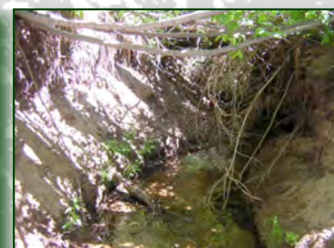
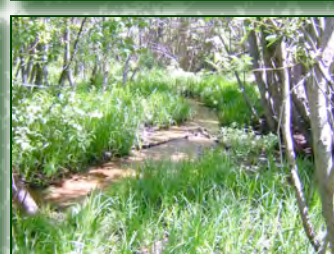
Middle Rosewood Creek

Geomorphic and Riparian Assessment

November 30, 2005





Nevada Tahoe Conservation District

MIDDLE ROSEWOOD CREEK

Geomorphic and Riparian Vegetation Assessment

FINAL

November 30, 2005

Prepared for:

Nevada Tahoe Conservation District
P.O. Box 4605
297 Kingsbury Grade, Suite G
Stateline, NV 89449-4605

Prepared by:

Mainstream
Restoration, Inc.
P.O. Box 1723
Bozeman, MT 59771-1723
(406) 522-0072

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1. Executive Summary

This study was conducted, under the direction of the Nevada Tahoe Conservation District, to characterize the current conditions of Rosewood Creek, a tributary to Third Creek in Incline Village, NV. The study also included preparation of a conceptual-level Stream Environment Zone (SEZ) Restoration Plan. The study area encompassed the reach of stream from SR 28 upstream to the Incline Village Mountain Golf Course, a length of about 7,400 feet. This study was undertaken on Rosewood Creek because it has been identified in previous studies as a high contributor of sediment to Third Creek and Lake Tahoe.

There is a long history of impacts to the streams in Incline Village, including Rosewood Creek. The Comstock era (1880s to 1890s) brought large-scale clear cutting of timber, milling and transportation of lumber to the mines in Virginia City. These activities redirected and obliterated stream courses. Subsequent cutting of second growth forests occurred between the 1940s and 1960s, at a time before the existence of streamside best management practices. Rapid land development in the 1960s and 1970s was marked by the construction of roads, beaches, golf courses and ski areas. Subsequent development continued to increase the amount of impervious surface in the Rosewood Creek watershed. As a result, Rosewood Creek as it exists today is very different than it was 150 years ago.

The objective of the study was to investigate the geomorphic and riparian character of the stream and riparian zone. An understanding of the fluvial processes and related vegetative community succession was to serve as a basis for the eventual development of a stream and riparian restoration plan. The study included several subcomponents, as follows.

- Flood flow frequencies were estimated.
- The surficial geology of the area was described.
- Topographic surveys were undertaken to measure the longitudinal profile of the stream and 32 channel and floodplain cross-sections.
- The hydraulic conditions in the stream channel at the cross-sections were estimated.
- The geomorphic conditions and ongoing trends were characterized and the study area was divided into 17 stream reaches.
- Streambed and bank samples were collected, measured and analyzed for their potential to be mobilized.
- Volumes of eroded sediment were estimated.
- Vegetation communities along Rosewood Creek were identified and their boundaries defined.
- A series of 15 vegetative transects across the floodplain were sampled to quantitatively describe the composition and character of these plant communities.

The assessment indicated that channel incision is the dominant geomorphic process in about half of the studied length of Rosewood Creek (3,900 feet). Most of the incised stream is in the early stages of incision, exhibited by deep, narrow channels with vertical, unvegetated banks. These channel reaches contain a wide range of flows, which exert high erosive energies on the unstable bed and banks, further exacerbating the incision and erosion process. Most stream reaches that are not incised have been armored with rocks along the stream banks. One reach consists of a dozen rock grade controls, which serve to stabilize a segment that was probably incised at some previous time. Using anecdotal information on development history and the timing of road culvert installation and observations of plant age, it is suggested that the observed incision began about 50 years ago. Incision actively continues today.

The vegetative assessment indicated that the overstory health, canopy cover and age class are variable, although most of the stream exhibits a pronounced lack of vegetation recruitment, senescence (aging of vegetation stands) and conifer encroachment. Quantitative analysis of the 15 vegetative transects identified Rosewood Creek as an early seral (drying) riparian complex. These results are based on approximately 30 percent of the vegetation having been rated as late seral. As a result of the incision, the water table in the adjacent floodplain has been lowered, which is the primary reason that the vegetation has been characterized as a seral complex. This trend suggests that the riparian corridor will continue to decline and that conifers will eventually encroach upon the former floodplain.

As part of this study, efforts were made to characterize the potential mobility of stream bank and bed sediment as well as the degree of impacts that incision has had, and would continue to have, on the clarity of Lake Tahoe. Comparison of streambed material size gradations sampled at 17 sites with the estimated hydraulic conditions at nearby surveyed cross-sections indicate that the Rosewood Creek streambed is highly mobile. It is likely that the incision process will continue.

Gross estimates were made of the volume of sediment that has been eroded from the stream channel within the study reach, and the amount that might be further eroded if the incision process continues. Although nine samples of stream bank materials indicated a low percentage of fine clays (an average of less than 5% at 20 microns or less in size), the ready availability of this material suggests that this is a large sediment source.

As a foundation for potential SEZ restoration, a ranking is provided, by stream reach, of the potential for continued adjustment. The greatest risk of adjustment was identified as in those stream reaches where early stages of incision were observed. The secondary risk of adjustment is in the stream segments that are susceptible to avulsion. Many of these segments were not located in the topographic low points of the valley cross-section (having been previously relocated).

Finally, a conceptual SEZ Restoration Plan is incorporated into this document. The plan provides a description of a variety of floodplain and channel restoration measures that have potential application to this site. It also provides reach-specific conceptual designs that can be considered in the future planning and development of SEZ restoration designs for Rosewood Creek.

2. INTRODUCTION

Project Location

Rosewood Creek is located in the Lake Tahoe Basin within the town of Incline Village in Washoe County, Nevada. The U.S. Geological Survey map of the area does not provide a name for Rosewood Creek. Although previous studies (Glancy, 1988) have referred to the stream as the West Branch of Third Creek, it is now commonly called Rosewood Creek. The Rosewood Creek watershed encompasses a total area of 1.15 square miles, originating at about 8,500 feet elevation in the Carson Range (Figure 1). The watershed, like those of the adjacent streams, is relatively long and narrow. The stream flows for about 2.7 miles until it enters Third Creek immediately upstream of Lakeshore Blvd., about 600 feet upstream from Lake Tahoe.

The study area includes the reach of Rosewood Creek between SR 28 and the Incline Village Mountain Golf Course (just upstream from Titlist Drive). The length of stream within the study area is 7,400 feet and comprises the middle portion of Rosewood Creek. Rosewood Creek above the Golf Course and Mount Rose Highway is small and ephemeral. The elevation of the study area ranges from 6,371 to 6,835 feet (MSL). For reference, the natural sill elevation of Lake Tahoe is 6,223 feet and the maximum water surface elevation mandated by law is 6229.1 feet. The entire length of Rosewood through the study area has been affected by encroachment by condominiums and single residences located adjacent to and within the riparian corridor.

Project Background

The Third Creek drainage has been identified as one of the highest contributors of sediment to the Nevada side of Lake Tahoe. Based on over two decades of sampling data, of the 63 drainages in the entire basin, only the Truckee River, Blackwood, Second and Trout Creeks contribute more *total* suspended sediment than Third Creek, measured in mean annual tons. Normalized to drainage area, however (and using only those streams with data collected for periods longer than 5 years), Third Creek produces more *total* suspended sediment yield than any other drainage, except for Blackwood Creek. Normalized to drainage area, Third Creek also produces large amounts of *fine-grained* suspended sediment. It produces about 54% of the amount of the fine-grained sediment delivered from Ward Creek and 94% of that from Blackwood Creek (Simon et al., 2003).

Until recently, Rosewood Creek entered Third Creek only a few hundred yards downstream from SR 28. Rosewood Creek, between its former confluence with Third Creek and the SR 28 crossing, exhibits a relatively healthy channel with well-vegetated riparian margins. This reach of stream is stable, despite (or maybe because of) having been relocated as part of the construction of the Incline Village Middle School and associated sports complex and ball fields. Indeed, hidden beneath the dense willow along this reach, large rocks line portions of the stream banks. Upstream of SR 28, however, Rosewood Creek shows evidence of extensive vertical instability. It is this middle reach of Rosewood Creek that likely contributes to the high suspended sediment load of Third Creek.

The Third Creek/Rosewood Creek SEZ Project (Phase I) undertaken in 1997 by the Natural Resources Conservation Service was the first step in alleviating the high sediment load supplied to Third Creek. This project involved the installation of structural controls (rock lined inlets, oil separation vault and two detention basins) in lower

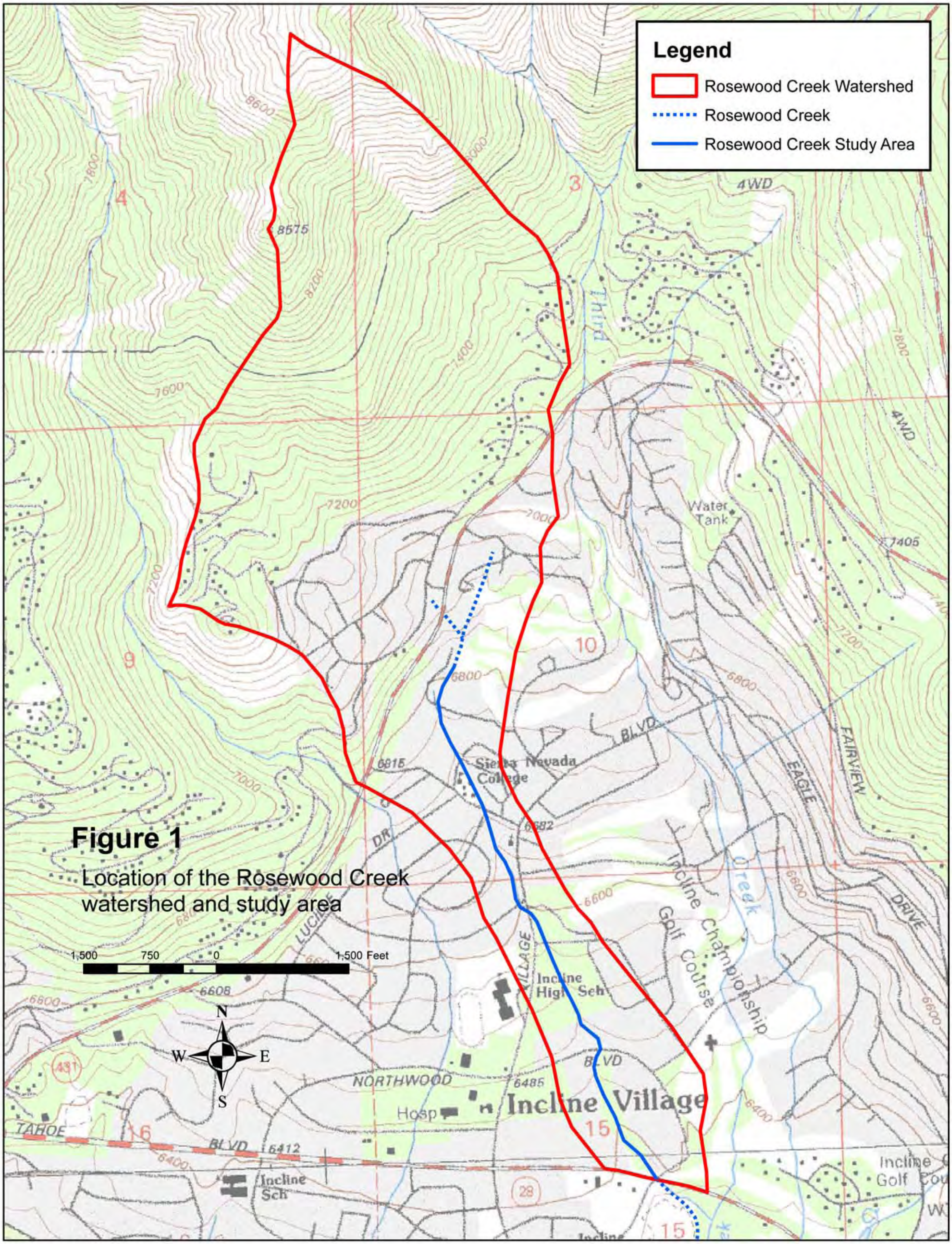


Figure 1

Location of the Rosewood Creek watershed and study area

Rosewood Creek. The work did not fully meet the desired performance criteria. The Rosewood Creek SEZ Restoration Project, completed late in 2003, was a second sediment reduction project. The project involved extending the Rosewood Creek channel 3,000 feet further downstream, through a total of five flow spreading basins, before it enters Third Creek at Lakeshore Blvd. Strategically placed along the stream course, these vegetated spreading basins allow fine-grain sediment to deposit before it reaches Third Creek. The Rosewood Creek Restoration Project, however, did not address the source or control of sediment originating in middle Rosewood Creek.

