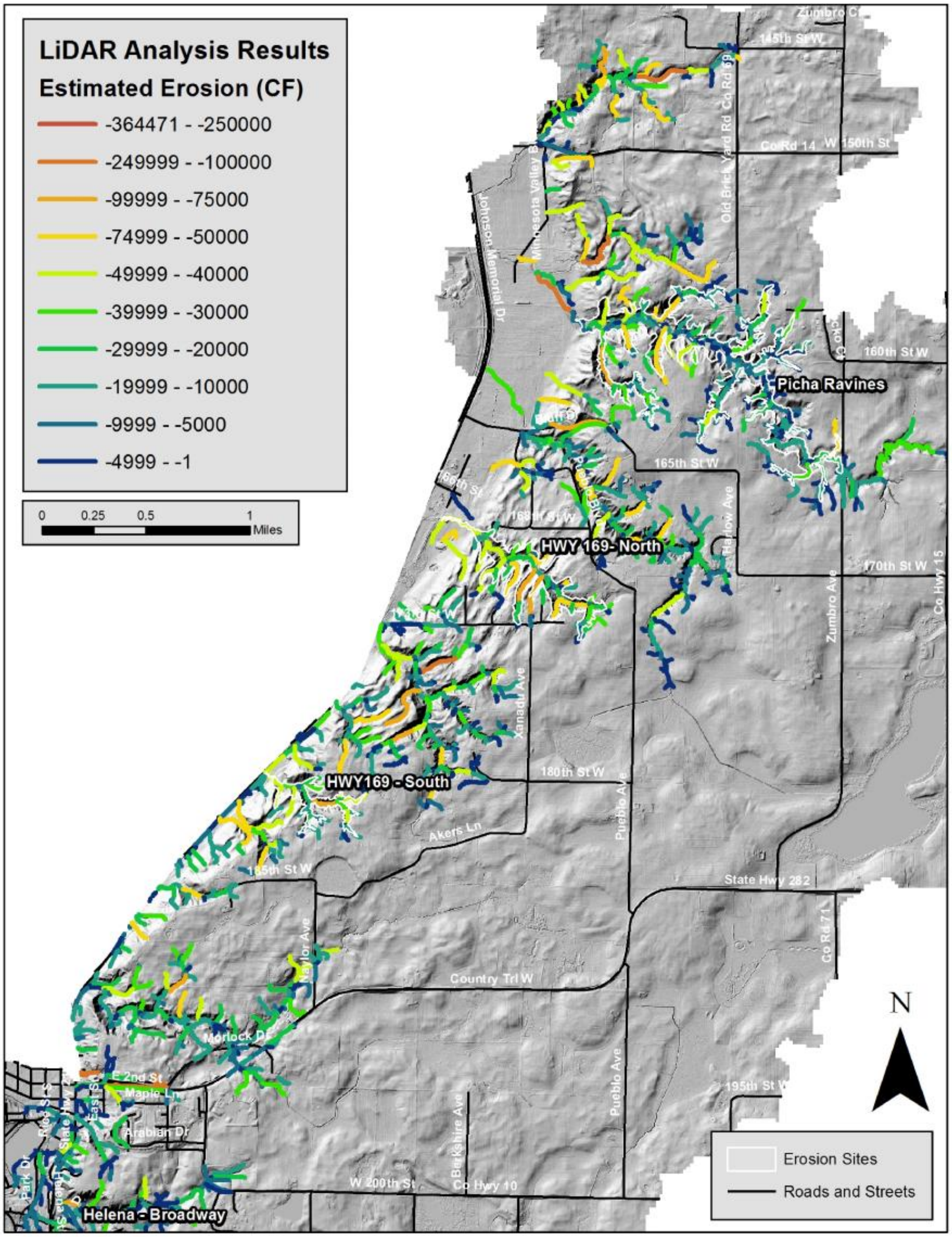

Figure 6. Estimated erosion within the Sand Creek system in Scott County (North) based on LiDAR geomorphic change analysis. Ravines along Highway 169, north of 180th St W, tend to have high erosion rates, especially at side channels in the upper reaches.

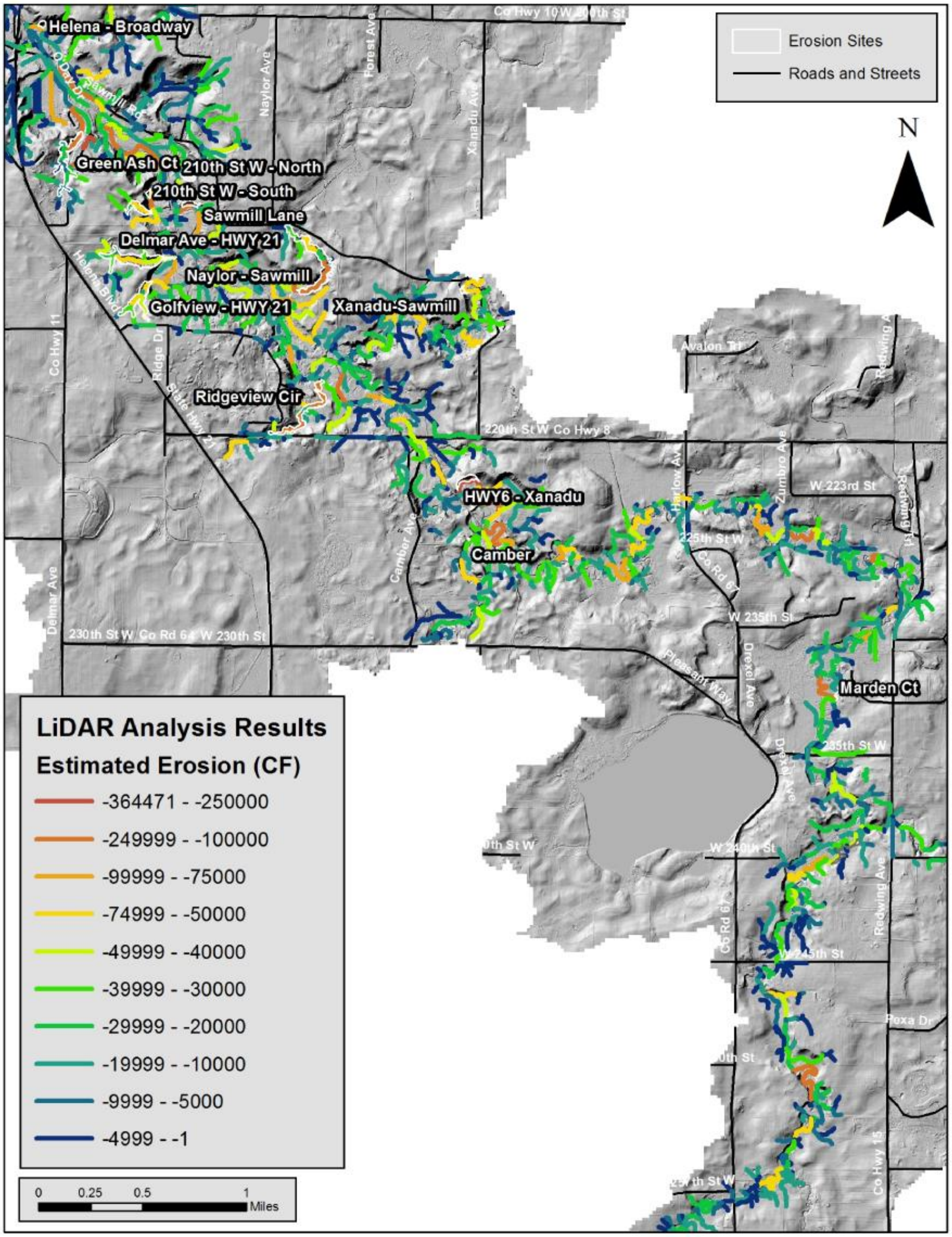

Figure 7. Estimated erosion within the Sand Creek system in Scott County (South) based on LiDAR geomorphic change analysis. High erosion areas are located along ravines between Jordan and County Highway 8, and at bluff sites along most of Sand Creek, but especially downstream West 235th Street. Bank erosion in "non-bluff" reaches also occasionally produces significant volumes of sediment.

Table 2. Sediment production data for sites chosen for further evaluation based on LiDAR analysis and previously identified problem areas.

Site			Sed Yield	Per Length	Per Area	Erosion	Per Length	Per Area
	Area (SF)	Length (Ft)	CY/YR	SF/YR	F/YR	CY/YR	SF/YR	F/YR
Ridgeview Cir	256190	2562	-1070	-11.3	-0.11	-1241	-13.1	-0.13
HWY189 - North	1752187	17522	-954	-1.5	-0.01	-4507	-6.9	-0.07
HWY8-Xanadu	62335	750	-807	-29.1	-0.35	-1060	-38.2	-0.46
Sawmill - Naylor	400437	4004	-788	-5.3	-0.05	-1046	-7.1	-0.07
Golfview - HWY21	190402	1904	-441	-6.2	-0.06	-771	-10.9	-0.11
Lower Picha Ravine	586963	5870	-370	-1.7	-0.02	-1900	-8.7	-0.09
210th St W - North	13382	250	-291	-31.4	-0.59	-331	-35.8	-0.67
Delmar - HWY21	310462	3105	-276	-2.4	-0.02	-853	-7.4	-0.07
Helena - Broadway	23029	180	-204	-30.6	-0.24	-309	-46.3	-0.36
Sawmill Lane	45559	355	-189	-14.4	-0.11	-280	-21.3	-0.17
Xanadu - Sawmill	14668	295	-80	-7.3	-0.15	-127	-11.6	-0.23
Marden Ct	3021	145	-5	-0.9	-0.04	-13	-2.4	-0.11
Camber Ave	3217	100	-4	-1.0	-0.03	-6	-1.6	-0.05
Green Ash Ct	263497	2635	53	0.5	0.01	-443	-4.5	-0.05
210th St W - South	94998	950	102	2.9	0.03	-263	-7.5	-0.07
HWY189 - South	798246	7982	483	1.6	0.02	-2093	-7.1	-0.07

***Data taken from comparison of 2003 and 2010 LiDAR
Sediment Yield = Total change in sediment volume within the area of interest (total bluff or 40 ft stream buffer (each side)).
Erosion = Total volume of erosion within the area of interest (does not factor in deposition).

The sites in Table 2 and Figure 8 include reaches with the highest amount of sediment production, including the Ridgeview Circle and Highway 169-North ravine areas, and the bluff at Highway 8-Xanadu, which produce more than 800 CY of material per year according to the LiDAR analysis. Smaller sites, such as the Helena-Broadway and 210th St W – North sites, appear to produce less overall sediment, but have relatively high erosion rates for their size (>0.2 CF/SF/YR). The list includes a mix of bluff and ravine sites in both the north and south sections of the study area.

Sand Creek ravines are in various stages of evolution, but the more active ravines appear to be in Stage II or early Stage III (Figure 3), with some incision and clear evidence of active widening. Smaller bluffs, 20-50 ft long and 10-15 ft high, are common in the ravines as are relatively large rotational slump blocks. Accumulations of slumped material and woody debris often block the channel, creating upstream ponded areas that store sediment, at least temporarily (Figure 9).

Along the main channel of Sand Creek, streamside bluffs appear to be maintained by erosion at the base of the slope, caused, in part, by depositional bars directing high flow vectors at the bluff toe. Active and partly healed bluff faces often feature multiple failure sites, with active scarps, debris flows, debris cones, rills, and gullies. Large cobble/boulder bars in the adjacent channel often flank the larger bluffs. In some cases, such as Helena-Broadway and Highway 8-Xanadu, some of the slump blocks appear to originate along the upper face, instead of the bank toe.

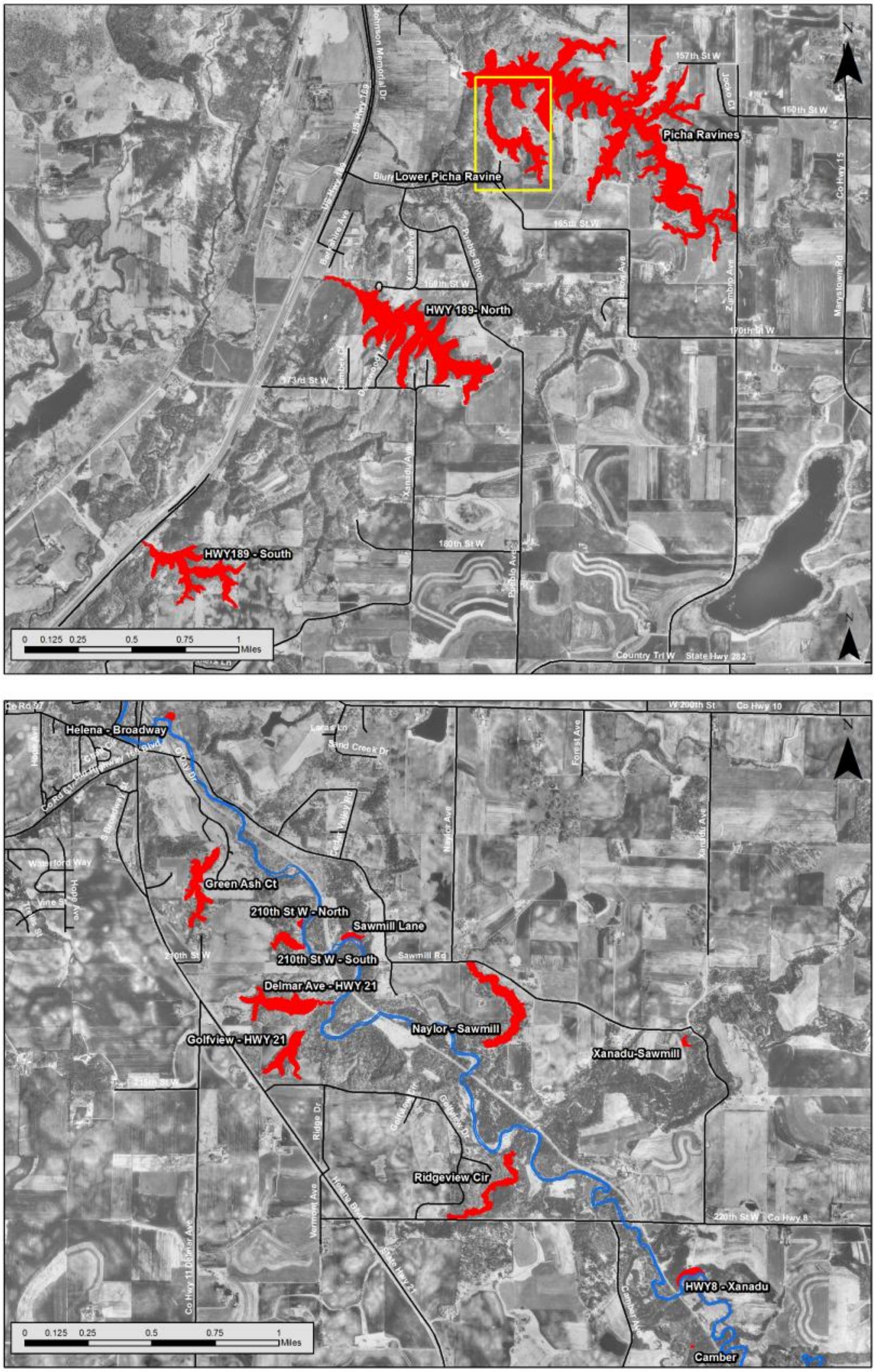

Figure 8. Site map of major erosion sites identified in LiDAR analysis and evaluated in the overall site prioritization (Tables 2 and 3).

