Restoration Concepts and Approaches for Lulu Creek, Colorado River, and the Lulu City Wetland Impacted by the May 2003 Breach of Grand Ditch, Rocky Mountain National Park, Colorado (DRAFT 9/8/14)

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INTRODUCTION

In May 2003, a breach of the Grand Ditch in Rocky Mountain National Park (RMNP) initiated a massive debris flow on the hillslope below the ditch (Figure 1). Approximately 48,000 yd^3 of sediment was mobilized during the debris flow, entered Lulu Creek, and deposited a large debris fan at the confluence with the Colorado River. Abundant sand- to boulder-sized sediment was transported, sorted, and deposited along the Colorado River and the Lulu City wetland for over 2.5 km downstream. The debris flow caused extensive damage to channel, riparian, and wetland areas in RMNP and a civil lawsuit was filed by the U.S. Justice Department on behalf of the National Park Service in 2004. In 2008, an out-of-court settlement with the owners of Grand Ditch was reached. The Record of Decision on the Final Environmental Impact Statement (FEIS) was filed in August 2013. Rocky Mountain National Park (RMNP) and the National Park Service (NPS) have supported field assessments of the impacts of the debris flow in preparation for channel, riparian, and wetland restoration. This report describes the design concepts and recommendations for restoring the channel and floodplain of Lulu Creek, the Colorado River, and the Lulu City wetland.

Airborne lidar flown over the study areas in September 2012 was used to quantify topographic changes that occurred since an initial 2004 lidar survey. Major channel changes and redistribution of 2003-debris flow sediment occurred during snow melt runoff in 2011, the highest flow in 60 years of record, and again during snow melt in 2014. During both of these seasons, extensive channel morphologic changes occurred along Lulu Creek and the Colorado River as a result of excessive 2003-sediment and wood transport that either blocked footbridges or created new log jams around which channel avulsions occurred. Restoration base maps (1 ft contour interval) are derived from the 2012 lidar (vertical accuracy <5 cm) and hence, the base maps no longer document existing topographic conditions. It is estimated, however, that lidar-derived base maps from 2012 are within approximately 10-20% of existing channel and floodplain conditions, variability that is deemed suitable for implementing restoration channel and wetland designs.

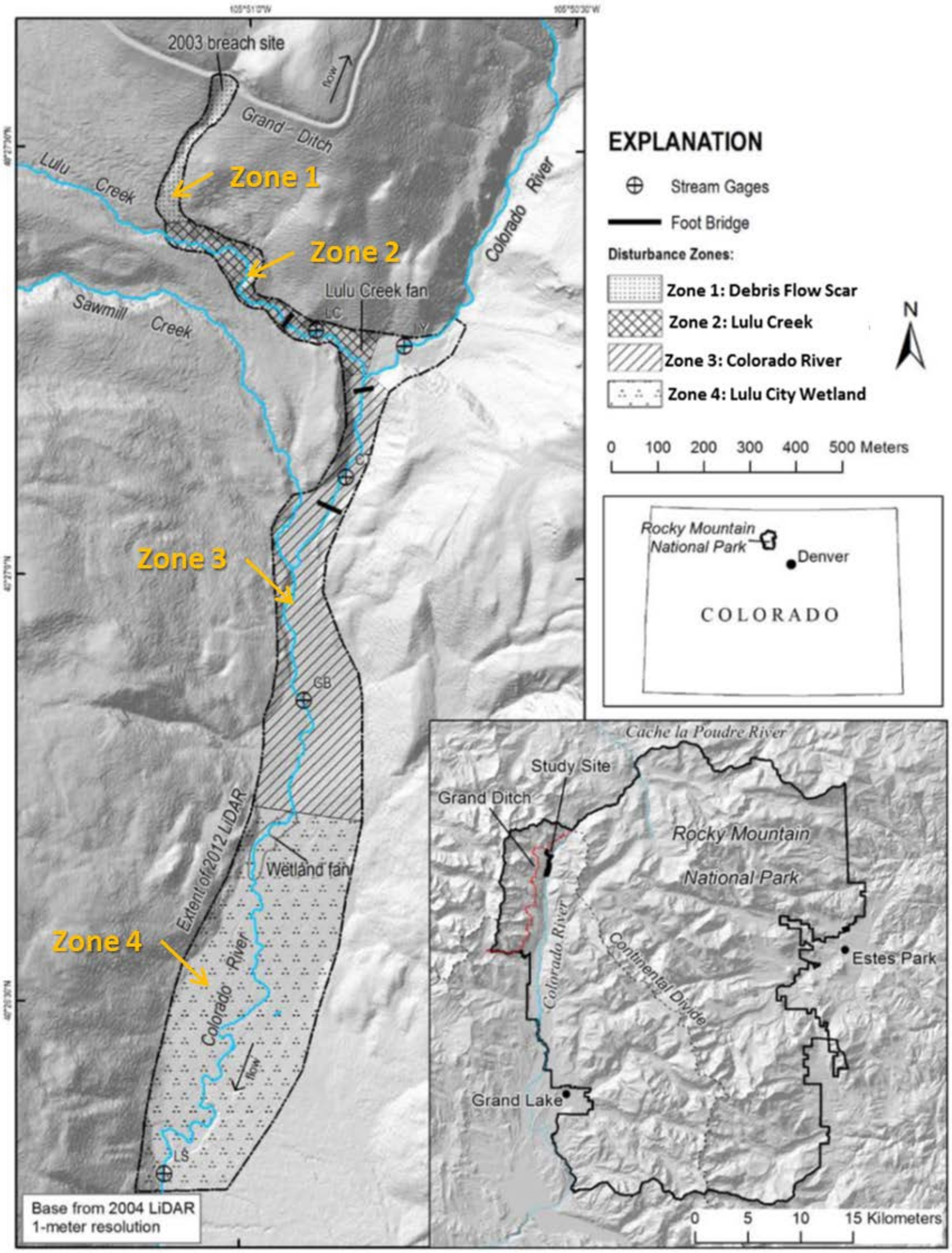

Figure 1. Channel and wetland restoration area, Upper Colorado River, Rocky Mountain National Park (modified from Mangano, 2014).

Figure 2. Oblique aerial view looking north up the Colorado River Valley. The Grand Ditch is the tan horizontal line to the middle right of the image and extends to where the Ditch meets Cache la Poudre Pass. The 2003 Ditch breach is located at the arrow that bisects the Ditch, with Zone 1 on the hillslope below. Additional arrows identify Zones 2 (Lulu Creek), 3 (Colorado River), and 4 (Lulu City wetland). Long Draw Reservoir is just off the image at upper right.

Restoration Goals and Approaches

Channel and wetland restoration within the impacted areas of Rocky Mountain National Park are proposed to begin in 2016. The primary objectives of the restoration, as stated in the FEIS are:

> "to restore the natural hydrological processes, ecological services, and wilderness character of the area in the Upper Kawuneeche Valley impacted by the 2003 Grand Ditch breach."

While these broad objectives in the FEIS serve as a guiding principle for the overall project, additional detail and background information is provided in this report for RMNP personnel and reviewers to assess the channel and wetland designs within the context of clear, measureable restoration goals. As such, the primary restoration goal is to reduce sediment and wood loading to the Colorado River and Lulu City wetland. Under normal conditions, sediment and wood are important, desirable components of fluvial systems that introduce nutrients, bed and bank substrates, influence hydraulics, sediment dynamics and channel forms, and create in-channel and overbank habitat for a myriad of aquatic and riparian organisms. When sediment and wood fluxes overwhelm downstream transport, large deposits of sediment and wood may occur and persist causing some or all of the following: channel and overbank aggradation that alters the surface/groundwater interactions, multi-thread flow and channel widening that further decreases sediment transport capacity, and in-stream log jams causing channel avulsions and additional sediment entrainment that augments upstream inputs. Given that the primary source of sediment and wood is residual 2003 deposits within and adjacent to Lulu Creek, below the debris flow scar (Figure 1), and the Lulu Creek fan, at the confluence with the Colorado River, we present recommendations to reduce downstream transport of the 2003-related sediment and wood. Since 2003, abundant quantities of unconsolidated sediment from the breach that had been temporarily stored along Lulu Creek have been transported downstream during high flows, and deposited within the Colorado River channel and floodplain and the Lulu City wetland. Reducing the excessive sediment and wood loading will help restore natural, pre-breach hydrologic conditions, ecologic services, and wilderness character. Removal and/or stabilization of the 2003-sediment is critical to ensuring that channel and wetland restoration in and along the Upper Colorado is achieved.

One approach to restoration is to identify the historical range of variability (HRV) of an ecosystem or the range of conditions that existed prior to intensive human alteration (Morgan et al., 1994; Nonaka and Spies, 2005). HRV is frequently established using historical documents or extrapolated from nearby, less-altered reference reaches to quantify the range of temporal and spatial variations in a particular landscape component as a desirable target for restoration. Because of uncertain future climate conditions and variability, the role of HRV in guiding landscape management has come under question (Sanfford et al., 2008). Alternative restoration ideas include identifying site-specific restoration priorities, rather than recreating an historical condition that may or may not be sustainable (Marris, 2011), or restoration that achieves environmental resilience, accommodating disequilibrium and nonlinear change in ecological (and social) systems (Benson and Craig, 2014). Nonlinear climate change renders stationarity (the idea that natural systems fluctuate within an unchanging envelope of variability) invalid (Milly et al., 2008), and drastically expands the range of potential forms and processes that an ecosystem can exhibit. HRV is still a useful starting point for restoration, to capture the variability of the system and define the range of possible conditions that can be supported by current processes (Wohl, 2013). Restoration recommendations herein are, therefore, based on a quantitative understanding of past and existing ecosystem characteristics to define a trajectory that supports resilience against uncertain future conditions, while at the same time aligning restoration with other park management plans (e.g. Elk and vegetation management). To this end, restoration designs are *inspired* by the past (Marris, 2011), but address specific 2003 impacts of sediment and wood loading to achieve the broader goals of restoring natural ecosystem processes and services along the Upper Colorado River corridor.

The approach utilized here is ecological restoration, defined as bringing a disturbed ecosystem back to its former state. Restored ecosystems must be self-perpetuating, require little or no human maintenance or manipulations after the first few years, other than large ungulate exclusion, and function in a similar manner over time to the ecosystems that existed historically. The introduction of appropriate plant species in suitable densities is required after site grading in all portions of the impacted area. A suitable and detailed monitoring plan is required to follow the progress of channel and floodplain changes, water table depth, and vegetation development through time to ensure that the grading and plantings are persisting and surviving.

Historical Context – History of Grand Ditch and the Upper Colorado River

The Grand Ditch was one of the first large trans-mountain water diversion projects built in the US, and has been in operation since 1890. The ditch captures streams that naturally flow from the Never Summer Range to the Colorado River and divert them north over La Poudre pass into the east flowing Cache la Poudre River to support irrigated agriculture on the eastern plains of Colorado. The Ditch was built in phases, with each phase extending it farther south from La Poudre Pass to capture more streams and greater flow. After Rocky Mountain National Park was formed in 1915, increasing demand for water led to the construction of Long Draw Reservoir (Figure 2) in 1923, on land that formerly was within RMNP. In addition, an act of Congress allowed the Grand Ditch to be further lengthened in 1936. Currently the ditch is a 14-mile long diversion canal that captures the flow of 11 streams. There is considerable interannual variability in the ditch flow, but it typically operates from mid-May through September, and reduces the stream flow and stage of the Colorado River (Woods and Cooper 2005). Head gates exist where tributaries enter the ditch allowing water to be released down existing streams. In the early to middle 20th century "waste ways" were used to dispose of extra water when Long Draw Reservoir was full. The waste ways were locations where water in the ditch was diverted over the ditch banks and down to the Colorado River.

Historically, the Colorado River from Lulu Creek through the Lulu City wetland was a meandering, coarse-grained river with a broad, tall willow-dominated floodplain (Figure 3) that supported large beaver colonies, especially in the wetland where nearly continuous beaver dams were built across the river, but also in the Colorado River upstream from the wetland. Beavers play a key role in the hydrogeomorphic functioning of the Colorado River floodplain and its riparian vegetation in RMNP (Westbrook et al. 2006, 2011, 2013). The beaver dams and associated ponds likely date from the early 20th century. Excess sediment inputs from debris flows over the last at least 70 years now support a conifer-dominated forest. These sediment inputs are, in part, due to anthropogenically-induced breaches and failures associated with the Grand Ditch. While debris flows are common disturbances in mountainous drainage basins and introduce large clasts and wood into steep-gradient channels (Wohl, 2010), Rubin et al. (2012) found that aggradation rates of coarse-grained sediments from either debris flows (or large floods) in the Lulu City wetland are six times higher in the last 200 years than over the past 4000. The increased aggradation in the last two centuries corresponds to logging and mining activities at Lulu City, a short-lived mining camp (Figure 3 upper left image) and operations of the Grand Ditch. Remnants of the former town site are still visible and remain a popular day-hike for park visitors. The patterns of debris flows down the Colorado River and into the Lulu City wetland was documented on a set of historical air photos by Cooper (2007) and Grimsley (2012) confirmed that debris flows that originate from the west side of the Colorado River Valley, where the Grand Ditch is located, were more frequent and of larger magnitude than debris flows from the east side.

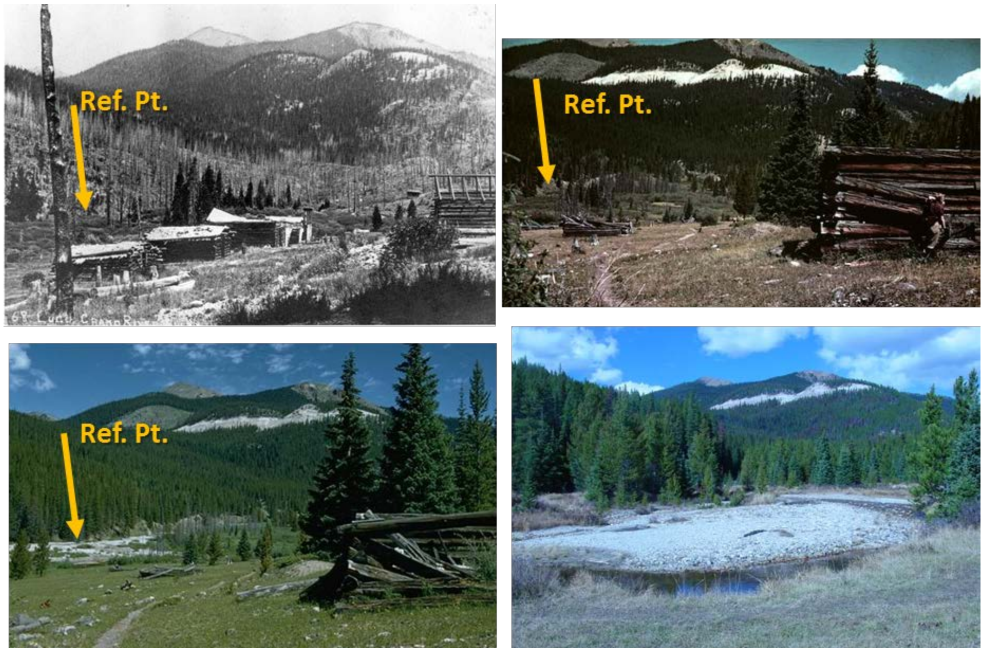

Figure 3. Colorado River and its riparian zone in 1880s (top left), 1940s (top right), 1953 (bottom left) and 2007 (bottom right). The tall willow-dominated floodplain is evident in the historic images, with the gold arrow providing a reference point along the river that highlights willow decline over time. A close-up view of the channel is provided in the bottom right showing 2003-related debris flow deposits with no willow community.

RESTORATION AREAS

Three main zones of restoration are the focus in this report including Zone 2 Lulu Creek, Zone 3 the Colorado River, and Zone 4 the Lulu City wetland (Figure 1), following nomenclature in the FEIS. Within each zone, restoration emphasizes; i) remove and/or stabilize unconsolidated banks, bars, and slopes, ii) remove fine sediment within the Lulu Creek fan from flow access and remobilization, iii) remove excessive wood within unconsolidated sediment deposits to limit remobilization, iv) reroute the Colorado River into its historic channel within and above the Lulu City wetland to enhance channel-floodplain connectivity and facilitate the restoration of wetland processes and vegetation, and remove sediment deposited in the wetland, and v) plant desirable species within riparian and wetland areas throughout zones 2, 3, and 4. The emphasis on sediment mitigation is directed at removing or stabilizing in place the finer sediment fraction (<4mm; ~D_{84} of bedload). In addition, channel restoration recommendations for Lulu Creek and the Colorado River propose minimal to no changes in bed elevation. Current bed elevation is adjusted to two years of bankfull or greater discharges, in 2011 and again in 2014, an elevation to which the entire study reach is graded.

