Reach Y Restoration Feasibility Assessment

Final Draft

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EXECUTIVE SUMMARY

This report examines opportunities for restoring geomorphic and ecosystem function of the Truckee River between East McCarran Blvd. and near the Truckee Meadows Water Reclamation Facility (TMWRF), herein referred to as Reach Y. The report was prepared for the Cities of Reno and Sparks and TMWRF, who are seeking opportunities to improve water quality and the ecosystem of the Truckee River, especially opportunities for early implementation.

Reach Y is an extraordinarily complex geomorphic environment. There is a distinct transition in fluvial geomorphic processes within the reach. Channel dimensions and hydraulic characteristics are far different in the upper end of the reach than in the lower end. Prior to human disturbance, riparian ecosystems were likely also very different, dominated by shrubs and trees at the upstream end and herbaceous, meadow-forming species at the lower end.

The river has been highly modified by human activities throughout the reach. Straightening, channel enlargement, removal of obstructions and levee construction, undertaken to improve the channel for agriculture and flood control, have resulted in significant incision (lowering of the channel bed through erosion) throughout most of the reach. Channel response to the initial disturbance continues today, with relatively high rates of bank erosion and lateral instability. In the absence of artificial stabilization, the channel will continue to erode, with the eventual formation of a new floodplain at a lower elevation.

Due to the inherent geomorphic complexity within Reach Y, the river has responded to human disturbance in different ways in different locations. Incision has been more rapid in some areas than in others. Streambank erosion and lateral stability subsequent to incision have also occurred in different ways and at different rates throughout the reach.

To be effective, restoration measures implemented for this reach should recognize its inherent geomorphic and ecosystem complexity, which have important implications both for the potential characteristics of the restored system as well as its stability. Restoration measures should also be designed with an understanding of the effects of human disturbance, and should be capable of accommodating continuing channel adjustment to past human disturbance.

Restoration of the floodplain, through benching or similar techniques, represents the best opportunity to restore functional riparian ecosystems. However, this alternative will magnify many of the factors that tend to enforce instability and dynamics:

- Construction of a floodplain or benching will reduce the ability of the channel to transport coarse sediment, thus promoting coarse sediment deposition in the reach and subsequent lateral instability;
- Excavation of the existing streambanks will make likely make them more erosive in the short-term, until they are stabilized by vegetation;
- Constructed floodplains or benches will also be susceptible to erosion until stabilized by vegetation.

Assurance of stability for this alternative will therefore require a relatively high degree of engineering, and thus high cost. Throughout much of the reach, establishing functional native vegetation communities would also require intensive and expensive revegetation and erosion control techniquies, as well as a long-term commitment to maintenance of planted materials.

Because this reach has a high potential for substantial erosion, it is extremely sensitive to modifications of the channel upstream for flood control or restoration. The success of any restoration treatment in Reach Y will require careful integration with upstream restoration and flood control strategies, with consideration of potential changes in sediment transport and flood magnitude. We recommend that restoration in most of Reach Y be implemented in conjunction with upstream channel improvements.

The most feasible project for short-term implementation is bank stabilization in the vicinity of TMWRF, which can be implemented prior to other flood or restoration alternatives. Due to flood control constraints, bank stabilization is the sole feasible riparian restoration alternative in this location, and could be designed to integrate effectively with any restoration alternative upstream. Riparian habitat, aquatic habitat, and water quality improvements provided by bank stabilization would be limited. However, our analysis of geomorphic evolution in this area suggests that bank erosion is likely to continue in this area, even though erosion rates may be relatively slow. Bank stabilization may be required to protect infrastructure.

INTRODUCTION

This report describes the results and conclusion of a restoration feasibility assessment for a reach of the Truckee River in Reno and Sparks, Nevada. The assessment was conducted for the Cities of Reno and Sparks and the Truckee Meadows Water Reclamation Facility (TMWRF). Funding was obtained from the sewer enterprise fund. Restoration of this reach may allow for permit relief for TMWRF.

The portion of the river assessed here is termed Reach Y, and is located on the east end of the Truckee Meadows (Figure 1). The lower end of the study area is the railroad crossing near Vista; the upstream end is the east McCarran bridge. This reach is bordered by commercial buildings in Sparks to the north, and by the University of Nevada Agricultural Farms and the TMWRF to the south.

Reach Y was selected for assessment of restoration potential for several reasons:

- It has been highly altered for flood control and development;
- Physical habitat and water quality have been significantly degraded by human disturbance in the surrounding areas, and by the resulting channel response to human disturbance;
- The aquatic and riparian ecosystems have very low function and aesthetic value.

The purpose of this study is to identify opportunities for improving riparian and aquatic habitat, water quality, and aesthetic values, through stream restoration and streambank stabilization. While restoration of the Truckee River is being considered by other planning efforts, most notably flood control and mitigation currently being planned by the U. S. Corps of Engineers (COE), project managers for this study have determined that Reach Y warrants additional planning effort because it is the most seriously degraded reach within the Truckee Meadows area. Moreover, the outflow from the TMWRF enters the river in this reach, and the poor condition of the river resulting from past human disturbance complicates understanding the potential effects of TMWRF effluent on the river ecosystem. Low function in the aquatic ecosystem is due to many factors other than TMWRF effluent, including: poor water quality from tributaries (Steamboat Creek and the North Truckee Drain); channelization of the river; and human development of the historic floodplain.

While it is not within the scope of this assessment to evaluate the relative contribution of these various factors to ecosystem degradation, project managers recognized prior to this study that the extremely poor physical condition of the river in this reach represents a potentially significant opportunity to improve ecosystem function. It was also recognized that a feasible restoration project, planned and designed to fit within other ongoing river planning efforts, would be a valuable early implementation project for restoration of the Truckee River system, providing both ecosystem improvement and valuable insight and data for subsequent restoration efforts.

The purpose of this study is therefore to evaluate, at a conceptual level, restoration opportunities for Reach Y. It is not the purpose of this study to evaluate restoration projects proposed under other planning efforts. It is hoped, however, that this analysis proves useful for other organizations working to restore the Truckee River.

We believe that the most effective ecosystem restoration focuses on reestablishing geomorphic and ecosystem processes that supported functional ecosystems prior to human disturbance. Restoring these processes, such as sediment transport and sorting, regular disturbance by flooding, and nutrient cycling, ensures that restored ecosystems have appropriate function through time without regular maintenance. It also ensures that restored ecosystems are dynamic and vigorous, important properties of functional natural riparian systems.

This approach requires an understanding of pre-disturbance geomorphic and biological functions and how the ecosystem has changed with human development. Our analysis therefore has the following basic outline:

- Description of pre-disturbance geomorphic and ecosystem function;
- An overview of human development and it's effects on the pre-development ecosystem;
- Analysis of potential restoration strategies, and their ability to restore ecosystem function.

A great deal of work has already been done on the geomorphology and riparian ecosystem of the Truckee River. We have primarily relied on existing data for this study, and have focused our efforts on the development and analysis of restoration opportunities for Reach Y.

SITE DESCRIPTION

GEOLOGIC SETTING

Reach Y is located at the east end of the Truckee Meadows, a valley containing the cities of Reno and Sparks, Nevada (Figure 1). Above the USGS streamflow gage at Vista, which is the downstream end of Reach Y, the watershed is 1,431 square miles. Major tributaries include Grays and Bronco Creeks draining the west slope of the Carson Range, the Little Truckee River and Prosser Creeks draining the east slope of the Sierra north of the river, Donner Creek draining the Donner Pass area, several tributaries in the Canyon between Truckee and Lake Tahoe, and the Lake Tahoe basin.

Above the Truckee Meadows, the watershed contains a mix of granitic and volcanic rock types (Otis Bay Riverine Consultants 2002). Most of the granitic rocks are found in the Sierras, at higher elevations. Volcanic rocks comprise most of the Carson Range, and are also found in the Sierras, often at very high elevations in glaciated landscapes. These Tertiary volcanics (the Mehrten Formation) include both extrusive flow formations and a high proportion of breccias (mudflows or mass wasting deposits) and tuffs (ash deposits) (Birkeland 1966). The breccias and tuffs, in particular, are highly erosive and tend to weather to fine particles.

Otis Bay Riverine Consultants (2002) describe the complex regional geology comprising the upper portion of the watershed. Drainage patterns are antecedent to Basin and Range faulting patterns, which has resulted in steep slopes through much of the watershed, especially the canyon between Truckee and the Truckee Meadows. Severe slopes are also common in glaciated oversteepened landscapes near the Sierra crest. The combination of weak rock types (breccias, tuffs) with structural conditions that have created steep slopes results in relatively high rates of overall sediment yield, with the volcanic rocks yielding a substantial proportion of fine particles (silt or smaller).

The Truckee Meadows basin is bounded by basin-and-range faults on the east and west sides, and was formed as a graben, a down-dropped and down-warped structural block (Gates and Watters 1992). East-dipping rocks of the Carson Range form the western boundary of the basin, west-dipping rocks of the Virginia Range form the eastern boundary, and the Steamboat Hills (mostly intrusive igeneous rocks) form the southern boundary. The faulting and tilting that formed the valley began at least 7 million years ago and are still active. The dropped block which forms the structural basement of the valley has been tilting downward to the east for about the last 2 million years (Bell et al. 1984), resulting in a relative uplift of the Virginia Range with respect to the meadows.

