# UPPER TRUCKEE RIVER REACH 5

## FINAL Design Guidance Report

## Prepared for

USFS LAKE TAHOE BASIN MANAGEMENT UNIT
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# I. INTRODUCTION

The Upper Truckee River in El Dorado County, California is the largest tributary to Lake Tahoe (Lake) with a drainage area of around 54 square miles. It is also one of the largest contributors of sediment and nutrients to the Lake. The Reach 5 section of the Upper Truckee River encompasses approximately 8,000 feet of channel in the northern section of the Sunset Stables Management Planning Area (MPA), just east of the South Lake Tahoe Airport (Figure 1), a few thousand feet downstream of the U.S. Hwy 50 crossing at Elks Club Drive. The existing channel in this reach has been impacted by various site-specific and watershed-wide land use practices past and present, including urban development, gravel mining, grazing, logging, road building, bridge construction, airport construction, and buried utility line installations. The river response to past disturbances is complex, but includes processes and conditions that have degraded floodplain ecosystem values and accelerated fine sediment delivery downstream to Lake Tahoe. The Lake Tahoe Basin Management Unit (LTBMU) of the USDA Forest Service is leading the effort to restore the natural geomorphic function and floodplain connectivity to the Upper Truckee River within Reach 5 in order to improve water quality in the river and the Lake, increase riparian and wetland species health and diversity, and enhance aquatic and terrestrial wildlife habitat.

## Project Background

An assessment of the river and surrounding system in the MPA was conducted beginning in 2003 under the leadership of the California Tahoe Conservancy (Conservancy) in support of the Sunset Stables Restoration and Resource Management Plan (RRMP) project. The RRMP goals for the MPA include restoring geomorphic function to the channel configuration, improving water quality through improved floodplain functionality and reduced erosion, improving aquatic and terrestrial habitat, improving riparian, meadow and upland vegetation and providing for compatible public access uses (ENTRIX, Inc. 2008c). Concurrently and in support of the RRMP, stream restoration alternatives for the Upper Truckee River that encompassed Reaches 5 and 6 in the MPA were developed and evaluated and a preferred alternative was recommended to and agreed upon by the Technical Advisory Group (ENTRIX, Inc. 2008b). Fifty percent design plans of the preferred channel restoration alternative were generated for agency review in December 2008 (ENTRIX, Inc. 2008d).

In 2009 the Conservancy and LTBMU agreed to share the channel restoration efforts for the MPA by dividing work into two projects. Agency leadership for Reach 5 was transferred to the LTBMU, while the Conservancy retained leadership of Reach 6. The LTBMU owns a large portion of the land in the vicinity of Reach 5 and has the funding and permitting mechanisms to proceed efficiently into final design development. In the fall of 2009, the LTBMU contracted with Stream Solutions, LLC (Stream Solutions) to build on the prior analyses and products and proceed with design development.

## Scope of Work and Status

The scope of work contracted to Stream Solutions (USDA #AG-9A63-S-09-0037) includes focused field investigations, literature review, and supplemental analyses to improve the understanding of site history and conditions and the anticipated flow and sediment regimes; substantiate and/or modify the existing fifty percent design to ensure compatibility with adjacent reaches and capacity to deliver on project goals.

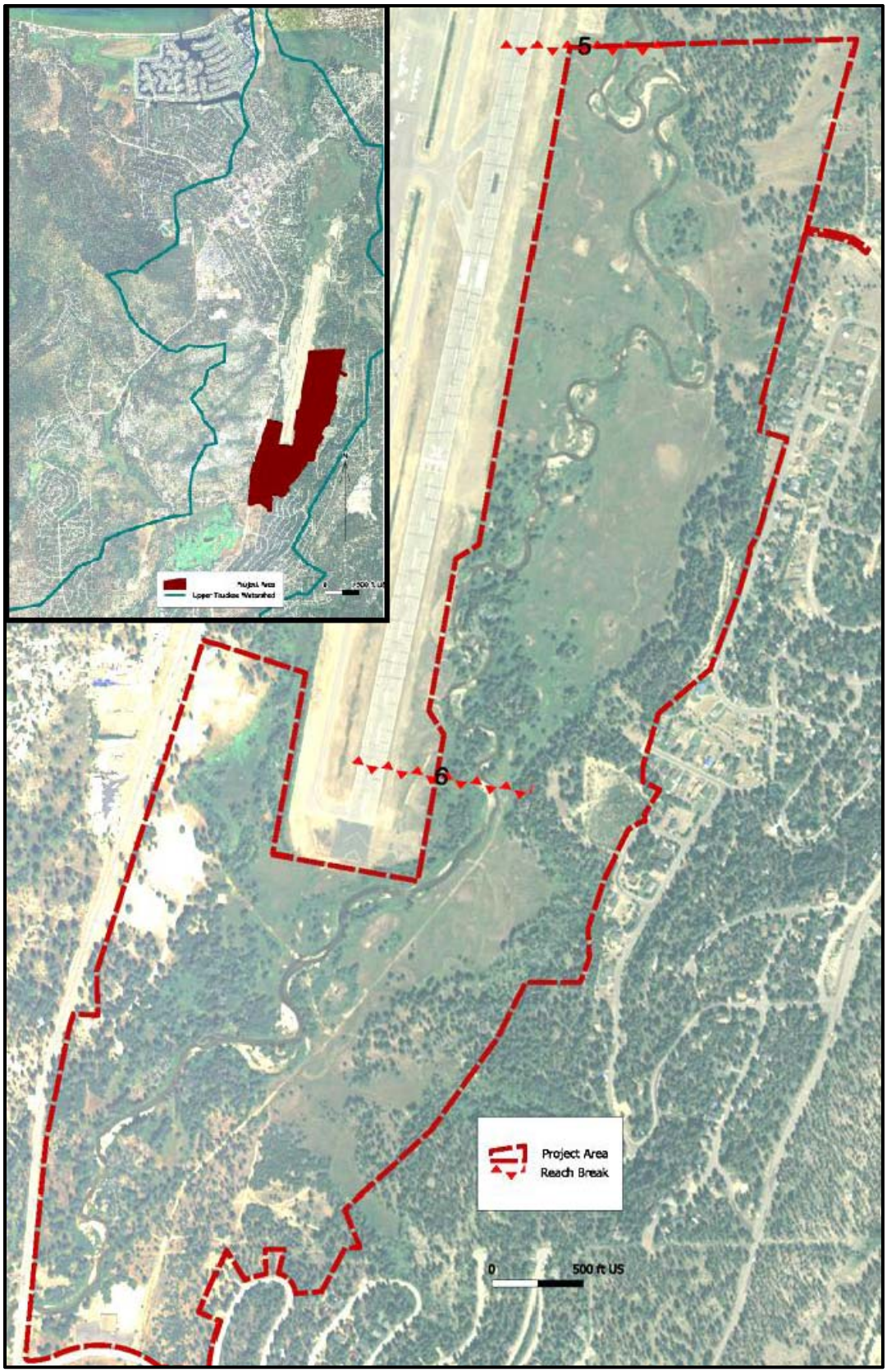



**FIGURE 1: UPPER TRUCKEE RIVER REACH 5 PROJECT SITE AND VICINITY**

A summary of the work performed to-date and reported herein, includes:

### Soils, meadow soil stratification, and vegetation characterization

Compile the latest available information on meadow soil composition in and near the project area and conduct soil sampling within the project area to assess historic river and floodplain patterns and conditions and determine feasibility for new channel construction. Assess the potential effects of expected range of hydraulic forces, including large flood events, on the proposed new channel banks to evaluate the effectiveness of various channel bank designs. Characterize the current vegetative structure and provide a suitable sod harvest and willow planting area map.

### Additional resource data review

Assess and determine how the design can integrate existing wildlife habitat components and processes in the project area to improve upon habitat conditions. Utilize information on existing sensitive vegetation communities, public utility locations and depths, known heritage resources and land ownership boundaries to determine optimal construction implementation strategies and placement of staging and access areas.

### Assessment of appropriate channel substrate material size

Determine appropriate channel bed and bank substrate material sizes for new channel construction and in-stream structures such as aquatic habitat features and protection measures for buried utilities.

### Preliminary Design Validation

Assess particle transport capability through the project reach using information collected above and consider upstream and downstream physical constraints to determine whether a different channel planform or dimensions would improve channel functionality during the range of expected flows. Compare proposed channel characteristics, including dimensions, planform, bedform and substrate sizes with reference conditions in an analogous channel if appropriate. Complete a multiple reach flood hydraulics assessment based on existing topography and results from the HEC RAS model used during alternatives evaluation to determine whether there may be any potential project impacts, such as flood attenuation, to downstream reaches.

## Purpose of the document

The primary purpose of this design guidance report is to provide the framework for entering into seventy five percent design development by: (1) reporting on the findings of the Task 1 investigations and analyses completed-to-date; (2) discussing what those findings mean regarding the feasibility and functionality of the proposed 50 percent channel design; and, (3) describing an approach to design revisions based on improved understanding of historic, existing, and anticipated conditions.

# II. SOILS AND MEADOW SOIL STRATIFICATION

## METHODS

### LITERATURE REVIEW

Several project reports, maps, and data sets for the Sunset Stables RRMP provided by ENTRIX, Inc. for the California Tahoe Conservancy (ENTRIX, Inc. 2008c), along with other prior studies of the middle reach of the Upper Truckee River (TRCD 2003) were reviewed and integrated into this analysis.

Project reports, maps, and data for other reaches of the Upper Truckee River were reviewed and integrated into this analysis, including primarily data and reports of the adjoining Middle Reaches 3 and 4 site downstream (i.e. Airport Reach) (CDM 2006), personal communications regarding conditions observed on Reaches 3 and 4 during construction (Scott Carroll, Pers. Comm. Jan 2010), and background studies for the Upper Truckee Marsh Project (CTC and DGS 2003).

Analysis conducted by the USDA ARS-National Sedimentation Laboratory for the Lake Tahoe TMDL (Simon et al., 2003, Simon 2006) and continuing research within the Project Area collected between 2007-2009 (Langendoen, Pers. Comm. 2010) were incorporated.

The NRCS soil survey map ( NRCS 2007) and all of the available field and laboratory data associated with NRCS sampling locations in the project vicinity were reviewed. Three NRCS field sites are within Upper Truckee River (UTR) Reach 5, two on the valley bottom (NRCS ID #'s 9-30, and 02-ca693-067) and one on the adjacent hillside (jgc04025). Two NRCS fields sites are along the valley bottom in UTR Reach 6 (02ca693-072 and 02ca693-073), and several sites are along the UTR downstream in Reaches 1 through 4. The mapped series descriptions and the field note sheets were examined with regard to: soil texture and structure; buried soils/sedimentation; hydric indicators; and, specifically, presence and depth to redoximorphic[1] features and/or lake sediment.

### MAP AND AERIAL INTERPRETATION

All available detailed maps and historical aerial imagery covering the project reach were reviewed and several were obtained digitally for GIS analysis (Table 1).

For the entire Reach 5-Reach 6 valley section, some basic characteristics of valley and channel pattern were analyzed on the historic images (both reaches were included to facilitate geo-registration of the images using control points visible on all images). Valley floor area was determined on topographic maps using vegetation signatures on images to locate the distinct break between valley floor and side slopes. As a location reference that is independent of the river channel position, Valley Stations (VS) along the valley axis were established by using the approximate centerline of the available valley floor and assigning distances beginning at approximate ENTRIX river station 132+ 00 just upstream of the historic river crossing structure in Reach 4 visible on all the images. Valley width measurements of channel/floodplain confinement were made perpendicular to the valley axis at 500 feet interval (Figure 2).

After review of background reports, initial map and aerial image analysis, and a field reconnaissance of the entire Project Site, several transect zones (Figure 3) were roughly outlined to guide selection of soil sampling locations that would represent the entire site, covering the full range of valley confinement, channel sinuosity, vegetation, and topographic conditions (Table 2).

[1] Redoximorphic features are color patterns in a soil due to loss (depletion) or gain (concentration) of pigment relative to the matrix color and they are formed by oxidation/reduction of Fe and/or Mn, along with removal, translocation, or deposition; they may occur in the maxtrix, on or beneath the surfaces of peds, or associated with pore surfaces.

### TABLE 1: HISTORIC AERIAL IMAGERY OF THE PROJECT AREA

| Year | Month Day | Type / Source | Scale / Resolution | Projection / Units |
|---|---|---|---|---|
| 1940 | July 13 | USGS digital ortho-image-BandW / USFS | 1:20,000<br>1 m resolution | NAD 1983 UTM Zone 10N meters |
| 1952 | August 14 | BandW / USFS | 1:20,000 | NAD 1983 UTM Zone 10N meters |
| 1969 | August | USGS digital ortho-image- BandW / USFS | 1:40,000<br>1 m resolution | NAD 1983 UTM Zone 10N meters |
| 1987 | July | USGS digital ortho-image- color / USFS | 1:24,000<br>1 m resolution | NAD 1983 UTM Zone 10N meters |
| 2002 | July | IKONOS natural color / USFS | 1 m resolution | NAD 1983 UTM Zone 10N<br>meters |
| 2003 | July (some data from 2002, also July) | Color ortho-image mosaic (associated with LIDAR topo) / Merrick and Co. for CTC | 0.3 feet vertical accuracy | NAD 1983 CA State Plane II<br>FIPS 0402<br>US Survey Feet<br>NGVD 1929 (vertical) |
| 2005 | August 20 | Color mosaic /<br>NAIP series USFS | 1:15,840; 1 m resolution | NAD 1983<br>UTM Zone 10N<br>meters |

### TABLE 2: REACH 5 STUDY TRANSECT CHARACTERISTICS

| Transect ID | Valley Station Range | Valley Confinement | Channel Sinuosity | Vegetation | Topography |
|---|---|---|---|---|---|
| AA | 176+00 to 170+00 | High | Moderate | Lodgepole forest | Somewhat irregular |
| A | 170+00 to 165+00 | Moderate | Low | Lodgepole forest / Meadow | Relatively level with micro topography |
| B | 165+00 to 159+00 | Low | Moderate | Meadow | Relatively level with micro topography |
| C | 159+00 to 154+00 | Low | Moderate | Meadow | Relatively level with micro topography |
| CD | 154+00 to 148+00 | Low | Very High | Meadow | Relatively level with micro topography |
| D | 148+00 to 141+00 | Low | High | Meadow | Relatively level with micro topography |
| E | 141+00 to 135+00 | Very High | Very High | Meadow | Somewhat irregular |

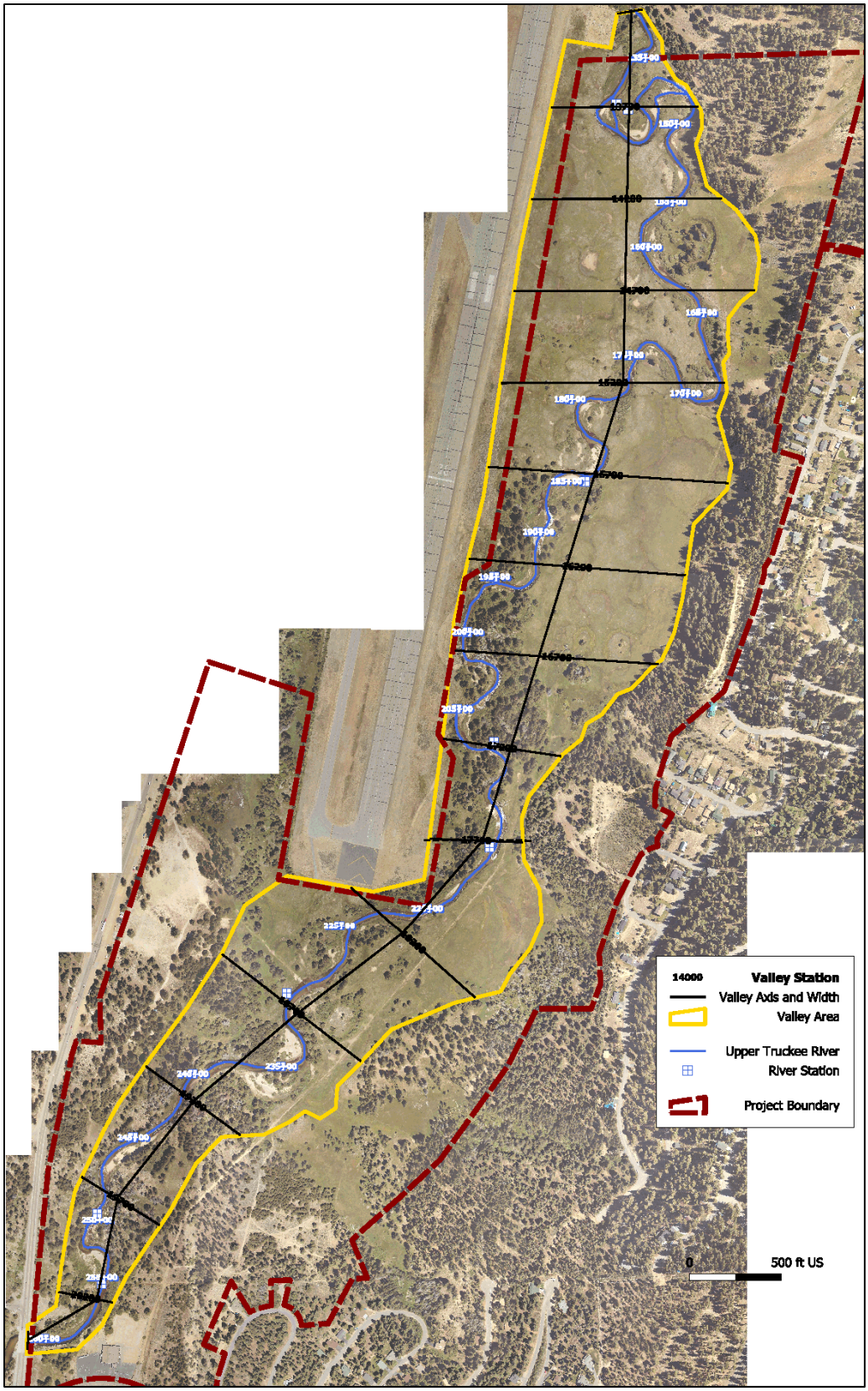



**FIGURE 2: PROJECT AREA VALLEY STATIONING**

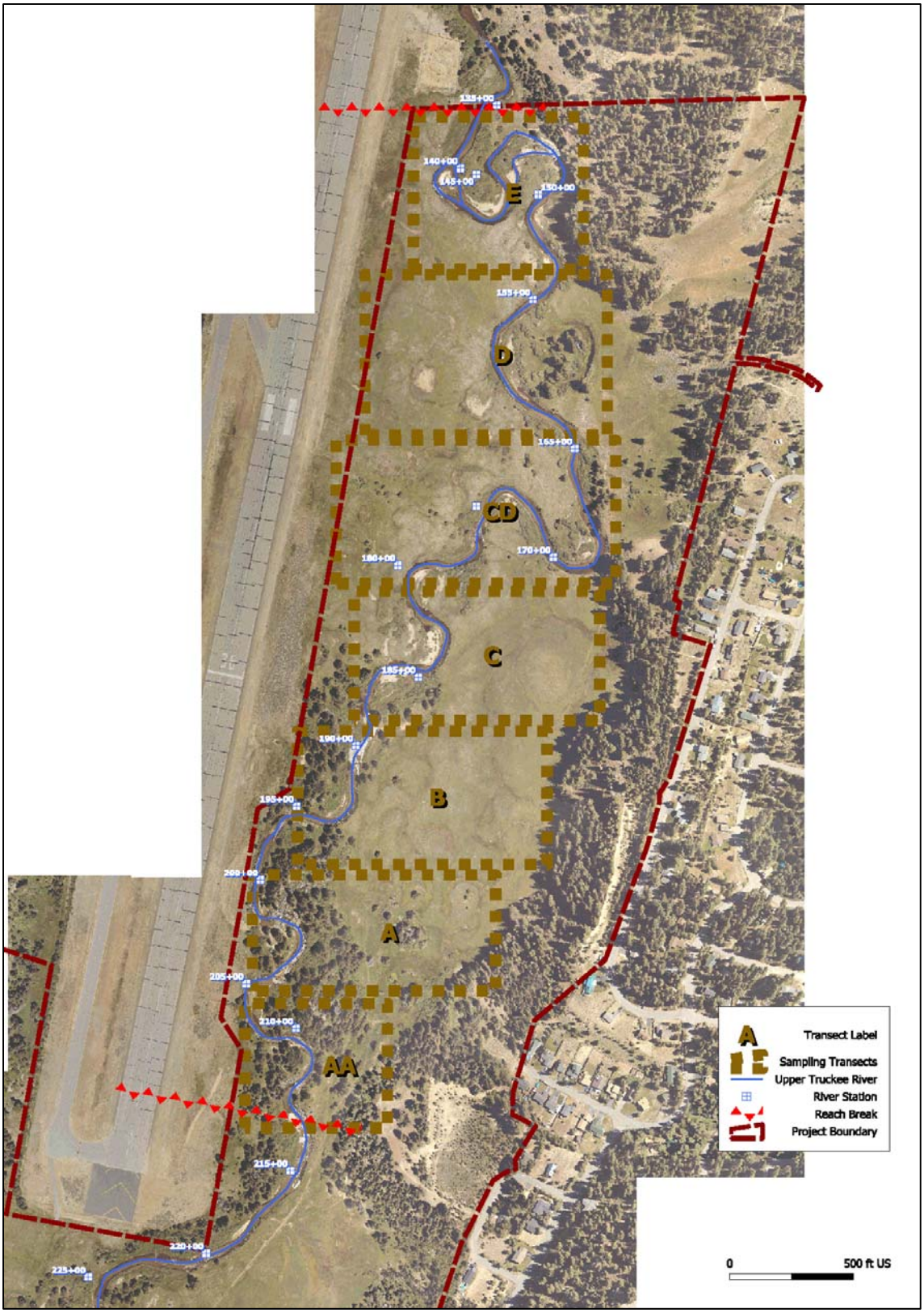



**FIGURE 3: PROJECT AREA AND REACH 5 STUDY TRANSECTS**

Channel location and pattern data used the digitized centerline of the main channel and any visibly connected (at low flow) secondary channels. Channel width measurements tracked both the low flow water surface and the whole active channel (low flow channel plus adjacent unvegetated bar deposits. Channel width was measured at the same twenty two VS positions between VS 132+00 and 212+00 on each of the 1940, 1952, 1969, and 2003 images. The 1987 image quality was unsuitable for observation of point bars and low flow water.

The 1940, 1952, 1969, 1987, and 2003 images were examined for floodplain features. The 2003 LIDAR image and accompanying topographic data was interpreted first, with the benefit of field observations to verify surface characteristics of the features. Older images were similarly mapped and analyzed for the presence of floodplain features and patterns, although no additional topographic information could be determined.

Remnant channels (RC) on the floodplain/terrace were identified based on visible closed depression topographic contours of at least 1 foot. The RCs did not appear to have present-day connections and were just isolated meander bends with varied orientation and planform. Some are parallel to the existing channel and others nearly cross valley, but all were included as remnant channel features if they were deep enough to meet the topographic criteria. Width and depth were estimated on the 2003 topographic data, as well as the radius of curvature.

Return flow (RF) swales on the floodplain/terrace were identified as distinct, but shallow linear depressions (vegetation differences from surrounding meadow, but not deep enough for any closed topographic contours). The RFs have present drainage connectivity, which were mapped along the center of each swale and typically form a dendritic pattern oriented to return down valley and downstream off the floodplain.

Unvegetated areas on the floodplain/terrace were identified on the 2003 LIDAR image and, along with the detailed topographic data and 2009 field observation, were classified as either: deposits, scour, or other unvegetated areas (e.g., buried utility cover, riprap; trails, or exposed hillslope face).

### Field Observations

Specific soil observation and sampling sites were located throughout the Project area (Figure 4), with representative locations in each of the seven transect areas (Table 3). Sampling sites were selected to include locations along the proposed 50 percent design channel alignment and to capture the range of surface topography and vegetation characteristics indicated by the reconnaissance visit and background reports. Ten samples with a 1m gouge core, eight samples with a standard hand auger (up to 2 m), and three samples with hand shovel pits were examined, along with eight streambank exposures.

Field locations of cross-section surveys and sampling previously conducted and reported by other parties are depicted along with sampling points established in the present study to facilitate interpretations in Figure 4.

### TABLE 3: STREAM SOLUTIONS SOIL SAMPLING LOCATIONS

| Transect | Field ID | Description | Observation Method(s) | Date(s) |
|---|---|---|---|---|
| AA | AA Stop 1 | streambank | cut bank exposure | 15Nov09<br>05Nov09 |
| AA | AA1 WP 716 | overbank surface | standard auger | 15Nov09 |
| A | A1 WP 558 | meadow swale | gouge core | 05Nov09 |
| A | A2 WP 559 | meadow surface | gouge core<br>standard auger | 05Nov09<br>15Nov09 |
| A | A3 WP 560 | overbank surface | gouge core | 05Nov09 |
| A | A4 | streambank | cut bank exposure | 05Nov09 |
| B | B1 WP 562 | meadow surface | gouge core | 05Nov09 |
| B | B3 WP 563 | meadow swale | gouge core<br>standard auger | 05Nov09<br>13Nov09 |
| B | B4 WP564 | meadow surface | gouge core | 05Nov09 |
| B | B | streambank | cut bank exposure | 05Nov09 |
| B | WP 715 | meadow swale | 1m square bulk sample | 15Nov09 |
| C | C1 WP 565 | meadow | gouge core | 06Nov09 |
| C | C2 WP 566 | meadow | gouge core<br>standard auger | 06Nov09<br>13Nov09 |
| C | C3 WP 567 | meadow | gouge core<br>standard auger | 06Nov09<br>13Nov09 |
| C | C4 WP 726 | streambank | cut bank exposure | 06Nov09<br>19Nov09 |
| C | J1 WP 729 | meadow surface | 0.5ft interval soil samples | 19Nov09 |
| CD | CD1 WP 720 | meadow swale | standard auger | 16Nov09 |
| CD | WP 721 | streambank | cut bank exposure | 19Nov09 |
| CD | WP 722 | streambank | cut bank exposure | 19Nov09 |
| CD | WP 723 | streambank | cut bank exposure | 19Nov09 |
| CD | WP 724 | streambank | cut bank exposure | 19Nov09 |
| CD | WP 725 | streambank | cut bank exposure | 19Nov09 |
| D | D | streambank | cut bank exposure | 06Nov09 |
| D | D1 WP 568 | remnant channel | gouge core / shovel pit | 06Nov09 |
| D | D2 WP 569 | overbank surface | gouge core | 06Nov09 |
| D | D3 WP718 | meadow swale | standard auger | 16Nov09 |
| D | D4 WP 719 | gravel barren | shovel pit | 16Nov09 |
| D | AJ728 Stop 7 | gravel barren | shovel pit | 06Nov09 |
| E | E1 | meadow surface | standard auger | 16Nov09 |
| E | Stop 3 | streambank | cut bank exposure | 06Nov09 |
| E | Sideslope | streambank | cut bank exposure | 06Nov09 |
| E | Stop 5 | streambank | cut bank exposure | 06Nov09 |
| E | Stop 6 | streambank | cut bank exposure | 06Nov09 |

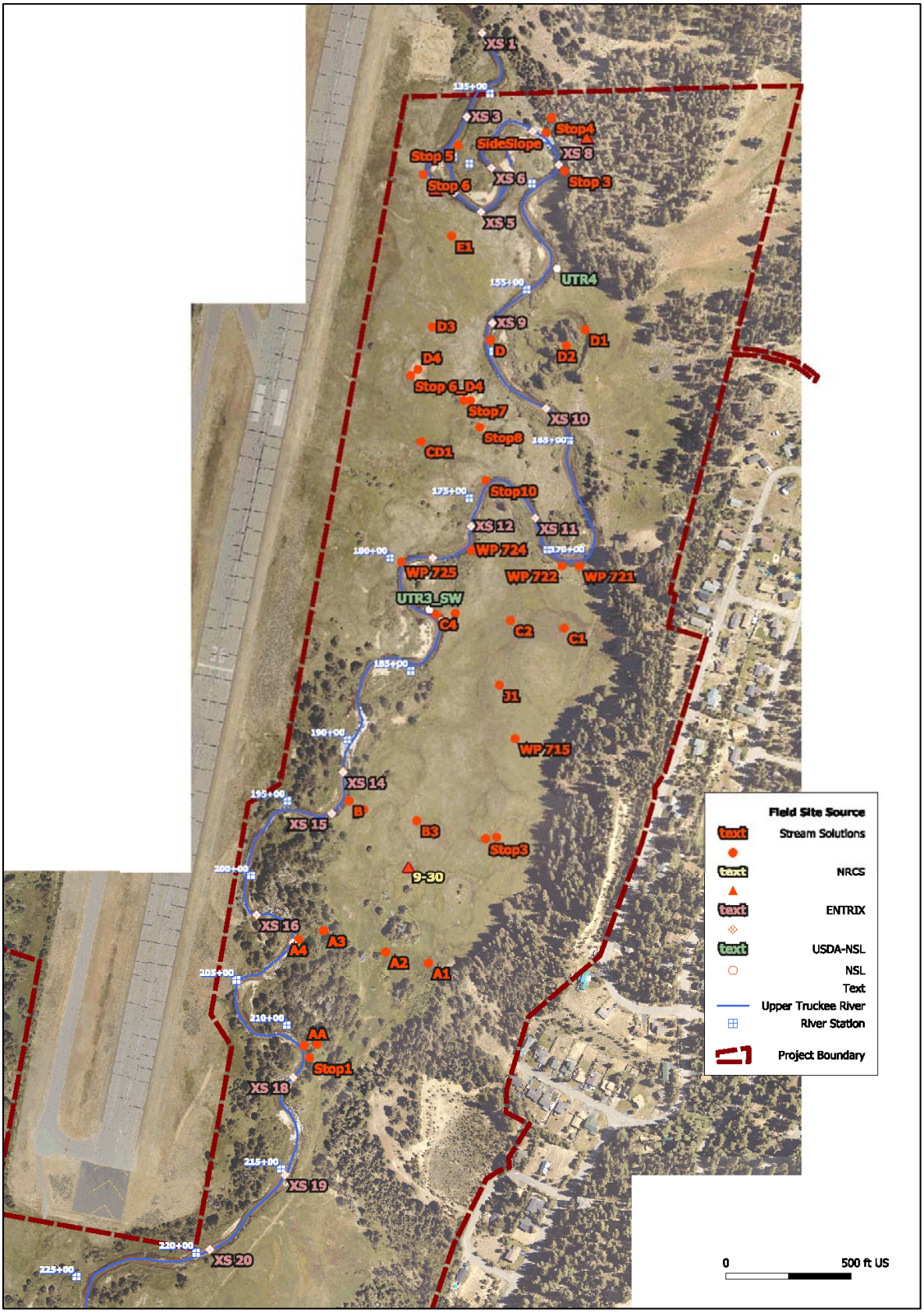



**FIGURE 4: PROJECT AREA FIELD SAMPLING SITES**

### Laboratory Analyses

Charred organic material recovered within gravel deposits at two of the field soil sampling sites was radiocarbon dated by BETA Analytic, Inc. (Appendix A) to provide a calendar calibration result using the newest (2004) calibration database.

Selected soil parameters of the surface horizons (A horizons) from two sites (one in the most common meadow vegetation cover (site J1 WP729); and, the other in the second-most common sod cover (site E1) were analyzed for several parameters relevant to restoration specifications (Appendix B). Total organic matter content was selected as a surrogate for a suite of individual nutrient analyses; the primary purpose of these analyses was to provide a measure of the depth of high-organic-content soil that should be applied in order to provide a physical environment for meadow vegetation restoration that is similar to that of the desired natural community. Organic content is also an important factor in determining soil moisture regime during the time period that immediately follows the drop in groundwater level below the root zone. Soil textures were also determined (as percentage sand/silt/clay), and water content at saturation, and at -1/3 bar and -15 bar water potential. These are the main parameters of the soil moisture retention curve (or characteristic curve), which, after seasonal groundwater levels, is probably the single most important factor in determining the characteristics of potential future meadow vegetation.

One sample from a site in the best quality salvageable sod (site WP 715) was collected and analyzed for direct determination of bulk density and organic matter content.

### Hydrologic Data

Eight shallow groundwater wells within the Sunset Stables (Reaches 5 and 6) study area were installed by the Conservancy in late 2005 (Figure 5). Seven of the eight wells have been monitored for the past four water years (excluding GW#1 which was only monitored for one year). Wells # 2, 3, and 4 are just upstream of Reach 5 (VS 181+50) and wells # 6, 5, 7 and 8 are within Reach 5 (VS 155+50). Wells # 2, 6, and 5 are west of the river, while wells #4, 7, and 8 are east of the river. The raw data converted to relative elevations below ground was provided by the Conservancy, along with survey location and elevation data. This data was converted to absolute elevations on the same datum as the topographic survey (NGVD 29) to facilitate further analysis of groundwater levels, gradients and relationships to the existing valley floor surface and the river channel. Groundwater hydrograph shapes and descriptive statistics were calculated for each well for all four water years. All available data is presented in the graphs, but obvious outlier data points were deleted from the data set prior to statistical calculations. The mean daily streamflow hydrograph of the Upper Truckee River at the upstream and downstream USGS gages (#103366092 and #10336610, respectively) was analyzed for the same four water years to assess temporal patterns in the surface and groundwater relationships.

## Results

### Soil Characteristics

The NRCS soil survey (NRCS 2007) designates nearly all the site as map unit 7041 (Tahoe complex, 0 to 2 percent slopes), which is typically dominated by Tahoe silt loam, Tahoe silt loam wet, and similar soils. Additionally, areas of Marla, Tahoe gravelly, and Watah sedges and similar soils would be expected within suitable locations on the valley floor. Ubaj soils occur on the side slope along the east margin of the site. Ubaj soils are very deep, moderately well drained soils in colluvium and/or outwash derived from granodiorite overlying lacustrine deposits (light gray to gray clay) at a depth of 50 to 100 cm (NRCS 2007). At the downstream end of Reach 5, lateral erosion of the river is exposing a hillslope with Ubaj soils, but they are not present within the main floodplain meadow surface.

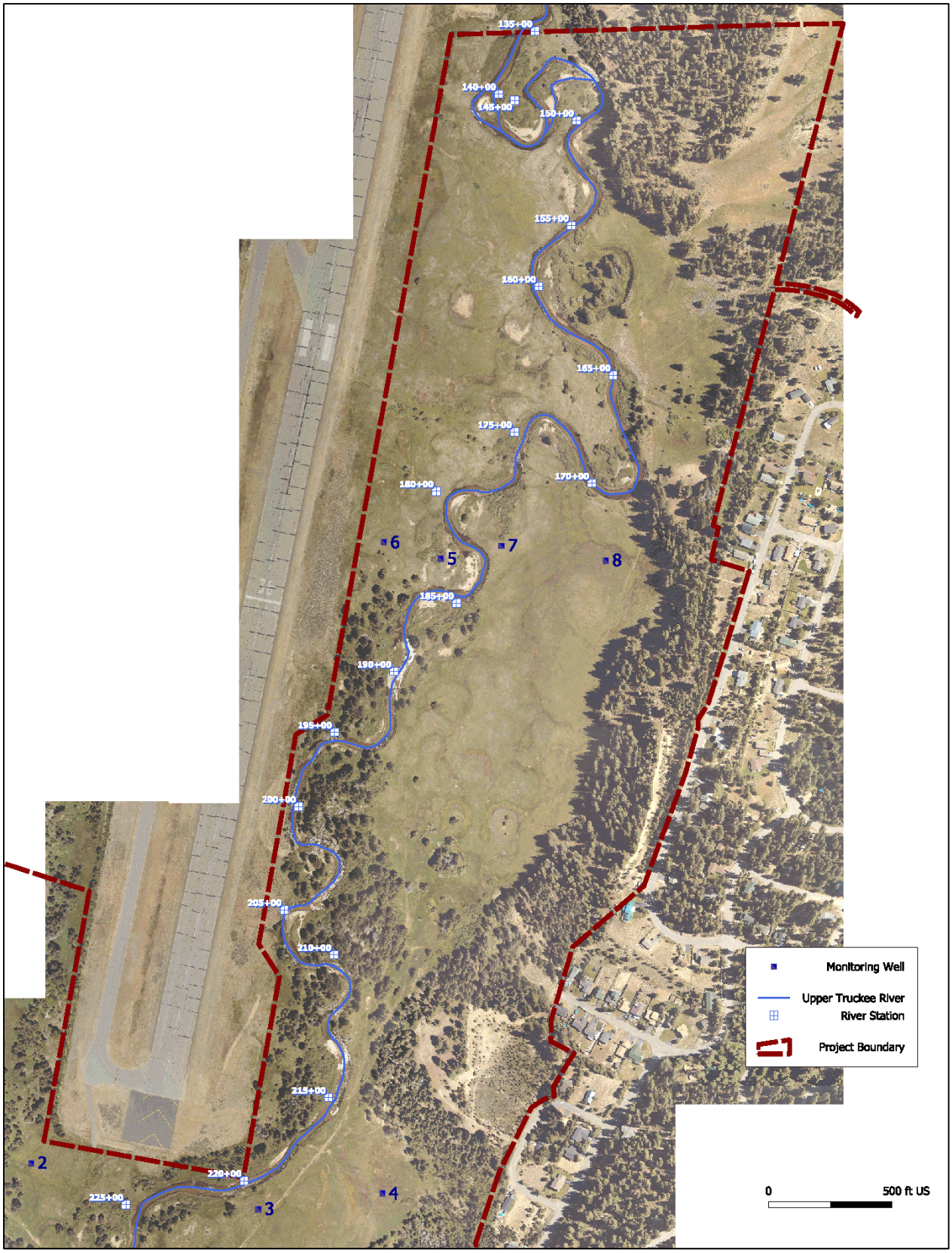



**FIGURE 5: PROJECT AREA GROUNDWATER MONITORING WELLS**

The Tahoe series typically consists of very deep, very poorly drained soils with a surface layer of mucky silt loam on floodplains that formed in alluvium derived from granitic and andesitic rocks. . Vegetation is typically a grass and sedge community, with a mixed willow and sedge community in wetter areas (NRCS 2007). The Tahoe and related soils have relatively strong A-horizon development given the geologic parent material and cool climate, and this likely represents a long time period for soil formation (Loftis 2010 pers. Comm.). In depressions and wetter portions of the floodplains, Watah peat soils with dense sedge community (*Carex utriculata; Carex vesicaria*; other *Carex spp*.) occur. The Watah soils are thick organic peat over sandy alluvial material (NRCS 2007).

Selected soil properties relevant to stability, erodibility, water movement, and productivity of the Tahoe silt loam, Tahoe silt loam, wet, and the Watah peat soils according to the NRCS (2007) are summarized in Table 4. All of the soils have relatively low clay content (0 to 16.5 percent) and distinct variation of characteristics by soil horizon as a reflection of the layered parent material and differential accumulations of organic material. Available water capacity (AWC) is quite low in the sand dominated sub-surface horizons, but moderate for the entire profiles. Bulk densities are low, particularly in the organic-enriched surface horizons. The saturated hydraulic conductivity (Ksat) values have large ranges due to texture and porosity differences, but overall are moderately high to high, indicating rapid water transmission potential. The hydrologic properties of the soils are described as having very slow infiltration rates when wet (NRCS Group D). However, due to their field observed-drained condition in the project vicinity (from stream channelization and subsequent head-cutting/incision), they have high infiltration rates (NRCS Group A) (NRCS 2007).

2009 field observations at the Stream Solutions sampling locations across the meadow surface (e.g., A2, B3, C2,D3) are consistent with the Tahoe series (Figures 6A,B,C,D), as are the sites under lodgepole and willow stands in overbank locations (e.g., AA1, A3, D2) (Figures 7A,B,C). The soils are most similar to the drained variant of the Tahoe series rather than the typical profile (they have increased depth to redoximorphic features). In meadow swales (RF channels) and shallow RCs channel depressions soils similar to the Tahoe silt loam, wet and Watah peat soils occur (e.g., B3, CD1, D1, E1) (Figures 8A and B). However, in the deeper remnant channels, only a shallow soil is present over the lacustrine sediments (Figure 8C). The site representing a few unvegetated sand/gravel surfaces (D4) lacks any A horizon development and is comprised of stratified sand and gravel parent material (C horizons) more than 4.5 feet thick (Figures 9A and B). Charcoal samples taken from the C2 horizon at a depth of 0.65 to 0.76 feet within the sand and gravel deposits at site D4 were radiocarbon dated to 790 +/- 40 BP (Appendix A). Charcoal samples taken from the same horizon and depth within one of the other unvegetated sand and gravel deposits (site AJ 728) was radiocarbon dated to 800 +/- 40 BP (Appendix A).

The surface soils are fine textured, low density, with limited cohesion: typically silt loams, fine sandy loams, loamy fine sands, and some areas of mucky silt loams in depressions (Table 5). Surface horizons range between 1.9 and 3.0 feet thick on the meadow surface, with shallower surface soils in some of the depressions. Analysis of bulk density on a surface horizon (upper 8 inches) sample from a meadow surface site in Transect B (site WP 715) was 0.636 g/cc (Appendix B), which is extremely low but within the range expected based on NRCS soil survey data (Table 4).

Subsurface materials include lenses and layers of coarse sand and small gravel, but are still dominantly fine textured, with little soil structure and low cohesion to the depths sampled (4 to 6 feet). The coarser sand and fine gravel layers have increased hydraulic resistance compared to the surface horizons, but reduced cohesive strength. Surface areas of sand and gravel deposits outside the active channel bars are limited to a few discrete locations west of the river in Transect D (Figure 9). Some subsurface sand and gravel lenses were observed at the soil auger sites, but no coarse (>2mm) surface materials. The subsurface sand and gravel units remain of uncertain thickness and lateral extent (in the absence of additional studies). Therefore, it is possible that coarse sands/small gravel may be present within the new channel excavation zone (assuming a 4 to 6 ft excavation depth) along any potential alignment on the valley floor in Reach 5.

**TABLE 4: SELECTED PROPERTIES OF MAPPED FLOODPLAIN SOILS IN REACH 5**

| | Texture | Thickness | Clay | AWC | Bulk Density | K Sat | Organic Matter |
|---|---|---|---|---|---|---|---|
| Horizon | | (ft) | % wt | (in/in) | (g/cc) | (µm/sec) | (%) |
| **Tahoe silt loam, wet** | | | | | | | |
| A1 | Mucky silt loam | 0.8 | 16.5 | 0.22-0.24 | 0.8-1.0 | 10-100 | 6-20 |
| A2 | Loam | 1.4 | 16.5 | 0.16-0.18 | 0.85-1.05 | 10-100 | 6-15 |
| Cg1 | Loamy fine sand | 0.4 | 6.0 | 0.05-0.07 | 1.6-1.7 | 100-200 | 1.0-5.0 |
| Cg2 | Fine sand | 1.2 | 4.0 | 0.0 | 1.6-1.7 | 100-200 | 0.5-2.0 |
| **Tahoe silt loam** | | | | | | | |
| Oe | Mod. decomposed plant | 0.3 | - | - | - | - | - |
| A1 | Mucky silt loam | 0.7 | 15.0 | 0.19-0.24 | 0.7-1.05 | 1-10 | 10-20 |
| A2 | Mucky silt loam | 0.3 | 15.0 | 0.17-0.22 | 0.7-1.05 | 1-10 | 10-20 |
| A3 | Gravelly coarse sand | 0.4 | 2.0 | 0.02-0.04 | 1.05-1.35 | 10-100 | 5-10 |
| A4 | Mucky silt loam | 0.8 | 15.0 | 0.20-0.22 | 0.8-1.10 | 1-10 | 8-20 |
| Cg1 | Loam | 1.6 | 7.5 | 0.14-0.19 | 1.4-1.8 | 10-100 | 0.3-1.5 |
| Cg2 | Loamy sand | 0.8 | 4.0 | 0.08-0.10 | 1.4-1.8 | 10-100 | 0.5-1.5 |
| **Watah peat** | | | | | | | |
| Oi | Peat | 0.3 | 0.0 | 0.55-0.65 | 0.2-0.09 | 100-705 | 70-90 |
| Oe | Mucky peat | 0.4 | 0.0 | 0.45-0.55 | | 100-200 | 70-90 |
| A | Gravelly coarse sandy loam | 0.6 | 4.0 | 0.09-0.11 | 1.5-1.6 | 10-100 | 10-21 |
| C | Gravelly loamy coarse sand | 4.0 | 4.0 | 0.02-0.03 | 1.6-1.7 | 10-100 | 0.0-2.0 |

Source: NRCS 2007.
AWC = Available water capacity; the quantity of water that the soil is capable of storing for use by plants;
Bulk density is the weight of oven dry soil per unit volume when the soil is at field moisture capacity.
Ksat = Saturated hydraulic conductivity; the ability of soil to transmit water or air, the rate of water movement in micrometers per second when the soil is saturated and is based on soil structure, porosity, and texture.
Organic matter is the plant and animal residue in the soil at varied stages of decomposition.