Study Objectives and Scope

The purpose of this study was to determine the current conditions of middle Rosewood Creek and identify opportunities for SEZ restoration. The primary objective was to analyze channel stability with regard to sediment contributed to Lake Tahoe. The secondary objective was to analyze the ecological health of the stream and riparian corridor. The study was undertaken during the period of May through September of 2005. The work scope included the following tasks:

- Review of previous work, reports, community planning, and other existing information;
- Preparation of a GIS-level site map based on existing 2004 aerial photography;
- Completion of a longitudinal profile and floodplain/channel cross-section survey (using relative topographic point locations but referenced to local elevation datum);
- Characterization of the hydrology, soils, geology and fluvial geomorphology of the study area;
- Estimation of the hydraulic parameters associated with different return interval flows;
- Characterization of the stream bed and bank sediments and the sediment transport characteristics within the study area;
- Characterization of the vegetation within the riparian zone and the factors that affect the plant communities along Rosewood Creek;
- Preparation of an existing conditions report supported by the data and analysis collected and referenced to study area base maps; and
- Recommendations for Stream Environment Zone restoration planning, with identification of conceptual techniques and measures that might be employed within specific segments of the study area.

3. Previous Work

Over the last half a dozen years, studies have been undertaken on Rosewood, Third and Incline Creeks to assess flooding, stability and fish passage. This section addresses the known studies and projects on Rosewood Creek.

Studies, Assessment and Planning

The Rosewood Creek area has been studied by others for the purpose of assessing opportunities for stream improvement, fish passage and flood management. Several documents from these efforts were reviewed during the undertaking of this current study. These documents include the following.

Title: Effectiveness of the Rosewood Creek Restoration Project at Reducing Suspended Sediment Loading to Lake Tahoe: 2002 to 2004. 2004 (Agency Review Draft). R.B. Susfalk, Desert Research Institute, Reno. Nevada Division of State Lands. 40 pages.

Annotation: *Field study of sampled discharge, turbidity, specific conductivity, water temperature and suspended sediment to determine the effectiveness of the project to alter sediment transport. Preliminary results showed the effects were event-dependent, but that the average particle size diameter of suspended sediment, about 40% of which was less than 20 microns in diameter, was not altered. This study was based on data collected over a period of about a year following project implementation.*

Title: Draft Environmental Assessment. Third, Incline and Rosewood Creeks Section 206 Aquatic Ecosystem Restoration, Washoe Co., NV. 2004. U.S. Army Corps of Engineers, Sacramento, CA. 43 pages plus plates and 5 appendices.

Annotation: *EA for fish passage and ecosystem restoration in Third and Incline Creeks. Ten segments of Rosewood Creek upstream of SR 28 were evaluated using Rapid Bioassessment Protocols (Barbour et al., 1999). The segment locations were not identified, the data were qualitative, and the restoration recommendations did not include consideration of dominant geomorphic processes.*

Title: Draft Engineering Appendix. Third, Incline and Rosewood Creeks Section 206 Aquatic Ecosystem Restoration, Washoe Co., NV. 2004. U.S. Army Corps of Engineers, Sacramento, CA. 35 pages.

Annotation: *Preliminary engineering design for fish passage improvement on Third and Incline Creeks. No information on Rosewood Creek is provided.*

Title: Draft Detailed Project Report and Environmental Assessment. Third, Incline and Rosewood Creeks Section 206 Aquatic Ecosystem Restoration, Washoe Co., NV. 2003. U.S. Army Corps of Engineers, Sacramento, CA. 40 pages.

Annotation: *Environmental documentation for fish passage improvement on Third and Incline Creeks. Provided information on historical land use in the Rosewood Creek area.*

Title: Rosewood Creek Design Report, Rosewood Creek Stream Restoration, Washoe Co., NV. 2003. Harding ESE. Incline Village General Improvement District. 29 pages.

Annotation: *Basis of design report for the Rosewood Creek Restoration project, located between Lakeshore Blvd. and SR 28 and implemented in 2003.*

Title: Draft Partial Fish Passage Assessment, Incline and Third Creeks Upstream of State Route 28. Third, Incline and Rosewood Creeks Section 206 Aquatic Ecosystem Restoration, Washoe Co., NV. 2003. U.S. Army Corps of Engineers, Sacramento, CA. 14 pages.

Annotation: *Brief identification of fish barriers associated primarily with road crossings. No barriers on Rosewood Creek were identified.*

Title: Lake Tahoe Basin Hydrology Study: Compilation and Evaluation of Available Hydrologic Information. 2002. Northwest Hydraulic Consultants, Inc., Contract DACW05-99-D-0015, U.S. Army Corps of Engineers, Sacramento, CA. 30 pages.

Annotation: *Compilation of precipitation, snow survey, stream gaging and lake level data and development of regional hydrologic relationships for the Lake Tahoe Basin. These relationships included hydrographs, flow duration analyses and flood frequency analyses.*

Title: Third and Incline Creek Watershed Assessment for Sediment Reduction: Incline and Third Creeks, Lake Tahoe Basin, NV. 2000. Swanson Hydrology and Geomorphology. Tahoe Regional Planning Agency. 33 pages.

Annotation: *Cursory level assessment of sediment from stream channels and roadway sources with identified priorities for erosion control projects in the Incline Village area.*

Title: Incline Village, Washoe County, NV, Floodplain Management Services Study: Hydrology Report, Volume 1 of 2. 2000. U.S. Army Corps of Engineers, Sacramento, CA. 157 pages.

Annotation: *Results of a study using HEC-1 model to predict the 10-, 50-, 100- and 500-yr* ***storm flows*** *in nine streams within Incline Village, including Rosewood Creek (West Fork Third Creek). The estimated 100-yr recurrence interval flows are higher than those reported as part of the current study.*

Erosion Control and Stream Restoration Projects

Two completed erosion control projects fall within the Rosewood Creek watershed. These include EIP No. 231 (Village Blvd.) and EIP No. 10066 (Incline Village 1). The Incline Village Tourist/Fairway Phase II Water Quality Improvement Project No. 231 is also slightly within the watershed and is currently underway.

The Third Creek/Rosewood Creek SEZ Project (Phase I) was implemented in the fall of 1997 by the Natural Resources Conservation Service, in conjunction with the Incline Village General Improvement District and the Nevada Resource Conservation District. This project involved the installation of grouted rock-lined chutes, an oil separation vault, two rock-lined channel inlets, step pools, debris removal, channel restoration and two wetland basins in lower Rosewood Creek. The road runoff treatment portions of the project were successful, but the remainder of the work did not fully meet the desired performance criteria. Phase 2 of the project was to have included rock drops, vortex rocks, channel restoration, three wetland lakes and vegetative planting. It was never constructed (U.S. Army Corps of Engineers, 2004).

The Rosewood Creek Restoration Project, implemented in the summer of 2003, involved extending the channel 3,000 feet further downstream from its confluence with Third Creek. The entire stream channel was reconstructed with a series of rock drops interspersed between reaches consisting of bioengineered stream banks and an immobile bed. Five flow spreading basins were incorporated where the surrounding topography allowed. Rosewood Creek now flows through these vegetated basins, which provide for fine-grain sediment to deposit before it reaches Third Creek. Flows resulting from a thunderstorm in August 2003 caused a number of the rock drops to fail. These were subsequently reconstructed in November of that year.

Fish Passage Projects

The Nevada Department of Wildlife (NDOW) has a limited amount of information about the type and extent of a resident fishery in Rosewood Creek. Some species diversity and population estimate studies were apparently undertaken in the 1970s, although documentation of these studies was not found. More recently, studies were undertaken in the last few years in coordination with fish passage inventories in the area.

Fish passage in Third Creek has been addressed in assessments and planning by the U.S. Army Corps of Engineers for barrier replacement. Projects have been implemented at SR 28 with the removal of dual 60-inch diameter CMP culverts and replacement with a single, concrete 12- foot wide box culvert. Additionally, five culverts and a rock drop that served as impediments to fish passage through the Incline Village Championship Golf Course have been (or soon will be) replaced with segments of stream designed to provide fish passage.

Conversely, the Rosewood Creek Restoration Project, implemented in 2003, included the installation of three culverts, two of which are impassable to fish due to the inclusion of vertical standpipes at the upstream end of the culverts. Furthermore, the culvert under SR 28 likely serves as a depth and velocity barrier to fish. Impeded upstream fish passage is typically defined in terms of barriers associated with leap, water depth and velocity limitations. Passage of resident fish within the study reach of Rosewood Creek was not considered as part of this study.

4. WATERSHED CHARACTERISTICS

Land Use

From 1881 to 1896, the Sierra Nevada Wood and Lumber Company, one of the three large combines harvesting timber from the Lake Tahoe Basin for use by the Comstock mines, used the Sand Harbor and the Mill Creek area as a base of operations. The steamer Niagara towed log rafts from company land at the south end of Lake Tahoe to Sand Harbor, where they were loaded on narrow-gauge railway cars and transported two miles north to a sawmill on Mill Creek. From that point they were transported over the incline tramway and down a V-flume to Washoe Valley for transport to the Comstock (Nevada Division of Water Resources, undated). During this period, the Rosewood Creek and surrounding watersheds were essentially clear-cut to provide timber to these milling operations. By the 1940s a second-growth forest had become established in this area.

The dramatic effects of historic, large-scale logging in the Incline Village area on Rosewood Creek are difficult to estimate. Lindström et al. (2000) suggest that many of the log haul roads and skid trails created by logging in the basin, which at the time eroded into trenches, are now only recognizable as drainage channels and "are appropriately characterized as sensitive environmental zones". The current Rosewood Creek might merely be a remnant of log haul road patterns.

Lakeshore Blvd. was constructed in the 1920s and eliminated much of the historic beach and lagoon system that occurred at the confluence of the Rosewood, Third and Incline Creeks with Lake Tahoe. Construction of this highway, later to become SR 28, apparently involved a combination of channelization activities that affected the vertical and lateral stability of these streams (U.S. Army Corps of Engineers, 2003a).

In the late 1950s, Crystal Bay Development Company purchased 9,000 acres previously held by lumber and real estate interests. Timber had again been harvested in much of this area. Incline Village was established in the 1960s. Roads were cut, a ski area and golf course were designed, and beaches were developed. A development map of Incline Village from January of 1963 indicates that the first parcels sold and developed in Incline Village included those west of Village Blvd, with a smaller number in the Mill Creek subdivision east of what is now Country Club Drive (Figure 2).

The map clearly indicates the location of Rosewood Creek during the early 1960s. The stream at that time flowed directly into Lake Tahoe, parallel to Third Creek. Furthermore, the map shows that Rosewood Creek was likely relocated when the Middle School and associated sports complex were developed between Incline Way and SR 28.

Land development progressed rapidly during the period between the late 1950s and early 1970s (Glancy, 1988). Photographs of land development activities adjacent to Rosewood Creek during the later part of this period (Figure 3A and B) show:

- SEZ Best Management Practice (BMP) measures within the SEZ were not used;
- Stream channel and stream bank disturbance was extensive; and
- Riparian vegetation was entirely removed.

These dramatic alterations to channel slope, geometry, bank stability and sediment supply provide an insight into the geomorphic and riparian condition and response of Rosewood Creek during the last 30 years.

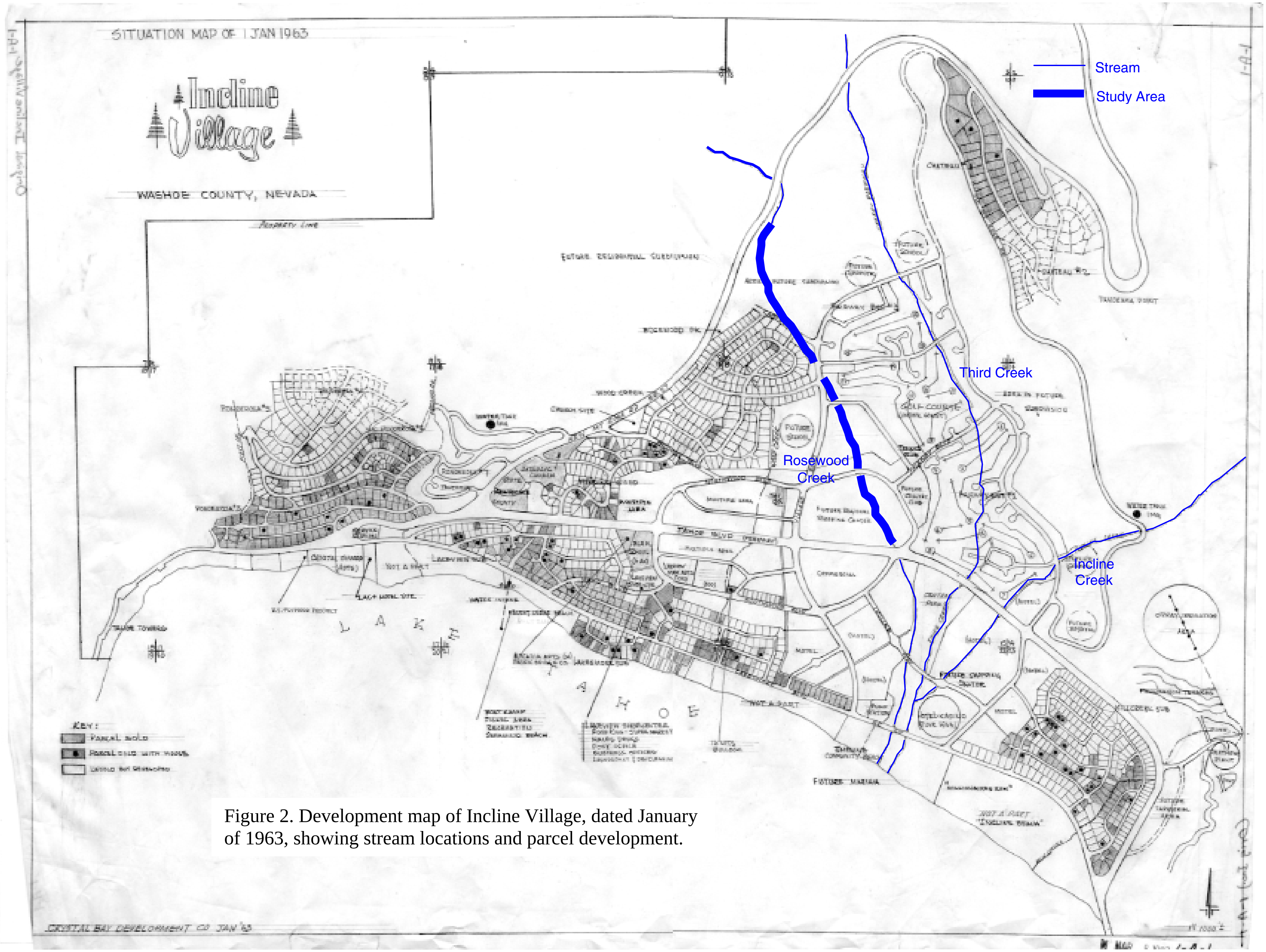


Figure 2. Development map of Incline Village, dated January of 1963, showing stream locations and parcel development.