Figure 9. Woody debris accumulated just downstream of a rotational slump. Wood has created a natural "check dam" at the pinch point, blocking the channel and creating a wider, deeper, less steep ravine upstream. The debris attenuates larger flows and stores water and sediment.

Prioritization

The initial list of sites (Table 2) was further evaluated during field visits and discussions with WMO staff, and the sites were ranked using the matrix defined in Table 1 to produce a list of potential project sites. Table 3 provides the list of high priority sites and additional information on how the project sites were ranked. The project site list primarily consists of major bluffs, with only one ravine site.

- The bluff sites tend to be areas where large amounts of sediment are added to the channel over relatively small lengths or areas. Treating these areas likely will provide the most sediment reduction per length of treatment.
- Ravine projects will likely involve numerous smaller treatments along longer channel lengths, causing more disturbance associated with access, and potentially, a lower cost versus benefit (tons of sediment) ratio.
- Many of the problem ravines delineated in the LiDAR analysis have been, or will be worked on as part of other soil and water management programs. For example, sediment traps have been constructed downstream of the Highway 169-North and the Green Ash Court sites and a flow and sediment control structure was placed along the Delmar Site channel.
- Ground-truthing also indicated some sites were relatively stable (Stage IV or V; Figure 3). For instance, riprap has recently been placed at the upstream end of the Ridgeview Circle ravine, and downstream, although valley wall erosion was present, the channel showed signs of developing an inset vegetated floodplain. Evidence corroborating the site’s position as the highest producer in the system (Table 2) was limited. The Naylor-Sawmill tributary also had some smaller bluffs at the outside of bends, but overall, appeared relatively stable, leaving its predicted high sediment yield from the desktop analysis in doubt.

Table 3. Sand Creek Project Prioritization

Sites	Type	Project Types	Recommendation	Status	Sediment Nutrient loading	Erosion	Project cost	Project complexity	Infrastructure risk	Final Score	Notes
HWY8-Xanadu	Bluff	Toe Stabilization	Geotech Investigation, Log Jam, Flow Deflection, Cribwall at DS Bluff	Priority	7	5	3	3	6	30.5	Concentrate on DS end of Bluff/ US end has geotechnical issues (seeps, etc)
Helena - Broadway	Bluff	Toe Stabilization	Log Jam, Flow Deflection	Priority	3	7	3	4	1	24	Clear signs of rilling and slope failure, Log Jam analog at US end of site
210th St W - North	Bluff	Toe Stabilization	Log Jam, Cribwall	Priority	4	5	3	3	1	22	Bluff erosion and meander migration evident in air photos (~7000 CY Yield/ ~8000 CY erosion)
Sawmill Lane	Bluff	Toe Stabilization	Log Jam, Flow deflection, Cribwall	Priority	3	4	4	4	2	21	Not much erosion on air photos, clear signs of slope failure and rilling
Xanadu - Sawmill	Bluff	Meander Cutoff	Meander Cutoff	Priority	3	3	5	3	1	19	Tributary Channel/ Pull bend inside of existing log jam/slump
210th St W - South	Ravine	Control Basins Grade Control	WASCOB/Channel Wood, Check Dams	Priority	2	3	6	4	1	19	Narrow, deep ravine along abandoned road
Lower Picha Ravine	Ravine	Grade Control	Wood jams (check dams), Channel wood	Alternate	3	3	3	3	4	18.5	Previous work is failing, DS ravine does not appear to impact Picha Creek significantly
Golfview - HWY21	Ravine	Grade Control	Wood jams (check dams), Channel wood	Existing Project	3	3	3	3	4	18.5	Not part of field investigation
Marden Ct	Bluff	Meander Cutoff	Meander Cutoff or Cribwall	No Action	2	2	7	2	4	18	Meander will be naturally cut at neck in the near future
Delmar - HWY21	Ravine	Grade Control	Wood jams (check dams), Channel wood	Existing Project	3	3	3	3	3	18	Not part of field investigation
Camber Ave	Bluff	Toe and Slope Stabilization	Geotech Investigation, Roughened Toe, Log Jam, Cribwall	Future Project	2	2	4	3	7	17.5	May require geotech work to save yard
HWY189 - North	Ravine	Grade Control	Wood jams (check dams), Channel wood	Existing Project	2	3	3	2	7	17	Sediment stored at DS end of channel and in constructed sediment traps below ravine.
HWY189 - South	Ravine	Grade Control	Wood jams (check dams), Channel wood	Future Project	2	2	3	3	2	14	Not part of field investigation
Ridgeview Cir	Ravine	Grade Control	Wood jams (check dams), Channel wood	No Action	1	2	3	3	3	12.5	Channel appears to be adjusting well, field investigation suggested less erosion than LiDAR data
Sawmill - Naylor	Ravine	Grade Control	Wood jams (check dams), Channel and bank toe wood,	No Action	1	2	3	3	3	12.5	Channel appears to be adjusting well, some exposed bluffs at outside of bends, field investigation suggested less erosion than LiDAR data
Green Ash Ct	Ravine	Grade Control	Wood jams (check dams), Channel wood	No Action	1	2	2	2	5	11.5	Sediment basin at downstream end, infrastructure risk, but no sediment to Sand Creek

RAVINE AND BLUFF EROSION SOLUTIONS

The primary performance goal for projects conducted along Sand Creek is to reduce erosion, downstream transport of eroded sediment, and total suspended solid concentrations. The WMO and its project partners would like to accomplish this goal while meeting secondary aims of creating a natural looking solution that improves aquatic habitat.

More specifically, project criterion should include the following:

- Stabilize the toe of eroding bluffs to minimize soil loss contributing to dry granular flow and rotational failure of the upper slope (mass wasting) and encourage long-term (10+ years) vegetative stabilization of the bluff toe and face.
- Reduce the flow and sediment transport through ravines during large runoff events. If necessary, stabilize actively failing banks/bluffs along the ravine channels.
- Design the stabilization measures to withstand flood discharges up to a 100 YR flood.
- Increase in-stream habitat complexity for fish and other aquatic and riparian habitat.
- Maximize the amount of treatment that can be completed with the available funding.

Possible erosion solutions range from traditional site treatments using large rock (riprap) to more bioengineered solutions that include the use of trees, vegetation, and rock to provide stabilization at the toe of bluff slopes or to provide storage for sediment and runoff.

Strategies for Ravine Stabilization

In general, ravines are often difficult to stabilize as they are usually actively adjusting in both the vertical and horizontal directions. During recent Scott County and Minnesota River partnership workshops, it was decided that the best approach to ravine stabilization is a two pronged approach targeting both the hydrology through rate and volume control in the upper watershed, and the physical erosion through grade control within the ravines. Water and Sediment Control Basins (WASCOB's) and larger detention basins have been used effectively in the Minnesota River basin, and are typically placed at the head of and along the upstream portion of ravines (Figure 10). Smaller check dams and stream bank stabilization measures can be employed along the channel within the ravine. Rate and volume control and smaller grade control reduce slopes over short reaches and store water to attenuate larger flows. Reduced stream energy then limits erosion and allows some sediment to be stored in the bed behind the dams. Access to most ravine sites in the Middle Sand Creek watershed will likely be costly and result in significant disturbance, but most can be accessed through the channel bottom at either end of the ravine. The exact location of WASCOB or detention basins depends on the topography of each ravine and the hydrology of each tributary branch.

In the Scott County ravine and bluff workshop, it was noted that studies in both India and the United States indicated that the success of grade control structures in gullies and ravines is directly proportional to engineering due diligence. Check dam design must include an analysis of step spacing, apron design, filter material, potential jet scour, risk of undermining and risk of flanking. Flanking of grade control structures is the most common mode of failure, but can be avoided by proper embedment into the ravine walls. Check dams can be built from stone, wood, concrete or a variety of materials. We recommend either stone, large wood or a combination of both. The conceptual drawings provided for the 210 St W – South Ravine Site (Appendix E; Sheet 5) provide an example of the use of the aforementioned treatments.

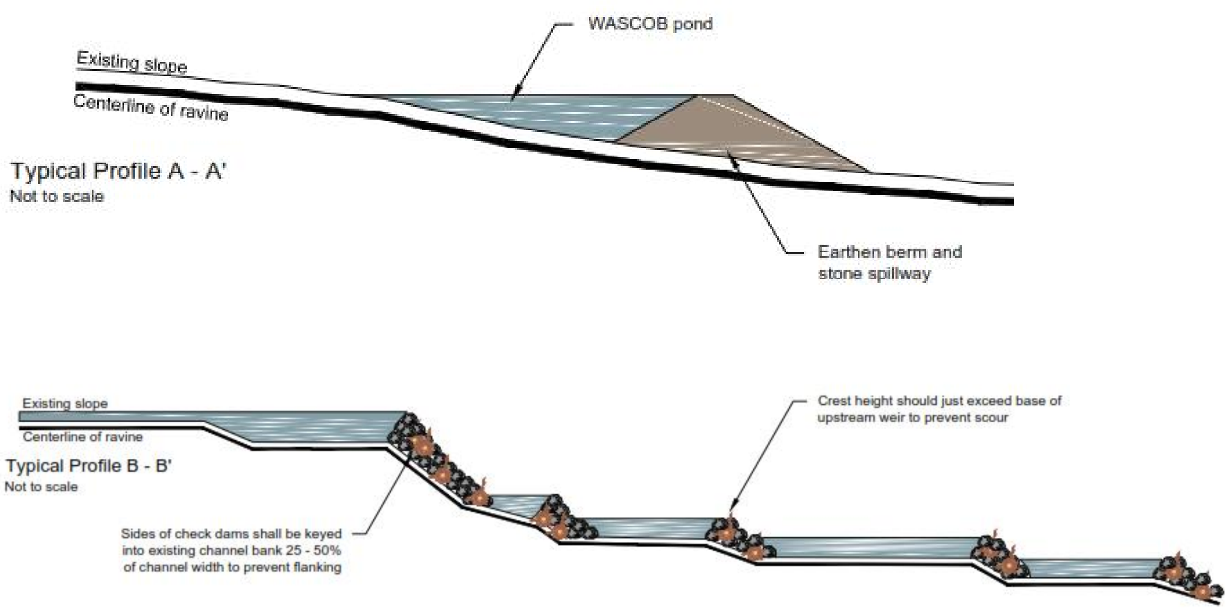

Figure 10. Conceptualized drawings of a WASCOB pond and rock and wood check dams for use in limiting sediment transport and production in ravines.

Strategies for Bluff Stabilization

For general stabilization purposes, bluffs can be divided into the bluff toe and the bluff face, or upper bluff. Most bluff failures initiate via fluvial entrainment and failures at the toe, which in turn, may lead to mass wasting along the face. In order to slow this cycle, the toe must be protected, and the upper slope can then be treated (e.g., excavation, grading, riprap, piles, etc.) or left to passively stabilize. In the latter case, the face will continue to erode at the top and deposit at the base, creating a less steep, more stable slope suitable for vegetation establishment (Figure 11). In general, Inter-Fluve recommends toe treatment and passive upper bluff stabilization, unless infrastructure or safety issues require a different approach.

However, along the Sand Creek focus reach, bluff heights and upper bluff instability appear to create additional risks that are not always encountered at other sites. The main risk to projects is rotational failures along the bluff. Inter-Fluve is only proposing to stabilize bluff toes, and adding logs and rock at the base of a bluff should limit toe erosion and increase the resistance to slope failures. However, if a rotational failure occurs, either at the toe or higher along the slope, a large volume or weight of material moving along the slope could damage any installed treatments. Additional slope stability analyses may be required at some sites to address this issue. Also, the steep, unstable nature of many of the bluffs will pose safety risks for survey, detailed sediment analysis, and construction. Log jams and cribwall stabilization will likely require piles and rock, as opposed to burial into the banks to reduce inducing a slope failure.

Long-term bluff toe protection requires a fixed channel boundary be installed at or near the bluff toe. This can be accomplished through the installation of rock toe (e.g. riprap), rock vanes (e.g. bendway weirs), large wood spurs, increased roughness elements, toe wood, or engineered log jams, followed by either passive or active stabilization of the upper slope. In order to both provide habitat for fish and wildlife, and minimize the cost of sediment reduction, we recommend large wood based solutions and passive upper slope stabilization. The first involves construction of a log jam or log crib at the toe, either directly on the bluff to or away from the bluff toe to create a floodplain bench. The floodplain bench can be designed as a geotechnical structure to add weight to the bluff toe or prevent turning, thus minimizing mass wasting. This method has been used successfully at Porter Creek, and will likely have a similar effect in Sand Creek. Following construction, the highest shear stresses are then encountered at the log or stone portion of the crib, and not at the bluff toe. Thus, the bluff stabilizes naturally and vegetation begins to move up the slope (Figures 11 and 12).

A second, less intensive approach involves the placement of regularly or strategically spaced clusters or smaller log jams along the bluff toe. These act in the same way as bendway weirs or spur dikes and are designed to break up circulating cross currents, thus minimizing toe erosion and creating depositional features between the spurs.