6A: Auger Soil Samples at Site A2

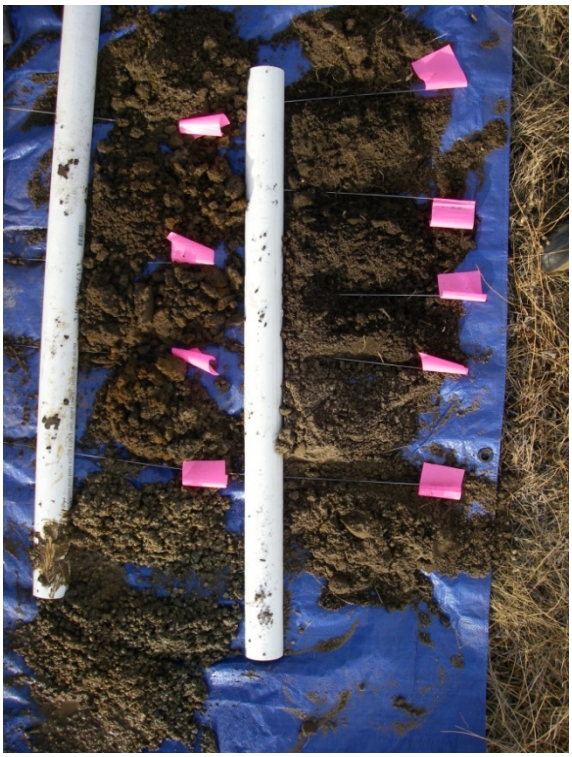


Figure 6B: Auger Soil Samples at Site B3

Figure 6C: Soil Sampling Location C2.

Figure 6D: Auger Soil Samples at Site D3.

**FIGURE 6: SOIL SAMPLES REPRESENTING THE MEADOW SURFACE (CONTINUED)**

Figure 7A: Auger Soil Samples at Site AA1.

Figure 7C: Sampling Site D2.

Figure 7B: Core Soil Sample Site A3

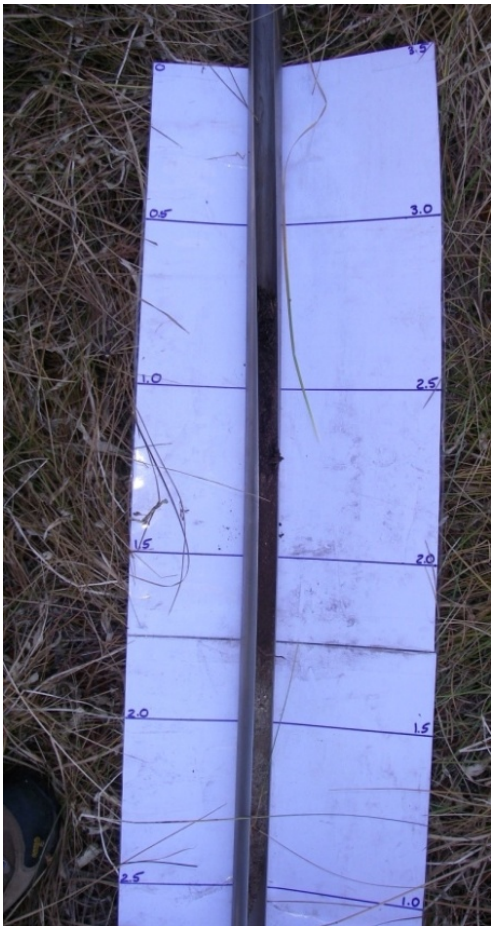


Figure 7D: Core Soil Sample at Site D2.

**FIGURE 7: SOIL SAMPLES REPRESENTING LODGEPOLE STANDS (CONTINUED)**

Figure 8A: Soil Sampling Site CD1.

Figure 8B: Auger Soil Samples at Site CD1.

Figure 8C: Soil Profile at Site D1.

**FIGURE 8: SOIL SAMPLES REPRESENTING REMNANT CHANNELS**

Figure 9A: Sampling Site D4.

Figure 9B: Soil Profile at Site D4.

**FIGURE 9: SOIL SAMPLES REPRESENTING UNVEGETATED GRAVEL DEPOSITS**

### TABLE 5: OBSERVED SOIL CHARACTERISTICS WITHIN REACH 5

| Field ID | Location Description | Surface Horizon(s) * | | Sub-Surface Horizon(s)* | Depth to Lake Sediment ** |
|---|---|---|---|---|---|
| | | Texture | Thickness (ft) | Texture | (ft) |
| AA1 | overbank surface | Silt Loam | 3.0 | Sand | >4.7 |
| A1 | meadow swale | Loamy Fine Sand | >1.0 | n/a | n/a |
| A2 | meadow surface | Silt Loam / Loam | 1.8 | Sandy Loam / Sand | >4.0 |
| A3 | overbank surface | Fine Sand / Sand | 2.8 | Med and Coarse Sand | >2.8 |
| B1 | meadow surface | Sandy Loam | 1.3 | Med and Coarse Sand | >2.5 |
| B3 | meadow swale | Silt Loam | 2.5 | Fine Sandy Loam / Fine Sand | >4.4 |
| B4 | meadow surface | Loamy Fine Sand | 1.9 | Med and Coarse Sand / Coarse Sand | >3.1 |
| C1 | meadow | Loamy Fine Sand | 1.9 | Fine Sand | >3.1 |
| C2 | meadow | Silt Loam | 2.1 | Loamy Fine Sand / Med and Coarse Sand | 5.2 |
| C3 | meadow | Loamy Fine Sand | 3.0 | Silt Loam / Loamy Sand | >6.0 |
| J1 | meadow surface | Sandy Loam | 1.9 | Coarse Sand | |
| CD1 | meadow swale | Silt Loam / Mucky OM | 2.9 | Silt Loam / Fine Sand | >4.6 |
| D1 | remnant channel | Loamy Fine Sand | 0.7 | Silty Clay Loam | 0.7 |
| D2 | overbank surface | Loamy Fine Sand | 1.6 | Med and Coarse Sand | >2.7 |
| D3 | meadow swale | Silt Loam | 1.8 | Sand | >2.2 |
| D4 | gravel barren | n/a (all C horizons) | 0 | Sands / Fine Gravel | >4.5 |
| E1 | meadow surface | Silt Loam/Sandy Loam | 2.4 | Loamy Fine Sand / Sand | 4.3 |
| 9-30 | NRCS sample | Silt Loam | 2.3 | Fine Sandy Loam/ Sands and Fine Gravel | >5.0 |

* Surface horizons are all "A" horizons; If textures are stratified both dominant textures are listed using "/ "
** Depth listed if lake sediment observed; otherwise assumed deeper than sampling depth (>xft)

Three streambank bulk samples analyzed by ENTRIX (2007b) for particle size are within the Reach 5 project area at XS 5 and XS 15 (Figure 4). Samples from approximately 4.5 feet depth on the left bank at XS5 and from approximately 3.0 feet depth on the right bank at XS 15 were determined to have a median particle diameter ($D_{50}$) of 0.08 mm (very fine sand), zero gravels and around 10 percent clay. These characteristics are consistent with the light sandy loam soil textures observed at several auger sites across the floodplain (Table 5). The sample from approximately 1.5 feet depth on the left bank at XS 5 had slightly coarser sands, with a $D_{50}$ of 0.21 mm (fine sand) and very little clay (3.9%). These characteristics are consistent with the loamy sand and sand layers observed at auger sites across the floodplain (Table 5). ENTRIX (2004) reported the USACE (2000) description of stream bank material just upstream of Reach 5 (RS 20700) as having a very fine gravel median particle diameter in the lower bank and fine to medium sand in the upper bank. ENTRIX (2004) also cites the USACE (2000) description of streambanks between RS 188+75 to 220+50 (the Reach 5/6 transition area) as having cohesionless sand and gravel bank toes, but cemented and overlain with Pleistocene-age lacustrine sediments in some areas. These prior observations are also consistent with the 2009 samples.

Bank toe, bank face, and internal bank material were sampled at two locations within Reach 5 by Simon and Others (2003) (Site Id#s 44-48 and 44-75 at RS 138+00 and 185+25, respectively; see Figure 4). The bank toe and bank face material consists primarily of fine to medium sand (81-94.4 percent), with minor silt and clay. Only one of the four samples had any traces of gravel. The internal bank materials are similar to the toe and face samples, with median particle sizes in the fine to medium sand classes, relatively low combined total silt and clay (9.6 to 28.3 percent), and little or no gravel (0 to 3.2 percent). Additional bank samples from the USDA ARS-NSL site UTR3 within Reach 5 (see Figure 4) were recently analyzed (Langendoen 2001 pers. Comm.). The upper bank sample (at depth of 1.5 feet) was fine grained, with a $D_{50}$ of 0.007 mm (fine silt) and about 41.5% sand, which is consistent with a silt loam/loam soil texture. The lower bank sample (at depth of 3.6 feet) had higher sand content (69.4%), but a $D_{50}$ in the coarse silt class (0.027 mm), which would relate to a loamy sand texture.

USDA-ARS, NSL field tests using hydraulic jets and bore-hole shear vanes has measured the in-situ streambank hydraulic resistance and cohesion properties at their sites within Reach 5, as shown in Table 6 (Simon and Others 2003, Langendoen 2010).

### TABLE 6: GEOTECHNICAL AND HYDRAULIC PROPERTIES[2] OF REACH 5 STREAMBANK SAMPLES

| Site | Depth | Material | Apparent Cohesion | Effective Cohesion | Pore Water Pressure | Critical Shear Stress | Erodibility Coefficient |
|---|---|---|---|---|---|---|---|
| | (ft) | texture | (kPa) | (kPa) | (kPa) | (Pa) | (cm3/N-s) |
| 44-78 | 1.2 | Sand | 4.20 | 0.9 | 75.7 | n/a | n/a |
| 44-75 | 3.3 | Silty Sand | 3.30 | 2.60 | 4.20 | 0.28 | 29.6 |

Source: Simon and Others 2003
kPa = kilopascal; Pa = Pascal (1 Newton/meter$^2$).

Although several prior studies, including ENTRIX (2008b), report bank materials in the project area dominated by sands with very little clay, qualitative summaries of the bank properties in reports supporting the Sunset Stables RRMP (ENTRIX 2008a and 2008b) label the banks 'cohesive' and selection of channel dimensions assumed moderately cohesive to cohesive banks (ENTRIX 2008). These generalizations are inconsistent with the field observations of soil structure and texture in most locations across the main meadow surface. There are important variations in cohesion and hydraulic resistance with depth that require consideration in terms of proposed channel dimension and bank configuration. The surface horizons' low inherent cohesion (approximately 3.0 to 5.0 kPa for silts) is enhanced by rooted vegetation, the underlying non-cohesive sand and gravel layers are slightly coarser and have higher hydraulic resistance, while the lacustrine materials are highly cohesive (approximately 10 to 15 kPa).

Field measurements of roots at the 15 core and auger sample sites were limited due to the observation methods, but provide an initial indication of rooting depth and the likely cohesive benefits of live vegetation under existing conditions. Only three sites had a density of roots extending over 2.0 ft deep that seemed sufficient to significantly enhance the cohesion of the soil

[2] Apparent Cohesion=the combined effect of electro-chemical bonding within a soil and the cohesion due to surface tension due to unsaturated conditions (for example, the cohesion that is measured with field equipment in-situ).
Effective Cohesion= the cohesive status of the soil material after adjusting to remove the effects of pore water pressure at the time of a measurement.
Pore Water Pressure=the stress transmitted through the interstitial fluids within the soil; increases with saturation that fills pore spaces).
Critical Shear Stress=the minimum shear stress needed to mobilize/erode soil material (primarily based on the non-cohesive particle diameters).
Erodibility Coefficient=A coefficient used to calculate the average erosion distance (into a streambank) based on the 'excess' shear stress (shear stress greater than critical); the coefficient is developed from empirical data.

profile (AA1, C2, E1), while roots extended between one and two feet at most sites. Four sites within swales and remnant channels had rooting depths less than one foot (C3, CD1, D1, D3).

Depth to dense silty clay lacustrine sediments varies across the site, as indicated by its intermittent presence in soil sampling sites (Table 5), by field inspection of the streambed and banks, and review of the 2005 ENTRIX cross-section survey photographs (ENTRIX, 2007 Task 4C2). In some areas it is exposed within the streambed (Figure 10A) and up the streambanks (Figure 10B), and it was encountered in some of the soil auger holes (Figure 11). The elevations of observed lake sediment throughout Reach 5 indicate that these materials are within a few feet of the existing meadow surface only in the downstream portion, between VS 135+00 and 155+00 (Figure 12). The position and fractured condition of lake sediment in the hillslope exposure and at the NRCS data point on the hill east of VS 137+00(Figure 12) may have resulted from fault displacement, relative to the lake sediment elevations under the adjacent valley floor. The known lake sediment elevations underlying the valley floor of Reach 5 do; however, appear to be aligned at a slope similar to the valley surface

The massive fine grained lake sediments have distinctly higher cohesion and hydraulic resistance relative to the overlying sediments and soils. The higher resistance of streambed materials where the lake bed sediment is exposed would alter channel erosion processes, retarding the rate of incision, but favoring widening. The lake bed sediments may also affect local groundwater storage capacity and/or flow rates above that unit. As an indicator of soil groundwater conditions, the level of observed redoximorphic features plotted by valley station and elevation appear to be fairly deep below the ground surface, but close to the underlying lake sediment elevation downstream of VS 155+00 (Figure 14). However, farther up valley the soil redoximorphic features are higher, so the relative effect of other factors on soil groundwater may be more important than the depth to lake sediments.

Figure 10A: Lake Sediment Exposure in Streambed, VS 13700

Figure 10B: Lake Sediment Exposure in Hillslope Cut Bank, VS 137+00

**FIGURE 10: LAKE SEDIMENT EXPOSURES IN STREAMBED AND HILLSLOPE BANK AT VS 137+00**

Figure 11A: Auger Soil Samples at Site C2.

Figure 11B: Subsurface Sediments at Site C2.

**FIGURE 11: REPRESENTATIVE SOIL UNDERLAIN BY LACUSTRINE CLAY**

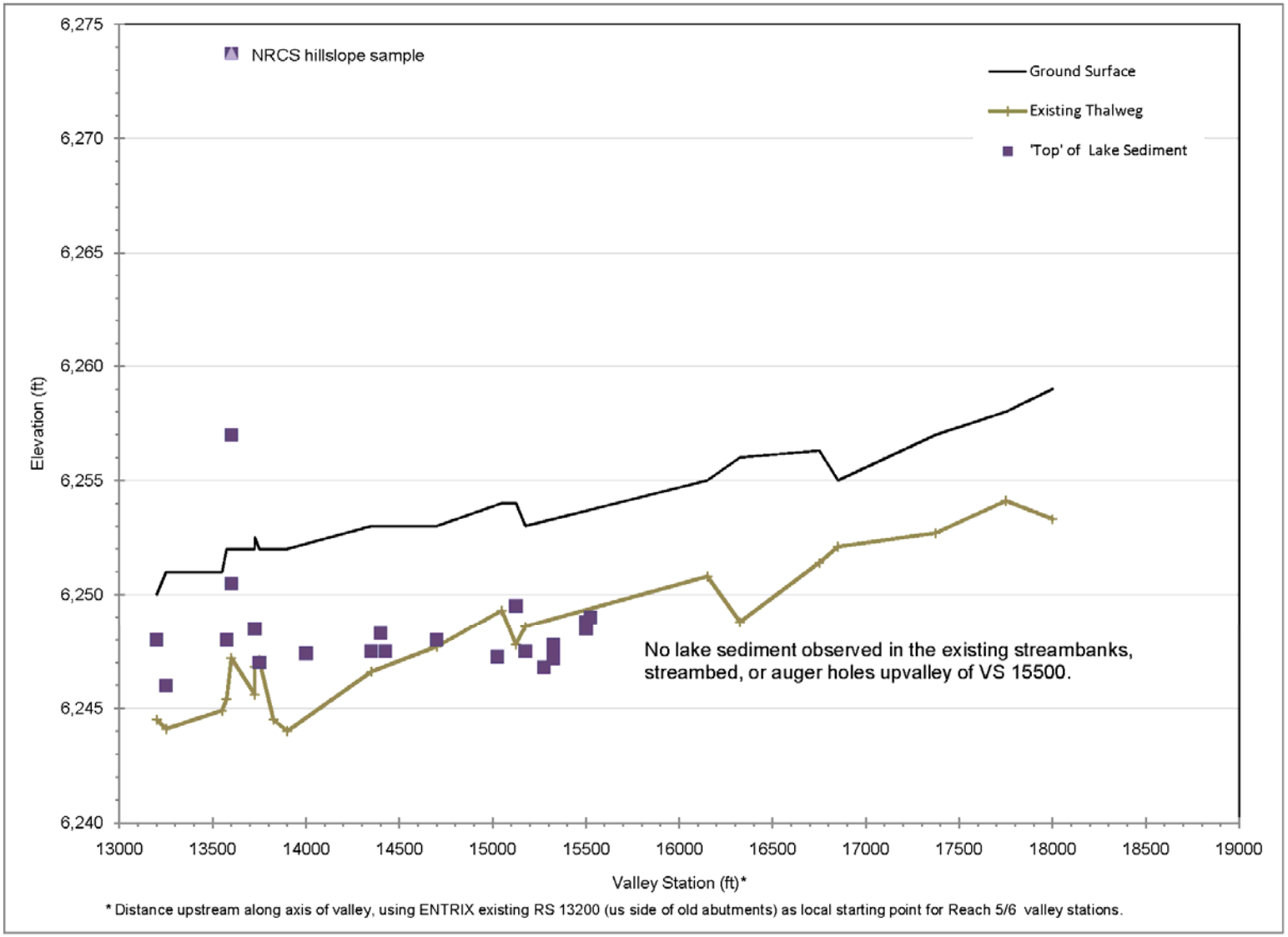



**FIGURE 12: VALLEY PROFILE OF LAKE BED SEDIMENTS AND EXISTING CHANNEL BANK AND BED ELEVATIONS**

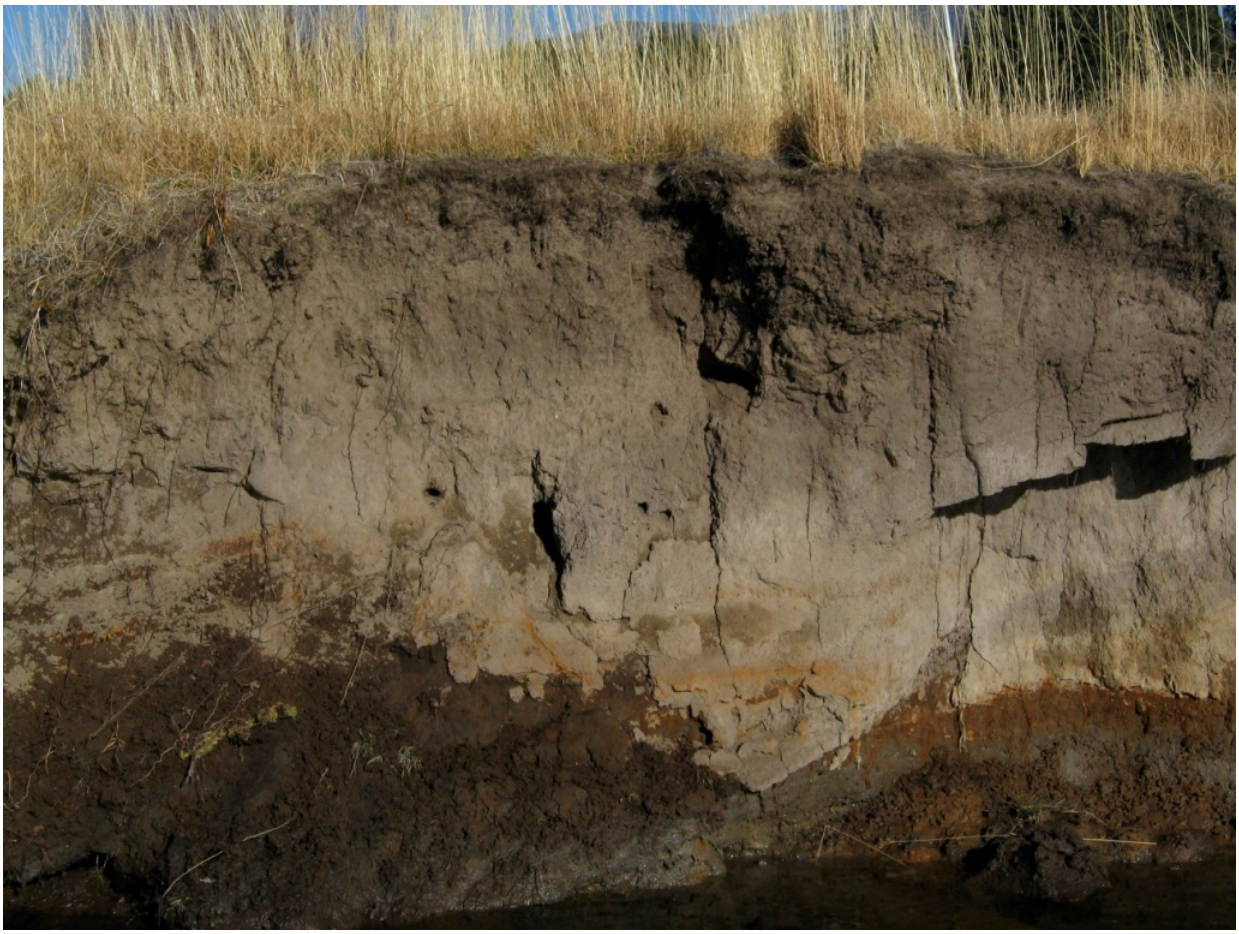


**FIGURE 13: DEFORMED REDOXIMORPHIC FEATURES EXPOSED IN STREAMBANK NEAR RS 155+50**

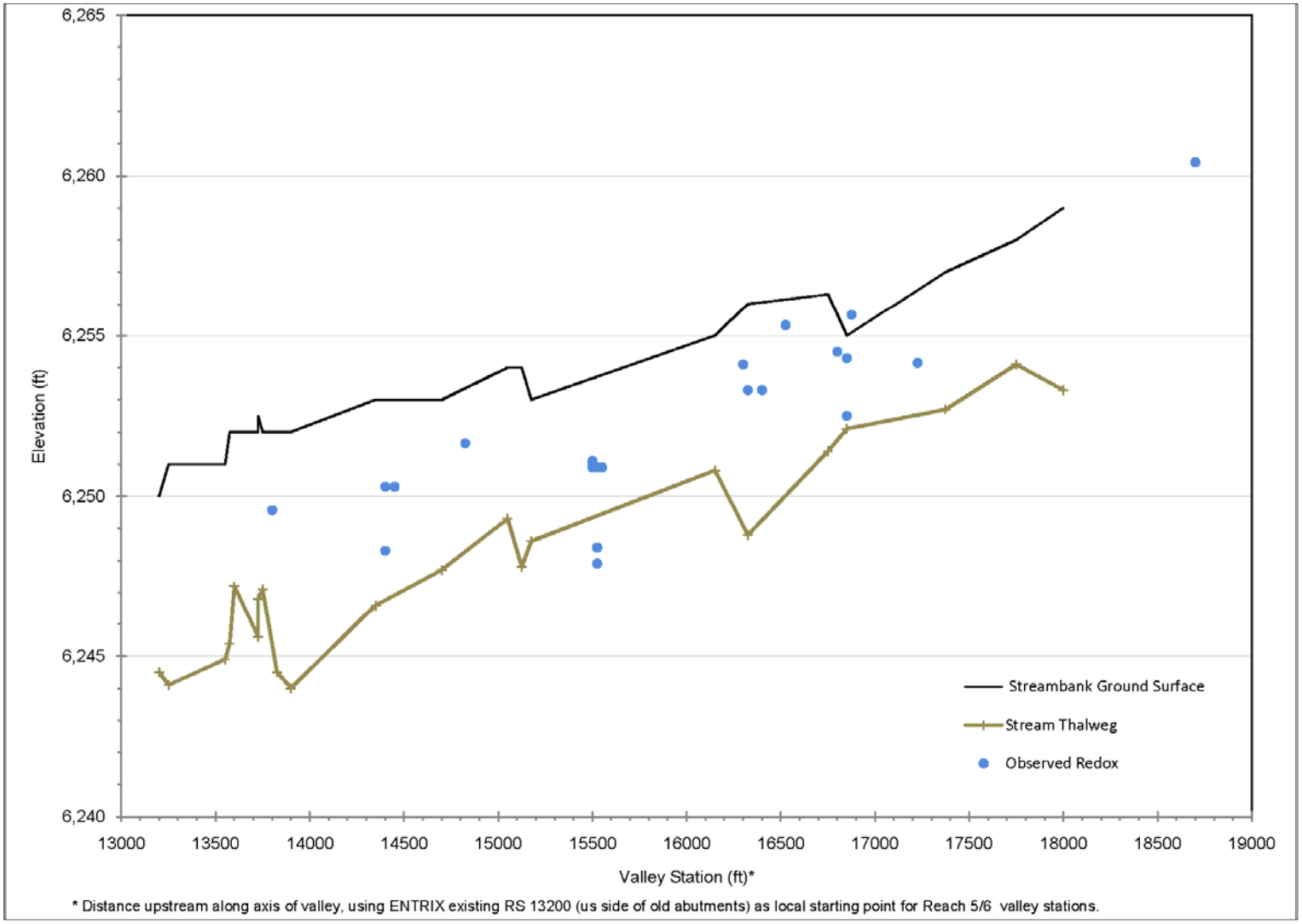



**FIGURE 14: VALLEY PROFILE OF OBSERVED SOIL REDOXIMORPHIC FEATURE ELEVATIONS**

## Groundwater and Surface Water Relations

The geologic and topographic context for groundwater conditions in the project area indicate down valley flow patterns parallel to the surface water as well as seasonal and base discharge of groundwater off the side slopes of outwash and till ridges. This reach of the Upper Truckee River has been characterized (Rowe and Allander 2000) as 'steady' (i.e., neither 'gaining' nor 'losing') which indicates that the groundwater table and surface flow in the river are generally in balance. This reach of the river has relatively low down valley groundwater gradients (10 ft/mile; 0.0019 ft/ft) compared to some upstream and downstream reaches (Rowe and Allander 200). However, the gradients of groundwater flow off the side slopes are higher, particularly the moraine ridge east of the river (170 to 1300 ft/mile; 0.0322 to 0.2462 ft/ft) (Rowe and Allander 2000). The down valley groundwater gradient in the valley is similar to the overall valley floor gradient of 0.00145 (or 0.145 percent).

Materials comprising the surface valley floor sediment are fine grained, but relatively porous and transmissive sandy materials overlying the dense fine grained lake sediments. The lake bed sediment unit likely limits vertical groundwater movement, which may support surface groundwater levels. Its depth and/or orientation may affect down valley gradients. However, the characteristics and position of the lake bed sediments remain poorly documented. Its horizontal extent, depth below surface, orientation, and fissures/fractures may have been modified by fault displacement in the project vicinity. Given the limited knowledge of sub-surface geologic conditions and lack of groundwater monitoring near the downstream end of Reach 5, the following interpretations of observed groundwater should be considered preliminary.

Monitoring of shallow groundwater at several wells within Reaches 5 and 6 (Figure 5) has only occurred over the last four years, but these years happen to include above and below average surface runoff conditions (Figures 15A, B, C, and D). Therefore, analysis of data from these four years provides an opportunity to describe groundwater relationships under a range of surface water conditions.

The observed maximum, minimum, and average groundwater elevations relative to local ground surface elevations at each of the groundwater wells show that annual maxima nearly reach the surface, while annual average levels are at least three to four feet below ground surface (Figures 16A, B, C, and D). The annual range of groundwater elevations between observed maximum to minimum levels is consistently on the order of five to eight feet for all four years. In the wetter year, Water Year (WY) 2006, groundwater maxima reached the surface at most of the monitoring wells, even a couple distal from the river (e.g., GW# 2, GW#8), while the average groundwater level remained 2.5 to 3.5 ft below the surfaces (Figure 16A). WY 2006 may have experienced minor, brief overbank flows during the December 31st storm peak and some sections of the river may have water near the top of bank in May 2006 (Figure 15A), but overbank processes would not have been the dominant recharge process. In the driest year (WY 2007), groundwater maxima only came within one foot of the ground surface at GW#3, #4, and #8 while average levels were 3.0 to 4.6 feet below the surface (Figure 16B). Groundwater maxima in WY 2008 and WY 2009 were slightly higher than in WY 2007and reached near the ground surface despite relatively low runoff volumes, but average levels were similar or slightly lower (Figures 16C and 16D).

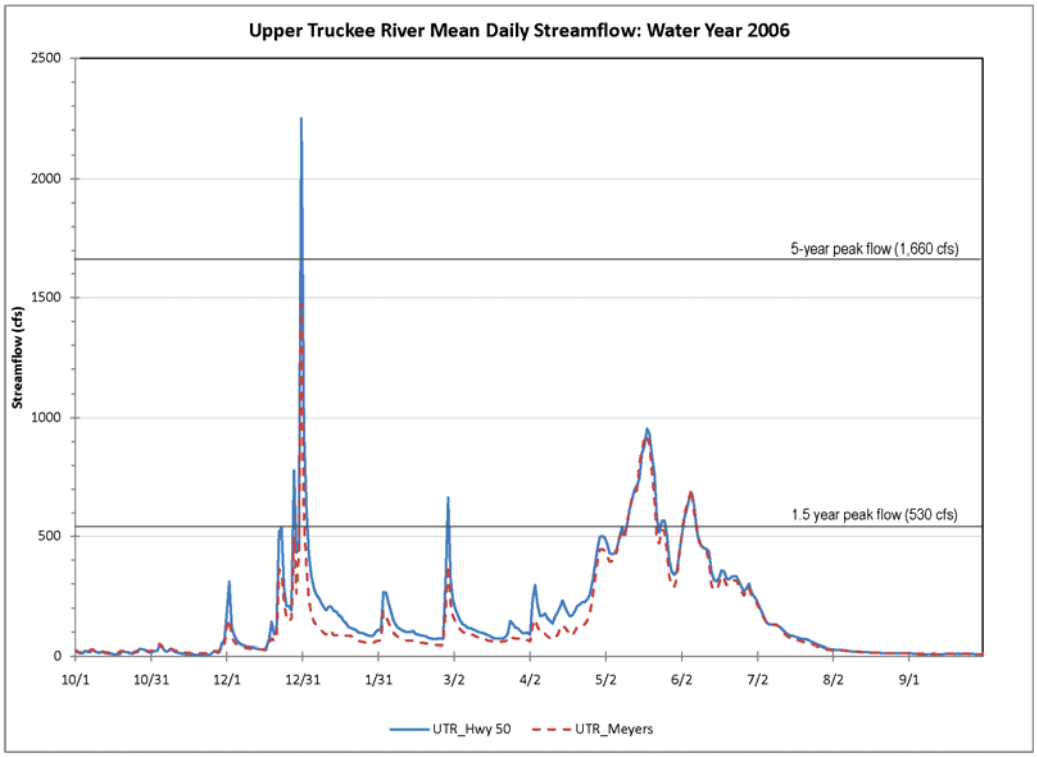



**FIGURE 15A: UPPER TRUCKEE RIVER STREAMFLOW, WATER YEAR 2006**

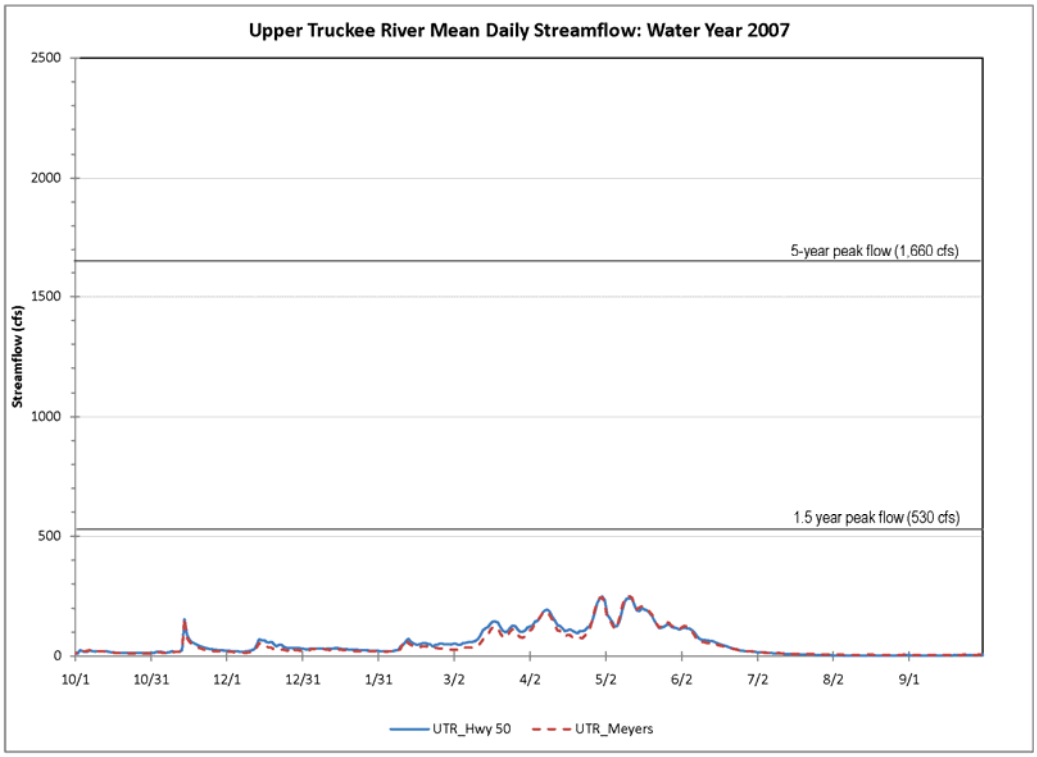



**FIGURE 15B: UPPER TRUCKEE RIVER STREAMFLOW, WATER YEAR 2007**

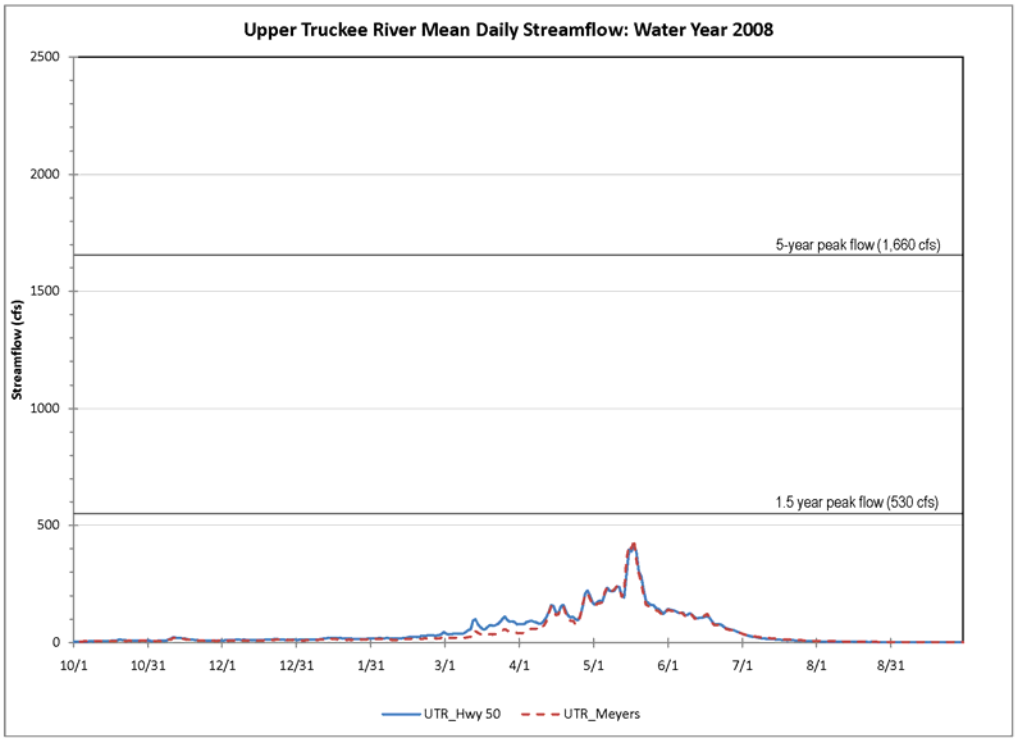



**FIGURE 15C: UPPER TRUCKEE RIVER STREAMFLOW, WATER YEAR 2008**

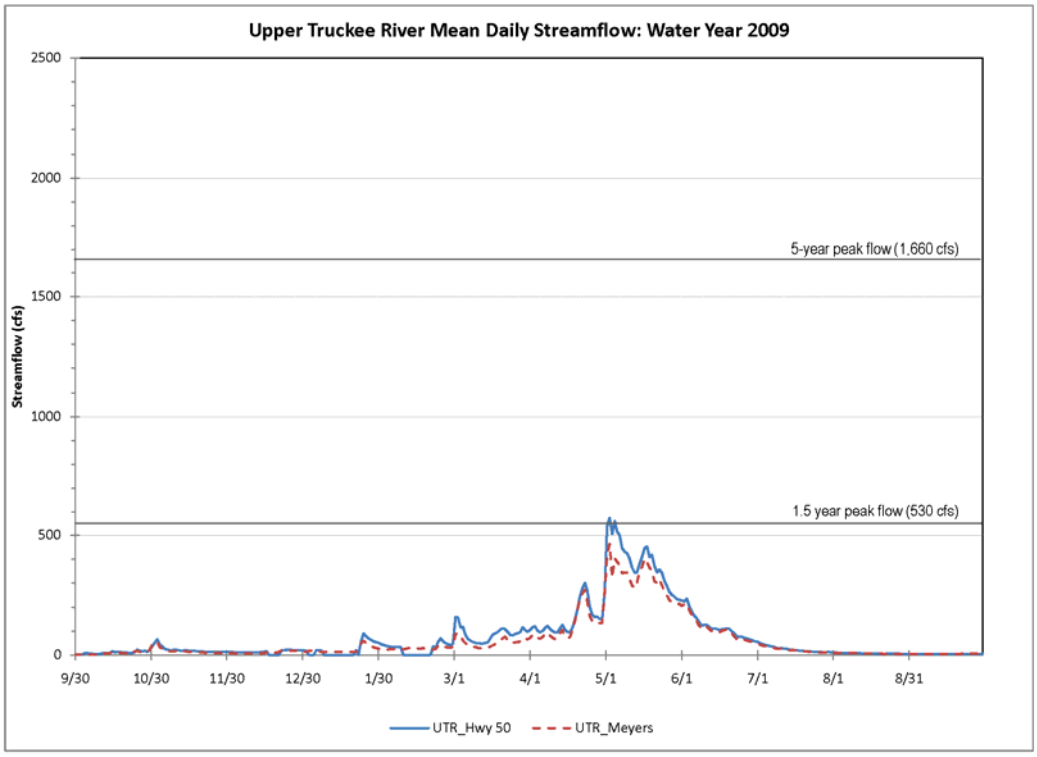



**FIGURE 15D: UPPER TRUCKEE RIVER STREAMFLOW, WATER YEAR 2009**

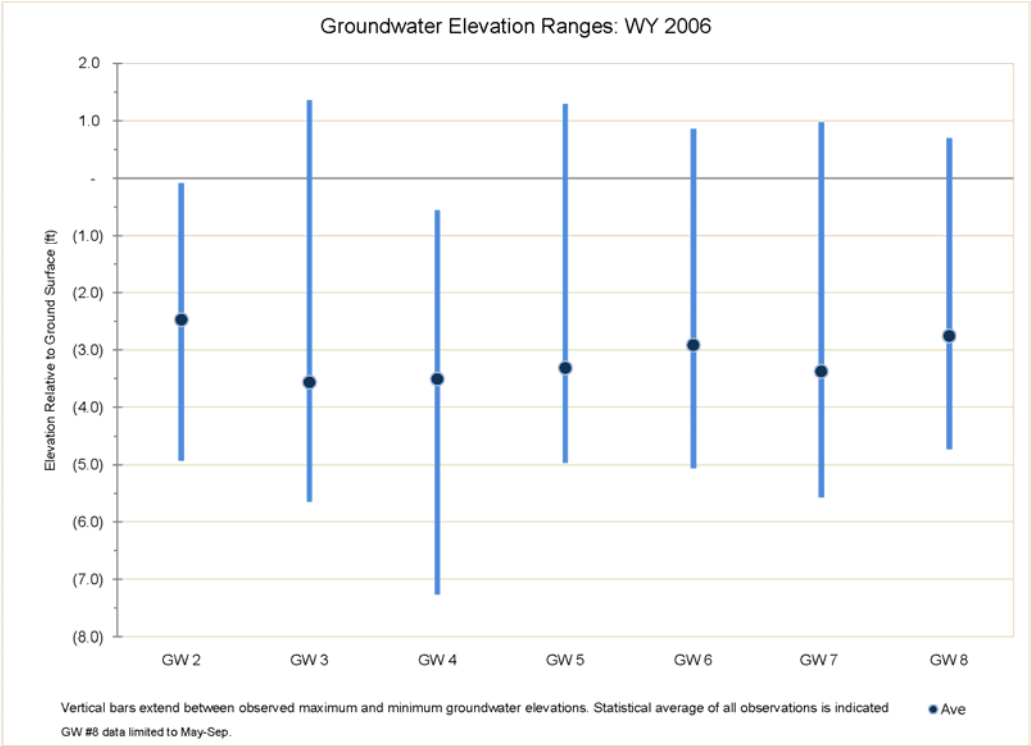



**FIGURE 16A: GROUNDWATER RELATIONS TO GROUND SURFACE, WATER YEAR 2006**

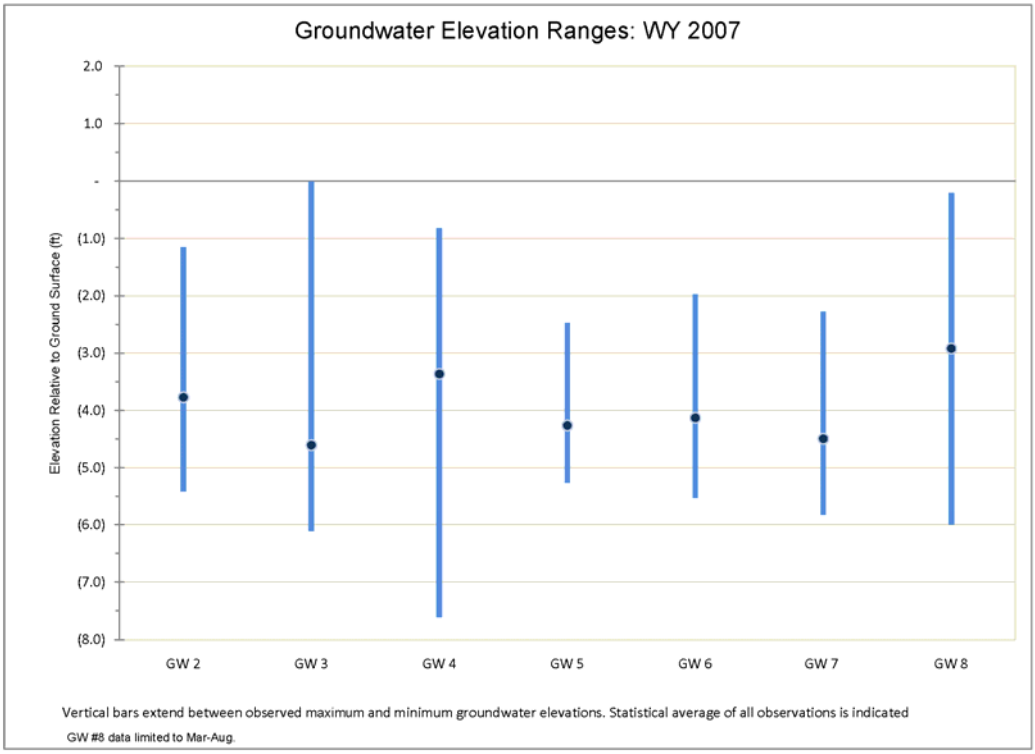



**FIGURE 16B: GROUNDWATER RELATIONS TO GROUND SURFACE, WATER YEAR 2007**

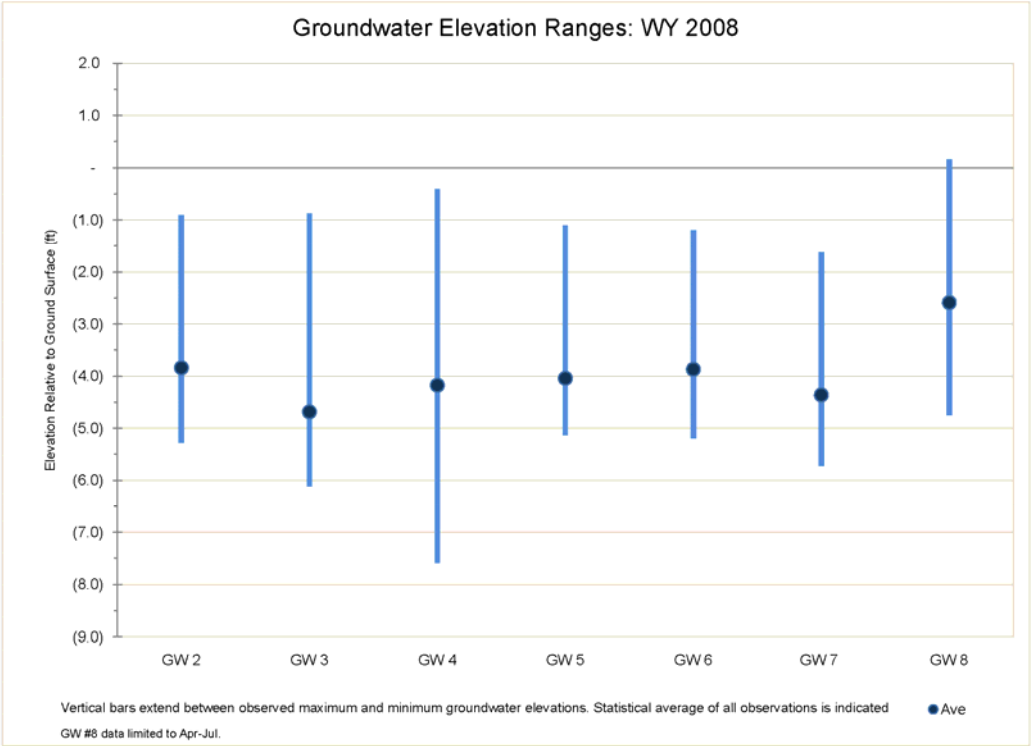



**FIGURE 16C: GROUNDWATER RELATIONS TO GROUND SURFACE, WATER YEAR 2008**

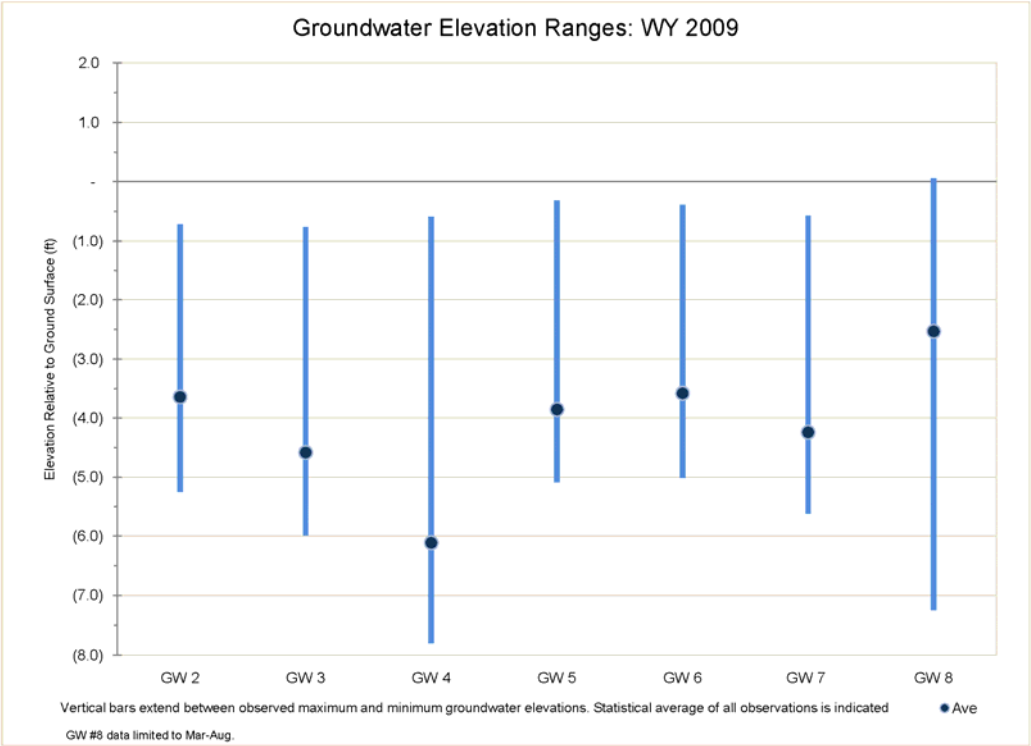



**FIGURE 16D: GROUNDWATER RELATIONS TO GROUND SURFACE, WATER YEAR 2009**

Seasonal groundwater hydrographs of the monitoring wells provide a temporal comparison with the stream flow hydrographs and facilitate review of absolute and relative elevations between and within the two well transects (Figures 17A, B, C, and D). All of the wells display high short-term variability within their seasonal range, a nearly synchronous response to the streamflow hydrograph (Figures 15A, B, C, and D) and little or no delay in well response at increasing distance across the valley. As might be expected, GW# 2 and #4 have the smallest short-term signal from surface runoff and the highest absolute groundwater elevations due to their position on the valley margins at the upstream transect (i.e., they receive groundwater from the side slopes too). However, even these wells have general seasonal hydrographs that mirror the surface runoff. The rapid and consistent groundwater response to the surface water regime supports an interpretation of uniform, relatively high transmissivity near-surface sediment. The seasonal maxima reached in each transect is relatively similar for all four years, and the down valley gradient is also consistent.