Figure 3 A and B. Photos of Rosewood Creek showing SEZ impacts resulting from unregulated development activities. Figure 3A taken October 1969 of cleared subdivision; specific location unknown. Figure 3B taken April 1970 of relocated reach of Rosewood Creek upstream of confluence with Third Creek. Both photos from Glancy (1988).

Geology and Soils

Document Review

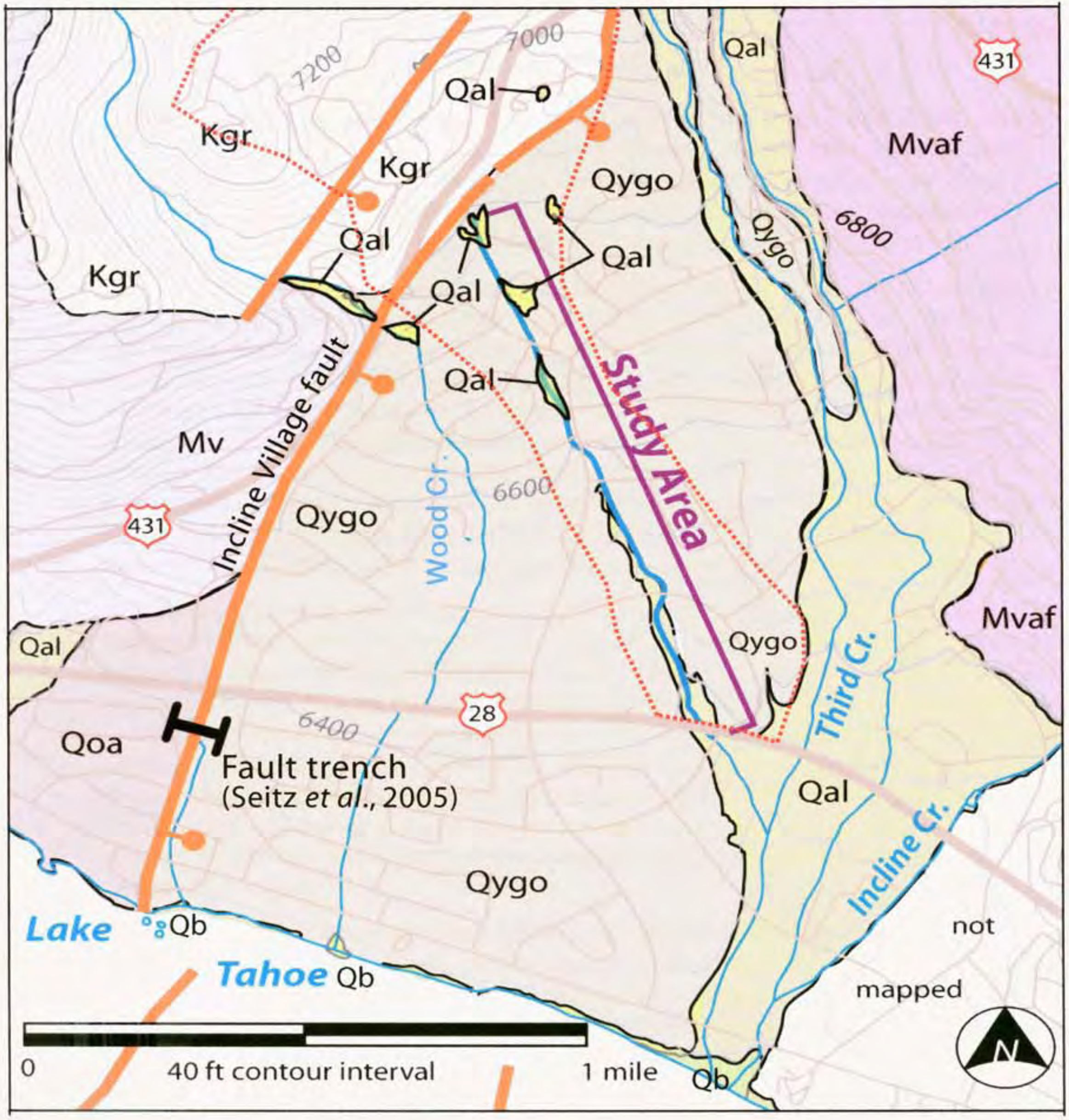
The existing documents relevant to the geologic conditions in the middle Rosewood Creek watershed were reviewed. The review of these documents included:

- Evaluation of the geologic maps of and publications on the geology of Incline Village area;
- Stereoscopic examination of three sets of historical aerial photographs of the study area, available at the Nevada Bureau of Mines and Geology at the University of Nevada Reno;
- Mapping of the study area, based largely on pre-development aerial photographs; and
- Compilation of existing information and photo-geologic mapping to produce a geologic and soils map of the study area.

Relevant Findings

Subsurface Geology and Soils

The study reach of Rosewood Creek flows across a broad glacial outwash sheet consisting of two large and contemporaneous alluvial fans (*Geologic Unit Qygo* in Figure 4), based on mapping for this project, which is consistent with the recent mapping, by Saucedo (2005) of this area. The channel location or its geomorphic position is confined by the opposing flanks of these gently sloping glacial outwash fans. The eastern fan is composed of layers and lenses of alluvial sand and gravel derived from late Pleistocene (Tioga?) alpine glaciers in the Third Creek watershed to the northeast. The interfingered



LEGEND

Geologic contact

Quaternary fault; bar-ball symbol shown on relative downthrown side; activity within past 15 ka with repeated late Quaternary activity, most recent surface-faulting event occurred only about 500 years ago (Seitz et al., 2005), as shown by paleoseismic trench site on the Incline Village fault (see Figure 1a).

Watershed boundary

EXPLANATION

Qb — Quaternary beach deposits (late Pleistocene and Holocene, mostly historical)

Qal — Quaternary alluvial deposits (Holocene)

Qygo — Quaternary younger (Tioga?) glacial outwash deposits; composed of layers and lenses of sand and gravel (latest Pleistocene)

Qoa — Quaternary older (Tahoe? or older) alluvial deposits; include consolidated layered sands and gravels (late to mid Pleistocene)

Mv — Miocene volcanic rocks; undifferentiated

Mvaf — Miocene volcanic rocks; andesite and dacite flows

Kgr — Cretaceous granitic rocks

Figure 4. Geologic map of the study area.

western fan is composed of similar alluvial deposits derived from Wood Creek, which is sub-parallel to the upper study area of Rosewood Creek. These watersheds are comprised of Cretaceous granitic bedrock capped by Miocene volcanic rocks (*Geologic Units Kgr* and *Mv* or *Mvaf* in Figure 4, respectively). Hence, the glacial outwash deposits are mainly composed of granitic detritus with fewer amounts of volcanic materials.

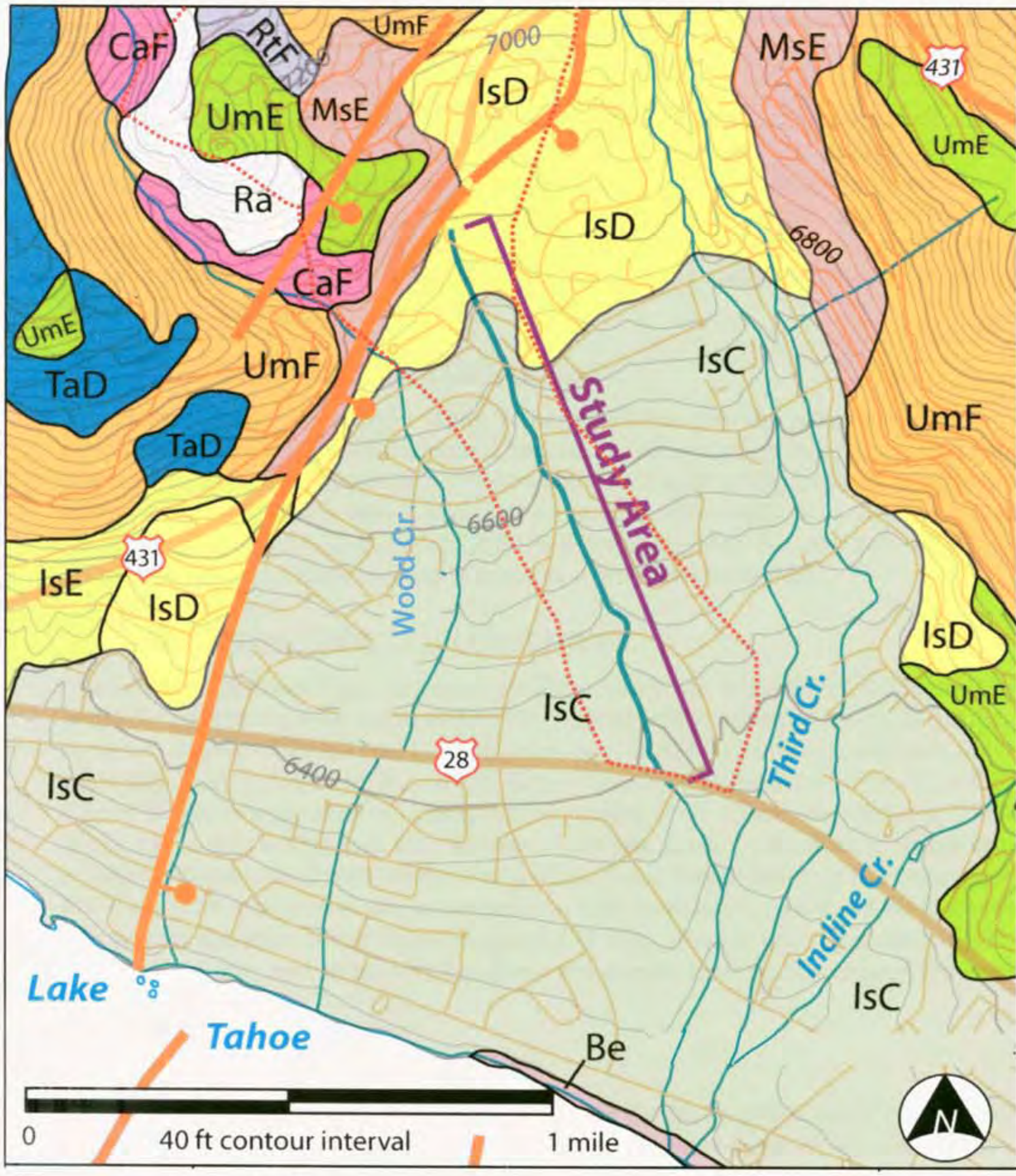
The relatively small Rosewood Creek watershed heads on the steep granitic escarpment of the Incline Village fault and flows across glacial outwash; this outwash material interfingers basinward with lacustrine sediment. Isolated accumulations of Holocene stream alluvium, reworked with outwash deposits, occur along the upper study area (*Geologic Unit Qal* in Figure 4) and their occurrence may reflect recent faulting (discussed below). The lower ½ of the study area has incised below the surface of the outwash fans and also flows on recent stream alluvium. This incision might be accounted to a response to base level changes resulting from lowering of the water surface of Lake Tahoe during the Holocene period. The human-induced impacts to the watershed, however, have probably obscured any channel responses to lake level lowering.

Soils in the study area are comprised of the Inville Stony Coarse Sandy Loam soil. This soil type has been subdivided into three groups, *Soil Units, IsC, IsD and IsE* (Figure 5), based on the slope of the ground surface ranging from 2 to 9%, 9 to 15%, and 15 to 30%, respectively. *Soil Unit IsC* occurs along most of the study area of Rosewood Creek while *Soil Unit IsD* occurs only in the uppermost part of this reach. Generally these soils units correspond to *Geologic Units Qygo, Qal, and Qoa* (Figure 4). These soils are composed of more then 50 percent sand, mostly coarse arkosic sand, 20% or more granitic and volcanic rocks 10 inches or more in diameter, with lesser amounts of clay and silt. These soils are moderately well to well drained and may be consolidated where associated with *Geologic Unit Qoa*.