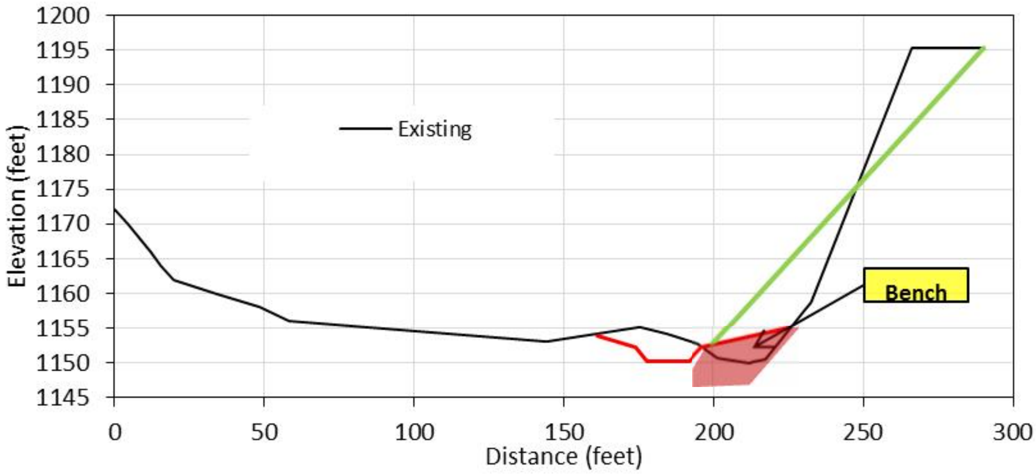

Figure 11. Existing, proposed, and expected typical cross section at a typical bluff stabilization site. The existing ground (black line) shows the channel scouring at the toe of the bluff on the right side of the valley. The proposed channel (red line) will be excavated away from the bluff toe to allow room for placement of the treatment (riprap or cribwall) and to provide room for the upper bank material to slump over (green line).

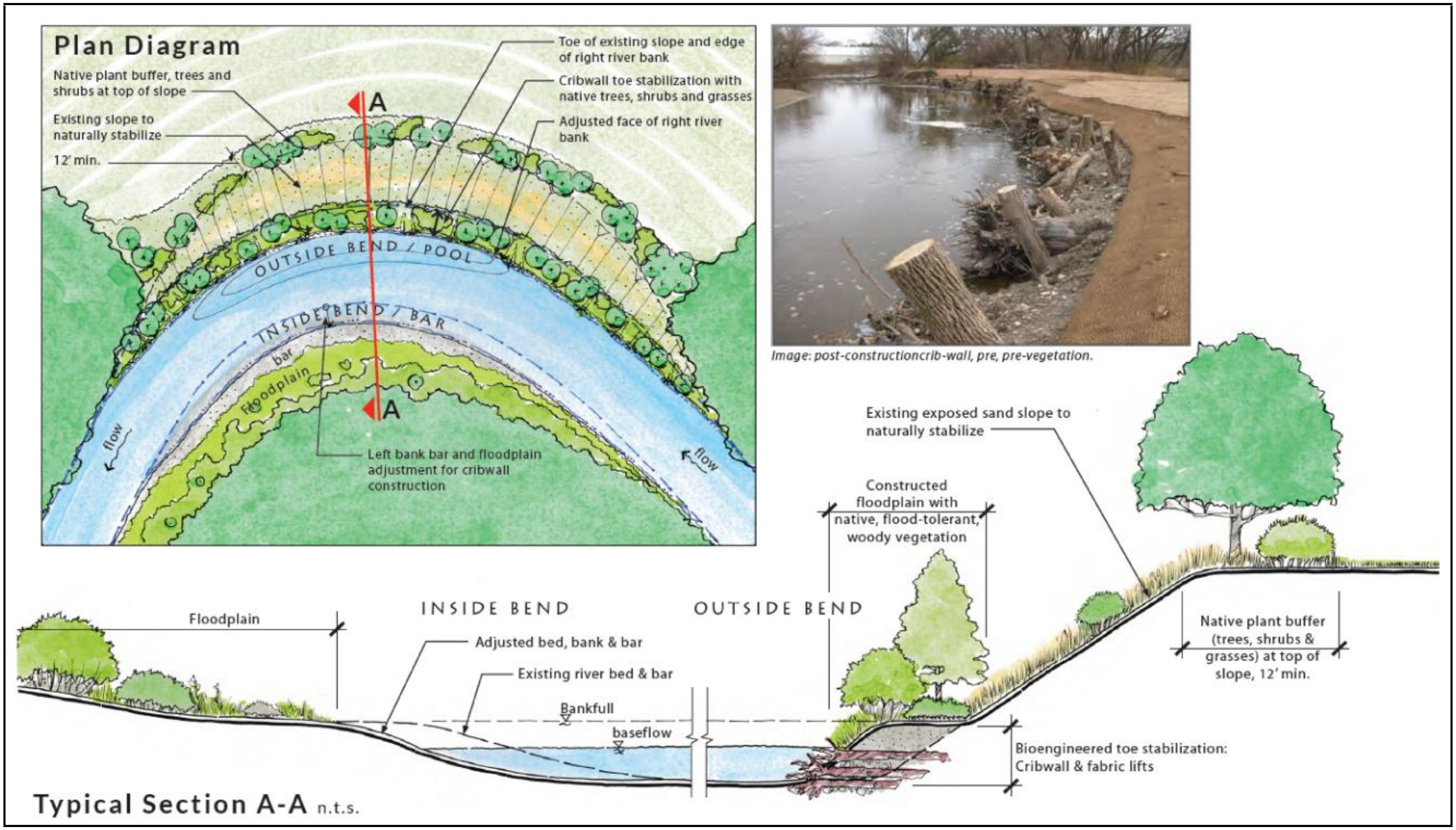

Figure 12. Planview schematic of a log cribwall stabilization project.

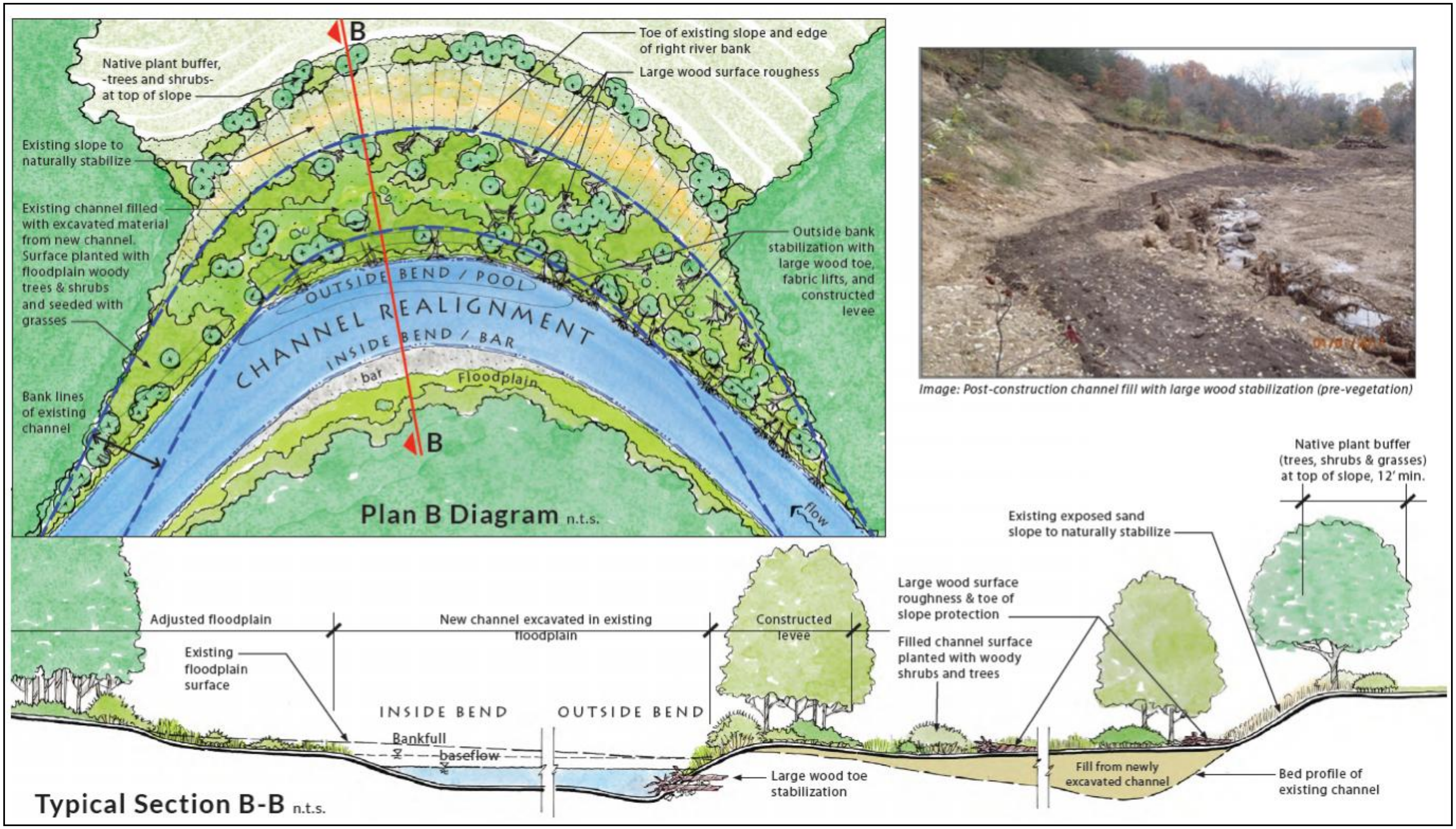

Figure 13. Planview schematic of a log cribwall stabilization project with a new channel constructed on the inside of the bend, and the existing channel filled and converted to floodplain.

In some cases, moving the channel away from the eroding bluff entirely may be more practical from both a construction and safety standpoint and project effectiveness. Under this scenario, the inside bend of the meander is moved slightly inward and the excavated material is used to backfill the crib and floodplain bench. The constructed floodplain should then be planted with native trees, shrubs, and understory plants (Figure 13).

Engineered wood toes can either be low density log jams 1-2 layers high for low floodplains, or can be more extensive log cribs with several layers of logs. Log cribs are a lattice-like structure of logs and rootwads, placed horizontally and vertically, with slash, local boulders, and soil intermixed within the log matrix (Figures 14 to 16). They are primarily used to protect bank and bluff toes. Woody debris jams are smaller, less dense, less structured treatments, used for limited toe stabilization and flow deflection. Logs exposed to wet/dry cycles are expected to decay in 15 to 30 years, and submerged wood can last as much as 200 years or more. As with any bioengineering treatment, by the time the structural elements have degraded, natural vegetation will have established and their root structures will have made the bank stronger. Trees with vegetative reproduction qualities (e.g. black willow, cottonwood) can be incorporated into the structure, which then becomes a living entity with added structural stability from root growth. Boulders and cobbles can be added to the structure to provide self-armoring material for added long term toe protection.

Figure 14. Example of a large wood cribwall under construction at the toe of a failing sand bluff on Porter Creek, near the study area. The space between the interlocking logs was filled by additional wood and rock, before being covered with soil. After construction, the bench was planted with native vegetation.

Figure 15. Vegetation established on the bench and slope face behind the cribwall noted above

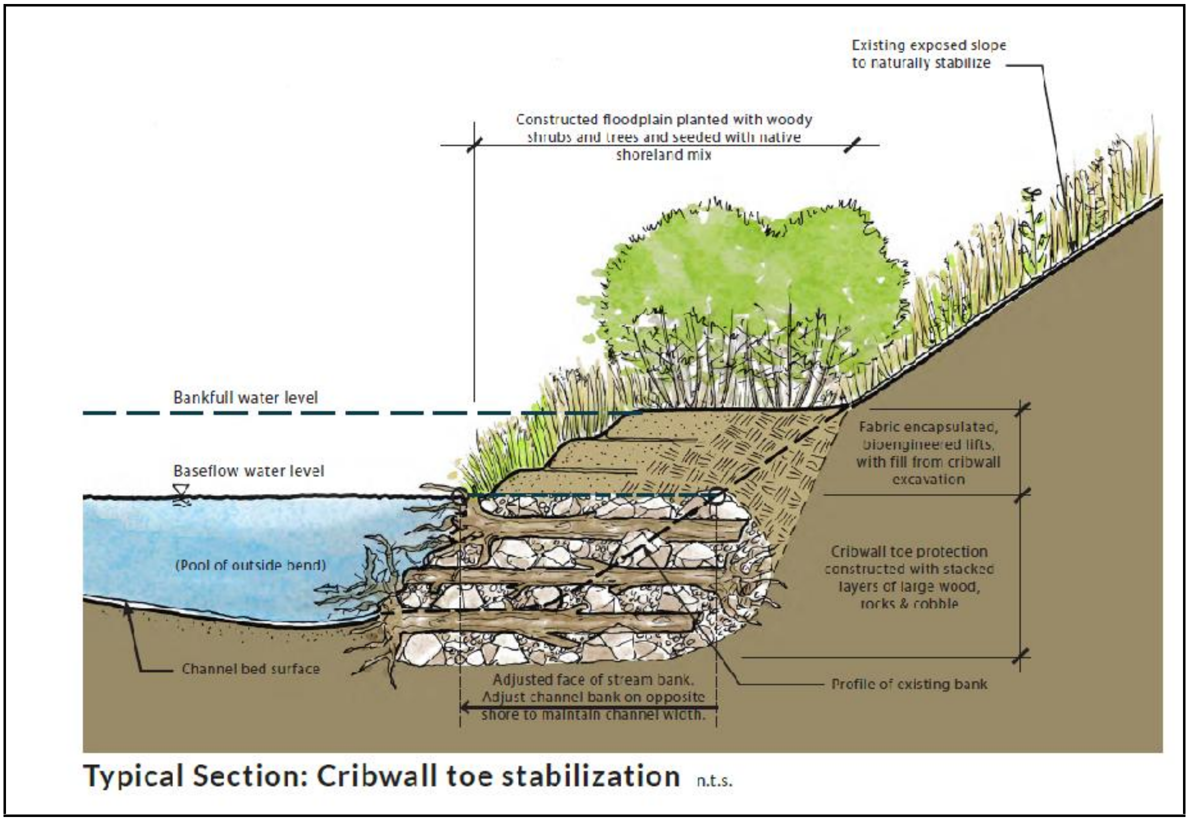

Figure 16. Schematic of a cross section through a log cribwall.

Other Considerations for Bluff Stabilization - *Traditional Riprap*

Riprap can be an effective approach, as its design and placement is a well-established practice . Riprap can be dropped down slope faces or constructed from the river side of the bank. Placement typically involves excavation to a subgrade, followed by a filter gravel or filter fabric, and then placement of stone. Riprap has significant drawbacks, including a disconnection of the aquatic environment from the terrestrial and riparian zone. Reptiles, amphibians, birds, fish and mammals that might use undercut banks or require movement along the bank vertical profile cannot do so. Riprap creates an unnatural aesthetic that can be strikingly different from the natural. The latter can be somewhat mitigated by planting among the voids (joint planting) to develop a vegetative cover over the rock. Riprap or rounded stone toes can be prudent where large wood would be subject to wet and dry cycles and thus would rot away quickly. Stone toe material can also be blended into log jams to provide launchable, self-armoring toe material upon disintegration of log jams.