Groundwater levels at the monitoring wells remain low through fall each year until rainfall runoff begins, with the exception of GW #4, which tends to begin rising prior to the streamflow hydrograph (Figures 17A,B,C, and D). Groundwater elevations peak during winter and early spring and remain near their annual maxima until the stream runoff peak has passed, when they recede rapidly.

The seasonal groundwater hydrograph recessions illustrate that losses are highly controlled by surface water despite varied WY conditions. In WY 2006, all the groundwater hydrographs begin a seasonal decline in early June, about a week after the last streamflow peak. In WY 2007, all the groundwater hydrographs begin seasonal recession in early May, coincident with the last minor peak in streamflow. In WY 2008, the groundwater hydrographs begin to fall in early April, with a minor recovery before full seasonal recession that matches a small increase in surface runoff in late May. In WY 2009, groundwater hydrographs also begin to fall in early April, but again experience a brief recovery in early May at the time of a small surface runoff increase. In all cases, the end of the surface runoff season represents the end of high groundwater levels, and the rate of groundwater decline is rapid. Groundwater levels have lowered to their annual minimums by late July or early August in all years, at all wells.

To evaluate the potential groundwater support to vegetation capable of resisting erosion from surface flows and enhanced removal of fine sediment, it is useful to consider the groundwater data in the context of the growing season and of groundwater depths that have been observed in other functional meadows. The growing season at the project site might be defined as beginning around June 15, based on a 50 percent likelihood of temperature below 28 degrees F. However, native vegetation is likely more tolerant of frost than agricultural plants, and the growing zones at the leaf bases of the sedges and rushes (which are more sensitive to low temperature than the aerial parts of the leaves) are located below the organic/duff layer. Therefore, the temperature-defined growing season could reasonably be deemed to extend from about June 1 to September 30. It is possible that under the present degraded conditions, the functional growing season for desired meadow vegetation ends somewhat earlier (August 31 or earlier) than the temperature defined growing season as a result of the lack of sufficient soil moisture.

Data from various sources suggest that to support vigorous growth of wet meadow vegetation dominated by strongly rhizomatous species (e.g., *Carex nebrascensis, Juncus balticus*), the depth to groundwater must be less than two feet, preferably less than one foot, through a significant portion of the growing season (LTBMU, 2009; Oehrli, 2010). There is a close correlation between occurrence of redoximorphic features within 12 inches of the soil surface and the presence of vigorous wetland vegetation. This is consistent with the USACE wetland delineation criterion of saturation within 12 inches of the mineral soil surface for a significant period during the growing season, and with literature pertaining to the capillary fringe (Tiner, 1999, and other references cited therein). Some engineering and hydrogeological literature has shown a capillary rise more than one foot (Fetter, 2001; Lu and Likos, 2004), this is of questionable relevance to wetland restoration.

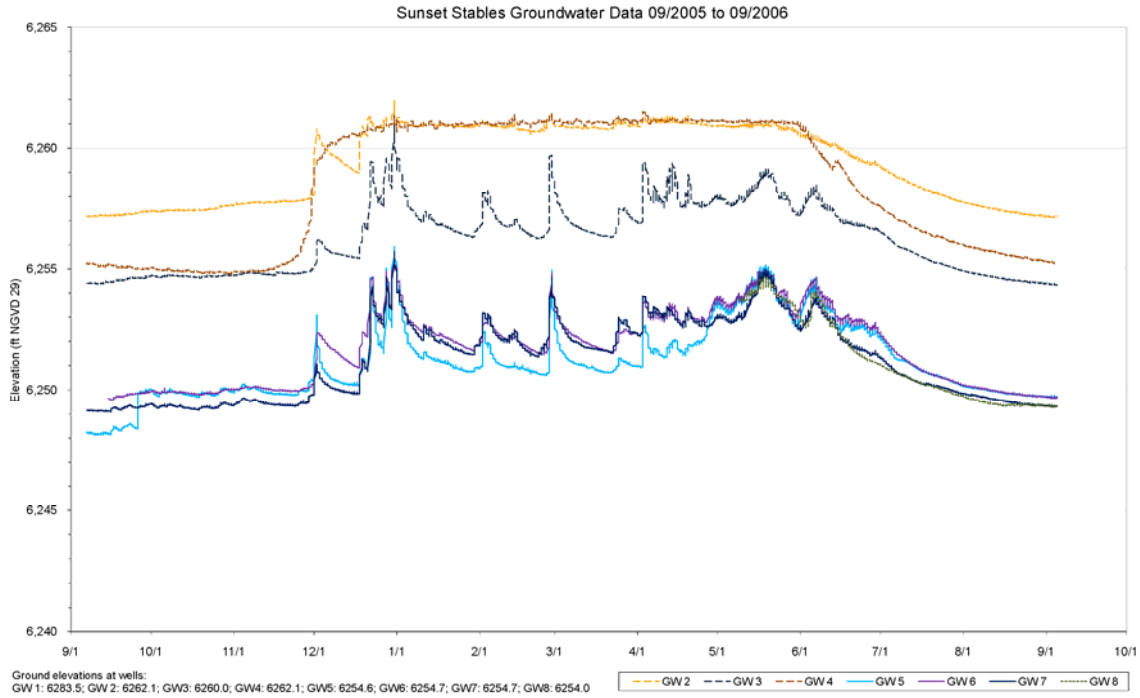



**FIGURE 17A: GROUNDWATER ELEVATION HYDROGRAPH, WATER YEAR 2006**

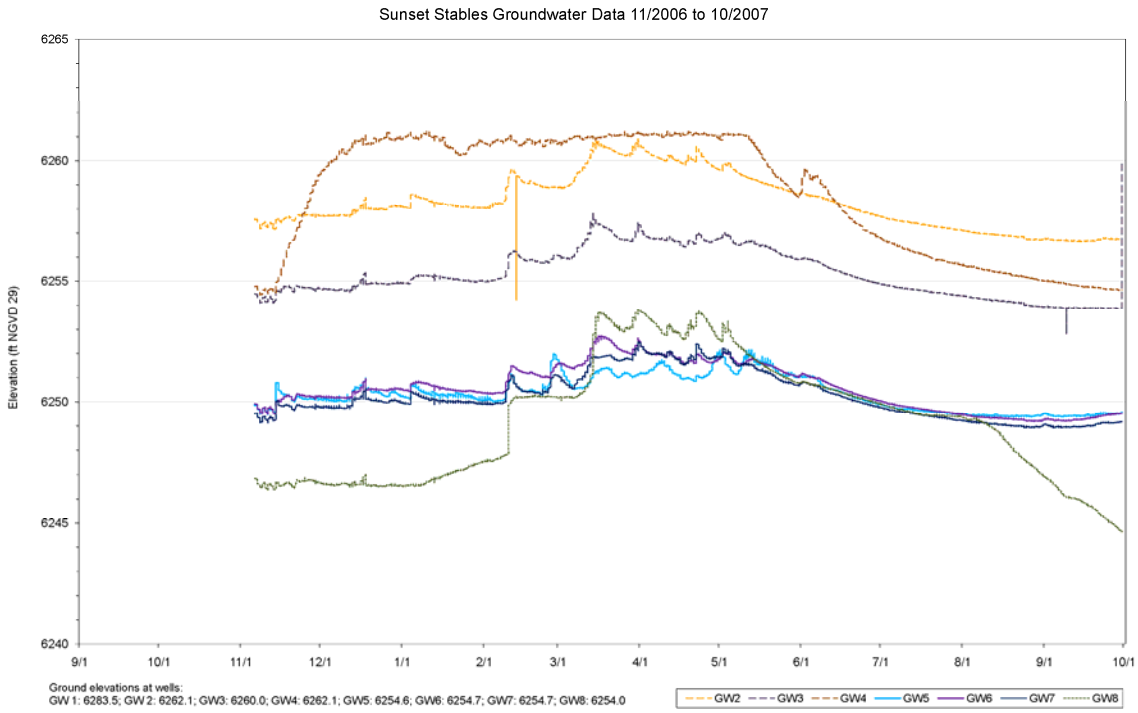



**FIGURE 17B: GROUNDWATER ELEVATION HYDROGRAPH, WATER YEAR 2007**

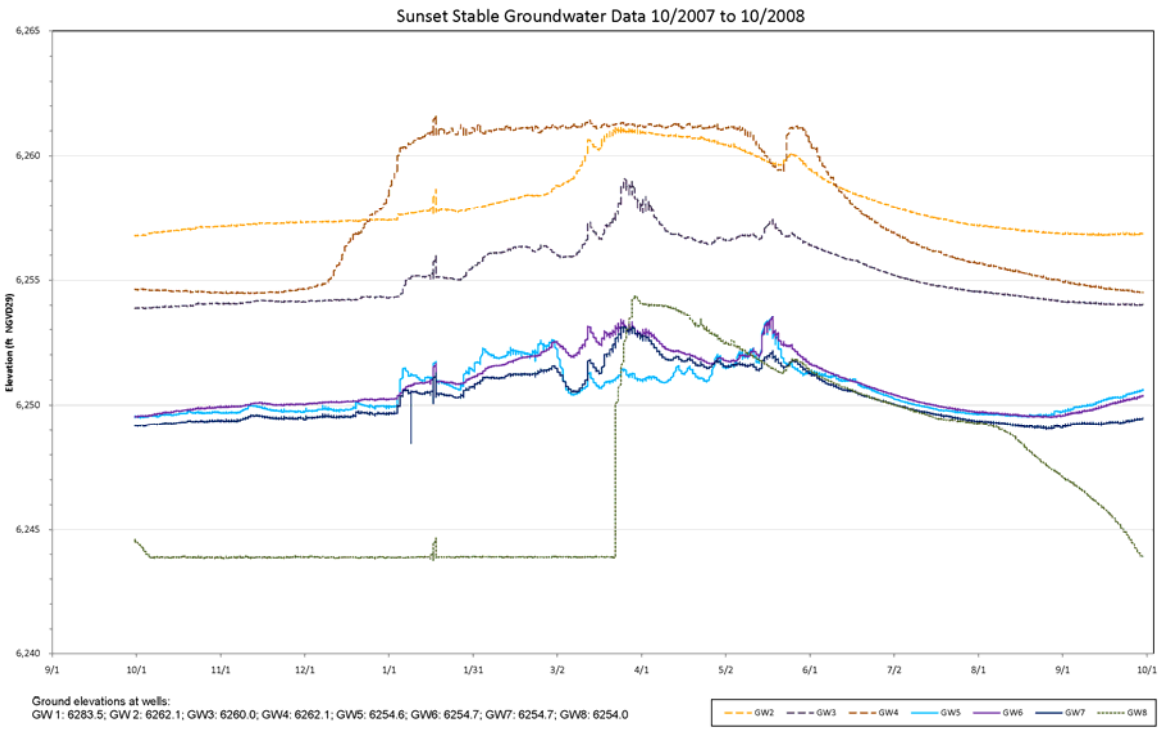



**FIGURE 17C: GROUNDWATER ELEVATION HYDROGRAPH, WATER YEAR 2008**

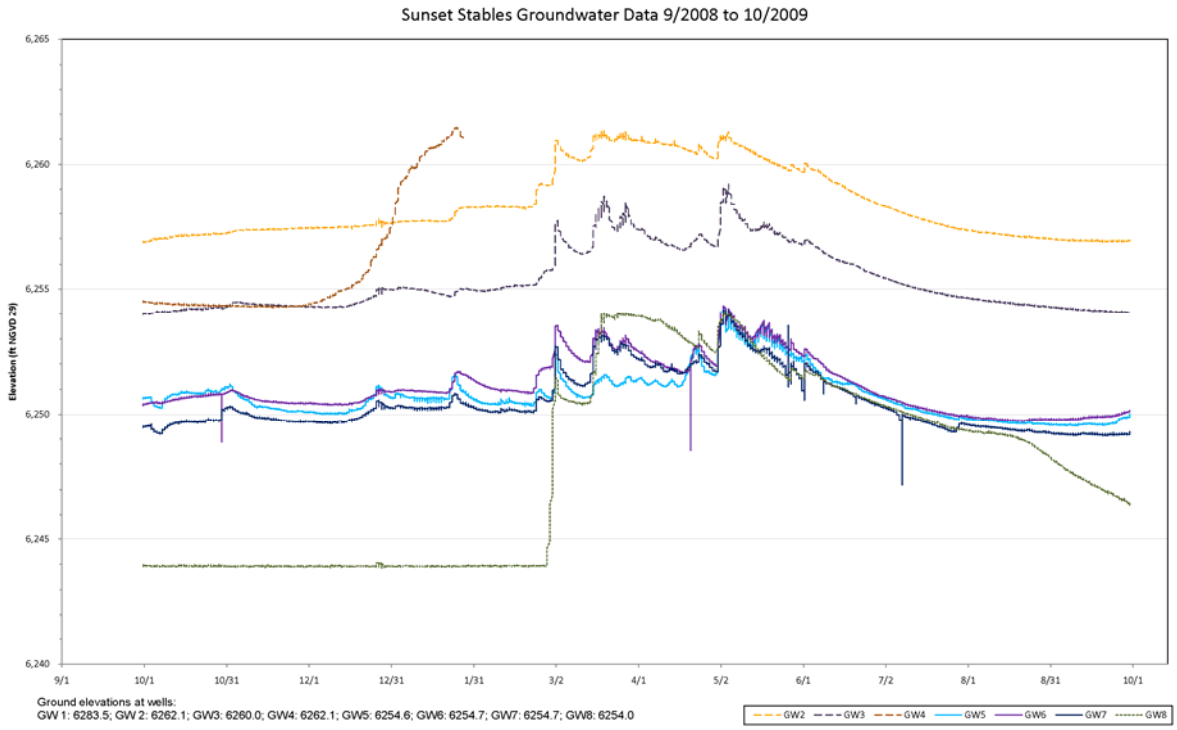



**FIGURE 17D: GROUNDWATER ELEVATION HYDROGRAPH, WATER YEAR 2009**

The groundwater data from the project area wells indicate that at least for the range of runoff years represented by recent monitoring, groundwater levels during the core of the growing season are unlikely to support shallow rooted vegetation and/or wet meadow vegetation, and that the rate of groundwater recession is so rapid that it may even be detrimental to the successful natural colonization of deep rooted woody riparian species (although intentionally planted cuttings can be successfully established by various means).

Further corroboration of the interpretation of the calculated average groundwater depth (Figures 16A, B, C, and D) effects on the existing ecosystem vegetation is provided by the observed depth to redoximorphic indicators. Active redoximorphic features, such as the ones noted in our soil studies, are typically correlated with the occurrence of seasonally peak saturation during the growing season, specifically with the zone where saturation is present at the early part of the growing season and absent later (Hurt and Vasilas, 2006; Vepraskas and Sprecher, 1997).

The role of the existing channel bed elevation in controlling minimum groundwater levels in the study area has previously been suggested, but not quantitatively established. Recent monitoring data verify the degree and consistency of this effect over a range of surface water conditions (Figures 18A and B). At the upstream well transect in Reach 6 (GW # 2, 3, 4), maximum and minimum groundwater elevations are compared to the closest surveyed channel thalweg (approximate VS 181+50, ENTRIX XS # 20) (Figure 18A). Maximum groundwater levels display just a small amount of year-to-year variability regardless of surface runoff, but minimum elevations are consistent year-to-year and in relation to the local river thalweg. These patterns are also seen in the data at the well transect in Reach 5 (GW # 6, 5, 7, and 8), when compared to its closest surveyed channel thalweg (approximate VS 155+50, ENTRIX XS #12) (Figure 18B). The rate of groundwater recession and its close temporal link to the surface water recession, along with the consistent control of the local river thalweg elevation on minimum groundwater elevations are key factors to consider relative to a proposed new channel. It is uncertain whether adding more water (via overbank flooding) to recharge/surcharge the adjacent meadow during snowmelt season would necessarily increase total water retained following the end of snowmelt season. In each of the last few years the local aquifer nearly 'fills' from surface runoff (streamflow and off side slopes) and local snowmelt over the range of water year types without overbank flows. While improved surface water recharge/surcharge could be beneficial, the more critical factor appears to be the streambed elevation. If the streambed elevation is not raised, the groundwater levels after snowmelt runoff ends and through the growing season should not be expected to increase beneficially, since the effect of the existing thalweg elevation on minimum groundwater levels is very pronounced.

The final topography and sediment properties of the backfilled existing channel may have a substantial effect on groundwater conditions within the site, and it is recommended that the particle size distributions, degree of compaction and overall stratigraphy of the backfill be supportive of desired conditions and prevent adverse consequences.

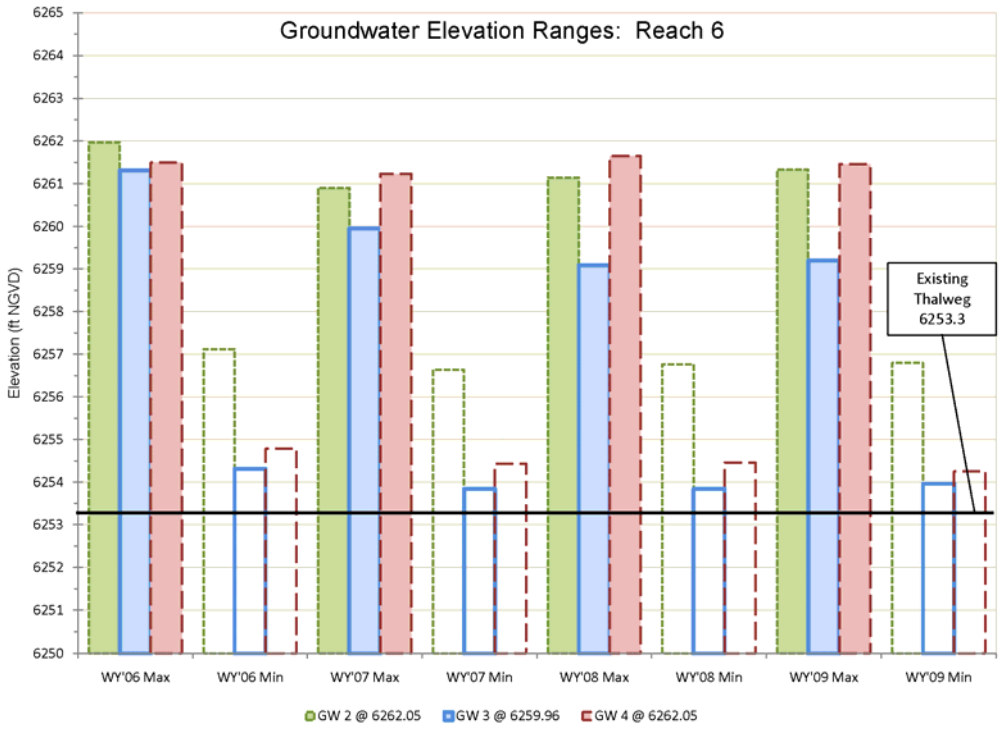
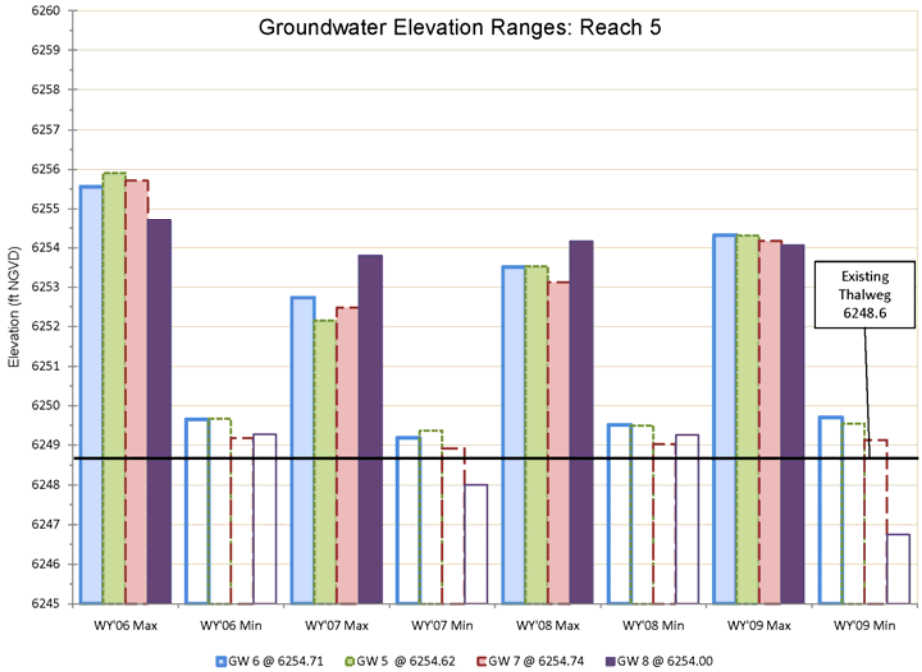



**FIGURE 18A: GROUNDWATER ELEVATIONS AT UPSTREAM WELL TRANSECT, WY 2006-2009.**




*Missing seasonal data at GW#8 record obscures interpretation of statistics for that site.

**FIGURE 18B: GROUNDWATER ELEVATIONS AT DOWNSTREAM WELL TRANSECT, WY 2006-2009**

## Channel and Floodplain History

The highly uniform and fine sandy texture of the surface soils and the silty clay subsurface lacustrine sediment across a very flat valley floor are indicative of low-velocity/slack water depositional environments. Although pit and trench studies could reveal differently, streambank exposures and the grid of core and auger samples to-date provide limited evidence of recent alluvial dynamics. There are some, but not extensive distinct remnant channel segments and a limited number of alluvial deposits outside the active channel corridor within the Project area. Along the valley margins, colluvial reworking of till and outwash slopes have delivered some coarser materials and isolated boulders to the valley floor. Streambed materials measured within Reach 5 by Simon and Others (2003) and by ENTRIX (2007) range from coarse sand to coarse gravel, with little or no observed materials in the cobble/boulder range. In some locations near the downstream end of the reach, the streambed is comprised of the lacustrine sediment, partially overlain by sand and gravel. Further upstream (i.e. Reach 6 and particularly in and beyond the State Parks Reach), streambed materials are coarser in both their median particle diameters (gravel to cobble) and in the maximum particle sizes (cobble to boulder). The natural valley slope break and change in depositional environment from outwash delta to outwash/lacustrine plain above Reach 6 may have limited coarse sediment delivery downstream to Reach 5. It is also possible that human disturbances to bed continuity (e.g., grade control structures, bridge footings, low water crossings) may have modified historic down valley transport of coarse bed materials except during major flood events. These general observations support an interpretation of the dominant context for river processes in this reach as very low gradient, low energy alluvial re-working of the late Pleistocene/early Holocene lacustrine and fine grained outwash deposits.

The following discussion highlights some of the observable, measureable characteristics of the valley floor, channel, and floodplain features as a basis for both interpretation of channel history and guidance for suitable channel design.

### Valley Characteristics

Reach 5 spans about 4500 feet of valley length (VS 132+00 to 177+00) and its valley width averages 926 feet (Figure 19 and Table 7). The portion of valley floor area accessible to the UTR was reduced by the construction of the airport in 1958). The airport runways extended onto the valley floor primarily encroaching on the northwest side and southwest corner of Reach 5 (Figure 19). This reduced the area of valley floor available in Reach 5 by about 28 percent and modified the valley alignment. The valley width remains over 1,300 feet in some sections but was dramatically reduced in others, particularly near the downstream end of Reach 5 where the former 1,292 feet wide valley is constrained to just 140 feet. A several hundred feet reduction in valley width extends up valley to about VS 150+00 and another substantial constriction is at the Reach 5 and 6 transition (VS 172+00 to 177+00) (Table 7).

In comparison, Reach 6 has an existing valley width averaging 565 feet and under 1,000 feet at the widest. Reach 6 is most constrained at its upstream end by the US U.S. Hwy 50 bridge crossing (less than 100 ft). The historic confinement at the upstream end of Reach 6 by the bridge and road crossing occurred before 1940. Prior to airport construction, the average valley width of Reach 6 was 706 feet, as some areas near the transition to Reach 5 were 1,000 to 1,400 feet wide.

**TABLE 7: UPPER TRUCKEE RIVER VALLEY AND CHANNEL CHARACTERISTICS IN REACH 5***

| Valley Station | Pre-1960s Valley Width | 1969-2003 Valley Width | Historic Reduction in Width |
|---|---|---|---|
| (ft) | (ft) | (ft) | (%) |
| 13200 | 1,292 | 140 | 89.16 |
| 13700 | 1,503 | 803 | 46.6 |
| 14200 | 1,559 | 1,034 | 33.7 |
| 14700 | 1,726 | 1,312 | 24.0 |
| 15200 | 1,340 | 1,219 | 9.0 |
| 15700 | 1,314 | 1,309 | 0.4 |
| 16200 | 1,187 | 1,182 | 0.4 |
| 16700 | 1,070 | 1,113 | 0 |
| 17200 | 937 | 646 | 31.1 |
| 17700 | 1,039 | 506 | 51.3 |
| Total | | Averages (length-weighted) | |
| 4500 | 1,297 | 926 | 28.6 |

* Reach 5 extends from VS 132+00 to 177+00.

## Channel Characteristics

As its been previously reported, no substantial planform changes occurred historically (since the earliest aerial image in 1940) in either Reach 5 or 6 of the Upper Truckee River (Figure 19). The river position has been very consistent in all historical images since 1940. However, only general analysis of the planform adjustments and/or potential controlling factors has been completed. The only obvious changes to planform in Reach 5 appear to be located near direct disturbances, such as lateral confinement from airport construction near VS 132+00, and channel straightening and riprap placement by the airport near VS 167+00. Within Reach 6 the planform has been somewhat dynamic from VS 207+00 to 182+00, downstream of the U.S. U.S. Hwy 50 bridge (which has had several replacements / modifications over the years), downstream of placed riprap, and on either side of the low water crossing.

As expected from the limited planform changes, the main channel length in Reach 5 has remained within a small range (8,070 to 8,405 feet) since 1940 (Table 8). However, variations in the presence and length of secondary channels occurred, as low flow channels crossing active channel bars were obvious in the 1950s and 1960s photos, but are very limited in other historic images. These minor planform differences may reflect changes in the area of active point and mid-channel bars and related decreases in coarse sediment loads (discussed below). As of 2003, the main channel length in Reach 5 (only) is 8,233 feet over 4,500 feet of valley length (Table 7), for an average sinuosity of 1.83 and an overall channel slope of 0.13 percent. While the average channel slope is consistent in Reach 6 (0.13 percent), other characteristics differ: the main channel length is 4,630 feet over a valley length of 3,000 feet, for an average sinuosity of 1.54 (and the valley floor slope of 0.205 percent is greater than the 0.17 percent valley floor slope in Reach 5).

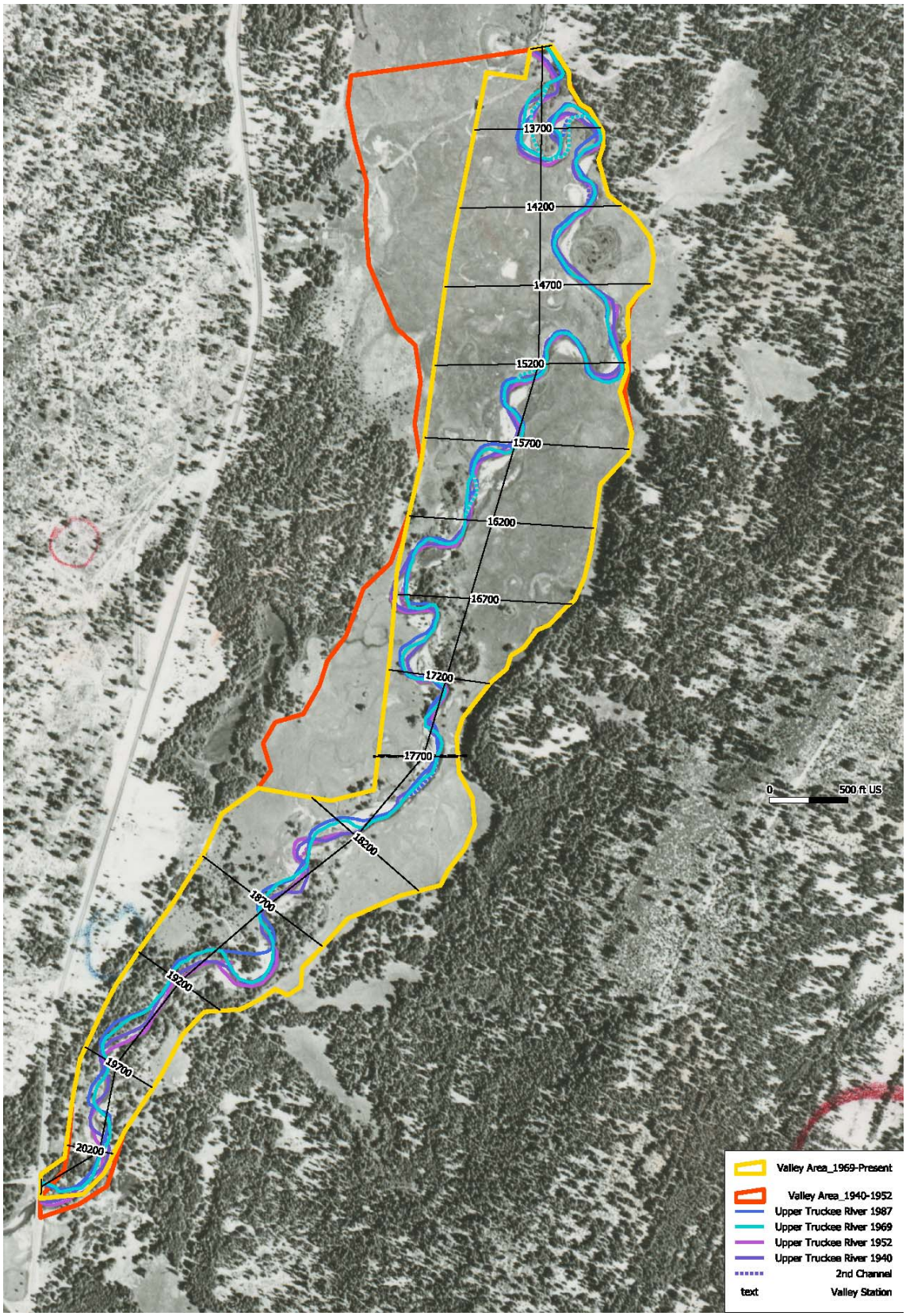



**FIGURE 19: HISTORICAL UPPER TRUCKEE RIVER POSITION AND AVAILABLE VALLEY AREA**

### TABLE 8: HISTORIC UPPER TRUCKEE RIVER CHANNEL LENGTH IN REACH 5 *

| Channel Type | 1940 | 1952 | 1969 | 1987 | 2003 |
|---|---|---|---|---|---|
| | ft | ft | ft | ft | ft |
| Main Channel | 8,070 | 8,149 | 8,298 | 8,405 | 8,233 |
| Secondary Channel (s) | 192 | 623 | 1,466 | 259 | 681 |
| Total | 8,262 | 8,773 | 9,764 | 8,664 | 8,915 |

* Between the channel crossing within the Airport reach at ENTRIX RS ~ 132+00 and the upstream end of Reach 5 near the south end of the runway; centerline length measured in GIS on rectified aerial imagery taken during 2003 mid-summer season (July/August)

The average width of the summer (low flow) channel has been consistent on all historic aerials with average and median widths of summer water surface between 48 and 51 feet on the 1940, 1952, 1969, and 2003 images. However, the average width of the active channel (identified on aerial images as the total width between banks when unvegetated point bar deposits are included) has been decreasing historically (95 feet in 1940; 86 feet in 1952; 72 feet by 1969 and 58 feet as of 2003). This information differs from some of the past qualitative statements that the reach is experiencing channel widening. However, it is consistent with prior descriptions of a vegetated, incipient floodplain developing 'behind' point bars within the incised terrace banks (TRCD, 2003; ENTRIX 2004b). It seems likely that widening may have happened in the early historic period (pre-1940) after initial incision and also that some localized widening has continued to occur in recent decades, but not reach-scale widening. The decreasing width and area of exposed unvegetated bar deposits could be attributed to vegetative stabilization of previously unvegetated point bar surfaces, but net removal of channel sediment may also have occurred particularly since the trend begins well before grazing pressure declined (peak area of in-channel deposits in the 1952 image—decreasing since then as shown in Table 9).

### TABLE 9: HISTORIC UPPER TRUCKEE RIVER ACTIVE CHANNEL DEPOSITS IN REACH 5*

| Channel Deposit Type | 1940 | 1952 | 1969 | 1987 | 2003 |
|---|---|---|---|---|---|
| | $ft^2$ | $ft^2$ | $ft^2$ | $ft^2$ | $ft^2$ |
| Point Bars | 182,095 | 214,068 | 169,371 | 154,741 | 36,795 |
| Mid-Channel/Traverse | 4,626 | 34,833 | 18,001 | 0 | 0 |
| Total | 186,721 | 248,901 | 187,373 | 154,741 | 36,795 |

* Between the channel crossing within the Airport reach at ENTRIX RS ~ 13200 and the upstream end of the airport runway, about VS 180+00 ; surface area measured in GIS on rectified aerial imagery taken during 2003 mid-summer season (July/August)

The presence (visible areas) of point bar and middle channel bar deposits measured as surface area declined from relatively consistent values in 1940, 1952, and 1969, dropping modestly by 1987 and dramatically by 2003 to around 19 percent or less of the historic condition (and mid channel / traverse bars were essentially gone as of 1987 and 2003) (Table 9). While aerial image interpretation could not determine whether the volume and/or elevation of channel deposits changed, the large decrease in surface area suggests that the volume and/or elevation of unvegetated channel deposits was reduced, since the low flow channel width and flows have remained similar. A portion of the most recent decrease of unvegetated bars could be a result of reduced grazing pressure since closure of the Sunset Stables equestrian center around 1999 (Joe Pepi Pers. Comm. 2010). Other potential influences on the extent of exposed channel deposits could be those that directly decreased coarse sediment supply. The timing and magnitude of these factors is not well documented, but could include: upland forest recovery once Comstock Era logging ended and fire suppression was practiced; and/or, reported in-channel gravel extraction that occurred upstream in Reach 6 near the U.S. Highway crossing (Joe Pepi Pers. Comm. 2010).

### Floodplain Characteristics

Examination of the 2003 topographic data and all historic aerial images identified RCs and RFs across the floodplain (Figure 20). All of the features in 2003 are visible and have similar characteristics on all the historic images, with the exception that the RFs entering the river near RS 133+00 only becomes distinct after construction of the airport. All other RCs and RFs are present as of the 1940 image and only display minor changes in vegetation cover, particularly increased density of conifer cover along a couple of the remnant channels.

As noted by ENTRIX (2004), the remnant channel features have long intervening areas without apparent prior planform connection evidence. The remnant channel segments are oriented somewhat randomly without any obvious modern drainage connections. One or two large distinct remnant channel segments with tight radius curves and woody vegetation margins occur east of the main channel, the largest near RS 160+00 and the other is the southwest remnant near RS 205+00, Figure 20). The other remnant channels are topographically more distinct than the return flow swales and infilled with organic-enriched fine sediment, but have only limited woody vegetation along flow margins and very few areas with visible coarse sand or gravel deposits.

The return flow swales are shallow and have modern connectivity, oriented to drain down valley off the floodplain to the channel. They have varied width and depth, but generally lack sand or gravel deposits and are sparsely vegetated. The width, depth, and extent of the return flow swales is consistent on all the historic images, with the exception of downstream (north) end of the return flow swale along the airport by RS 133+00. A portion of this return flow swale drainage area was directly covered over by airport construction between the 1952 and 1969 image. The downstream portion of the swale subsequently modified its main flow path.

There are small areas of the floodplain (outside the active channel margins) that are unvegetated under existing conditions, including a few sites with scour/erosion, and some overbank deposits and remnant channel fills (i.e., soil site D4). However, analysis of the historical imagery and the field observations indicate little or no recent erosion or deposition has occurred. For example, there are no visible effects of the flood-of-record in January 1997 flood event in terms of deposits or scour outside the main channel. The overall trend on the floodplain has been one of vegetative 'recovery' of barren areas since the peak of unvegetated conditions in the 1950s (Table 10).

**TABLE 10: HISTORIC UNVEGETATED FLOODPLAIN FEATURES IN REACH 5***

| Floodplain Feature | 1940 | 1952 | 1969 | 1987 | 2003 |
|---|---|---|---|---|---|
| | $ft^2$ | $ft^2$ | $ft^2$ | $ft^2$ | $ft^2$ |
| Sediment Deposits | 22,263 | 22,363 | 20,467 | 18,163 | 13,719 |
| Erosion Scour | 5,411 | 5,679 | 10,033 | 4,706 | 3,323 |
| Other Unvegetated | 80,920 | 79,314 | 5,719 | 1,665 | 1,934 |
| Trails | 32,189 | 356,258 | 92,269 | 34,225 | 0 ** |
| Total | 140,783 | 463,615 | 128,488 | 58,759 | 18,976 |

* Between the channel crossing within the Airport reach at ENTRIX RS ~ 13200 and the upstream end of the airport runway, about VS 180+00 ; surface area measured in GIS on rectified aerial imagery taken during 2003 mid-summer season (July/August).
** Although some narrow unvegetated trails may have existed as of 2003, no unvegetated trails were wide enough to be detected on the 2003 imagery using the same visual analysis technique that was applied to all the other years of historic images.