This structural basin has subsequently been filled by several types of Quarternary (last two million years) surficial sediments, including glacial (ablation till) outwash deposits, landslide deposits, alluvial fan deposits, and Holocene (last 10,000 years) fluvial and flood deposits (Gates and Watters 1992). Outwash deposits form the bulk of these sediments, which vary in depth from hundreds of feet at the west end of the valley to approximately 2,800 feet at the east end due to tilting of the underlying graben (Birkeland 1966).

Birkeland (1966) mapped surficial deposits in the Truckee Meadows. Outwash from the Illinoian-stage Donner Lake glaciation, which occurred about 400,000-600,000 years before present (ybp), underlies a large portion of south and southwest Reno, forming a mantle hundreds of feet thick from the west end of the valley to near Highway 395 (Figure 2). These deposits range from sands to large boulders 12 to 16 ft. in diameter. The next glaciation was the Tahoe, which occurred approximately from 60,000 to 90,000 ybp. Tahoe outwash deposits are found throughout much of northeastern Reno and Sparks along the I-80 corridor, set within the older Donner Lake deposits at the western end of the valley. Tahoe outwash consists of similar materials to the Donner with abundant large boulders. Tahoe sediments range in depth from about 300 ft. in western Reno to about 1,000 ft beneath Sparks (Gates and Watters 1992).

Subsequent mapping of surficial deposits has generally agreed with Birkeland's 1966 mapping for the Donner and Tahoe glaciations, but includes deposits from the youngest glaciation, the Tioga, which occurred from 10,000 to 30,000 ybp (geology field trip guidebook map, author unknown, based on Bell et. al 1984). These deposits are found on the northern half of the eastern end of the valley, generally underlying Sparks (Figure 3). Tioga sediments are similar to the other outwash deposits, although they appear to lack the largest boulders.

From Highway 395 east to the Virginia Range, outwash deposits have been covered by Holocene floodplain deposits over much of the Truckee Meadows. These deposits consist of both channel-type sediments, with inter-bedded sands and gravels, and overbank floodplain deposits consisting of finer materials. These overbank deposits become the dominant surficial sediment type near the east end of the valley and are at least tens of feet thick.

Glacial Geomorphic Processes

At certain times during glacial periods, enormous amounts of sediment are supplied to streams. Rates of sediment supply are especially high during deglaciation, when surfaces eroded by glaciers are typically oversteepened, glacial deposits such as moraines are available for fluvial transport, and vegetation cover is low (Benn and Evans 1998). The largest deglaciations occurred at the end of the major glacial periods, such as the Donner Lake (200k ybp) and the Tahoe (60k ybp), but glacial advance and retreat also occurred within the glacial periods. Major pulses of sediment therefore entered the Truckee Meadows throughout the Pleistocene on decadal- or century-length time scales as glaciers retreated in the upper watershed.

More discrete Pleistocene events resulted in extremely high rates of sediment supply to the Truckee Meadows. Birkeland (1963) found evidence of massive Truckee River floods that probably occurred during the Donner Lake and Tahoe glaciations. Based on the size of boulders assumed to have moved during the floods, discharge may have reached as much as one million cubic feet per second (cfs) at Truckee. These floods are the source of large boulders buried in outwash throughout the Truckee Meadows.

Birkeland (1963) describes the process thought to have produced the large Pleistocene floods. He identified morainal deposits high up on the east side of the Truckee Canyon that were deposited by glaciers, probably emanating from Squaw Creek and other west side tributaries. These glaciers are thought to have dammed the Truckee River, raising the water surface of Lake Tahoe up to 600 ft during the Donner Lake glaciation and up to 90 ft during the Tahoe glaciation. Evidence of terraces in the Lake Tahoe basin corroborates the occurrence of high lakestands. There is some evidence for lower lakestands (up to 30 ft) during the Tioga glaciation. Catastrophic failure of the ice dams released the water in Lake Tahoe rapidly, resulting in jökulhlaups, large floods caused by the failure of damming by glacial processes (moraine dams, ice dams). Jökulhlaups are relatively common occurrences in glaciated landscapes and have been observed in modern times (Benn and Evans 1998).

Throughout glacial periods, immense quantities of sediment were therefore transported through the Truckee River canyon to the Truckee Meadows during large, often catastrophic floods, forming the large outwash deposits underlying much of Reno and Sparks. Because the valley through which the river is flowing widens abruptly at the west end of the Truckee Meadows, the deposits took the form of an extensive alluvial fan. During this period, the basement rock forming the Truckee Meadows was downwarping and tilting to the east, and alluvial sediments are therefore thicker on the east.

It is important to note that the coarser sediment (cobble and larger) was transported during large floods. During these transport periods, a pool likely developed at the east end of the meadows where the river flows through the narrow, bedrock-controlled canyon in the Virginia Range. Coarser materials would have been deposited at the upper end of the pool, forming a toe to the alluvial fan, while mostly finer sediment would have deposited in the pool. Geotechnical explorations by the Army Corps of Engineers (COE 2004) in the area of the Steamboat Creek confluence (likely a pool area during flooding) are consistent with this hypothesis. No sediment larger than silts was encountered during drilling in the upper 30 ft of these explorations; some small to medium gravel was found at a depth of 40 ft, and may represent paleo-channels.

Tilting of the basement graben downward to the east has probably also contributed to sediment deposition patterns in the meadows. As the graben has tilted, the Virginia range has raised relative to the valley floor. Exposed Virginia Range bedrock in this area (a series of outcrops along the channel bottom over the distance of a couple of miles near Vista, known today as the Vista Reefs) is relatively non-erosive and thus forms a rising base level relative to the meadows due to uplift, promoting pooling of streamflow, especially during larger floods, at the eastern end of the valley. Due to these processes, Pleistocene alluvial fill therefore contains a large wedge of finer materials at the eastern margin of the meadows, with a potentially steep western boundary where coarser material was deposited at ponding margins.

Between glacial periods, sediment yield from the upper watershed slowly declined as erosion reduced slope angles and vegetation became established. As sediment yield declined, the river, with increased erosive capacity, began to erode landforms that during periods of high sediment supply had been depositional. Thus the river eroded and incised within alluvial fan outwash deposits at the western end of the meadows, forming a new alluvial valley bottom at a lower elevation. During long interglacial periods, such as between the Donner Lake glaciation and the Tahoe, the valley eroded was relatively wide, leaving remnants of the previous outwash surfaces as terraces along the margins; these terraces are clearly visible in meadow topography today (Figure 4). Material eroded during these periods may have been transported downstream to form deposits in the east end of the meadows. Outwash sediments from subsequent glaciations were deposited in the valleys formed during interglacial periods, such that Tahoe outwash is set within the older Donner outwash (see Figure 3).

Holocene Geomorphic Processes

Rates of sediment supply from the upper watershed have slowly declined since the end of the Tioga glaciation about 10k ybp. The river has eroded and incised within Tahoe outwash through western Reno, and perhaps through Tioga outwash in eastern Reno and Sparks. Floodplain and channel deposits formed during the Holocene are set within and below the older outwash terraces. West of Highway 395, the more modern floodplain deposits are narrow and well-entrenched within outwash. The channel in this area has eroded and sorted the older deposits, which were often composed of larger sediment particles than the current channel is capable of moving. Relatively immobile riffles common in parts of western and central Reno represent sorted outwash deposits (WET 1990, Miller et al. 1994).

East of Highway 395, much of the valley is mapped as Holocene floodplain deposits (Figure 3), and the floodplain has therefore been extensively reworked by the river in the last 10,000 years. However, floodplain sediments in the upstream half of this reach (McCarran Blvd. upstream to Highway 395) are far different than floodplain sediments in the downstream half (McCarran downstream to Vista), suggesting a different set of Holocene geomorphic processes in these two areas. In the upstream half, gravel and larger sediment is common in the upper five feet of geotechnical borings (Figure 5). These sediments are typical channel-type materials, indicative of floodplains created by meander translation across the floodplain and some overbank deposition. The Holocene river probably constructed floodplain from reworked in-situ outwash deposits and sediment supplied from upstream.

About one-half mile downstream of McCarran Blvd., the nature of floodplain sediment changes dramatically. At five feet depth, COE geotechnical borings retrieved very little material larger than sand in size (Figure 5). Instead, streambanks and the floodplain are entirely composed of very fine-grained, cohesive lacustrine deposits (WET 1990). These sediments are termed lacustrine or lake deposits because they were deposited in ponded water during large floods. The lake in which they were deposited was temporary, only occurring for a few hours or days during flooding, but the characteristics of the deposits are similar to deposits in permanent lakes. Mazama ash, deposited during the eruption of Mount Mazama 6,845 ybp (Carrara 1989), is evident in lacustrine deposits exposed in eroding streambanks near the middle of Reach Y (Photo f, Figure 6). About four feet of lacustrine sediment has been deposited on top of the Mazama ash in nearly 7,000 years. Similar underlying sediments exposed in this bank are either early Holocene or later Pleistocene in age.

THE PRE-DISTURBANCE RIVER

The following section describes the form and function of Reach Y immediately prior to human disturbance (hereafter referred to as the historic channel). While much of this discussion is necessarily conjectural given that human disturbance began in the mid-19th century, evidence for historic channel characteristics is relatively robust and provides a solid basis for inferring channel form and function.