Zone 2–Lulu Creek Channel and Fan

Prior to the 2003 Ditch breach, Lulu Creek was a typical steep-gradient, cascade and step-pool channel. Channel slope varies from approximately 18% at the footbridge crossing to approximately 4% at the fan (Figure 1). Reference reaches along Sawmill Creek, a tributary to the Colorado River immediately south of Lulu Creek (Figure 1), and other cascade and step-pool reaches in the literature (Rathburn et al., 2013) provide characteristic bed geometry in the absence of pre-2003 debris flow data. Ongoing field measurements of bed geometry on Lulu Creek indicate that dynamic bed adjustments are occurring, especially after the high flows of 2011 and 2014, such that a cascade bed configuration is now more dominant within Zone 2. Where large in-channel clasts and wood are setting step location, the step-pool geometry is consistent with reference conditions. As such, minimal bed reconfiguration is recommended for Zone 2 to allow for natural processes to occur. Restoration efforts should instead be directed at the abundant, unstable fine sediment in banks and debris flow levees of Lulu Creek and the fan that get transported episodically downstream to the Colorado River and Lulu City wetland, and the extensive in-channel and overbank wood introduced during and since the 2003 event. Simultaneous wood and sediment mitigation is necessary in Zone 2, given the abundance of wood deposited in the debris flow sediment along the length of Lulu Creek (Figure 4). At present, safety is a major concern during restoration of Zone 2 with the high, unstable banks and debris flow levees, tangle of wood protruding from banks and strewn on top of the fan surface and numerous large standing dead trees (Figure 5).

Upstream from the footbridge on Lulu Creek, channel slope exceeds 20%. Because of this steep gradient and uncertain access for heavy equipment, three restoration options are presented (Table 1). Should sufficiently heavy equipment be available and safe access attained, removal of fine sediment and wood upstream to the junction with Zone 1 is recommended. Wood mitigation may include a combination of cutting and either stockpiling, chipping, or burning buried and standing dead logs. A second option is the use of hydraulic hoses to wash sediment from the piles, and capturing the sediment downstream where it is removed to a storage area. This approach is detailed in Appendix C (written by Shaw and Cooper). If heavy equipment is unavailable and human power employed, then stabilizing fine sediment and wood in place is recommended. Zone 2 downstream from the Lulu Creek footbridge has wider valley geometry and lower gradients that are more reasonable for maneuvering heavy equipment to remove wood and fine sediment.

The water table depth along Lulu Creek likely varied seasonally, but was relatively shallow and allowed a range of riparian and non-riparian plant species to occur. Vegetation in the riparian zone was dominated by Engelmann spruce, subalpine fir, willows (*Salix monticola* and *Salix drummondiana*), and herbaceous species such as *Senecio triangularis, Mertensia ciliata, Ribes lacustre*, and *Arnica cordifolia*.

Figure 4. Lulu Creek upstream from the confluence with the Grand Ditch debris flow scar (left) photographed in 2007, and Lulu Creek downstream from the debris flow confluence the same year (right; view downstream). The types and extent of in-stream wood introduced into the reference reach and because of the 2003 debris flow are shown.

Figure 5. Downstream view of Lulu Creek showing current channel conditions with unstable banks and levees, and in channel and overbank wood.

Figure 6. Upstream view of Lulu Creek showing the existing condition of the left overbank area.

Figure 7. View downstream on Lulu Creek showing log jam, flow bifurcation, and sediment deposition at approximately Station 55.

Zone 3–Colorado River

The Colorado River is a meandering, gravel-bed channel with high sediment transport capacity. Channel morphology includes step-pool and pool-riffle reaches and a floodplain that supported extensive tall willow communities in the past (see Figure 3). Channel gradient of the Colorado River in Zone 3 varies from 4% near the confluence with Lulu Creek to 1.5% at the head of the Lulu City wetland. The Colorado River, in a manner similar to Lulu Creek, is undergoing dynamic adjustment during high flows as pulses of 2003 sediment are transported downstream from Lulu Creek. This episodic transport induces channel geometry changes outside of historic conditions for reference reaches (Rathburn et al., 2013). In addition, several channel avulsions occurred during high snowmelt runoff years (especially 2011), when log jams were created at footbridges followed by sediment deposition at the jams and channel avulsions. In a lidar differencing analysis, valley geometry and local controls (proximity to fan deposition, locations of footbridges) were the strongest predictors of aggradation or degradation between 2004 and 2012 (Mangano, 2014). Based on measured fluvial processes along the Colorado River, restoration efforts in Zone 2 (Lulu Creek and the fan) that mitigate wood and sediment transport downstream will support natural processes and the recovery of the Colorado River. Channel restoration recommendations on the Colorado River are thus directed at removing sediment deposition along banks sufficiently to enhance overbank flows and summer floodplain water tables to support tall willows (Figure 8), mitigate in-stream wood and sediment (Figures 8-10), removing sediment within mid-channel bars at the head of the Lulu City wetland (Figure 11), and reestablishing flow in the historic channel (Figure 12) through the Lulu City wetland to support channel and wetland floodplain connectivity and restoration.

Figure 8. View downstream of deposition along the left bank resulting from a channel avulsion in 2011. Current bank heights are above average annual water table fluctuations to support willow. Reducing/lowering the bank slope is recommended to enhance lateral channel-floodplain connectivity. Area corresponds to red polygon on Figure 19.

Figure 9. View downstream of in-stream wood mitigation area along the Colorado River, Zone 3. Corresponds to purple polygon in Figure 19.

Figure 10. View upstream of fine sediment mitigation along the Colorado River Zone 3. Corresponds to green polygon in Figure 19.

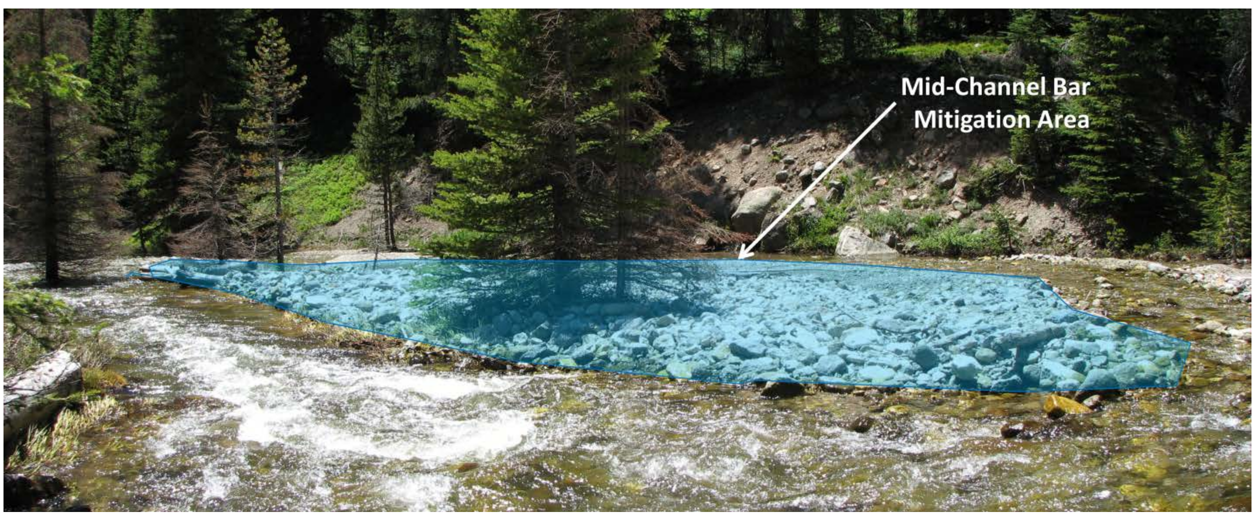

Figure 11. View across and downstream of the Colorado River, Zone 3 showing mid-channel bar sediment mitigation. Corresponds to yellow polygon in Figure 19.

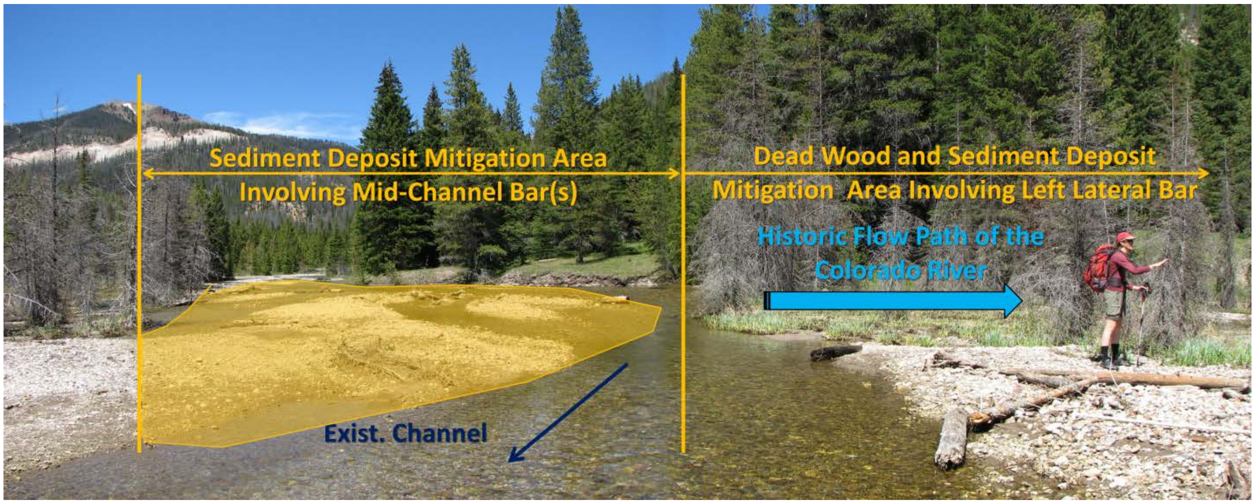

Figure 12. View upstream on the Colorado River at the head of the Lulu City wetland. A lateral bar on the left bank of the Colorado River (where person is standing) is designated for wood and sediment mitigation to realign the Colorado River with its historical flow path. View from Station 1010. Corresponds to purple and red polygons in Figure 20.

Zone 4–Lulu City Wetland

The Lulu City wetland had a single dominant meandering Colorado River channel with a tall willow community sufficient to support beaver colonies. Nearly continuous beaver dams down the length of the historic and now largely abandoned Colorado River likely date from the early 20th century and can be seen on 2003 air photos (Figure 13).

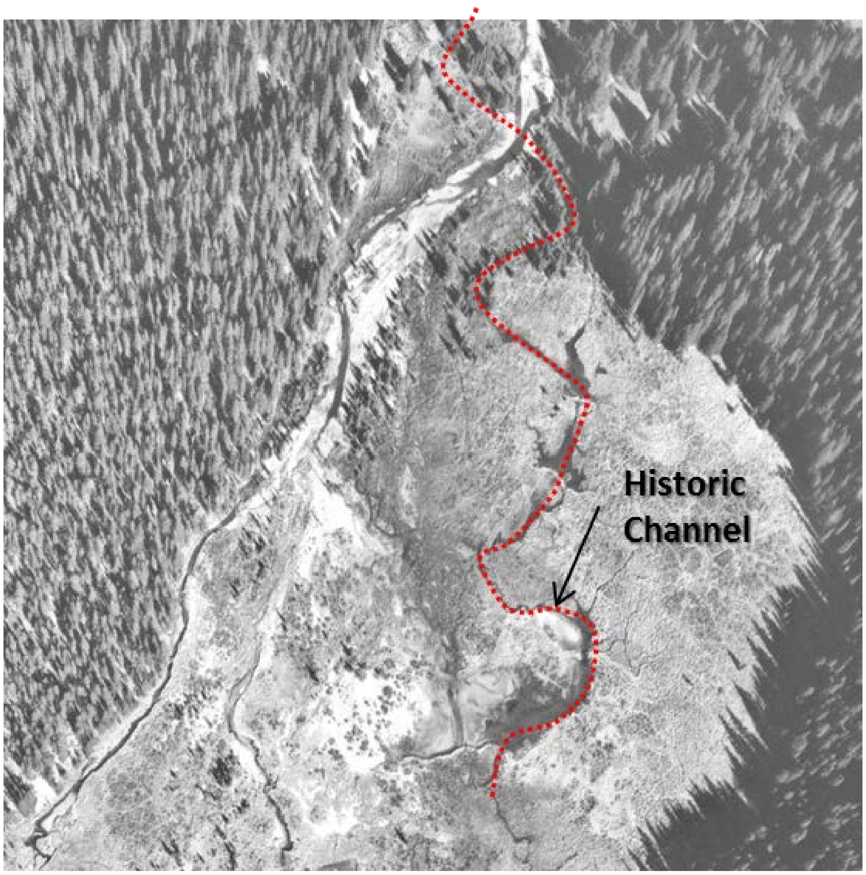

Figure 13. 2003 aerial photograph of the Lulu City wetland. The historic Colorado River channel is shown as the dotted red line, and the arrow points to one of the former beaver ponds. The presence of beaver ponds that dammed up the Colorado River means that a tall willow community was present through this reach of the river.

Sediment deposition from the 2003 breach was concentrated largely at the head and down the center and western portion of the wetland, with little to no sediment deposition on the eastern side of the Colorado River channel (Figure 14). The deposition of this highly permeable substrate pushed the Colorado River to the west, leading to the abandonment of its historic channel (Figure 15). River water infiltrates this coarse sediment and emerges as a number of springs and ground water flow systems that produce sheet flow and saturated conditions across the Lulu City wetland. In response, the historic tall willow ecosystem, required by beavers to create dams and form a winter food cache, disappeared and was replaced by a sedge-dominated meadow with short willow species. However, today the short willows have also disappeared and the wetland is dominated entirely by sedges (*Carex aquatilis* and *C. utriculata*) and the grass *Calamagrostis canadensis* (Figure 16). The functioning of the wetland today is completely different from the historical condition and, with the current topography and hydrology, will never recover to support tall willows with beaver colonizes as is typical for mountain valleys in Rocky Mountain National Park. The restoration of a tall willow community will require removal of the fan sediments, and the creation of a single channel with floodplain soils that are not permanently saturated.

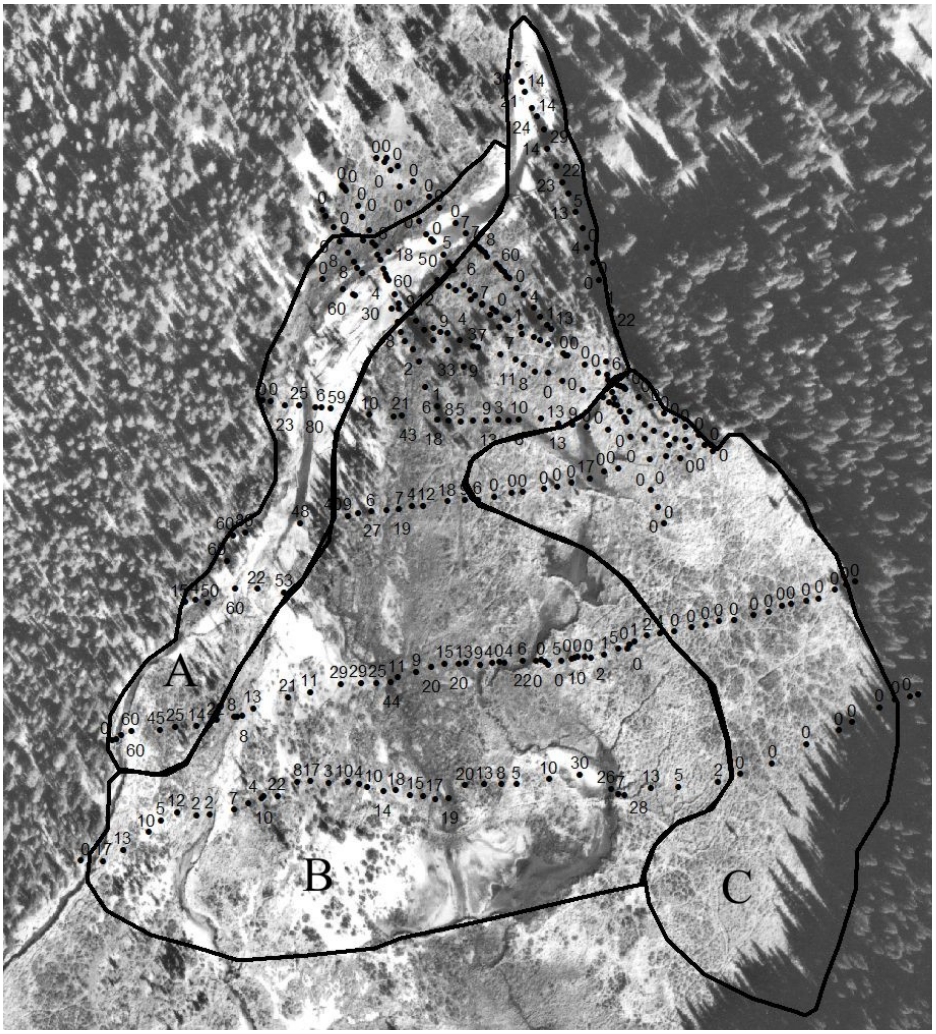

Figure 14. Thickness of sediment (cm) deposited in the Lulu City wetland by the 2003 breach as measured in hand excavated pits in August 2003. Number labels indicate sediment thicknesses (cm) at each point, and letters indicate zones of similar sediment thickness. Zone A has the thickest sediment, B intermediate thickness, and C no sediment.

Figure 15. Looking south at the lowest part of the Colorado River just before it enters the Lulu City wetland. A large alluvial fan of sediment has been deposited here causing the channel to braid and the flow to separate into multiple channels.

Figure 16. Historic Colorado River channel in the upper portion of the Lulu City wetland, looking north. Sedge dominated vegetation now dominate the entire wetland. Conifer trees in the meadow have drowned from the perennial soil saturation.

Table 1. Recommended restoration locations, objectives, details, options, requirements and project priority.