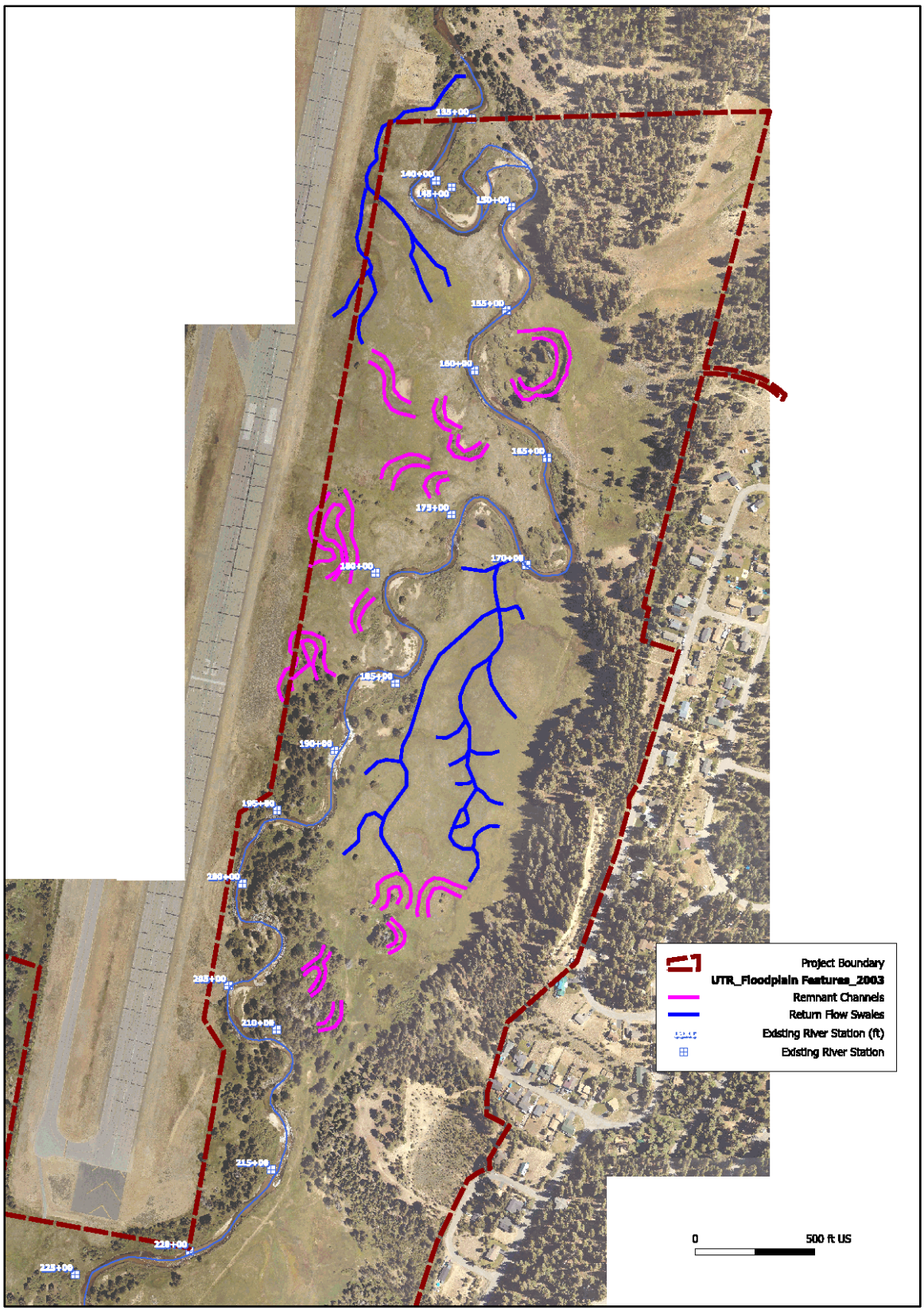



**FIGURE 20: REMNANT CHANNELS AND RETURN FLOW SWALES IN REACH 5**

Comparing the locations and extent of unvegetated surfaces along the main channel (Table 9) and on the floodplain (Table 10) digitized from each of the historic images permits identification of trends (Figure 21 A, B, C, D, and E). Some direct human floodplain disturbances are evident in certain images, such as the valley road crossing downstream of Reach 5 in 1940 and 1952 (Figures 21A and B), the pipeline alignments in 1969 and 1987 (Figures 21C and D), and the airport margin riprap protections in 1969 (Figure 21C). However, traces of such direct floodplain disturbances fade, and there is no evidence of any subsequent floodplain erosion or scour at these sites, despite several flood events since 1960 (e.g., 1963-64; 1981-83; 1986; 1995; 1997, 1998, 2003, and 2005). By 2003, no direct floodplain disturbances (outside of the airport footprint) remain unvegetated (Figure 21E). These data are consistent with the low energy hydraulic conditions on this extremely low gradient floodplain with valley floor slope. Only one adverse erosion change since 1969 appears directly related to the floodplain disturbances and valley width constrictions, that being the initiation and progressive worsening of hillslope erosion at the downstream end of Reach 5 (Figures 21B, C, and D).

Cattle grazing in the vicinity began in 1854 (ENTRIX 2004), and W.D. Barton established a ranch in about 1928 near this portion of the Upper Truckee River. The Sunset Ranch was established in 1929 on a portion of the original Barton holdings (Lindstrom 1994:20). Recreational horseback riding on established trails out of the 'Sunset Stables' equestrian facility occurred from the mid-1900s up to around 1999. These facilities were located between present day U.S. Hwy 50 and the south end of the airport runway.

The area along the Upper Truckee River near the present airport was identified as one with "drier meadow conditions" that required construction of elaborate waterworks to move water out of the stream channel and onto the grazing land (Johnson, personal communication in Lindström and Rucks 2003).

Channel incision has been described in several reports as a historic river process in Reach 5 (USACE 2000; TRCD, 2003; Simon et. al. 2003; ENTRIX 200a). There is general agreement that within Reach 5, incision is deeper in the downstream portion, although there has been disagreement about the overall severity, causal mechanisms, and date(s) of incision.

The downstream portion of Reach 5 that exhibits a steeper channel bed slope than bank slope (or valley profile) between RS 130+00 and 150+00 (ENTRIX 2007c) is considered actively incising. This is the reach immediately upstream of the channel reach that was straightened for the airport construction. However, review of the topographic data and profiles indicates that the bed slope remains about constant through this reach, rather than steepened as in active incision (a function of the increased length in the tight meander bends). In other portions of Reach 5, evidence of active incision is limited, although the protected pipeline crossings and a paved low-water crossing have small channel bed grade breaks (ENTRIX 2007c).Review of the plotted profile suggests these areas are local scour effects (but it is possible that future incision could occur if the protected crossings were removed). Simon and Others (2003) and TRCD (2003) suggest that much of Reach 5 has progressed past incision into the widening and aggradation phase of channel response. This may be consistent with our map and aerial analyses that suggest incision, widening and abundant bar deposits as of 1940.

The combination of little or no channel planform migration or widening along with the decrease in active channel bar deposits suggests that net removal of in-channel deposits (i.e., deepening of the active channel cross section) may have been a primary factor leading to increased channel capacity during the historic period. Decreasing watershed coarse sediment yield due to upland vegetation recovery from Comstock Era logging and fire suppression practices may have reduced coarse bed load replenishment. Reportedly, in-channel gravel extraction occurred upstream in Reach 6 near the U.S. Highway crossing and locally altered coarse sediment supply (Joe Pepi Pers. Comm. 2010), but the timing or magnitude of removal is not known. Net channel incision may also have occurred, at least in the downstream reach affected by airport straightening since the 1950s.

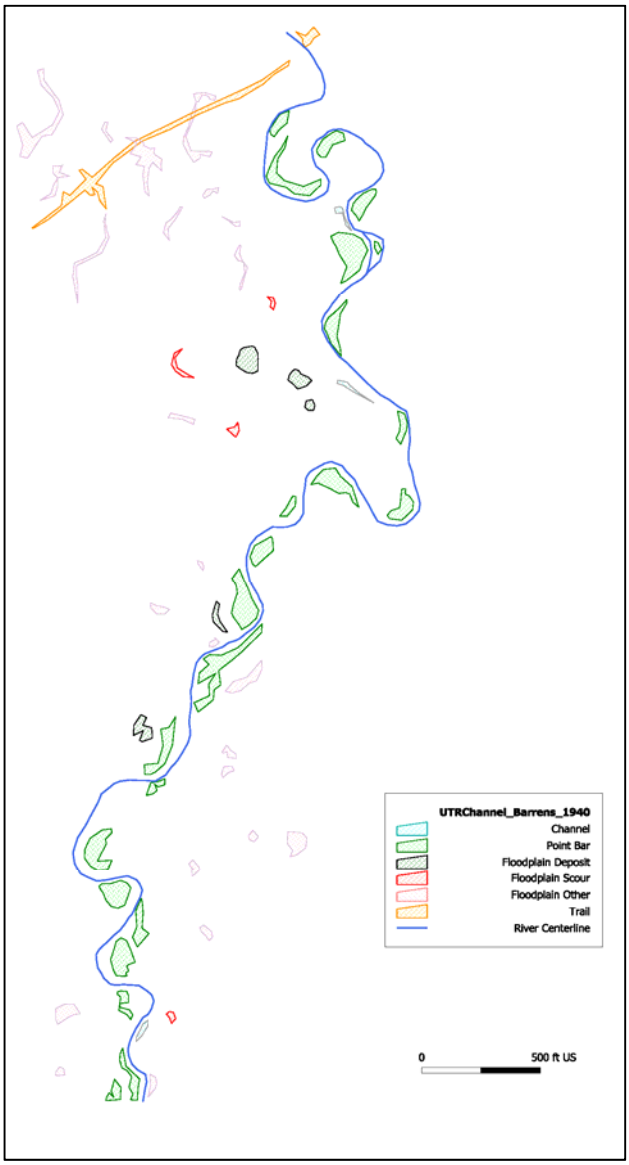



**FIGURE 21A: UNVEGETATED SURFACES OF THE UPPER TRUCKEE RIVER CHANNEL AND FLOODPLAIN, 1940**

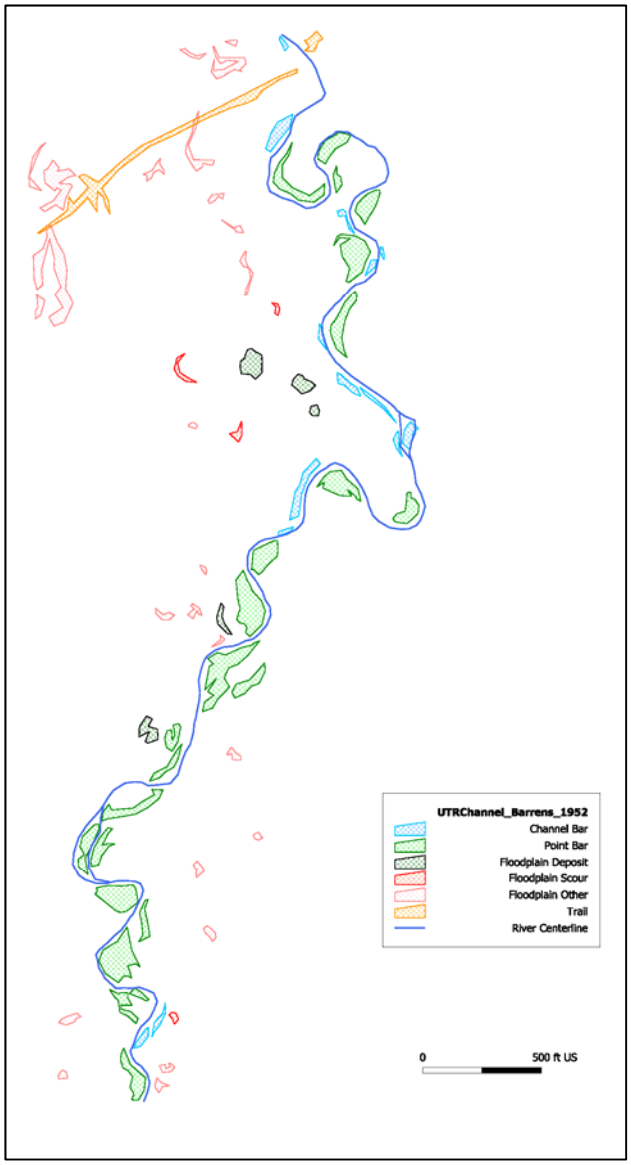



**FIGURE 21B: UNVEGETATED SURFACES OF THE UPPER TRUCKEE RIVER CHANNEL AND FLOODPLAIN, 1952**

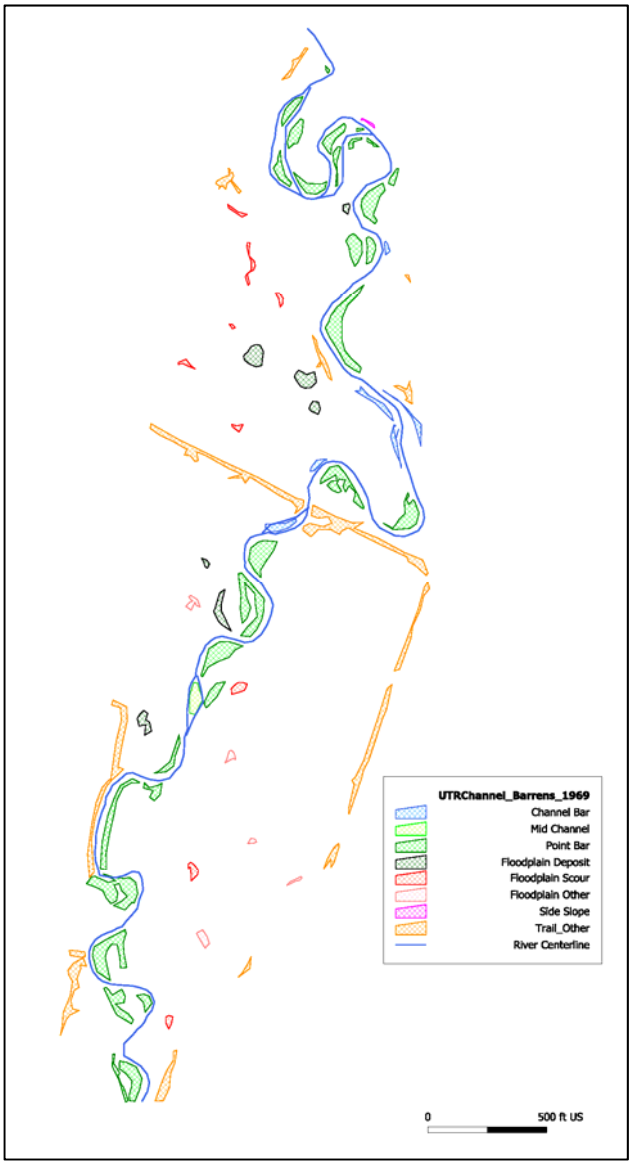



**FIGURE 21C: UNVEGETATED SURFACES OF THE UPPER TRUCKEE RIVER CHANNEL AND FLOODPLAIN, 1969**

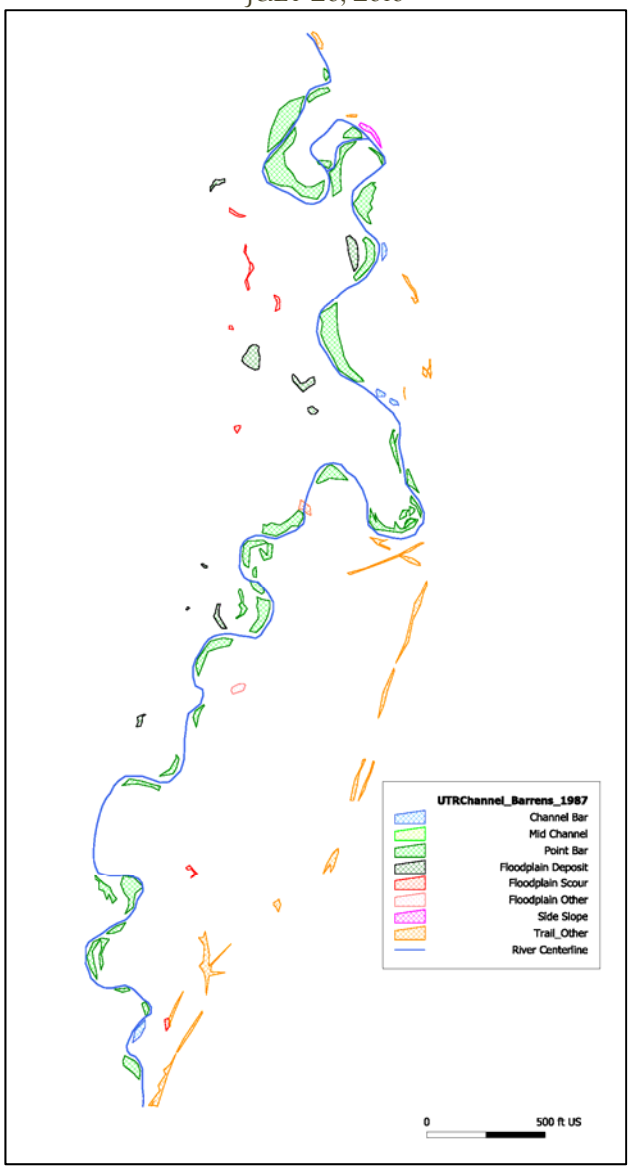



**FIGURE 21D: UNVEGETATED SURFACES OF THE UPPER TRUCKEE RIVER CHANNEL AND FLOODPLAIN, 1987**

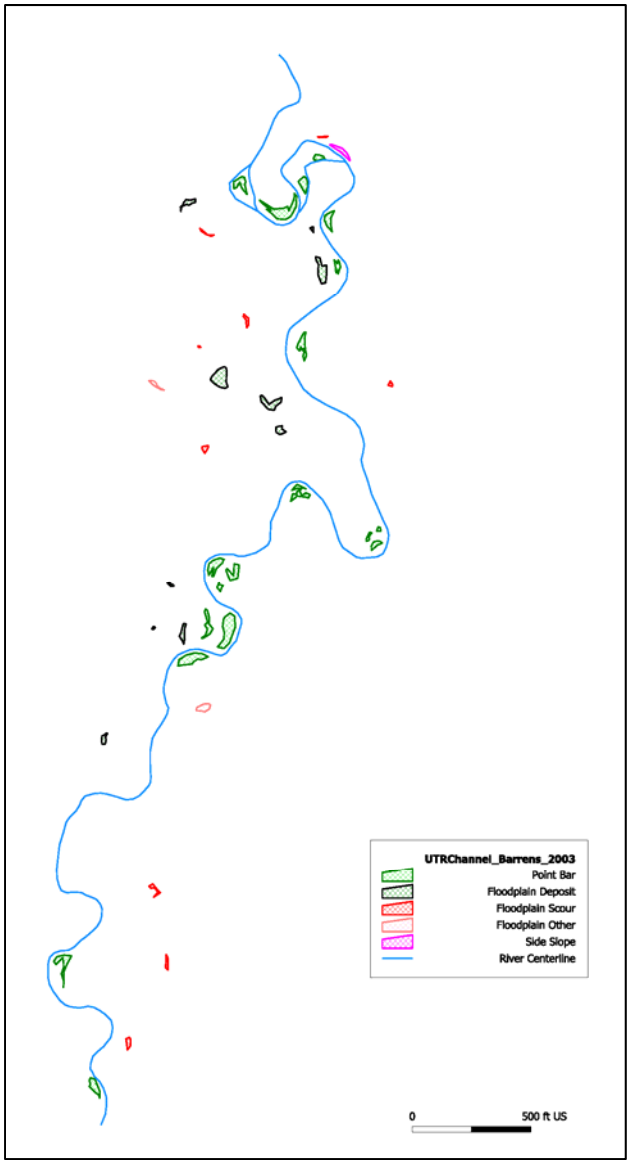



**FIGURE 21E: UNVEGETATED SURFACES OF THE UPPER TRUCKEE RIVER CHANNEL AND FLOODPLAIN, 2003**

The most consistent floodplain features are three small areas of gravel deposits along the sinuous remnant channel west of RS 16000 (Figure 20). These three deposits have remained similar in location and extent on all images since 1940 (Figure 21). The only visible change has been a minor decrease in unvegetated area since 1969 (Figures 21 C, D, and E).

The charcoal fragments from a zone about one foot deep within the over 4 feet thick gravel deposits (Figure 9) has been radiocarbon dated at two of the three gravel deposit sites to about 800 years ago (Appendix A). Therefore, these deposits, and the remnant channel features that they have filled are distinctly older than simply 'pre-Comstock'. No other datable material has been recovered from other remnant channel areas, so the absolute and relative ages of other remnant channel features has not been established. The age of charcoal samples within the gravel deposits is similar to the dendrochronologic age of submerged, rooted stumps in Fallen Leaf Lake (Biondi et. al. undated). Without additional research, it is not feasible to confidently interpret the pre-historic watershed processes, but it is possible that if rapid change in hydrology at end of Medieval drought (around 700 to 1,100 years ago) was the mechanism that quickly raised the lake level to submerge rooted trees, the river system might have seen large changes in runoff, sediment loads, and floodplain processes.

Channel conditions for the last few hundred years up to the historic period (approximately 1850s-present) remain uncertain, with limited definitive information about the channel pattern, dimensions, and/or sediment loads. However, the soils information gathered during this study, along with the analysis of historic channel deposit and floodplain features from aerial imagery provides some context. The well developed surface soil horizons (A horizons) in uniformly fine sands and silty sands across the entire valley floor, the organic accumulations in deeper remnant channels, the lack of sand and gravel deposits near the surface of the meadow, and the age of gravel deposits that are present all suggest a relatively long time (hundreds of years to more than a thousand years) during which very limited channel dynamics occurred across the floodplain. If there was a single thread channel, there is little evidence that it was regularly/freely meandering across the valley floor, more likely it may have avulsed to occupy different locations briefly. If there was a multiple thread channel a few hundred years ago (i.e., during the Little Ice Age, approximately 150 to 600 years ago), it did not leave many areas of coarse sand/gravel deposits at the surface, and may have occupied a few relatively stable locations without broad braiding. There is limited information to discern whether or not a single thread channel had become dominant by the time of Comstock logging. Data to determine whether or not the previous channel may have been multi-thread is also lacking.

Early in the historic period, Comstock logging practices incorporated use of the river for log-rafting all the way to Lake Tahoe from splash dams upstream of Reach 5. A distinct single thread channel, lacking braided sections and/or debris jams, would have been a valued condition for attempting the log rafting to the lake. Additionally, log rafting events, with sudden releases of water and the floating logs, could certainly have contributed to channel scour and definition of a single thread, deep channel.

After the Comstock logging had modified vegetation cover and disturbed upland soils throughout much of the watershed, increased coarse sediment delivery down the river system to the lake occurred, at least for some period of years to decades. This response has been documented as a spike in lake sedimentation rates (Haevyart 1998) as well as in beach-building that advanced the shoreline along the Upper Truckee Marsh lakeward between 1861 and 1914 and perhaps as recent as when the first vertical aerial photographs of the shore were taken in 1930 (CTC and DGS 2003: Chapter 3). Little information regarding the characteristics of the river channel(s) at the end of Comstock Logging and/or in the following couple of decades is available, but the resulting documented effects on lake sedimentation and beach growth suggest that sediment availability and transport through the river system were both high.

Qualitative discussions of historic channel widening within Reach 5 have been presented in several prior reports, noted as a factor contributing to the overall excess channel capacity. However, no prior quantitative analysis of historic channel width or planform changes has been used to verify the timing, rate, or amount of postulated channel widening. Mapping and measurement as part of the present study indicates a trend of decreasing width of the active channel, while the low flow channel width has remained very steady (Table 11). There has consistently been a wide channel near the downstream end of Reach 5 (approximate VS 137+00). Between VS 157+00 and VS 177+00 the active channel was widest in 1940, decreasing subsequently. This narrowing began prior to the reconstruction of the channel for the airport (started between 1940 and 1952). While it is possible that changes in grazing pressure may also have affected the presence of unvegetated sediment deposits, the trend of decreasing active channel width began decades before grazing ended

Although insufficient data is available at this time to verify the sequence and specific characteristics of the river channel in Reach 5 as it responded to natural climatic shifts and direct human disturbances over the last few hundred years, reasoned interpretations can be made on the basis of available information and typical channel evolution stages (Simon and Hupp, 1986; Simon 1989). One possibility is that the channel experienced incision, widening, and some aggradation during the five decades between the end of Comstock logging and the earliest aerial images (1940). Vegetative stabilization of a natural inset floodplain was proceeding, but new disturbances such as downstream channelization in the 1950s and 1960s, and/or continuing trends of decreased in coarse sediment supply from upstream may have induced an overlay of complex response by a new phase of incision (with or without narrowing). Renewed channel widening may have begun in some sub-sections of the Reach 5 and/or be the likely future condition without intervention.

### Erosion and Sedimentation

Surface erosion on the meadow within Reach 5, evidence of direct human disturbance and/or river processes, has dramatically decreased from high levels during the first half of the 1900s (Table 12). Exposed unvegetated surfaces at the time of the 1952 image peaked at 441,252 square feet (approximately 10 acres) as various construction and land use activities affected the valley floor (i.e., roads, residential building pads, water and sewer pipelines, the airport, and grazing) (see also Figure 21). Unvegetated areas decreased after 1969, and dropped to less than 0.23 acres by 2003.

Historic stream channel erosion in the constricted valley section at the downstream end of the project site began to impinge laterally on the east valley side slope sometime after 1952. An unvegetated hillslope erosion scar first becomes visible on the 1969 aerial image as a small (392 square feet) area of light colored, fine-grained lake sediments. The surface area of the hillside erosion scar increased to 1,972 square feet on the 1987 image but appeared slightly smaller (1,239 sq ft )on the 2003 image (Figures 21C, D, and E).

Other areas of Reach 5 have not displayed unusual or rapid lateral channel erosion (bank erosion-widening), but given the relatively low erosion resistance of the native soil materials, there may need to be careful consideration to limit (or satisfactorily blend the hydraulic changes from) hardened protections in areas of buried infrastructure to prevent potential degradation to water quality. Sudden discontinuities in resistance to lateral migration and/or vertical scour may result in undesirable channel erosion in the vicinity of proposed infrastructure protection.

### TABLE 11: HISTORIC UPPER TRUCKEE RIVER CHANNEL WIDTH IN REACH 5

| | Low Flow Channel* | | | | Active Channel** | | | |
|---|---|---|---|---|---|---|---|---|
| | 1940 | 1952 | 1969 | 2003 | 1940 | 1952 | 1969 | 2003 |
| **Valley Station*** ** | (ft) | (ft) | (ft) | (ft) | (ft) | (ft) | (ft) | (ft) |
| 132+00 | 38 | 32 | 29 | 47 | 38 | 32 | 29 | 47 |
| 37+00 west | 46 | 75 | 82 | 96 | 70 | 103 | 82 | 96 |
| 137+00 mid | 128 | 40 | 140 | 107 | 128 | 109 | 140 | 107 |
| 137+00 east | 48 | 35 | 36 | 39 | 48 | 42 | 50 | 56 |
| 142+00 | 57 | 57 | 42 | 34 | 126 | 158 | 63 | 50 |
| 147+00 | 67 | 57 | 51 | 41 | 91 | 91 | 77 | 52 |
| 152+00 east | 53 | 46 | 51 | 43 | 84 | 92 | 84 | 51 |
| 152+00 mid | 50 | 42 | 49 | 36 | 67 | 64 | 63 | 42 |
| 152+00 west | 56 | 45 | 39 | 60 | 75 | 55 | 66 | 63 |
| 157+00 | 38 | 44 | 35 | 39 | 104 | 99 | 62 | 62 |
| 162+00 | 50 | 47 | 43 | 41 | 102 | 84 | 53 | 46 |
| 167+00 | 38 | 52 | 42 | 42 | 138 | 90 | 66 | 42 |
| 172+00 | 27 | 34 | 35 | 49 | 126 | 85 | 86 | 49 |
| 177+00 | 51 | 55 | 44 | 51 | 133 | 94 | 80 | 51 |
| | | | | | | | | |
| Reach Summary | | | | | | | | |
| Average | 53 | 47 | 51 | 52 | 95 | 86 | 72 | 58 |
| Median | 50 | 46 | 43 | 42 | 96 | 90 | 66 | 51 |
| Maximum | 128 | 75 | 140 | 107 | 138 | 158 | 140 | 107 |
| Minimum | 27 | 32 | 29 | 34 | 38 | 32 | 29 | 42 |

*Low flow channel as indicated by summer (July/August) water surface visible in images.
** Active channel including low flow water surface and adjacent exposed, unvegetated channel bar deposits
*** In areas with highly sinuous channel segments, the channel crosses the valley station more than once, hence there can be multiple channel crossings at a particular VS (see Figure 4).

### TABLE 12: HISTORIC SURFACE EROSION AREA IN REACH 5*

| Surface | 1940 | 1952 | 1969 | 1987 | 2003 |
|---|---|---|---|---|---|
| | $ft^2$ | $ft^2$ | $ft^2$ | $ft^2$ | $ft^2$ |
| Floodplain Scour | 5,411 | 5,679 | 10,033 | 4,706 | 3,323 |
| Other Unvegetated Floodplain scars (aside from deposits) | 80,920 | 79,314 | 5,719 | 1,665 | 1,934 |
| Trails | 32,189 | 356,258 | 92,269 | 34,225 | 0 |
| Hillslope | 0 | 0 | 392 | 1,972 | 1,239 |
| Total | 118,521 | 441,252 | 108,413 | 42,568 | 6,495 |

* Between the channel crossing within the Airport reach at ENTRIX RS ~ 13200 and the upstream end of the airport runway, about VS 180+00; surface area measured in GIS on rectified aerial imagery taken during mid-summer season (July/August)

Downstream in Reach 4 (approximately RS 128+00) a pre-1940 grade control structure that had been stabilizing streambed elevations (ENTRIX 2007b) was recently (2008) removed and replaced by engineered cobble grade controls finished to existing grade. Based on this recent change as well as the continuing valley confinement since airport construction, hydraulics between Reach 5 and Reach 4 may be adverse for both in-channel flows and return flows off the floodplain during low to moderate floods under existing conditions and for any potential design. Valley confinement creates backwater effects that reduce velocities and shear stress under larger floods, but the potential for adverse hydraulics during flood hydrograph recession will still need to be considered prior to final design for this transition.

Upstream in the transition to Reach 6, extreme valley confinement from the airport may also affect flood hydraulics to be considered in final design of the channel and overbank configuration/roughness within Reach 5. Additionally, the potential for Reach 5's raised streambed to result in backwater effects and/or aggradation in Reach 6 will need to be evaluated prior to finalizing the channel form and dimensions at the transition.

While it is beyond the scope of this analysis to verify some of the hypothesized pre-historic and historic conditions in this reach of the river, the channel and floodplain parameters described in all the preceding sections are linked to and/or reflective of erosion and sedimentation processes. The results of the field study on floodplain soils and geomorphic features, and analysis of the channel and floodplain on historic aerial images highlight the key role of erosion and sedimentation at the watershed scale as a factor affecting past channel conditions. Understanding of past trends and reasoned expectations of future watershed hydrology and sediment load trends are critical factors to be integrated into project design development. However, design studies to-date have focused on existing sediment loads and transport, without sensitivity analysis or modeling of proposed channel response to a range of future sediment conditions.

A long-term trend of decreasing suspended sediment yield from the Upper Truckee River to Lake Tahoe has been predicted by Simon and Others (2003) using a 50-year simulation (assuming hydrologic inputs similar to historic). The emphasis of their analyses was on fine sediment (which was validated with historic suspended sediment data), and output from the whole watershed to the lake rather than specific locations within the watershed. However, the CONCEPTS model included spatially discrete simulations of changes in channel conditions (e.g., channel width, bed elevation, bed material sizes) along the entire river over the modeling period (50 years). The model results indicate widening with possible shallowing may occur for this reach of the river in the future. The bed material simulations suggest a D50 fluctuating between 10 and 20 mm (coarsening), but no calibration of the coarse fraction sediment model results was performed. Most of the simulated channel changes occur within the first 25 years of the simulation period.

A channel design such as the proposed 50 percent channel with a lower width/depth ratio than the existing channel, but a similar planform sinuosity and slope implies that the constructed channel would be more efficient at sediment transport. This could potentially exacerbate rather than counteract historic trends of deepening and incision.

# III. VEGETATION CHARACTERIZATION

## METHODS

### LITERATURE REVIEW

A literature review was done of past vegetation surveys conducted in the project area in support of the Sunset Stables RRMP. Previous reports provided community descriptions, a species list for the project area, and occurrences of sensitive plant species as well as noxious and invasive weed populations. A list of potentially occurring plant species of

interest to the Washoe Indians was also compiled (ENTRIX 2004c). No special-status plants were found within the Sunset Stables survey area during the 2004 field surveys.

Review of background information included the Table 1 plant list and Figure 1 of the ENTRIX (2004c) report, titled Vegetation Communities in the Management Planning Area. These were evaluated in the context of standard vegetation references including DFG (2003), Sawyer and Keeler-Wolf (1995), and Sawyer et al. (2009), and on the basis of field studies described below.

The 2004 text and map were based upon the Holland (1986) plant community system, which had been superseded by both Sawyer and Keeler-Wolf (1995) and DFG (2003) and several earlier editions of the same list at the time of the 2004 study. The latter reference in particular, itself now superseded by Sawyer et al. (2009) is useful for vegetation mapping for restoration planning because it provides a listing not only of alliances but also of the many associations within them that occur in the planning area. For both upland and restoration planning, it is important to distinguish vegetation associations wherever possible, because these provide strong indications of soil moisture regime and other key parameters of the soil profile, usually at a finer level of resolution than is available from NRCS soil surveys. Also, vegetation that is intermediate between described associations, or is a mosaic of more than one association, is often indicative of ecological condition and trend. These considerations in turn are important to the determination of the planform layout, final design, and successful implementation of the restoration project.

Within the Reach 5 Project area, only one herbaceous community is identified in the ENTRIX (2004a) document (Wet Montane Meadow). Although one presumes this equates either to the Holland Montane Meadow or Wet Subalpine Meadow or to the TRPA (1971) wet mesic meadow vegetation "types," neither of those sources provide adequate and accurate characterization of the hydrologic regime or description of a plausibly coherent constituent plant cover. Our 2009 field observations were that the herbaceous cover varies from completely barren areas through mesic meadow associations to obligate-wetland marsh vegetation.

In addition, the 2004 description of Wet Montane Meadow does not correspond well with 2009 field observations of the vegetation. For example, the most abundant plant species within the meadow portion of the study area, *Deschampsia cespitosa* (tufted hair grass), is not even mentioned in the 2004 description, nor is *Juncus balticus* (Baltic rush) which is of great importance in ecological interpretation and restoration planning.

Because the 2004 vegetation community mapping did not provide the level of detail that would have arisen from use of the most current classification system at the time, the hydraulic and geomorphic designers may not have had the opportunity to fit the design concept closely to the existing ecological landscape. Based on the 2009 field work, it appears that the proposed 50 percent design channel location passes through or very near to several plant community types and barren areas (which in a sense is also a community type) which are either inappropriate as near-channel communities or pose significant potential stabilization and revegetation challenges.

Review of the 2004 plant list indicates that a large number of species on the list (as many as 40 to 50 species) are either misidentifications or seem extremely unlikely to actually occur here. Neither of the present study team's botanists observed them in the area despite extensive experience with the study area's vegetation and the plant species in question. Also, several of the most important meadow plant species that are present are not found on the 2004 list, including both of the two most important *Carex* species (*C. nebrascensis, C. utriculata*) from the perspective of vegetation dominance and restoration planning

The plant nomenclature used in the present report is according to the Jepson Manual (Hickman, 1983) since those names are more familiar to California botanists than the recently updated scientific names of many important plant species found in the authoritative Flora of North America series and used by Sawyer et al. (2009).

Distribution and populations of previously identified noxious and invasive weeds most likely has changed since the 2004 surveys and will likely change again by the time construction takes place for this reach. Re-survey during final design is highly recommended to insure that proper avoidance and treatment of noxious weeds is specified as part of construction, and that construction does not contribute to the spread of noxious or invasive species. Final designs will include measures outlined in the Noxious Weed Risk Assessment (ENTRIX 2009) such as requiring off-road equipment to be washed before entering the Project site, flagging and avoiding weed-infested areas particularly for staging areas, using only weed-free products and materials, minimizing area of disturbance and re-establishing vegetation in areas that are disturbed to prevent the spread of noxious weeds (ENTRIX 2009). The previous vegetation reports done in support of the Sunset Stables RRMP are a more broad interpretation of the site related to planning efforts and offer limited specific information that can be applied to design development particularly in terms of soil bioengineering and restoration design needs.

GIS shape files of existing willow resources in the Project area provided by the LTBMU from work in support of the Morrison Report (Bormann, Gross and Morrison 2008) were incorporated into a map of the site (Figure 23). Having received the data after the field work was completed and snowpack covered the site, it was, reviewed in reference to the 2003 aerial image and comment is provided below. Suitable areas for willow plantings are generally anywhere in the lower elevations outside of "unsuitable areas" delineated in Figure 22.

### Field Observations

Vegetation surveys were initiated beginning on November 17, 2009. This was a suboptimal time for species identification and vegetation mapping, but due to anticipated construction schedule demands it was performed as soon as possible after contract authorization and prior to the onset of winter. However, most dominant species could still be determined. Although it would be in addition to what was originally scoped, a second field review and boundary adjustments of the vegetation during a more favorable identification time in early to mid-summer 2010 to confirm accuracy would be prudent prior to development of final plans, specifications, and engineer's estimates. Mapping is focused on salvageable sod for engineering purposes, e.g. material with dense and vigorous rhizomes, primarily *Carex nebrascensis* (Nebraska sedge) and *Juncus balticus* (Baltic rush). Stands of sod and meadow vegetation were mapped on aerial photos (the high resolution 2003 LIDAR image) and verified with GPS way-points.

## Results

### Moist and Wet Meadow Plant Species

Although the field work for the present report was conducted at a sub-optimal time of year, we were able to make subjective observations about vegetation dominance, vigor, and other species present that are relevant to restoration planning. Generally, observations provide specific corroboration of the mention made without explanation in ENTRIX (2004a) that the meadow is tending toward dry meadow conditions. However, if a new channel is introduced with a raised thalweg elevation and increased overbanking frequency there is the potential to increase meadow wetness and reverse this trend. The dominant species are important not merely as indicators of soil moisture regime, but also because of their characteristics with respect to control of erosion and potential removal of pollutants in surface waters. Tufted (or "bunch") grasses (specifically tufted hair grass itself), and non-rhizomatous forbs such as the most common associated species in the Reach 5 meadows (e.g., *Potentilla gracilis, Sidalcea oregana*, and others), provide poor erosion control. Also, to the extent that the precise composition of surface vegetation is important in removing sediment and/or other pollutants, these species are less effective in that regard as well.

The vast majority of the present meadow vegetation within Reach 5 is tufted hair grass meadows (Sawyer et al., 2009), the sod cover type C- 'Suitable Organic Matter Salvage'

discussed below. However, the specific associations within this alliance that occur in the study area do not correspond well with any that are noted in the standard reference or in DFG (2003). Notably, the main species mentioned as being associated with tufted hair grass meadows are facultative-wetland species (FACW; regarded as being found in wetlands 67 to 99 percent of the time). AA significant proportion of the vegetation found in the hairgrass meadows within the study area is comprised of facultative-upland species (FACU; found in wetlands only 1-33 percent of the time): Kentucky bluegrass (*Poa pratensis*), yarrow (*Achillea millefolium*), and, in some patches, minor components of Lemmon's yampah (*Perideridia lemmonii*) and needle grass (*Achnatherum cf. nelsonii*). Also, the small proportion of the critical wet meadow species Nebraska sedge and Baltic rush that is present in the hairgrass-dominated meadows is of comparatively low stature and is all or nearly all non-reproductive. These characteristics are indicative of low vigor, therefore of sub-optimal growing conditions.

Most of the return-flow swales (RFs discussed in prior section) support relatively more vigorous Nebraska sedge and Baltic rush vegetation (sod cover types A and B 'Salvageable Sod' and 'Potentially Salvageable Sod' described below), however, springtime observations would be necessary in order to determine the vigor of even these vegetation cover types. In the course of the meadow studies, we also examined the immediate surroundings of remnant channels (RCs discussed in prior section), which also often supported sedge-dominated, rather than hair grass dominated vegetation. The possible benefits of supplemental soil moisture, which might be (but were not directly confirmed to be) associated with the RF and RC depressions appeared to extend only a short distance laterally, probably just tens of feet. The estimated extent of this effect is based on only a few qualitative observations made in late fall, and it might vary within the Reach 5 study area and might change under a different overall soil moisture regime.

The natural establishment characteristics of some of the meadow species that are common within the study area are also relevant to the interpretation of the meadow history and restoration potential. For example, both of the main wet meadow species (Nebraska sedge and Baltic rush) colonize new area more readily by vegetative spread of rhizomes than by establishment of new plants from seed; and conditions must be very wet in order for any seedling establishment to occur. Within the study area and other locations in the Lake Tahoe region, small plants of these two species can sometimes be found in locations (such as underneath sagebrush plants near meadow edges) which, from historical aerial photographs, we know to have been much too dry for establishment of new sedge and rush plants for at least several decades. Therefore, they are able to persist under what would be experienced by the plant as drought conditions for decades if not hundreds of years. It is possible, if not likely, that the present extent of occurrence of Nebraska sedge and Baltic rush within the Reach 5 study area represents vegetation establishment that occurred either during the Little Ice Age (pre-1850), or during the more immediate pre-Comstock period.

The predominant species in the Reach 5 meadows that reproduce primarily or exclusively from seed (e.g., hair grass, cinquefoil [*Potentilla*], yarrow, and so on) are representative of mesic meadow conditions, or of conditions that vary from somewhat dry to mesic meadow moisture regime from year to year.

### Suitable Sod Characterization

To provide information on the applicability and availability of on-site vegetation materials for salvage and reuse, five different herbaceous cover types were identified, with species composition (community names according to Sawyer et al., 2009), physical description, suitability for restoration applications, and areal extent as described below and depicted in Figure 22. Although the scope of study did not include detailed mapping, classification, and characterization of plant communities in the study area, some of this general information is included in the cover type descriptions.

### Salvageable Sod (Type A)

This cover type provides excellent erosion-control sod in its present condition. It is a mixture or mosaic of Nebraska sedge and Baltic rush (meadows and marsh alliances), with a very high relative percentage of the total cover provided by one or both of those two species. Therefore the vegetation is dominated by one or both of these species and salvaged sod from these areas can be expected to provide sufficient structural material to protect disturbed surfaces from moderately (but not highly) energetic surface flows. Salvageable Sod mostly occurs in old channels and in places along existing sewer lines. Approximately 2.66 acres of Salvageable Sod type cover occur in the mapped study area, in stands of various sizes and shapes. Most of this cover type is not currently proposed to be intercepted by the 50% proposed new channel alignment. Therefore, only a limited area would be assumed available as salvage from disturbance limits.

### Potentially Salvageable Sod (Type B)

This cover type has a similar vegetation composition to that of the Salvageable Sod, but was much less vigorous, and it is not recommended to be relied upon for protection against surface flows until it has been grown for at least 2 years under good soil moisture regimes or applied irrigation. Although the vegetation of Potentially Salvageable Sod is dominated primarily by Nebraska sedge and Baltic rush, some portions of this community are co-dominated by *Carex praegracilis* (slender sedge). Most areas of Potentially Salvageable Sod support more forbs and grasses than are found in the Suitable Sod type. Approximately 3.86 acres of Type B cover occur in the meadow in stands of various sizes and shapes.

### Suitable Organic Matter Salvage (Type C)

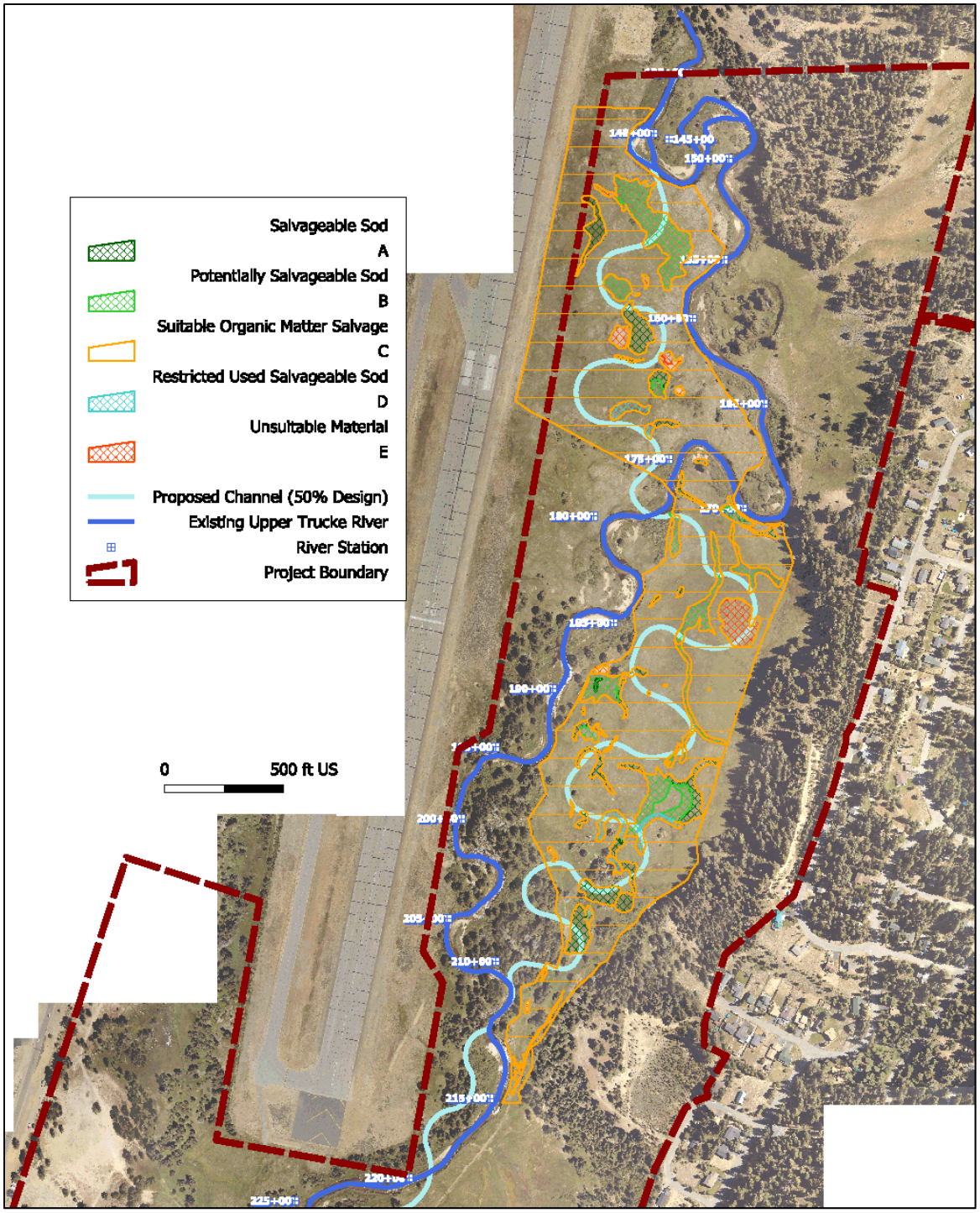
This cover type is dominated by grasses (tufted hairgrass; *Leymus triticoides,* creeping wildrye), but also includes a wide variety of other species of grasses and forbs, and is considered as Suitable Organic Matter Salvage, but not sod. In some portions of Suitable Organic Matter Salvage type, stunted plants of Nebraska sedge and Baltic rush are present, but in such low relative cover and vigor that they cannot reasonably be expected to grow into a dense rhizomatous turf necessary for erosion control. The majority of the Suitable Organic Matter Salvage would be classified as tufted hairgrass alliance (tufted hair grass meadows); some areas are probably creeping wildrye alliance (creeping rye grass turfs); and many areas seems to be intermediate between several different associations and alliances, which is suggestive of a landscape that is ecologically transitional (whether ecotonal [spatially] or temporally successional due to change in physical environment). Notably, the wetland indicator status of the many species that are common within the Suitable Organic Matter Salvage area varies from obligate through facultative-upland. This is most likely indicative of an ecosystem that is in transition from a substantially wetter (aquic) soil moisture regime (which previously supported a dominance of obligate and facultative-wetland species that are now present only as non-reproductive relics) to a currently mesic or even seasonally xeric one that favors facultative and facultative-upland species. Significantly, few of the predominant plant species in Suitable Organic Matter Salvage is strongly rhizomatous. However, the upper part of the soil profile in this type cover could be salvaged and reused as a revegetation supplement, but the material is not suitable for erosion control as sod. This material may be top-dressed on banks of new channels and any disturbed floodplain areas within the higher elevation parts of the restoration work area, which would not be expected to be subject to frequent flood flows. Approximately 41.18 acres of Suitable Organic Matter Salvage cover occur in the mapped study area. This type was not mapped as a discrete polygon but was designated as the default dominant vegetation type.