Other Considerations for Bluff Stabilization – *Active Upper Slope Stabilization*

Interfluve only briefly considered extensive soil removal or grading of upper slopes, primarily to provide project level cost comparisons. Because of the size of the upper slopes, ranging from 50-100 feet high and several hundred feet long, grading of bluff slopes was viewed as not cos effective and likely undesirable. To be successful, upper slope treatments may involve grading, topsoil placement, bioengineering slope stabilization measures, seeding, and planting. Such treatment would also need to be accompanied by the same toe treatment outlined above. In most cases, toe treatments should have a larger impact on reducing sediment loads in Sand Creek, as they not only reduce fluvial entrainment and slope failures but also are often designed to catch and store material coming from upslope. Money saved by letting the upper slopes stabilize passively, as opposed to grading, can be spent on providing greater lengths of toe protection or treating toes at a larger number of sites.

PRIORITY SITES

Helena-Broadway Bluff

The Helena-Broadway Bluff Site consists of multiple rotational hillslope failures that currently release sediment to Sand Creek (Figure 17). The site lies at the outside of an eastward bend in Sand Creek. Bedrock was observed flanking the impacted bank, immediately downstream of the site, and it is unclear how far the bedrock extends upstream. Historic photos indicate the toe of the slope erodes at the upstream end of the bluff, which may trigger slope activity. In addition to the main scarps, the slope face includes numerous smaller scarps, small debris flow deposits, and rilling. A water tower lies within 150 feet of the slope break at the top of the bluff.

The propped plan for the Helena-Broadway Site combines a cribwall or toe wood treatment and spaced log spur dikes on the approach (Appendix E, Sheet 2). There is no need for toe stabilization on the downstream end due to bedrock protrusion. Final design of the Helena-Broadway bluff site will include geotechnical investigation and a slope stability analysis. In this case, secondary slumps on the upper hillslope and potential seep issues could compromise toe stabilization. If bedrock limits the installation of log piles, a constructed cribwall may not be an appropriate treatment and alternative measures, such as drainage modification, rock toe, or rock weirs will be examined.

Figure 17. Helena-Broadway Bluff. The bluff includes an upper and lower slump, and the face features smaller slumps and rills. Bedrock limits erosion at the downstream end of the bed (left).

Sawmill Lane Bluff

The Sawmill Lane bluff site is a high, steep, sandy bluff along a large bend in the river (Figure 8; Figure 18). The bluff face is lined with small, leaning trees, rills, and sediment cones. A cobble bar lies at the inside of the bend and sand and gravel has deposited downstream. At the upstream end of the site, a woody debris jam forces flow away from the bank and protects the vegetation growing on the toe of the slope behind and immediately downstream (Figure 19).

We propose a series of spur dikes constructed from small jams (Appendix E, Sheet 3). The effect of the existing woody debris analog on site and roughly half of the bend planform is straight indicates spaced log jam spurs could be used effectively to reduce toe erosion and encourage deposition and vegetation growth. Some excavation of the existing mid-channel bar may also be required.

Figure 18 (left). Sawmill Lane Bluff Site featuring shallow slope failures, leaning trees, sediment cones and rills. A large cobble bar has formed on the inside of the bend (right).

Figure 19 (right). Existing debris jam at the toe of Sawmill Lane Bluff. The jam forces flow away from the bank and protects vegetation downstream and behind the wood.

W 210th St-South Ravine

Of the six sites selected for potential projects, the W 210th St -South Ravine, is the only ravine site. The ravine runs along an abandoned road, and shows signs of recent incision. Valley wall erosion is evident along the entire reach, including both toe erosion and slumping along upper banks. The downstream end of the channel is an actively incising gully only 5 feet wide, but over 8 feet deep. This gully will likely widen over time, releasing a significant amount of sediment into Sand Creek (Figure 20). The road provides excellent site access.

The solutions proposed in the concept drawings include WASCOB or detention basin installation at the headwaters and channel widening and check dam installation downstream (Appendix E, Sheet 4).

Figure 20. Narrow ravine channel at the downstream end of the W 210th St – South Ravine.

210th St W – North Bluff

This bluff site lies at the downstream end of a relatively steep, straight reach of Sand Creek, directly before the channel bends to the west (Figure 8). The upstream end of the bluff deposit includes a bouldery channel deposit, which may help protect the bluff, whereas the downstream end is predominantly sand (Figure 21). A large, sandy, cobble bar at the base of the slope directs low flows to the inside of the bend, but erosion along the downstream, east bank indicates high flows have sufficient shear to move material (Figure 22). Historical photos indicate the channel has migrated significantly at this location.

The proposed solution (Appenidix E, Sheet 5) involves a cribwall stabilization of the steep bluff toe, including creation of a low profile floodplain bench consistent with the downstream bankfull depth. Stabilization of the lower end of the project area would include either placement of strategic roughness elements (log jams) that force flow away from the eroding bank, or a toe wood treatment along the eroding bank. If this site is chosen for final design, additional analysis of the downstream end of the site will be completed to ensure that the chosen treatment is appropriate.

Figure 21. 210th St W – North Bluff.

Figure 22. Cobble Bar and bank erosion downstream of the 210th St W – North Bluff

Highway 8 – Xanadu Bluff

The Highway 8 – Xanadu Site is one of the highest sediment producing areas along the channel. It consists of two failing slopes. The upstream bluff recently failed and appears to be highly unstable (Figure 23). The downstream bluff is steep, with debris cones and rills along the face, but does not appear to be actively collapsing (Figure 24). The site occupies a large compound bend along Sand Creek, and the failures are likely related to toe erosion along the outside of the bend. A residence/business occupies the top of the bluff and structures are often within 100 feet of the slope break.

The Xanadu bluffs are high (60-80 ft) and very steep, with near vertical slopes in some areas. Whereas, the other project sites have no infrastructure immediately affected by slope retreat, the Xanadu site has homes and other structures built near the bluff edge. Stabilization of the toe of these bluffs may slow down further mass wasting, but the bluff tops will continue to lose material until an angle of repose is met. Continued slope retreat may be a slow process or it could occur episodically at any time. The exact stable angle of repose is currently unknown, but a range of values could be determined through geotechnical analysis. Slope stability would not be achieved without either passive or active removal of material from the top of the slope, with either case involving relocation of infrastructure. For example, if a 1.5H to 1.0V slope was desired, the top of the bank would need to be moved back 120 feet.

The proposed treatment (Appendix E, Sheet 6) includes toe stabilization, but it is recommended that if this approach is taken, that either the slope be excavated or the infrastructure adjacent to the upper slope be moved to allow for natural failure of the upper slope. We have not included active excavation design in the concept plans, but excavation is included in the estimated costs for the project (Appendix E).

Figure 23. Upstream bluff at the Highway 8 – Xanadu Site. The bluff has recently failed and is relatively unstable.

Figure 24. Downstream bluff at the Highway 8-Xanadu Site. Sediment cones and rills line the bluff face.

Xanadu-Sawmill Bluff

The Xanadu-Sawmill Site consists of a recent (2014-2015) bluff failure into Porter Creek, a primary tributary of Sand Creek. The failure appears to have pushed Porter Creek to the east, and the channel currently flows through a debris jam at the toe of the collapsed slope. The channel, which is approximately 20 feet wide downstream, is only about 5 to 10 feet through the impacted area, and higher flows appear to be flanking the existing jam at the inside of the bend. The failed slope is sandy, relatively loose, and cut by rills. Additional erosion along the base and face of the slope is expected.

The proposed treatment involves installation of either a series of small spur jams, as depicted in Appendix E, Sheet 7. Alternatively, a low profile and low density log jam could be constructed along with some channel excavation to achieve a stable cross-section. Excavated material would be used to backfill the log jams and provide ballast against buoyant forces acting on the installed wood. This approach is similar to the one used successfully at Porter Creek bluff sites in 2011.

PROJECT COSTS

Costs for river projects vary widely due to a number of factors, including the availability of materials, the complexity of site access, the need and complexity of water management for channel work, the experience of the contractor, and economies of scale. In recent years, we have seen the unit prices for excavation and installation measures increase by as much as 50% over the previous decade, largely due to the limited number of construction contractors available.

Costs are also highly variable by area and time of year. Inter-Fluve has constructed wood based bluff erosion solutions under a wide range and combination of circumstances. The price per installed piece has varied from $100 to $900 per piece depending on the location and installation details. Average costs for installed wood in the Minneapolis-St. Paul Metropolitan Area are generally between $300 and $400 per piece. If Scott County can acquire the wood, installation costs can be reduced to $100 - $300 per piece. Planning level estimated project costs are provided in Appendix F. Costs will be refined during the final design process.

CITATIONS

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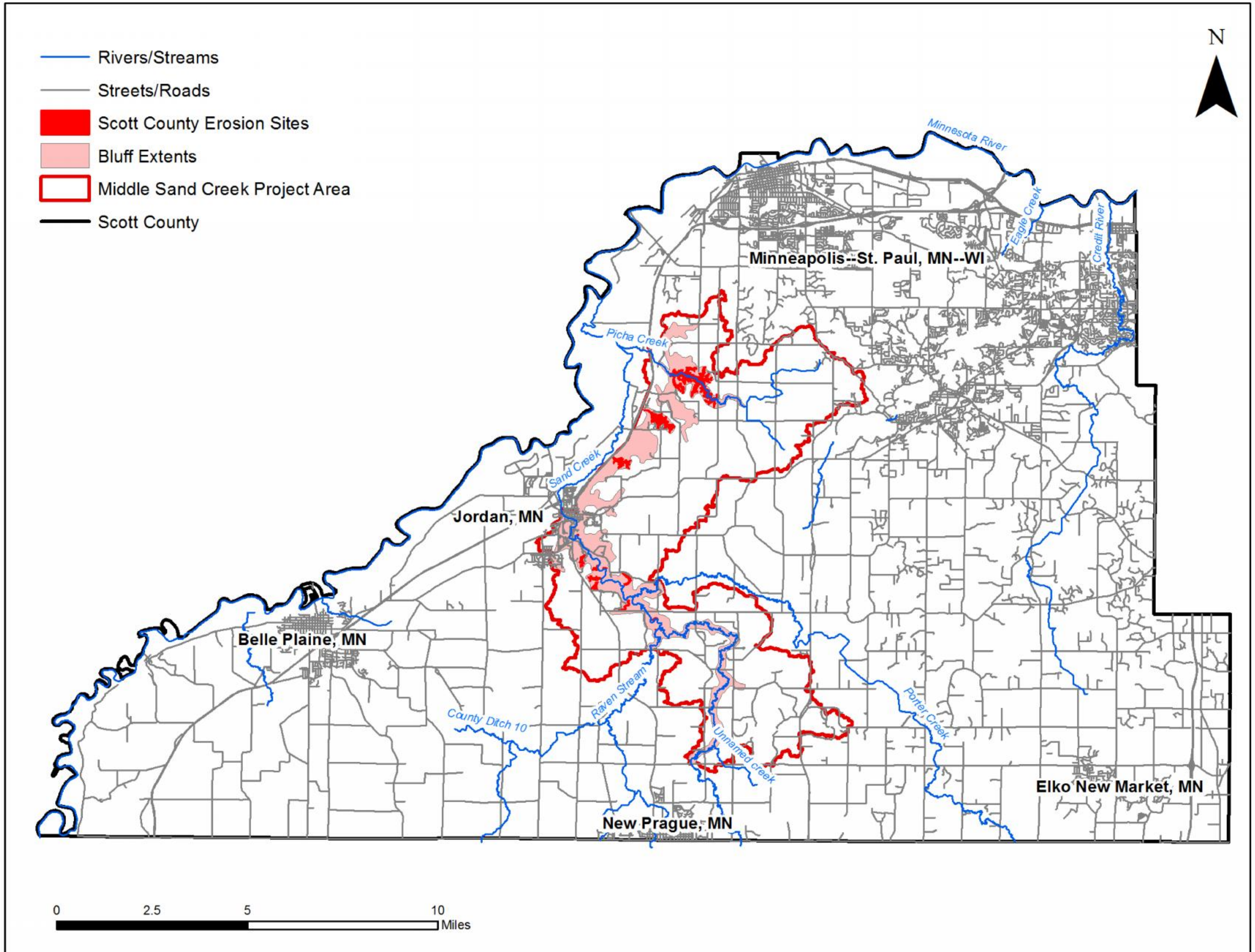
APPENDIX A. Prioritization Scoring Rubric for Sand Creek Projects.

Parameter	Weight	1	3	5	7
Sediment/nutrient loading (Sand and Picha Creeks)	2	No significant load reduction to Sand or Picha Creek	Minor reduction in sediment loading (0-250 CY/YR); sediment is managed or deposited before reaching Sand or Picha Creeks	Moderate reduction in sediment yield to Sand or Picha Creeks (250-500 CY/YR), reduced yields to perennial tributaries	Significant reduction in sediment yield to Sand and Picha Creeks and perennial tributaries (>500 CY/YR)
Erosion/Channel Stability	1.5	Minimal improvement to erosion and stability	Low to moderate improvement (<25 CF/FT/YR)	Moderate improvement (<40 CF/FT/YR)	Significant improvement to overall stream stability and function; (> 50 CF/FT/YR)
Project cost	1	> $300K	$200 - $300K	$50 -$200K	$0 - $50K
Project complexity	1	Geotechnical considerations, specialty design services required, difficult access, heavy oversight, major earthwork, EAW/EIS permitting	Geotechnical consideratoins, difficult access, engineering plans required, earthwork, significant permitting	Moderately complex, no specialty engineering required, some access issues, minor earthwork, basic permitting	Elementary solution, shelf design, volunteer and hand labor implementation, no permits
Infrastructure risk	0.5	No risk to infrastructure with no action, or no infrastructure present	Low to moderate infrastructure risk and minimal risk to public safety with no action (100-150 ft from eroding bluff or bank face), or infrastructure value <$100,000	Infrastructure at moderate but not immediate risk, moderate public safety risk, (50-100 ft from eroding bluff or bank face) or infrastructure value <$200,000	Infrastructure at high or immenent risk of failure with no action. Public safety at risk. (<50 ft from eroding bluff or bank face) or infrastructure value >$200,000