Location	**Objective**	**Details, Cross Sections, Specs**	**Options and Requirements**	**Priority**
Lulu Creek Upper; purple polygon Fig. 17 and 18	Sediment and wood mitigation, reduce downstream sed/wood flux, restore surface-groundwater interactions, phreatophytic planting	Typ. Sec. 1; Tables S1 and S2	1) Heavy equipment, available: disposal area, stockpile, chip or burn wood 2) Hydraulic washing (optional) 3) Manual labor: stabilize in place using existing materials	High
Lulu Creek Fan, Figs. 4; blue & green polygons Fig.17	Sediment and wood removal/mitigation, reduce sed/wood flux,	Typ. Sec. 1; Tables S1, S2, and S3; Detail 1	Heavy equipment, disposal area left overbank area of Typ. Sec. 1 (App. A), stockpile, bury, chip or burn wood	High
Lulu Creek Fig. 5; red polygon Fig. 17	Breach logjam, channel realignment	Typ. Sec. 2; Table S4	Heavy equipment, disposal area, cut, stockpile, bury, chip or burn wood	Medium
Colorado River Fig. 6; red polygon Fig. 19	Sediment and wood removal; support overbank flows and willow establishment	Typ. Sec. 5; Tables S1 and S2	Heavy equipment, disposal area, stockpile, chip or burn wood	High
Colorado River Fig. 7; purple polygon Fig. 19	In stream wood mitigation only	Typ. Sec. 5; Table S1	Heavy equipment, wood disposal area, stockpile, chip or burn	Low
Colorado River Fig. 8; green polygon Fig. 19	Sediment and wood removal	Typ. Sec. 5; Tables S1 (except Item 2) and S2	Heavy equipment, disposal area; stockpile, chip or burn wood	Low
Colorado River Fig. 9; yellow polygon Fig. 19	Sediment (mid-channel bars) removal, for single thread flow	Typ. Sec. 4	Heavy equipment, disposal area	Medium
Colorado River Fig. 10; purple polygon Fig. 20	Sediment (mid-channel bars) removal at head of wetland	Typ. Sec. 4	Heavy equipment, disposal area	Medium
Colorado River Fig. 10; red polygon Fig. 20	Sediment (lateral bar) and wood removal to realign into historic channel	Typ. Sec. 3; Table S5	Heavy equipment, disposal area; stockpile, chip, or burn wood	Medium
Lulu City wetland;	Sediment removal to concentrate flow into one dominant channel and to reconnect river and floodplain hydrology	Lulu Wetland Cross Sections 1-4	Heavy equipment, disposal area for sediment, storage area for salvaged plants, propagated ecotypes of appropriate plants	High

RESTORATION RECOMMENDATIONS

Zone 2 – Lulu Creek Channel and Fan

Three main restoration strategies are presented for Zone 2, including 1) wood mitigation, 2) fine sediment mitigation, 3) channel realignment, and 4) suitable planting plan (Table 1). Each strategy is presented, with typical sections and details included in Appendix A.

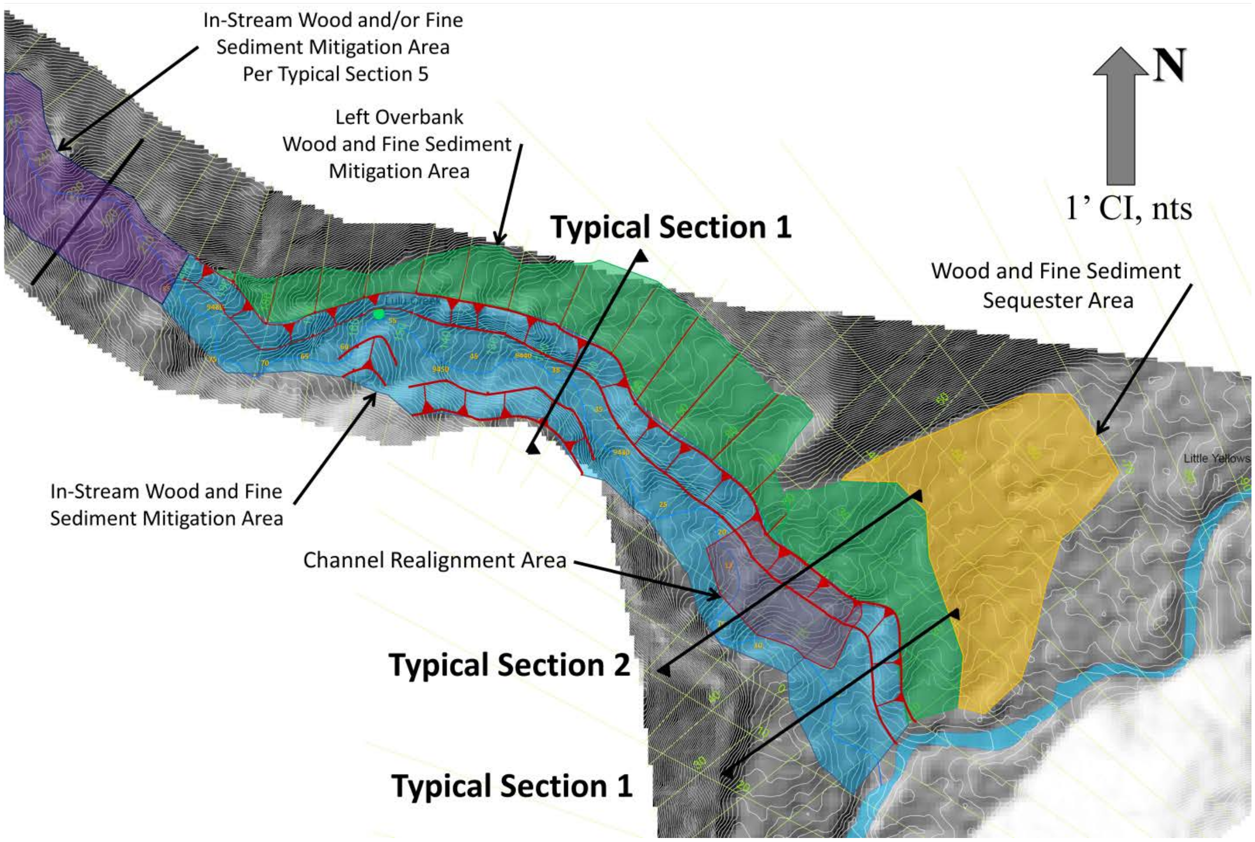

Figure 17. Site map of Zone 2 along Lulu Creek downstream from the footbridge (black bold line in purple polygon) showing areas of wood and sediment mitigation, the channel realignment area, and locations of typical sections. Red lines depict mitigated bank slope with red arrows pointing downslope. (nts is "not to scale")

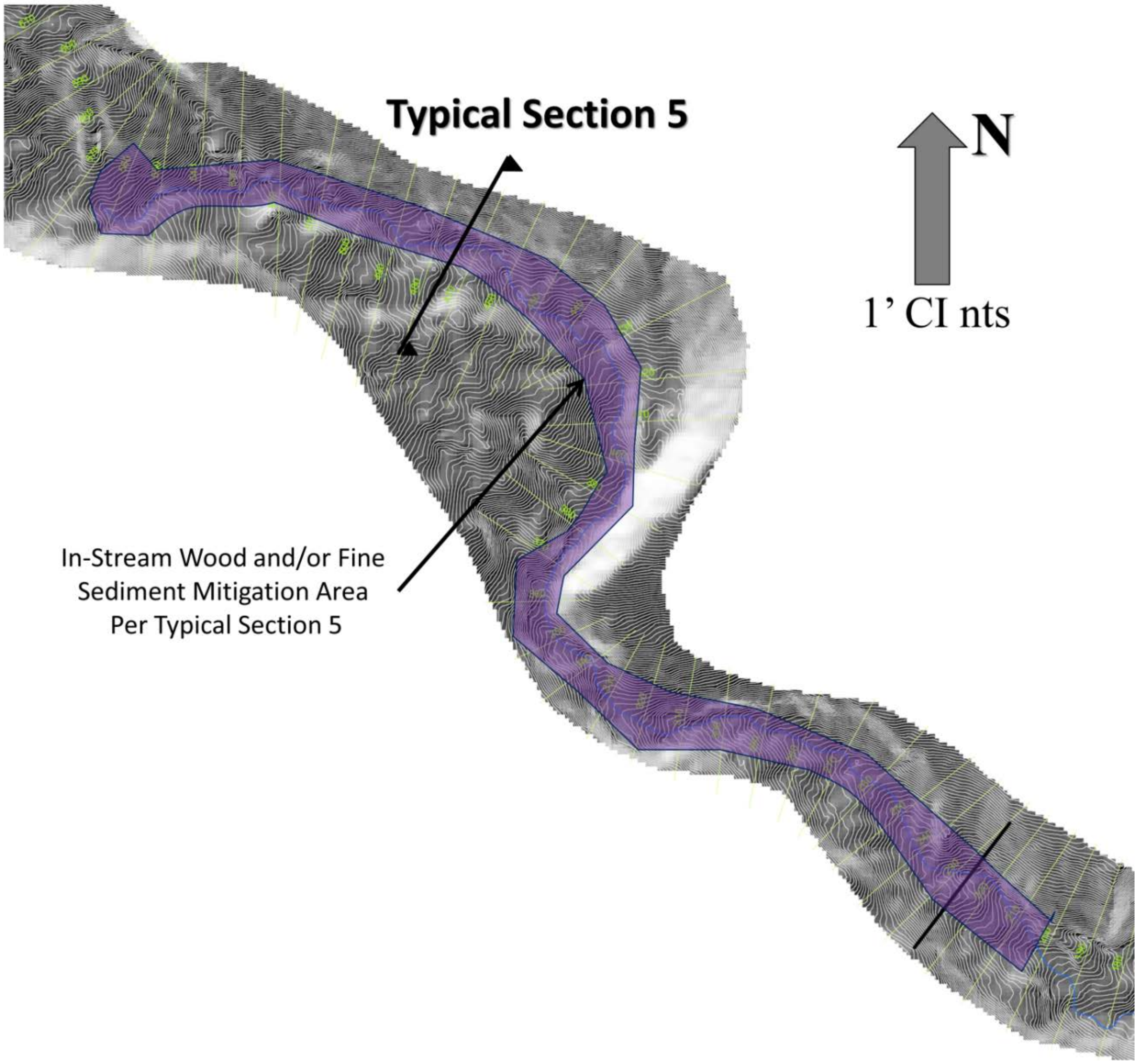

Figure 18. Site map of Zone 2 along Lulu Creek upstream from the footbridge showing areas of wood and sediment mitigation, and location of a typical section. Black bold line in purple polygon is a footbridge. (nts is “not to scale”)

Overall Wood Mitigation Strategy

The debris flow associated with the 2003 Grand Ditch breach caused mortality of approximately 20,000 trees. Many of the trees were buried in the initial deposition following the breach, are becoming exposed and transported during high, erosive discharges, and/or the standing gray-phase trees continue to die off and become in-stream wood transported during high flows. Normally, instream wood induces hydraulic complexity, traps sediment and nutrients, and creates important riverine habitat. The wood loading to the Colorado River, as a result of the 2003 breach, exceeds natural wood recruitment in unconfined reaches of subalpine regions. A key strategy of the restoration of Lulu Creek is, depending on availability of heavy equipment, to either remove the wood, cut it up into transportable segments or stabilize it in place in areas outlined in Figures 17 and 18. See Table S1 in Appendix A for design details and specifications.

Overall Fine Sediment Mitigation

Excessive amounts of fine sediment are transported episodically downstream to the Lulu City wetland, a key natural resource in RMNP. In addition, the excessive sediment loads are altering the channel morphology from pre- breach conditions during high discharges that cause channel avulsions. Hence, a key strategy in the restoration of Lulu Creek is to reduce the amount of fine sediment readily available for transport in the natural banks and levees that have formed along Lulu Creek. It is recommended that bank slopes are flattened to within the range of 3:1 to 6:1 and moving the fine sediments in Zone 2 to the left and/or right overbank areas if heavy equipment access is available. Where slopes are too steep or rocky for safe access of heavy equipment, options to either stabilize sediment in place or hydraulically wash fine sediment downstream are presented (Table 1).

Overall Wood and Fine Sediment Mitigation

The excessive amounts of wood incorporated into fine sediment deposits from the 2003 event necessitate simultaneous removal and or stockpile. A key strategy in the restoration of Lulu Creek is to reduce the amount of wood and fine sediment readily available for transport by moving in-stream wood and fine sediment away from the main channel of Lulu Creek into the overbank areas, or stabilize in place.

Channel Realignment Strategy

At approximately Lulu Creek Station 50 (Figure 17) a 6 feet high log jam formed during 2014 snowmelt that has resulted in both channel bifurcation and the trapping of sediment within the main channel of Lulu Creek (Figure 17). The key objective within the Channel Realignment Area extending from approximately Station 35 to 65 is to artificially breach the log-jam at Station 50 and remove in-stream wood/fine sediment out of the main channel onto the left overbank. Matching existing thalweg elevations at Stations 35 and 65, the channel bottom width and the bed slope within the Lulu Creek Channel Realignment Area will approximately be 30 feet and 8.5%, respectively. See Typical Section 2, Table S4 of Appendix A for further details.

Planting Plan

Lulu Creek above zone 2 has a large-diameter conifer overstory dominated by Engelmann Spruce, with scattered shrubs and patches of herbaceous species understory. Restoration approaches of washing, in-place sediment stabilization, and floodplain creation will disturb much of the existing vegetation. Engelmann spruce appears to invade the bare sediments well and may not need to be planted. Streamsides within 2 vertical feet of the Lulu Creek late summer stage should be planted with *Lonicera involucrata* and *Salix drummondiana* at a density of one plant of each species per 1 square yard, and *Calamagrostis canadensis* and *Mertensia ciliata* at a density of one plant of each species per square yard. Many of the other common plant species found invading the 2003 debris deposits including *Epilobium angustifolium* and *Senecio triangularis* have wind-blown seed and appear to colonize sufficiently to recruit on the final surfaces without manual planting. Prior to earth work, it might be possible to collect clumps of plants that occur on the debris deposits and plant into pots or a small nursery developed on the Lulu Creek fan. The added benefit to this would be the transplanting of associated soil along with each plant. The study reach for planting is approximately 1200 feet long and 10 feet wide on each side of the creek, totaling 2,667 yd^2, necessitating 666 individual *Lonicera* and *Salix* and 5333 *Calamagrostis* and *Mertensia* individuals.

Zone 3 – Colorado River

The main restoration strategy presented for Zone 3 includes wood and sediment mitigation to i) reduce/flatten banks to enhance lateral connectivity between the channel and floodplain and willow reintroduction (based on annual fluctuations in water table elevations) (Figure 19), ii) remove in-stream wood that presents the potential for large logjams that cause channel avulsions (Figure 19), and iii) facilitate historic channel realignment of the Colorado River (Figure 20). The strategy is presented, followed by typical sections and details in Appendix A.

Overall Wood and Sediment Mitigation Strategy

The debris flow associated with the 2003 breach in Grand Ditch delivered an abundance of trees and fine sediment into Lulu Creek and the Colorado River. Multiple high flows since 2003 resulted in remobilization and transport of both wood and fine sediment into the Lulu City wetland, including augmenting a preexisting fan at the head of the wetland that directs a majority of Colorado River flow to the west side of the valley and away from the historic channel. Hence, a key strategy of the Colorado River channel restoration is to redirect flow back into the historic channel by removing deposits within a lateral bar (Figure 20) along the left bank from approximately Station 985 to 1020. In addition, removal of mid-channel bars formed by historic debris flow deposition at the head of the wetland is recommended (Figure 20).

Planting plan

To restore willows to this part of the study area, dormant stem cuttings, 20-24 inches in length, and planted 16 inches deep, would be placed on 3 ft centers. Because the bars are cobble, a stinger on a track hoe or bucket of a hoe, must open sufficient holes to insert the willow cuttings past the water table. Plantings should be done as early in summer as possible. Because there are relatively few willows that survived the breach in the Colorado River valley study area, willows would be collected from adjacent reaches of the Colorado River downstream of the study area. Herbaceous species will be collected from the Lulu City wetland, or grown from field-collected seed within the study area, and grown as seedlings in 8-10 cubic inch super cells. We recommend planting *Calamagrostis canadensis* at a density of 2 plants/yd^2 as the understory species to develop cover and stability for the floodplain soils. Other species will invade over time to increase species diversity.