### Restricted Use Salvageable Sod (D)

This cover type is an excellent example of a *Carex utriculata* alliance (beaked sedge meadow) and is overwhelmingly dominated by beaked sedge, sometimes with minor components of other obligate wetland species that are indicative of long-duration standing surface water (e.g., *Sparganium*, bur-reed). The Restricted Use Salvageable Sod cover type occurs in somewhat deeper depressions (remnant channels RC discussed in prior section) than does Salvageable Sod. The upper portion of the soil profile (which would be most of what could be salvaged and used for revegetation) appeared to have a very high organic content, which is prone to decompose or to dry out, shrink, and be washed away if the moisture or surface flow regime is altered (for example, by salvaging and relocating sod for revegetation purposes). For this reason, and also because beaked sedge is not found growing as long-term self-sustaining stands in micro sites adjacent or close to channels such as the Upper Truckee River in Reach 5, the Restricted Use Salvageable Sod type is not suitable for channel banks or near bank floodplain use, but it is very useful in specialized revegetation applications, in areas that will be saturated, ponded, and only subject to slow velocity surface flows. Approximately 0.66 acres were mapped in the study area.

### Unsuitable Material (E)

Areas of Unsuitable Material do not have any material for salvage and reuse in riparian restoration. Unsuitable Material is a heterogeneous map type including some areas that might previously have been suitable sod for salvage purposes but are too disturbed (e.g., footpaths); some patches of *Carex filifolia* alliance (shorthair sedge turf), which is an uncommon and interesting meadow type in the Upper Truckee River floodplain; some small patches of upland vegetation; and a unique land form which we describe as gravel barrens (see discussion of soil site D4 in Section II, above). The gravel barrens are areas consisting of very fine gravel (larger than the 2 mm threshold between sand and gravel) and coarse sand and do not support any vascular plant vegetation (and very little cryptogamic vegetation (e.g., mosses, ferns, lichens)) and most likely have not done so for hundreds of years, according to carbon dating conducted on samples taken from those areas (Appendix A). The gravel barrens are the only areas identified as not being suitable for willow plantings (other than upland areas). These barrens are highly erodible and, under any realistic engineering and revegetation treatment, would remain a very high risk for channel avulsion or other large-scale erosive change if disturbed. Accordingly, any new channel alignment must be set back from these features. Unsuitable Material is fairly limited within the mapped study area, totaling just 1.13 acres. However, the proposed 50 percent channel alignment goes through or immediately next to Unsuitable Material in two locations: (1) west of the existing channel between RS 160+00 to 165+00; and, (2) east of the existing channel between RS 185+00 to 182+00 (Figure 22). These areas would be priorities for alignment adjustments during the 75 percent design phase.




The mapping boundaries were limited to a subset of the total project area, but covered the proposed 50% design channel alignment and adjoining meadow surfaces.

**FIGURE 22: RE-USABLE SOD AND ORGANIC MATTER RESOURCES**

## Willow Planting

### Willow Scrub Presence

The mapped areas of "willow scrub" (specifically, Lemmon's willow shrubland alliance), have a density of large willow clumps that could provide a good supply of decent-sized cuttings. The previous willow mapping prepared by Borgmann, Groce and Morrison (2008) shows the outermost extent of willow occurrence throughout the study area (Figure 23), based on measuring clumping of willows (i.e. branches of nearby shrubs in contact with each other) greater than 0.5 meters tall (Borgmann et. al. 2008). This approach did not differentiate different types of willow occurrences or actual densities, which can often be of crucial importance to their utility for restoration purposes.

Based on field observation for the present study, nearly all of the willow vegetation within the study area is Lemmon's willow thickets (*Salix lemmonii* shrubland alliance; Sawyer et al., 2009). Portions of it occur as understory shrub fragments within lodgepole pine forest. Several important distinctions could be made during field or photo-interpretation work as follows:

Areas where only very small, colonizing plants are present (almost exclusively point bars and other near-channel areas usually on the centripetal side of meanders);

Individual clumps (single large plants, or perhaps up to three closely juxtaposed plants);

Areas of patchy willow shrubland vegetation with gaps of meadow vegetation between clumps that are smaller than the clumps themselves;

Willows within lodgepole pine forest, which are tentatively considered to be relic occurrences, and consist of plants of relatively low branch density.

Due to the overall mapping approach and generous field or photo-interpretive methodology, the prior willow mapping (Figure 23) suggests a more extensive willow occurrence than the fall 2009 field observations support. Our overall impression of willows in the project area is that they are quite limited in extent and the areas with natural willow recruitment are not as dense as would be expected. There are a few areas of observed willow occurrences that are not mapped (possibly less than 0.5 meters in height), and a few small lodgepole pines that are mapped as willows (although it is possible that very small willows are present underneath them).

Willow occurrences of the types denoted as 1 and 4 in the list above are of limited significance as sources of restoration material. Cuttings might be sourced from the listed types 2 and 3, although the relatively patchy nature of even the most exuberant willow vegetation within the site means that the amount of material is limited. Prior to determining what methods might be applicable for bank stabilization, it would be desirable to quantify the number of large clumps present and the number of vigorous, healthy, and usable branches available for soil bioengineering, without substantially decreasing the vigor or habitat values of the source shrubs. Adequate size would be large diameter (0.5 minimum to 1.0 inch) that are at least 3-4 feet long, so they can be inserted in auger holes or otherwise planted deep enough to escape meadow turf root competition and access groundwater. Even longer cuttings would be needed for willow mattresses.

### Areas Suitable for Willow Planting

With the exception of the gravel barrens which are mapped as part of the unsuitable material (Figure 22) (visible on the 2003 aerial and represented by soil site #D4), virtually the entire valley floor of the project area would be suitable for willow planting for restoration purposes. However, modification of existing topography and/or vegetation might be necessary in order to achieve maximum vigor of the planted cuttings, salvaged clumps, willow mattress etc. Additionally, specialized methods would be necessary in the case of plantings in existing intact meadow vegetation (all of the vegetation types in Figure 22).

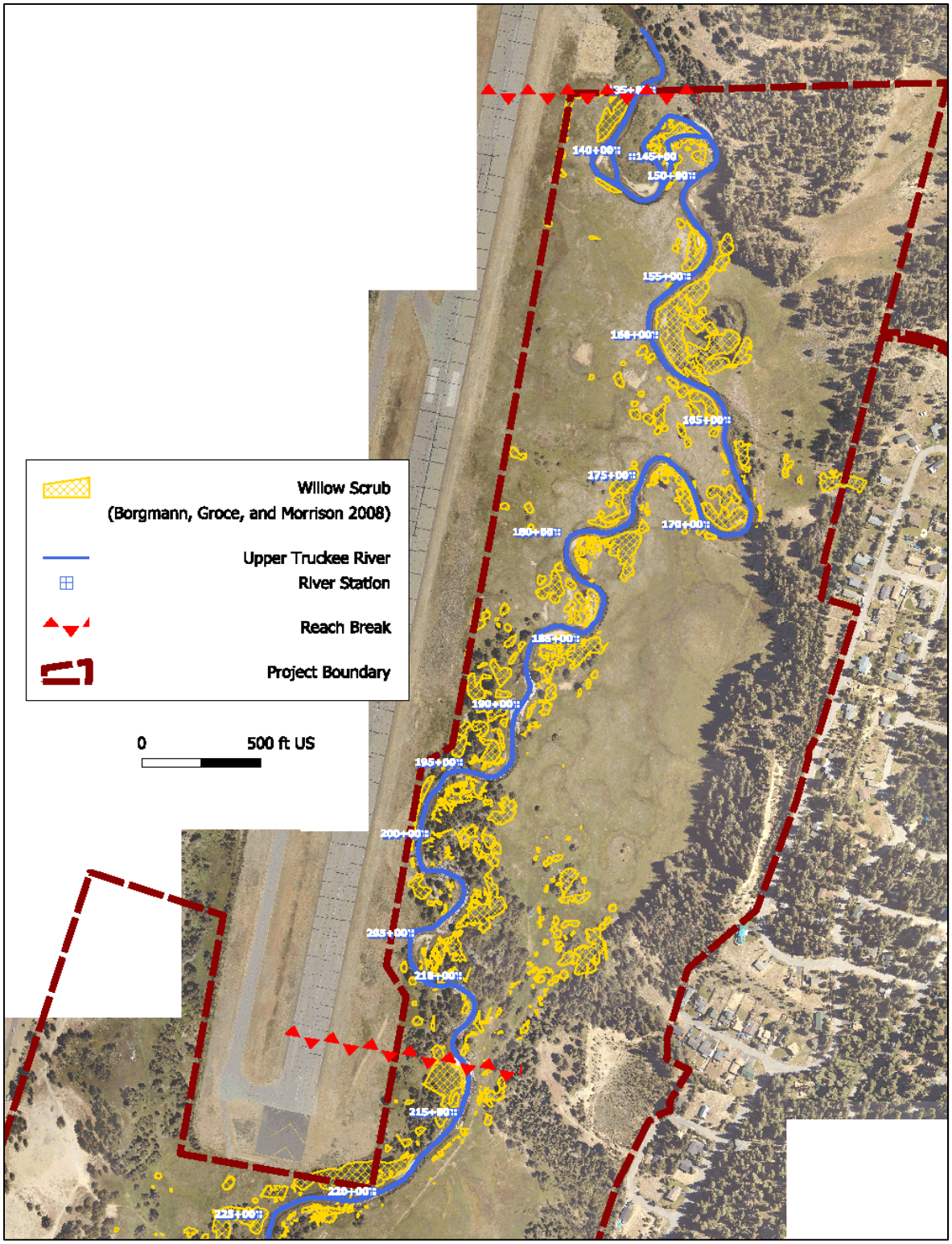



**FIGURE 23: EXISTING WILLOW SCRUB DISTRIBUTION**

For example, deep guide holes would be required, created either by hand auger or with a backhoe-mounted "Stinger" or an auger. This method would be necessary to place the base of the cuttings at a level where groundwater is accessible throughout the growing season and competition from the graminoid root systems is lessened. If sufficient numbers of branches with adequate vigor, length, and diameter are available, willow mattresses would be one of the best methods for bank stabilization and could potentially be installed along a large percentage of the new channel alignment.

# IV. WILDLIFE HABITAT CONDITIONS

## INTRODUCTION

Several wildlife surveys and assessments were conducted in support of the Sunset Stables RRMP and general goals and approaches to improving wildlife habitat in the area of Reach 5 have already been defined. Given the extensive wildlife survey and monitoring efforts completed since 2004 for the Conservancy and Sunset Stables RRMP and additional monitoring conducted for the USFS from 2006 to 2008, the direction for this task was not to conduct any additional wildlife surveys, but to use the existing literature assessments as a basis to extract more definitive design prescriptions that would improve upon wildlife habitat conditions in the immediate Project area.

This section summarizes the previous wildlife monitoring evaluations and discusses how our approach and understanding either concurs or differs with those evaluations. Finally this section details specific strategies to improve upon wildlife habitat conditions in the Project Area.

In addition to restoring natural geomorphic function and floodplain connectivity to the Upper Truckee River, the purpose of the Project is to improve water quality and aquatic and terrestrial wildlife habitat within the Project area (ENTRIX 2008f).

A shallower channel with improved instream cover via added channel features and increased bank vegetation is in agreement with these goals. The creation of pond habitat will need to be done in a way that doesn't intensify the risk for airport/bird conflicts or exacerbate vector control issues. Noxious plant populations should be confirmed in the field so that they may be flagged and avoided and/or targeted treatment controls may be implemented according to the species that are present. Potential beaver impacts will need to be anticipated for all aspects of restoration.

Consistent with the Borgmann, Groce and Morrison (2008) report (i.e., Morrison Report), pre-restoration wildlife monitoring surveys of songbirds, butterflies, amphibians, reptiles, bats and small mammals were conducted along Reaches 5 and 6 and two control sites from 2006 to 2008 in order to identify wildlife specific project objectives.

According to the Morrison Report, restoring the natural geomorphic function of the channel and increasing floodplain connectivity should increase riparian and meadow community diversity and complexity and also benefit the wildlife species associated with those communities (Borgmann et. al. 2008). The list of specific recommended restoration actions and objectives from the Morrison Report are discussed in the Results section below and later refined based on Task 1 efforts for inclusion in the design components at the end of this section.

## METHODS

### LITERATURE REVIEW

Reports reviewed for this effort include the Sunset Stables Administrative Draft RRMP (ENTRIX 2008), the Morrison Report (Borgmann et. al. 2008) and various focused wildlife survey reports including a draft Amphibian and Reptile Survey Report (ENTRIX 2007d), a

Meso-carnivore Survey Report (H.T. Harvey & Associates 2007), a Final Aquatic Vegetation Survey Report (ENTRIX 2007e), an Aquatic Resources Report (ENTRIX 2005), and a Beaver Management Analysis Report (V&M Consulting and ENTRIX 2005). Combined with the literature review were recommendations by the USFS restoration group staff regarding practical application of the previous wildlife habitat improvement prescriptions and knowledge of the project area gained from site visits and aerial image review related to parallel investigations conducted for this report.

# Results

## Existing Wildlife Species, Habitat Features and Conditions

### Wildlife Species

According to the Sunset Stables RRMP, the area encompassing Reaches 5 and 6 supports a variety of habitats and a diverse array of native and non-native wildlife species. Previous surveys documented 56 terrestrial species, of which 44 were birds, 9 mammals, 2 reptiles and one amphibian (i.e. Pacific tree frog) (ENTRIX 2008c). Special status species known to occur in and adjacent to the area included American marten, long-eared myotis and fringed myotis, and mule deer. Targeted meso-carnivore camera surveys detected an American marten just outside of the Sunset Stables area, but not within it and concluded that its absence from the area may be due to habitat fragmentation (H.T. Harvey 2007). The camera surveys also recorded bobcat and flying squirrels and track evidence revealed presence of American black bear, coyote, bobcat, mountain lion, mule deer, Douglas squirrel, snowshoe hare and various mice and voles. Special status species that could occur but were not observed in focused surveys include: the mountain yellow-legged frog; northern leopard frog; northern goshawk; osprey; and, willow flycatcher. Wildlife surveys conducted for the Morrison report (Morrison et al 2008) resulted in one possible willow flycatcher siting.

During aquatic vegetation surveys five common species were found mostly along the runs of Reach 5, including duckweed (*Lemna minuscula*), coontail (*Ceratophyllum demersum*), common elodea (*Elodea Canadensis*), filamentous green algae (*Cladorphora spp.*) and common water moss (*Fontinalis antipyretica*). Aquatic vegetation can provide cover for fish and mussels particularly in deep runs or pools. Fortunately, the noxious perennial aquatic plant, Eurasian watermilfoil (*Myriophyllum spicatum* L.) was not found in either Reach 5 or 6.

Evidence of North American Beaver activity along Reaches 5 and 6 was collected in 2004 where observations of two colonized areas with active and complete dams, one just upstream of Reach 5 and the other within Reach 5 at approximate RS 188+00 were reported as well as evidence of several bank burrows, trails, cuttings and food caching throughout (V&M and ENTRIX 2005). Evidence of beaver in Reach 5 was also reported in the Aquatic Resources Report (ENTRIX 2005) where they observed five partial dams, one complete dam at RS 192+00 with pool habitat extending 300 feet upstream and evidence of beaver foraging.

### Habitat Features

Similar to what was reported in the above discussion of meadow soil and groundwater conditions (Section II), the RRMP (ENTRIX 2008c) noted that the meadow is drier than under historic conditions with direct consequences to the plant and animal communities that rely upon a wetter environment. Additionally, soil moisture sampling along two transects in the eastern and western meadow portions of Reaches 5 and 6 in June 2008 (Borgmann et al 2008) found all sample points to contain only dry soils and the extent of willow cover in the existing meadow is minimal.

Snags with a minimum diameter breast height (dbh) of 18.5 inches in the Sunset Stables conifer forest areas were recorded at nine trees per acre which meets the Sierra Nevada Forest Plan Amendment recommendation of at least 4 snags per acre. These snags serve an important role for many cavity nesting species, however it was noted that snag quality is

limited in terms of type (i.e. only 17% Jeffrey pine) and size (i.e. dbh averaged less than 20 inches) (ENTRIX 2008c).

The instream habitat conditions are mediocre at best with poor substrate, insufficient areas of undercut banks and riparian vegetation, widely fluctuating instream temperatures and insufficient overbanking to support seasonal shallow water habitat (ENTRIX 2008c).

Aquatic habitat surveys done in 2004 on Reaches 5 and 6 documented substrate composition, spawning substrate quality and quantity and cover type available for fish at moderate (i.e. 110 cfs to represent spring spawning conditions) and low flows (i.e. 10 cfs to represent summer rearing). They also documented general distribution and relative abundance of native Western Pearlshell mussels along the same reaches. During moderate flows, Reach 5 is predominantly run habitat (i.e. long reach with uniform width and depth) with just 23 percent of the reach length pool habitat (i.e. greater than 3 feet maximum depth), 11 percent riffle habitat and 3 percent side channel habitat at the tortuous meander at the lower end. Substrate in Reach 5 was reported as 47 percent sand, 31 percent gravel, just 4 percent boulder and cobble size substrate and 19 percent silt and clay mostly in the form of hardpan found in the lower 0.8 miles of Reach 5. During summer low flows, temperature fluctuations spanned more than 10 degrees Celsius during the day time with potential detrimental effects to invertebrate production and fish growth. Potential spawning substrate is limited occurring mostly within riffle habitat and overall cover in pools is extremely limited in Reach 5. Cover was identified as the limiting factor under moderate flows and cover and depth as the limiting factors under low flow conditions. Freshwater mussels were found to be more prevalent in Reach 5 then Reach 6 and primarily associated with run and pool habitats containing either coarse sand or a mixture of coarse sand, gravel and cobble. In general habitat conditions in Reach 5 are fair to good for native species and poor for trout (including native Lahontan cutthroat trout) due in part to limited pool/riffle runs, general absence of cover and poor substrate conditions. Substrates are too fine, not well sorted or present only as a thin layer over hardpan (lake sediments) making for poor spawning and invertebrate production conditions. Backwater areas important to minnow, sucker and trout fry growth and development are generally lacking in the incised channel providing few opportunities for the small fish to move out of the cold fast waters. In all Reach 5 provides fair to poor aquatic habitat conditions due to the incised channel condition, limited riparian development and overall homogenous setting with limited pool/riffle patterns (ENTRIX 2005).

A large mammal wildlife corridor (e.g. American marten, bobcat, and mule deer) exists outside of Reach 5 on the southern end of the Sunset Stables area at Reach 6.

### Improvement Potential

General management actions for wildlife habitat in the Sunset Stables area based on the Morrison Report and the 2004 Sierra Nevada Forest Plan Amendment include (ENTRIX 2008c):

Enhance willow clumps as potential habitat for willow flycatchers.

Maintain and enhance snags in forest habitat for terrestrial wildlife.

Maintain and enhance connectivity along riparian corridor and river valley.

Enhance ephemeral wetlands and ponds for amphibians and aquatic reptiles.

Evaluate effects of invasive wildlife species and develop control programs if necessary.

### Willow Flycatcher and other Avian Species Habitat Improvement

One specific focus of the Morrison Report was to increase density and size of willow stands along the river and nearby meadow and to increase structural diversity in the understory. It was expected that channel restoration would increase inundation and soil moisture and as a result improve recruitment and survival of willows and wet meadow vegetation. Supplemental plantings of willow cuttings were proposed to increase vegetation density (ENTRIX 2008c).

Restoring riparian vegetation would provide more cover and minimize temperature fluctuations by providing shade to aquatic species. Riparian habitat was also reported to be lacking along the existing channel with opportunities to increase willows and aspen stands to benefit species such as willow flycatcher, yellow warbler, rufous hummingbird, sharp-shinned hawk, mountain yellow-legged frog and snowshoe hare (ENTRIX 2008).

Recommendations for willow habitat improvement made in the Morrison Report (Borgmann et al 2008) based on reference areas include:

Create dense willow patches along the stream channel and through the meadow where microhabitats are suitable to benefit songbirds and small mammal species.

Increase total willow cover to approximately 60 percent of the entire meadow area.

Increase willow cover >2 meters in height to occupy at least 4.6% of suitable willow establishment area in meadow.

Increase spatial clumping of meadow willows

Additional avian habitat improvements under the Morrison Report (Borgmann et al 2008) include:

Maintain large snags (i.e. greater than 38 cm diameter) and/or provide nest boxes for mountain bluebird.

Improve willow density and diversity and improve understory plant community by planting various species at different times or at different stages of growth to increase height variation to create habitat for willow flycatchers, yellow warblers, calliope hummingbirds and Lincoln's sparrows.

Establish river side gravel banks/bars and patches of dense vegetation for increased foraging and nesting opportunities for spotted sandpiper.

Provide clear and shallow water areas within stream channel and areas clear of vegetation along the stream to provide good nesting and hunting conditions for belted kingfisher.

Avoid increasing abundance of waterfowl species of concern to FAA in areas close to the airport.

It is agreed that increasing willow species diversity, variation in age classes and percent cover in the Project area are important measures to improve willow flycatcher and songbird habitat, as well as habitat for small mammals. However a distinction needs to be made in terms of proper approach to enhancing willow stands. Willow seed require a disturbed surface in order to colonize; therefore natural willow recruitment and increased establishment in a quiescent wet meadow won't occur if it is outside the channel or areas of disturbance with appropriate hydrology. It is recommended that increases in willow populations be focused along the active channel banks and within the floodplain margins where new construction will allow for soil bioengineering. If seed production occurs concurrently with newly exposed soils, there may be additional natural recruitment via seed establishment.

Design emphasis should include preserving large snags, designating dense willow stands interspersed with open areas along the active channel for willow flycatcher and belted

kingfisher foraging opportunities, and minimizing standing water in areas close to the airport to reduce the potential for waterfowl conflicts.

### Aquatic Species Habitat Improvement

Aquatic habitat improvement opportunities include enhancing substrate, cover and seasonal shallow water habitat to benefit species such as Lahontan redside, Lahontan speckled dace, Tahoe sucker, mountain whitefish, rainbow trout, Paiute sculpin, pacific tree frog, and a variety of waterfowl and bats.

Recommendations for improving stream habitat include (ENTRIX 2008):

Increase cover along the banks with vegetation or woody debris.

Place engineered log jams at strategic locations along the channel where willows would also be planted in order to complement the willows in providing bank cohesion and pool development.

Suggestions for improving aquatic habitat include increasing opportunity for side and backwater channels in the meadow to provide slower, warmer water habitat during late spring runoff conditions, integrating Western pearlshell mussels and spawning and rearing habitat into restoration considerations, and increasing cover and complexity to the homogenous channel via streambank vegetation, woody debris and increased riffle/pool sequences (ENTRIX 2005). Specific habitat features that would target individual fish species were not described in detail in the reports reviewed.

Aquatic vegetation is expected to colonize the new channel  at it is seasoned or be carried from upstream unaltered reaches once the new channel is connected, therefore specific measures to protect or replace aquatic vegetation that currently resides in the existing channel is not recommended (ENTRIX 2007e).

### Meadow Dependent Species Habitat Improvement

Opportunities to increase overbank flows via a smaller channel were expected to raise the groundwater elevation and increase the soil moisture levels in order to benefit wet meadow plant species, associated soil fauna, and discourage lodgepole pine encroachment.

Specific meadow improvements under the Morrison Report (Borgmann et al 2008) include:

Increase extent and duration of wetness within Sunset Stables reach to benefit songbirds and desirable small mammal species, increase willow regeneration, provide ephemeral pools for reptiles and amphibians and increase foraging habitat for bats.

Improve butterfly richness and abundance by enhancing flowering species within meadows and alongside the river, particularly ones listed as host plants for desired condition butterfly species and important nectaring plants, including western asters, wandering daisies, pussypaws, yarrow, long-stem clover and bistort. Increase soil moisture and limit human access to maintain flowering populations.

Increase wet meadow and ephemeral pool areas to provide standing water locations for common garter snakes and Pacific treefrogs.

Increase wet meadow area to improve willow generation and reduce ability of predators to access songbirds.

Increase extent and duration of meadow wetness particularly in areas impacted by recreational access and use to minimize songbird predation and provide bat foraging sites.

Maintain open, wet meadows, retaining adequate downed woody debris and snags and increasing willow cover to provide condition for desired small mammal species. Downed wood minimum of three logs > 30 cm diameter at midpoint per 0.4 hectare and three snags >38 cm dbh per 0.4 hectare.

As relayed in previous sections the existing river channel appears to be a drain lowering the surrounding groundwater table, particularly in the meadow and during the dry summer months and additionally, the meadow appears to be transitioning from a wetland supporting system to one that favors upland species. This indicates ample opportunity for wetland habitat enhancement via raising the channel bed sufficiently to minimize the "drain" effects and increasing overbanking frequency and depth.

If the current incised river is modified so that it no longer functions as a drain in the Project area and overbanking frequency is increased there are opportunities to increase soil moisture regimes in those areas and push the wetland plant community towards more obligate wetland species.

An additional flowering species that should be added to the list for butterfly habitat is milkweed.

### Amphibian Habitat Improvement

Suggestions for improving wildlife ponds include (ENTRIX 2008c):

Recontour some remaining portions of former channel to create ephemeral ponds for amphibians and birds, but avoid these features in areas close to the airport to reduce bird/airport conflicts or design them shallow enough to be non-usable by geese.

Provide slow moving water and riffle features for the earlier amphibian stages (i.e. frog, tadpole).

Expanding pool and riffle features will be a target goal for several aquatic species including amphibians. Retaining ephemeral ponds along the existing channel outside of areas adjacent to the airport is agreed to as long as they're created with an awareness of what impacts they may have on vector control.

### Terrestrial Habitat Improvement

Recommendations specific to the meso-carnivore surveys included maintaining a diverse array of habitats within the area to facilitate wildlife utilization, preserving or creating patches of dense large diameter trees for suitable marten habitat and minimizing the occurrence of free-roaming domestic dogs (H.T. Harvey 2007).

An effort to preserve and protect large snags and large diameter trees within the project area conform to what is recommended. The large mammal wildlife corridor (e.g. American marten, bobcat, and mule deer) that exists near Reach 6 on the southern end of the Sunset Stables should also be preserved and protected during any construction activities.

The context of beaver management within restoration was reported for the Reach 5 and 6 areas in two ways, one of which assumed a restored smaller capacity channel with increased overbanking and floodplain connectivity under high flows. Under this scenario beaver dams were reported as having increased longevity from existing conditions due to a reduction in in-channel hydraulic forces during high flows allowing an increase in wetland habitat and groundwater stabilization. There could still be excessive browsing of vegetation, particularly newly planted vegetation, impediments to fish migration and changes to water quality and aquatic habitat. It was recommended that beaver activity effects be anticipated and protection measures be included in design (V&M and ENTRIX 2005). According to the Aquatic Resources Report, beaver dams can provide increased pool and backwater habitat areas, possibly ice-free habitat for fish during winter and cover in the form of woody debris from lodge and dam construction and food caches. However beaver dams may also limit fish migration under low flow conditions (ENTRIX 2005).

Potential detrimental impacts to restoration improvements per direct manipulation by the beaver will be anticipated and protection measures will be incorporated into the design as necessary (i.e. temporary fencing for immature plantings, bank protections, etc.). Potential indirect impacts such as increased channel complexity, overbanking and meadow wetness will also be examined for ways the existing beaver population may be accommodated to

benefit the design. An adaptive management approach which may include future responses such as physical protection measures such as fences, barriers, or stream flow control devices would occur during operation of the project, particularly during the first few years following restoration. This would decrease the risk of damaging effects from beaver activities on the stability of the new channel or health of the surrounding habitat

## Proposed Design Components to Improve Wildlife Habitat

In reviewing the previous literature regarding wildlife restoration objectives and recommendations for Reach 5, we have identified the following themes grouped into primary restoration tactics. These primary tactics would result in multiple secondary benefits and facilitate secondary tactics for wildlife habitat improvements. These tactics should be considered the focus of wildlife restoration actions in the project design and include:

### Primary Tactic 1: Restore geomorphic function and floodplain connectivity (i.e. channel capacity, overbanking frequency, groundwater regime, soil moisture conditions).

**Secondary Benefits:**

Increase extent and duration of meadow wetness.

Increase soil moisture.

Increase willow and wetland plant health, production, diversity and longevity.

Increase total willow cover and increase areas of mature willows of greater height.

Enhance availability of wetland ponds and standing water for desirable amphibians and reptiles (Pacific tree frogs, Mountain yellow-legged frogs, common garter snakes).

Increase habitat for meadow dependent species.

Provide increase in bat foraging sites.

Increase available habitat for willow flycatcher.

Reduce lodgepole pine encroachment.

Reduce occurrence of repeat beaver dam failure from high stream velocities within high streambanks.

One stipulation to Primary Tactic 1 is that recent data review and field investigations show that increasing meadow wetness is not only reliant upon increasing overbanking frequency and duration but also requires reversing the existing groundwater gradients, particularly during the drier months away from the channel, which currently acts as a drain.

### Primary Tactic 2: Increase in-channel geomorphic complexity (i.e. pool/riffle pattern, woody debris, overhanging cover, bed materials).

**Secondary Benefits:**

Increase areas suitable for fish spawning and rearing.

Improve aquatic invertebrate productivity.

Reduce instream temperature fluctuations.

Increase bank stability.

Create and enhance capture of desirable channel substrate if available via import or upstream sources (i.e. gravels and cobbles)

Provide improved habitat for initial amphibian life stages.

Increase foraging and nesting opportunities for spotted sandpiper via gravel banks/bars if material is either imported or recruited.

**Secondary Tactic:**

Increase opportunity for seasonal watering of side, backwater and return flow channels within adjacent floodplain to provide protective habitat during high flows for fish.

Apply engineered log structures or boulder features with dual purpose to increase channel stability and create habitat.

### Primary Tactic 3: Protect, preserve and incorporate existing wildlife habitat features including existing large snags, woody debris, willow stands and wetland sod.

**Secondary Benefits:**

Provide habitat for meso-carnivores, predatory birds and cavity nesting birds.

Increase instream fish cover, bird and small mammal cover along the floodplain.

Allow for continued pool and backwater habitat available to fish via beaver dams.

Stabilize channel banks and floodplain surfaces to protect in-stream water quality.

**Secondary Tactics:**

Incorporate measures to allow for anticipated beaver activity that will protect new channel banks and newly planted vegetation and maintain fish passage during low flows.

Incorporate existing and salvaged woody debris into channel and floodplain features.

Protect or salvage and replant existing wetland sod in strategic areas as prescribed in Vegetation Characterization section.

### Primary Tactic 4: Improve desirable plant species diversity, population and stages of growth.

**Secondary Benefits:**

Increase spatial and understory complexity.

Improve bird foraging habitat.

Increase cover and habitat allowing opportunities for unplanned expansion of plant species as birds and rodents act as vectors, moving seeds and microflora and fauna and inoculants.

Increase in plant species provides opportunities to increase pollinator presence and activity leading to a more diverse, sustainable, and resilient food web.

**Secondary Tactics:**

Plant an array of wetland species, flowering plants, berry and nectar producing plants.

Create ecotones and plant berry-producing native species such as serviceberry, roses, and currants to diversify structure and create edge effect.

Plant an array of riparian species including willows, alders and aspens.

Incorporate various willow planting salvage and planting methods (e.g. willow stakes, salvaged willow root balls, planting in dense or X patterns).

Plant willow stands strategically next to depressions or areas of standing water, this should include areas where the remnant channel is only partially filled but is located a substantial distance away from the airport.

Preserve open areas along the channel with no willow stands to improve kingfisher habitat.

Additionally there are proposed modifications to some of the earlier recommendations in order to increase feasibility and functionality to the design that include:

Instead of aiming for 60% willow cover of the entire meadow as recommended in the Morrison Report, identify suitable locations to prescribe willow installations along the new channel and active floodway. Willows should be integrated into willow mattresses and used in combination with salvaged willow clumps and cuttings to reinforce new channel banks, provide erosion control and increased habitat and shade.

Rather than limit the aquatic improvement targets to a "narrower shallow channel with pool-riffle features" as stated in the RRMP, prescribe a new or restored channel that is of appropriate size and depth to increase floodplain connectivity and overbank frequency, minimize the potential for groundwater losses from adjacent meadows and remain stable under all expected flow conditions.

# V. HYDRAULIC FORCES RELATED TO BED AND BANK STABILIZATION

## APPROACH

Detailed hydraulic analyses and modeling were completed for the conceptual design phase of the Sunset Stables RRMP project. This assessment of hydraulic forces related to bed and bank stabilization therefore relies on review and use of this previous modeling to characterize channel velocities and shear stresses under existing and proposed conditions. The one-dimensional (1-D) model results provided average velocities and shear stresses, which are fairly applicable to bed stability but must be interpreted or adjusted to estimate hydraulic conditions most relevant to bank stability, such as flow along the outside of bends. In the context of past channel behavior, comparison of average hydraulic forces under existing and proposed conditions can also provide guidance for design of the new channel.

Previous hydraulic modeling represented existing conditions and several alternatives that were evaluated in the preliminary design process. The proposed 50 percent design shown on preliminary plans (ENTRIX, 2008) is a variation of Alternative 3, which was modeled during the Alternatives Evaluation process. Hydraulic models were not developed to represent specific changes between concept Alternative 3 and the 50 percent design, but that is of limited concern for this analysis since the 1-D modeling approach is not too sensitive to the type of changes made. Additional changes to the project design are under consideration by the project team, as discussed in Section X, below, but won't be fully defined until 75 percent design. Therefore, the approach for this analysis is to use the available multi-reach modeling to evaluate hydraulic forces and potential bed and bank stabilization relative to the 50 percent design, and then to estimate the likely differences associated with anticipated changes in the project design using more general computations.

## METHODS

### LITERATURE REVIEW

Several previous reports and memoranda were completed by ENTRIX, Inc. for the Sunset Stables project that provides information on existing and proposed channel hydraulic conditions in the Reach 5 project area. The primary documents reviewed include:

Final Geomorphic Assessment Report for Sunset Stables Restoration and Resource Management Plan Project, ENTRIX, October 2004;

*Results of Sunset Stables Sub-task 4C1: Supplemental Geomorphic Assessment*, ENTRIX Memorandum to Joe Pepi, California Tahoe Conservancy, dated 8 March, 2007;

Results of Sunset Stables Sub-task 4C2: Topographic Longitudinal Profile and Cross Section Surveys and Hydraulic Modeling, ENTRIX Memorandum to Joe Pepi, California Tahoe Conservancy, dated 23 March, 2007;

Conceptual Channel Restoration Design and Hydraulic Modeling Report (Draft), ENTRIX, January 2008;

Preliminary Plans for Sunset Stables/Upper Truckee River Watershed Restoration Project, ENTRIX, December 2008.

The Sub-task 4C2 memorandum (ENTRIX 2007c) provides a summary of topographic information and calibration of their hydraulic model, and the appendices provide numerous graphics illustrating field data collected, model set-up, and model results. The Conceptual Channel Restoration Design and Hydraulic Modeling Report (ENTRIX, 2008a) describes existing channel conditions, hydrology, sediment loads and at-a-station transport computations, basis for the new channel design, and hydraulic modeling of alternatives. The appendices to this report also provide numerous graphics showing model results, including velocities and shear stresses under a variety of alternatives and flow conditions.

### Field Observations

Various reports have qualitatively discussed bed and bank stability within the project reach of the Upper Truckee River, and a review of some of the pertinent conclusions about historic channel trends and conditions, along with new aerial imagery analysis, is presented in Section II of this document.

### Modeling

ENTRIX provided hydraulic model digital files in HEC-RAS software format (HEC, 2009). The files include two "projects", as defined by the software, and numerous "plans" which represent different channel and floodplain geometries for existing conditions and alternatives. ENTRIX (pers. comm., 2010) provided additional guidance on appropriate HEC-RAS plans representing various existing and proposed conditions that may be appropriate as the Reach 5 design progresses. The models include approximately 28,000 lineal channel feet of the Upper Truckee River Middle Reach. The downstream end of the model includes Reaches 1 and 2 that begin at the U.S. Hwy 50 crossing in the City of South Lake Tahoe limits, the Airport Reach (Reaches 3 and 4) in its recently modified as-built condition and Reaches 5 (Project Reach) and 6 of the Sunset Stables RRMP. The upstream boundary of the model is about 1500 feet upstream of the U.S. Hwy 50 crossing at Elks Club Drive.

Due to the prior modeling and reporting of model results in earlier documents listed above, this task effort was not focused on additional modeling, but on review and analysis of the models and results. Data discussed in the following results section relies mainly on previously reported model output. To date, we have been unable to reproduce all of the previously reported values by re-running the models, but at this time, we assume these discrepancies are due to our lack of familiarity with the previous model datasets and scenarios.

The main comparisons made in this report are between the model of existing conditions and the model representing Alternative 3 for the Sunset Stables RRMP (Reaches 5 and 6). The Alternative 3 model is a very simplified representation of the proposed channel, with a uniform shape, size, and slope. The cross section used as a template is intended to represent the channel cross section at the riffle crests. The simplified representation provided preliminary velocity and shear estimates that were used by ENTRIX to support the conceptual channel design. An actual constructed channel would incorporate much more variability in channel shape and depth than the simplified model, and actual hydraulic conditions would differ from model results. The level of detail for a hydraulic model at 50 to 75 percent design would benefit from incorporating more of the desired variability in cross section dimension and shape.

# RESULTS

## DESIGN FLOWS

ENTRIX (2008a) estimated peak flows at various recurrence intervals and analyzed flow duration characteristics using records from USGS Gages 10336610 (with records 1972 to present) located near the most downstream crossing of U.S. Hwy 50 in South Lake Tahoe, and 10336600 (with records 1961-1986) located near the most upstream crossing of U.S. Hwy 50 in Meyers. Estimated flood peaks are shown in Table 13 and flow duration characteristics are shown in Table 14.

**TABLE 13: UPPER TRUCKEE RIVER PEAK FLOWS AT VARIOUS RECURRENCE INTERVALS**

| Recurrence Interval | Flow |
|---|---|
| (years) | (cfs) |
| 1.4 | 450 |
| 1.5 | 530 |
| 2 | 760 |
| 5 | 1,660 |
| 10 | 2,550 |
| 25 | 4,130 |
| 50 | 5,690 |
| 100 | 7,650 |
| 200 | 10,100 |

Source: ENTRIX, 2008.

ENTRIX used the flow duration characteristics, measured sediment bedload data, and sediment transport calculations to estimate effective discharge. Effective discharge is the flow that performs the most work in terms of sediment transport when considering both transport capacity and the time over which the discharge occurs. The effective discharge computations yielded a flow of 400 cfs. ENTRIX had previously estimated a bankfull discharge of 450 cfs, and decided to retain this value for design because it was close to the result for the effective discharge and to the statistical 1.5-year recurrence flow (ENTRIX 2008). The 1.5-year flow has been frequently used as an estimator of appropriate bankfull flow, but the field observations (e.g., Williams 1978) show wide variation in the relationship of bankfull flow to flood frequency. The effective discharge computation is more related to channel processes, but subject to some uncertainty in sediment transport calculations.

**TABLE 14: UPPER TRUCKEE RIVER FLOW DURATION CHARACTERISTICS**

| Mean Daily Streamflow | Percent of Days Exceeded | Average Days per Year Exceeded |
|---|---|---|
| (cfs) | % | (days/year) |
| 1,000 | 0.2 | 0.8 |
| 800 | 0.7 | 2.7 |
| 600 | 2.1 | 7.7 |
| 500 | 3.4 | 12.4 |
| 400 | 5.6 | 20.4 |
| 300 | 8.9 | 32.8 |
| 100 | 29.6 | 108 |
| 50 | 44.5 | 162.4 |
| 25 | 59.2 | 216.1 |

Source: ENTRIX, 2008.

The selected bankfull flow of 450 cfs corresponds to a recurrence interval of about 1.4 years, and is exceeded on average about 15 days per year. Note that this latter estimate is a statistical long term average. Review of the gage records indicates that in many years that flow is not exceeded at all, but in some years it may be exceeded for an extended duration. For example, the record at USGS Gage 10336610 shows mean daily flows did not exceed 450 cfs in 6 of the 8 years between 1986 and 1994.

Hydraulic model runs were made by ENTRIX at many different flow rates. The model for the proposed alternatives has 19 computed water surface profiles between 5 cfs and 7,650 cfs. For the purposes of this section, review focused mostly on the 450 cfs model run, because this value was used for proposed 50 percent channel design and is considered the most geomorphologically significant as the estimate of bankfull flow. Section VII gives more attention to results from the 5-year flow (1,600 cfs) and the 100-year flow (7,650 cfs) in a discussion of flooding. In the conceptual alternatives model, runs at flows between these two values were not provided, but would be appropriate during the 50 to 75 percent process, as these flows are significant in floodplain processes.

## EXPECTED HYDRAULIC FORCES

### Bed Shear Stress

At the bankfull design flow of 450 cfs, ENTRIX estimated average channel velocities for the proposed channel to be between 3.0 and 3.5 feet per second (fps) and average boundary shear stresses to be between 0.2 and 0.3 pounds per square foot (psf) in most of Reach 5. Notable differences from these generalized conditions for the project reach are described below.

The downstream boundary of Reach 5 is about 300 feet upstream of a historical timber structure in the channel. This structure was recently replaced with a cobble riffle that maintains the same bed elevation as existing (CSLT 2008). At this structure and for about 1,500 feet upstream in Reach 5, modeled velocities are higher than the Reach 5 average velocities, and are up to 4.5 fps. Average boundary shear stress is also significantly higher in this area than the reach average, up to about 0.55 psf.

The upstream end of the proposed new channel in Reach 6 is located about 400 feet downstream of the U.S. Hwy 50 Bridge at Elks Club Drive. While this area is not within the Reach 5 project site, elements of the hydraulic conditions that may occur near the transition between the existing channel and proposed new channel in Reach 6 could also occur near the transition between the existing channel and proposed new channel in Reach 5. At the Reach 6 location, the hydraulic model predicts velocities and shear stresses in the existing channel will be reduced by the higher thalweg elevations and decreased cross sectional

area in the downstream proposed new channel. Average velocity in this area drops to less than 1fps and average shear stress drops to near zero. Although this modeled location is not in the Reach 5 project area, a similar discontinuity may occur at the upstream end of Reach 5 if the Reach 6 restoration is not constructed simultaneously, but was not represented in available prior model run output. Reduced velocities and shear stresses would likely result in aggradation and potentially induce lateral channel adjustments.