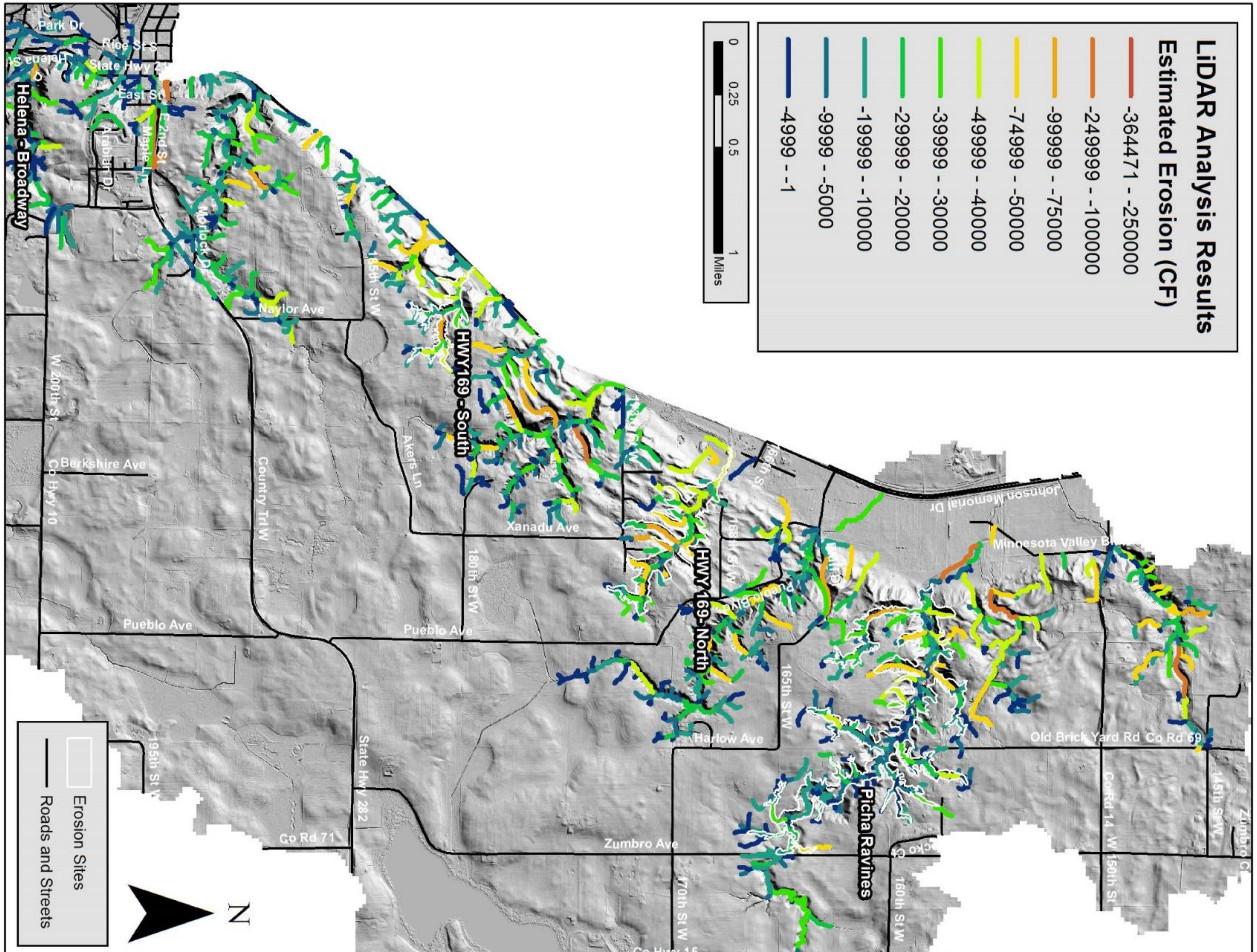
APPENDIX B. Sand Creek – Instability Areas and Potential Solutions.

Sites	Type	Project Types	Recommendation	Status	Sediment Nutrient loading	Erosion	Project cost	Project complexity	Infrastructure risk	Final Score	Notes
HWY8-Xanadu	Bluff	Toe Stabilization	Geotech Investigation, Log Jam, Flow Deflection, Cribwall at DS Bluff	Priority	7	5	3	3	6	30.5	Concentrate on DS end of Bluff/ US end has geotechnical issues (seeps, etc)
Helena - Broadway	Bluff	Toe Stabilization	Log Jam, Flow Deflection	Priority	3	7	3	4	1	24	Clear signs of rilling and slope failure, Log Jam analog at US end of site
210th St W - North	Bluff	Toe Stabilization	Log Jam, Cribwall	Priority	4	5	3	3	1	22	Bluff erosion and meander migration evident in air photos (~7000 CY Yield/ ~8000 CY erosion)
Sawmill Lane	Bluff	Toe Stabilization	Log Jam, Flow deflection, Cribwall	Priority	3	4	4	4	2	21	Not much erosion on air photos, clear signs of slope failure and rilling
Xanadu - Sawmill	Bluff	Meander Cutoff	Meander Cutoff	Priority	3	3	5	3	1	19	Tributary Channel/ Pull bend inside of existing log jam/slump
210th St W - South	Ravine	Control Basins Grade Control	WASCOB/Channel Wood, Check Dams	Priority	2	3	6	4	1	19	Narrow, deep ravine along abandoned road
Lower Picha Ravine	Ravine	Grade Control	Wood jams (check dams), Channel wood	Alternate	3	3	3	3	4	18.5	Previous work is failing, DS ravine does not appear to impact Picha Creek significantly
Golfview - HWY21	Ravine	Grade Control	Wood jams (check dams), Channel wood	Existing Project	3	3	3	3	4	18.5	Not part of field investigation
Marden Ct	Bluff	Meander Cutoff	Meander Cutoff or Cribwall	No Action	2	2	7	2	4	18	Meander will be naturally cut at neck in the near future
Delmar - HWY21	Ravine	Grade Control	Wood jams (check dams), Channel wood	Existing Project	3	3	3	3	3	18	Not part of field investigation
Camber Ave	Bluff	Toe and Slope Stabilization	Geotech Investigation, Roughened Toe, Log Jam, Cribwall	Future Project	2	2	4	3	7	17.5	May require geotech work to save yard
HWY189 - North	Ravine	Grade Control	Wood jams (check dams), Channel wood	Existing Project	2	3	3	2	7	17	Sediment stored at DS end of channel and in constructed sediment traps below ravine.
HWY189 - South	Ravine	Grade Control	Wood jams (check dams), Channel wood	Future Project	2	2	3	3	2	14	Not part of field investigation
Ridgeview Cir	Ravine	Grade Control	Wood jams (check dams), Channel wood	No Action	1	2	3	3	3	12.5	Channel appears to be adjusting well, field investigation suggested less erosion than LiDAR data
Sawmill - Naylor	Ravine	Grade Control	Wood jams (check dams), Channel and bank toe wood,	No Action	1	2	3	3	3	12.5	Channel appears to be adjusting well, some exposed bluffs at outside of bends, field investigation suggested less erosion than LiDAR data
Green Ash Ct	Ravine	Grade Control	Wood jams (check dams), Channel wood	No Action	1	2	2	2	5	11.5	Sediment basin at downstream end, infrastructure risk, but no sediment to Sand Creek

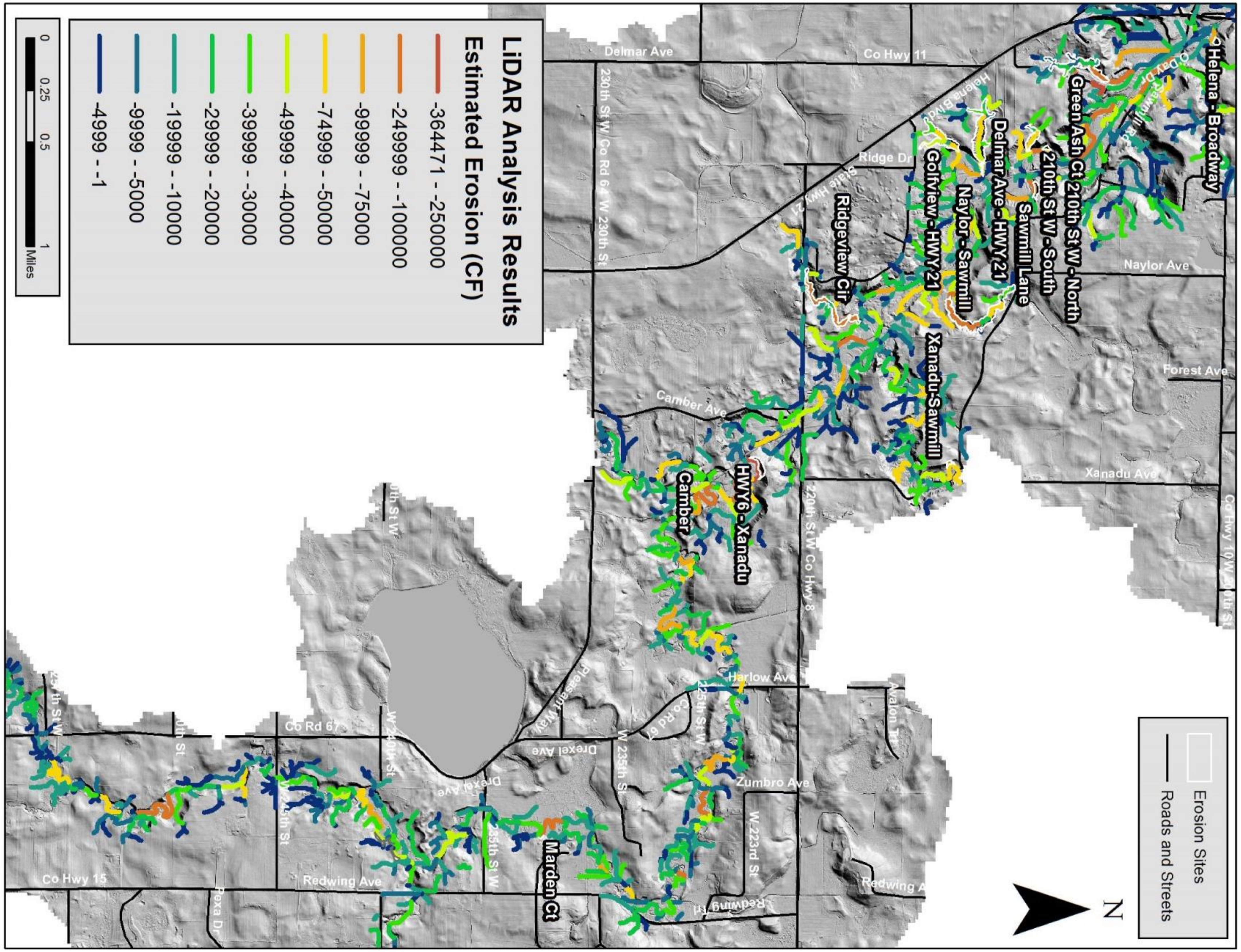
APPENDIX C. Scott County Site Map



APPENDIX D1. Erosion within the Sand Creek system in Scott County (North).



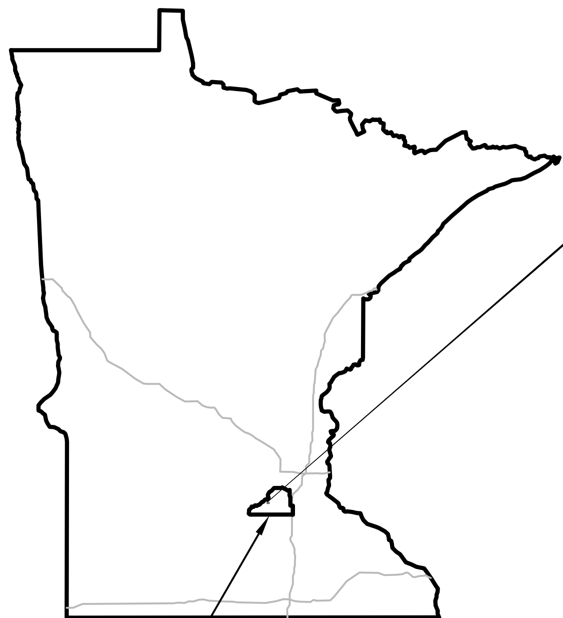
APPENDIX D2. Erosion within the Sand Creek system in Scott County (South).



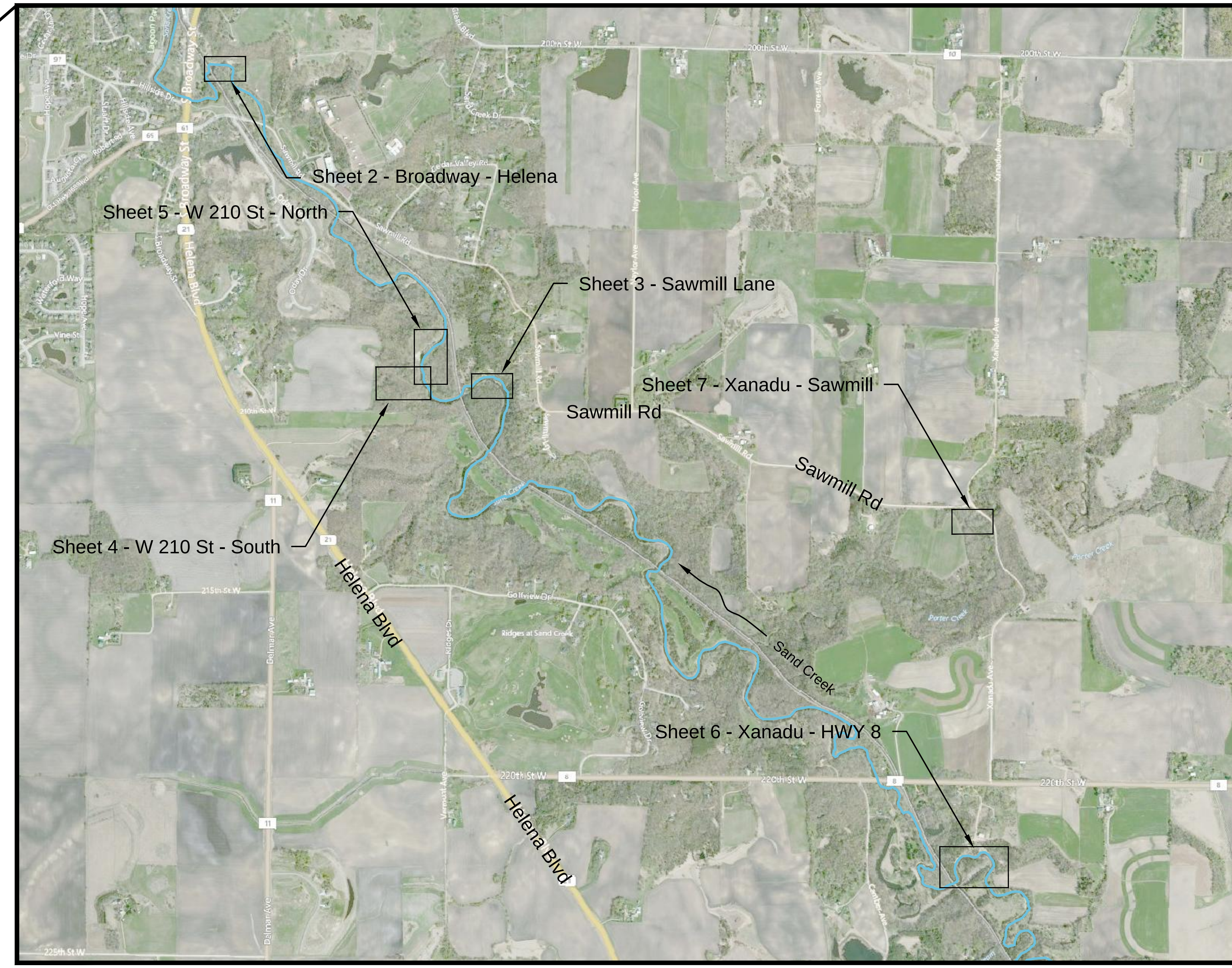
Appendix E. SITE CONCEPTUAL DRAWINGS

SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION
SCOTT COUNTY, MN

Conceptual Design, September 16, 2015



STATE MAP - MINNESOTA
NOT TO SCALE



LOCATION MAP
SCALE 1" = 2000'