Detailed geologic subsurface information is generally lacking in the Incline Village area (U.S. Army Corps of Engineers, 2003b). Logs obtained for wells drilled in the Incline Village area indicate that approximately 80% of the subsurface material, at least down to 150 feet, is composed of alluvial sand. The remainder is composed of boulders, clay and silt. A seismic reflection line was surveyed at Incline Beach State Park by the U.S. Bureau of Reclamation (Markiewicz, 1992) approximately 50 feet inland of the water's edge. These data are interpreted to indicate the presence of bedrock at a depth of about 1,200 feet near the shoreline. Although the upper part of the study area is near bedrock outcrops, it is on the downthrown side of the fault. Nearby wells at the Incline Village Championship Golf Course were drilled to depths of 40 to 45 feet into alluvial materials (U.S. Army Corps of Engineers, 2003b). Thus, alluvial deposits are expected to be from 30 feet to a hundred feet thick at the upstream end of the study area and to thicken to 300 feet or considerably more at the downstream end.

Local Faulting

The north-northeast-striking Incline Village fault is marked by a prominent range front escarpment along Mount Rose Highway. Scarps as much as 16 to 32 feet high on Quaternary alluvial deposits exist near SR 28 (Figure 4), and scarps about 10 feet high along the offshore continue along this major fault (Sawyer, 1999 and Kent et al., 2005). The fault has produced three large surface-faulting earthquakes during the late Quaternary (Seitz, 2005 and Kent et al., 2005) (Figure 4). Each of these events vertically offset the ground surface an average of 75 feet at the Incline School. The most recent event occurred about 500 years ago (G.C. Seitz, personal communication).



LEGEND

Soil boundary

Watershed boundary

Quaternary fault; bar-ball symbol shown on relative downthrown side; activity within past 15 ka (see Figure 1).

EXPLANATION

Be	BEACH SAND
CaF	CAGWIN-ROCK OUTCROP COMPLEX, 30 TO 50 PERCENT SLOPES
IsC	INVILLE STONY COARSE SANDY LOAM, 2 TO 9 PERCENT SLOPES
IsD	INVILLE STONY COARSE SANDY LOAM, 9 TO 15 PERCENT SLOPES
IsE	INVILLE STONY COARSE SANDY LOAM, 15 TO 30 PERCENT SLOPES
MsE	MEEKS VERY STONY LOAMY COARSE SAND, 15 TO 30 PERCENT SLOPES
Ra	ROCK LAND
UmE	UMPA VERY STONY SANDY LOAM, 15 TO 30 PERCENT SLOPES
UmF	UMPA VERY STONY SANDY LOAM, 30 TO 50 PERCENT SLOPES

Figure 5. Soils map of the study area.

The headwaters of Rosewood Creek have been largely beheaded from the study area as a result of considerable vertical displacement along the active Incline Village fault during the late Quaternary. The study area is entirely on the downthrown side of the fault. Rosewood Creek has deposited several isolated accumulations of recent stream alluvium along the upper study area. In addition, this reach of Rosewood Creek channel flows on glacial outwash deposits. Thus the character of the upper study area appears to reflect tectonic base level changes.

Geologic Influences on Groundwater

It has been suggested that major faults in Incline Village provide pathways for groundwater flow (U.S. Army Corps of Engineers, 2003b). Several springs issue from bedrock slopes in the headwaters of Rosewood Creek west of the Incline fault, but no springs or surface waters were noted on the east side of the fault. This difference may reflect the greater infiltration capacity of the alluvial deposits, but may also reflect infiltration along the fault, causing it to act as a groundwater conduit.

Lake Tahoe Water Level Fluctuations

Glaciation in the basin began around 1.5 million years ago when all but the highest peaks in the Sierra Nevada were inundated by ice. Subsequently, at least three more glaciations occurred between 100,000 and 120,000 years ago, at 20,000 years ago and at 10,000 years ago. During these events, ice was largely restricted to the Sierra Nevada, as the Carson Range was situated in a precipitation shadow (U.S. Corps of Engineers, 2003b). While the Incline Valley area may not have been glaciated, it was affected by the change in lake level associated with ice damming of the Lake Tahoe outlet. It has been reported that during the most recent glaciation periods, lake level likely rose about 60 to 90 feet (the current elevation of the lake averages 6,225 feet). Recent investigations suggest that the lake level also rose about 200 feet above the current level (U.S. Corps of Engineers, 2003b).

General Vegetation Communities

Current vegetation assemblages in place today are the result of processes initiated over several million years, with climate as the major driver for vegetation dynamics at the evolutionary scale. Various processes have and continue to influence the vegetation composition, structure and abundance that we see today in Sierra Nevada ecosystems. Vegetational change is most influenced by factors including disturbance events like fire, flood and volcanic eruption; variations in precipitation and temperature; and the amount of atmospheric carbon dioxide (Woolfenden, 1996).

The study area is located between the Sierra Nevada Mountain Range to the west and the Carson Range to the east. Pacific storms provide the bulk of the basin precipitation, most of which occurs as snow during the winter months. As the Pacific storms travel east, the air masses rise over the Sierra Crest, losing most of their moisture. As a result, the east side of the basin receives approximately 20 to 25 inches of annual precipitation. Occasional thunderstorms and infrequent tropical storms from the south provide some summer precipitation. Daytime winter temperatures typically range from 35-45 degrees F, with the nighttime lows in the “teens” to the high 20s. The summer climate is generally mild, with the mean maximum temperatures in the 70s (TRPA, 1971).

Current vegetation in the study area also reflects the establishment of second and third growth forests that resulted from the commercial timber harvest activities dating from the late 1870s through the 1960s, and the urbanization of the watershed initiated in the 1970's (Swanson, 2000 and ENTRIX, 2001). Vegetation within the study area most closely conforms to two vegetation series (Sawyer and Keeler-Wolf, 1995), as described below.

The Jeffrey Pine Series is dominated by Jeffrey pine (*Pinus jeffreyi*) in the overstory with white fir (*Abies concolor*), incense cedar (*Libocedrus decurrens*) and ponderosa pine (*P. ponderosa*) as occasional to common tree associates. The understory is highly variable, with montane chaparral providing shrub cover in open areas and under more closed, shaded canopies, creeping snowberry (*Symphoricarpos mollis*) as a dominant shrub. Under shade producing canopies, white fir is regenerating, often in a thick litter layer composed of pine needle duff. Openings are frequently populated by Jeffrey pine seedlings and saplings with assorted grasses and forbs. Montane chaparral shrubs include greenleaf manzanita (*Arctostaphylos patula*), antelope bitterbrush (*Purshia tridentata*), snowbrush ceonothus (*Ceonothus velutinous*), and whitethorn ceonothus (*C. cordulatus*). These upland plant species generally tolerate drought, cold temperatures, deep snow, and low nutrient conditions.

The Mountain Alder Series is dominated by mountain alder (*Alnus incana ssp. tenuifolia*) in the tall shrub/tree layer, with occasional tree willow species including Pacific and Scouler's willow (*Salix lucida ssp. lasiandra* and *S. scouleriana*). Shrub associates include redosier dogwood (*Cornus sericea*), Lemmon's willow (*S. lemmonii*) and Sierra currant (*Ribes nevadense*). The understory varies from sparse to moderate cover of mesic graminoids and forbs including small-fruit bulrush (*Scirpus microcarpus*), bigleaf sedge (*Carex amplifolia*), stinging nettle (*Urtica dioica*), starry false-solomon's-seal (*Smilacina stellata*) and sweetanise (*Osmorhiza occidentatlis*).

5. Existing Conditions Assessment

Hydrology

The hydrology of Rosewood Creek was characterized based on a review of existing analysis and existing gage data of nearby streams and Rosewood Creek.

Previously Generated Information

Recurrence intervals of instantaneous peak discharge on Rosewood Creek were estimated by MACTEC Engineering and Consulting, Inc. (formerly Harding ESE) for the design of IVGID's Rosewood Creek Restoration Project (MACTEC, 2003), located downstream of SR 28. This analysis included using several methods to establish design flows for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. These included using regional regression equations, regional flood-frequency curves from nearby gaged drainages and hydrologic modeling. The analysis did not rely on any recorded flow data from Rosewood Creek.

Following construction of the Rosewood Creek Restoration Project, Rick Susfalk at Desert Research Institute (DRI) collected continuous flow data on Rosewood Creek for the purpose of evaluating project effectiveness (for water quality). Data were collected using a pressure transducer to measure stage, with a rating curve developed from direct measurements (Susfalk, personal communication). Although this is a short-term data set (2003-present), it is nevertheless valuable for comparison with adjacent gaged watersheds during this period.

U.S. Geological Survey (USGS) stream gages on nearby Third Creek, First Creek and Wood Creek provide daily mean discharge from which Rosewood Creek hydrology can be extrapolated. The gage name, number and period of record for each basin are shown in Table 1. Each of these three creeks has discharge records adequate to characterize mean periodic flows, and each is physically comparable to the climate, geology, aspect and vegetation of Rosewood Creek. The Rosewood Creek watershed, however, is distinctive in its lower mean elevation with a higher proportion of urbanization. Incline Creek data were not used for extrapolation of Rosewood Creek flows because its geology, aspect, watershed size and shape are the least analogous to Rosewood Creek than the other referenced streams.

Table 1. Flood frequency of Rosewood Creek at SR 28 (in bold) based on drainage basin area comparison of four adjacent watersheds with gage records. Previous (MACTEC, 2003) flood frequency estimates of Rosewood Creek at Lakeshore Blvd are also shown.

Gage Name	Gage Number/Source	Period of Record	Years of Data	Watershed Area (mi^2)	2-year (cfs)	5-year (cfs)	10-year (cfs)	100-year (cfs)
Incline Creek nr Crystal Bay	USGS Gage 10336700	1969 to 1973 1975 1987 to present	22	7.00	39	79	116	304
Third Creek nr Crystal Bay	USGS Gage 10336698	1969 to 1973 1975 1977 to present	32	6.05	62	102	131	219
Wood Creek abv Jennifer St. nr Incline Village	USGS Gage 10336692	1991 to 2000	10	1.97	13	26	38	78
First Creek nr Crystal Bay	USGS Gage 10336688	1970 to 1974 1991 to 2000	15	1.07	6	15	23	57
Rosewood Creek	MACTEC 2003	N/A	N/A	1.15	12	24	35	98
ROSEWOOD CREEK	**THIS STUDY**	N / A	N / A	**1.15**	**6**	**16**	**23**	**40-60**

Hydrologic Characterization

Peak Discharge

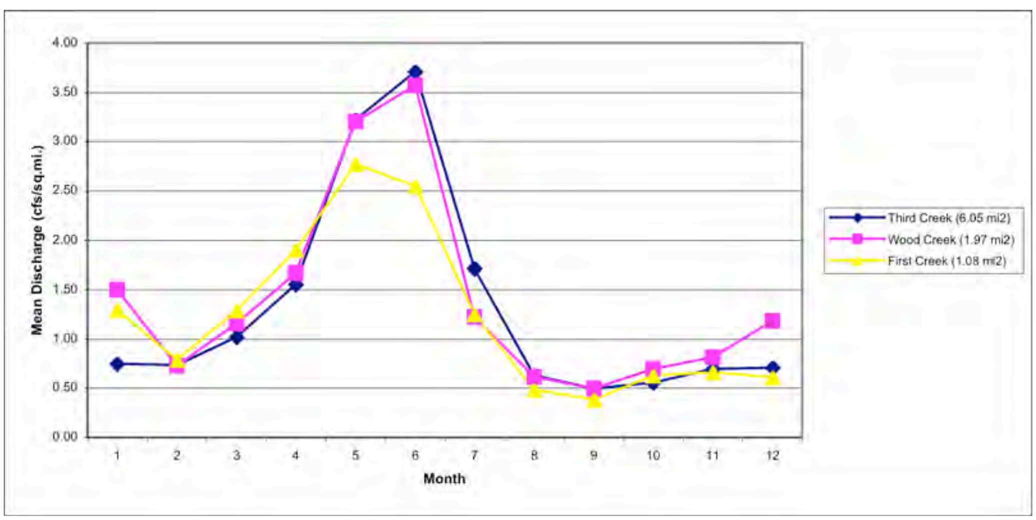
For this study, USGS gage data of adjacent watersheds were used to generate anticipated instantaneous peak discharge for Rosewood Creek (Table 1). Peak discharge shown in this table was calculated by directly comparing watershed area of Rosewood Creek with each of the aforementioned gaged streams. For flows with a recurrence interval of 10 years or less, the relationship between watershed size and discharge was fairly consistent. There was greater variability, however, for the 100-yr recurrence flow. The calculated Rosewood Creek 100-yr flow ranged from about 40 to 60 cfs. Because there was no basis for refining this range, the 100-year peak discharge is reported as 40 to 60 cfs.

The calculated recurrence intervals of Rosewood Creek are somewhat lower than those generated by MACTEC (2003). The lower values are supported by gaging information from DRI for the 2003-2005 period. The MACTEC study may have overestimated the effect of urbanization or may have underestimated the influence of lower mean elevations on Rosewood Creek as compared to surrounding gaged watersheds.