Velocity and shear stress at the bankfull condition are often associated with incipient motion of bed material particles in channel stability assessments and restoration design projects. This approach assumes that bankfull flow corresponds to the flow range that is dominant in shaping channel morphology, and therefore bed sediments should be mobilized at about this flow. In recommending new channel dimensions, ENTRIX used an equilibrium slope approach that was based on specifying channel width and bedload supply. The recommended channel width was taken from hydraulic geometry relationships in the literature (Soar and Thorne 2001; Huang and Nanson 1998). Sediment transport calculations were then used to estimate a design channel slope (0.00105) and mean depth (3.9 feet). This resulted in a rectangular channel geometry assumed to represent the riffle sections. The reach average modeled channel boundary shear stress for this hypothetical rectangular channel at bankfull flow is 0.21 psf and the mean velocity is 3.0 fps.

Based on the recommended channel geometry, ENTRIX calculated average channel boundary shear stress and critical grain size at each model cross section. In estimating critical grain size, two relationships were used: one that applies the entire boundary shear to the bed; and, one that partitions drag to account for the effects of hydraulic resistance such as vegetation, meander bends and large woody material. The resulting shear stress and critical grain size plots (ENTRIX 2008a, Appendices I and H) show that average shear stress at the bankfull design flow is estimated to be higher for the proposed channel than in the existing channel. The existing channel shear stress varies more than the proposed at individual cross sections due to the uniform channel assumed in the proposed models, but averages about 0.15 psf compared to 0.21 psf for the proposed Alternative 3. Similarly, critical grain size is predicted to be higher for proposed conditions than for existing: about 20 mm vs. 10 to 20 mm based on boundary shear stress; and, about 8 mm vs. 5 mm based on the drag partitioning relationship. The higher shear stress and critical grain size estimates are a result of a lower width to depth ratio in the proposed channel (about 10) than in the existing channel (variable, but reported as an average of 23).

These calculated shear stress and critical grain size values can be compared against bed material and bedload sizes measured at the site. ENTRIX (2007b) provides bed material grain size distributions from bulk sampling and Wolman counts at 14 locations in their study area (Reaches 5 and 6). The samples were taken on plane bed and riffle sections. The plane bed samples have $D_{50}$ sizes that are generally in the range of 1 to 7 mm and $D_{90}$ sizes mostly less than 20 mm, although a few samples have $D_{90}$ sizes up to 50 mm. The riffle samples have $D_{50}$ sizes in the range of 10 to 30 mm and $D_{90}$ sizes generally less than 50 mm, but with one sample at 72 mm. ENTRIX also measured bedload at Station 25+670 using a Helley-Smith sampler at seven discharges during the receding limb of the snowmelt hydrograph in June and early July 2006. Bedload transport rates calculated from the sampling varied from 9 to 48 tons per day, and particle size distributions for the captured bedload samples gave a $D_{50}$ between 0.9 and 1.3 mm for all samples, and a $D_{90}$ between 1.9 and 5.0 mm. ENTRIX also notes that the median grain diameter from samples taken at three recently deposited mid-channel bars averages 5.3 mm, and suggests that this material is characteristic of the coarser sized material typically transported as bedload. The percentage of sand (<2 mm) in the bar samples ranged from 39 percent to 98 percent and averaged 69 percent, and in the bedload samples ranged from 69 percent to 94 percent.

Excluding the riffle pebble counts, the sampled bed material is somewhat smaller than the critical grain sizes computed for the proposed channel even with the drag partitioning relationship, and substantially smaller than that computed using the average boundary shear stress. Bed samples from the riffles are more comparable, but given their location on

the riffles and the presumption that the existing channel is slightly incised, this material may be somewhat coarser than the bedload expected to be transported in the new channel. No evaluation of bed load supply to the project reach has been made except the bedload measurements in Reach 6. These are subject to uncertainty and were measured at flows below the design bankfull discharge; the material in transport was mostly sand. Significant gravel supply and transport may not occur until much higher flows are reached; these volumes or rates have not been estimated.

Increased values of shear stress for the proposed channel relative to existing conditions and computed critical grain sizes larger than observed bed material suggest a relative change in proposed channel hydraulic conditions that might continue or aggravate the historical trend for incision. Lower slope, smaller channel sizes, and higher width to depth ratios are design options that would reduce shear stress, sediment transport capacity, and critical grain size. Section IX presents observations on the 50 percent design and guidance for the 75 percent design in more detail.

Observations from the historical imagery review and previous studies (Conservancy and DGS 2003) indicate that bedload supply may be declining. If bedload supply is lower than estimated or bed material characteristics are finer, a smaller channel or lower slope would be appropriate. The conceptual design was based on hydraulic geometry from the literature, limited bedload information, and at -station sediment transport calculations. Sediment transport into (i.e., supply) or through the project reach was not modeled. A sediment transport model that includes upstream channel sections within the golf course and the Reach 6 project areas are recommended during 75 percent design to better define sediment supply. A range of possible future sediment supply conditions need to be evaluated for potential effects on design performance, including sensitivity analysis of the design to varied sediment loads and the potential range of short-term versus long-term conditions in both upstream reaches (Golf Course and Reach 6) that are in the planning phase of channel restoration projects and may or may not be constructed within a few years of the Reach 5 project.

### Appropriate Channel Substrate

Riffles and Pools

The shear stress values computed in the proposed Alternative 3 model are relatively uniform at about 0.2 psf throughout Reaches 5 and 6 because the channel is represented as uniformly 40 feet wide by 4 feet deep. In the existing conditions model, shear stress is somewhat more variable, ranging between about 0.1 psf and 0.3 psf. Some of this variation is associated with morphology of the channel as it passes through deeper sections at bends and shallower riffle sections. The presence of riffles is somewhat unusual given that the bedload appears to be dominated by sand sized material, but may be a natural morphology because of mixed bed materials and occasional supply of gravels from upstream in larger events. In any case, the variability in energy gradient and bed materials provides more varied aquatic habitat and larger substrate sizes in at least a portion of the project area that are beneficial for food production, cover, and spawning for trout species. Assuming that energy slope might locally be about two to three times the average slope in riffle areas of the proposed channel, critical grain sizes would be in the range of 20 to 40 mm. These sizes match the existing riffle bed material gradations from Wolman counts reasonably well, and a material that is a mixture of gravel and coarse sand with a $D_{50}$ around 20 mm or 30 mm is probably appropriate for construction of the riffle or run sections of the new channel. Material graded more like the plane bed samples, dominated by sand and small gravel and with a $D_{50}$ of 1 to 2 mm, is acceptable for the deeper pool sections. These sections might also simply be excavated into native materials if the material encountered is not excessively silty or organic.

The 50 percent design shows a combination of gravel and sand bed materials, consistent with the analysis above. Although gradations are not specified, "riffle gravel" is shown in the channel between pools and native material is shown in the pool sections. A layer of

sand is shown on the banks for use in transitions – this particular section would not be very stable and requires refinement in the 75 percent design.

Buried Utility Crossings

There are several utility crossings of the proposed channel in Reaches 5 and 6. In Reach 5, these include a treated effluent force main crossing approximately 900 feet upstream of the downstream project limit and a gravity sewer and water line crossing about 2600 feet upstream of the downstream limit. These are locations where degradation of the channel bed could threaten the utilities. Lowering of the treated effluent force main and water line is feasible, but the gravity sewer line cannot be lowered without creating an undesirable sag in the line. Based on the invert elevations of the gravity sewer line at manholes on either side of the proposed crossing, the 50 percent proposed channel grade would occur just over two feet above the top of the existing sewer line. If the proposed new channel thalweg is raised further (to improve groundwater levels and bed and bank stability) and its location is shifted slightly eastward, the three feet minimum clearance required by the District should be achievable during 75 percent design. At this location, grade control and protection of the sewer line from scour is necessary.

One approach to protecting the sewer line is to maintain a suitable channel grade at this location as the crest of a riffle section. Assuming that the local energy slope might be up to five times the average gradient, or that the riffle might incorporate about 0.5 feet of drop over 100 feet, the bed protection at this location can be sized for an energy slope of about 0.005. The procedures outlined in Smith and Murray (1975) were used to size appropriate bed material for both bankfull and 100-year flood conditions, and yield a $D_{50}$ of about 0.3 feet (90 mm). A riffle formed of cobble sized material thus appears to be appropriate, with larger rock (12 to 18 inches) incorporated subsurface both upstream and downstream of the pipelines to provide assurance that the utilities are protected. A graded material should be used, with sizes ranging between about 3 inches and 9 inches. Gravels would be incorporated upstream, downstream, and in the interstices of the top layer of the cobble materials. Given the lack of available gravel and cobbles in the Project site, all required cobble and gravel materials would need to be hauled onsite. Design of the riffle will be responsive to fish passage criteria that maintain appropriate depths and velocities over as wide a flow range as possible for the migration season(s) of target species.

Downstream Reach Transition

As noted above, the hydraulic model for the bankfull design flow of 450 cfs shows increased energy slope and higher velocities for about 1,500 feet at the downstream end of Reach 5. This increase in energy slope is associated with drawdown to the transition between Reach 5 and the Airport Reach. Critical grain sizes in this area were computed at 40 to 45 mm. Very little material in this size range is present in the existing bed material samples. Because sediment transport capacity at bankfull flow would exceed the supply from the upstream section of channel, channel incision might occur. An interesting switch in relative velocities and shear stresses occurs in this area at higher flows. At about the 5-year flow of 1,660 cfs, the velocities and shear stresses become roughly equivalent to those upstream in the remainder of Reach 5, and for the 100-year flow of 7,650 cfs they become significantly less than the upstream values. This effect is due to the constriction of the valley width at the upstream end of the Airport Reach. Because larger gravel may be mobilized and transported through Reach 5 primarily in large events, this constriction presents some potential for aggradation during high flows as opposed to potential for degradation during bankfull flows.

The combined trends of degradation and aggradation might maintain the long-term channel profile in this transition zone, but assurance in the form of grade control or constructed riffles is recommended. Riffle structures similar to that described for the utility crossing above could be used, but perhaps without the larger rock necessary at the gravity sewer crossing. Multiple structures with small drops are preferable to a larger drop to provide reliability and flexibility for some adjustments, and provide better passage for

aquatic organisms. One such riffle structure might be used near the downstream limit of the Reach 5 project, as shown in the 50 percent design, and one near the crossing of the existing treated effluent force main. A third structure could be located approximately midway between these two structures. At 0.5 feet drop per structure, the crest profile would have a slope of about 0.0011, or approximately equal to the average bed slope upstream.

### Bank Shear Stress and Resistance

Computed average channel boundary shear values are useful as an index of shear stresses on the bed of the channel and to some degree on the banks. However, the shear stress distribution within a channel is related to its morphology, and shear stresses at various portions of streambanks may be considerably lower or higher than computed average boundary shear stress. In addition, bank stability around bends is influenced by development of secondary currents and the presence of local irregularities or vegetation that affect the distribution of velocity in the channel.

Bank materials are characterized in Section II of this report, in ENTRIX (2007b, 2008a), and in Simon, et al (2003) as sand and silty sand, underlain in some locations by cohesive lacustrine deposits. Fortier and Scobey (1926) estimate permissible velocities for trapezoidal channels in sandy loam at 1.75 to 2.5 fps for sandy loam and allowable shear stress at 0.04 to 0.075 psf. Simon and Others (2003) estimated critical shear stress for the two samples in the project area at less than 0.01 psf.

Computed average velocities for Alternative 3 are 3 to 4 fps and average shear stresses are 0.2 to 0.4 psf. At the outside of bends, maximum shear stress can be predicted as a function of the ratio between radius of curvature and channel width (Corps of Engineers, 1970). For a radius of curvature to channel width ratio of 2, which is similar to the existing channel planform, maximum shear stresses in bends may be 2 to 2.5 times the average channel shear stress. Under bankfull conditions, shear stress around the outside of bends can therefore be expected to reach about 1 psf. Under higher flow conditions, shear stresses will be locally higher, for example at the 2-year flow of 760 cfs, the hydraulic model computes average boundary shear stresses up to 0.8 psf that could result in a maximum shear stress at a bend of 2 psf.

Based on these estimated velocities and shear stresses for the proposed channel, reasonable design shear stress targets might be taken as 0.5 to 1 psf in the straight portions of the channel and 1 to 2 psf in the bends. Fischenich (2001) provides guidance on allowable velocities and shear stresses for various channel lining materials (Table 15). The reported values have a very wide range, in part due to differences in monitoring and reporting empirical values among several sources. The native soil materials (described above in Section II) have very low permissible shear stress (see for example sandy loam, alluvial silt and silty loam in Table 15), except where vigorous vegetation is rooted. Bank stability in the proposed new channel will depend entirely on adequate establishment of vegetation and bio-technical protection along the banks, particularly at outside bends. The 50 percent design plans include details for willow mattress, fascines, rock bank protection, stacked sod and related treatments, but the proposed locations were not yet specified.

### TABLE 15: PERMISSIBLE SHEAR STRESSES AND VELOCITIES

| Boundary Category | Boundary Type | Permissible Shear Stress (lb/sq ft) | Permissible Velocity (ft/sec) | Citation(s) |
|---|---|---|---|---|
| *Soils* | Fine colloidal sand | 0.02 - 0.03 | 1.5 | A |
| | Sandy loam (noncolloidal) | 0.03 - 0.04 | 1.75 | A |
| | Alluvial silt (noncolloidal) | 0.045 - 0.05 | 2 | A |
| | Silty loam (noncolloidal) | 0.045 - 0.05 | 1.75 – 2.25 | A |
| | Firm loam | 0.075 | 2.5 | A |
| | Fine gravels | 0.075 | 2.5 | A |
| | Stiff clay | 0.26 | 3 – 4.5 | A, F |
| | Alluvial silt (colloidal) | 0.26 | 3.75 | A |
| | Graded loam to cobbles | 0.38 | 3.75 | A |
| | Graded silts to cobbles | 0.43 | 4 | A |
| | Shales and hardpan | 0.67 | 6 | A |
| *Gravel/Cobble* | 1-in. | 0.33 | 2.5 – 5 | A |
| | 2-in. | 0.67 | 3 – 6 | A |
| | 6-in. | 2.0 | 4 – 7.5 | A |
| | 12-in. | 4.0 | 5.5 – 12 | A |
| *Vegetation* | Class A turf | 3.7 | 6 – 8 | E, N |
| | Class B turf | 2.1 | 4 - 7 | E, N |
| | Class C turf | 1.0 | 3.5 | E, N |
| | Long native grasses | 1.2 – 1.7 | 4 – 6 | G, H, L, N |
| | Short native and bunch grass | 0.7 - 0.95 | 3 – 4 | G, H, L, N |
| | Reed plantings | 0.1-0.6 | N/A | E, N |
| | Hardwood tree plantings | 0.41-2.5 | N/A | E, N |
| *Temporary Degradable RECPs* | Jute net | 0.45 | 1 – 2.5 | E, H, M |
| | Straw with net | 1.5 – 1.65 | 1 – 3 | E, H, M |
| | Coconut fiber with net | 2.25 | 3 – 4 | E, M |
| | Fiberglass roving | 2.00 | 2.5 – 7 | E, H, M |
| *Non-Degradable RECPs* | Unvegetated | 3.00 | 5 – 7 | E, G, M |
| | Partially established | 4.0-6.0 | 7.5 – 15 | E, G, M |
| | Fully vegetated | 8.00 | 8 – 21 | F, L, M |
| *Riprap* | 6 – in. $d_{50}$ | 2.5 | 5 – 10 | H |
| | 9 – in. $d_{50}$ | 3.8 | 7 – 11 | H |
| | 12 – in. $d_{50}$ | 5.1 | 10 – 13 | H |
| | 18 – in. $d_{50}$ | 7.6 | 12 – 16 | H |
| | 24 – in. $d_{50}$ | 10.1 | 14 – 18 | E |
| *Soil Bioengineering* | Wattles | 0.2 – 1.0 | 3 | C, I, J, N |
| | Reed fascine | 0.6-1.25 | 5 | E |
| | Coir roll | 3 - 5 | 8 | E, M, N |
| | Vegetated coir mat | 4 - 8 | 9.5 | E, M, N |
| | Live brush mattress (initial) | 0.4 – 4.1 | 4 | B, E, I |
| | Live brush mattress (grown) | 3.90-8.2 | 12 | B, C, E, I, N |
| | Brush layering (initial/grown) | 0.4 – 6.25 | 12 | E, I, N |
| | Live fascine | 1.25-3.10 | 6 – 8 | C, E, I, J |
| | Live willow stakes | 2.10-3.10 | 3 – 10 | E, N, O |
| Hard Surfacing | Gabions | 10 | 14 – 19 | D |
| | Concrete | 12.5 | >18 | H |

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

**A**. Chang, H.H. (1988).
**B**. Florineth. (1982)
**C**. Gerstgraser, C. (1998).
**D**. Goff, K. (1999).
**E**. Gray, D.H., and Sotir, R.B. (1996).
**F**. Julien, P.Y. (1995).
**G**. Kouwen, N.; Li, R. M.; and Simons, D.B., (1980).
**H**. Norman, J. N. (1975).
**I**. Schiechtl, H. M. and R. Stern. (1996).
**J**. Schoklitsch, A. (1937).
**K**. Sprague, C.J. (1999).
**L**. Temple, D.M. (1980).
**M**. TXDOT (1999)
**N**. Data from Author (2001)
**O**. USACE (1997).

*ERDC TN-EMRRP SR-29*

Source: Fischenich (2001)

If the channel banks are somewhat shallower (i.e., 3 feet or less) in relatively straight portions of the channel and on the inside of bends, vigorous herbaceous vegetation will likely provide adequate resistance to maintain adequate bank stability. However, on the outside of bends, more intensive treatments such as willow brush mattress and willow fascines will be needed. The ability of vegetative methods to resist erosion depends on bank geometry and local scour. Block failure is the dominant bank failure mechanism under existing conditions in Reach 5. These failures are caused by erosion of the lower (toe) and middle bank below the surface layer that is stabilized by roots. As the vegetated surface layer becomes undercut, shear strength in the soils is insufficient to support the bank, especially as water levels decrease river and pore water in the bank is still high. Under these conditions cantilever failure occurs and blocks of upper bank material fall to the toe. Because the vegetation and soil can fail intact, these blocks can form a vegetated toe along the channel that may persist for some time, but without a long-term benefit to bank protection (Figure 24).

An incised channel profile and excessive bank height contributes to this failure mode by exposing bank materials with low shear strength under the effective rooting depth to hydraulic forces. A shallower channel with the same vegetation type would be more resistant to this type of erosion, and a shallower channel with more dense, vigorous and/or deeply rooted vegetation would be much more resistant to this type of erosion.

Local scour at the outside of bends is also a factor in vegetated bank stability. Local scour may result in a bank height that extends above the summer water surface by several feet, especially where bank and bed materials are sandy and bends have a low radius of curvature relative to channel width. Because rooting depth typically does not extend very far below the saturated surface, a subaqueous portion of the bank comprised of sandy materials would have very low strength. If scour reaches a sufficient depth, failure of even a highly vegetated bank could occur. Controls against this type of failure include establishment of hydraulic roughness low on the bank to reduce shear stress and push maximum scour depths away from the bank.

More structural control measures might include installation of engineered large woody material structures, bendway weirs or rock vanes, and vegetated rock toe stabilization. Rock sizes for these types of structures depend on habitat considerations as well as hydraulic forces, and larger rock may be appropriate for hydraulic diversity or in-stream cover. Wherever harder structures are used, more intensive vegetative transitions will probably be required upstream and downstream to prevent localized erosion in the less resistant native bank materials. The feasibility of vegetative treatments to maintain bank stability depends on channel geometry, and a shallower channel would reduce shear stress, reduce scour potential in bends, and increase the effectiveness of some types of treatments on steeper banks such as expected on the outside of bends. Therefore, a shallower channel could substantially reduce the need for more structural types of bio-technical treatments

Installation of engineered instream woody material (IWM) structures might be a useful technique where lateral controls are needed in Reach 5. These structures may be vegetated, and may incorporate specific features to improve aquatic habitat. In the Reach 5 project area, such structures could be incorporated at locations where the new channel is in close proximity to (parallels) or crosses utilities, where it intersects the existing channel, and at the transition to Reach 6. IWM is not recommended as a bed stabilization technique at the utility crossings due to uncertain longevity, but it could be incorporated into the banks at the crossings to improve stability and aquatic habitat. However, it may be limited to locations that are in the forested portion of the reach.

Figure 24A: Upstream view near RS 182+00 on June 6, 2009 (about 123 cfs mean daily flow)

Figure 24B: Downstream view near RS 182+00 on August 18, 2009 (about 5 cfs mean daily flow)

**FIGURE 24: CANTILEVER STREAMBANK FAILURES ALONG THE UPPER TRUCKEE RIVER IN REACH 5**

## Floodplain Shear Stresses and Stability

Computed velocities across the floodplain surface are generally in the range of 1 to 2 fps for flood events up to the 5-year flow of 1,600 cfs. At the 100-year flow of 7,650 cfs, velocities reach 3 to 4 fps in a few locations and estimated average shear stress is less than 0.5 psf. These average velocities and shear stresses are within acceptable ranges for a vegetated floodplain. Significantly higher velocities than these general values could occur at locations where flow overbanks onto the floodplain or reenters the channel across the top of banks. The available 1-D HEC-RAS model results are not able to predict these locations or their hydraulic conditions. The recommended approach to 75 percent design would increase the importance of floodplain processes. A two-dimensional (2-D) model would provide critical guidance for design to address overbanking, reactivation of relict floodplain features, future return flow patterns, potential needs for protection of the backfilled existing channel, along with selection of appropriate vegetation treatments for areas to be disturbed by necessary grading.

## Biotechnical Bank Protection

### Effectiveness of Native Vegetation for Stabilization

There are a number of options for restoration and erosion control emphasizing soil bioengineering that have been used on other similar and successful projects in the Tahoe basin. However, the availability of particular resources in this project area may limit the options, as discussed below.

Stacked sod for new channel banks

This methodology, even if technically sound for construction of proposed new channel banks, is not an option for this project primarily due to lack of availability of usable material. Instead it is recommended that any sod salvaged be re-planted in strategic locations on the floodplain adjacent to the new alignment, especially in erosion prone areas such as tie-ins to the existing channel, or used in combination with other bank stabilization treatments. With respect to the utility of the stacked sod approach for construction of river channel banks, it is also appropriate to note that soil testing showed that the bulk density of a sample of the Salvageable Sod (Type A) (upper 8 inches) was only 0.636 g/cc, which is extremely low for any soil material to be used in an engineering application. Moreover, this sample had an organic content of 14.3 percent, plus an additional 2.2 percent (by weight) of living roots and rhizomes. When placed in a stack that is more than two or three layers thick the lower layers of the highest quality sod that is available in the Reach 5 area can reasonably be expected to compress significantly, and also ultimately lose organic content to decomposition in the somewhat aerated environment of a channel bank. In an application where some layers of stacked sod end up too high above the level of summer groundwater, much of the organic content might be lost and not replaced by new vigorously growing rhizomes, leading to dimensional shrinkage that is not desirable in an engineering application. This consideration exists to some extent in all applications, but is a greater concern where the bank is relatively high (e.g., the proposed 50 percent design) than it is where the bank height is much lower, and the sod vegetation has better access to soil moisture which supports additional rhizome development (e.g., some other projects in the southern Lake Tahoe basin such as Trout Creek).

Salvaged Sod

Notwithstanding the potential concerns relating to use of Suitable and Potential sod in a stacked sod application to construct new channel banks, this material would be excellent for use in a single layer for surface erosion protection in relatively frequently inundated floodplains. The material must be planted where the soil moisture regime will be favorable for summer-long growth (thus, should be more moist than the majority of the existing meadow area is now), and, in the case of Potential Sod material, a minimum of 2 years of growth under irrigation would be necessary prior to exposure to the design surface flow regime. There is insufficient erosion-controlling sod material available to cover the entire floodplain surface area, therefore the

available Suitable and Potential Sod material will be targeted at the most vulnerable areas such as along the top edge of new channel banks, at tie-ins, placed in bands extending perpendicular to the anticipated flow direction of overbank flooding where floodwaters are predicted to have higher velocities and/or within return flow channels from large meadow-wide flow events. When re-planted, sod should be arranged in a staggered pattern so that joints alternate and the seams are less vulnerable to erosion.

Willow brush mattresses

Mattresses are layers of willow branches anchored perpendicular to the flow line along channel banks. This is an excellent method for controlling bank erosion and creating habitat. However, it takes a few years of growth, supplemented with irrigation, before newly constructed banks can be deemed stable via the mattress. This method was used extensively on the Upper Truckee River Reaches 3 and 4, however, these reaches were constructed through areas that had existing extensive and dense stands of willows, allowing for easy salvage and reuse of the large supply of vigorous branches that is required for this treatment. In contrast, willows in Reach 5 are relatively sparse and the proposed 50 percent alignment would disturb very few existing willows. Off-site sources would need to be identified, harvested, and prepared for transplant at appropriate times during construction phases. This method is labor-intensive and cost would be increased (and possibly off-site environmental effects on willow scrub habitat for wildlife could result) by the need to import material.

Willow root wads

Root wads have been used extensively for erosion control and to create roughness as well as habitat in the floodplain. However, there is a lack of material in this reach, even in the existing channel. Disturbed willows and resulting roots wads, where available could be used as erosion control and habitat improvement features in the main channel at strategic locations.

Lodgepole pine root wads

Large root wads, particularly when connected to large wood, can be effective elements for erosion control (via hydraulic redirection and increased roughness) as well as in-channel habitat features. The proposed 50 percent design calls for the new channel construction to traverse some stands of lodgepole pines (*Pinus contorta ssp murrayana*) at the south end of the project area. Root wads generated by their removal could be used for bank stabilization in strategic locations in combination with other bioengineering methods.

Willow cuttings and poles

Willow cuttings and poles are also used for erosion control and habitat improvement but they take longer to establish and reach their effectiveness for erosion control in comparison to mattresses. Extensive use of cuttings and poles is proposed for this project, as a function of availability of quality material. A significant difference between the use of cuttings and of willow mattresses is that the latter provides some immediate energy dissipation, whereas cuttings provide little surface erosion protection initially; their function in bank stabilization is primarily from long-term development of a dense root network within the soil. Sole reliance on poles and/or cuttings would significantly increase the length of time needed for channel stabilization.

Willow Fascines

Willow fascines, also known as wattles, are linear cigar-shaped bundles of willow branches. These can be used for toe stabilization, but as with the mattresses, they require a lot of material to properly construct. They can be used in combination with other soil bioengineering. As with the poles and cuttings, fascines would not provide adequate bank stabilization as a stand-alone initial treatment since they don't protect the bank itself unless subsequent braches are anchored, as with the mattresses.

Imported native wetland sod

Given the size and extent of Reach 5, this is probably not a cost-effective method for this project. In addition, there are permitting and NEPA issues related to the fact that existing high-quality wet meadow vegetation must be excavated (off- site) in order to provide the material (with consequent mitigation requirements).

Propagated wetland mat/sod

This is not a cost-effective method for large applications such as this project, although it may be appropriate for site-specific, localized sections where the benefits of a rapid, effective shear-resistant biotechnical surface warrant the additional cost.

Soil wraps with geotextiles

Numerous riparian restoration projects in the Tahoe Basin, including restoration along Griff Creek, Snow Creek and Angora Creek have used this method for bank stabilization. It can be used in combination with willows and may be an alternative to willow mattresses for this project. Soil can be obtained from the new alignment excavation. Wraps can also be built in combination with willow branches.

Native seed and straw

The meadow is a likely good source of native straw and possibly seed. With proper planning, the material can be salvaged and reapplied as native straw. In addition, with enough lead time and resources, custom seed collection can either be implemented by in house staff or contracted out to regional seed specialists. These materials would be generated from vegetation types Potential Sod and Sod Starter for re-use in the floodplain.

Propagated wetland plugs

There does not currently appear to be an application for wetland plugs planting on this project, which is more commonly seen in wetlands restoration. It is likely that the goals that are normally achieved by use of this method are readily achievable by utilization of Suitable Organic Matter Salvage cover type material.

## Recommendations

### Channel Geometry, Vegetation, and Water Relationships

The proposed 50 percent channel design is based on a bankfull flow estimate of 450 cfs, literature-based hydraulic geometry relationships to select a channel width, and hydraulic design computations to estimate a stable slope under expected sediment loads. Each of these computational steps is subject to some uncertainty. The proposed 50 percent channel design would result in shear stresses at the bankfull flow that are higher than for existing conditions at the same flow. Critical grain sizes associated with these shear stresses are higher than the reported characteristics of bed material samples, except at the riffle sections where bed material may be coarser than material typically in transport.

Detailed sediment transport modeling has not been performed, and very limited data is available on sediment supply from upstream. Observations from the historical analysis and previous reports indicate that coarse sediment supply from upstream may be decreasing, which could drive the appropriate hydraulic design toward a smaller channel or lower slope. Although the absolute values of various hydraulic parameters include uncertainty, the relative differences between existing and proposed conditions can provide a reliable indicator of expected behavior of the proposed channel in the context of existing or historical behavior. The channel is believed to have undergone enlargement and incision in the past, and the relative increase in shear stress from existing to proposed conditions indicates some risk that this could reoccur if the new channel is constructed with similar slope and planform to the existing channel.

The hydraulic geometry for the proposed design assumes that the banks are resistant to erosion, although the native bank materials are relatively low in hydraulic resistance and at the proposed bank heights will not resist hydraulic forces without reinforcement, especially around the outside of bends. Bank stability under proposed conditions therefore depends largely on successful revegetation and installation of bio-technical measures, and this is difficult at the proposed heights due to distance above summer water levels and suitable soil moisture.

The key elements of the proposed 50 percent channel dimensions relationships to bank height, vegetation rooting depths, and surface and groundwater elevations are depicted in Figure 25.

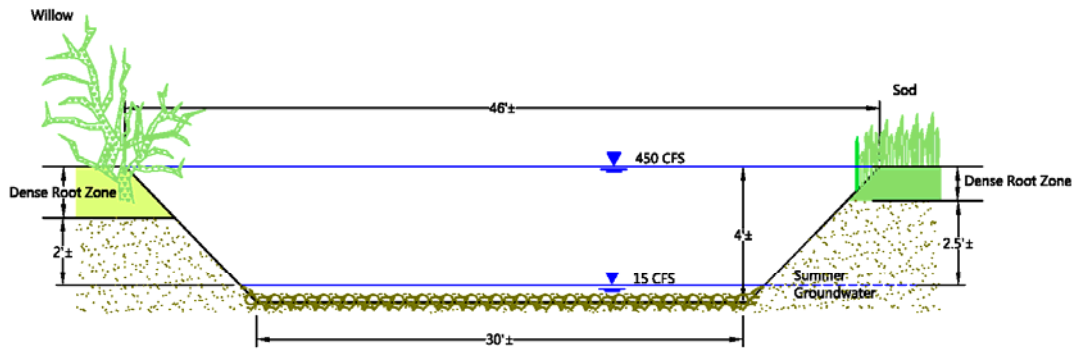
Several aspects of our analyses support a recommendation that the 75 percent design move towards a smaller capacity, shallower channel. This modification could reduce channel shear stress and scour potential, make vegetative stabilization of banks more feasible, and increase the frequency of inundation of the floodplain surface. The channel must be adequately sized to convey the estimated bedload, and refinements of sediment supply estimates are recommended to provide necessary sensitivity testing on proposed design changes. The improved bank height, vegetation rooting depths, and surface and groundwater elevations that would result from a conceptual modified channel dimension for the 75 percent design are depicted in Figure 26.

While the specific information and treatment details for the 75 percent design have yet to be developed, the conceptual shift in channel dimension and relationships illustrated in Figure 26 would be carried into the next steps of design analyses. The recommended approach, rationale, additional data and/or methods are discussed below.

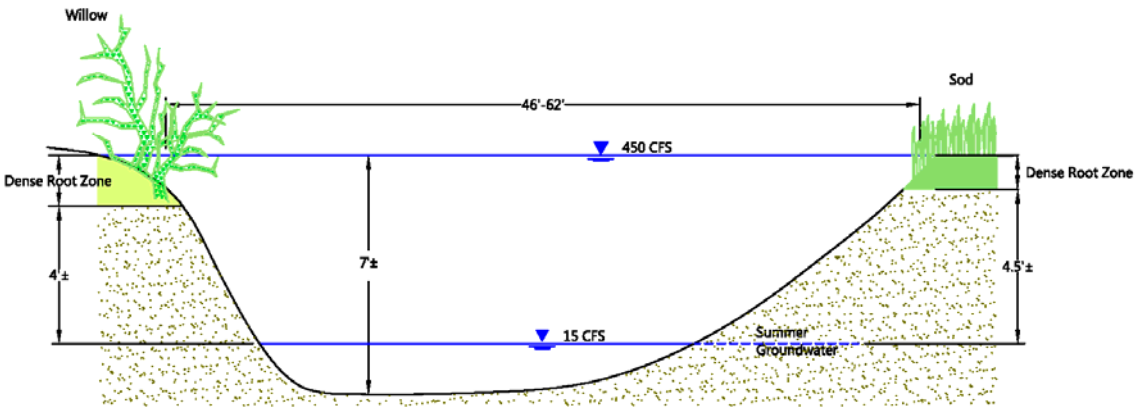
## Bed and Bank Treatment Options

While the specific measures to be applied as bed and bank treatments for the proposed new channel will be further analyzed and selected during the 75 percent design process as part of Subtask 2.1.b, a variety of treatment options will be considered. A baseline of options available for the Project are listed in Table 16. This "toolbox" of treatment measures will be expanded upon and refined by researching and adding new techniques that may be advantageous and feasible and eliminating any options that are deemed infeasible due to reasons such as high cost, inappropriate for setting or low rate of success.. The options listed so far are wide ranging and include measures that might only be applied on a very limited scale within the Project area along with other measures that may be useful on a more widespread basis. Some of the treatments may be used on floodplain or upland revegetation, but the focus of this list is on potential channel margin treatments.

Combinations of several of the prescriptions will be considered. Combinations are beneficial in areas that require both bed and bank stabilization and habitat improvement. Combinations will aid transition areas by providing a variety of materials to work with when moving from the softer existing bank substrate to the harder installations. Regardless of final bed and bank treatments selected, any new channel alignment would require irrigation for a minimum of two years in order to develop a vigorous rhizome and root network that is of sufficient density and strength to provide adequate erosion protection for flows that are expected to occur relatively frequently, and to minimize the likelihood of channel avulsions or erosion of return channels as a consequence of large, uncommon flow events.



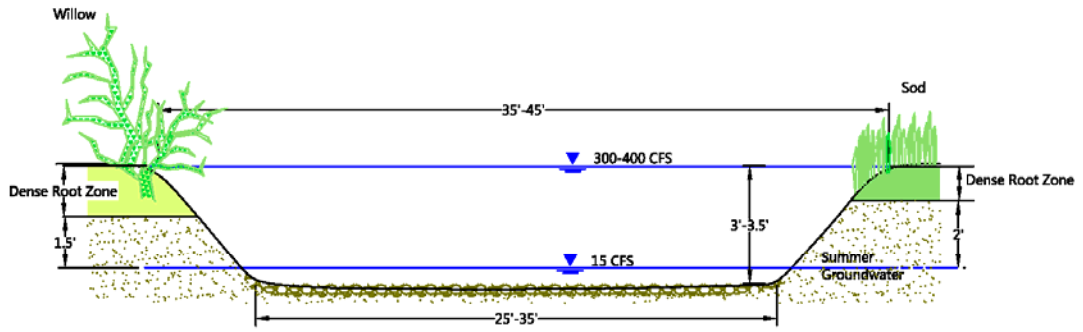

A. Riffle Channel Relationships
(50% Design)



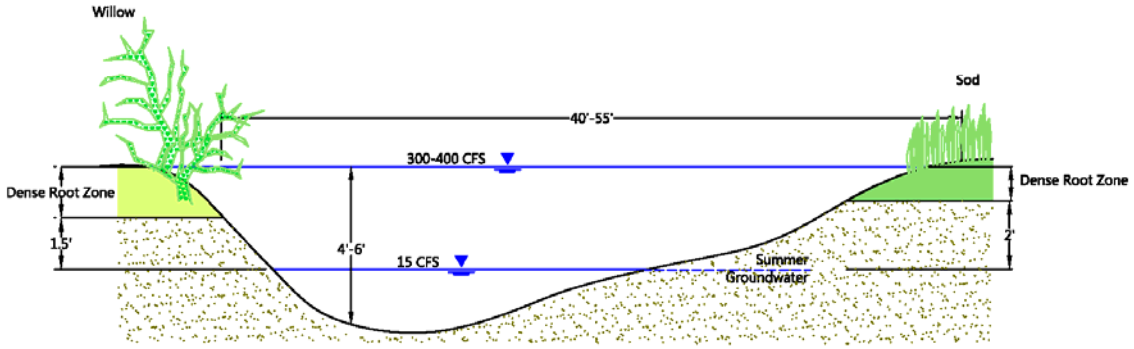

B. Pool Channel Relationships
(50% Design)

Note: These sketches are intended to represent the proposed channel dimensions and resulting anticipated streambank heights, dense rooting zones for varied vegetation types, and low flow surface and groundwater relationships. The sketches do not include particular treatment types or details that might be applied to bed or banks.

**FIGURE 25: CHANNEL DIMENSION RELATIONS TO BANK HEIGHT, VEGETATION ROOTING DEPTH AND WATER ELEVATIONS: PROPOSED 50 PERCENT DESIGN**




A. Riffle Channel Relationships
(75% Concept)




B. Pool Channel Relationships
(75% Concept)

Channel capacity decreased to improve floodplain connectivity, maintain higher thalweg elevation, reduce boundary shear stress and improve channel stability. Lower banks and shallower depth to summer surface water and groundwater to increase effectiveness of vegetation for bank stabilization.

Note: These sketches are intended to represent the proposed channel dimensions and resulting anticipated streambank heights, dense rooting zones for varied vegetation types, and low flow surface and groundwater relationships. The sketches do not include particular treatment types or details that might be applied to bed or banks.

**FIGURE 26: CHANNEL DIMENSION RELATIONS TO BANK HEIGHT, VEGETATION ROOTING DEPTH AND WATER ELEVATIONS: CONCEPTUAL 75 PERCENT DESIGN**

**TABLE 16: BED AND BANK TREATMENT OPTIONS**

| Treatment | Description | Benefits/Applications | Limitations |
|---|---|---|---|
| Native Seed and Straw | Use of native seed and straw for providing ground cover and protection from wind and water erosion. | The meadow is a likely good source of native straw and possibly seed. With proper planning, the material can be salvaged and reapplied as native straw. Application would target disturbed meadow surfaces or upland areas and decommissioned haul roads. | Straw provides initial protection from wind erosion, but not from concentrated flows. Requires a few years of growth before plants from seeds provide erosion protection. |
| Erosion Control Blanket | Pre-formed protective blanket or netting made of straw or jute anchored in the ground to protect soil from the impact of precipitation and surface flow. | Blankets are used typically in combination with native or commercial seeding applied underneath. May be placed in strategic locations along sloped banks or in secondary floodplain channels where blankets are appropriate for the calculated velocities. | Can be a high cost if extensive areas require covering. Depending upon thickness and composition, some blankets hinder plant growth. |
| Salvaged Sod Blocks | Native wetland plant material salvaged onsite and placed in areas with adequate soil moisture regime in order to provide surface erosion protection. | Ideal for re-planting in a single layer along strategic locations in the floodplain adjacent to the new alignment. Vulnerable areas that could be targeted include along the top edge of new channel banks, at tie-ins, placed in bands extending perpendicular to the anticipated flow direction of overbank flooding and within return flow channels from large meadow-wide flood flow events. | Area of application will be limited by on-site material availability. Currently 2.66 acres of Salvageable Sod and 3.86 acres of Potentially Salvageable Sod. |
| Stacked Sod Revetment | Anchored salvaged sod blocks stacked in brick-work pattern to form bank stabilization | A good application for stabilizing banks on small meadow streams with shallow depths, high soil moisture, and available sod material. | Extensive use of Stacked Sod for this project is limited due to proposed new channel bank heights and lack of availability of usable material. Further consideration should be given to using it in combination with other treatment methods at strategic locations. |
| Enhanced Wet Meadow Vegetation | Herbacous native plants planted as sod and/or seed generally at the top/crest of bank. | A good application for stabilizing banks with shallow depths, high soil moisture. Will be targeted on banks with lower calculated shear stresses, such as banks along the inside of meander bends. | Rooting depth effectiveness limits, need for appropriate hydrology and time to reach maturity. |

| Treatment | Description | Benefits/Applications | Limitations |
|---|---|---|---|
| Willow Brush Mattresses | Mattresses are layers of willow branches anchored perpendicular to the flow line along channel banks. | Excellent biotechnical method for controlling bank erosion and creating habitat. When installed correctly they can provide immediate energy dissipation. Appropriate for channel restoration within sandy soils and open meadow habitat. Will likely target banks where shear stresses are higher than the existing substrate will tolerate, for example along the outside of meander bends. | Requires a few years of growth, supplemented with irrigation, before newly constructed banks can be deemed stable via the mattresses. Willows in Reach 5 are relatively sparse and offsite sources such as Reach 6 would need to be identified, harvested, and prepared for transplant at appropriate times during construction phases. This treatment and other willow treatments described below need to be implemented tactically to prevent forming homogenous "willow-lined" channels and preserve open areas and variability. |
| Willow Root Wads | Salvaged and planted root balls from willows that are disturbed to create roughness as well as habitat in the floodplain. | Disturbed willows and resulting root wads, where available could be used as erosion control and habitat improvement features in the main channel at strategic locations. | There is a lack of material in this reach, even in the existing channel. |
| Willow Cuttings and Poles | Willow cuttings and poles can also provide erosion control via development of a dense root network within the soil over time. | Extensive use of cuttings and poles is proposed for this project, as a function of availability of quality material. Willow cuttings will likely be used in combination with several other treatment measures. | Willow stakes and poles provide little erosion protection initially and take longer to establish and reach the same effectiveness as willow mattresses. Sole reliance on poles and/or cuttings would significantly increase the length of time needed for channel stabilization. |
| Willow Fascines | Linear cigar-shaped bundles of willow branches also known as wattles. | They can be used for toe stabilization and also in combination with other soil bioengineering. If used, would combine with other treatment measures or use where shear stresses are not too high since they don't provide structural protection as quickly as willow brush mattresses. | Similar to the mattresses, they require a lot of material to properly construct. As with the poles and cuttings, fascines would not provide adequate bank stabilization as a stand-alone initial treatment since they don't protect the bank itself unless subsequent braches are anchored, as with the mattresses. |
| Propagated Wetland Mat | Specialized mat with wetland plugs propagated off-site prior to placement. | May be appropriate for site-specific, localized sections where benefits of a rapid, effective shear-resistant biotechnical surface warrant the additional cost. | Not a cost-effective method for large areas of disturbance. |

| Treatment | Description | Benefits/Applications | Limitations |
|---|---|---|---|
| Soil Wraps with Geotextiles | Soil wrapped with geotextile to provide reinforcement and installed along the toe or bank to prevent scour and erosion. | It can be used in combination with willows and may be an alternative to willow mattresses for this project. Soil can be obtained from the new alignment excavation. Wraps can also be built in combination with willow branches. | Application can be complex and expensive. |
| Propagated Wetland Plugs | Wetland material taken from the area and propagated off-site for replanting as individual plugs. | The goals that are normally achieved by use of this method are readily achievable by utilization of Suitable Organic Matter Salvage cover type material. | This application is more commonly seen in wetlands restoration. |
| Instream Woody Material Structures (IWM) | Salvaged trees can be positioned and placed along the banks and in the bed in a variety of ways for increased channel roughness, bed or bank stability, re-direction of flow and/or in-channel habitat features. | Large trees with root wads can be effective elements for erosion control (via hydraulic redirection and increased roughness) as well as in-channel habitat features. Lodgepole pine trees with intact root wads generated by removal where the new channel traverses existing stands at the southern end of the project could be used for bank stabilization in strategic locations in combination with other bioengineering methods. | Given the non-cohesive, sandy soils tying in of any large wood structures will require special attention to avoid increasing instability on either end and/or erosion behind the structure at the native material interface. |
| Constructed Riffle | Engineered riffle section with appropriate particle size distribution, overall morphology, and volume of material to meet target recurrence interval peak event stability. | Recommended for buried utility crossings and downstream reach transition. Use graded, cobble-sized material (3" to 9") with gravel in the interstices and larger (12"-18") rock incorporated into the subsurface. | Limited availability of on-site gravel and cobble resources; all material would require import. |
| Rock Cross Vanes/Boulder Weir | Grade control structure of rock material that completely crosses the channel with appropriately sized rock for target recurrence interval peak event stability. Decreases near bank shear stress and redirects the energy to the center of the channel. | Installations can maintain grade control and width to depth ratio, reduce bank erosion, and provide improved aquatic habitat via pool creation. If used, would only be in steepest sub-reach, such as downstream transition, but only if hydraulic modeling indicates necessity. | More intensive vegetative transitions will be required to prevent localized erosion where the installation ties into the less resistive native bank materials. Special attention to placement along the bed is important to avoid potential undermining. Given the meadow setting an extensive use of rock in the channel would not be appropriate. If used at all, it should be kept to a minimum. |

| Treatment | Description | Benefits/Applications | Limitations |
|---|---|---|---|
| Bendway Weirs / Rock Vanes | A rock vane keyed into the outer bank of a bed with a gradually sloping upstream profile angled to direct flows away from the bank. | Installations may be beneficial at bends in close proximity to the airport and/or at buried utilities where bank failure is not an option. | Similar to rock cross vanes, these are hard structures where careful consideration must be paid to the transitional areas and seams to avoid redirected erosion to less resistant bank materials.<br>Given the meadow setting an extensive use of rock in the channel would not be appropriate. If used at all, it should be kept to a minimum. |
| Vegetated Rock Toe Bank Protection | Specified-sized rock placed at the toe-of-bank with vegetation incorporated into the joints and immediately above. | Installations may be beneficial at bends in close proximity to the airport and/or at buried utilities where bank failure is not an option. | Careful consideration of how to transition in and out of areas with this application will be critical to avoid erosion at the seams and the upstream/downstream transitions.<br>Given the meadow setting an extensive use of rock in the channel would not be appropriate. If used at all, it should be kept to a minimum. |
| Vegetated Rock Slope Protection | Specified-sized rock placed on the surface of a slope, with vegetation incorporated into the joints throughout. | May be needed in localized sites where lateral bank erosion cannot be tolerated (such as at pipeline crossings). | Limited vegetation growth potential, inconsistent with 'natural' landscape features and requires hydraulic transition to be treated carefully, as for the Vegetated Rock Toe Bank Protection. |
| Launching Rocks | Buried rock in the bank and/or under the bed designed of sizes, thickness, and volume anticipated to be needed to launch into a predicted scour hole. | May be needed in localized sites where lateral bank erosion or vertical bed erosion cannot be tolerated (such as at pipeline crossings). | Given the meadow setting an extensive use of rock in the channel would not be appropriate. If used at all, it should be kept to a minimum. |
| Geoweb/Geogrid | A cellular confinement system that stabilizes slopes or steep banks where sloping options are prohibited via "honeycomb" like system of anchored soil/vegetated cells. | Typically used for very steep banks or where shear stress is very high, but may be planted with vegetation (as opposed to rock rip rap at the same angle). | Unlikely to be suitable for this site, and would only be considered for specific areas where erosion potential is extremely high, such as the base of the eroded side slope near the downstream end of the site. |
| Rock Ramp Fishway | Placement of rock to provide for fish passage and habitat, typically in locations where there are steep drops in the channel or fish passage impediments. | Can be designed to simulate natural step-pool configurations where bed grade control is required, but fish passage must be maintained. | Given the low gradient and sandy channel bed throughout much of the reach, these types of installations are not necessarily needed, and the constructed riffles are likely sufficient and better suited. |

| Treatment | Description | Benefits/Applications | Limitations |
|---|---|---|---|
| Buried Boulders/Rock | Specific-sized rock installed below grade (and below rooting zone) at the crossings of the existing channel by the proposed higher bed elevation new channel. | Protects against backfilled channel re-capture by surface flow and/or controls the rate of down valley/down channel groundwater flow. | Rigid material and/or high resistance required that differs from surrounding sediment. |
| Buried Sheet Piling | A series of panels with interlocking connections, driven into the ground (below grade (and below the rooting zone) with impact or vibratory hammers to form an impermeable barrier at the crossings of the existing channel by the proposed higher bed elevation new channel. | Similar to buried boulders/rock, to prevent backfilled channels from being recaptured by surface flows and modifies rate of groundwater flow. | Rigid and non-natural material and/or high resistance required that differs from surrounding sediment. |
| Buried Compacted Soil Lenses or Layers | Specified soil types installed below grade (and below rooting depth) within backfilled channel segments | Within backfilled channel segments, simulates natural variations in groundwater transmissivity to control the rate of vertical and down valley/down channel groundwater flow. | Imported fines (including clay) may be needed to provide adequate compaction and low permeability. |

## 75 Percent Design Elements

Our recommended design concept will increase the emphasis on maintaining a stable channel with more active floodplain dynamics by improving the ability of biotechnical stabilization of the channel margins to be successful. The recommended design development will build on the information that led to the 50 percent design, but add some key new data, design refinements and additional analyses that the studies herein indicate are critical for achieving project goals and objectives. Some of the recommended key elements of the 75 percent design process based on the hydraulic analyses reported in this section are described below.