SHEET INDEX

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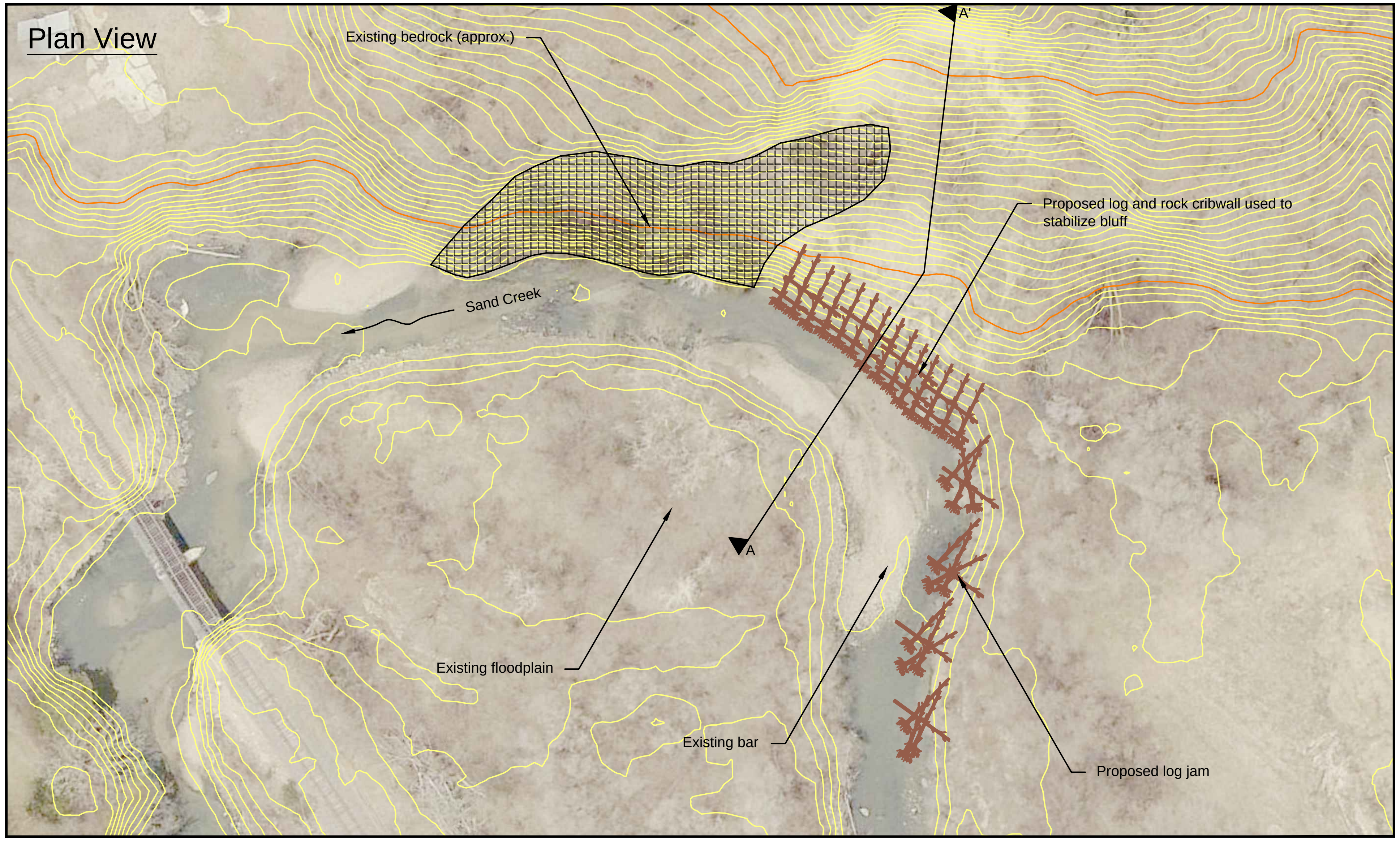

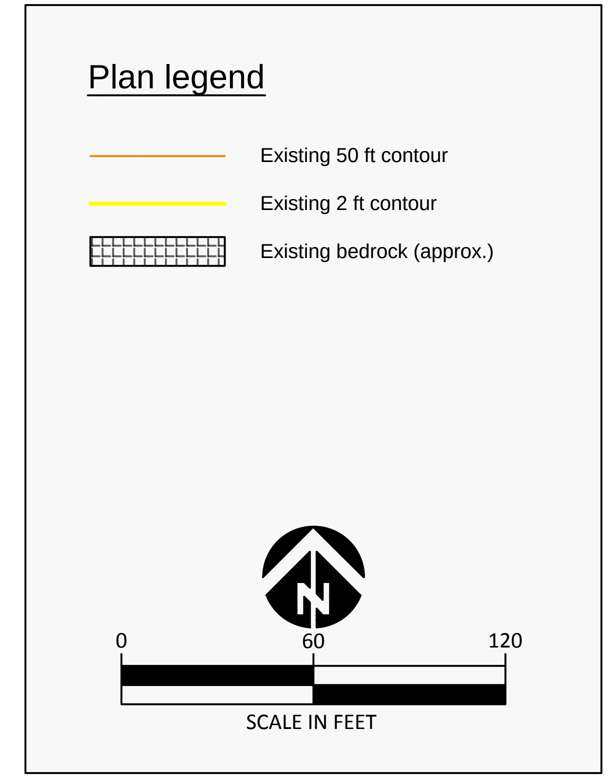

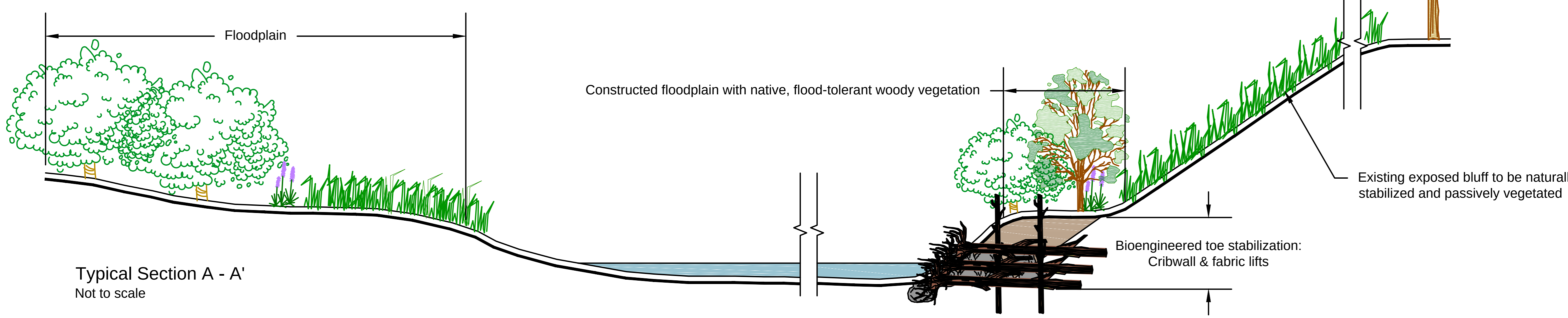

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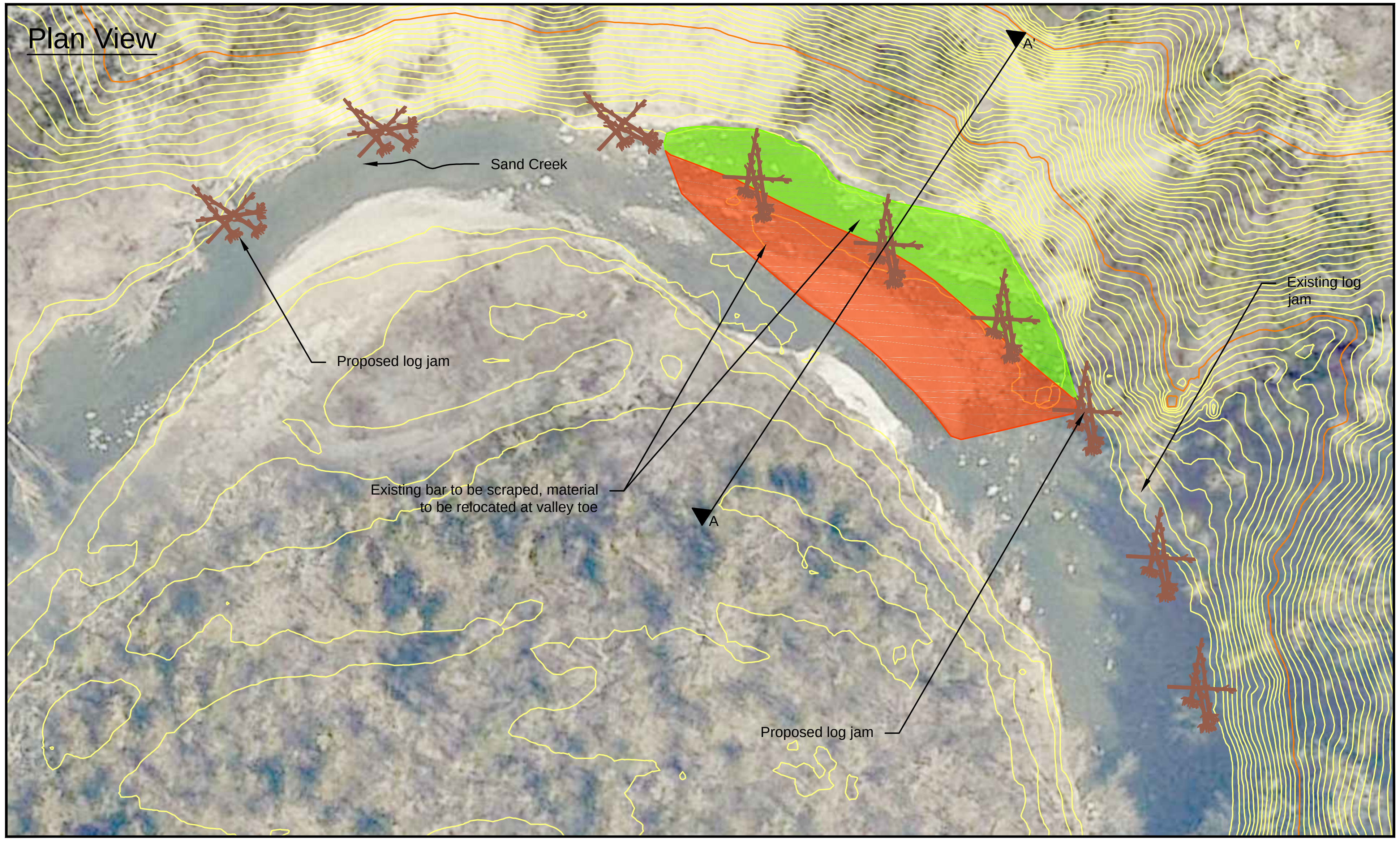
SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

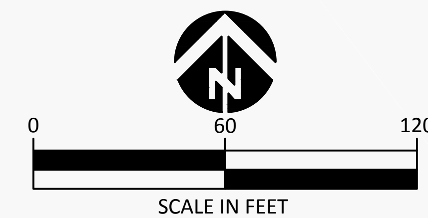
Broadway - Helena Proposed Conditions

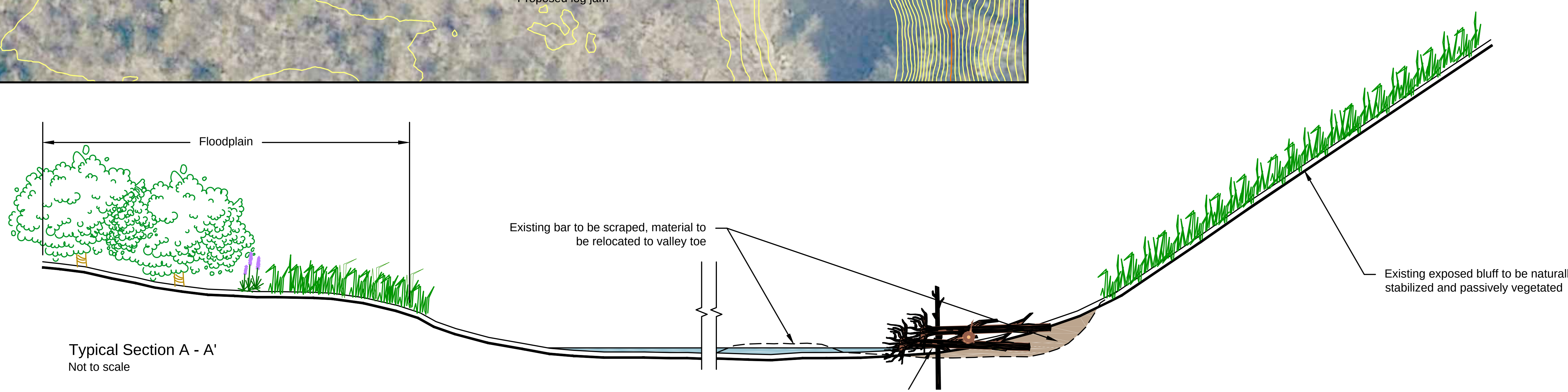
September 16, 2015



Plan legend

- Existing 50 ft contour
- Existing 2 ft contour
- Proposed material excavation
- Proposed material relocation