Mean Monthly Discharge

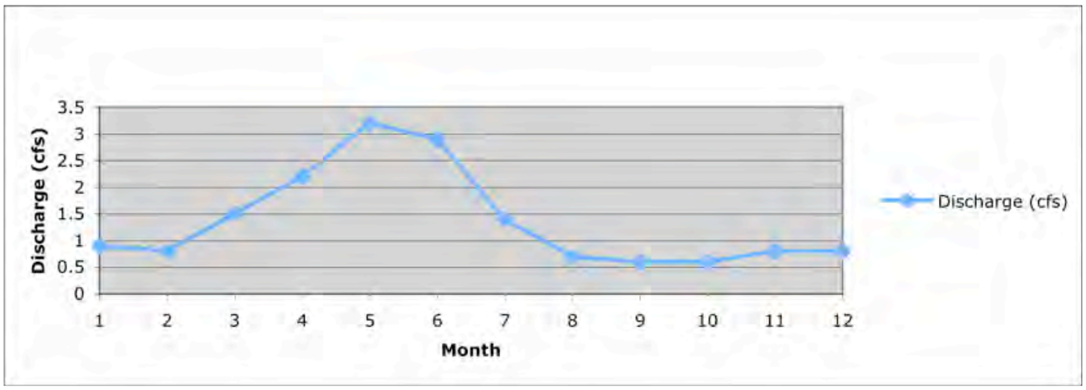
Mean monthly discharge provides a general indication of typical flow conditions throughout the year. Mean monthly flow reflects baseflow and snowmelt runoff, rather than instantaneous peak flows that result directly from short duration rainstorms. Mean monthly discharge for Rosewood Creek was estimated by comparing gage data from Third, Wood and First Creeks. Mean monthly flows were calculated for the three creeks and then fractioned into unit flow per square mile. Unit flows for each creek are shown in Figure 6.

Figure 6. Unit area flow over a 12-month period for Third, Wood and First Creeks based on USGS gage data.



Calculated unit flows for these three creeks are rather similar. First Creek peaks earlier in the season and has a lower average unit discharge during the spring snowmelt peak. This earlier and lower peak is likely because the First Creek drainage has a lower mean elevation than Third and Wood Creeks. The Rosewood Creek watershed is much closer in mean elevation to that of First Creek and is approximately the same area. Based on this similarity, the First Creek unit discharge was used to extrapolate Rosewood Creek mean flows through the annual snowmelt period (March-July) (Figure 7). Baseflow estimates through the remainder of the year for Rosewood Creek were extrapolated from Third Creek unit discharge, because Third Creek has the longest and most consistent period of record. The Third Creek watershed also has a similar geology and soil type as that of the Rosewood Creek watershed. Wood Creek has a smaller data set than First and Third Creeks, and it appears to be skewed by a few extreme values. Because of this, Wood Creek data were not directly used for this analysis.

Figure 7. Mean monthly discharge of Rosewood Creek based on discharge per unit area of adjacent gaged drainages.



Historic Flows

There is inadequate gage data from adjacent drainages to correlate recent high flows with the current geomorphic condition of Rosewood Creek. In the gaged watersheds in the basin, there were documented large-magnitude floods resulting from a rain-on-snow event that occurred on January 2-3, 1997. The runoff event of January 1997 impacted western streams (Ward, Blackwood and General Creeks) and the Upper Truckee River most severely; however, effects were minor in the northern streams. Upper Incline Creek and Third Creek had relatively low return periods of 6 to 13 years while the Incline Creek at the mouth experienced a calculated 50-year event (Simon et al., 2003).

Lindström et al. (2000) provide an excellent summary of the overall Tahoe Basin hydrology during the last few decades. "Wet years from 1982 to 1986 contributed to an average annual snow water content of up to 200 percent of normal. The year 1983 became the standard "high water year" for virtually all waterways within the Truckee River drainage basin. Between 1987 and 1994 there was a period of drought in the Truckee River drainage basin. Although of the same duration as the 1928 to 1935 drought, the 1987 to 1994 drought was far worse. In the Lake Tahoe basin, the average annual snowpack water content was recorded at 29 percent of normal."

Geomorphic Assessment

Assessment Process

Assessment of the geomorphic conditions of the Rosewood Creek channel and floodplain within the study area involved a series of steps to collect qualitative and quantitative information. These steps included:

- Initial ground reconnaissance and identification of dominant geomorphic processes;
- Division of the study area into subreaches of similar channel morphology;
- Survey of the longitudinal profile of the channel bed and adjacent (lowest elevation) stream bank;
- Topographic survey and photo-documentation of channel and floodplain cross-sections at representative locations within the identified subreaches;
- Sampling and analysis of streambed and bank sediments;
- Calculation of hydraulic conditions at surveyed cross-sections at various flows; and
- Evaluation of sediment transport conditions and sediment supply.

The following sections in this report address the geomorphic assessment and are organized according to the aforementioned assessment process. Plates 1 through 6 depict the study area and various features discussed in the Geomorphic Assessment section.

Intentional Anthropogenic Modifications

Reaches of Rosewood Creek have been altered within the last 50 years as a result of land development activities. The condition of specific reaches is addressed later in this document. However, a general description of these modifications follows.

Road Crossings

Rosewood Creek flows through eight culverts within the study reach. As part of this study, attempts were made to determine the dates these culverts were installed or replaced. The Nevada Department of Transportation was contacted regarding the installation timeframe of the culvert under SR 28. No records were found that indicate when this culvert was installed, but sequencing of activities and anecdotal information suggests that this culvert was placed in the late 1950s (A. Sulahria, NDOT, personal communication). Both Washoe County and Incline Village General Improvement District (IVGID) were contacted regarding the installation timing of the culverts under Northwood Blvd., Harold Dr., Village Blvd. and College Dr. No records were located which provide a date of installation of these crossings. These roadways have all been in place since the early development of Incline Village; the culverts were likely installed in the early- to mid-1960s (D. Minto, IVGID, personal communication).

Hardened Boundaries

Rocks have been placed along segments of the Rosewood Creek stream bank and bed to stabilize the channel. The extent of rock-lined channel is almost continuous along the upper one-third of the stream within the study area, extending from College Blvd.

upstream to the Mountain Golf Course (a distance of about 2,300 feet). It is through this reach that condominium and single home developments have encroached directly onto the stream. Rocks were likely placed in some locations as a preventative erosion control measure, in others as a means to stabilize a channel that had become entrenched as a result of land development activities, and in others to secure the position of a reach of channel that had been relocated. Based on the timeframe of the development in the immediate area (Glancy, 1988), it is likely that rock was placed along middle Rosewood Creek during the late 1960s or early 1970s.

In some locations the rocks are obscured by riparian vegetation that has grown in around them. In one reach, the stream is dominated by a series of pronounced rock drop grade controls. Through some reaches the native vegetation has been cleared and the rocks serve as a component of the decorative urbanized landscape.

Relocated Channels

The downstream half of Rosewood Creek within the study area flows within topographic lows, which suggests that this reach of stream flows within its original course. Within this reach, there are two short segments immediately upstream and downstream of Northwood Blvd. that appear to be relocated. In contrast, most of the upper half of Rosewood Creek does not lie within an obvious topographic low point. It is possible that much, if not all, of this reach has been moved into its present location. There is evidence to indicate where it has clearly been relocated. Such evidence includes:

- Stream banks with berms located along the margins;
- Stream reaches that run parallel to roads;
- Straight stream segments; and
- Stream reaches located on ground higher than adjacent topographic low points.

Incision: Dominant Geomorphic Process

Channel incision is the dominant geomorphic process within the study area of Rosewood Creek. In order to discuss the incised condition of the stream, it is important to provide some discussion of the channel incision process in general.

Definition of Channel Incision

Channel incision involves the lowering of a streambed by erosion. There is no clear consensus on the definition of an incised channel (Watson et al., 2002), but it is generally agreed that a channel has incised when the floodplain does not become inundated when flows exceed the bankfull or dominant discharge. Dominant discharge is commonly the flow that occurs at about the 1.5- and 2-yr recurrent interval, although somewhat higher intervals have been documented for some streams.

Nickpoints are streambed features that are associated with incision. Where there is an abrupt change in elevation of a stream channel, the feature is referred to as a nickpoint (from the German, knickpundkt), or headcut. The initial change in grade is termed a primary nickpoint; however, *secondary nickpoints* occur within an incising channel. Nickpoints move upstream as erosional features.

An incised channel not only has a lowered streambed and nickpoints, it commonly exhibits a channel cross-section that is wider than normal. The stream banks within an incised reach are typically steep, mostly vertical, and are usually unstable. An incised channel may develop a new vegetated floodplain that has many of the same attributes as the floodplain that existed prior to incision.

Causes of Channel Incision

There are numerous processes responsible for channel incision. More than one process may combine to cause incision; the actual cause(s) of channel incision are often difficult to identify. In all cases, the erosive force of flowing water exceeds the resistive force of streambed materials (Table 2). The development of an incised channel may result from controls acting on the site, or may result from controls acting upstream or downstream of the site. This concept of upstream and downstream influence is addressed further in this section.

Decreased Erosional Resistance	**Cause**
• Decreased vegetative cover • Decreased large woody material • Disturbed bed armor layer	*Timber harvest* *Livestock grazing* *Fire* *Drought* *Land disturbance due to urbanization*
Increased Erosional Forces	
• Increased flow magnitude • Increased flow duration	*Water control and diversion* *Altered hydrology due to urbanization* *Constriction of flow by berms* *Concentration of flows by roads*
• Base level lowering	*Land changes due to urbanization* *Channel alterations*
• Increased slope	*Channelization* *Sedimentation in the channel*
• Decreased sediment load	*Channel armoring* *Impervious surfaces due to urbanization*

Table 2. Causes of channel incision, modified from Schumm et al. (1984).

Geomorphic Thresholds

Channel incision commonly occurs when a geomorphic threshold is exceeded. A geomorphic threshold involves a progressive change in an external variable that triggers an abrupt change in the affected system. Such a threshold is an extrinsic threshold, meaning that the threshold exists within the system but will not be crossed and change will not occur without the influence of an external variable (Schumm et al., 1984).

Incised Channel Evolution Model

Researchers have proposed incised channel evolution models (reviewed by Darby and Simon, 1999), some involving channelized streams. The work by Schumm et al. (1984) provides the best representation of the multi-stage process through which incised channels progress from onset to natural recovery. This model has been modified to apply to the conditions found in Rosewood Creek; five steps in the incision process are identified (Figure 8):

- *Channel Type 1*: The channel is in an undisturbed state. The channel geometry is in dynamic equilibrium with flow and sediment. Healthy riparian vegetation exists. The floodplain is functional.

- *Channel Type 2*: Rapid downcutting of the channel bed results in over-steepened stream banks. The dominant progression of the channel bed is downward. The streambed profile exhibits pronounced nickpoints and associated

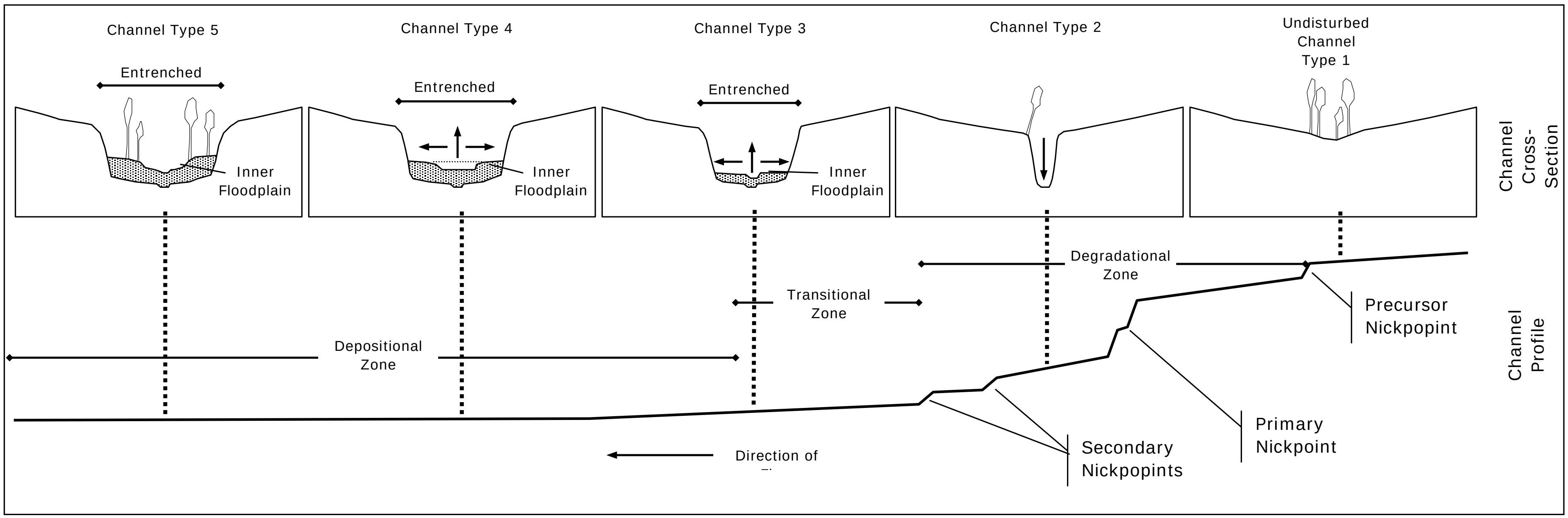


Figure 8. Incised channel evolution model, after Schumm et al. (1984). Arrows within the channel indicate the trend in adjustment.

grade instability. Riparian vegetation may be lost by physically falling into the stream, or may die due to water table lowering below the root zone.

- *Channel Type 3*: Excessive widening of the stream channel by collapse of stream banks occurs. Some sediment aggrades due to an oversupply of material. The stream grade may have reached equilibrium. A defined channel may not occur.
- *Channel Type 4*: The dominant process is aggradation, although channel widening continues at a slower rate. A defined stream channel is gradually formed, the dimensions of which approach dynamic equilibrium with flow and sediment. Vegetation begins to form on the aggraded sediment, promoting further sediment deposition.
- *Channel Type 5*: The channel is in a stable state. The channel geometry is in equilibrium with flow and sediment. Slowly failing side walls cause berms along the inner floodplain margins that provide a growing surface for vegetation. Mature vegetation becomes well established within the inner floodplain and along the channel margins.