Although Reach Y is only about 3.7 miles in length, geomorphic characteristics of the channel and floodplain vary significantly throughout due to the transition in geomorphic processes described above. For the following discussion, Reach Y can be divided into three distinct geomorphic sub-reaches (Figure 7). Reach 1, 4,750 ft in length, is from the railroad trestle upstream to near TMWRF. The river is generally constrained by the valley and bedrock in this reach. Reach 2 is from near TMWRF to 6,750 ft upstream. Streambanks, the streambed, and the surrounding floodplain are composed of fine sediment throughout this reach, which is commonly ponded during larger floods. Reach 3 is the upper portion of Reach Y, from McCarran Blvd. downstream. At the upper end of Reach 3, the streambed, banks and surrounding floodplain all are composed of a substantial portion of larger (gravel and larger) sediment. This reach is transitional in nature, grading into finer sediment downstream toward Reach 2.

Hydrology

The average annual flood on the Truckee River is about 1,000 cfs (Table 1), and is caused by spring snowmelt. Snowmelt floods may be of extended duration (weeks), but typically do not exceed about 5,000 cfs. More infrequent, larger floods result from winter rain, often with snowpack or saturated soils, and typically occur between November and March. These floods are much larger than the snowmelt floods, though typically of short duration (hours). The 100-year flood is estimated to be over 21,000 cfs at the Vista gage, 20 times larger than the average annual flood. While rain-on-snow floods are less common, they still occur regularly (1937, 1963, 1964, 1986, and 1997) and due to their magnitude, perform enormous geomorphic work in spite of short duration. In many reaches of the Truckee River, the coarser fraction of the bedload (larger cobbles) may only be moved during rain-on-snow floods, though smaller gravels may be moved in large quantities during snowmelt floods. Dam construction on major tributaries has significantly altered the magnitude and frequency of larger flood flows, with important consequences for geomorphic function (discussed in a following section).

Table 1. Flood recurrence intervals calculated by Otis Bay (2002) for the Vista gage, near the downstream end of Reach Y.

Recurrence Interval (yrs)	Vista (Q cfs)*
1.05	921
1.11	1,186
1.25	1,625
2	3,057
5	5,981
10	8,631
25	12,920
50	16,880
100	21,560
200	27,090
500	35,880

Channel Morphology

Reach 1 is highly confined by bedrock and the adjacent valley. Although it has been channelized, the historic planform was likely similar to today's channel in general characteristics; it was relatively straight, and followed faults or other bedrock controls. A photograph of the upper end of this reach in 1868 shows an abrupt, right-angle bend, probably where the channel flowed along bedrock fracture (Figure 8). Channel width was variable, and some adjacent surfaces are relatively low and were likely regularly flooded.

Reach 2 has been highly modified, but an aerial photograph from 1940 (Figure 9) preserves some evidence of pre-disturbance channel pattern. At this time, the main channel, highly modified by human disturbance, was in its current location. To the north, a large abandoned channel is visible. The width and meander pattern of this channel suggest that it was the main channel prior to human disturbance. It has very high sinuosity (ratio of channel length to valley length), with wide, long meanders. It is possible that more than one channel was active in this area historically; multiple channels appear to be visible in an 1869 photograph taken of the reach from near the current I-80 (Figure 10).

The upstream end of Reach 3 is at the very left margin of the 1940 photograph in Figure 9. The abandoned channel segment extends upvalley to nearly the upstream end of Reach 3, suggesting that high sinuosity and long meanders may have been characteristic of much of this reach historically as well. However, a distinct transition in channel pattern occurred between Reach Y and the west portion of the valley. Historic photos taken on the west end of the Truckee Meadows suggest that the channel was straighter, and the active portion of the floodplain was relatively narrow (Figure 11). In this area, channel form was the product of incision within Pleistocene outwash deposits as sediment yield from the watershed declined throughout the Holocene. This entrenched channel type at the western end of the valley transitioned to the meandering, unconfined channel type at the east end of the valley, a transition which may have included at least the western part of Reach Y.

Geomorphic Processes

Channel pattern is highly related to the processes of sediment transport (Schumm 1977). Highly meandering channels almost always have relatively low slope, and are not capable of transporting substantial quantities of coarse bedload. The highly meandering pattern of the historic channel throughout much of the historic Reach Y is reflective of a channel that carries most of its load as suspended material rather than bedload (Figure 12). Most of the sediment transported by the channel was probably sand size and smaller.

If the abandoned channel in the 1940 photograph is the historic channel prior to human disturbance, as seems likely, bedload transport rates through this reach were likely low. Our field observations support this hypothesis; we found very little gravel and no cobbles or larger sediment exposed in the streambanks throughout Reach 2 and the lower part of Reach 3. Historic photographs (Figure 8) also tend to support this hypothesis, as there is little evidence of instream bars formed by transported gravel and cobble. Because ample coarse bedload was likely supplied and transported in upstream reaches, there may have been an intervening area where bedload tended to deposit before moving through Reach Y. This may have been near the upstream end of typical pool formation during the larger floods when bedload was in transport. The active 1940 channel shows evidence of braiding near the upstream end of Reach 3, perhaps indicative of this process.

Functional Characteristics of the Historic Ecosystem

Throughout Reaches 1 and 2, the eastern end of the Truckee Meadows was historically a very wet meadow or a marsh (see Figures 8 and 10). Riparian shrubs appeared to be common along the channel, but most of the floodplain was covered by herbaceous vegetation. There is little evidence of cottonwoods in these photographs. It is likely that the deep, dense floodplain soils were saturated for long periods, favoring marsh and wetland herbaceous species over riparian shrubs and trees, most of which prefer well-drained soils with high groundwater for relatively short periods.

This is the type of vegetation landscape that would be expected in a relatively unmodified ecological situation with a highly sinuous channel such as that seen in the 1940 aerial photograph (Figure 9), and which is typically seen in low-gradient valleys with fine-textured soils. The dominant vegetation (in terms of areal coverage) is usually meadow sedges and rushes (with dominance shifting more toward grasses in drier situations), with willow clumps or stringers along the active channel. Isolated willow clumps or patches remain for many years, probably decades, in locations that have subsequently been abandoned by lateral movement of the channel.

Historic aquatic habitat in Reaches 1 and 2 appears to reflect the backwatering effect of the bedrock control and Virginia range canyon. Near the lower end of reach, little pool and riffle formation is apparent in historic photographs (Figure 8). Although the highly meandering channel likely had substantial bedform diversity, substrate may have generally been small and velocity low. Riparian cover appeared to be extensive.

Reach 3 may have had more gravel and cobble bar development, which would have been colonized by shrubs and trees. The gravel bars would have created a more typical pool and riffle morphology, with larger substrate and higher velocity.

The extensive historic marsh and wet meadow system at the eastern end of the Truckee Meadows likely had important water quality functions. It would have served to filter and store fine sediment, and provided an extensive area for nutrient uptake and storage by wetland and meadow plants. Erosion rates were also low, such that the system likely functioned as a sink for both sediment and nutrients. Extensive connections between groundwater and surface water, as well as the shading provided by robust riparian vegetation, likely served to moderate water temperature.

HUMAN DISTURBANCE

WET (1990), Miller et al. (1994) and Otis Bay (2002) reviewed the history of human development in the Truckee River basin. Miller et al. (1994) provide a list of known channel modifications in or near Reach Y based on research of historic documents. These include:

- Irrigation structures (e.g., dams) were constructed in the Truckee Meadows in the 1850's;
- Channelization of the river through Reno in the 1930's;
- Partial removal of the Vista Reefs by the Nevada Department of Transportation in 1938;
- The river was straightened, dredged and rip-rapped from E. 2nd St. to Vista in 1959;
- The COE removed much of the Vista Reefs and straightened, cleared and enlarged the upper portion of Reach 1 in 1963, probably including construction of levees along the north bank throughout Reach Y;
- Relatively minor modifications since that time have included skimming of gravel bars following larger floods to maintain channel capacity, and maintenance of levees.

It is important to note that the earliest channel modifications are the least poorly documented. In the 1940 aerial (Figure 9), the channel has obviously been straightened and cleared; meanders and width are very uniform. While this work may have been undertaken by NDOT in 1938, it is also possible that channelization had occurred much earlier. There is evidence throughout the region of large-scale channel modifications on other rivers in the 1800's and early 1900's: large dams were constructed on the East Fork of the Carson River for transport of logs (MACTEC 2003); millponds were constructed on Donner Creek, and the stream was channelized (River Run Consulting, in prep.); Squaw Creek was likely extensively channelized in meadow reaches to improve grazing conditions (PWA 2006). There is no documentation of channelization occurring on Reach Y during this, but it is likely given the marshy character of the historic floodplain, which would not have been conducive to agricultural uses. While it is often assumed that these early modifications must have been relatively minor given technical capabilities at the time, the examples of channel modifications cited above demonstrate that large-scale projects were possible with limited resources, perhaps conducted over a period of several years. It is also important to note that early channelization projects often relied on the river to do much of the work; the river was diverted into small, straighter channels constructed on the floodplain, which it subsequently enlarged during floods. The 1940 aerial photograph strongly suggests large-scale channel modifications prior to 1940; this work may have done mostly in 1938, or may have begun much earlier.