Typical Section A - A'
Not to scale

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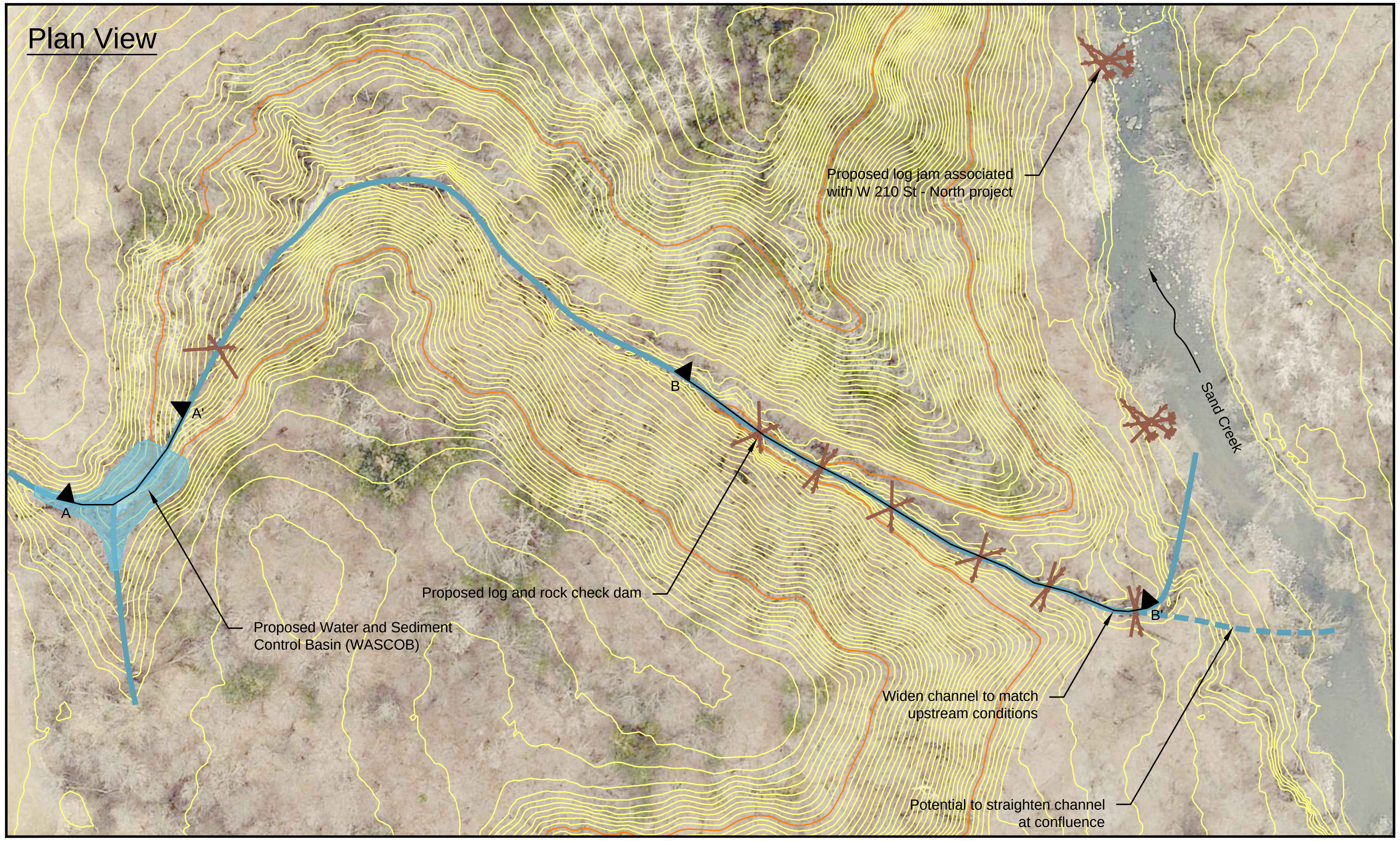
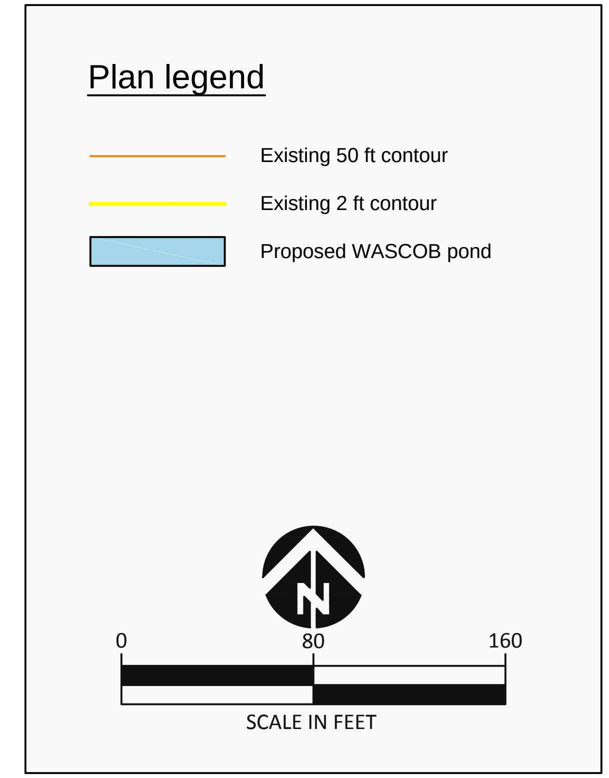
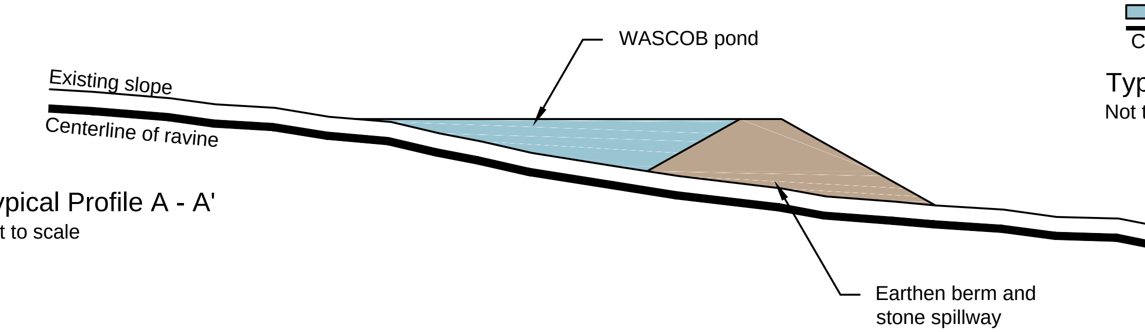
SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

Sawmill Lane Proposed Conditions

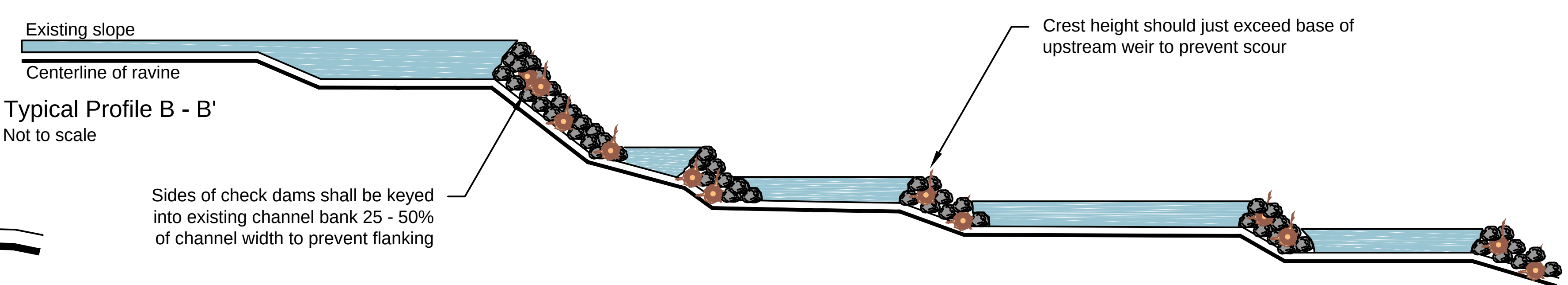
September 16, 2015







Typical Profile A - A'
Not to scale



Typical Profile B - B'
Not to scale

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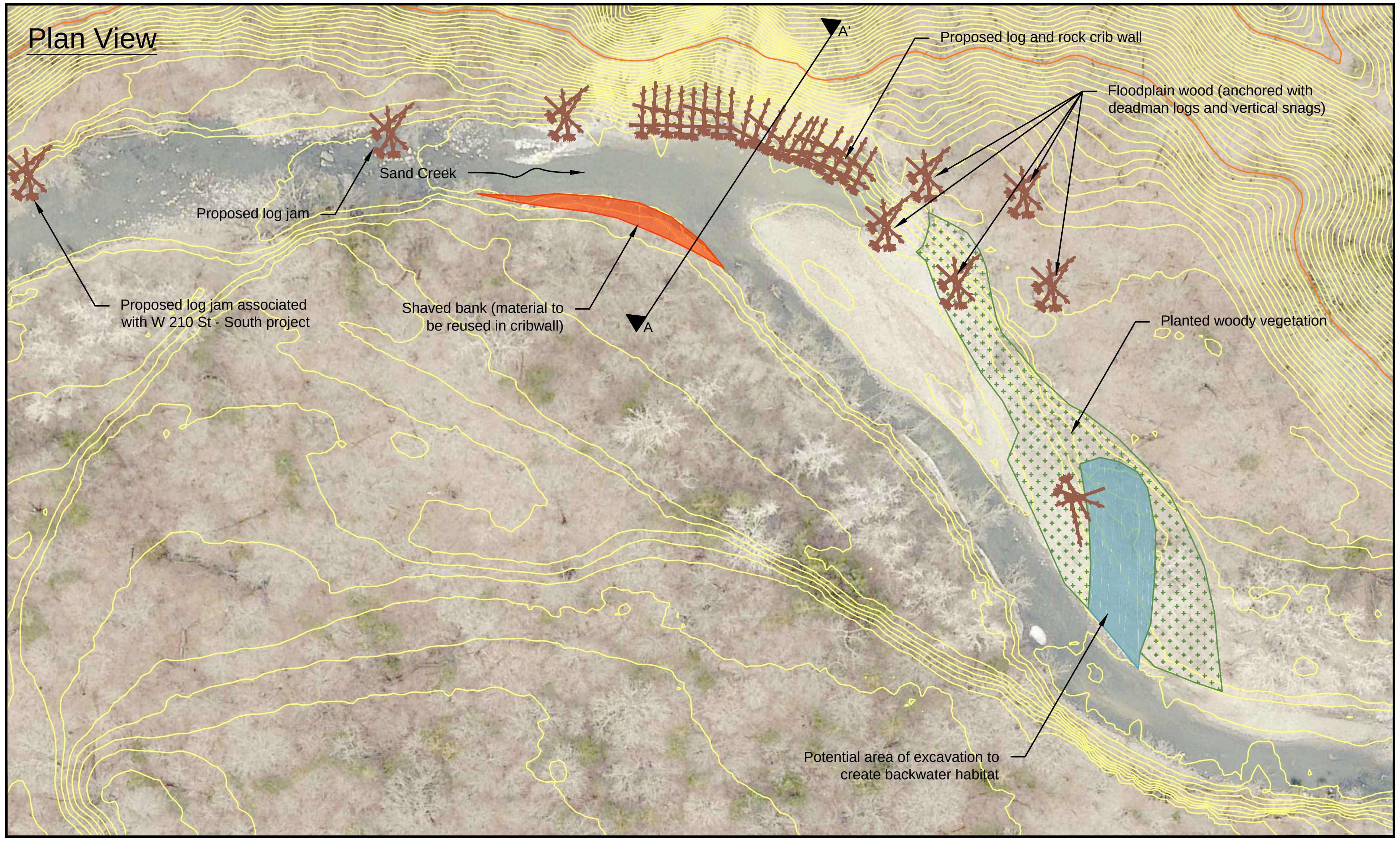
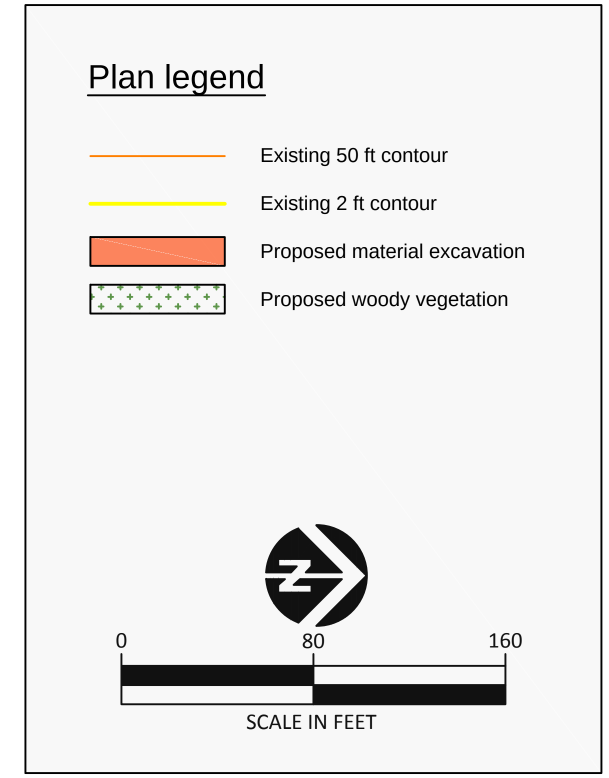
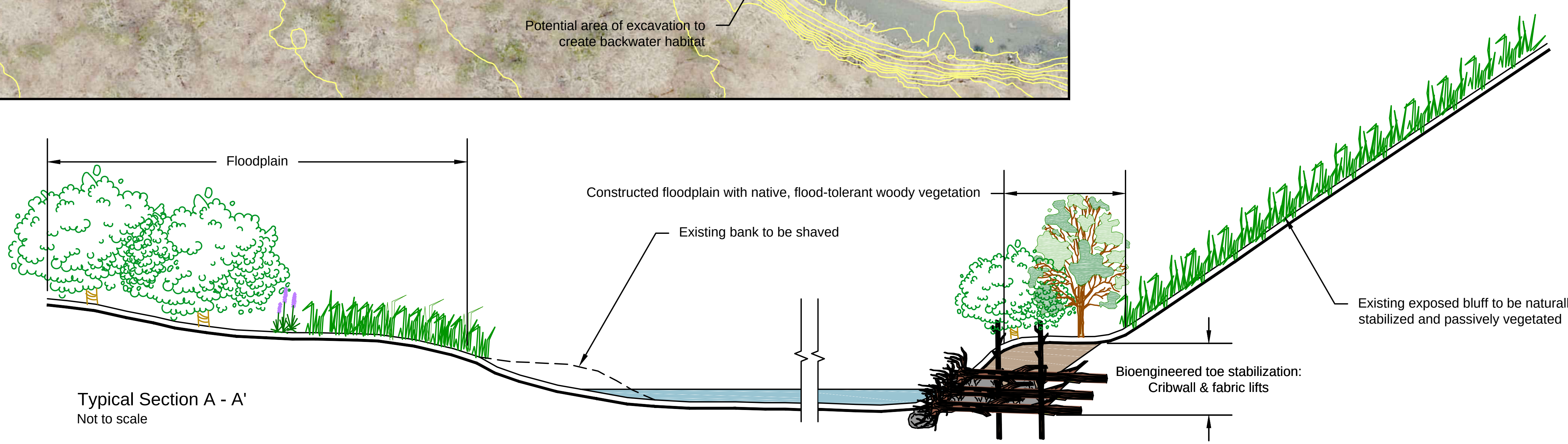
SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