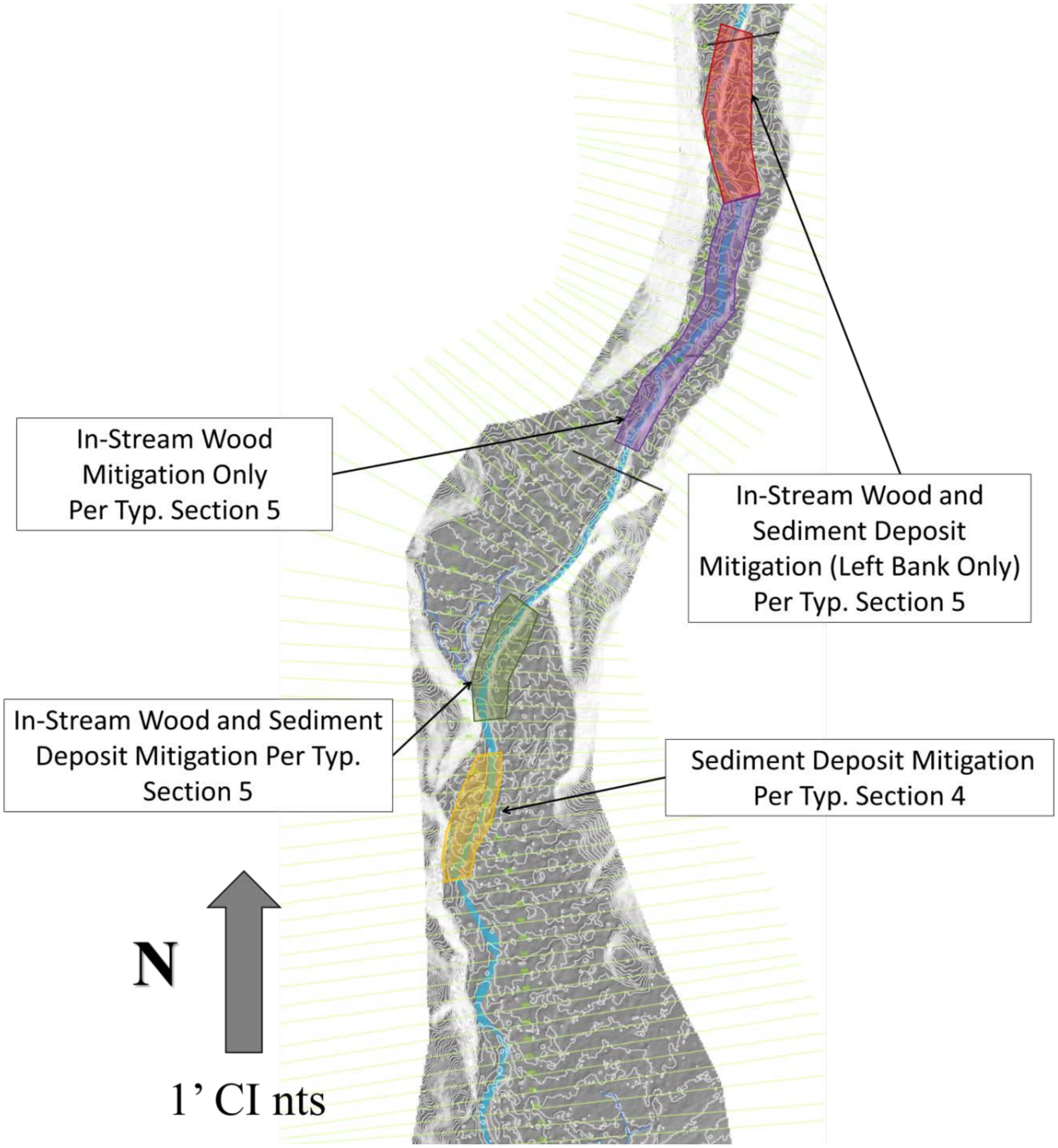

Figure 19: Site map of Zone 3 along the Colorado River showing areas of wood and sediment mitigation. Black lines crossing the channel are footbridges. (nts is "not to scale")

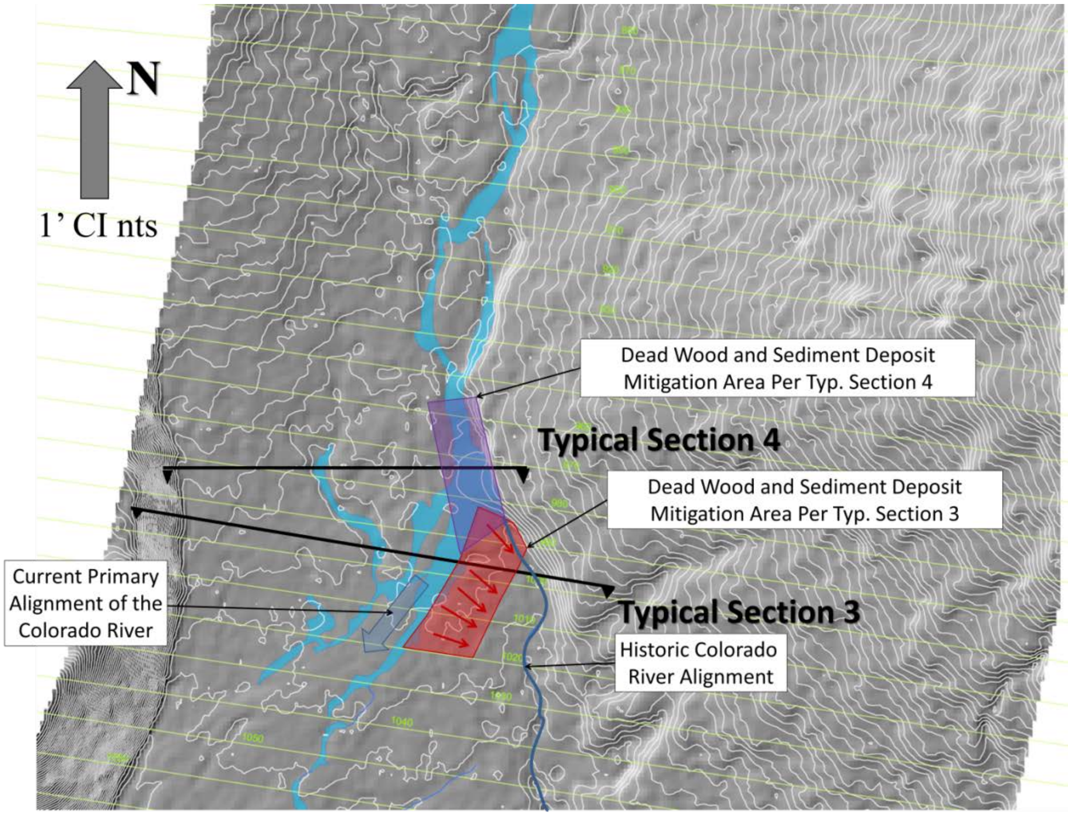

Figure 20: Site map of the connection of Zone 3 and Zone 4 along the Colorado River showing areas of wood and sediment mitigation, and locations of typical sections. (nts is "not to scale"). Typical sections are included in Appendix A.

Split Flow Analysis for the Colorado River as it enters the Lulu City Wetland

A split flow analysis was performed to assess the hydraulic effectiveness of the lateral and mid-channel bar sediment mitigation at the head of the Lulu City wetland reflected in Typical Sections 3 and 4 (Appendix A). The objective of the mitigation effort is to redirect the Colorado River flow away from the 2003 sediment deposit on the west side of the wetland and back to the historic channel in the center left of the wetland (Figure 20), by removing a lateral bar that has formed on the Colorado River at the head of the wetland (see Typical Section 3). The approach attempts to minimize the amount of sediment removed from this area. Complete details of this approach are in Appendix A. A different approach is proposed in the following section, Lulu City Wetland, and is based on the removal of all recently deposited sediment.

Zone 4 – Lulu City wetland and Colorado River

The main goal for the Lulu City wetland is to reestablish a tall willow ecosystem within the floodplain of the Colorado River. The large sediment deposits do not currently allow for a river and floodplain morphology as is seen in other high elevation Rocky Mountain rivers. Once the flow from the river is redirected into the historic channel as described above, sediment removal within Lulu City wetland will facilitate overbank flooding and alter the overall ground water gradient from its current eastern flow direction to the desirable southern flow direction.

Sediment excavation strategy

The proposed channel orientation uses the channel location from the August 1937 photo and ties in to the restoration designs of the Colorado River outlined above and shown in Figure 20. Earthwork would remove ~8,500 yd^3 from the Lulu City wetland as shown in Appendix B, with the option of removing more debris should funding permit to the maximum allowable sediment removal as described in the FEIS.

If necessary, filling of side channels in the wetland would require 1,500 yd^3, leaving a net 7,000 yd^3 that would have to be moved to the sediment disposal area on the disturbed alluvial fan of Little Dutch Creek (Appendix B, Figure B4). This volume of sediment would cover approximately 1 acre 4.33 feet deep. The fill surface would then be planted with Engelmann spruce and lodgepole pine. The final grading should not produce a flat ground surface as conceptualized in Figure 21. These contour lines represent an average elevation across the floodplain. Microtopography of 4-8 inches is desirable to facilitate seed germination in a variable and complex hydrologic environment.

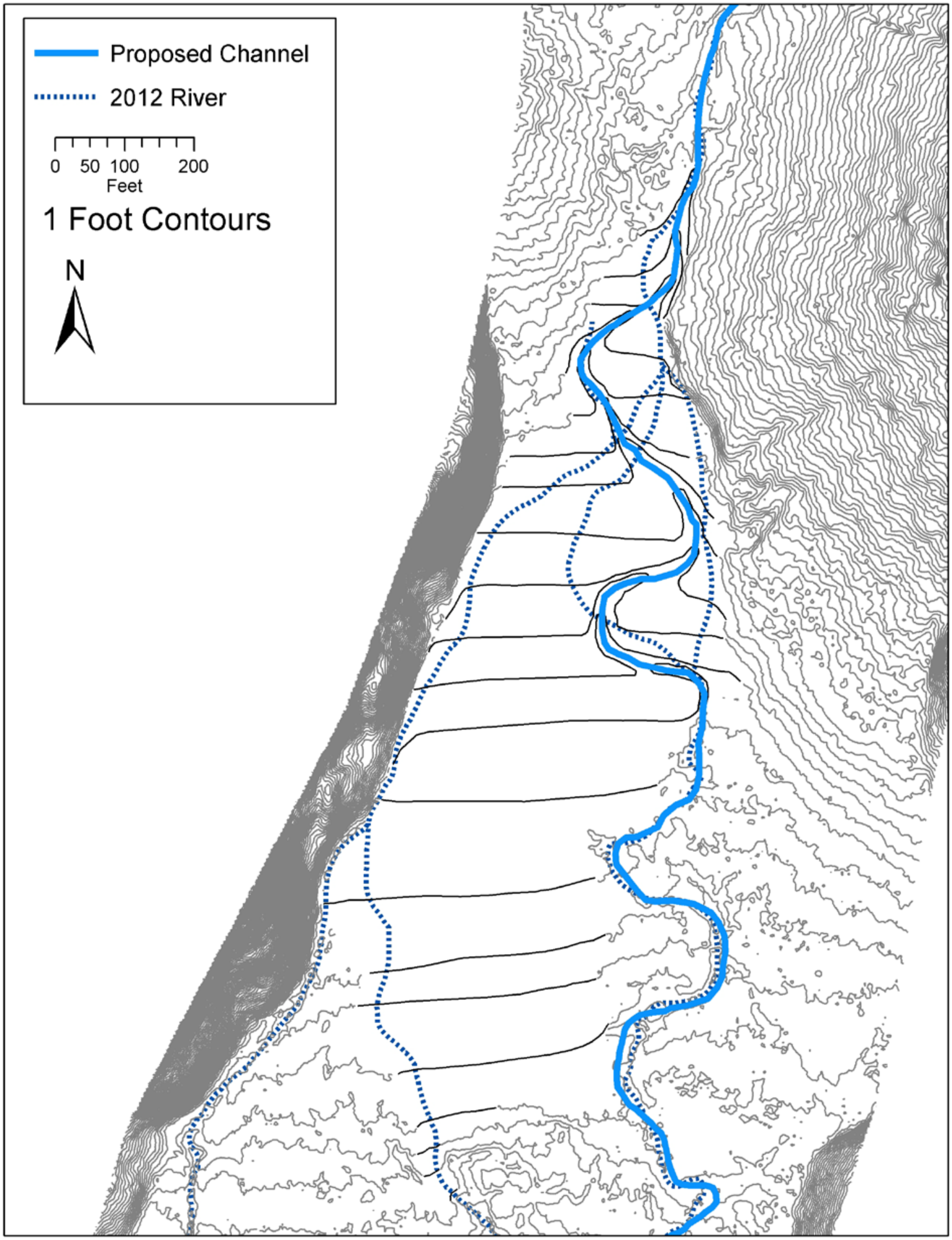

Figure 21. Proposed Colorado River channel orientation and generalized land surface topography for the Colorado River and Lulu City wetland.

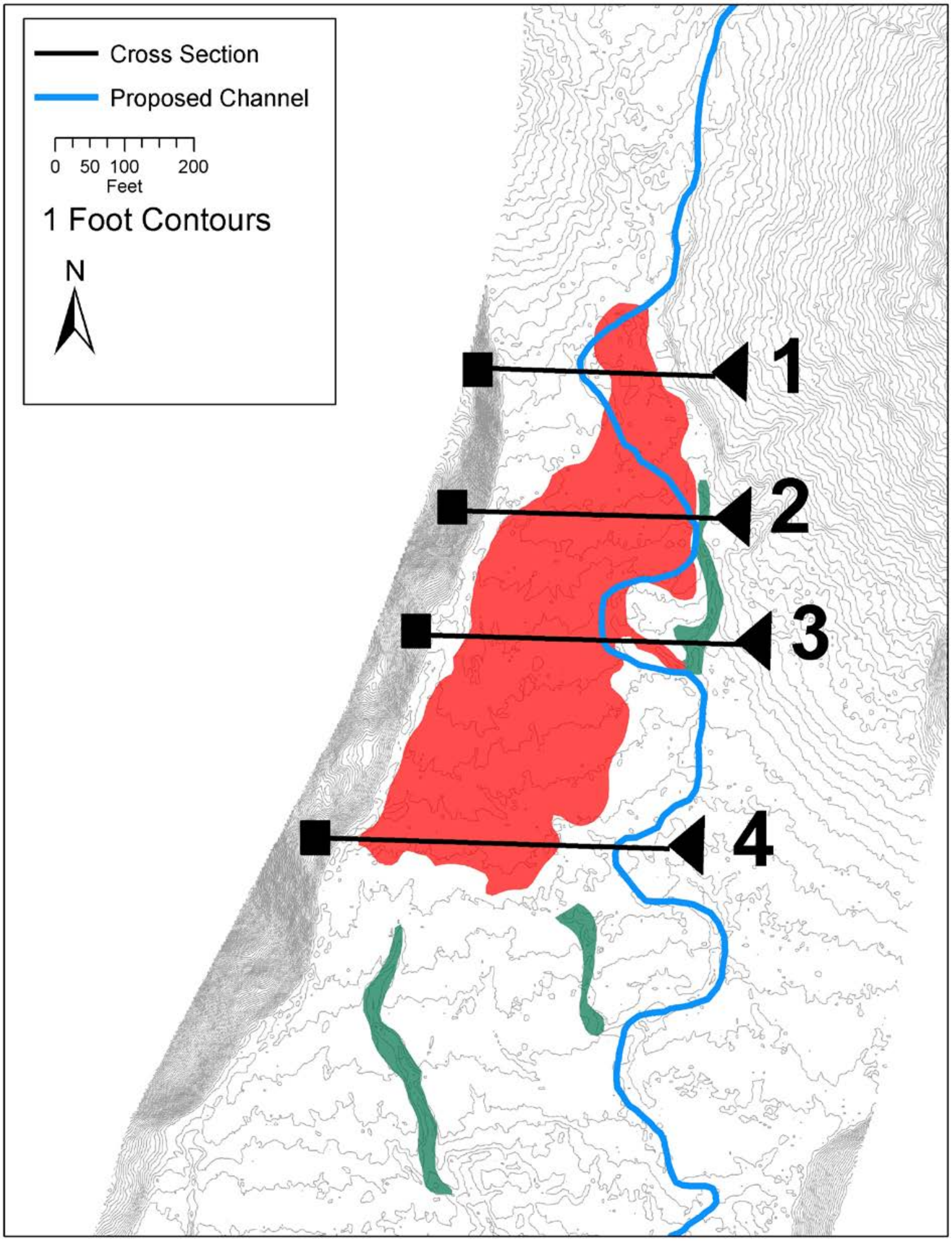

Figure 22. Location of sediment cut zones with an option for side channel fill, and cross section profiles used to depict current and proposed land surface elevations in Appendix B. Cross section 1 corresponds generally to the Colorado River sediment mitigation depicted in Figure 20.

Planting Plan
Willows will be introduced using the species and methods described above for the Colorado River. A dense cover of wetland sedges (*Carex aquatilis, C. utriculata*) and Canada bluejoint (*Calamagrostis canadensis*) occur in the wetland today. We recommend scraping and stockpiling the top 7-12 inches of soil and spreading this soil once the site grading is complete. The topsoil will contain rhizomes, roots and seeds of Calamagrostis and Carex, and will facilitate the development of an herbaceous understory. Willows should be planted at a density of 1 plant per 10 ft^2. The majority of willows planted should be *Salix drummondiana, S. monticola,* and *S. geyeriana*. It will likely be possible to plant by hand without the use of a stinger or backhoe to open holes for the willow stems. Bare and largely dormant willow plantings would occur as early in the next spring as possible once the soils are thawed.

CUT AND FILL VOLUMES

Table 2. Estimates of cut and fill for channel and overbank areas along Lulu Creek and the Colorado River.

Map/Fig No.	Location of Sediment Mitigation	Stations (m)	Cut Volume (yd^3)	Fill Volume (yd^3)
Figs. 17 &18	Lulu Creek Upstream of Bridge (purple polygon)	200-560	2390	
Fig. 17	Lulu Creek Fan/Downstream of Bridge (blue polygon)	40-200	1040	1080
Fig. 19	Colorado River at Upstream Bridge (red polygon)	20-120	110	
Fig. 19	Colorado River (green polygon)	400-470	150	
Fig. 19	Colorado River (yellow polygon)	490-560	180	
Fig. 20	Colorado River at Head of Wetlands (purple polygon)	955-995	190+	
Fig. 20	Colorado River at Head of Wetlands (red polygon)	985-1020	260+	
Fig. 21	Lulu City Wetland	1020-1100	8500*	1500 (opt.)
	Total Cut/Fill Volumes		**12820**	**2580**

+This is an optional strategy. More comprehensive fill removal is included in the Lulu City Wetland volumes.
*****Additional removal can be completed should funding permit.