Other watershed impacts have affected Reach Y, but have probably had less impact on the channel and ecosystem than direct channel modification. Development of the floodplain throughout Reno and Sparks has concentrated flood flows within the channel and has likely increased the magnitude of peak floods in Reach Y to some extent. Dams in the upper portion of the watershed have significantly changed flow patterns (TRRIT 2003). At Reach Y, the most important effect has been reduction in the magnitude of moderate-sized snowmelt floods, which has probably affected sediment transport of small- to moderate-sized bedload typically transported during these events. The dams have also reduced the magnitude of the largest, rain-on-snow floods as well, although this effect has probably been smaller than for the more frequent floods (Otis Bay 2002). The impacts of changes in flow patterns due to dams are being addressed by the Truckee River Recovery Implementation Team (TRRIT), which has recommended and implemented water management strategies to help promote ecosystem restoration (TRRIT 2003).

Dams have also cut off sediment supply from major tributaries, including the Little Truckee and Prosser Creek, and many researchers speculate that a reduction in sediment supply has affected much of the river (Miller et al. 1994) and may be partly responsible for morphological changes in Reach Y (WET 1990). However, as noted above, Reach Y is a complex geomorphic environment and may have always been a region of discontinuity in sediment transport, especially the larger bedload fraction. Furthermore, while changes in sediment supply have likely had some impact on Reach Y channel morphology, it seems far more reasonable, given the extensive nature of channel modifications, that the current channel has been most influenced by direct human modifications in the reach.

Channel Response

All previous geomorphic studies of the Truckee River note that Reach Y has incised (the channel has eroded more deeply within the floodplain) over the last 50 years (WET 1990, Miller et al. 1994,. Otis Bay 2002). The basis for this conclusion is a series of repeated channel surveys from 1946 to 1989 compiled by WET (1990). Channel degradation is clearly seen in repeat surveys of a cross section about 1/8 mile upstream of the Steamboat Creek confluence and longitudinal profiles of the channel bottom through the entire reach (Figure 13). Based on these data, WET (1990) concluded that degradation occurred after 1959; the channel appeared to be relatively stable, at least at the cross section, between 1946 and 1959 (no longitudinal profile was available for 1946).

Incision has been clearly linked to channel modifications through a number of mechanisms (Darby and Simon 2004):

- Direct excavation of the streambed;
- Enlargement of the channel, which results in more flood capacity and increased erosive power;
- Lowering of base level downstream, which increases local slope and erosive power;
- Confinement with levees, which increases flood capacity and erosive power.

All of these channel modifications occurred within Reach Y, and it is reasonable to assume that they have been the primary cause of incision. WET (1990) note that reduction of sediment supply through reservoir impoundment may also have contributed to incision, but if it had been the primary cause incision would have occurred throughout the Truckee River system, which is not the case. Direct channel modifications are far more likely to have caused the incision response.

Which of the specific channel modifications resulted in incision, and how much, is a more complicated question. Although WET (1990) suggests that incision began in 1959, it is important to note that channel surveys were not conducted before 1946. As noted earlier in this document, channelization had already occurred by the time of the 1940 aerial photograph and may have occurred much earlier. If channelization took place well before 1940, the resulting incision response may have occurred and the channel had stabilized again by the time of the survey (see the following section for a discussion of incised channel evolution). Note that the channel is already 15 ft deep by 1946 (Figure 13), indicating that substantial incision had already taken place; the channel appears much shallower in the 1868 photos (Figures 8 and 10).

As described above, additional incision is documented between 1959 and 1989. The occurrence of incision immediately following channel modifications in this reach by the COE in 1963 strongly suggests that channel work was the direct cause of incision. Degradation of the channel was likely caused both by direct excavation and the resulting channel incision response; WET (1990) notes that the presence of distinct erosion features in the incised area indicate that the observed changes are not due to excavation alone.

It is important to note that the reach directly upstream of Reach Y has aggraded over the same period (Figure 13). WET (1990) states that aggradation probably reflects a response to previous channel improvements for flood control in this reach (construction of levees, channel modifications). The upstream aggradation response, in combination with downstream incision, has had the important consequence of magnifying geomorphic transitions in this already highly transitional area. A distinct break in channel slope occurs about one-half mile downstream of McCarran Blvd. (Figure 13). This is interpreted as the transition in channel geomorphic processes resulting from the hydraulic control imposed during large floods by the downstream canyon, and resulting changes in channel and floodplain sediments. The break in channel slope in the upper portion of Reach Y has become clearly more pronounced since 1959 due to upstream aggradation and downstream incision.

Other data highlight the dramatic transition in geomorphic processes through Reach Y. WET (1990) calculated the ratio of channel width to depth throughout the Truckee Meadows (Figure 14). About one mile downstream of McCarran Blvd., width-depth ratio abruptly declines by nearly one-half. The low width-depth ratios in the lower portion of Reach Y are likely reflective of two factors: substantial degradation (resulting in high depth); and relatively little subsequent widening, as the lacustrine sediments are resistant to erosion (WET 1990).

Human alterations have increased the size of the channel Reaches 1 and 2 and have probably increased local slope by removing downstream base level controls, both factors that would tend to increase the ability of the channel to move sediment. Nonetheless, the lower portion of Reach Y is still far less competent to transport coarser bedload than the upper half. Using hydraulic models based on 1989 survey data, WET (1990) estimated the size of particles that the river is capable of moving during a large flood at various locations throughout the lower Truckee Meadows. At McCarran Blvd. the river was capable of moving sediment at least 500 mm (about 20 in) in diameter (Figure 14). The particle size that can be moved decreases progressively through the geomorphic transition downstream of McCarran such that, about one mile upstream of Steamboat Creek, the river is only capable of moving 10 mm (less than one-half inch) grains during a large flood. These data show that there is a strong discontinuity in coarser bedload transport through Reach Y; coarser bedload is probably mostly deposited either above the reach or in the upper portion of the reach.

Such geomorphic discontinuities are inherently unstable. Deposition of coarser bedload is likely to cause subsequent channel adjustments, such as widening or avulsion. It is interesting to note that the historic, meandering channel in the lower portion of Reach Y would probably have been even less capable of transporting bedload than the current river. It nonetheless appears stable in the 1940 photograph, which suggests that it was transporting little coarse bedload. At some point upstream of Reach Y, where the river transitioned from a low-gradient, meandering channel to a higher-gradient, straighter channel, bedload deposition was likely common and the channel was relatively dynamic. This point has important consequences for restoring the river; any restoration measures which seek to replicate historic floodplain and channel processes should recognize the potential for a highly dynamic channel through this transition.

Probable Future Trends

Simon et al. (2004) and Schumm (1999) present similar conceptual models for evolution of incised river systems (Figures 15, 16 and 17). Stage 1 represents the pre-disturbance channel. In Stage 2, human disturbances, such as channel straightening, increase the erosive capacity of the channel with respect to its bed. In Stage 3, the channel begins to incise due to increased erosive power in the larger channel. As incision progresses, the surrounding floodplain becomes drier and riparian vegetation is lost, decreasing bank stability. In Stage 4, an increase in streambank height, increased shear stress at the toe, and reduced vegetative stability lead to widening in addition to continued degradation. Progressive widening will eventually create conditions conducive to aggradation (deposition and increase in elevation of the streambed), both by producing excess sediment through erosion and through reduction in sediment transport capacity in the wider, shallower section. In Stage 5, widening continues, but aggradation starts to occur, with the eventual formation of a new floodplain, typically at a lower base level (Stage 6). This conceptual model has been extensively peer-reviewed and is widely accepted among researchers and managers of incised channels.

Repeat topographic surveys clearly show that, within Reach Y, the channel was incising (Stage 3) between 1959 and 1989 (Figure 13). Both WET (1990) and Miller et al. (1994) note the presence of knickpoints within Reach Y during their field surveys. Knickpoints are features created by streambed erosion, and they indicate that the channel was still degrading at that time of their surveys. We did not observe significant knickpoints during this study, suggesting that incision of the streambed has slowed considerably or is complete.

The model predicts that initial channel degradation will be followed by substantial lateral erosion and channel widening. Some widening has occurred throughout Reach Y, but it appears to be progressing more rapidly in the upstream portion, in outwash sediments, than in the lower portion in lacustrine deposits. Schumm (1999) notes progression through the stages of this channel evolution model is strongly influenced by the character of floodplain sediments. Channels incising into cohesive sediments, such as the lacustrine deposits in the lower portion of Reach Y, tend to degrade rapidly (Stage 3), but subsequently widen relatively slowly (Stages 4, and 5). Channels in less cohesive sediments, such as sand and gravel, tend to degrade and widen far more rapidly. WET (1990) noted the influence of lacustrine deposits in the lower portion of Reach Y, stating that the overall effect of incision has been to increase channel capacity without promoting lateral instability because bank sediments are generally erosion-resistant.

Other factors have also influenced the channel incision response. During floods, backwater from the narrow Virginia Range canyon slows water velocity in the lower portion of Reach Y, reducing bank erosion and lateral instability (Figure 6, photos a and b show pictures of this area during the December 31, 2005 flood). Also, rip-rap that has been placed to protect levees has limited erosion on most of the north bank, and some rip-rap has been placed in locations on the south bank.

Another important factor for channel evolution in Reach Y is the movement of coarse sediment through the reach. The storage of coarse sediment in bars is driving bank erosion and channel widening in Reach 3 (Figure 18, photo f). This process is clearly visible at the downstream boundary of the reach, where a large portion of the south bank has eroded in response to deposition of a bar on the opposite bank (Figure 7). Channel widening would probably progress more rapidly in this area were it not for the reduction in coarse sediment supplied to Reach Y due both to sediment capture in upstream dams and to aggradation in the reach upstream of McCarran Blvd.