W 210 St - South Proposed Conditions

September 16, 2015







Typical Section A - A'
Not to scale

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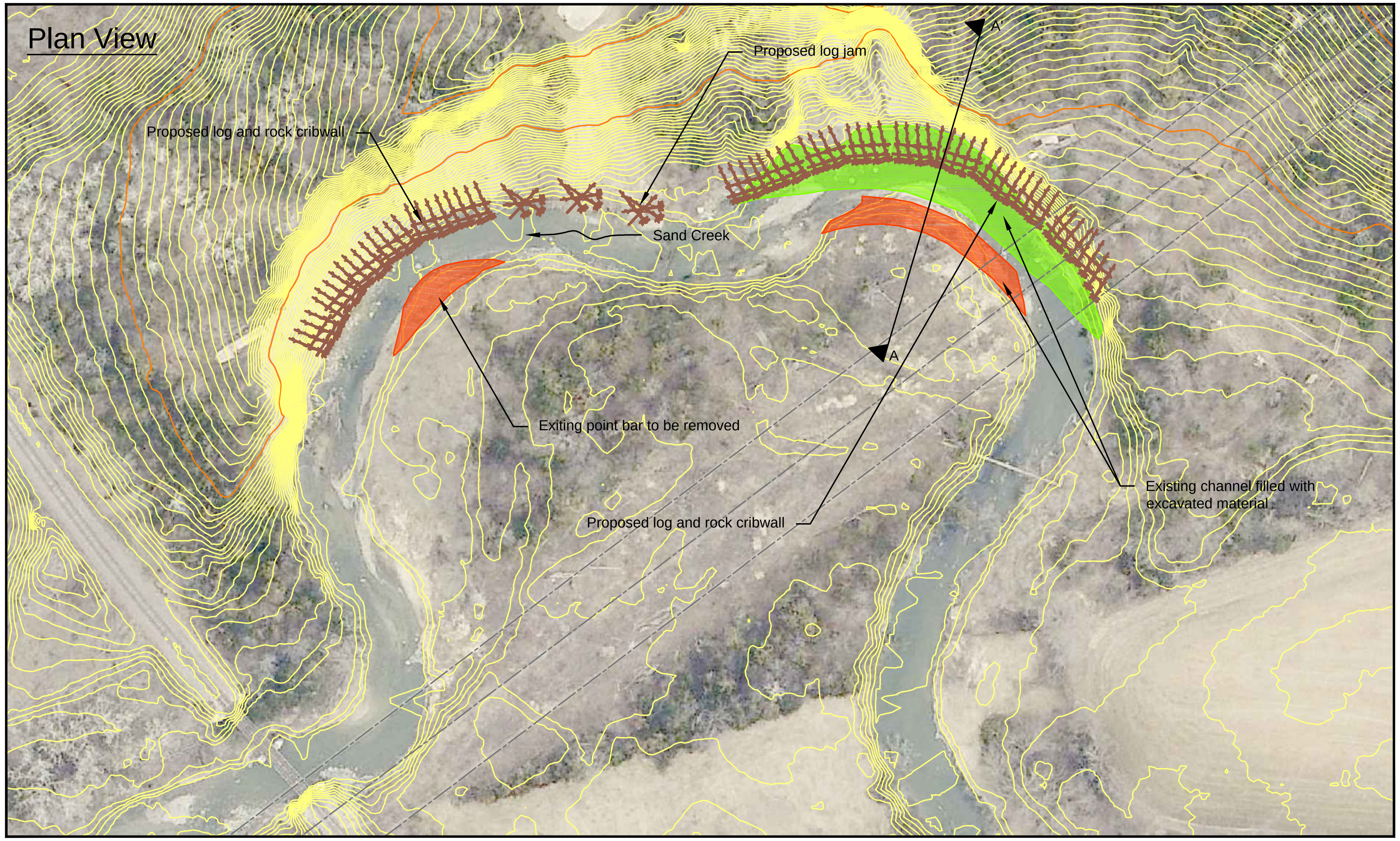
SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

W 210 St - North Proposed Conditions

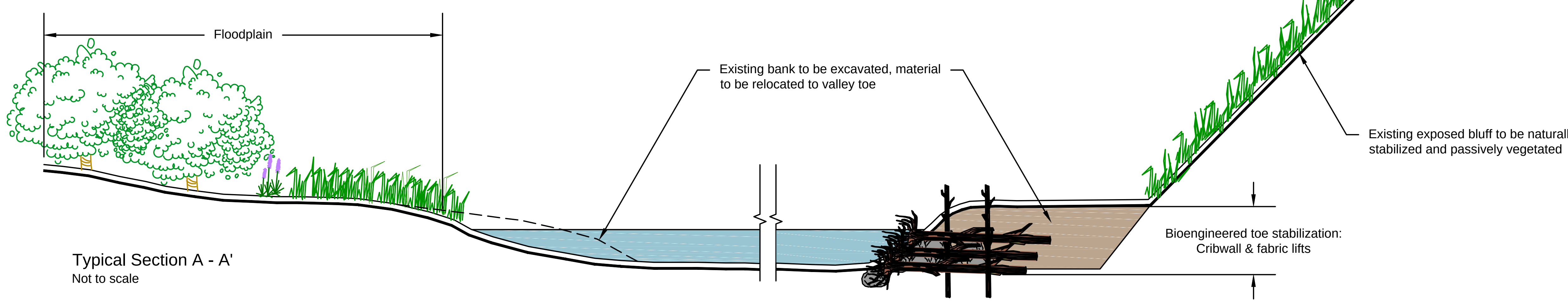
September 16, 2015



Plan legend

- Existing 50 ft contour
- Existing 2 ft contour
- Proposed material excavation
- Proposed material relocation
- Existing power lines

0 100 200
SCALE IN FEET



Typical Section A - A'
Not to scale

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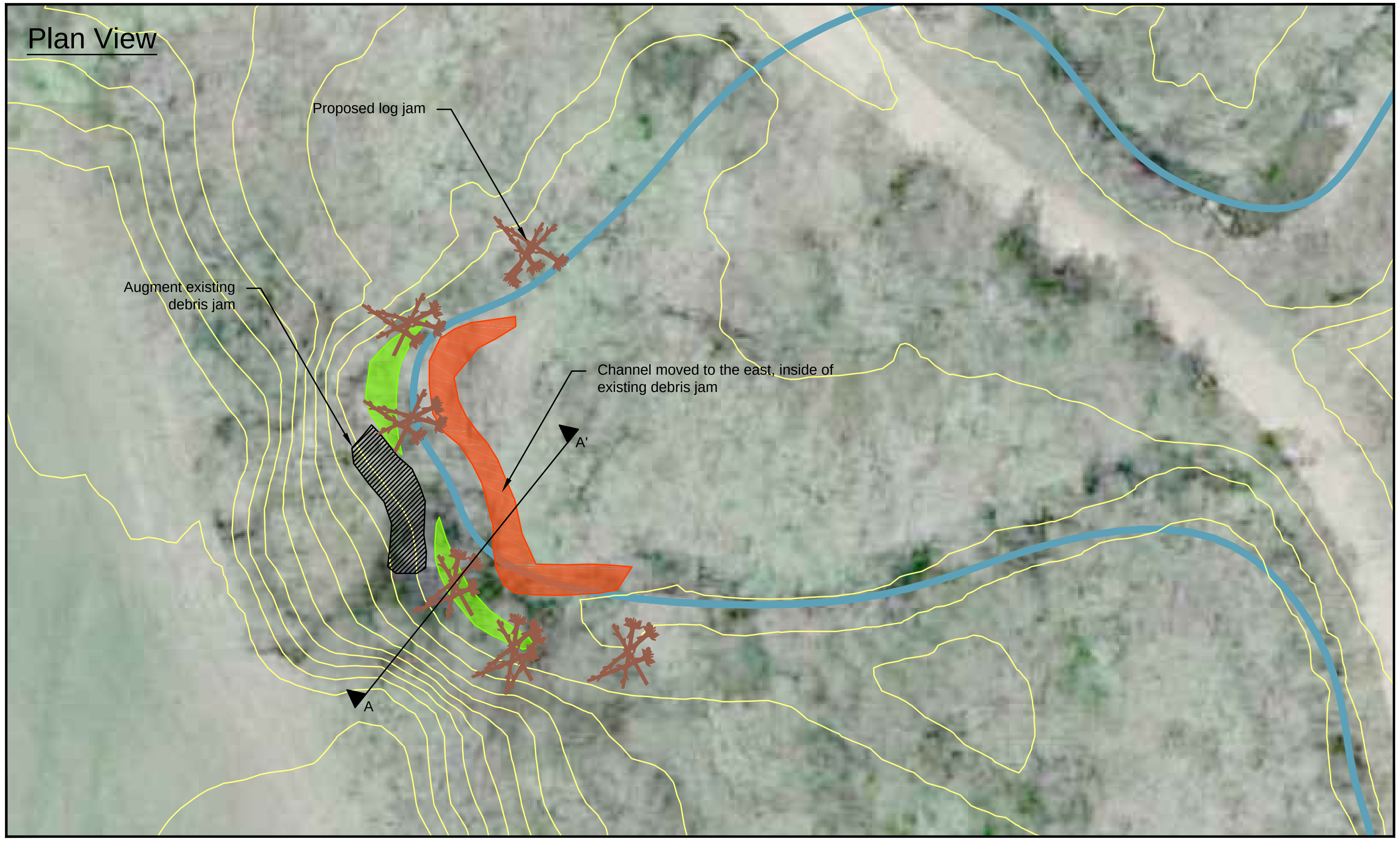
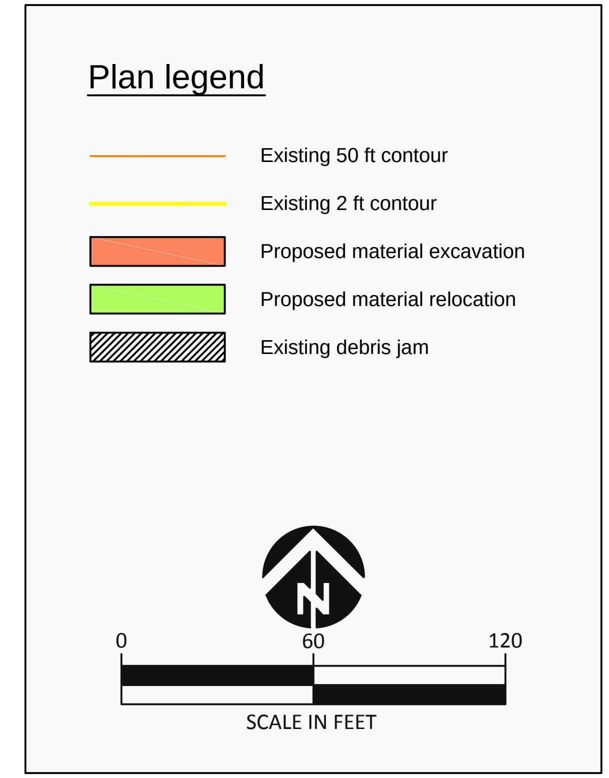
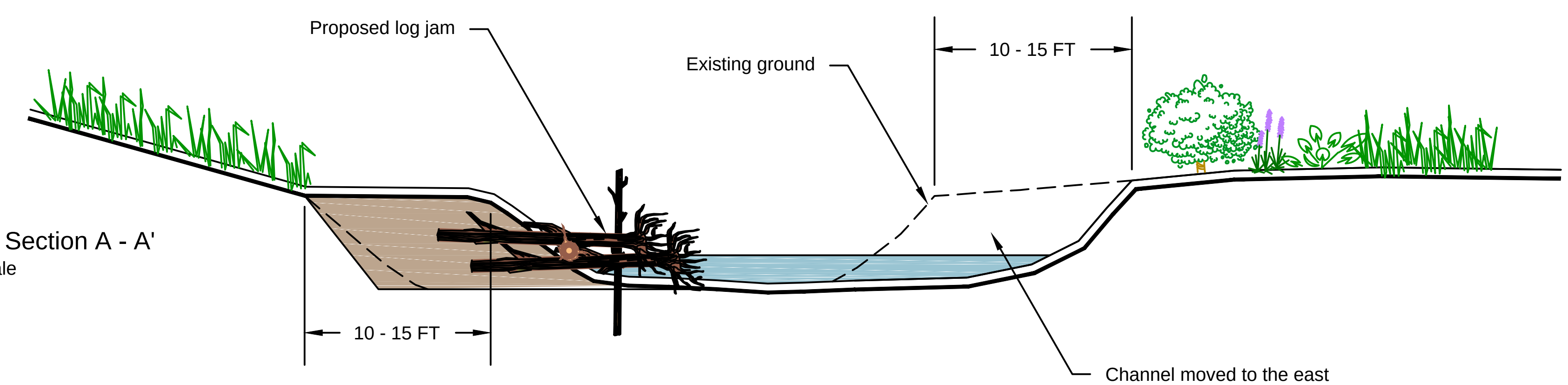
SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

Xanadu HWY 8 Proposed Conditions
September 16, 2015







Typical Section A - A'
Not to scale

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SAND CREEK NEAR CHANNEL SEDIMENT REDUCTION

Xanadu - Sawmill Proposed Conditions

September 16, 2015

Appendix F. PROJECT COST ESTIMATES

Sand Creek Near Channel Sediment Reduction

Summary Concept Cost Estimate 9/27/2015

Site	Final Design, Permitting and Const. Mgmt. Cost	Construction Management Cost	Toe Stabilization Cost	Optional Upper Slope Stabilization Cost
Helena - Broadway	$ 35,000	$ 14,000	$ 181,894	$ 1,541,000
Sawmill Lane	$ 30,000	$ 14,000	$ 174,507	$ 962,167
W 210th St South	$ 34,000	$ 22,000	$ 181,125	NA
W 210th St North	$ 27,000	$ 18,000	$ 247,308	$ 782,000
Hwy 8 Xanadu	$ 145,000	$ 40,000	$ 3,239,898	NA
Xanadu - Sawmill	$ 23,000	$ 16,000	$ 95,803	NA

Costs are planning level in nature, actual costs may vary +/- 50%
Construction costs include contingency (15%)
Design costs assume concepts and 30% are complete with grading surfaces built
Construction management includes construction observation