In some fluvial systems, channel incision can be a complex response. Once a geomorphic threshold is crossed, incision may occur rapidly during a single large flood event. Conversely, an incised channel may remain "dormant" during extended periods of drought. Nickpoints may migrate upstream rapidly, or they may be slowed by intermittent accumulations of large woody debris, resistant sublayers (e.g., peat and clay) and infrastructure (such as riprap at bridge footings). A series of small indistinct nickpoints, spread over a reach of channel, may develop. A large runoff event may cause these nickpoints to migrate upstream until they combine to form a single, large-scale nickpoint that causes extensive erosion and even more rapid upstream migration.

Bank failure and channel widening resulting from incision can also occur at varied rates. As groundwater lowers, the reduced matric pressure (negative pore pressure) in stream banks may actually result in increased bank stability (Darby and Simon, 1999). Banks with a high percentage of silts and clays may reach near-vertical slopes. Vegetation along the channel may hold stream banks in place, or the surcharge associated with large trees may trigger bank collapse. Large woody material that falls in the stream channel may form local grade control and upstream aggradation, or it may constrict and deflect flow against banks to promote channel widening.

A segment of stream may reach some level of stability as it approaches Type 4, only to be destabilized as a downstream nickpoint that migrates up into the reach. Such nickpoint progression can reset the incised channel evolution process, returning the reach to Type 2 conditions. The rate at which a Type 4 channel develops depends in part on the rate at which vegetation becomes established in the inner floodplain.

Incision Timeframe

An important aspect to characterizing the incision of Rosewood Creek is establishing a timeframe during which the entrenchment occurred. Swanson (2000) reports that in the "Third Creek Estates Development…Rosewood Creek incised 3 to 8 feet since the 1997 winter season." No data are provided to identify where this incision occurred or how it was measured. Nonetheless, it is clear that incision is an ongoing process.

It appears that incision in the lowermost portion of the study reach occurred at the onset of land development. The culvert at SR 28, likely placed in the late 1950s, was no doubt installed at the grade elevation of the stream channel at that time. This culvert placement indicates that the lower reach of Rosewood Creek had reached the incised base level where it currently exists today. Vegetation in the lowermost portion of the study reach supports this observation. Pacific willow (*Salix lucida ssp. lasiandra*) is found within the narrow inner floodplain. This species prefers a year-round high water table and repeated flooding. Mature specimens may grow up to 8 inches in diameter at an age of 30 to 40 years. The diameter of the larger willows found in this reach were measured at 6 to 8 inches, suggesting that they became established around 1965 to 1975 (although no tree ring counts were conducted as part of this study). This timeframe would coincide with placement of the culvert and suggests that incision occurred some time beforehand.

The channel upstream of College Drive has been stabilized with 12 grade controls spaced over a distance of 500 feet. It appears that an attempt was made to stabilize this reach in order to halt the incision process. Again, considering the at-grade placement of the culvert under College Drive in the early 1960s and mature willows along the channel in the 6 to 8 inch diameter range, it is likely that incision occurred during the early development of Incline Village.

Overall, it appears that incision has occurred or continues to occur throughout the majority of the study area. The individual reach descriptions in the subsequent section discuss the variable location and stage of incision.

Delineation of Stream Reaches

Middle Rosewood Creek is 7,470 feet in length. Throughout this document, locations along the stream length are indicated by stationing, with Station 0+00 at the downstream end at SR 28 and Station 74+70 at the upstream end near the Incline Village Mountain Golf Course.

Reach Descriptions

The study area was divided into 17 stream reaches (Table 3). These reaches were delineated based on observed channel morphology. Selected photographs of each reach are shown in *Appendix 1 Reach Photographs*. The average reach length is 380 feet, with reaches varying in length from 83 to 895 feet. Culverts were not included in the reach lengths where culverts served as reach endpoints.

The reaches were qualitatively described according to several descriptive parameters. These parameters included the degree or extent of channel relocation, riprap, functional floodplain, stage of incision, amount of incision, aggradation, entrenched valley top width, inner floodplain formation, former channels and stream bed material. An entrenched valley is the feature that is formed as an incised channel degrades. An inner floodplain develops within an entrenched valley as the incision process evolves (Figure 8). A qualitative description of these parameters is contained in Table 3. A general description of each reach follows.

Reach 1

Reach 1 exhibits advanced stages of an incised channel. A narrow inner floodplain has formed. Multiple inner floodplain geometries suggest multiple periods of incision. Extensive mature alder and willow have become established on the inner floodplain. There is evidence of systematic cutting and pruning of some large willows, potentially in an effort to maintain conveyance. The streambed consists of sand and fine gravel. Reach 1 is confined by SR 28 on the south, with road fill that extends up to the channel margin. On the east side of the valley, a former, well-developed channel appears to carry

Table 3. Qualitative description of the reaches of Rosewood Creek within the study area.

Reach No.	Station Begin		Station End	Distance (ft)	Reach Relocated	Riprapped Margins	Functional Floodplain[1]	Stage As Per Incised Channel Evolution Model (Schumm et al. 1984)	Entrenched Valley Top Width	Where Incised, Inner Floodplain Formed	Where Incised, Channel Stable	Where Incised, Vegetation Growing on Inner Floodplain	Evidence of Former Channels on Floodplain (Left and Right as Viewed Downstream)	Controlling Bed Materials
1	0+00	to	2+90	290	Yes	No	No: incised	5	30-40 ft	Poorly Developed	Yes	Extensive mature alder and willow	Far left side of floodplain	Sand/fine gravel
2	2+90	to	4+15	125	No	No	No: incised	5	40-50 ft	Well Developed	Yes	Extensive sedge, some willow	Far left side of floodplain	Small gravel
3	4+15	to	6+00	185	No	No	No: incised	2	10-20 ft	No	No	None	Far left side of floodplain	Small gravel, resistant peat layer at nickpoint
4	6+00	to	8+80	280	No	No	Yes	1	Not Incised	Not Incised	Not Incised	Not Incised	Active multiple thread channel; also on far left side of floodplain	Small gravel
5	8+80	to	17+75	895	Upper 100 ft	No	No: incised	2	30-40 ft	No	No	No	Lower half, far left side of floodplain; upper quarter, right side of floodplain	LWD, some introduced large rock
6	18+50	to	22+10	360	Lower 100 ft	No	No: aggraded	Not Incised	Not Incised	Not Incised	Not Incised	Not Incised	Active multiple thread channel	Gravel
7	22+10	to	28+50	640	No	No	Yes	1	Not Incised	Not Incised	Not Incised	Not Incised	Far left side of floodplain	Angular colluvial material (80%); LWD (20%)
8	28+50	to	31+00	250	No	No	No: bermed	4	30-40 ft	Well Developed	Yes	Yes	Far left side of floodplain	Cobble and LWD
9	31+00	to	32+90	190	No	No	No: bermed	4	30-40 ft	Well Developed	Generally	Yes	Far left side of floodplain	Gravel and LWD
10	33+30	to	34+50	120	No	No	Yes	1	Not Incised	Not Incised	Not Incised	Not Incised	No	Gravel
11	34+50	to	37+00	250	Yes	No	No: bermed and incised	2	20 ft	No	No	No	Between Village Blvd. and channel	Gravel
12	37+72	to	41+20	348	Yes	10 to 20%	No: confined by road	2	10-20 ft	No	No	No	Obscured by Village Blvd. and development	Gravel
13	43+20	to	50+15	695	Yes	No	No: incised	2	5-10 ft	No	No	No	No	Gravel and LWD
14	51+70	to	58+90	720	Yes	Yes	No: riprapped	3	25-30 ft	Yes	Yes	Yes	No	Large imported rock
15	58+90	to	65+50	660	Yes	Yes	No: riprapped	1	5-10 ft	Not Incised	Not Incised	Not Incised	Short intermittent reaches	Sand/fine gravel
16	66+15	to	72+30	615	Yes	Yes	No: riprapped	2	10-20 ft	No	No	No	Far right side of floodplain	Large imported rock and gravel
17	72+30	to	74+70	240	Yes	Yes	No: confined by road	1	Not Incised	Not Incised	Not Incised	Not Incised	Obscured by golf course	Large imported rock and LWD

[1] Functional Floodplain is defined as a floodplain that is innundated by flow from the stream channel at an annual or biannual frequency.

groundwater seepage year round. The remainder of the former floodplain is well vegetated.

Reach 2

Reach 2 consists of a channel in the advanced stages of channel incision, with an inner floodplain and a meandering channel. This reach is the most advanced of any of the incised stream segments within the study reach, having the widest top width and the most developed inner floodplain. The channel and entrenched valley condition suggest that this reach is near the end of the incised channel evolution continuum. It serves as an example of the state that other incising reaches of Rosewood Creek might reach as the incision process matures. The channel grade is stable and is controlled in places by collections of small woody material. The streambed consists of small gravel. The former floodplain is densely vegetated, with a former channel on the east side that seeps year-round (per Reach 1). The landowner of this reach, 41 years old, recalls that during the 1970s and 1980s, a grass meadow existed in the current channel location through much of this reach (Tony Robinson, landowner, personal communication).

Reach 3

Reach 3 reflects the dramatic initial stages of incision. A 3-foot high nickpoint exists at the lower end of the reach. Upstream, the channel is almost 6 feet deep but in places less than 10 feet wide, with vertical and undercut banks. The subsurface stratigraphy does not show evidence of former alluvially-deposited gravel lenses, which would indicate a paleochannel at a lower elevation. The former floodplain is wide and densely vegetated. A remnant channel is located along the east boundary of the former floodplain, adjacent to the Third Creek Condominiums. Anecdotal information suggests that the first phase of the condominium development was completed in 1981 and the last phase in 1996.

Reach 4

Reach 4 appears to be the most geomorphically functional segment of stream within the study area in terms of bankfull channel geometry and connection to the floodplain. It serves as a template for probable desirable post-restoration conditions for the stream and floodplain. The channel banks are stabilized with vegetation. The streambed substrate is predominantly comprised of small gravel. The adjacent floodplain is wetted during higher flows. An active secondary channel reflects the tendency for multiple channels to occur across the active floodplain. There are several remnant channels within the former floodplain (between the channel and the east valley margin).

Reach 5

Reach 5 exhibits extreme, severe incision, generally reflecting the initial stages of rapid downcutting with vertical banks. Similar to Reach 3, there are some segments that are almost as deep as they are wide. There is no evidence in the stratigraphy of gravel lenses. Large woody debris provides some temporary grade stabilization. The topographic extent of the former floodplain is generally much narrower through this reach than that of the downstream reaches. A remnant channel runs much of the length of the east boundary of the valley bottom. Property owners within the Third Creek Condominiums have cleared upland and riparian vegetation; in some locations this clearing is extensive. Clearing does not appear to have affected the channel function nor caused incision.

Reach 6

Reach 6 exhibits channel and floodplain aggradation, the only segment within the study with such conditions. The channel slope through this reach was likely reduced by the placement of the Northwood Blvd. culvert. Subsequent aggradation has resulted in a wide, saturated floodplain supporting moisture-tolerant vegetation. The presence of dead and dying upland vegetation suggests that the floodplain aggradation is recent (within a few decades) and likely ongoing. The construction of Northwood Blvd. appears to be the primary driver that caused the aggraded conditions. It appears that construction of Northwood Blvd. included the following activities: relocation of the channel to the east (evidenced by the channel not located in the topographic low area downstream of Northwood Blvd.); fill placed north of Northwood Blvd.; and culverts installed at a relatively flat slope.

Reach 7

The character of Reach 7 differs from much of the remainder of Rosewood Creek because the cobble and small boulders that comprise much of the streambed form a stable channel. Although rock provides about 80% of the streambed control and large woody debris provides the remaining bed stabilization. There are some isolated locations where the stream banks are eroding. The channel flows through a relatively narrow floodplain and pedestrian pathways are extensive along and immediately adjacent to the channel. A remnant channel is located along the east side of the valley through this reach.

Reach 8

Reach 8 exhibits evidence of earlier incision that has progressed almost to the final stages (per the incised channel evolution model). Mature riparian vegetation has become established on a narrow but well-developed floodplain. Streambed materials consisting of cobbles and woody debris stabilize the channel bed. A remnant channel is located along the east side of the valley through this reach (this remnant channel begins upstream and extends downstream of this reach). A large berm has been placed along the west margin of the channel throughout all of this reach, and along a portion of the upstream reach. It is unclear if this berm is a result of placement of material excavated from the channel, but this is certainly a possibility. If so, it would suggest that much of Rosewood Creek between Northwood Blvd. and Harold Drive was relocated.

Reach 9

Reach 9 shows evidence of earlier incision and now supports mature riparian vegetation on the 20-foot wide inner floodplain. Short subreach segments exhibit aggradation due to small accumulations of woody material in the channel. The streambed consists of small gravel and woody debris. A continuation of the remnant channel in Reaches 7 and 8 occurs along the east valley margin. Fill has been placed along the east side of the channel. If the channel has been relocated, this berm would have been placed to separate the current channel from the remnant channel.

Reach 10

Reach 10 is a short reach of stable channel that is connected to its floodplain. Gravel comprises the streambed. It appears largely unaffected by Harold Drive, other than the fact that the culvert has provided grade control.