The boundary of Reaches 2 and 3 is the downstream extent of coarse instream bar formation, either because of limits in sediment supply or sediment transport capacity (backwater from the canyon). Though the lower portions of Reach 3 are in lacustrine deposits, which are relatively resistant to erosion, bar development is nonetheless causing bank erosion (Figure 18, photo b). This highlights the important role of coarse sediment transport in erosion and progression through the channel evolution model. Reach 3 appears to be in Stage 4 or Stage 5, with active widening accompanied in some locations by the development of in-channel bars and aggradation. The coarse sediment driving these processes may have been derived from erosion of upstream portions of Reach Y, or perhaps from upstream sources.

Reach 2, in lacustrine deposits, has widened far less than Reach 3 (Figure 7) probably due to a combination of factors: lower coarse sediment supply; relatively erosion-resistant streambanks; and lower flood velocities due to backwater from the canyon. Nonetheless, there is still substantial bank instability (Figure 19, photos b, d and e). Incision has caused block failures of the lower bank and rotational failures of the upper bank (WET 1990) (Figure 6, photos c, d, e, and f). The reach is therefore actively widening, though there is as yet no development of instream bars and aggradation. This reach is likely in Stage 4.

Most of Reach 1 is bounded by bedrock or extensively rip-rapped (Figure 20). Although some limited bank erosion is evident, the planform is relatively stable due to resistant bank materials low hydraulic stresses during floods (WET 1990). The channel is currently in Stage 3, and subsequent evolution is likely to be limited or will occur very slowly.

The two upper reaches, however, are likely to continue to adjust according to the evolution model in the absence of active stabilization. As Schumm (1999) notes, once incision has commenced, it is unlikely that erosion will cease naturally until the channel has progressed through the several stages of the channel evolution model or has encountered very resistant materials (such as the bedrock in Reach 1). The unique hydraulic characteristics of Reach Y, with backwater from the canyon and low velocities during the largest floods, has slowed rates of streambank erosion and widening. Limits on coarse sediment supply, and streambanks composed of erosion-resistant lacustrine deposits, further limit rates of widening. Thus, Reach 3 has widened most rapidly, while Reach 2 probably incised rapidly but is subsequently widening relatively slowly.

In many streams, progression through the channel evolution model is rapid with impressive rates of erosion. This is especially true of streams with high rates of coarse sediment supply, streambanks composed of less cohesive particles such as sand and gravel, and steeper floodplains. The unique characteristics of Reach Y allow for relatively slow rates of erosion when compared to other gravel-bed streams. However, Reach Y nonetheless has fairly high rates of lateral instability for the Truckee River upstream of Wadsworth (Miller et al. 1994) (Figure 21). And this trend is likely to continue; in the absence of active stabilization, the channel evolution model suggests that Reaches 2 and 3 can be expected to continue to widen and aggrade, the upstream reach more quickly, the downstream more slowly, with the eventual formation of a new floodplain at a lower elevation.

Ecosystem Impacts

Development on the north bank of the river has eliminated the historic riparian ecosystem. Incision has disconnected the river from its floodplain; former floodplain surfaces flood infrequently, during only the largest floods, with the loss of natural disturbance and enrichment with flood deposits critical to properly functioning riparian ecosystems (Kaufmann et al. 1997). Groundwater levels have also dropped as much as 10-15 ft. As a result, the historic marsh and meadows on the south side of the river have been converted to an upland ecosystem, dominated by sagebrush, rabbitbrush, and other dryland species. Streambanks have become much higher and more instable, and the dense, continuous belt of riparian vegetation along the river in 1868 photos (Figures 8 and 10) has been significantly degraded. Actively eroding streambanks are barren, and where vegetation currently occurs, it often consists of species adapted to the drier conditions created by incision.

The willow species that predominates throughout the riparian vegetation of Reach Y is coyote willow. In the relatively rare circumstances in which this species is present as significant populations in non-degraded riparian systems, it is found in highly geomorphically unstable situations such as sediment bars in desert arroyo settings, or in other highly flashy river systems. However, the overwhelming majority of occurrences of coyote willow are found in degraded riparian systems where significant incision and/or loss of summertime flows have occurred. Compared with other willow species, coyote willow has lower habitat and geomorphic stabilization values than do the other species of willows that occur in less degraded riparian systems.

Ironically, the channel has incised so much and the groundwater level has dropped so much throughout parts of Reach Y that infestations of tall whitetop are, although present, at least much less prevalent than they are in areas upstream of Reno and downstream of Reach Y. However, the potential for this plant to rapidly colonize and dominate disturbed soils, especially ones that are excavated so that they lie closer to the groundwater level, is a critical consideration for any restoration planning effort.

Aquatic habitat has been simplified, particularly in Reach 2, where riffles and pools are virtually absent (Figure 7). Streambank vegetation provides far less cover along streambanks, and less shade, potentially creating higher water temperature. As channel evolution progresses in Reach 3, bar formation results in increases in channel complexity (pools and riffles). Riparian vegetation is also actively establishing on the bars, nearer the water surface than the high streambanks, providing more cover and shade. These processes have yet to occur in Reach 2, and may take place here only very slowly.

Water quality has been negatively impacted by channel degradation and surrounding development. Sediment and nutrient storage functions of the historic marsh have been lost. Erosion rates have increased, and the reach now likely exports more sediment than enters. The wide, shallow channel, with low velocity and degraded riparian vegetation, gathers and retains more solar radiation. Agricultural and commercial development has negatively affected water quality in Steamboat Creek and the North Truckee Drain (see, for example, photos of the north truckee drain during field surveys, Figure 19, photos c and d). The outflow of TMWRF also enters this reach, with addition of nutrients and associated potential effects.

REACH Y RESTORATION OPPORTUNITIES AND CONSTRAINTS

Two conceptual-level restoration alternatives representing different levels of intensity were analyzed for this study to evaluate restoration opportunities and constraints. Alternative 1, the lower intensity alternative, focuses on stabilization of streambanks; enhancement, expansion and restoration of riparian vegetation; and enhancement of aquatic habitat. The more intensive Alternative 2 would have the primary objective of restoring, to the extent feasible, historic channel and floodplain geomorphic processes.

It was assumed that these alternatives must work within the current flood planning framework. Specifically, restoration practices cannot increase flood elevations in Reno or Sparks. Current conveyance capacity must be retained in Reach Y; this will not allow a substantial increase in the channel elevation, or decrease in channel area. Channel capacity is especially important downstream of TMWRF, as this section is a major hydraulic control influencing water surface elevations upstream. It is also assumed that the extensive commercial development along the north bank of the river will remain, thus allowing for no floodplain on the north side of the river. The main opportunity for restored floodplain is therefore the UNR Farms area to the south of the river (Figure 7).

Restoration opportunities and constraints of these alternatives were analyzed with respect to several factors:

- Geomorphic function and channel stability;
- Riparian ecosystem improvement;
- Aquatic habitat improvement;
- Water quality improvement, and;
- Feasibility of early implementation.

BRIEF DESCRIPTION OF ALTERNATIVES

Alternative 1: Stabilization and Enhancement

The primary objective of this alternative would be to stabilize streambanks and enhance riparian and aquatic habitat. Streambanks would be stabilized using techniques emphasizing riparian vegetation enhancement, such as slope reduction and bioengineering, with rip-rap toes likely necessary in many locations to ensure stability (Figure 22). Aquatic habitat would be enhanced by creating complexity and cover using boulders or woody debris.

Alternative 2: Restoration of Geomorphic and Ecosystem Processes

Restoration of historic function would require reestablishing the historic relationship between the channel and the floodplain. In general, two approaches are available to restore floodplain function in highly incised systems—raising the channel bed, or lowering the adjacent floodplain. In this case, raising the channel bed is not feasible, as it would increase flood elevation in the Truckee Meadows. Under this alternative, the ground surface on the south side of the river would therefore be lowered to restore, to the extent feasible, the historic relationship between the channel and the floodplain and historic geomorphic and ecosystem processes (Figure 22). This alternative would be generally similar conceptually to benching alternatives currently under consideration as mitigation for flood control impacts (Montgomery Watson Harza 2002). Floodplain would be constructed on the south side of the river through the UNR farms, from McCarran Blvd. downstream to approximately the Steamboat Creek confluence (Figure 7).

ANALYSIS OF ALTERNATIVES

Geomorphic Function and Stability

Alternative 1. Alternative 1 would not restore historic geomorphic function in Reach Y. Instead, it would intervene in predicted channel evolution, arresting erosion and lateral instability. Geomorphic analysis predicts that much of Reach Y will continue to undergo substantial erosion in the absence of intervention. This suggests that most or all of the reach will require stabilization.

Revegetation alone is unlikely to stabilize the very high streambanks that have resulted from channelization and incision Vegetation that can be sustained on the high banks is limited to upland species and phreatophytic ones (deeply rooted plants which, when mature, access the groundwater year-round). Such vegetation will form an insufficient density of roots to provide structural stability to the soil profile at the level of the bank where erosion can be expected to take place during large flow events (several to many feet below the surface where the plants are located). Conversely, vegetation that becomes established at the water's edge during ordinary summertime flows could be located at too low of an elevation to stabilize the near-vertical bank above, which is the site where exceptionally high, geomorphically-effective flow events impinge on the exposed soil profile. Stability of this alternative will therefore require fairly extensive use of harder techniques, such as rock barbs or rip-rap toes.