ADDITIONAL CONSIDERATIONS

Footbridge Dimension
Existing footbridge crossings along impacted reaches of the Colorado River continue to create constrictions in channel width, trapping entrained logs and initiating sites of aggradation and channel avulsion. Despite replacement of one bridge on the Colorado River downstream from the confluence with Lulu Creek following high flows in 2011, additional undercutting of rock gabions has occurred at this bridge following snow melt in 2014. The likelihood of restoration success of channel, riparian and wetland areas will be increased if simultaneous replacement of footbridges occurs. Following standard specifications for bridges within RMNP, we recommend increasing bridge widths, bridge opening spans, and elevating the bridges above the current floodplain.

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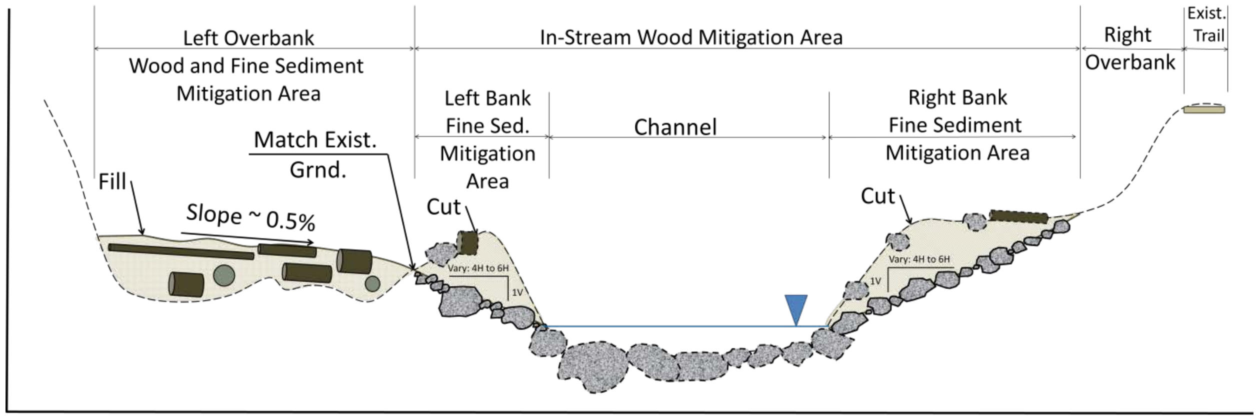
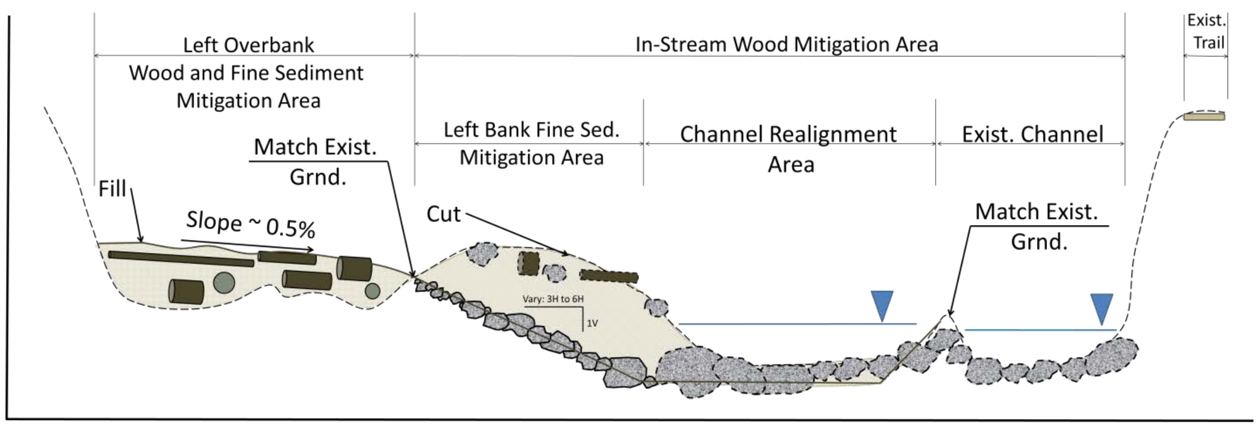
Appendix A

Lulu Creek and Colorado River
Typical Sections, Details and Specifications

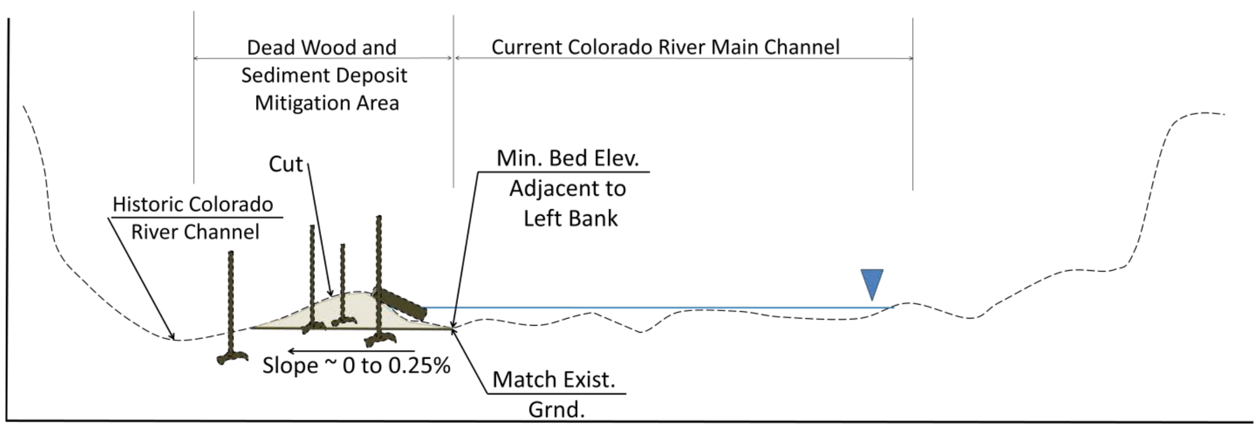


Typical Section 1: Sediment and Wood Mitigation Areas Along Lulu Creek

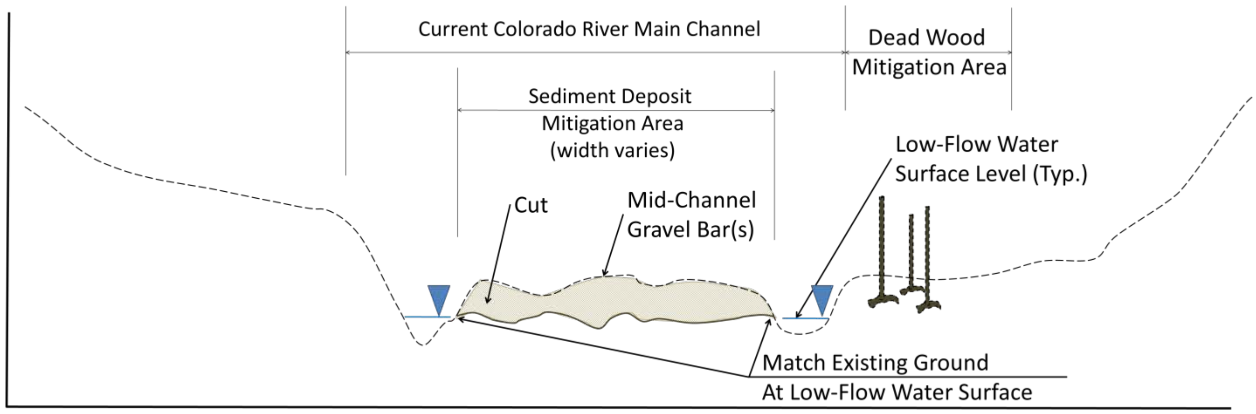


Typical Section 2: Channel Realignment Area Along Lulu Creek

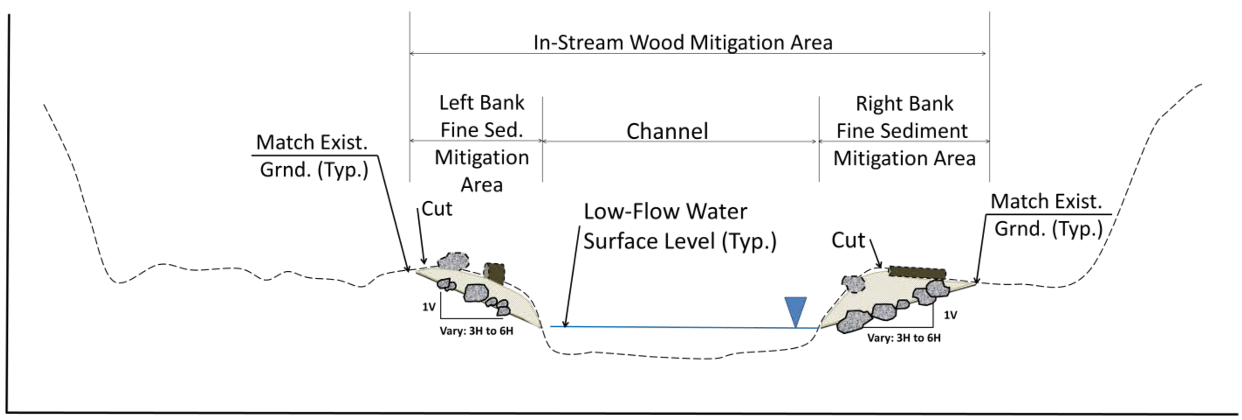
Typical Detail 1: Schematic of Wood Mitigation in Left Overbank



Typical Section 3: Sediment and Wood Mitigation along Colorado River

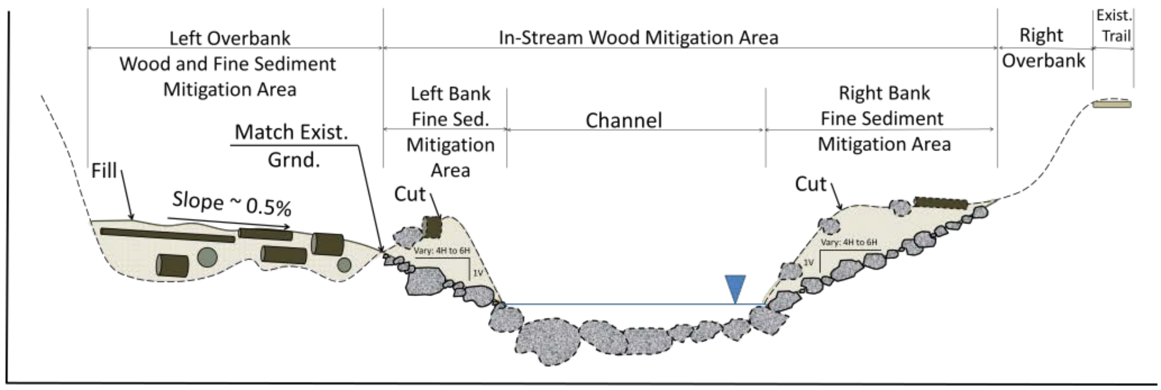


Typical Section 4: Sediment and Wood Mitigation along Colorado River



Typical Section 5: Sediment and Wood Mitigation Areas Along Colorado River

Table S1: Lulu Creek In-Stream Wood Mitigation Specifications



Typical Section 1: Sediment and Wood Mitigation Areas Along Lulu Creek

In-Stream Fallen-Tree Mitigation Specifications:

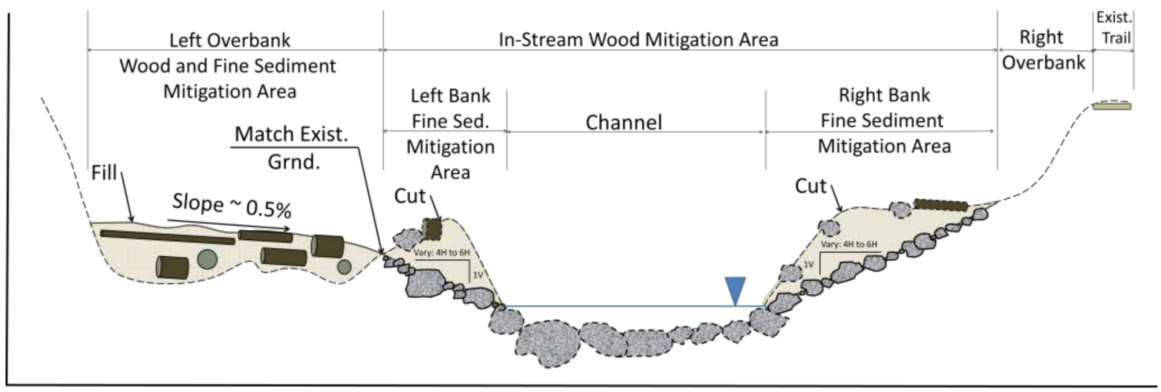
1) Leave in place fallen trees that are buried in and are an integral part of the channel bottom.
2) Where practical remove fallen trees in whole or in segments from the In-Stream Wood Mitigation Area (per Typical Section 1) to the left-overbank area and apply Overbank Fallen Tree Mitigation Specifications per Table S3.
3) For fallen trees and tree trunks that cannot be readily removed from the Channel:
   a) Cut off the root-wad.
   b) Trim off branches 4 inches in diameter or greater at their base.
   c) Cut the trunk into segments not greater than 10 feet in length, when the trunk is 6 inches in diameter or less.
   d) Cut the trunk into segments not greater than 8 feet in length, when the trunk is greater than 6 inches and less than 18 inches in diameter.
   e) Cut the trunk into segments not greater than 6 feet in length, when the trunk is 18 inches in diameter or greater.

In-Stream Standing-Tree Mitigation Specifications:

4) For dead standing trees located within the In-Stream Wood Mitigation Area, cut down the tree as close to ground level as possible, and when possible remove from the channel in whole or in segments to the left-overbank area and apply Overbank Fallen Tree Mitigation Specifications per Table S3.

For cut down trees that cannot be readily removed from the In-Stream Wood Mitigation Area, apply specifications 3-b) through 3-e) as appropriate.

Table S2: Lulu Creek Left & Right Bank Fine Sediment Mitigation Specifications

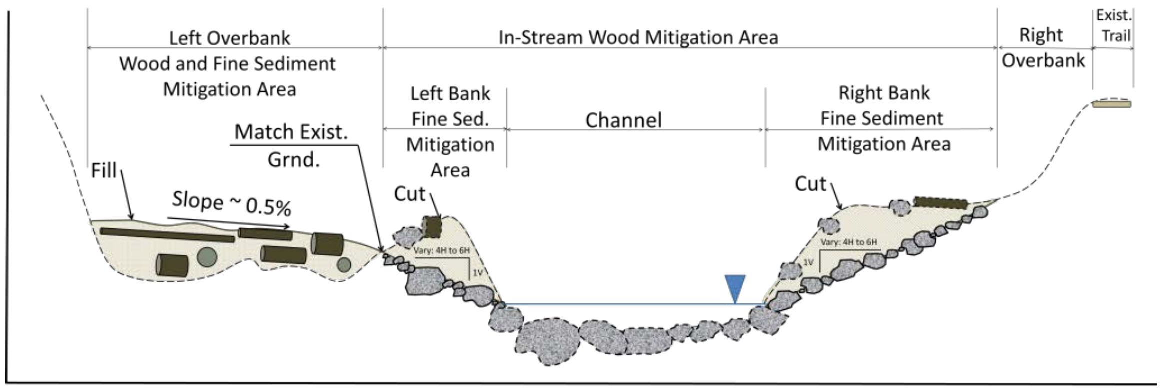


Typical Section 1: Sediment and Wood Mitigation Areas Along Lulu Creek

Bank Earthwork/Fine Sediment Mitigation Specifications:

1) Mitigate fallen and standing trees per the In-Stream Wood Mitigation Specifications in Table S1.
2) Limit the bank grading activities to outside of the wetted perimeter of the existing channel, at the time of the grading activities.
3) Per Typical Section 1, flatten the left and/or right stream bank slope to within the range of 3:1 to 6:1 by moving the relatively fine material (i.e., less than approximately 4 inches in diameter) to the adjacent overbank area, while leaving the coarser material on or embedded in the new flatter bank slope.
4) Where practical, large boulders on the surface of the existing banks and impeding the flattening of the bank slopes can be moved into the channel.
5) Large boulders (i.e., greater than 30 inches in diameter) embedded in the existing bank should be left in place and flattening of the bank slope should extend around the boulder, where practical.