Reach 11

Reach 11 is a segment of Rosewood Creek that has been relocated from a former location to the west (between the current location and Village Blvd.) It appears that the stream was relocated in order to move it an adequate distance from Village Blvd. For much of this reach, the conditions include: no riparian vegetation other than upland trees; pronounced, unvegetated berms on both sides of the channel; and incision up to 5 feet in depth; and bank failure caused by undercutting.

Reach 12

Reach 12 is a confined segment of stream with the Village Blvd. and associated bike path immediately to the east (forming a vertical left bank) and individual private parcels to the west. The channel was clearly moved to this position in order to accommodate the location of Village Blvd. The bed consists of gravel. Vegetation is sporadic. The channel is stable, although there are locations where it has degraded and banks are undercut. Riprap has been placed in a few locations. Upstream of this reach Rosewood Creek flows through 100 feet of culvert along Village Blvd.

Reach 13

Reach 13 comprises the segment of stream from Driver Way (on the east side of Village Blvd.) to College Drive. It exhibits varying degrees of the first stage of incision, from minor (less than two feet deep) to extreme (over five feet deep with a top width of 10 feet and vertical banks). The streambed consists of small gravel but the grade is maintained by woody material. Downed large trees in the upper part of the reach provide evidence of how this material plays a vital role in stabilizing the channel and floodplain. Overall, the floodplain is relatively narrow, but widens somewhat at the upstream end. Riparian vegetation is only moderately dense.

At Station 47+30 within this reach, a man-made log feature was found buried three feet beneath the ground surface. The function of the log feature is unknown. It does not appear to be the remnant of a bridge crossing Rosewood Creek. The location of the log feature below the current floodplain grade indicates that the stream within this reach was once three feet lower in elevation. It is likely that this log feature is a remnant of former logging activities, indicating that this reach was highly modified some time ago (potentially as long ago as the 1890s).

Reach 14

Reach 14 consists of an incised channel that has reached an advanced stage of incision, and then was stabilized with a series of 12 large rock grade controls. The grade controls have functioned to provide grade stabilization through this reach. Riparian vegetation in the narrow inner floodplain is well developed; willows 6 to 8 inches in diameter are estimated to be 30-years old. The willows, which established on depositional surfaces that formed subsequent to rock placement, suggest that the grade controls were placed sometime in the late 1960s or early 1970s. Furthermore, fill material has been placed in the adjacent floodplain. This reach is the site of the former Sierra Nevada College Mountain Campus (to the west) and a trailer park for student housing (to the east). The property on the east is currently being redeveloped into high-density condominiums as the Incline Creek Estates. The property to the west will be developed as a later phase.

Reach 15

Reach 15 consists of segments of channel that have been modified and relocated. The stream banks are armored with large rock; as a result, this reach is stable. The channel is not incised, and is generally connected to a poorly defined floodplain. Several former secondary channels, cut off by channel manipulation, are apparent. The upper portion of this reach is relatively straight and may have been moved to this location. It is likely that the channel was modified and armored through this reach as the property was developed. Riparian vegetation in the lower half is lacking, but exists as a narrow but dense strip along the stream in the upper half of this reach. Even though no flood risk analysis was undertaken as part of this study, the residences along the lower portion of this reach may be at risk of flooding due to their proximity to the stream.

Reach 16

Reach 16 has been highly modified. The culverts at Titlist Drive were placed substantially below grade, requiring an abrupt drop in the channel elevation. The channel was relocated to the east and lined with riprap along the entire length. The likely former channel location is to the west; portions have been obscured by the construction of residences, but some former channel segments are clearly visible. Most of the reach exhibits primary and secondary stages of incision. In one location, the riprap failed as the channel widened, resulting in vertical eroding banks. At the upper end of the reach, the channel has been confined by berms in an attempt to protect an adjacent residence. The former channel orientation and elevation put this structure at risk of flooding.

Reach 17

Reach 17 has been confined by Titlist Drive to the west and the Incline Village Mountain Golf Course to the east. Because the channel is not flowing in the topographic low of the valley, it is fair to assume that this reach was relocated when the roads and golf course were constructed. The entire length of channel within this reach has been lined with riprap; it is vertically and horizontally stable. A narrow, dense strip of riparian vegetation contributes to this stability. Upstream of this reach, Rosewood Creek bifurcates and flows under Mount Rose Highway (SR 431). It is likely, given the location in the watershed, that Rosewood Creek upstream from this point was once a set of poorly defined tributary channels.

Road Crossings and Adjacent Infrastructure

Road Crossings

Rosewood Creek flows through eight culverts within the study reach (Table 4). These culverts range in length from 20 feet to 200 feet, over a total distance of about 657 feet. The culverts are generally single 30 to 36 inch diameter corrugated metal pipe (CMP), although the upper and lower culverts are dual barrel culverts with greater capacity than the other culverts.

The culverts are in good condition; however, a few have reduced capacity due to accumulations of sediment. Four culverts have drops at the outlet of 1 to 2.5 feet; these outlets are all stable. Although generally clear of sediment and debris, a few culverts are partly filled with sand and fine gravel. Table 4 indicates those culverts with accumulated sediment.

Table 4. Culverts within the study area through which Rosewood Creek flows.

Culvert No.	Road Crossing	Station Begin		Station End	Length (ft)	No. of Culverts	Culvert Dimension Left (in)	Culvert Dimension Right (in)	Channel Condition Upstream	Channel Condition Downstream	Culvert Condition Left Downstream	Culvert Condition Right Downstream	Culvert Condition Left Upstream	Culvert Condition Right Upstream
A	Culvert at Northwood Blvd.	17+75	to	18+50	75	2	36 x 60 arched CMP	48 CMP	Aggraded	Controlled by riprap	50% open	60% open	Clear	Clear
B	Culvert at Harold Dr.	32+90	to	33+30	40	1	36 CMP	--	Aggraded	2.5 ft drop	Clear	--	50% open	--
C	Culvert at Village Blvd.	37+00	to	37+72	72	1	36 CMP	--	Clear, right angle approach	Backwatered by rock drop	45% open	--	Clear	--
D	Culvert at Donna Dr.	38+55	to	38+85	30	1	36 CMP	--	Clear	1-1.5 ft drop	Clear	--	Clear	--
E	Culvert	41+20	to	43+20	200	1	36 CMP	--	Clear	2-2.5 ft drop	Clear	--	80% open	--
F	Culvert at College Dr.	50+15	to	51+70	155	1	30 CMP	--	Clear	Clear	Clear	--	Clear, partly crushed	--
G	Culvert at Private Crossing	57+30	to	57+50	20	1	30 CMP	--	Clear	1.5 ft drop	Clear	--	Clear	--
H	Culvert at Titlist Dr.	65+50	to	66+15	65	2	36 CMP	36 CMP	Controlled by riprap	Minor aggradation	75% open	75% open	Clear	Clear

CMP = corrugated metal pipe

Adjacent Infrastructure

In addition to the segments of stream that flow through culverts, most of the remainder of the reach of Rosewood Creek through the study area is unaffected by infrastructure. The only exception is the reach of Rosewood Creek that flows along Village Blvd. This reach, approximately 550 feet in length, is situated immediately adjacent to the bike path located to the west of Village Blvd. It has clearly been straightened and channelized to accommodate the road and the adjacent residential properties. The channel also flows for a portion of this length within a culvert along Village Blvd.

Profile and Cross-Section Survey

Methods

Longitudinal profile and cross-section surveys were tied to local elevation datum. The northing and easting locations were approximated using a fiberglass tape (for distance) and an aerial photo (for spatial reference). Horizontal survey control points were set along all of the road crossings within the project reach; control was set to an accuracy of a hundredth of an inch using a total station. Stations were set along the stream at one hundred foot intervals, measured using a fiberglass tape. Accuracy was likely on the order of ±25 feet per 1,000 feet of stream length. The location of the stream was marked on the aerial photo base map using adjacent buildings and discernable vegetation features for reference.

The longitudinal profile survey measured streambed elevation at apparent breaks in slope (typically as close as 5-10 feet and no more than 50 feet apart). Elevations were surveyed to the nearest tenth of a foot using a self-adjusting level. Level loops were typically no more than 1,000 feet apart; eight loops closed at an average of 0.14 of a foot and no more than 0.33 of a foot.

Thirty-one floodplain and channel cross-sections were surveyed. The locations of the cross-sections were visually selected to represent average conditions for the stream reaches within the study area. A fiberglass tape and level were used to measure the sections. The elevation of the thalweg was tied to that of the longitudinal profile.

Longitudinal Profile

The longitudinal profile of the streambed of Rosewood Creek provides a graphical representation of the slope within each reach. Figure 9 shows the profile by station and reach. The adjacent bank elevation is shown; this is an approximation drawn from the cross-sections. The profile also indicates the culverts, observed nickpoints and locations of the streambed and bank sediment sample locations (discussed in a subsequent section).

The streambed slope for each of the reaches was calculated from the profile data (Table 5). Large nickpoints that occurred at reach breaks were not included in the slope calculation for either reach in order to better represent the average reach slope. The average reach slope was 7.0% (range of 3.6 to 15%); the slope of the entire study area was 6.2%.

Channel and Floodplain Cross-Sections

Thirty-one cross-sections within the study area were surveyed (Table 6). The average distance between sections was about 240 feet (range of 110 to 555 feet). These sections are shown graphically in Figure 10, as viewed downstream.