It is difficult to predict the eventual geomorphic consequences of stabilization in this complex, transitional area, where sediment transport is highly influenced by the hydraulic characteristics of the channel downstream of Steamboat Creek. Because the channel would no longer be able to adjust its width, the backwater produced by the downstream canyon during larger floods may promote aggradation, which would reduce channel capacity. Alternatively, the stabilized channel might more effectively transport sediment due to the maintenance of a lower width-depth ratio. It is beyond the scope of this study to quantitatively analyze the effects of restoration opportunities on sediment transport, but such a study should be considered prior to implementing stabilization due to the potential for dynamic response in this reach.

Alternative 2. If successful, this alternative would restore much of the historic geomorphic function of Reach Y. However, it is important to note that historic function may have included considerable dynamics near the upstream end of the reach, in the area of McCarran Blvd. Under current conditions, this area has been stabilized by the bridge structure itself, rip-rap, and adjacent levees. Under Alternative 2 adjacent floodplain would be reactivated, promoting the more dynamic historic geomorphic function. Assuring sufficient stability to protect infrastructure and improvements in the area will be a significant design and engineering task. The detailed design of this alternative must address the extraordinary transition in all geomorphic characteristics through Reach Y; slope, sediment transport, and bank and floodplain sediments. As noted earlier, rapid reductions in slope tend to encourage coarse sediment deposition, which in turn promotes lateral instability. Currently, levees, rip-rap and the McCarran Bridge all stabilize the river against its natural tendency for dynamics in this area.

Several aspects of Alternative 2, however, would tend to promote instability. First, the excavation of a bench will significantly reduce the capacity of the channel to transport sediment, especially coarse bedload. This is because the new channel, with increased floodplain area, would be much larger, resulting in decreased depth and velocity and therefore sediment transport capacity. Coarse sediment entering the reach from upstream will be more likely to deposit within the channel, potentially resulting in aggradation and lateral instability.

Second, throughout much of Reach Y where the streambanks are composed primarily of lacustrine sediments, excavation of a bench will make the streambanks more susceptible to erosion in the short-term, prior to revegetation. Though these lacustrine sediments are currently eroding, they are doing so more slowly than if they were composed of other types of material; far more slowly than if they were composed of sand, for example. The slower rate of erosion is due to the fact that the fine lacustrine sediments are cohesive. Excavation during construction will not only significantly disturb the cohesiveness of these sediments; in some locations, far more erosive channel deposits (sands and smaller gravels) may be exposed. The net result is that while streambanks will be lower following construction of the bench or floodplain (which tends to reduce erodibility), they are likely to be more erosive in the short-term due to disturbance during construction. Lateral instability of the channel may increase as a result, especially in combination with the increased tendency for coarse sediment deposition.

Third, the constructed floodplain is also likely to be highly susceptible to erosion in the short-term. Several acres of fine-grained sediment, disturbed during the construction process, would be exposed to regular flooding. Until extensive vegetation cover is established, the floodplain would be susceptible to sheet and rill erosion, especially considering that the floodplain would be transitional in down-valley slope throughout the reach. Given that coarse sediment deposition will also be more likely at the upper end, channel avulsion (rapid relocation of the channel during a single flood) is also possible, with erosion of a new channel in the constructed floodplain.

In many geomorphic environments where human disturbance has caused an incision response in the channel, floodplain construction provides an opportunity to anticipate and reduce the resulting instability and erosion. Where floodplain sediments are coarse-grained and hydraulic characteristics consistent, floodplain creation may be relatively stable with relatively little additional effort. In the complex Reach Y geomorphic environment, the conditions described above suggest that floodplain construction may significantly increase the potential for large-scale planform instability, at least in the short-term. There are several techniques that could be considered to promote the short-term stability of this alternative:

- Large-scale channel and floodplain grade control, which would define both the elevation and planform location of both the channel and floodplain;
- Rip-rap, barbs, revetment or other structures for streambanks;

- Erosion control fabrics on streambanks and the floodplain;
- Phasing of construction to allow for revegetation of floodplains and streambanks prior to exposure to flooding (for example, leave levees along the streambank during construction to protect new floodplains).

Some or all of these measures are likely to be necessary to provide sufficient assurance of stability for this alternative. In a river the size of the Truckee, these measures would require substantial engineering and construction cost.

Long-term stability of this alternative would be strongly dependent on establishment of vigorous riparian and floodplain vegetation. Where floodplains are composed of coarse-grained materials that are close to the water table yet well-drained during the summer, extensive natural recruitment of riparian species, especially trees and shrubs, can be expected. In the portions of Reach Y where the floodplain would consist of fine-grained soils with poor drainage, revegetation will be more difficult, as native recruitment of riparian shrubs and trees will be very low. Substantial effort in revegetation of the herbaceous species typical of these environments can be expected, including seeding, erosion control, irrigation, and long-term weed control (see the following section for a more extensive discussion of revegetation).

Given these factors, stabilization of a constructed floodplain through Reach Y, while probably feasible, is likely to be complex and expensive. It is important to note, however, that this alternative does not address complete reconstruction of the channel into the highly meandering planform that likely existed prior to human disturbance (Figure 9). Widening the floodplain, which would restore many of the historic characteristics of channel and floodplain geomorphic processes, will probably promote the development of the meandering planform over time. The specific way in which the new channel would develop is uncertain. In the best scenario, a highly vegetated floodplain would first be established, and the meandering channel would subsequently develop over time through slow erosion of outside bends. There is a risk, however, that erosion would be very high without substantial stabilization measures along much of the channel and new floodplain. Reconstruction of the meandering channel during initial restoration is also possible, but would entail a far larger restoration effort with a high degree of risk in this complicated geomorphic environment.

Finally, several potential construction constraints for this alternative will have to be addressed. Probably the most significant is that equipment access to and on the new floodplain, if constructed at a relatively low elevation with respect to the current channel, is likely to be difficult due to wet conditions resulting from capillary action in the finer floodplain sediments. Our photographs clearly show capillary action in streambanks at least one to two feet above the river water surface during all seasons (see Figures 6 and 19). Typical heavy equipment will not be able to operate on surfaces near the capillary fringe. Excavation to this elevation would require the construction of very expensive access roads. Material near the capillary surface will also be muddy and difficult to handle. These issues will likely not be a significant concern in areas where the floodplain is composed of coarser sediment (upper portion of Reach 3), but will substantially increase the effort and cost to construct low floodplains in areas where floodplain sediments are fine.

Another important construction consideration in fine floodplain sediments is that stabilization measures constructed of larger rock, such as grade control or rip-rap, will require careful engineering to function appropriately. Larger rocks placed in a fine-grained matrix actually tend to attract and contribute to erosion and scour without additional measures. Successful rip-rap stabilization of fine-grained streambanks, for example, requires filter layers of intermediately-sized material between large rip-rap rocks and the finer streambanks, significantly increasing construction cost.

Riparian Ecosystem Restoration

Alternative 1. Alternative 1 would improve the structure and function of riparian vegetation in a thin strip along the river. However, incision has left many of the streambanks very high, with a low groundwater table. Establishing and maintaining riparian vegetation on the high streambanks will require irrigation and continual maintenance. Because most streambanks do not have functional riparian hydrology, invasion of maintained riparian vegetation by weeds and drier vegetation is also likely to be a continual problem. Alternatively, drier vegetation types might be installed on the higher portions of the streambanks, leaving a narrow band of riparian vegetation along the stream. Due to the magnitude of incision and subsequent lowering of the stream channel, establishing and maintaining a riparian, marsh or meadow community away from the channel (e.g., the UNR Farms) would require extraordinary effort to maintain hydrology, by diverting flow and creating artificial channels, constant irrigation, or both. Such improvements would be expensive and are not likely to be cost-effective.

On the high banks, the palette of potentially suitable native woody riparian species is limited to Fremont's cottonwood and peach-leaf willow (which has an uncertain degree of adaptation to the fine textured lacustrine materials and to the likely dissolved-solids conditions of the site). Non-native, non-riparian trees and shrubs could also be supported (black locust being one example that is well known to be successful in soils and climatic circumstances that are very similar to those of Reach Y). Lower banks will support coyote willow and Woods's (interior) rose, possibly also box elder or golden currant. The latter two species have unknown ability to grow vigorously in the available soils. Establishment of vigorous vegetation would be most successful, or in places may require, augering of very deep planting holes through the partially cemented fine textured lacustrine strata to the groundwater level and application of irrigation, probably for several years, to induce development of roots extending down to the groundwater.

A very narrow band of riparian vegetation could be supported without artificial hydrology at approximately one to two feet elevation above and below the mean annual high water level. However, as is shown in Figures 6, 19, and 20, there is essentially no floodplain at this level, so any genuine naturally-supported riparian ecosystem under Alternative 1 would require substantial excavation and placement of riprap or larger rocks interplanted with riparian species. As noted above, ensuring relative stability of the banks requires both hard and/or soft engineered measures in addition to any vegetation that is established as part of an ecological restoration effort. Although the cost-effectiveness of the riparian habitat restoration on a per-area basis is uncertain, it is certainly feasible to establish a limited amount of robust rush and sedge turf (Baltic, soft, iris-leaved, and Nevada rush; clustered field, umbrella, and possibly Nebraska sedge), combined with willows (arroyo, Gooding's, and shining) and interior rose.