Table S3: Lulu Creek Overbank Sediment and Wood Mitigation Specifications

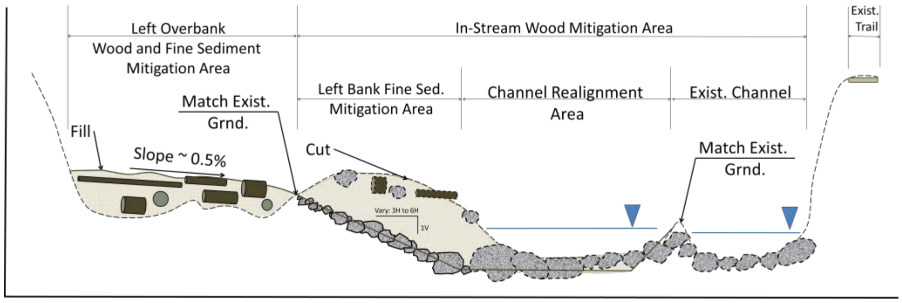


Typical Section 1: Sediment and Wood Mitigation Areas Along Lulu Creek

Overbank Wood and Fine Sediment Mitigation Specifications:

1) Cut down dead standing trees as close to ground level as possible.
2) For fallen trees and tree trunks located within or moved to an overbank area:
   a) Cut off the root-wad, when possible.
   b) Cut the trunk into segments not greater than 10 feet in length, when the trunk is 6 inches in diameter or less.
   c) Cut the trunk into segments not greater than 8 feet in length, when the trunk is greater than 6 inches and less than 18 inches in diameter.
   d) Cut the trunk into segments not greater than 6 feet in length, when the trunk is 18 inches in diameter or greater.
3) When practical, orient trunk segments in the overbank area perpendicular and parallel to the direction of flow in the Lulu Creek channel in a grid fashion, per Typical Detail 1.
4) Place sediments removed from the bank mitigation areas along with the wood in the overbank area leaving an irregular and undulating surface with an overall cross slope toward the Lulu Creek channel of approximately 0.5 %.

Table S4: Lulu Creek Channel Realignment Specifications



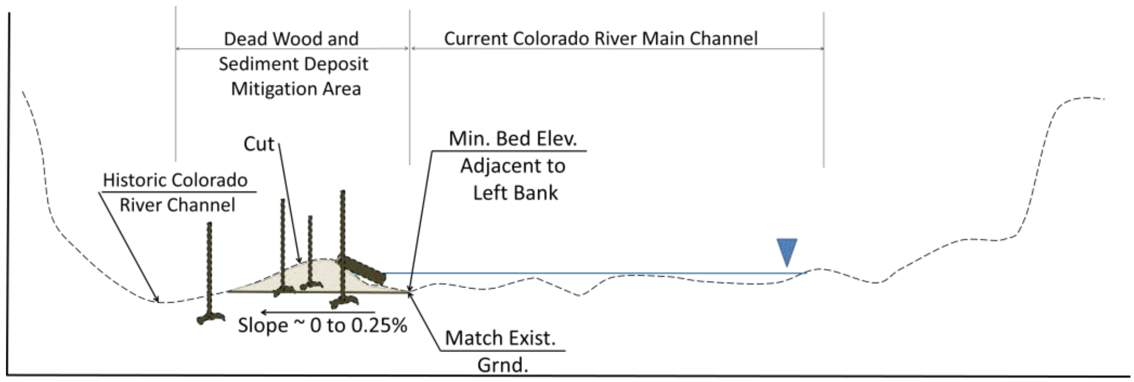
Typical Section 2: Channel Realignment Area Along Lulu Creek

Channel Realignment Strategy: At approximately Lulu Creek Station 50 a 6 foot high log jam has formed resulting in both channel bifurcation and the trapping of sediment within the main channel of Lulu Creek. The key objective within the Channel Realignment Area extending from approximately Station 35 to 65 is to artificially breach the log-jam at Station 50 and remove in-stream wood/fine sediment out of the main channel onto the left overbank. Matching existing thalweg elevations at Stations 35 and 65, the channel bottom width and the bedslope within the Lulu Creek Channel Realignment Area will approximately be 30 feet and 8.5%, respectively.

Channel Realignment Specifications:

1) Within the In-Stream Wood Mitigation Area, mitigate fallen and standing trees per the In-Stream Wood Mitigation Specifications in Table S1.
2) Within the Channel Realignment Area per Typical Section 2, reconstruct the main channel of Lulu Creek as follows:
   a) Remove the existing log-jam at approximately Station 50.
   b) Match existing bed elevation and channel bottom width at Stations 35 and 65.
   c) Lower the existing bed elevation by moving the relatively fine material (i.e., less than approximately 4 inches in diameter) to the adjacent left overbank area, while leaving the coarser material on or embedded in the new channel bed.
3) Within the Left Bank Fine Sediment Mitigation Area per Typical Section 2, reconstruct the left and right banks of Lulu Creek as follows:
   a) Flatten the left and/or right stream bank slope to within the range of 3:1 to 6:1 by moving the relatively fine material (i.e., less than approximately 4 inches in diameter) to the adjacent left overbank area, while leaving the coarser material on or embedded in the new flatter bank slope.
   b) Where practical, large boulders on the surface of the existing banks and impeding the flattening of the bank slopes can be moved into the channel.
   c) Large boulders (i.e., greater than 30 inches in diameter) embedded in the existing bank and/or bank should be left in place, while the flattening of the bank slope and or lowering of the channel bottom should extend around the boulder where practical.

Table S5: Colorado River Left Bank Wood and Sediment Mitigation Specifications



Typical Section 3: Phase I Sediment and Wood Mitigation along Colorado River

Specifications for the Removal of Existing Natural Levee along Left Bank:

1) Within the Dead Wood and Sediment Deposit Mitigation Area per Typical Section 3, cut/knock down dead standing trees and remove with root wade, where possible, from the mitigation area to a specified location.
2) Remove fallen trees and tree trunks from the mitigation area to a specified location.
3) From approximately Station 985 to 1020, excavate the existing natural levee per Typical Section 3 and remove sediments to a specified location.

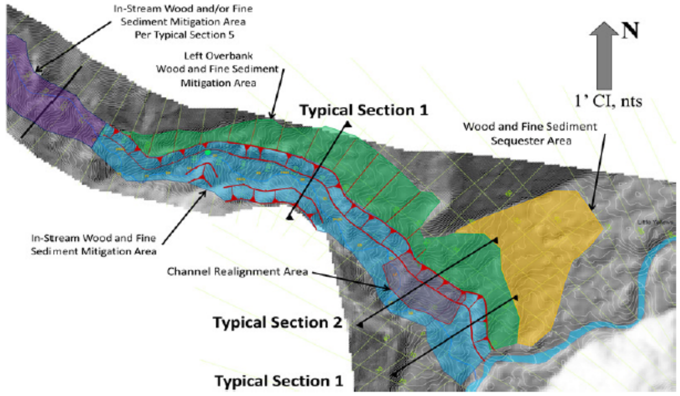
Table S6 is pending. Colorado River bar removal (Typ. Sec. 4 and 5)

Table A1- Estimates of cut and fill for channel and overbank areas along Lulu Creek and the Colorado River.

Map/Fig No.	**Location of Sediment Mitigation**	**Stations (m)**	**Length (m)**	**Area (m^2)**	**Cut Vol. (m^3)**	**Cut Volume (yd^3)**	**Fill Volume (yd^3)**
Figs. 17 &18	Lulu Creek Upstream of Bridge (purple polygon)	200-560	360	5.1	1830	2390	
Fig. 17	Lulu Creek Fan/Downstream of Bridge (blue polygon)	40-200	**See Table A2**		800	1040	1080
Fig. 19	Colorado River at Upstream Bridge (red polygon)	20-120	100	0.8	80	110	
Fig. 19	Colorado River (green polygon)	400-470	70	1.7	120	310	
Fig. 19	Colorado River (yellow polygon)	490-560	70	2.0	140	180	
Fig. 20	Colorado River at Head of Wetlands (purple polygon)	955-995	40	3.6	140	190*	
Fig. 20	Colorado River at Head of Wetlands (red polygon)	985-1020	35	5.6	200	260*	
	Total Cut/Fill Volumes				**3310**	**4320**	**1080**

* These actions are optional. A more comprehensive sediment removal option for this area is detailed in the Lulu City wetland analysis.

Table A2 - Earthwork Computations for Lulu Creek Restoration



	Left Bank				Right Bank			
Station (m)	Cut Area (m^2)	Length (m)	Cut Vol (m^3)	Total Vol (m^3)	Cut Area (m^2)	Length (m)	Cut Vol (m^3)	Total Vol (m^3)
200	1.7	10.0	16.9	16.9		10.0	0.0	0.0
190	1.9	10.0	18.6	35.5		10.0	0.0	0.0
180	2.8	10.0	28.2	63.7		10.0	0.0	0.0
170	0.2	10.0	2.4	66.1		10.0	0.0	0.0
160	1.1	10.0	11.2	77.4		10.0	0.0	0.0
150	0.5	10.0	5.3	82.6		10.0	0.0	0.0
140	3.1	10.0	31.1	113.7	2.5	10.0	24.9	24.9
130	5.2	10.0	51.9	165.6	2.5	10.0	25.2	50.1
120	3.0	10.0	30.3	195.9	2.8	10.0	27.6	77.8
110	2.6	10.0	25.7	221.7	5.3	10.0	52.6	130.3
100	3.1	10.0	31.3	253.0		10.0	0.0	130.3
90	2.6	10.0	25.9	278.9		10.0	0.0	130.3
80	4.0	10.0	39.7	318.6		10.0	0.0	130.3
70	3.7	10.0	36.6	355.2		10.0	0.0	130.3
60	4.4	10.0	44.0	399.2				
50	10.1	10.0	101.3	500.5				
40	12.3	10.0	122.8	623.3				
30	0.0	10.0	0.0	623.3				
20	3.4	10.0	33.8	657.1				
10	0.9	10.0	8.5	665.7				

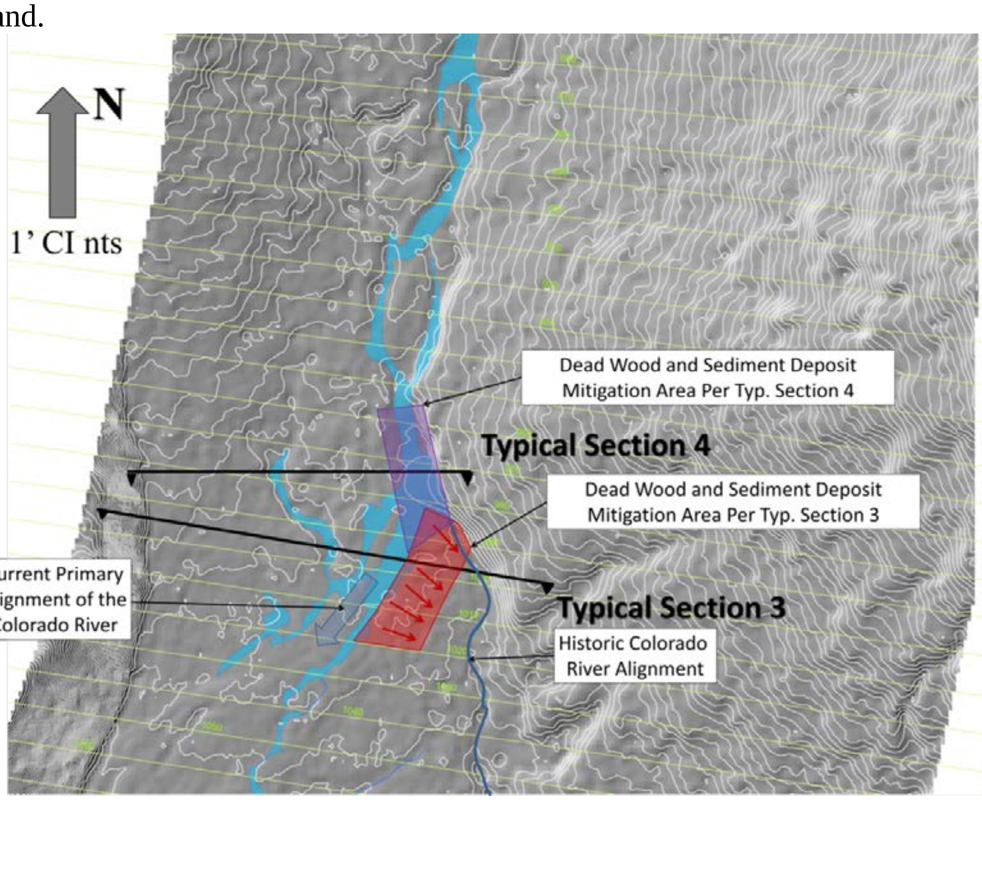
	Left Overbank			
Station (m)	Fill Area (m^2)	Length (m)	Fill Vol (m^3)	Total Vol (m^3)
200		10.0	0.0	0.0
190		10.0	0.0	0.0
180	5.0	10.0	50.3	50.3
170	6.1	10.0	60.8	111.1
160	0.2	10.0	1.9	113.0
150	1.3	10.0	12.6	125.6
140	2.1	10.0	20.6	146.3
130	4.0	10.0	39.9	186.2
120	5.5	10.0	54.7	240.9
110	11.2	10.0	111.8	352.7
100	10.1	10.0	101.1	453.8
90	13.1	10.0	131.1	584.9
80	9.2	15.0	138.3	723.3
70	1.8	5.0	9.1	732.3
60	2.2	10.0	21.9	754.3
50	2.0	10.0	20.0	774.3
40	0.0	10.0	0.0	774.3
30	0.0	10.0	0.0	774.3
20	4.2	10.0	42.1	816.4
10	0.6	10.0	6.0	822.4

Summary	Total Vol (m^3)
Cut: Left Bank	666
Cut: Right Bank	130
Total Cut	796
Fill: Left Overbank	822

Summary	Total Vol (yd^3)
Cut: Left Bank	871
Cut: Right Bank	170
Total Cut	1041
Fill: Left Overbank	1076

Split Flow Analysis - Text

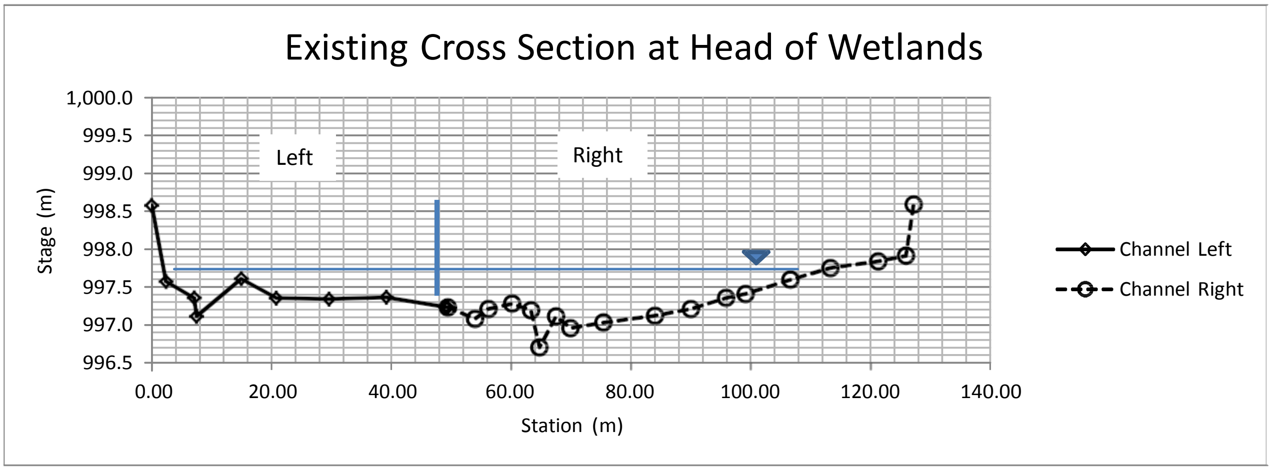
Based on detailed topographic data collected in August 2014, a split flow analysis was performed to assess the hydraulic effectiveness of the lateral and mid-channel bar sediment mitigation at the head of the Lulu City wetland reflected in Typical Sections 3 and 4 (Appendix A). The objective of the mitigation effort is to redirect the Colorado River flow away from the 2003 sediment deposit on the west side of the wetland and back to the historic channel in the center left of the wetland (Figure 20), by removing a lateral bar that has formed on the Colorado River at the head of the wetland (see Typical Section 3). Uniform flow computations were performed to assess the percentage of the total flow in the river splitting from the main channel and flowing to the southeast past the lateral bar location for both existing and proposed conditions. As summarized in Table A1 (Appendix A), the results of the split flow analyses indicate that under existing conditions approximately 20% of the total flow in the river splits to the southeast past the lateral bar and back into the historic channel during a moderately high flow. However, the proposed lateral bar sediment mitigation would result in approximately 70% of the total flow in the river splitting to the southeast and entering the historic channel under the same conditions. Furthermore, the hydraulic analyses indicate that flow velocities for the flow reentering the historic channel are sufficient to maintain channel form. Therefore, the flow split analyses suggests that the lateral bar sediment mitigation should be effective in redirecting the flow in the Colorado River into the historic channel and away from the 2003 sediment deposits in the wetland.