The bed material samples from existing riffles are considered to provide appropriate gradations for construction of riffle or crossover areas of the channel. Although this material may be slightly coarser than the bed material typically in transport, its use would assist in providing initial stability and improving aquatic habitat. Wherever resistant structures are installed, intensive vegetative or bio-technical treatments will be needed upstream and downstream to transition to the more erodible vegetated banks.

At the transition to the Airport Reach downstream of Reach 5, velocities and shear stresses are locally higher than in the remainder of Reach 5 under bankfull flow conditions. Grade control structures in the form of cobble riffles are recommended in this area, particularly if the channel planform design remains similar to the 50 percent design. A single grade control is shown in this location in the preliminary plans, but multiple smaller drops are preferable to improve reliability and passage for aquatic organisms.

Computed velocities across the floodplain are generally low, but locally higher velocities may occur in areas where flows overbank the channel onto the floodplain or return to the channel over the top of banks or in return swales. The 1-D HEC-RAS model is not able to simulate these hydraulic conditions. Given that a major benefit of the Reach 5 project could be reactivation of the floodplain and increased diversity associated with shallow topographic features, a 2-D model is recommended to assist and optimize the design to meet this objective while minimizing the potential for excessive erosion of the floodplain or head cutting of the channel banks.

Because the 2-D model geometry is represented by a mesh or grid, the entire channel and floodplain surface is represented. A 2-D model therefore captures the interaction between channel and floodplain flows more accurately and can provide information on the distribution of flows and velocities on the floodplain. We feel this is a very valuable tool for assessing floodplain dynamics, especially in more frequent flows, including the potential for minor scour and deposition. The 2-D model can relatively easily be used to identify potential overflow and return flow characteristics over a range of flows, thus helping to visualize floodplain hydraulics and support channel design, grading, and vegetation application. Although the 2-D model is a more sophisticated tool, its application could be less time intensive and more accurate than attempting to model floodplain flows in HEC-RAS. The available LiDAR data provides the basic geometry needed to construct the floodplain portion of the model using automated routines. Proposed channel geometry and vegetation (roughness) characteristics would be input on the basis of other steps in the 75 percent design process. 2-D modeling would be for the proposed condition only to conserve effort and focus on optimizing the performance of the proposed channel, not identifying potential adverse impacts.

Although many sediment transport calculations were performed in the previous ENTRIX analyses, little information is presented on sediment supply to the reach. The 50 percent hydraulic design (channel sizing calculations) relied on two sets of bedload measurements that differed by an order of magnitude and measured very different grain size distributions. Bedload is a key parameter in the stable channel approach used to size the 50 percent design channel, but measurements in a mixed sand-gravel stream are difficult, and many measurements (over a wide range of flows and/or years) might be needed to develop a reliable understanding of bed load supply. Additionally, there are upstream restoration

projects proposed that may modify coarse sediment delivery to Reach 5, at least for a period of years during channel adjustments and there may be continuing watershed trends in sediment supply that cannot be verified with a couple of added data points. Therefore, while additional field data collection would be beneficial, it would probably not provide a definitive estimate of future bed material supply. Instead, we propose to use sediment transport calculations representing the upstream reaches (Reach 6 and the golf course reach) as a way to assess the sensitivity of the revised channel design to variability in sediment supply. The calculations would also allow us to consider change that might occur in the future, including general decreases in sediment supply from the watershed, and implementation of the planned projects upstream.

HEC-RAS modeling should be used to supplement the 2-D modeling for some of the simple hydraulics and to perform sediment transport calculations for sensitivity testing the design to varied inputs from upstream.

# VI. ACCESS AND STAGING

Access and staging must be delineated in a way to facilitate construction, permits, and approvals, while protecting important environmental and cultural resources and essential utility infrastructure. Within the project area are a network of South Tahoe Public Utility District (District) water, wastewater and treated effluent pipelines and associated easements, neighborhood and public access trails, identified cultural and historical resources, and sensitive meadow and stream environment zones. The temporary construction access and staging locations described below for the proposed project will continue to be refined during 75 percent design development and into final design.

## Background

### Landownership and Agreements

An Access License Agreement (Agreement) is being developed between the Conservancy and the LTBMU in order for the LTBMU to initiate and lead the Reach 5 Project construction on the portion of Reach 5 lands owned by the State of California. The Agreement will also provide for access through Conservancy lands and for use of the Elks Club parking lot as a staging area. The adequate treatment of existing utility easements needs to be considered in terms of protection and preservation requirements and this information is key to the final drafting of the Agreement.

A "use agreement" may also be required from the City of South Lake Tahoe prior to filling in the existing channel segment that impinges on the airport runway.

### Utility Lines and Easements

Existing utility line locations within the Project area were identified during 50 percent design from utility as-built information in hard copy and image file format and a field survey by ENTRIX staff of the gravity sewer manholes in proximity to the existing and proposed channel locations in the Reach 5 area. These locations are displayed on plan sheets C-1 through C-4 of the 50 percent design plan set (ENTRIX 2008d) along with the proposed new channel alignment. However, they are absent from the plan sheet C-6 (staging and access). Designations of utility easements corresponding to each utility line were not presented in the 50 percent plan set.

During a December 22, 2009 Reach 5 coordination meeting with the LTBMU, Conservancy, and the District and members of the project team this requirement was discussed and the District offered to provide what information they had. Hardcopies of legal descriptions covering easement and parcel ownership descriptions were provided and laid out in CAD only to discover almost all of the legal information provided occurred outside of the Project area. Hardcopy and image files of the as-built conditions for the treated effluent force main

(Hill 1968) show an easement location and width and it is thought there are similar image files of the water and sewer gravity lines that would also display related easements. There is a current request to the District for these additional files. Further discussions with the LTBMU and Conservancy will be held prior to developing 75 percent design plans in order to determine if an approximate location and width of the utility easement can be shown on the plans based off existing as-built image files or if the legal definitions for all easements within the Project area need to be located, assimilated and drafted in CAD in order to meet the objectives of the Agreement and ensure adequate protection.

## Considerations

### Public Utility Avoidance/Protection

Based on communications during the December 22, 2009 coordination meeting, the District is not opposed to construction access occurring within their existing easements or temporarily crossing existing utility lines as long as the easements and pipelines are fully preserved and protected. The District requested that prior to finalizing 75 percent design, the proposed access and staging areas be shown on the same plan sheet as existing utility locations and easements and areas where the access would impinge upon or cross the existing utilities be noted. The 75 percent design should also include and present protection measures for the District to review/revision/approval to ensure utilities would not be compromised or damaged by construction activities, including: passing vehicles and equipment; stockpiling; grading; and, excavation.

### Sensitive Habitat Avoidance/Protection

A concentrated effort will be made to place all temporary haul roads and staging areas outside of sensitive resources and take advantage of already disturbed areas for access and high capability lands for storage. Field fitting in combination with high resolution aerial and topography information and designated TRPA land capability designations will be used throughout design development to ensure sensitive areas are avoided to the highest degree possible. Values for earthwork quantities, dewatering volumes, and imported storage quantities will be calculated and refined during 75 percent development through final design in order to size staging areas appropriately and minimize their footprint wherever possible. Peer review by the vegetation specialist will occur at each design development stage in order to ensure via avoidance and targeted protection measures haul routes and staging areas do not impact sensitive vegetation.

### Heritage Resource Avoidance/Protection

Cultural resource investigations have been conducted in the Reach 5 project area in various phases of the Sunset Stables RRMP process, including initial inventories (Lindström and Rucks 2002, 2003, and 2004), pedestrian surveys (ENTRIX 2005), record and sacred lands searches, followed by updates to the inventory and recordation in 2008 (with determination of significance and eligibility of sites for inclusion in the National Register of Historic Places 9NRHP) and California Register of Historic Resources (CRHR). The confidential mapped inventory of known cultural resources for the entire project boundary provided by ENTRIX has been reviewed as an electronic image file that depicts historic and pre-historic sites/features. The proposed 50 percent new channel alignment project could potentially require work in the vicinity of two locations with sensitive resources (site 58-Bedrock Milling and site 34-CTC Bike Trail), and if changes to alignment, access, staging, or vegetation salvage locations are contemplated during 75 percent design, a review for possible sensitive cultural resource sites will occur. The recorded locations in GIS would be cross checked electronically as well as visually prior to 75 percent design plan preparation. Measures required for mitigation as part of the environmental documents will be integrated in design and specifications once the measures are approved by lead agencies. Additionally, coordination with the LTBMU heritage resource staff will occur to formalize preferred protection measures and identify areas to be flagged and avoided, if necessary, during construction.

# Results

## Access Routes

Preliminary haul routes have been identified based on avoiding the existing gravity sewer line and treated effluent force main as much as possible to reduce the number of areas where additional protection measures would be needed (Figure 27). Two main haul routes are proposed at this time. The first starting on the southern project area boundary along Elks Club Road is a slightly modified version of one presented in the 50 percent design. A second access is proposed at the end of Washoan Boulevard to improve accessibility for construction of utility line modifications in the northern portion of the site. The northern access road would cross the Upper Truckee River via a temporary bridge. A cultural resource feature (i.e. milling stone) just south of the Washoan Boulevard entrance should easily be avoided as long as the access route remains within the current Project boundary.

It is difficult to create a haul route that avoids the utility lines and easements completely given the nature of their location, construction and maintenance has resulted in more disturbed and open areas along their alignment which provides for more useful and easier access. The southern haul route would need five crossings, two across the gravity sewer line and three across the treated effluent export line. The northern haul route at the end of Washoan Boulevard would cross the sewer gravity line in two locations.

The preliminary haul routes and staging areas do not appear to pose significant problems to vegetation with the majority of road going through dominant Potentially Salvageable Sod (Type B) and Suitable Organic Material (Type C) vegetation with very little Salvageable Sod (Type A) impacted. This alignment will be further adjusted and later staked in the field to avoid Salvageable Sod (Type A) vegetation. Sandy areas and the gravel barren will also be avoided in similar fashion to minimize any potential erosion impacts. Any sections of road that require travel through wet or sensitive meadow habitat will be identified on the 75 percent plans and installation of a specialized road surface (e.g. gravel or other appropriate base encapsulated with geotextile fabric, pre-fabricated mat, or other) will be required. Where the haul route runs along previously disturbed upland surfaces a specialized road installation won't be needed, however some type of delineation, such as t-posts with flagging, may be needed in order to keep trucks and equipment on the designated road and off of sensitive areas.

As we move into 75 percent design development, the easement locations will be designated on the plans per guidance provided by the LTBMU and the Conservancy, and the haul route locations will be further refined based on the easement information and any adjustments made to the proposed new channel design. Modifications will also be made to avoid encroachment upon sensitive plant species, wetland or open water habitat and/or to incorporate specific protections required by environmental permits and approvals. Where the haul route crosses or impinges on utility lines, specific protection measures will be identified in the plan sheets and specifications.

## Staging/Storage Sites

Two of the three staging areas that were previously presented in the 50 percent plans have been maintained as options as potential areas (Figure 27): the former Elks Club parking area and an open area within Reach 6 just southeast of Reach 5. The Sunset Stables fill area along U.S. Hwy 50 was eliminated from the potential locations at this time to avoid the need for a second temporary bridge. However, this option should remain as part of environmental review, if later design considerations require another staging area due to cost, environmental, or other construction needs.

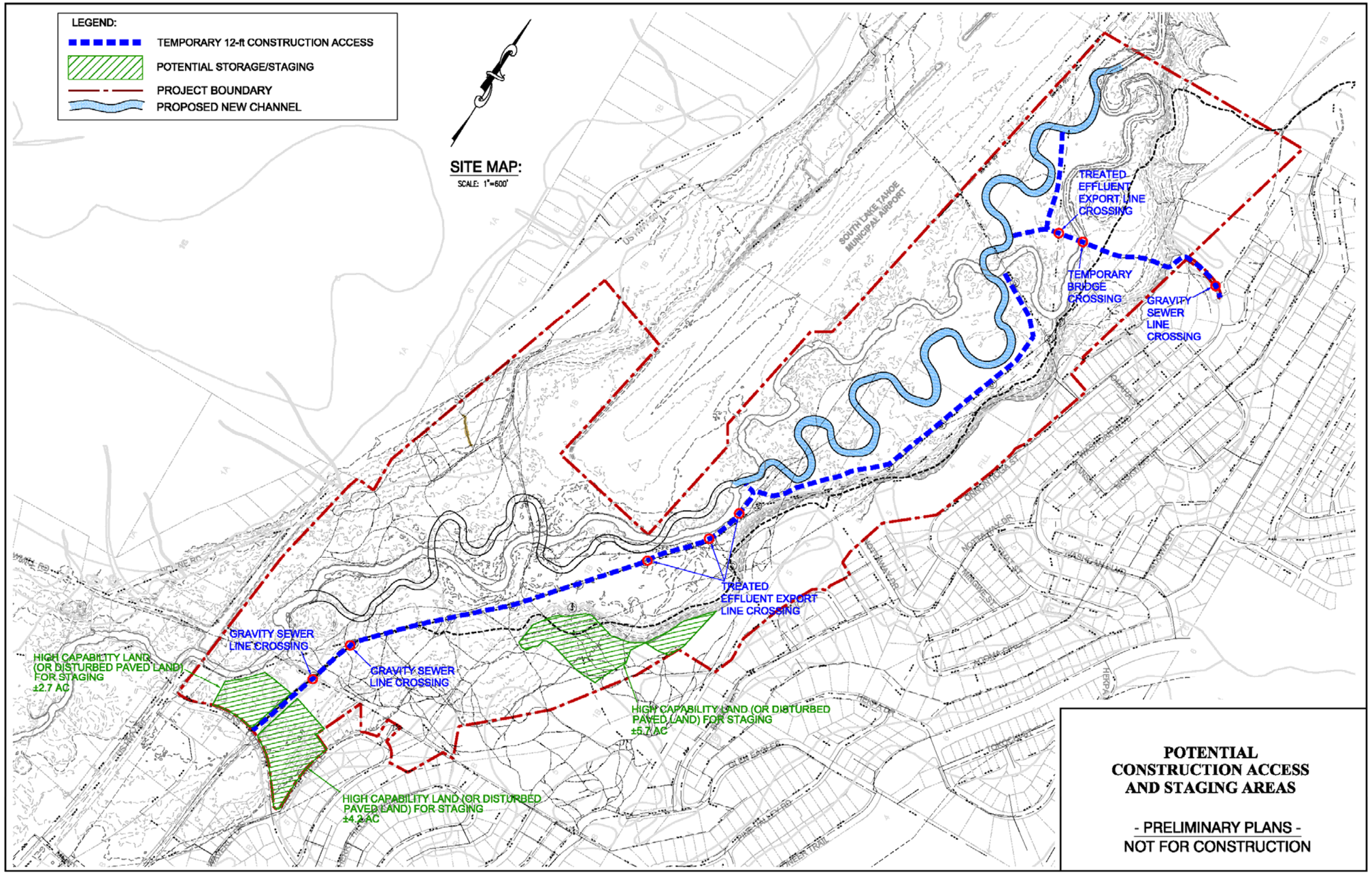



**FIGURE 27: POTENTIAL CONSTRUCTION ACCESS AND STAGING AREAS**

Staging area locations and size (Figure 27) are proposed to remain within the current project boundary. They will continue to be refined during 75 percent design development based on any adjustments made to the proposed new channel design and information determined regarding footprint requirements, as well as the imported and salvaged material transport and stockpile needs. Adjustments will also be made as necessary to avoid any encroachment upon sensitive biologic and/or cultural resources to meet environmental permit requirements.

### Pre-Construction Flagging

Although improvements in the mapping of utilities, easements, and sensitive resources are expected to occur during the 75 percent design process, inaccuracies and variations in images or geo-registered data versus field conditions can occur. Field flagging of the proposed haul routes and staging and storage sites by the design team prior to the start of construction is recommended to improve upon utility avoidance and adequately specify biologic and cultural protection measure locations.

# VII. Multiple Reach Flood Hydraulics

## Approach

Restoration of the channel in Reach 5 has the potential to affect flood water surface elevations and velocities in the river reaches downstream and upstream of the project. Previous hydraulic analysis and modeling completed by ENTRIX (2008a) indicates that small increases in water surface elevation and inundation area would occur due to the project. The LTBMU requested an assessment of potential flood impacts, with an emphasis on screening for increased velocities and scour at the downstream transition to the Airport Reach. The objective of the flood hydraulics evaluation presented here is not to estimate flood inundation areas and elevations, as these have already been mapped by ENTRIX. However, where helpful in explaining analysis of the upstream and downstream transition portions of the previous results they are briefly summarized below.

This analysis is not intended to determine whether a significant flood impact would result from implementation of the proposed Reach 5 improvements on its own or in combination with the City's recently constructed project (i.e. Airport Reach) downstream. The environmental documents for the project are being completed by others, and will include an evaluation of flooding impacts. The LTBMU acknowledges that minor changes may occur which increase the frequency or elevation of flooding to some degree on adjacent or downstream property. The main objective of this analysis is therefore to evaluate whether the project design in Reach 5 influences hydraulic conditions in the downstream reach during floods, and the main focus of this evaluation is the transition between the two projects.

Flood peak attenuation by storage across the broad floodplain would likely occur and the project may change the degree to which this occurs. However, unsteady flow hydraulic modeling or flood hydrograph routing is necessary to assess any hydrograph changes associated with floodplain storage modification. This level of analysis has not been requested by the LTBMU at this time, but further quantification and description of potential impacts based on steady state conditions modeling is desired. Because steady state hydraulic analysis and modeling has already been completed (ENTRIX 2007b, 2008a), the approach for this assessment primarily involves review and interpretation of available information.

# Methods

## Literature and Model Review

As noted in Section V, several previous reports and memoranda were completed for the Reach 5 as a subset of the entire Sunset Stables project reach. These data provide information on existing and proposed channel hydraulic conditions. The Conceptual Channel Restoration Design and Hydraulic Modeling Report (ENTRIX 2008a) provides water surface profiles at several different discharges for existing channel conditions and for Alternative 3, which is the alternative that most closely represents the proposed 50 percent design. ENTRIX also provided hydraulic model digital files in HEC-RAS format for the entire 'middle reach' of the Upper Truckee River. The hydraulic model extends from Reaches 1 and 2 downstream at the Highway 50 crossing, through the Airport Reach (Reaches 3 and 4) and the Sunset Stables Reach (Reaches 5 and 6) to about 1,500 feet upstream of the Highway 50 crossing at Elks Club Drive. The modeled reaches cover approximately 28,000 lineal feet of existing channel length.

The hydraulic model files include a HEC-RAS plan representing (1) the Constructed Airport Reach (Reaches 3 & 4) plus Existing Conditions for Sunset Stables (Reaches 5 & 6) Existing Conditions; and, (2) the Constructed Airport Reach plus Alternative 3 for Sunset Stables (ENTRIX, pers.comm., March and April 2010). Both models include a range of flows between 450 cfs and 7650 cfs, and the Alternative 3 model includes additional flows down to 5 cfs.

The results provided in the Conceptual Channel Restoration Design and Hydraulic Modeling Report (Hydraulic Modeling Report) and in the hydraulic models for the Airport Reach were reviewed to assess potential flood impacts of implementing the proposed 50 percent design on the Airport Reach.

# Results

## Alternative 3 Flood Hydraulics

The hydraulic conditions during flood events for the proposed Alternative 3 in Reach 5 and the transition to the Airport Reach are summarized below. Two subsequent sub-sections compare water surfaces, inundation area, and transition hydraulics in the proposed condition to those under existing conditions.

The Hydraulic Modeling Report (ENTRIX 2008a: Appendix K) includes figures showing areas of inundation for the existing and proposed Alternative 3 conditions mapped by the HEC-GeoRAS software for 450, 760, 1,600, and 7,650 cfs flows. These flows correspond to flood frequency recurrence intervals of 1.4, 2, 5, and 100 years (See Table 13 above). Selected figures reproduced from the Hydraulic Modeling Report's Appendix K are provided as Appendix C to this document for ease of reference

ENTRIX assigned n-values to different vegetation types in the existing conditions model based on literature references and used the same values corresponding to vegetation types for the proposed condition (ENTRIX, 2007b). The existing condition flood model and alternatives models are therefore consistent, but the proposed condition model apparently does not account for any changes in vegetation that may occur as a result of the project or future management of the project area.

The results indicate increased floodplain inundation area at 450 cfs and 760 cfs, and the hydraulic model results show that this flooding is very shallow and somewhat discontinuous across and down the valley (see Appendix C figures). Depressions in the valley surface are filled, but depths are mostly less than 1 foot and flooded areas are broken up by higher topography. The hydraulic conditions for these flows depend on assumptions regarding filling the existing channel and grading of the area near the new channel, as well as the effectiveness (or ineffectiveness) of local depressions in carrying flood flows down the valley.

For the 1,600 cfs flow, the entire valley surface is mapped as inundated for both existing and proposed conditions, but the hydraulic model shows that flows are still shallow, generally about 1 foot deep, except where local depressions create greater depth. The model indicates that conveyance on the left and right overbanks varies between about 45percent and 70 percent of the total conveyance, and averages around 55 percent at this flow. This calculation is sensitive to assumptions regarding hydraulic roughness coefficients (n-values) in the overbank areas.

Each cross section in the model is subdivided into several areas with differing n-values. In the absence of a specific planting or vegetation management plan, this level of specificity in the proposed condition may be unrealistic. In most cross sections, a substantial portion of the floodplain is assigned an n of 0.035, the same value that is used in the channel. For the shallow overbank flows in the 760 and 1,600 cfs simulations this may be too low, and thus the model may overestimate flows in the floodplain to some degree.

At 7,650 cfs most of the flow is carried on the floodplain and the entire valley is inundated to depths of 2 to 3 feet through most of Reach 5. The model indicates that combined conveyance on the left and right overbanks varies between about 75 percent and 90 percent of the total conveyance, and averages around 85 percent at this flow. Near the downstream end of Reach 5, depths on the overbank areas increase, due to the reduced valley width. Flow is confined between fill for the airport runway and windsock and the naturally steep east valley side slope. In the area upstream of the valley constriction a backwater effect occurs for the 7,650 cfs flow. Flow depths on the floodplain surface increase to about 5 feet and overbank velocities are low, generally between 1 and 2 fps. This effect can be seen as a flatter slope in the 7,650 cfs water surface profile between about 160+00 and 145+00 (see figures in Appendix CX).

The downstream end of Reach 5 is at about Station 14350 in the water surface profile plots and the new channel is proposed to re-join the existing channel at about 14600 (this corresponds to about Station 124+00 on the 50 percent design plans). Between 146+00 and 129+00 (using stationing as defined in the water surface profile plots) two grade control riffles were recently installed in the existing channel to replace the two existing timber and concrete structures (ENTRIX 2008b). Downstream of 129+00, a new channel was constructed in the Airport Reach and the modeling results presented in the profile plots reflect this construction. The existing channel with installed grade controls is a transition reach between the new channel in the Airport Reach and the proposed new channel in Reach 5. In this transition section, energy slope is locally increased compared o the upstream slope for all flow rates. For example, in the 7,650 cfs flow, average energy slope in the transition area is about 0.0022, or about double the average energy slope of 0.0010 for the new channel in Reach 5. However, overbank (floodplain) velocities computed by the hydraulic model for the 7,650 cfs flow remain relatively low, generally between 1 and 3 fps. Near the two existing structures that were recently replaced with cobble grade controls somewhat higher overbank velocities occur, reaching a maximum of 4.3 fps.

A more significant shift occurs in the fraction of flow carried in the overbank areas in the transition section compared to average values for Reach 5. At the 5-year flow of 1,600 cfs in the transition section downstream of Reach 5, the combined conveyance in the left and right overbank ranges only between zero and nine percent of total conveyance and averages about 3percent (compared to 55 percent upstream). At 7,650 cfs, total overbank conveyance ranges between about 30 percent and 60 percent of total conveyance and averages about 45 percent (compared to 85 percent upstream). These values illustrate that floodplain flows return to the main channel in the transition section and as would be expected, computed velocities in the main channel are correspondingly increased. At 7,650 cfs, velocities in the channel increase from averages of 4 to 5 fps in Reach 5 to 6 to 9 fps for the transition section. Velocities in the new Airport Reach channel downstream of 129+00 at 7,650 cfs are generally 4 to 5 fps in the main channel and 2 to 4 fps on the overbanks.

### Comparison to Existing Conditions – Water Surface Elevations

Appendix E of the Hydraulic Modeling Report shows computed water surface profiles for various discharges under both existing and proposed conditions (Sunset Stables Alternative 3). The Hydraulic Modeling Report uses pre-project conditions in the Airport Reach for these comparisons. At 1,600 cfs, the proposed water surface profile is slightly above the existing profile, consistent with a new channel sized to carry the bankfull flow and engage the floodplain more frequently. At 1,600 cfs differences in water surface elevation (and depth on the floodplain) are small, generally less than 0.5 feet in Reach 5 and less than 1 foot in Reach 6, except at the upper end of Reach 6 where water surface elevations are increased up to 2 feet. At 7,650 cfs, differences in computed water surface elevations are less than 0.5 feet through Reach 5, with differences up to 1 foot in Reach 6. These computed differences are small but nonetheless result in some variations in inundation, as shown in the GeoRAS figures. The most significant concern for increased inundation frequency and depth is at the airport runway, where flooding occurs along the margin of the airport property. At the 5-year flow of 1,600 cfs flow the water surface elevations are still 2 to 3 feet below the runway elevation. At the 100-year flow of 7,650 cfs, the airport runway and ramp areas are entirely inundated in the downstream portion of Reach 5 (below existing River Station 18000) for both existing and proposed conditions.

Small increases in water surface elevations during the 7,650 cfs flow for Alternative 3 apparently result in minor increases in inundated area under the proposed conditions (as shown on the GeoRAS figures in Appendix D of this document). Differences appear to be well within the uncertainty of the model calculations. The significance of the computed differences, if any, is being treated in a separate environmental document.

Flood water surface elevations are sensitive to assumed hydraulic roughness values, and increases in vegetation along the floodplain have the potential to increase flood elevations. Especially in the lower portion of Reach 5 where the floodplain width narrows and the runway is currently overtopped by large floods, the final design for Reach 5 should incorporate an assessment of vegetative roughness and flood elevations, including a sensitivity analysis of assumed n-values. Vegetation management, a planting plan that is sensitive to flood conveyance, and grading secondary swales to increase capacity are all options that could be used to lower future flood elevations if modeling indicates the need.

The prior steady state 1-D hydraulic modeling does not account for differences associated with flood routing effects under either the existing or proposed conditions. As the proposed project would modify the relationship of the channel to the floodplain, the timing of storage in the floodplain would also be affected. Because the valley is wide, significant storage occurs during a large flood, and this would likely attenuate the flood peak. An unsteady model or flood routing assessment would be needed to assess the flood storage effect and any changes the project might cause to the flood hydrograph. A 2-D modeling that is recommended to assist with channel and floodplain design (Section V) would also be valuable for assessing hydraulics during major flood events. HEC-RAS modeling of the proposed design under major flood flows (e.g., 100-year) could be advantageous since it can be readily connected to upstream and downstream flood hazard models as needed to confirm flood performance in a format familiar to and accepted by local floodplain managers and the Federal Emergency Management Agency (FEMA).

### Comparison to Existing Conditions – Downstream Transition

A comparison of modeled velocities under existing and proposed conditions in the lower portion of Reach 5 and the transition area (14600 to 12900 in the water surface profiles, or about 14000 to 12200 in existing river station) to the new channel in the Airport Reach was made using the HEC-RAS plan that represents the new channel in the Airport Reach and the existing Sunset Stables conditions (Table 17). This analysis assumes that the 'existing' conditions within the Airport Reach are the as-built conditions, rather than pre-project conditions. While a slightly higher percentage of flow is carried in the overbanks in the proposed Alternative 3 condition, overbank velocities remain at a similar range to existing

conditions. Similar results would be expected for an analysis using pre-existing conditions in the Airport Reach (i.e., no new channel) because velocities and overbank flows in the transition area were probably controlled by the previous grade control structures, which have now been replaced at the same elevations.

Based on this comparison, the computed overbank flows and velocities do not appear to be a significant erosion hazard for a well vegetated floodplain and the Reach 5 project does not significantly change conditions in the transition to the Airport Reach or downstream. However, the modeling results are average values and locally higher velocities and shear stresses may still occur. One observation from the historical aerial photo review was the increasingly distinct return channel pattern in the transition area following airport construction. Careful attention to floodplain grading and planting plans and methods will be needed to avoid concentrating return flows in a way that would cause overbank erosion or head cutting as return flows overtop the channel banks. As noted in Section V and shown in Table 17, this area is also subject to higher in-channel velocities and shear stresses, and additional streambed grade controls are advisable (likely in the form of cobble riffles, but dependent somewhat on final alignment and grade of the main channel through the transition sub-reach). Although the transition area is mostly downstream of the Reach 5 boundary, it is important to both channel and floodplain stability in Reach 5, and should be considered as a potential part of the project area moving forward with design.

### Upstream Transition

The previous modeling assumes that both Reaches 5 and 6 are constructed. During the next phase of design, additional model runs should be performed that represent a new channel in Reach 5 only with a transition to Reach 6. The ENTRIX Hydraulic Modeling Report includes a discussion of the transition at the upstream end of the Sunset Stables Reach 6 near Highway 50. This transition was relocated downstream from its original position to reduce backwater effects on the Highway 50 Bridge. Near the transition, now about 500 feet downstream of the bridge, the computed water surface profile for the 7,650 cfs flow is about 1 foot higher than for existing conditions and the bed profile has a discontinuity of 1.5 to 2 feet. Although relocating the transition downstream reduces the computed water surface at the bridge, aggradation should be expected in the channel upstream of such a change in bed profile. Eventually, this aggradation would affect water surfaces at the bridge, and in the interim would affect coarse sediment supply downstream. Although not in the Reach 5 project area, both of these topics should be addressed in coordination with Reach 6 planning and design. If Reach 5 is constructed prior to Reach 6 as currently envisioned, a similar question regarding sediment supply and stream behavior in the transition area is directly relevant to the upstream transition between Reach 5 and Reach 6.

The transition from Reach 5 to Reach 6 will involve a change in thalweg elevation – the downstream channel would be constructed at higher thalweg elevation than the upstream existing channel. The anticipated effects would be similar to those expected if a low dam were constructed. Coarse sediment is likely to accumulate upstream of the transition section, and as it does there may be increased tendency for lateral migration or widening upstream of the transition. There may also be an increased tendency for overbanking upstream of the transition. Downstream of the transition, the stream may be temporarily deprived of coarse sediment supply until the bed aggrades sufficiently upstream to provide adequate slope to transport he coarse sediment. Given the rather low expected supply of gravel and the wide floodplain, these potential problems may not be very significant, but should be analyzed and considered during 75 percent design.

### TABLE 17: COMPARISON OF OVERBANK FLOWS, VELOCITIES AND IN-CHANNEL VELOCITIES

| | | Airport Reach Project and Existing Sunset Stables | | | | | | | Airport Reach Project and Sunset Stables Alternative 3 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River Station[1] | Q | Overbank Velocities | | | Proportion of Flow on Floodplain | | | Ave. Channel Velocity | Overbank Velocities | | | Proportion of Flow on Floodplain | | | Ave. Channel Velocity |
| | cfs | fps | | | % | | | | fps | | | % | | | |
| | | Min | Max | Ave | Min | Max | Ave | fps | Min | Max | Ave | Min | Max | Ave | fps |
| 12900-14600 | 1,600 | 0.2 | 0.7 | 0.4 | 0 | 2 | 0 | 4.6 | 0.2 | 1.6 | 0.6 | 0 | 9 | 3 | 4.5 |
| 12900-14600 | 7,650 | 0.9 | 3.6 | 2.1 | 28 | 52 | 39 | 6.6 | 0.8 | 4.3 | 2.1 | 29 | 61 | 45 | 6.4 |
| 14600 - 16000 | 1,600 | 0.3 | 1.5 | 0.8 | 30 | 37 | 33 | 3.2 | 0.6 | 1.4 | 1.1 | 48 | 64 | 56 | 3.7 |
| 14600 - 16000 | 7,650 | 0.7 | 2.0 | 1.4 | 75 | 80 | 77 | 3.0 | 1.1 | 2.0 | 1.7 | 85 | 90 | 87 | 3.1 |
| 16000 - 21200 | 1,600 | 0.5 | 1.5 | 0.9 | 6 | 60 | 38 | 3.6 | 0.6 | 1.4 | 1.1 | 44 | 70 | 59 | 3.8 |
| 16000 - 21200 | 7,600 | 1.2 | 3.0 | 2.0 | 71 | 87 | 78 | 4.2 | 1.2 | 3.4 | 2.3 | 77 | 88 | 85 | 4.9 |

[1] River Stations correspond to those shown in Hydraulic Modeling Report appendices (ENTRIX 2008). Under these stations, Reach 5 boundary is at approximately 14350 and proposed 50 percent channel ends at 14600.

The approach to designing the transition will be to use the hydraulic model and some simple sediment transport calculations to assess the backwater effects of the transition during a range of flow conditions. A gradual transition with some bank stabilization to prevent excessive widening upstream and in the vicinity of the transition would be assumed. The assessment would determine whether the transition is best accomplished in a bend or a straight reach of the channel based on a detailed review of channel conditions and floodplain topography in the area of the proposed transition. Local overbanking patterns (using the 2-D model) would be anticipated so that the design can incorporate vegetative or grading changes necessary to prevent secondary channel enlargement, flanking, and/or return flow erosion of streambanks. The potential need for temporary supply of coarse sediment downstream or near the transition and at the upstream end of Reach 5, perhaps in the form of constructed bar surfaces, would be considered. These measures would provide material to counteract any forecast deficit in supply that might occur due to deposition upstream of the transition and/or decreased inputs from upstream.

# VIII. REFERENCE REACH

## APPROACH

A reference, or analog reach, can be a valuable aid in the stream restoration design process. Typically, the impetus for stream restoration is that the stream has been directly altered through channelization or indirectly through a change in flow or sediment characteristics such that it is no longer providing functional aquatic or riparian habitat, or has unacceptable rates of erosion. Therefore, an off-site analog that has many of the same driving forces, without the same disturbance history, can provide quantitative information regarding key design parameters for cross section geometry and sinuosity, as well as floodplain characteristics. Map analysis and field measurements of a selected reference reach can provide key inputs to several design parameters (e.g., planform, sinuosity, channel dimension and shape, variability of bedforms and slope, bed material).

While the concept of targeting restoration design from an example of a functioning stream has obvious appeal, with so many geologic, topographic, hydrologic, climate, vegetation and historic land/water use variables it is often difficult to find acceptable analogs. Theoretically it can be effective, but often a great deal of time and effort is required to verify that potential analog sites are appropriate.

In lieu of a specific analog channel or reach, regional hydraulic geometry relationships are often used as an input to design variables. It is relatively simple to develop a relationship between hydraulic geometry parameters and the primary drivers of hydraulic geometry; gross energy and sediment transport using some index of flow, effective discharge, or even simply the drainage area. When coupled with simple metrics of climate and geomorphic setting, such as a climatic province and valley gradient, useful relationships have been developed.

Regional hydraulic geometry relationships have the disadvantage of being approximate because they are developed from many streams, each one influenced by slightly different factors and inherently different sizes. But they have the advantage of increasing confidence in the appropriateness of a design target since they do not rely on measurements from a single selected reference station/reach that may not have the correct driving factors to match the target stream system.

## METHODS

Applying professional experience and in-house data resources, four senior project team members deliberated about options for potentially suitable watersheds and stream segments within the Lake Tahoe region that might have appropriate driving forces but have geomorphically and ecologically functional streams and be about the right size and scale

system for comparison to the Upper Truckee River. However, there are not many streams in a similar geologic and geomorphic setting in the region, and looking outside the region would be time consuming and ultimately of questionable value in terms of validating that the driving factors for such a system (e.g., climate, geology) where consistent and the that system had not experienced disturbance factors that would make it inappropriate.

Regional hydraulic geometry relationships developed for the Upper Truckee River in 1997 under a separate effort (Toby Hanes unpublished data, included herein as Appendix D) are presented here as an option for providing some design parallels given the practical and technical limitations for selecting a local/regional physical analog. The plotted relationships are between drainage area and bankfull flow, bankfull depth, bankfull width, and bankfull cross-sectional area (Appendix D). These relationships were built for eastern Sierra streams that represent a range of channel types, including three to five that are considered C5, similar to the study portion of the Upper Truckee River. While C3 or C4 channels probably represent the mode of the samples, they vary from B3 to a C5/F5. The determination of channel type was based on professional judgment and field acquaintance with the sites, not on a formal field evaluation of channel type at each of the stations. It was very challenging to find streams without any flow regulation influence from upstream reservoirs to include in the statistical analysis. Thirty-nine candidates were initially analyzed with periods of record ranging from 17 to 72 years, of which 23 had to be rejected for various reasons, principally flow regulation. Some of the remaining available stations have minor storage influences, such as Taylor and Independence creeks. The lower Truckee River stations also have effects of some regulation but the relative influence is diminished since the proportion of unregulated watershed area increases. The limited number of useable station data prevents development of valid statistics that are based only on C5 channel types.

## Results

### Physical Analogs

One of the principal concerns for the Reach 5 UTR project is the unique geomorphic setting of being contained in a valley of very low slope within nearly uniform fine sandy alluvium. This is further complicated by the broad floodplain and the land use history. There is uncertainty about the pre-Comstock channel pattern (single- vs. multi- thread) and condition. The nature and degree of direct channel disturbance during the early historic period (i.e., 1850-1940) is difficult to verify. Additionally, the size and scale of the contributing watershed area and the role of lacustrine sediments in controlling subsurface conditions and groundwater-surface water relationships may be somewhat unique. The result is that a regional analog of similar scale and natural conditions, but lacking historic disturbances may not exist. To determine whether (or not) certain specific streams would be appropriate analogs would require much further effort, including field investigations, that is beyond the level of effort scoped by the LTBMU for this stage in project design.

### Regional Hydraulic Geometry

The channel geometry relationships were developed from U.S. Geological Survey (USGS) streamflow measurement data included on the original "9-275" information recording forms for the streamflow measurement sites at 16 stations (Table 18). The form 9-275 data are for sites in close proximity to, but not typically at, the gauge cross-section. Individual relationships were developed between flow and the parameter of interest for each station and a flood frequency analysis was performed to determine the 1.5-year recurrence interval flood. Then, using the developed relationships, the channel geometry metric associated with that flow was computed and those values were in turn plotted against drainage area (Appendix D).

**TABLE 18: STREAMFLOW GAGE STATIONS USED IN DEVELOPMENT OF THE EASTERN SIERRA BANKFULL RELATIONSHIPS.**

| USGS ID Number | Station Name |
|---|---|
| 311000 | Carson River Nr. Carson City |
| 311400 | Carson River @ Deer Run Road, Nr. Carson City |
| 308200 | E. Fork Carson River Below Markleeville |
| 343000 | Independence Creek Near Truckee |
| 401500 | Indian Creek Near Crescent Mills |
| 348500 | Pit River Near Canby |
| 345500 | S. Fork Pit River Near Likely |
| 336626 | Taylor Creek Near Camp Richardson |
| 338000 | Truckee River Near Truckee |
| 348200 | Truckee River Near Sparks |
| 350000 | Truckee River @ Vista |
| 358500 | Willow Creek Near Susanville |
| 348000 | Truckee River @ Reno |
| 300000 | W. Walker River Near Hudson |
| 10336780 | Trout Creek Near Tahoe Valley |
| 10310000 | W. Fork Carson River Near Woodfords |

## DESIGN GUIDANCE

One of the major drawbacks of the hydraulic relationships developed to-date (Appendix D) is that they are based on Leopold's bankfull concept, wherein the effective discharge is assumed to be closely related to the 1.5-year recurrence interval flood. This concept is based on the floodplain being formed by the stream in the geologically modern climate. Since the concept was first popularized in the 1980s, it is generally recognized that exceptions are widespread and the overall utility of the concept is now considered to be modest. The relationships nonetheless provide a point of reference for the Reach 5 project design.

Using the hydraulic geometry relationships developed for the 16 regional stations (Table 18 and Appendix D), the following bankfull channel characteristics would be predicted, for a drainage area of approximately 50 square miles (Table 19). The Upper Truckee River has a total drainage area of 58 square miles and approximately 44 square miles feed into the upstream end of the Sunset Stables project area (ENTRIX 2004a).