Alternative 2. This alternative provides the best opportunity for restoring functional riparian and floodplain vegetation communities, as it would address the hydrologic impacts of incision and restore riparian and floodplain groundwater elevation. Although streambanks on the north side of the river would have to be treated similarly to Alternative 1, south streambanks would be lowered, eliminating the higher and drier upper streambanks. This alternative provides the opportunity to significantly expand functional riparian and floodplain habitats.

There are several constraints relating to vegetation community establishment. Soils are an extremely important consideration. Excavation to the level of the new floodplain or bench would require removing existing soil. As shown by Figure 6f, the soil level that the excavation must attain is largely within or below the level of the Mazama ash (6,600 years old). Therefore, a large portion of the sediment that will become exposed at the surface will not have had the benefit of normal soil biological processes for at least that period of time. They will also have unknown properties with respect to the illuviation and/or chemical precipitation of solutes that are of questionable suitability for the growth of riparian meadow and willow vegetation.

Accordingly, an essential element in any riparian restoration effort would be a comprehensive re-creation of a suitable soil profile to support rapid establishment of vigorous riparian meadow turf. This requires several measures beginning with the salvage of existing upland topsoil, proper storage (including organic and nutrient enhancement by means of a project-specific seed mix), and replacement following initial subgrade excavation. (Although the soil microflora and seed bank would not be those of a riparian community, this material would at a minimum have more suitable texture and overall soil organic matter content than the exposed subgrade material.) Placement of the soil profile requires deep-ripping or other heavy-equipment means of reducing compaction combined with simultaneous incorporation of organic amendments. These would ideally include suitable mycorrhizal inoculum to give an initial competitive advantage to the desired native species over invasive non-native species that are not dependent upon them. As explained above, the materials available for the restoration work will be fine textured, therefore very effective temporary erosion control measures will be required to keep the reconstructed soil profile and applied seed or other revegetation propagules in place long enough to form adequate root systems and erosion-controlling basal and aerial cover. Rapid establishment of very vigorous desired vegetation is also a fundamental element in combating infestation by tall whitetop and other weeds.

Another important consideration in revegetation is the recruitment of native riparian vegetation. Native riparian recruitment would be highly variable throughout the reach and is likely to be very slow in dense lacustrine sediments which remain saturated throughout much of the growing season. In the upper portion of Reach Y, where floodplains would be composed primarily of well-drained coarser sediment and sand, recruitment of riparian shrubs would likely be rapid, as they are adapted to disturbance and rapidly colonize gravel bars where the water table drops throughout the growing season (Kaufmann et al., 1997). In the lacustrine sediments of the lower reach, which would remain saturated much of the growing season, riparian shrub native recruitment would probably be very limited. The historic vegetation community on these surfaces was a marsh or very wet meadow, composed of vegetation species that are relatively slow invaders. Thus vegetation establishment on these surfaces would require extensive revegetation measures and maintenance.

It is important to recognize that no site along the relevant portion of the Truckee River provides an analog of the edaphic, climatic, hydrologic, and biotic ecological circumstances of Reach Y that is sufficiently similar in all important respects that it could be used as a model for revegetation design within Reaches 1 and 2. Design of the seed and planting strategy entails the reconciliation of several somewhat divergent goals. First, the initial planting must result in as rapid establishment of graminoid (grasses and grass-like) vegetation as possible, so that the highly disturbed soils are stabilized against erosion and piping of fine materials, and are not heavily invaded by weeds, primarily tall whitetop. This means that a substantial cover of grasses, which have much more rapid initial establishment than do sedges and rushes, should be planted. However, sedges and rushes provide much greater resistance to erosion, and are the taxonomic groups that probably comprise the majority of the climatic/edaphic climax vegetation of the physical environment that would be created. Therefore, the revegetation plan should be designed to favor ecological succession into these species as soon as possible after the floodplain has been stabilized. Presently there is no source material for these species within the project corridor. Plugs and/or rhizome fragments would have to be custom propagated or supplied by commercial sources.

Another important consideration for revegetation is weed control, which will be a problem for any restoration effort (Montgomery Watson Harza 2002). Like other restoration issues in Reach Y, problems associated with weeds will be highly variable throughout the reach. At the upper end, riparian shrubs highly adapted to colonization of coarser, regularly disturbed (by flooding) surfaces would have a competitive advantage over weeds, reducing the need for weed control. In the lower reach, however, an environment where native species tend to be slower in colonization and expansion, weed control would be far more problematic. Considering that several acres of floodplain would be excavated in lacustrine deposits, and several years of maintenance would likely be required for weed control, a substantial effort can be expected.

The most problematic weed to control would be tall whitetop. This plant occurs across a wide range of elevations relative to adjacent water bodies, but is less commonly found in saturated conditions or standing water and does not seem to persist in totally upland settings that are far removed from any water body. Nonetheless, it can be found at extremes of hydrology. At the ‘former’ pond at Heron’s Landing subdivision off Mira Loma Drive, tall whitetop occurs from 4,396 ft at the tops of the banks in an upland situation, to 4,391 ft, in amongst obligate wetland vegetation (cattails and bulrushes). At the 102 Ranch near Tracy, the floodplain at 4,237 ft is dominated by tall whitetop. Elsewhere on the property, tall whitetop is found at the highest elevation of 4,242 ft all the way down to the river’s edge at 4,229 ft, an elevation range of 13 feet. Throughout Reach Y, the species is also found in sites at a wide range of elevations above the water level, although its occurrence is relatively spotty at higher elevations (e.g., the high banks seen, for example, in Figure 6).

Few construction projects in the Truckee Meadows address noxious weed treatment or containment and they have undoubtedly contributed to the spread of tall whitetop. The

1997 flood also contributed to its distribution. Stands of tall whitetop along the river upstream of Reach Y must be considered as potential sources for contamination within the reach; likewise, movement of construction equipment will certainly introduce seed to areas where the plant is absent or scarce at present.

It is a truism of effective long-range weed control that the primary goal must be to establish sufficient competing vegetation of desired (in the present case, native) species to suppress the colonization and spread of the target weed species. In the case of tall whitetop, recent experimentation (J. Etra, personal communication) has shown promising preliminary results from mechanical treatment of the existing standing crop prior to flowering, followed by mycorrhizal inoculation of the soil and heavy seeding with species such as creeping wild-rye. This native grass forms dense turf and moderately tall aerial growth, and has similar wetland affinities to those of tall whitetop (facultative).

Nonetheless, as stated above, tall whitetop coexists with both upland species and obligate wetland ones, so the control of this plant should be regarded as a permanent maintenance agenda item unless and until the restored riparian vegetation demonstrates overwhelming competitive suppression of weedy species and the overall regional tall whitetop epidemic is at least partially controlled.

Finally, it is important to recognize the characteristics of the vegetation community likely to establish in response to restored geomorphic processes. In the upper portion of the reach, native riparian vegetation such as willows and cottonwoods will rapidly colonize well-drained gravel bars. In the denser lacustrine sediments, soils would be saturated throughout much of the year due to a high groundwater table and development of a capillary fringe common in fine-grained soils (Figure 6, photo f), resulting in anaerobic conditions. These are not conditions favorable to colonization and establishment of cottonwoods, which require coarse, well-drained substrates for establishment (TRRIT 2003). Thus cottonwoods and riparian shrubs would probably have to be established and maintained artificially through manipulation of substrates or plantings, a process that while feasible, would increase project cost.

Water Quality Improvements

Alternative 1. Alternative 1 would reduce the yield of fine sediment to the river. Temperature could also be reduced somewhat, especially with the incorporation of tall trees in revegetation along the south bank. We analyzed the potential shading effect on dissolved oxygen using the existing water quality model for the Truckee River, and found that extensive shading along the south bank could result in small but measurable increases in dissolved oxygen concentration downstream. The limited riparian vegetation restored under this alternative would restore very little of the historic sediment and nutrient storage function of the historic marsh and wet meadow.

Alternative 2. Alternative 2 is an opportunity to restore many of the important water quality functions of the historic Reach Y ecosystem. The extensive floodplain would provide sediment deposition and extensive contact between floodwater, groundwater and vegetation roots for nutrient uptake and storage. If stable, the alternative would significantly decrease erosion and sediment generated from the reach. Revegetation with tall trees, and the extensive contact between groundwater and the river, would probably help moderate water temperature. Constraints for this alternative with respect to water quality (such as instability) are described in previous sections.

Aquatic Habitat Improvements

Alternative 1. Alternative 1 would improve streambank cover along the channel. The effect on overall channel complexity is less easy to predict and depends on the potential geomorphic responses to stabilization described in the section on geomorphic function and stability. If the stable channel tends to transport sediment, pool and riffle structure would remain undeveloped, with little habitat complexity. Rock clusters or other types of cover would be effective in increasing habitat complexity under this scenario. On the other hand, if the channel tends to aggrade, pool and riffle structure would develop, with increased habitat complexity. Unfortunately, aggradation would also decrease flood capacity and would likely require dredging. Also, it is important to note that rock cluster or other artificial structures would not function effectively in an aggradational environment; they are likely to be buried in aggraded material. Thus, while the stabilization alternative will improve streambank cover, it is not likely to substantially improve overall channel complexity.