Split Flow Analyses at Head of Wetlands

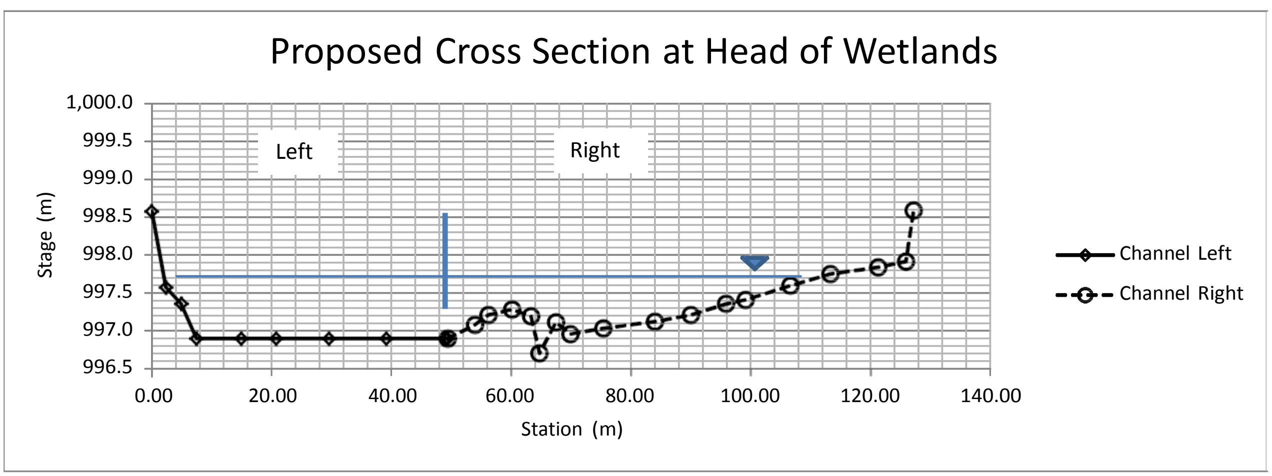
Existing Conditions

Stage (m)	Flow Left (cms)	Flow Right (cms)	Total Flow (cms)	Flow Split Left (%)	Flow Split Right (%)	Total Flow (cfs)	Average Vel. Left (fps)	Average Vel. Right (fps)
997.13	0.0	1.6	1.6	0%	100%	58	0	2
997.15	0.0	2.1	2.1	0%	100%	75	1	2
997.25	0.1	5.6	5.7	1%	99%	201	2	3
997.50	7.1	28.1	35.2	20%	80%	1243	4	5
997.75	36.0	67.4	103.4	35%	65%	3651	7	7



Future Conditions

Stage (m)	Flow Left (cms)	Flow Right (cms)	Total Flow (cms)	Flow Split Left (%)	Flow Split Right (%)	Total Flow (cfs)	Average Vel. Left (fps)	Average Vel. Right (fps)
997.13	3.5	0.3	3.8	91%	9%	135	3	2
997.15	16.2	2.8	19.0	85%	15%	670	5	3
997.25	28.4	6.8	35.2	81%	19%	1244	6	3
997.50	69.5	30.1	99.5	70%	30%	3515	9	5
997.75	126.3	70.0	196.4	64%	36%	6936	11	7



Appendix B
Lulu City Wetland
Cross Sections, Details and Specifications

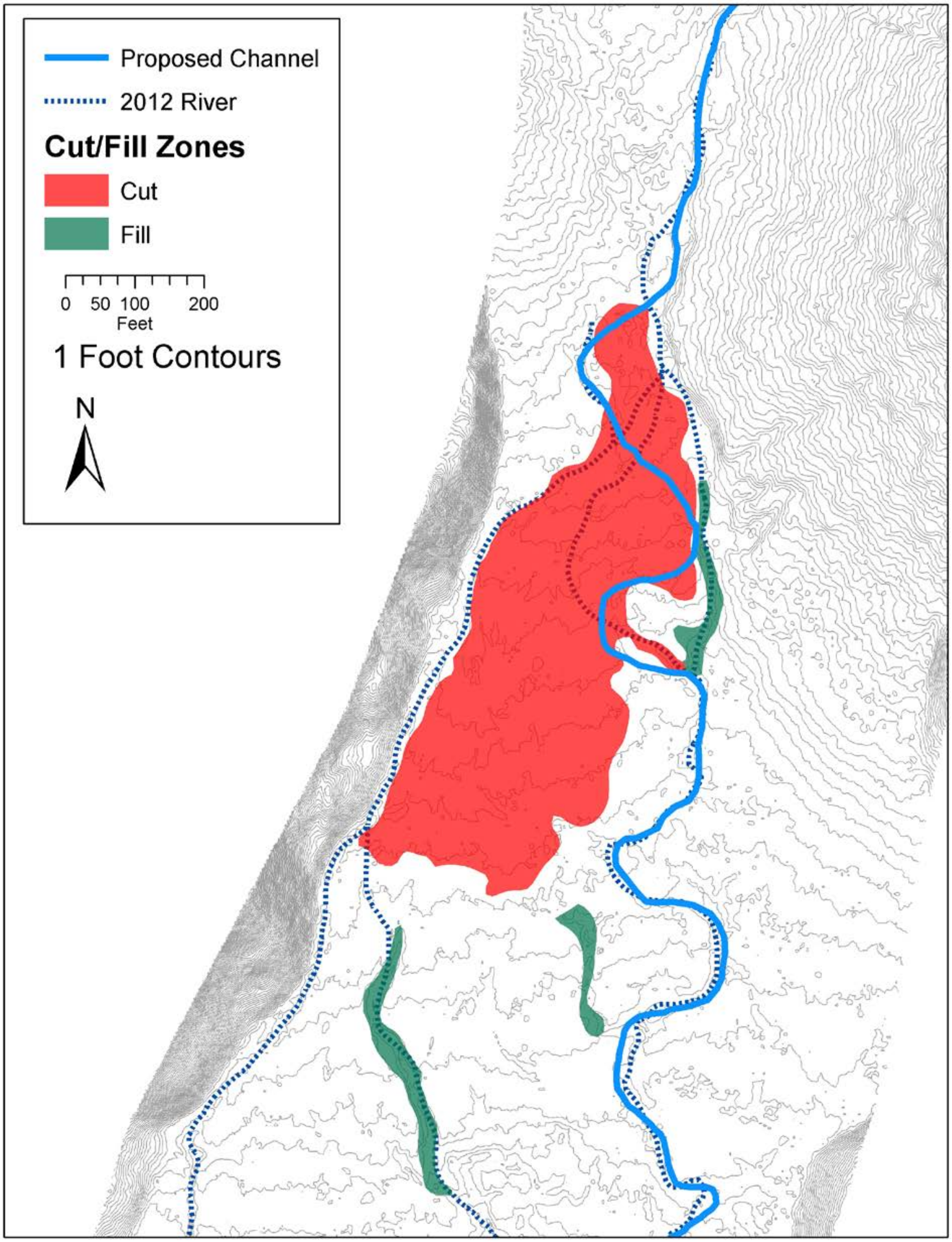


Figure B1. Cut and fill zones for proposed wetland.

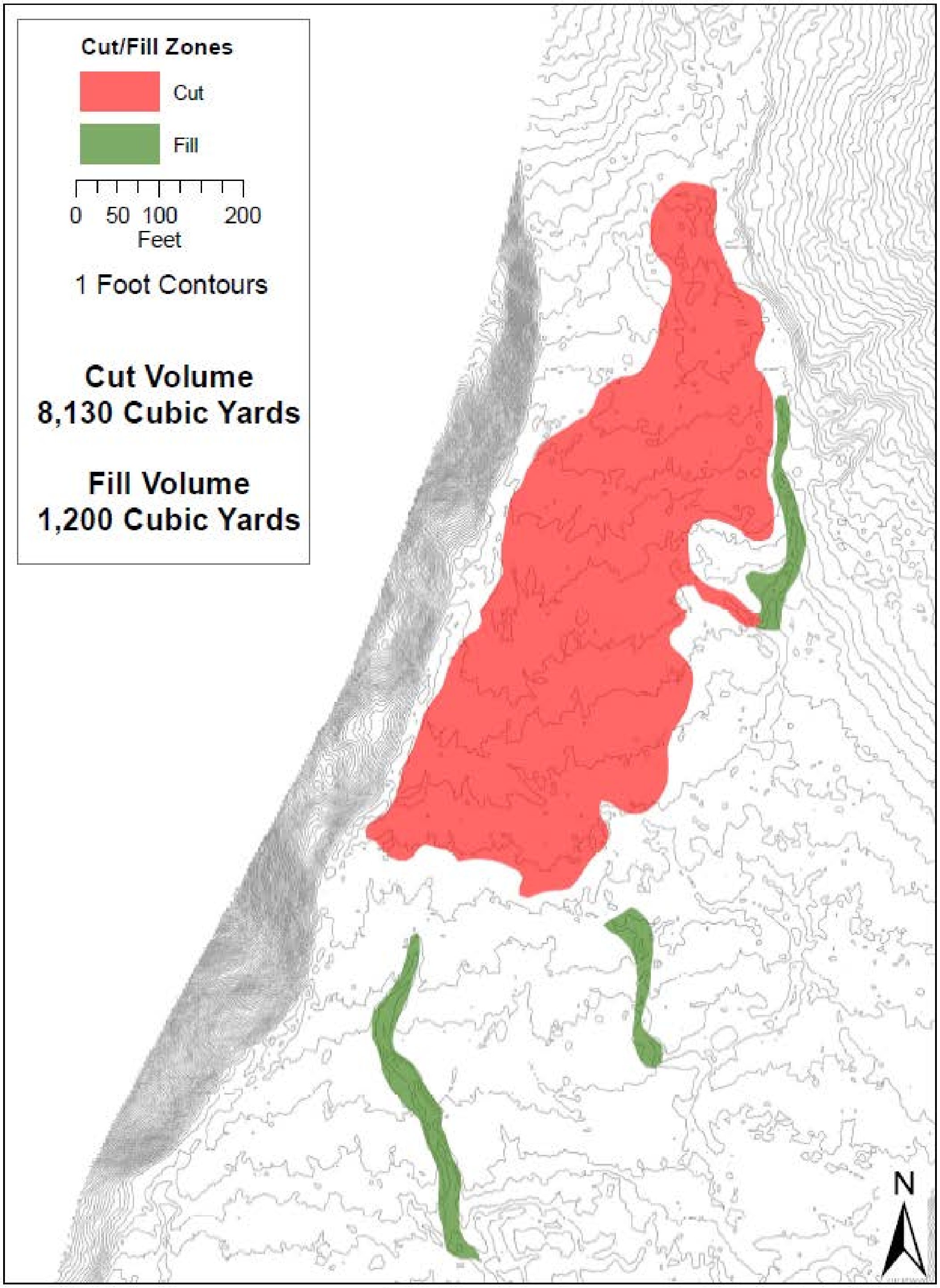


Figure B2. Cut and fill quantities.

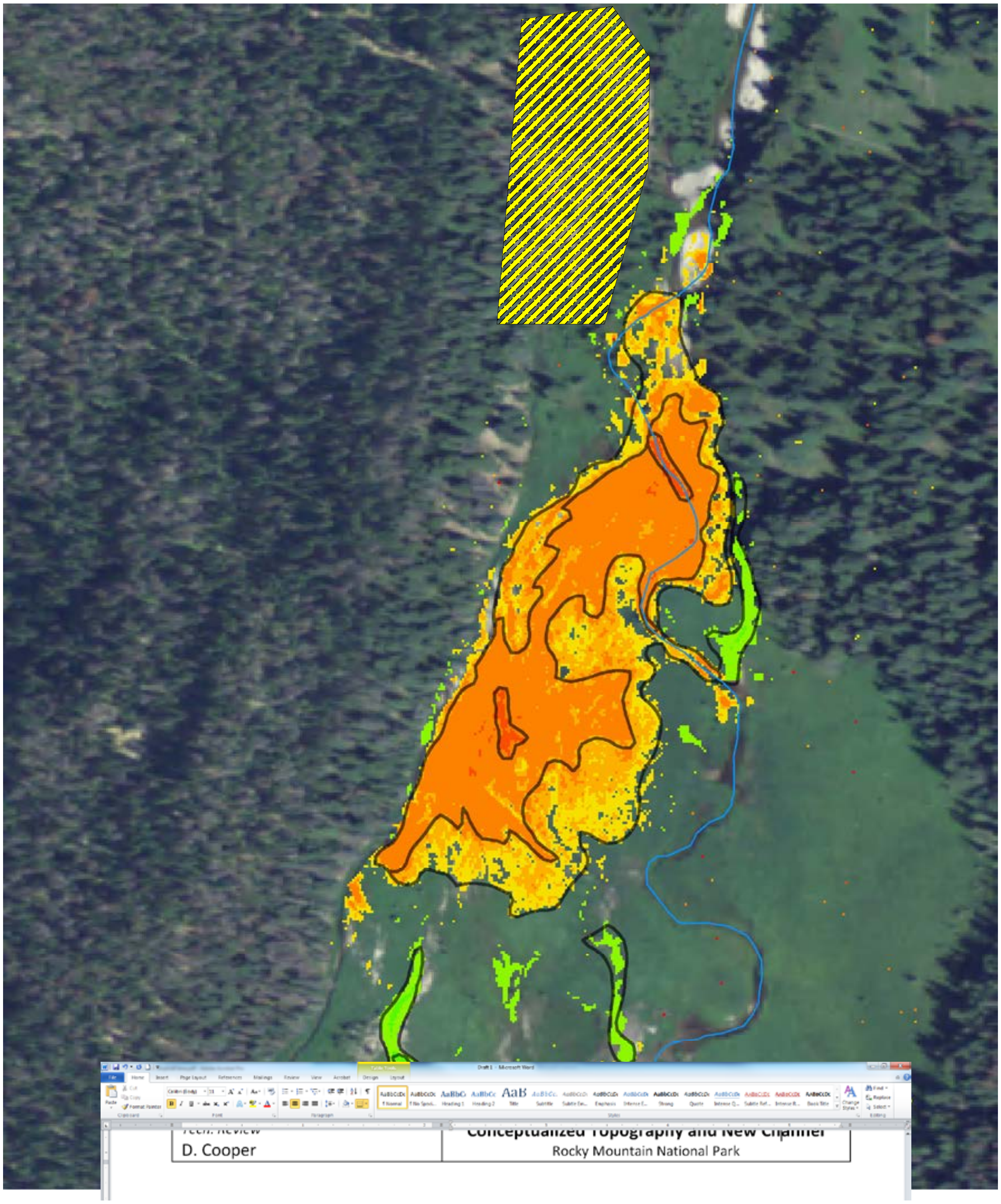


Figure B3. Proposed cut and fill thicknesses for the Lulu City wetland and location of sediment disposal area.

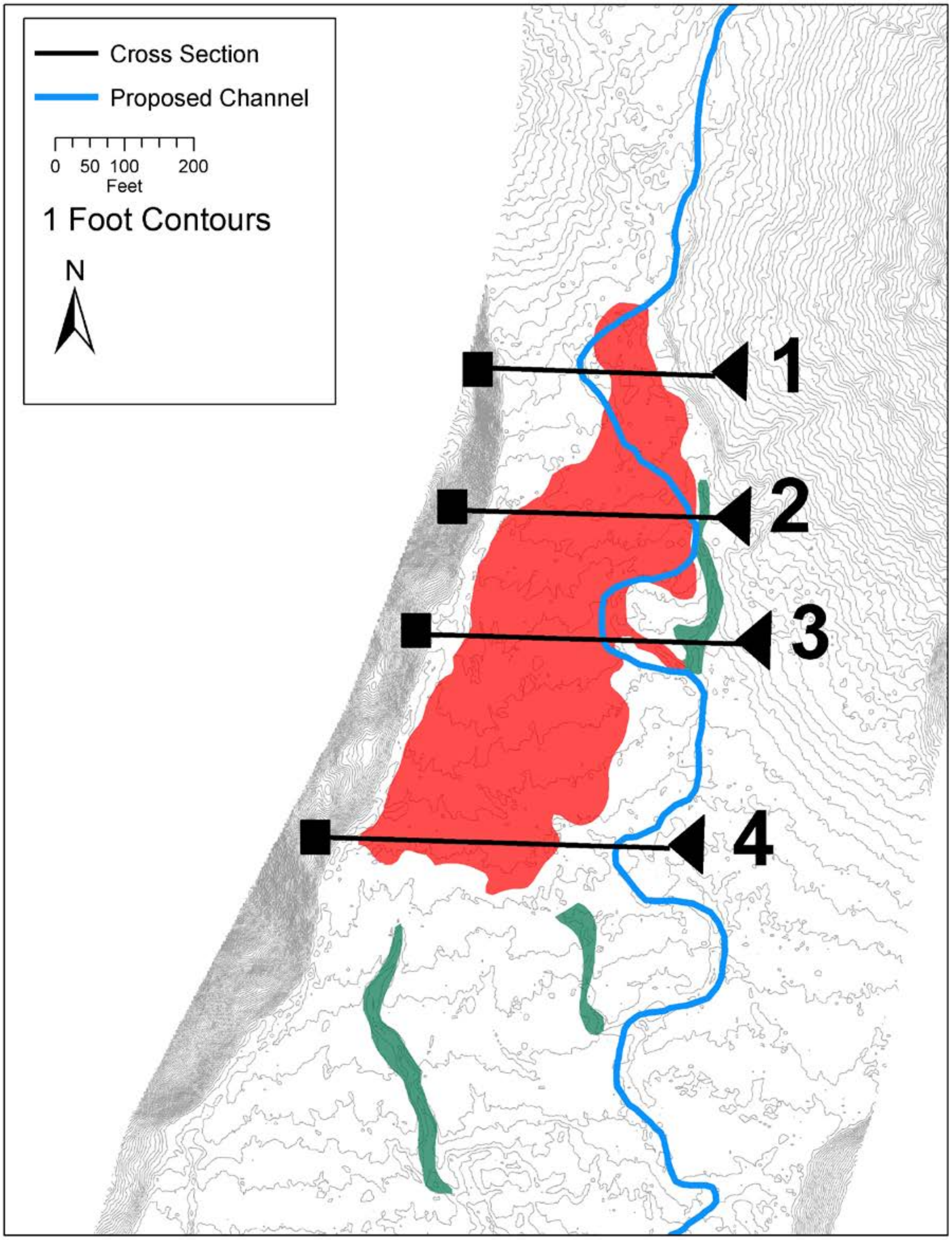
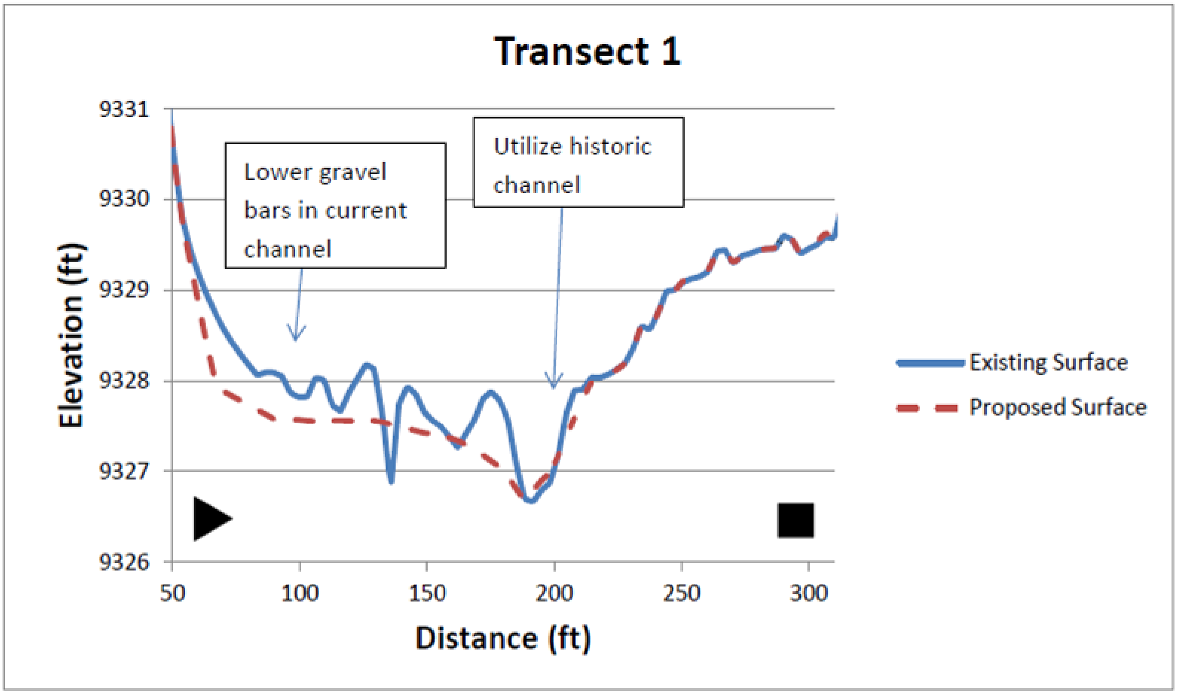