**TABLE 19: PREDICTED BANKFULL CHANNEL CHARACTERISTICS**

| Characteristic | Predicted Value |
|---|---|
| 1.5 Year Flow | 320 cfs |
| Bankfull Depth | 2.0 feet |
| Bankfull Width | 39 feet |
| Cross Sectional Area | 80 square feet |

The regional hydraulic geometry results (Appendix D) combined with other site-specific observations and historic analysis can be used to validate the direction for channel design along with hydraulic and geomorphic calculations and estimates. The regional hydraulic geometry data (Table 19) are supportive of the initial direction for 75 percent design revisions towards a smaller capacity, shallower channel than that proposed in the 50 percent design plans.

# IX. FINDINGS RELATIVE TO EXISTING DESIGN

## PROJECT OBJECTIVES

The previous conceptual channel alternatives were evaluated against the following Project objectives and desired outcomes, based on available information at the time and in comparison to existing conditions (ENTRIX 2008b):

Objective 1: Restore a more naturally functioning river and floodplain.

Restore channel form in balance with hydrology and sediment supply.

Increase frequency of overbanking.

Increase deposition of fine sediment and nutrients onto the floodplain.

Objective 2: Improve water quality by restoring natural stream and floodplain processes.

Reduce nutrient and fine sediment loads generated within the Project area or transported through the Project area.

Objective 3: Restore, enhance and protect aquatic and terrestrial habitat diversity and quality.

Enhance the habitat values of the river and floodplain for supporting native aquatic and terrestrial animals and plants.

Objective 4: Develop a cost-effective, timely and implementable design.

Provide a cost-effective project.

Provide a permittable project.

Minimize time to project maturity and benefit.

## FEASIBILITY OF 50 PERCENT DESIGN TO ACHIEVE OBJECTIVES AND BE SUSTAINABLE

The Alternatives Evaluation report (ENTRIX 2008b) didn't' consider constructability or sustainability of a new channel within the existing meadow soils as a criterion but rather the evaluations assumed that each of the conceptual alternatives were equally able to achieve and remain at the intended design state.

While the proposed new channel (based on capacity) would increase overbank frequency, information gained through our field examinations, literature review, and data analyses, reveals several concerns regarding the ability of the proposed 50 percent design to achieve specific channel restoration objectives and be sustainable.

The hydraulic geometry for the proposed design was selected based on an assumption of moderately cohesive bank material with an implied relative resistance to erosion at the proposed bank heights. 2009 soil and meadow field investigations have established that previous statements that the banks are composed of cohesive fine-grained sediment have over-estimated the strength of the bank material and resistance to shear stress. The majority of material is homogenous, typically silt loams and fine sandy loams (contains some silt but very little clay) with low cohesion, and lacking secondary structure. Limited evidence of alluvial deposits coarser than sand size was found. Additionally, the likely groundwater regime under the proposed channel thalweg elevation would not substantially improve the support for deeper, dense rooted, vigorous wetland sod. These data indicate that proposed 50 percent bank heights (4± feet typical for riffles and 7± feet typical for pools, respectively) are too great to expect sustainability under the expected range of velocities and shear stresses, particularly at outside bends.

The proposed 50 percent channel design would result in shear stresses at the bankfull flow that are higher than for existing conditions at the same flow. Critical grain sizes associated with these shear stresses are higher than the reported characteristics of bed material

samples, except at the riffle sections where bed material may be coarser than material typically in transport. The proposed channel cross section shape moves towards a lower width to depth ratio which ultimately increases mean channel velocities and shear stresses. This higher shear stress at design flow indicates a risk that incision could be induced.

The conceptual design was based on hydraulic geometry from the literature, limited bedload information, and at-station sediment transport calculations. Sediment transport into or through the project reach was not modeled. Design studies to-date have focused on existing sediment loads and transport, without sensitivity analysis or modeling of proposed channel response to a range of future sediment conditions. There is uncertainty in replenishment rate of bedload and sediment materials in the Project area. Simon and Others (2003) forecast sediment would be declining and there is evidence from historic image analysis that the area and number of active point bars in the project reach have been in decline , at least in part due to lower coarse sediment inputs. It will be important to address design sensitivity to potential reductions in coarse sediment supply given the lack of understanding of future trends, particularly in light of the potential future Golf Course reach restoration project's capacity to capture coarse sediment for an extended period of time once implemented.

Upon separation of Reaches 5 and 6, it was revealed that Reach 5 sinuosity was actually decreased slightly from existing conditions. Therefore it has been suggested by LTBMU to modify the current design to at least maintain the channel sinuosity that currently exists in Reach 5. The analysis herein agrees with earlier findings that Reach 5 planform and sinuosity have not changed dramatically since 1940, and may have been relatively static even longer. Also, in contrast to the Airport Reach (Reaches 3 and 4), Reach 5 alignment has not changed directly as a result of airport construction. Additionally, there are some indications that faulting and geologic influences may be controlling meander position and overall alignment relative to valley axis. There are very few remnant channels within the project area that provide improved certainty about pre-Comstock channel alignment or complexity (some of the remnant features have not been active for hundreds of years). A continuation of current sinuosity for the proposed new channel is justified.

The susceptibility of the soils and the rigid location of the underground utilities requiring protection limit the opportunity to include natural planform dynamics as a feature of the new channel and demand more measures to ensure adherence to constructed position. In other words, the new channel can't be allowed to meander further or cut its own path, in concern that it would continue the widening process to a detrimental level or impinge upon existing utility lines. There are currently 17 locations where hardening is proposed to protect existing utilities; so there may also be an opportunity to modify the new channel alignment further to reduce that number. The current proposed utility protection measures don't appear to adequately account for scour and will require further modifications for 75 percent design in order to achieve a comfortable factor of safety and receive District approval.

The ability of the proposed 50 percent channel to increase soil moisture levels in the adjacent meadow simply by increasing overbanking frequency is uncertain. The present channel likely acts as a seasonal drain to groundwater, even in wet years. The river bed elevation is strongly related to water level during the drier months, August through October although evapo-transpiration losses may also play a role. The presence of wet species across the meadow may be a relic feature that is on its way out, since it doesn't appear there is enough water to support a good wet meadow. With a proposed 4 feet deep typical riffle channel, the infiltration rates would likely remain high and summer losses of groundwater could also remain high.

The inventory of existing vegetation, specifically sod available for salvage and reuse indicates there is minimal usable material and stacked sod is not a viable option for streambank protection in this reach. Instead it is recommended that any sod salvaged be re-planted in strategic locations on the floodplain adjacent to the new alignment, especially in erosion prone areas such as tie-ins to the existing channel, or used in combination with other bank stabilization treatments. Additionally, given the proposed typical bank heights

(4± feet for riffles and 7± feet for pools) and remaining potential for growing season groundwater levels to lower near the thalweg, the expected variation in water surface level and soil moisture content would be unlikely to sustain healthy sod of adequate depth on the streambanks in general.

A variety of bank stabilization measures presented in the "tool box" (Table 16) will be evaluated, selected, combined and positioned based on local site needs and constraints. Softer measures incorporating stacked sod in limited applications and willows, particularly willow mattresses, would be proposed for several sections of channel banks given the native soil characteristics and anticipated design channel depths. The use of willow will be done in combination with other treatments in order to avoid the formation of a homogenous willow-lined channel, and provide for variability and intermittent open areas while maintaining stability. Minimal willow material is available onsite and will likely need to be supplemented by material within Reach 6 and along the margins of the Reach 5 project area. It would be advised to field verify the number of large stands present within Reaches 5 and 6 and the number of vigorous, healthy, and usable branches available for soil bioengineering, without substantially decreasing the vigor or habitat values of the source shrubs. Adequate size would be large diameter (0.5 minimum to 1.0 inch) and at least 3 to 4 feet long, longer for mattresses.

The 50 percent design shows a combination of gravel and sand bed materials; gradations are not specified, but "riffle gravel" is indicated for locations between pools, with native material (sand) in the pool sections. The 50 percent design shows a layer of sand for use in transitions – this would not be very stable and requires refinement in the 75 percent design.

At the transition to the Airport Reach downstream of Reach 5, velocities and shear stresses are locally higher than in the remainder of Reach 5 under bankfull flow conditions. Grade control structures in the form of cobble riffles are recommended in this area, particularly if the channel planform design remains similar to the 50 percent design. A single grade control is shown in this location in the preliminary plans, but multiple smaller drops may be preferable to improve reliability and passage for aquatic organisms.

# X. SUMMARY OF KEY FINDINGS AND 75 PERCENT DESIGN INFLUENCE

The following summarizes key information presented in each of the previous sections and discusses how individual findings will inform and influence the 75 percent design.

## MEADOW & SOILS

The majority of soils in the Project area are fine textured, low density with limited cohesion. They consist of silt loams, fine sandy loams, loamy fine sands, and some areas of mucky silt loams in depressions (Table 5). Surface horizons range roughly from 2 to 3 feet thick on the meadow surface with some shallower soil surfaces in the existing depressions. The surface horizons' low inherent cohesion is enhanced by rooted vegetation but only to a certain depth (from 1 to 2 feet). Patchy lenses of coarse sand and small gravel with higher hydraulic resistance do exist, but tend to be fine textured with no coarse gravel and little soil structure. Sand and gravel deposits on the surface are limited to a few discrete locations west of the river.

Stable channel design during 75 percent will amend the prior assumption of "cohesive" banks to "minimal to non-cohesive" in order to better characterize the existing substrate. Given the low erosion resistance of the native soils there will be careful consideration to limit hardened protection installations to areas only where they're needed such as at buried utility crossings and when used to adequately blend with softer transitional installations to avoid sudden discontinuities in resistance to lateral migration and/or vertical scour. Design will also anticipate for areas of coarse sands and small gravel that may be exposed during

excavation of the new channel and could impact bed or bank stability. Variations in cohesion and hydraulic resistance with depth will be considered when proposing new channel dimensions and bank configurations.

Intermittent evidence of the highly cohesive lacustrine materials was found along the lower reaches of the site but predictability of depth and location were sporadic at best. The measured lake sediment elevations underlying the valley floor of Reach 5 do appear to be aligned similar to valley slope, but only appear within a few feet of the existing meadow surface in the downstream portion of the Project site, between VS 135+00 and 155+00. The higher resistance of streambed materials where the lake bed sediment is exposed would alter channel erosion processes, retarding the rate of incision, but favoring widening. The lake bed sediments may also affect local groundwater storage capacity and/or flow rates above that unit based on observed soil redoximorphic features well below the ground surface and close to the underlying lake sediment elevations downstream of VS 155+00.

It is uncertain whether adding more surface water (via overbank flooding) to recharge the adjacent meadow during spring runoff will be enough to improve upon seasonal water levels. In each of the last few years the local aquifer nearly 'fills' from surface runoff (streamflow and off side slopes) and local snowmelt without overbank flows and recedes rapidly back to levels several feet below the ground surface by summer. To the degree that data is available, analysis of paired groundwater elevation and adjacent surface water stage data during 75 design development may provide an additional verification of desired conditions.

The rate of groundwater recession and its close temporal link to surface water recession and control of the adjacent river thalweg elevation on minimum groundwater elevations are central to how the 75 percent proposed channel will be shaped. While improved surface water recharge could be beneficial and a smaller capacity channel may also improve bank stability, a critical factor appears to be the minimum (thalweg) streambed elevation.

The final topography and sediment properties of the backfilled existing channel may have a substantial effect on groundwater conditions within the site, and it is recommended that the specified particle size distributions, degree of compaction and overall stratigraphy of the backfill be supportive of desired groundwater conditions and prevent adverse consequences.

General observations show the context of Reach 5 to be very low gradient, low energy alluvial re-working of the late Pleistocene/early Holocene lacustrine and fine-grained outwash deposits. The well developed surface soil horizons (A horizons) in uniformly fine sands and silty sands across the entire valley floor, the organic accumulations in deeper remnant channels, the lack of sand and gravel deposits near the surface of the meadow, and the age of gravel deposits that are present all suggest a relatively long time (hundreds of years to more than a thousand years) during which very limited channel dynamics occurred across the floodplain. If there was a single thread channel, there is little evidence that it was regularly/freely meandering across the valley floor, more likely it may have avulsed to occupy different locations briefly. Despite the possibility of a multiple thread system as a naturally occurring planform at some point in the past, design of a proposed new channel would assume a single thread main channel for constructability and sustainability.

Review of topographic data and profiles indicates the bed slope in the downstream portion of Reach 5 remains fairly constant (a function of the increased length in the tight meander bends) rather than steepened through active incision following airport construction as previously thought (incision had already occurred). Evidence of active incision is limited in the other portions of Reach 5 as well, with the exception of the protected utility crossings and paved low-water crossing that have small slope breaks likely due to local scour. The proposed channel alignment will make maximum use of the available valley width (previously constrained by continuing airport land use) and will target a channel length that either maintains or increases present sinuosity.

Quantitative analysis of historic channel width and planform changes indicates a trend of decreasing width of the active channel, while the low flow channel width has remained very consistent (Table 11). There has consistently been a wide channel near the downstream end of Reach 5 (approximate VS 137+00). Between VS 157+00 and VS 177+00 the active channel was widest in 1940, decreasing subsequently. This narrowing began prior to the reconstruction of the channel for the airport (started between 1940 and 1952). Interpretation of aerial imagery also shows a decrease in surface area of channel deposits while low flow channel widths and flows remained similar indicating volume and/or elevation of unvegetated channel deposits was reduced. Channel response to Comstock logging and/or climatic shifts may have resulted in initial incision, widening and some aggradation prior to the 1940 imagery consistent with models of channel evolution.

The combination of little or no channel planform migration or widening and the decrease in active channel bar deposits, suggests that net removal of in-channel deposits (i.e., deepening of the active channel cross section) may have been a primary factor leading to increased channel capacity during the historic period. Decreasing watershed coarse sediment yield over decades of recovery from Comstock Era logging (and fire suppression) may have reduced coarse bed load replenishment. Renewed channel incision may also have occurred, at least in the downstream reach affected by airport straightening since the 1950s.

Surface erosion on the meadow within Reach 5, evidence of direct human disturbance and/or river processes, has dramatically decreased from high levels during the first half of the 1900s (Table 12). Exposed unvegetated surfaces at the time of the 1952 image peaked at 441,252 square feet (approximately 10 acres) as various construction and land use activities affected the valley floor (i.e., roads, residential building pads, water and sewer pipelines, the airport, and grazing) (see also Figure 21). Unvegetated areas decreased after 1969, and dropped to less than 0.23 acres by 2003. Historic stream channel erosion in the constricted valley section at the downstream end of the project site began to impinge laterally on the east valley side slope sometime after 1952. An unvegetated hillslope erosion scar first becomes visible on the 1969 aerial image as a small (392 square feet) area of light colored, fine-grained lake sediments and increased to 1,972 square feet on the 1987 image but appeared slightly smaller (1,239 sq ft )on the 2003 image (Figures 21C, D, and E).

Future watershed hydrology and sediment loads are critical factors to design development. However, design studies to date have focused on existing sediment loads and transport using limited field data. A channel design such as the proposed 50 percent channel with a lower width/depth ratio than the existing channel, but a similar planform sinuosity and slope implies that the constructed channel would be more efficient at sediment transport which, under the reduced sediment input could exacerbate rather than counteract historic trends of deepening and incision. In the absence of definitive measured trends and projections of potential alterations to hydrology and sediment loads due to direct manipulation of upstream reaches for restoration purposes (i.e. Golf Course Reach, Reach 6) and/or climate change, the 75 percent design development should include a quantitative sensitivity analysis of the proposed channel response to a range of future sediment conditions.

## Vegetation

Based on the 2009 field work, it appears that the proposed 50 percent design channel location passes through or very near to several plant community types and barren areas which are either inappropriate as near-channel communities or pose significant potential stabilization and revegetation challenges.

During 75 percent design development and in collaboration with slope and planform designations determined by new stable channel design, the new channel location will be re-positioned within the existing ecological landscape to optimize channel stability and vegetation success.

There is a general lack of suitable sod material (i.e. Salvageable Sod Type A – 2.66 Acres) for salvage and re-use along the entire length of a proposed new channel. What is available can

be positioned strategically during 75 percent design in order to gain the most erosion control benefit, such as at tie-ins, along the immediate top of banks or along return flow channels where flood flow velocities are expected to be higher. There is also 3.86 acres of Potentially Salvageable Sod that could be used as long as it's subjected to good soil moisture via applied irrigation for a minimum of two years (i.e. while the new channel is seasoning).

The prior willow mapping (Figure 23) suggests a more extensive willow occurrence than the fall 2009 field observations support. Willows in the project area appear quite limited in extent and the areas with natural willow recruitment are not as dense as would be expected.

A second field review and boundary adjustments of the sod and willow vegetation in reach 5 during a more favorable identification time in early to mid-summer 2010 to confirm accuracy is recommended prior to development of final plans, specifications, and engineer's estimates. Given the large benefit of using willows in bank stabilization installations, and the lack of available material along the existing and proposed alignments in Reach 5 it is recommended that additional field review and mapping of willow vegetation in Reach 6 and the outlier areas of Reach 5 be conducted to determine the total amount of branches with adequate vigor, length and diameter available for harvest.

While existing willow resources are limited, virtually the entire valley floor of the project area would be suitable for willow planting for restoration purposes. Modification of existing topography and/or vegetation might be necessary in order to achieve maximum vigor.

Distribution and populations of previously identified noxious and invasive weeds most likely has changed since the 2004 surveys and will likely change again by the time construction is ready to proceed. Re-survey during final design is recommended to insure that proper avoidance and treatment of noxious weeds is specified as part of construction, and that construction does not contribute to the spread of noxious or invasive species. Final designs will include measures outlined in the Noxious Weed Risk Assessment (ENTRIX 2009) such as requiring off-road equipment to be washed before entering the Project site, flagging and avoiding weed-infested areas particularly for staging areas, using only weed-free products and materials, minimizing area of disturbance and re-establishing vegetation in areas that are disturbed to prevent the spread of noxious weeds (ENTRIX 2009).

## Wildlife

A shallower channel with improved instream cover via added channel features and increased bank vegetation is in agreement with Project goals. The creation of pond habitat will need to be done in a way that doesn't intensify the risk for airport/bird conflicts or exacerbate vector control issues. Potential beaver effects will need to be anticipated.

Increasing willow species diversity, variation in age classes and percent cover in the Project area are important measures to improve willow flycatcher and songbird habitat, as well as habitat for small mammals. Willow seed require a disturbed surface in order to colonize; therefore natural willow recruitment and increased establishment in a quiescent wet meadow won't occur if it is outside the channel or areas of disturbance with appropriate hydrology. It is recommended that increases in willow populations be focused along the active channel banks and within the floodplain margins where new construction will allow for soil bioengineering. If seed production occurs concurrently with newly exposed soils, there may be additional natural recruitment via seed establishment.

Opportunities to preserve large snags, designate dense willow stands interspersed with open areas along the active channel for willow flycatcher and belted kingfisher foraging opportunities, and minimize standing water in areas close to the airport to reduce the potential for waterfowl conflicts will be integrated in the 75 percent design.

Wetland habitat enhancement by the 75 percent design will be improved by raising the channel bed for groundwater support and increasing overbanking frequency and depth to increase soil moisture regimes and push the wetland plant community towards a more

obligate wetland species. Milkweed will be added to the earlier planting list for added butterfly habitat benefit.

The number and extent of pool and riffle features will be expanded during 75 percent development in order to provide increased habitat for fish, aquatic invertebrates and amphibians. Design will include consideration of ephemeral surface water features along the existing backfilled channel where it is a sufficient distance away from the airport and in a manner that would not increase vector control or nuisance species issues.

Potential detrimental impacts to restoration improvements per direct manipulation by beaver will be anticipated during design development and protection measures will be incorporated into the design as necessary (i.e. temporary fencing for immature plantings, bank protections, etc.). Potential indirect impacts of the beaver activity, such as modified channel complexity, overbanking and meadow wetness will be considered in terms of anticipated interaction with design function.

Primary Tactics to preserve and enhance wildlife features relative to channel restoration that will be followed during 75 percent design development and beyond include:

Restore geomorphic function and floodplain connectivity.

Increase in-channel geomorphic complexity (i.e. pool/riffle pattern, woody debris, overhanging cover, beg materials).

Protect, preserve and incorporate existing wildlife habitat features including existing large snags, woody debris, willow stands and wetland sod.

Improve desirable plant species diversity, population and stages of growth.

## Hydraulic Modeling

Previous model results used to support the conceptual channel design prior to moving into 50 percent represented a simplified channel cross section with a uniform shape, size and slope with a riffle crest provided as the cross-section. The level of detail for a hydraulic model at 75 percent design would benefit from incorporating more of the proposed variability in cross section dimension and shape in order to better predict hydraulic conditions.

The previous model provided preliminary velocity and shear estimates for the bankfull design flow of 450 cfs, that showed average channel velocities for the proposed channel in Reach 5 around 3 fps and average boundary shear stress around 0.2 psf. Important exceptions to these general conditions included the following areas:

The downstream boundary of Reach 5 close to where the historical timber structure in the Airport Reach was recently replaced with a cobble riffle to maintain the same bed elevation. At this structure and upstream 1,500 feet into Reach 5, modeled velocities are up to 4.5 fps and average boundary shear stress is up to about 0.55 psf. There is an interesting reversal at higher flows with velocities and shear stresses becoming less than those upstream. This valley constriction has degradation potential during bankfull flows and aggradation potential during high flows.

The upstream end of the proposed new channel in Reach 6 about 400 feet downstream of the U.S. Highway 50 Bridge at Elks Club Drive. Although outside of the Reach 5 Project area this location is worth mentioning since similar hydraulic conditions could occur near the transition from Reach 6 to Reach 5, given Reach 5 will likely be constructed prior to Reach 6. At this location modeled velocities and shear stresses in the existing channel are reduced with average velocity less than 1 fps and average shear stress near zero.

Design emphasis will be placed on these two critical transitional areas in order to prevent erosion and channel degradation at the downstream connection where velocities and shear are higher and minimize aggradation and prevent any lateral channel adjustments in the upstream connection where velocity and shear are low.

The proposed 50 percent channel design would result in shear stresses at the bankfull flow that are higher than for existing conditions at the same flow and this could continue or aggravate the historical trend for incision. Critical grain sizes associated with these shear stresses are higher than the reported characteristics of bed material samples, except at the riffle sections where bed material may be coarser than material typically in transport.

Bed load supply to the project reach showing mostly sand in transport was measured only in Reach 6 and at flows below the design bankfull discharge. Estimates therefore have not been made regarding gravel supply and transport that may occur under higher flows. Observations from the historical imagery review and previous studies (Simon et. al. 2003: Conservancy and DGS 2003) indicate that bedload supply may be declining.

Therefore 75 percent design will aim for lower slope, smaller channel sizes, and higher width to depth ratios to reduce shear stress, sediment transport capacity, and critical grain size. The improved bank height, vegetation rooting depths, and surface and groundwater elevations that would result from a modified channel dimension for the 75 percent design are depicted in Figure 26.

A range of possible future sediment supply conditions needs to be evaluated for potential effects on design performance, including sensitivity analysis of the design to varied sediment loads and the potential range of short-term versus long-term conditions in both upstream reaches (Golf Course and Reach 6) that are in the planning phase of channel restoration projects and may or may not be constructed within a few years of the Reach 5 project.

## Channel Substrate

### Riffles and Pools

Bed material for constructed riffles or run sections should be a mixture of gravel and coarse sand with a $D_{50}$ around 20 mm or 30 mm. Material graded more like the plane bed samples, dominated by sand and small gravel and with a $D_{50}$ of 1 to 2 mm, is acceptable for the deeper pool sections. These sections might also simply be excavated into native materials if the material encountered is not excessively silty or organic. The alignment would be modified to avoid highly erodible sub-surface materials (i.e., gravel barrens). Hydraulic modeling results during 75 percent design (recommended 2-D and sediment transport calculations) would provide additional verification of appropriate range of size classes for the modified channel size and profile.

### Buried Utility Crossings

Lowering of the treated effluent force main and water line is feasible, but the gravity sewer line cannot be lowered without creating an undesirable sag in the line. Based on the invert elevations of the gravity sewer line at manholes on either side of the proposed crossing, the 50 percent proposed channel grade would occur just over two feet above the top of the existing sewer line. The conceptual 75 design would raise the new channel thalweg (to improve groundwater levels and bed and bank stability) and its location can be shifted slightly eastward to meet the three feet minimum clearance required by the District.

Protection of the sewer line will likely be provided by maintaining a suitable channel grade as the crest of a riffle section. The riffle will be formed of cobble-sized graded material (ranging between 3 and 9 inches) with subsurface larger rock (12 to 18 inches) incorporated both upstream and downstream of the pipelines to ensure extended protection. Gravels would be incorporated upstream, downstream, and in the interstices of the top layer of the cobble materials. All cobble and gravel materials will need to be purchased and brought onsite. The riffle will meet fish passage criteria over as wide a flow range as possible for the migration season(s) of target species.

### Downstream Reach Transition

Assurance in the form of grade control (e.g., constructed riffles) feature(s) similar to that described for the utility crossing, but not requiring as large of rock is recommended for this section. Multiple structures with small drops are preferable to a larger drop to provide reliability and flexibility for some adjustments, and better facilitate passage for aquatic organisms. One such riffle structure might be placed near the downstream limit of the Reach 5 project, as shown in the 50 percent design, and one near the crossing of the existing treated effluent force main with a third structure located approximately midway between these two structures. At 0.5 feet drop per structure, the crest profile would have a slope of about 0.0011, or approximately equal to the average bed slope upstream. The features will meet fish passage criteria over as wide a flow range as possible for the migration season(s) of target species.

### Bank Shear Stress

Based on 0.2 to 0.4 psf average shear, maximum shear stress at the outside of bends under bankfull flow is predicted to be around 1 psf. Under higher flows average boundary shear stresses of 0.8 psf could result in maximum shear stresses of 2 psf at bends.

Based on this, the shear stress targets for 75 percent design are 0.5 to 1 psf in the straight portions of the channel and 1 to 2 psf in the bends. According to Fischenich (2001) guidance on allowable velocities and shear stresses for various channel lining materials (Table 15), the native soil materials (described in Section II) have very low permissible shear stress, except where vigorous vegetation is rooted. There are, however, several channel facing materials and treatment measures that would be more than adequate under the expected range of velocities and shear stress for the modified channel dimensions.

Bank stability in the proposed new channel will be secured via installation and establishment of vegetation and largely bio-technical protection along the banks, particularly at outside bends. In shallower relatively straight sections and along inside bends, vigorous herbaceous vegetation will likely provide adequate resistance to maintain bank stability. More intensive treatments will be needed on the outside of bends. Controls against local scour at bends will include establishment of hydraulic roughness low on the bank to reduce shear stress and push maximum scour depths away from the bank and will include willow brush mattresses or even possibly engineered instream woody material structures (IWM), bendway weirs or vegetated rock toe stabilization. Wherever harder structures are used, more intensive vegetative transitions will be provided upstream and downstream to prevent localized erosion in the less resistant native bank materials. An incised channel profile and excessive bank height contribute to block failure mode by exposing bank materials with low shear strength under the effective rooting depth to hydraulic forces. The 75 percent design will develop a shallower channel with reduced shear stress, reduced scour potential in bends, and provide for dense, vigorous and/or deeply rooted vegetation to be more resistant to this type of erosion. A shallower channel will also reduce the need for more structural types of bio-technical treatments.

Several bank protection measures, including the range of possible options listed in Table 16 will be analyzed and their best use, place, and position will be determined during 75 percent design based on site objectives, cost, material availability and constructability.

## Access and Staging

The preliminary construction access and staging locations (Figure 27) will continue to be refined during 75 percent design development based on adjustments made to the new channel design, changes in expected material storage requirements and continued protection and avoidance of existing utilities and sensitive environmental and cultural resources. Two access routes are proposed with the primary route at Elks Club Road and the second to be made available at the end of Washoan Boulevard, particularly if the utility crossings are constructed during a different phase. There are currently seven locations where the haul road would cross utilities that will require specific protection measures to be

identified during 75 percent design development. The current routes and staging areas do not appear to pose significant problems to vegetation, however where haul roads traverse sensitive meadow and Stream Environment Zones a specialized road (e.g. fabric encapsulated, pre-fabricated mat, etc.) will likely be proposed to adhere to TRPA and Lahontan RWQCB requirements.

Field flagging of the proposed haul routes and staging and storage sites by the design team prior to the start of construction is recommended to improve upon utility and SEZ avoidance and adequately specify biologic and cultural protection measure locations.

## Flood Hydraulics

Previous modeling results indicate increased floodplain inundation area at 450 cfs and 760 cfs with shallow (< 1 foot) and somewhat discontinuous flooding across and down the valley. At 1,600 cfs the entire valley surface is inundated however flows are still shallow at roughly 1 foot deep. At 7,650 cfs most of the flow is carried on the floodplain and the valley is inundated to depths of 2 to 3 feet. At this same flow, there is a backwater effect upstream of the valley constriction on the downstream end of Reach 5 with velocities as low as 1 to 2 fps and floodplain surfaces as high as 5 feet.

In the transition section at the downstream end of Reach 5 energy slope is locally increased compared to upstream for all flow rates. Near the two structures that were recently replaced with cobble grade controls overbank velocities are higher reaching a maximum of 4.3 fps. A much smaller proportion of flow is carried in the overbank areas in the transition section compared to average values for Reach 5 indicating that floodplain flows return to the main channel in the transition section and as would be expected, computed velocities in the main channel are correspondingly increased. For example at 7,650 cfs, velocities in the channel increase from averages of 4 to 5 fps in Reach 5 to 6 to 9 fps for the transition section.

In the conceptual alternatives model, runs at flows between the 5-year (1,600 cfs) and 100-year (7,650 cfs) were not provided, but would be recommended during 75 percent development, as these flows are significant in floodplain processes.

Floodplain hydraulics along the proposed backfilled (existing) channel should be analyzed using 2-D modeling to assist in selecting appropriate final topography, soil/vegetation treatments that can provide enhanced ecologic conditions without adverse surface erosion risk. Material from the excavated new channel, along with potential material from temporary haul roads and possibly imported clay could be part of engineered backfill design. Lateral and vertical variability in sediment, compaction below the rooting zone, and appropriate soil conditions in the rooting zone are elements of the 75 percent design that would help prevent undesired recapture of the existing channel while facilitating improved habitat features and fine sediment trapping.

### Water Surface Elevations

At 1,600 cfs, the proposed water surface profile is slightly above the existing profile, consistent with a new channel sized to carry the bankfull flow and engage the floodplain more frequently. At 1,600 cfs differences in water surface elevation (and depth on the floodplain) are small, generally less than 0.5 feet in Reach 5. At 7,650 cfs, differences in computed water surface elevations are less than 0.5 feet through Reach 5. The most significant concern for increased inundation frequency and depth is at the airport runway, where flooding occurs along the margin of the airport property. At the 5-year flow of 1,600 cfs flow the water surface elevations are still 2 to 3 feet below the runway elevation. At the 100-year flow of 7,650 cfs, the airport runway and ramp areas are entirely inundated in the downstream portion of Reach 5 (below existing River Station 18000) for both existing and proposed conditions.

Flood water surface elevations are sensitive to assumed hydraulic roughness values, and increases in vegetation along the floodplain have the potential to increase flood elevations. Design for Reach 5 will incorporate an assessment of vegetative roughness and include a

sensitivity analysis of assumed n-values, particularly for the lower portion of Reach 5 where the floodplain width narrows and the runway is currently overtopped by large floods, Design measures will incorporate a planting plan that is sensitive to flood capacity, and consider active grading of secondary swales to increase conveyance in order to modify future flood elevations if modeling indicates the need.

The prior steady state 1-D hydraulic modeling does not account for differences associated with flood routing effects under either the existing or proposed conditions. As the proposed project would modify the relationship of the channel to the floodplain, the timing of storage in the floodplain would also be affected. Because the valley is wide, significant storage occurs during a large flood, and this would likely attenuate the flood peak. A 2-D unsteady model or flood routing assessment is recommended to assess the flood storage effect and any changes the project might cause to the flood hydrograph.

### Downstream Transition

The Reach 5 project does not significantly change conditions in the transition to the Airport Reach or downstream. While a slightly higher percentage of flow is carried in the overbanks in the proposed condition, overbank velocities remain at a similar range to existing conditions and the computed overbank flows and velocities do not appear to be a significant erosion hazard for a well vegetated floodplain. The 1-D modeling results are however average values and locally higher velocities and shear stresses may still occur.

Floodplain grading, planting plans and methods developed in 75 percent design will need to avoid concentrating return flows in a way that would cause overbank erosion or head cutting as return flows overtop the channel banks. Since this area is also subject to higher in-channel velocities and shear stresses, additional streambed grade controls will be incorporated (likely in the form of cobble riffles). Although the transition area is mostly downstream of the Reach 5 boundary, it is important to both channel and floodplain stability in Reach 5, and should be considered as a potential part of the project area moving forward with design.

### Upstream Transition

During the next phase of design, additional model runs should be performed that represent a new channel in Reach 5 only with a transition to Reach 6. Existing model runs for the Reach 6 transition, about 500 feet downstream of the bridge, show the computed water surface profile for the 7,650 cfs flow is about 1 foot higher than for existing conditions and the bed profile has a discontinuity of 1.5 to 2 feet. Aggradation should be expected in the channel upstream of such a change in bed profile. Eventually, this aggradation would affect water surfaces at the bridge, and in the interim would affect coarse sediment supply downstream. Although the previously modeled transition is not in the Reach 5 project area, these topics should be addressed in coordination with Reach 6 planning and design, including the potential for Reach 5 to be constructed prior to Reach 6.

The approach to 75 percent design at the upstream transition will be to use the 1-D model with simple sediment transport calculations to assess the backwater effects of the transition during a range of flow conditions. A gradual transition with some bank stabilization to prevent excessive widening upstream and in the vicinity of the transition would be beneficial. The analysis would determine whether the transition is best accomplished in a bend or a straight reach of the channel based on a detailed review of channel conditions and floodplain topography in the area of the proposed transition. Local overbanking patterns (using the 2-D model) would also be anticipated so that the design can incorporate vegetative or grading changes necessary to prevent secondary channel enlargement, flanking, and/or return flow erosion of streambanks. The potential need for temporary supply of coarse sediment downstream or near the transition and at the upstream end of Reach 5, perhaps in the form of constructed bar surfaces, could be considered if model result suggest they are needed. These measures would provide material to counteract any

forecast deficit in supply that might occur due to deposition upstream of the transition and/or decreased inputs from upstream.

### Reference Reach

Previously developed hydraulic geometry relationships (Appendix D), examined for a drainage area of roughly 50 square miles indicate a 320 cfs bankfull flow with a depth of 2 feet and width of 39 feet. These data are generally supportive of the 75 percent design direction towards a smaller capacity, shallower channel.

## XI. Guidance for Seventy-Five Percent Design

### Modified Design Approach

Based on review of prior technical studies, hydraulic modeling, and the 50 percent design materials, along with new field data and analyses reported herein (Section X), it is recommended that the design approach be modified as we move forward into 75 percent design. Several concerns regarding the feasibility of obtaining the desired functional ecosystem improvements and the long-term sustainability of the proposed 50 percent design, outlined above (Section IX), lead to the following recommended approach as a guide for the next stage of design development.

The motivating factors as design progresses beyond the 50 percent new channel design are to: (1) develop a river alignment and channel dimensions with geomorphic variability that can satisfy the project goals and objectives while having a high potential for long-term stability; (2) lower velocity and shear stress in the new channel to ensure stability; (3) raise the groundwater table to better support floodplain wetness; and, (4) decrease channel depth to facilitate vegetative protection of the banks.

Within Reach 5, any proposed new river channel alignment would be excavated through fine grained non-cohesive soil materials, along a very low gradient floodplain that is highly constrained by existing utilities. The best restoration opportunity may be a smaller but stable main channel that is well-connected to its active floodplain on the adjoining meadow surface, including increased floodplain activity within existing meadow swales and remnant channel segments.

#### Key changes to 50 percent design

Develop a somewhat smaller capacity, shallower channel and optimize for tolerable shear stress that provides hydraulic diversity without excessive bank undercutting or bed scour.

Adjust planform as necessary to meet sinuosity and slope needs, protect utilities and avoid sensitive resources and/or high erosion risk substrate.

Integrate existing channel as backfilled floodplain habitat that enhances floodplain functions and connectivity without adverse hydraulics.

Incorporate overflow opportunities and return flow channels to re-activate the floodplain without adverse hydraulics.

#### Benefits

This approach takes advantage of the extensive assessment and design development already completed by building upon the general planform of the proposed 50 percent new channel, but making adjustments to design based on updated information and new insights. Some of the potential benefits are:

Increased dynamics on the floodplain via minor scour, erosion and deposition.

Improved ecological complexity and habitat benefits across the meadow.

Reduced potential for re-incision and/or widening.

Added opportunity for semi-stable undercut banks to enhance fish habitat.

Enhanced riparian habitat along the channel via raised groundwater tables and overbanking frequency.

Improved channel shape and bed form variability.

Reduced need for hard engineered protection measures.

Heightened ability for vegetative treatments to perform required stabilization and also meet other objectives.

### Uncertainties

Uncertainties such as long term operational sustainability in susceptible soils under extremely large flood events would be similar to, but likely less than the proposed 50 percent design, due to recommendation to decrease channel size and depth and direct a larger proportion of flood flows on the floodplain more often.

Uncertainties due to limited information on sediment supply trends are present for any of the approaches. If future coarse sediment supply is decreased (as appears to be possible from available data), the modification to a slightly smaller channel would better accommodate this future condition than the 50 percent design.

Uncertainties about the availability of adequate vegetative material resources is similar to that for the proposed 50 percent design, but may be lessened if decreased channel capacity and reduced bank heights may be adequately stabilized using fewer materials or different techniques.

Uncertainties about possible on- or off- site effects due to changes in import/export of rock, soil, or plant materials would be similar to those for the proposed 50 percent design.

## Recommended 75 Percent Design Process

The recommended process for proceeding with 75 percent design, based on all the recommendations above, is summarized in Table 20. The original scope assumed 75 percent design would be generated based on adding detail and refinement to the proposed 50 percent channel plan, profile and cross-section as long as all was deemed acceptable for meeting the design goals and maintaining stability. In light of the new information our recommended approach for moving forward modifies all three (i.e. plan, profile and cross-section) and additional effort is required. The overall process is described in Table 20 for completeness, including elements in the original scope compiled with additional steps and/or methods needed to fine-tune the channel design. The process is not entirely linear, as several iterative steps are required to optimize design, but the steps are generally arranged in sequence from top to bottom within the table.

In general, the steps are:

- Develop range of reasonable design flow estimates using previous analyses, hydrologic record, revisiting effective discharge, and adding regional relationships;
- Estimate range of probable sediment supply using previous data and analysis, along with sediment transport calculations for Golf Course reach and Reach 6 for long term trends;
- Use range of bankfull flows and sediment supply in a modified stable channel design analysis to develop potential channel size and shape combination and test sensitivity to varied supply.
- Select new channel typical dimensions, favoring a smaller channel to the extent feasible without undue risk of sediment transport and/or floodplain return flow problems;
- Fit typical channel template to floodplain surface and adjust typical channel geometry, profile, and alignment as necessary to best fit topography, accommodate utility crossings, and make upstream and downstream transitions;

- Update hydraulic model (2-D for channel and floodplain performance and HEC-RAS for flood hazard and sediment calculations) during design process to reflect modified new channel, provide hydraulic parameters for design, and identify any locations where iteration of alignment or geometry is needed to avoid unacceptable velocity or shear stress patterns.
- Develop and apply variations in channel shape, bed form and materials, and bank treatments for desired stability, aquatic habitat enhancement, and other site-specific needs.

**TABLE 20: RECOMMENDED 75 PERCENT DESIGN PROCESS**

| Design Element | Known Constraints/Targets | Preferred Methods | Effort and/or Data Needs for 75%Design |
|---|---|---|---|
| Sediment Input | Uncertainty over past and future sediment supply from upstream reaches and limited measured data. | Sediment transport calculations for the supply reaches (Reach 6 and Golf Course Reach) within HEC-RAS using appropriate equations for sand dominated and bi-modal systems. | Modeling of transport capacity within supply reaches for reasoned range of hydraulic conditions (existing vs. restored) |
| Modified Design Flow | Prior estimates vary and their range may be significant In terms of channel constructability and performance.<br>Climate Change trends may affect future performance and would likely decrease or hold frequent events (< 10 year) similar to present but increase magnitude of larger events. | Incorporate all methods<br>--Flood Frequency<br>--Effective Discharge<br>--Geomorphic Indicators<br>--Regional Relationships<br>Add sensitivity analysis to ensure desired outcome of more active floodplain (overbanking success) without adverse channel stability, and seek resilience to climate change. | Flood Frequency<br>--Review for desired return interval for overbanking ---given sporadic historic occurrence.<br>Effective Discharge<br>--Review graphic results for selection of best value and/or revise for appropriate sediment transport relation.<br>Geomorphic Indicators<br>-Review/reconsider 370 cfs (TRCD 2003)<br>Regional Relations<br>--DGR Appendix D information. |
| Modified Average Channel Dimensions | Desired average and maximum depth are critical drivers in terms of groundwater relations and bank stability.<br>Selecting appropriate sediment input and/or range of input | Use stable channel resistance equation method(s) appropriate for sand-bed channels; with empirical data (including regional hydraulic relations from Appendix D) as starting points for maximum or average depth. | Revisit this step with modified design flow; updated sediment supply; AND average/maximum depth limitations. |
| Channel Stability Checks | Critical bed elevation points;<br>Prevent re-incision;<br>Limit bank erosion<br>Limit aggradation/avulsion | Permissible Velocity and Shear Stress for average channel dimensions using known and assumed bed and bank materials (sand/bi-modal bed | Data required is available, but analysis would need to be performed; using the 1-D and 2-D model output and/or Bank Stability and Toe Erosion |

| Design Element | Known Constraints/Targets | Preferred Methods | Effort and/or Data Needs for 75%Design |
|---|---|---|---|
| | | methods). | (BSTEM) estimates to check bank instability for modified channel dimensions, known soils and anticipated groundwater elevations. |
| Bed Material | Bimodal existing particle size distribution;<br>Lack of in-reach source for gravel;<br>Low bank resistance relative to potential coarsened bed | Sensitivity test proposed dimensions and hydraulics to bed material sizes and supply during stable channel analysis. | Analysis would need to be performed, but could be limited to sensitivity testing. |
| Profile/Bed Slope | Reach 5 average slope to achieve sinuosity;<br>Local minimum grade separation for buried pipelines | Compute reach average from stable channel calculations using bed material load, bank conditions, and design flow values that are optimized for preventing in channel sedimentation or bed and bank erosion;<br>Sub-reach variations based on design channel 'hung' on existing surrounding surface and for required pipeline crossing elevations. | Data for valley slope, existing channel length and sinuosity are available and LiDAR based DEM available for use in determining varied local bed slopes. 2-D modeling grid could be used to refine initial slopes along modified alignment. |
| Meander Belt Width | Existing Land Use (Airport) and Buried Infrastructure | Design directive is to maximize use of available valley width | Data is available, and 2-D hydraulic modeling would identify any adverse issues to resolve. |
| Length / Sinuosity | Meet or exceed existing Reach 5 length and sinuosity | Design directive is to meet the minimum condition; stable channel calculations may provide cross check;<br>Visual fit of appropriate length to above MBW and Alignment criteria. | Data is available regarding existing conditions. |

| Design Element | Known Constraints/Targets | Preferred Methods | Effort and/or Data Needs for 75%Design |
|---|---|---|---|
| Alignment | Meet US/DS transitions to existing channel;<br>Avoid unsuitable materials;<br>Minimum buffers from airport and pipelines;<br>Reactivate remnant channels<br>Limit modifications by potentially faulted section | Visual fit of desired length to available meander belt width and constraints;<br>Integrate/reactivate Remnant Channel features;<br>Meander configuration to be non-uniform and have varied arc length (4-9 widths) | Iterative adjustments once channel dimensions /length/ profile estimated to see if utilities protection and/or fit to existing floodplain topography can be optimized. |
| Variations in Cross-Section Shape(s) | Preferred Width/Depth Ratio;<br>Riffle and Pool variations for the range of sub-reach bed slopes;<br>Minimum residual pool depths and/or other low flow targets for base flow (ENTRIX used 15 cfs) | Targeting channel bank heights that will be low enough (3 ft or less) to permit vigorous herbaceous vet to provide adequate resistance, but not targeting a particular w/d ratio | Revisit with range of output from stable channel analysis and results of sediment supply uncertainty/sensitivity analysis. |
| Variations in Bed Form(s) and material | Riffle and Pool spacing;<br>Number and size of pools needed for aquatic habitat goals? | Visual fit after alignment and length determined:<br>½ meander length at crossovers;<br>Clusters, or spacing range 4 to 10 channel widths | Review after average channel and alignment/profile variations, check on hydraulics for range of critical grain sizes (most likely sand/gravel combinations) with special conditions for utility crossings, other grade controls, and the downstream transition. |

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# XIII. APPENDICES