Alternative 2. As with riparian ecosystems, restoring the historic channel and floodplain function represents the best opportunity for improving aquatic habitat. A functional channel and floodplain would promote dense, stable riparian vegetation on streambanks, improving riparian cover. Pool and riffle development would likely extend downstream from its current extent at the downstream boundary of Reach 2, increasing channel complexity, cover for fish, and substrates for macroinvertebrates. Constraints for this alternative are described under geomorphic function and riparian vegetation above.

Early Implementation Feasibility

Alternative 1. Flood planning, and associated restoration components, is currently in the environmental review process. This includes specific measures for restoration in Reach Y, with alternatives similar to both of the alternatives reviewed here. Early implementation of bank stabilization throughout the reach on both banks would be largely wasted if benching were implemented as part of the flood control project, and is therefore not feasible. However, bank stabilization along the north bank could be designed to work with any alternative selected and is feasible. However, as described in previous sections, bank stabilization in this area would have limited benefits for water quality, riparian vegetation, and aquatic habitat and is not recommended.

Bank stabilization downstream from Steamboat Creek is the only feasible alternative for channel improvements in any flood planning alternative, and is therefore also feasible as an early implementation project. While bank stabilization in this area would also have limited ecosystem benefits, continued erosion is likely, even if at slow rates, and poses a threat to infrastructure.

Alternative 2. Successful implementation of this alternative is contingent on channel modifications for flood control upstream of Reach Y, which are likely to significantly affect both the magnitude of floods and sediment supply to the reach. For example, WET (1990) modeled the potential effects of flood alternatives being considered in 1989. Their analysis showed that the flood project analyzed would significantly increase the capacity of the stream to transport sediment in the lower part of Reach Y (Figure 14, bottom). A bench or floodplain and streambanks composed of fine sediments would be highly susceptible to severe erosion under these conditions. Although this 1989 project consisted of components that may no longer be under consideration, careful integration of this alternative into any flood project will be required. Early implementation of this alternative is not recommended.

SUMMARY

Prior to human disturbance, Reach Y was an extraordinarily complex environment, with a distinct transition in fluvial geomorphic processes resulting from a unique Quaternary geologic history. At the upper end of the reach, fluvial reworking of outwash deposits was the dominant historic process, with floodplains constructed by lateral channel migration and overbank deposition. The floodplain at the lower end of the reach was primarily constructed by overbank deposition of fines in pooling created by backwater from the Virginia Range outflow during floods. Historic riparian ecosystems adapted to these processes likely exhibited a similar transition, from riparian shrub communities on broad gravel bars at the upper end of the reach to broad marsh or wet meadows dominated by sedges, rushes and grasses at the lower end of the reach. Coarse sediment transport was also likely discontinuous through the reach, resulting in a highly dynamic channel at the upper end.

Human modification of the channel for flood control has resulted in relatively dramatic incision throughout most of the reach, disconnecting the channel from adjacent floodplain and lowering groundwater elevation. Continuing channel adjustments have been highly variable throughout the reach due to the transition in geomorphic processes and floodplain sediments. In some locations, incision has led to fairly rapid streambank erosion and subsequent widening. In others, streambanks are composed of relatively erosion-resistant lacustrine deposits and widening has progressed more slowly. Nonetheless, channel response to initial disturbance continues today throughout most of the reach, with relatively high rates of bank erosion and lateral instability within the Truckee River between Truckee Meadows and Wadsworth. In the absence of artificial stabilization, the channel will continue to erode, with the eventual formation of a new floodplain at a lower elevation. Any restoration measures for this reach must recognize its geomorphic and ecosystem complexity. Channel slope, sediment transport capacity, and floodplain sediment characteristics are all transitional through the reach.

Restoration of the floodplain, through benching or similar techniques, represents the best opportunity to restore functional riparian ecosystems. However, a high degree of engineering would be required to ensure the stability of constructed floodplain surfaces. Throughout much of the reach, establishing functional native vegetation communities would also require extensive revegetation and maintenance.

Because this reach has such a high potential for dynamics, it is extremely sensitive to modifications of the channel upstream for flood control or restoration. The success of any restoration treatment in Reach Y will require careful integration with upstream restoration and flood control strategies, with consideration of potential changes in sediment transport and flood magnitude. We recommend that restoration in most of Reach Y be implemented in conjunction with upstream channel improvements.

The most feasible project for short-term implementation is bank stabilization in the vicinity of TMWRF, which can be implemented prior to other flood or restoration alternatives. Due to flood control constraints, bank stabilization is the sole feasible riparian restoration alternative in this location, and could be designed to integrate effectively with any restoration alternative upstream. Riparian habitat, aquatic habitat, and water quality improvements provided by bank stabilization would be limited. However, our analysis of geomorphic evolution in this area suggests that bank erosion is likely to continue in this area, even though erosion rates may be relatively slow. Bank stabilization may be required to protect infrastructure.

REFERENCES

Bell, J. W., D. B. Slemmons, and R. E. Wallace. 1984. Neotectonics of western Nevada and guidebook for selected Nevada earthquake areas. In: Western geological excursions guidebook-Vol 4 (fieldtrip 18): Geological Society of America, Annual Meeting, November 1984, Reno, NV, v. 4, p. 387-472.

Benn, D. I., and D. J. A. Evans. Glaciers and glaciation. Oxford University Press, New York, NY. 734 p.

Birkeland, P. W. 1966. Tertiary and Quaternary geology along the Truckee River with an emphasis on the correlation of Sierra Nevada glaciations with fluctuations of Lake Lahontan. In: Guidebook for field trip excursions northern Nevada : Geological Society of America, Cordilleran Section Meeting, April 7-9, 1966, Reno, Nevada / co-editors: Joseph Lintz, Jr., S.K.M. Abdullah.

Birkeland, P. W. 1964. Pleistocene glaciation of the northern Sierra Nevada, north of Lake Tahoe, California. Journal Of Geology, Vol. 72, p. 810-825.

Carrara, P.E. 1989. Late Quaternary glacial and vegetative history of the Glacier National Park region, Montana. U.S. Geological Survey Bulletin 1902.

COE. 2004. Truckee Meadows, Nevada, general re-evaluation report phase F3 milestone report, geotechnical appendix. US Army Corps of Engineers, Sacramento District, Sacramento, CA..

Darby, S. E., and A. Simon, eds. 1999. Incised river channels: processes, forms, engineering and management. John Wiley and Sons, Ltd, West Sussex, England.

Gates, W. C. B., and Watters, R. J. 1992. Geology of Reno and Truckee Meadows, Nevada, United States of America. Bulletin of the Assoc. of Eng. Geol. Vol. 29, No. 3, pp. 229-298.

Hersh, L. K. 2000. The Central Pacific Railroad across Nevada 1868 and 1997: photographic comparatives. Lawrence K. Hersh, Fernley, NV.

Kauffman, J. B., R. B. Beschta, N. Otting, and D. Lytjen. 1997. An ecological perspective of riparian and stream restoration in the western United States. Fisheries Vol. 22, No. 5, p 12-24.

MACTEC. 2003. Carson River watershed assessment. Report prepared for: Carson River Watershed Group, Markleville, CA.

Miller, J. R., S. M. Orbock-Miller and L. Zonge. 1994. Regional, long-term assessment of channel stability along the Truckee River, Nevada, from Verdi to Pyramid Lake:

implications to the potential for catastrophic bridge failure. Report to the Nevada Department of Transportation, Carson City, NV.

Montgomery Watson Harza. 2002. Ecosystem restoration alternatives design paper. Prepared For: US Army Corps of Engineers, Sacramento District, Contract No. DACW05-01-0-0008, Delivery Order 2, Modification 4.

Otis Bay Riverine Consultants. 2002. Preliminary lower Truckee River geomorphic assessment (Vista to Pyramid Lake), design report (Vista to Wadsworth), design report (Wadsworth to Pyramid Lake). Report prepared for the Army Corps of Engineers, Sacramento District, Sacramento, CA. 345 p.

PWA (Phillip Williams and Associates). 2006. Lower Squaw Creek conceptual restoration plan: final draft report. Report prepared for: Placer County Planning Department, Placerville, CA..

River Run Consulting. In preparation. Coldstream Canyon watershed assessment. Report for: Truckee River Watershed Council, Truckee, CA.

Simon, A. and Hupp, C. R. 1986. Channel evolution in modified Tennessee channels. In: Proceedings of the Fourth Federal Interagency Sedimentation Conference, Vol. 2, U. S. Government Printing Office, Washington, DC, 5-71 to 5-82.

Schumm, S. A. 1999. Caused and controls of channel incision. In: Incised River Channels: Processes, Forms, Engineering and Management. S. E. Darby and A. Simon, eds. John Wiley and Sons, New York, NY, pp. 19-34.

Schumm, S. A. 1977. The fluvial system. Wiley, New York, 338 p.

Thorne, C. R. 1997. Channel types and morphological classifications. In: Applied Fluvial Geomorphology for River Engineering and Management. Thorne, Hey and Newson, eds. John Wiley and Sons, New York, NY.

TRRIT (Truckee River Recovery Implementation Team). 2003. Short-term action plan for Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) in Truckee River basin. Report to the US fish and Wildlife Service, Reno, NV.

Water Engineering & Technology, Inc. (WET). 1990. Geomorphology analysis of Truckee River from RM 56 (Ambrose Park in Reno) to RM 43 (Vista), Steamboat Creek, Boynton Slough. Final report prepared for the U.S. Army Corps of Engineers, Sacramento, CA, Contract No. DACW05-88-D-0044.