Figure B4. Location of sediment cut and fill zones, and cross section profiles used to depict current and proposed land surface elevations.



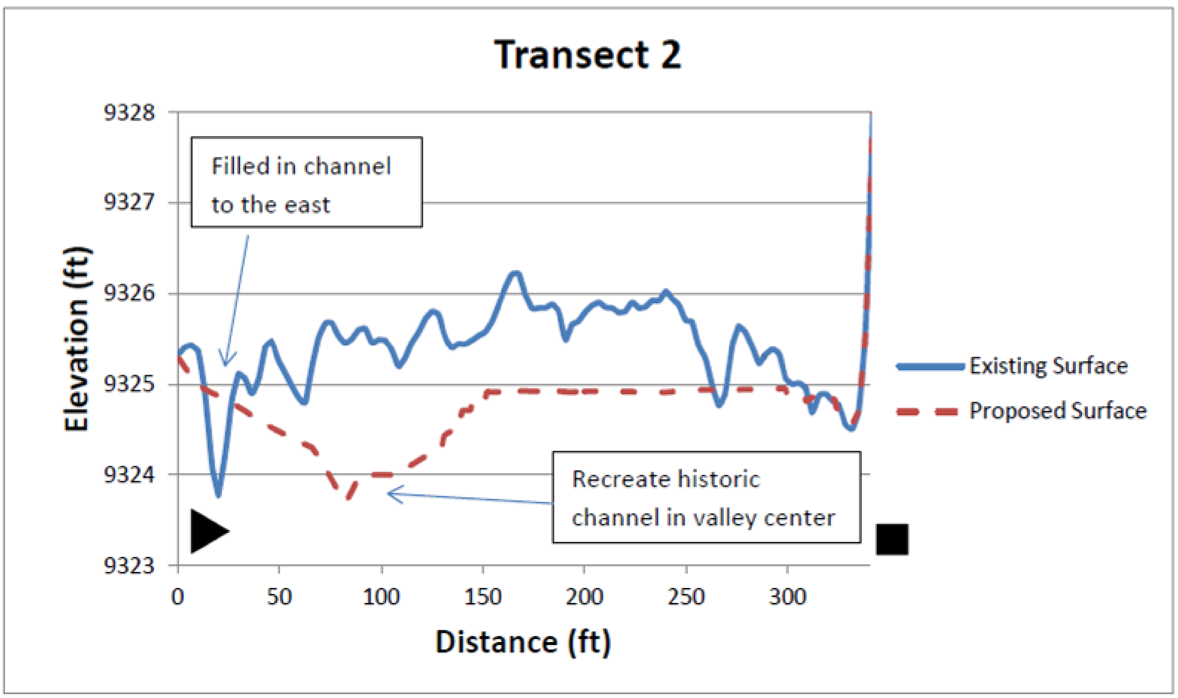
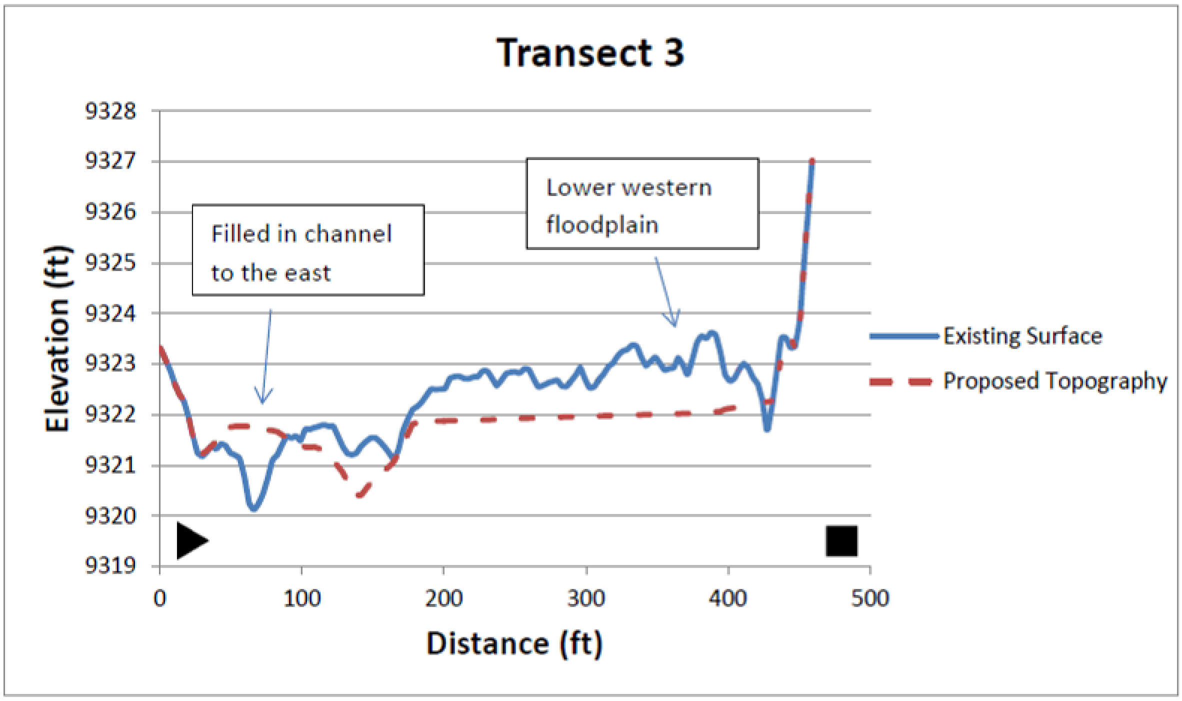


Figure B5. Existing and proposed tography for transects 1 and 2 depicted in Figure B6. Horizontal axis is distance from right bank looking upstream.



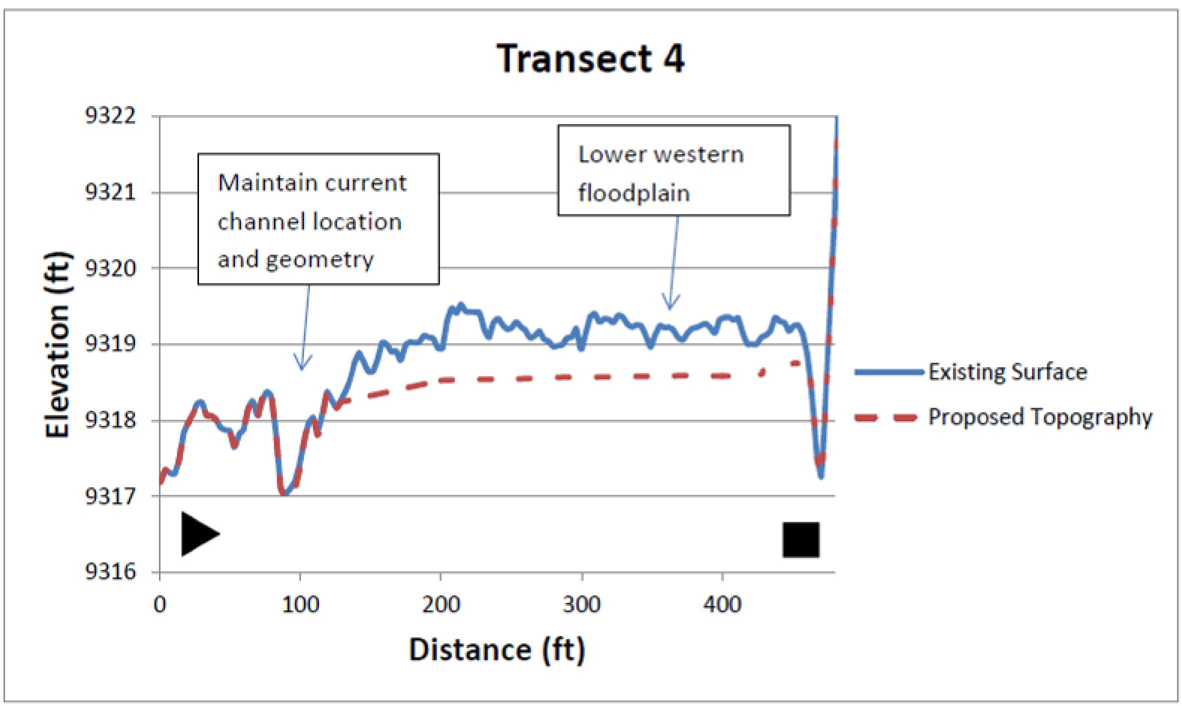


Figure B6. Existing and proposed tography for transects 3 and 4 depicted in Figure B6. Horizontal axis is distance from right bank looking upstream..

Figure B7. August 1937 air photograph of the Lulu City area. The location of the historic Lulu City town site is inked onto the photograph. The Colorado River flows north to south, top to bottom. Its meandering channel can be seen.

Lulu City Wetland Implementation Phasing

Earthwork for both options 1 and 2 would remove ~8,500 yd^3 from the Lulu City wetland as shown in Figures x and y. Filling of eroded channels in the wetland would require 1,500 yd^3, leaving a net 7,000 yd^3 that would have to be moved to the sediment disposal area on the disturbed alluvial fan of Little Dutch Creek (Figure x). This volume of sediment would cover approximately 1 acre 4.33 feet deep. The fill surface would then planted with Engelmann spruce and lodgepole pine.

Grade stakes would be placed throughout the wetland and channel area identifying the proposed surface elevation. A technician using a laser level would make regular elevation measurements to facilitate accurate grading. Fill removal is best accomplished by a track hoe or similar vehicle with a large bucket working with sediment hauling vehicles. The sediment removal operation should start in the southern part of the wetland in mid to late summer when water tables are low. The hoe would work its way north, removing and stockpiling the top 7-12 inches of topsoil, then remove the sediment. The topsoil would then be placed onto the new surface and roughly spread to reach the final proposed grade. We envision working relatively small areas (ie. 2500 ft^2). This would allow the topsoil to be moved back onto each area without driving over it with the hoe. It is most efficient if the hoe can excavate sediment from the wetland and place it directly into sediment haulers, several of which would cycle from the wetland to the disposal area up to 1/3 mile away. In the initial stages of sediment removal, the sediment can be used to fill the gully's in the southern portion of the study area (Figure B6). To improve the soil stability after grading and topsoil placement, it might be desirable to staple jute or coir matting over the bare earth surfaces. This material would decompose over time. This may be desirable since the site will be bare of plants through the fall, winter and spring, and the area has relatively fine-grained sediments that are easily erodible. At that time, *Calamagrostis* and *Carex* shoots should emerge from the soil and form an herbaceous plant cover that will reduce the site's erosion potential.

Before the Lulu City wetland work begins, the Colorado River must be captured and channeled into its historic channel via a temporary ditch, pipes, or other means. It would be best if a cross-valley trench, at least 3-5 feet deep and roughly 300 feet long spanning the head of the valley, was constructed above the wetland to capture ground water and divert it to the same location as the surface water. Dry conditions will facilitate earthwork in the Lulu City wetland. We anticipate that all earthwork could occur in one summer. Once the Colorado River channel to the northern extent of this project was constructed the trench would be filled and river water returned to the new river channel above the wetland.

Appendix C
Hydraulic Washing of Lulu Creek
By: Jeremy R. Shaw and David J. Cooper

This approach will employ high-pressure water jets from hand-held hydraulic canons to wash fine sediments from the channel and overbank deposits of Lulu Creek, and direct them downstream to a collection site. High-powered pumps will be used to pipe water from the confluence with the Colorado River up to a series of temporary stations along the valley margin of Lulu Creek. Beginning at the top of Zone 2, at least one hydraulic canon will be stationed on each side of Lulu Creek Valley, where operators will use water jets to push fine sediment into the channel and downstream. As each portion of Lulu Creek is washed of fine sediment, hydraulic canons will be moved downstream to the next temporary station (roughly 50 m apart), where the process is repeated. The use of small hand-held hydraulic canons will allow operators the precision to selectively treat the targeted sediment deposits, while avoiding impacts to valley walls and other sensitive areas. The fine sediment will be washed downstream to one or more geotextile-lined temporary settling ponds that are excavated in lower-gradient areas of Lulu Creek corridor. Excavators or loaders will be used to remove fine sediment from the settling pond(s) and transport it to storage sites. After washing and removal of fine sediment, channel modifications and management of downed trees within Lulu Creek may be performed. This approach will remove the majority of fine sediments otherwise available for downstream transport. Any fine sediments that are buried or contained within the debris flow matrix, will be armored by the residual surface layer of cobbles and boulders, and thus unavailable for downstream transport under typical conditions. Hydraulic washing will be conducted during annual peak runoff, likely in June, to take advantage of the additional sediment transport capacity of Lulu Creek, unless streamflow is too high to safely operate excavators within the channel. We present two options, with different levels of channel modification and heavy equipment involvement.

Alternative 1: Hydraulic Washing Only
In this alternative, heavy equipment operation is limited to areas near the mouth of Lulu Creek, and fine material is removed only by hydraulic washing. This approach may be the most efficient and safest sediment removal technique, because it will minimize the activities of personnel and heavy equipment within the more challenging terrain of Lulu Creek. The washing operation would be completed in 7-10 days.

One large temporary settling pond, with approximately 200 cu yd capacity (10 m x 10 m, 2 m depth), will be excavated on the alluvial fan above the mouth of Lulu Creek. The settling pond will be lined with permeable geotextile fabric to ensure full recovery of fine sediment. Operators will use water jets only to wash fine sediment from debris piles and log jams, and earth-moving equipment will not be used upstream of the settling pond. Removal and transport of sediment from the settling pond will occur as needed throughout the washing operation. After fine sediment removal is complete, the temporary settling pond will be backfilled and the lower channel segment of Lulu Creek will be restored. We can then perform active restoration of channel geometry and bed forms throughout Zone 2 using hand crews and a Schaeff Walking

Excavator, or allow channel evolution to proceed according to ambient rates of material transport and deposition.

Alternative 2: Hydraulic Washing with Backhoe Assistance

A more intensive alternative, combining a Schaeff Walking Excavator with hydraulic washing, would increase costs and operator time, but would remove a larger portion of fine sediment from the Lulu Creek corridor. This washing operation would require 10-15 days.

The excavator will be used to excavate three or four smaller temporary settling ponds along the course of Lulu Creek throughout Zone 2, as local topography allows. As above, all settling ponds will be lined with permeable geotextile fabric, and the washing procedure will start at the top of Zone 2 and work down to the confluence of the Colorado River. During the washing procedure, the Excavator will be used to manipulate log jams and debris piles, in order maximize removal of fine sediments that may be otherwise inaccessible to the hydraulic operators. Fine sediment trapped in the settling ponds will be removed and transported to storage sites along the margin of Lulu Creek corridor using the excavator**.** As washing progresses downstream, the temporary settling ponds will be backfilled and channel morphology will be restored. Because heavy equipment will be used throughout Zone 2 of Lulu Creek, this approach lends itself to larger-scale active restoration of channel form through strategic placement of log jams and boulders, and removal of downed trees.