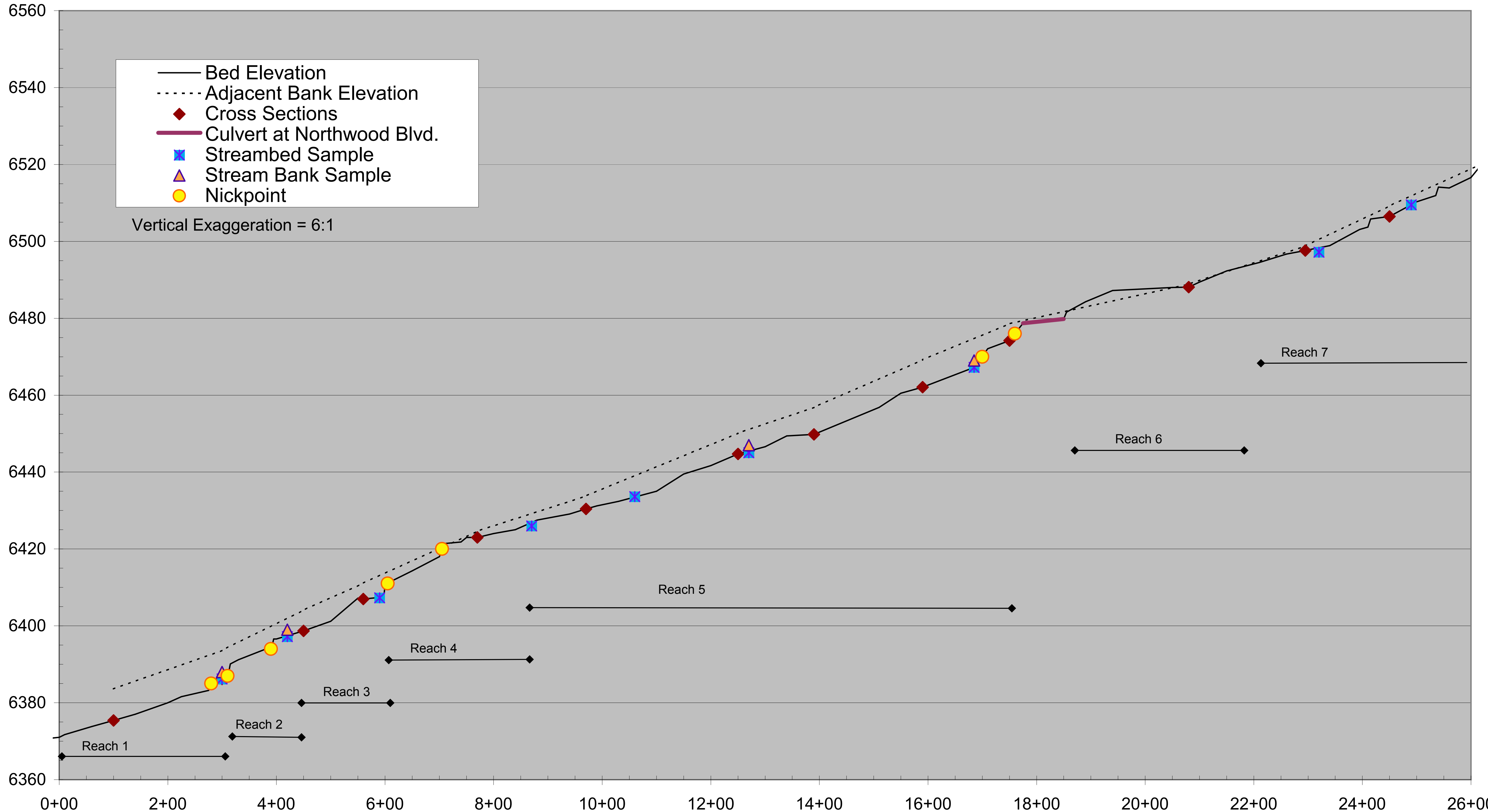


Figure 9A. Longitudinal Profile of Rosewood Creek

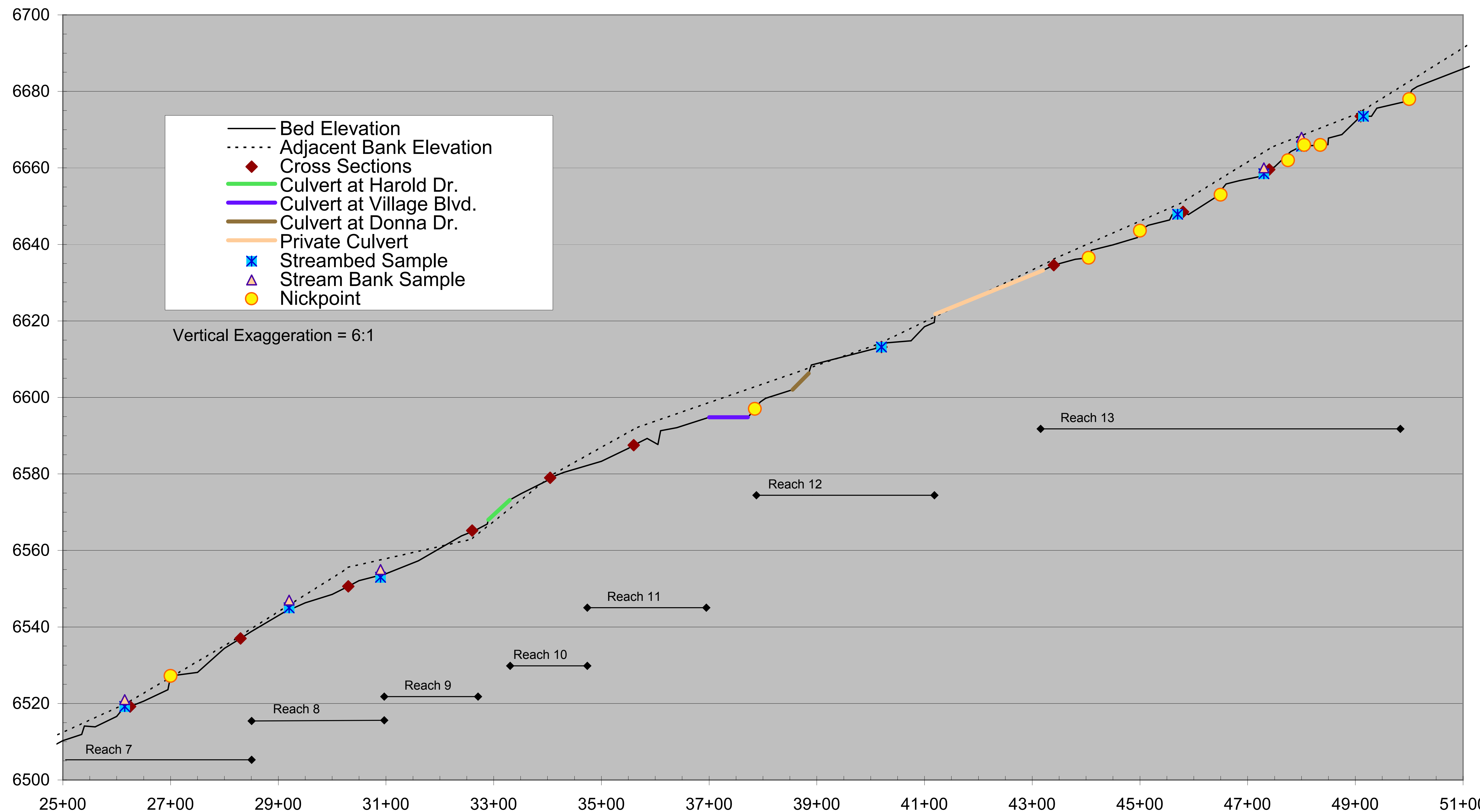


Figure 9B. Longitudinal Profile of Rosewood Creek

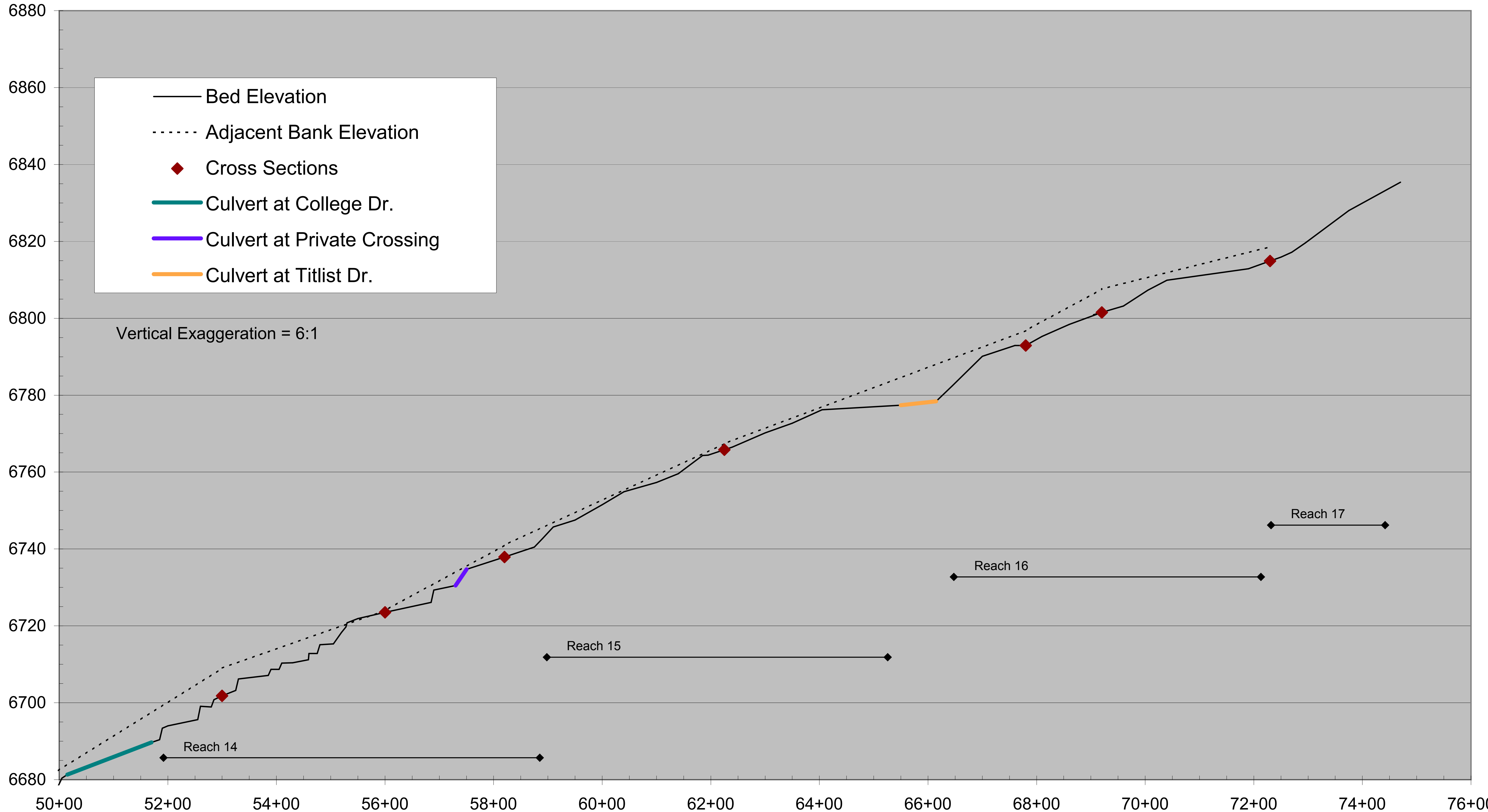


Figure 9C. Longitudinal Profile of Rosewood Creek

Table 5. Average slope of stream reaches within the study area.

Reach No.	Station			Distance (ft)	Slope[1]
	Begin		End		
1	0+00	to	2+90	290	4.3%
2	2+90	to	4+15	125	7.7%
3	4+15	to	6+00	185	6.0%
4	6+00	to	8+80	280	6.0%
5	8+80	to	17+75	895	5.6%
6	18+50	to	22+10	360	3.6%
7	22+10	to	28+50	640	7.1%
8	28+50	to	31+00	250	5.3%
9	31+00	to	32+90	190	7.5%
10	33+30	to	34+50	120	7.0%
11	34+50	to	37+00	250	6.3%
12	37+72	to	41+20	348	15.0%
13	43+20	to	50+15	695	7.1%
14	51+70	to	58+90	720	7.4%
15	58+90	to	65+50	660	6.5%
16	66+15	to	72+30	615	5.7%
17	72+30	to	74+70	240	11.7%
Reach Average					7.0% (S.D. of 2.7%)
Average Slope of Rosewood Crrek					6.2%

[1]Slope determined by the difference in elevation at the up- and downstream ends of the reach, divided by the distance, and exclusive of nickpoints that occur at the up- or downstream end of reaches.

Table 6. Floodplain and channel cross-section locations.

Number	Station	Distance Between Sections (ft)
1	1+00	200
2	3+00	150
3	4+50	110
4	5+60	210
5	7+70	200
6	9+70	280
7	12+50	140
8	13+90	200
9	15+90	160
10	17+50	330
11	20+80	215
12	22+95	155
13	24+50	175
14	26+25	205
15	28+30	200
16	30+30	230
17	32+60	145
18	34+05	155
19	35+60	460
20	40+20	320
21	43+40	240
22	45+80	160
23	47+40	170
24	49+10	390
25	53+00	300
26	56+00	220
27	58+20	405
28	62+25	555
29	67+80	140
30	69+20	310
31	72+30	240
Average		238

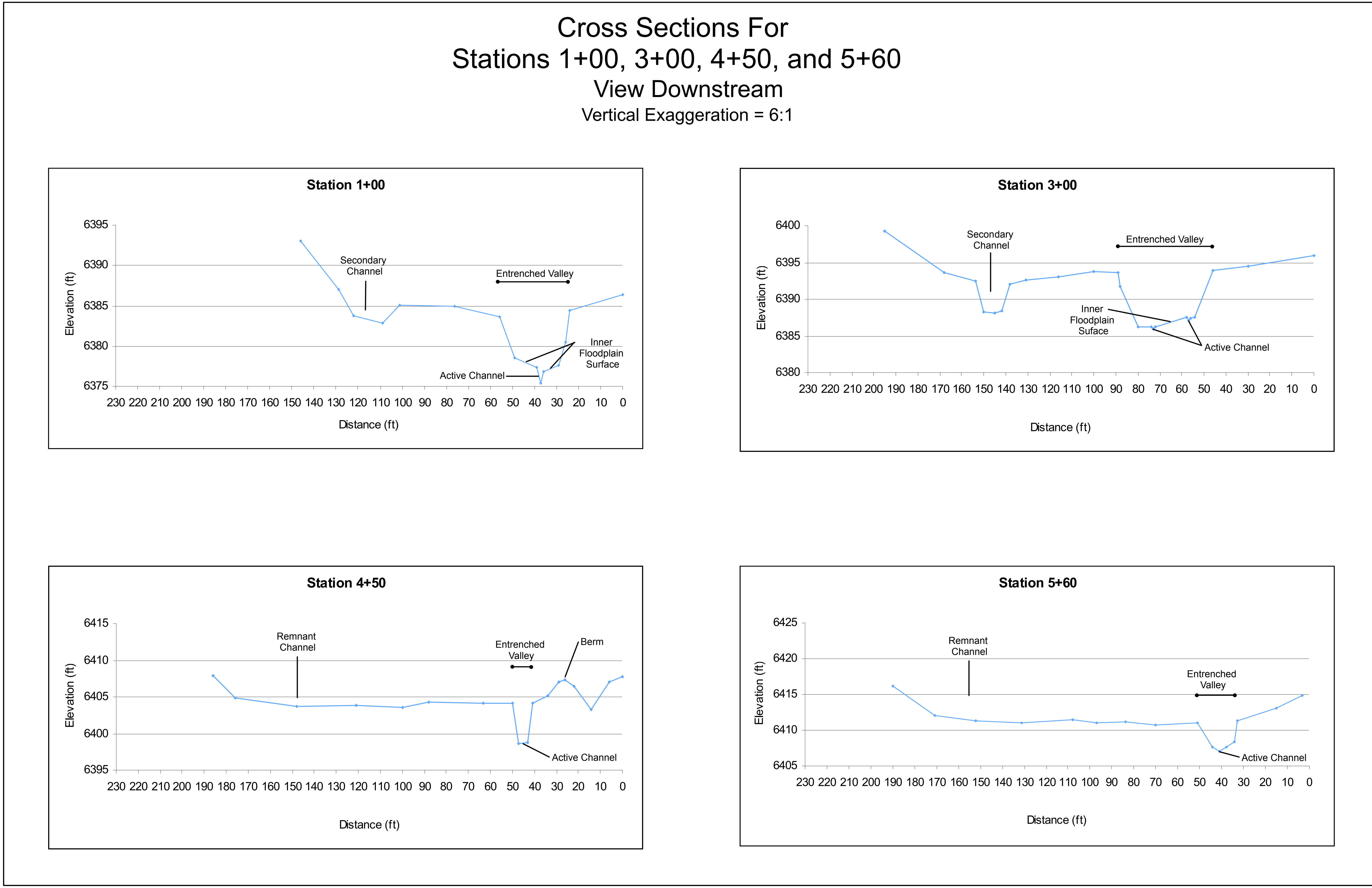


Figure 10A. Channal and Floodplain Cross-sections of Rosewood Creek

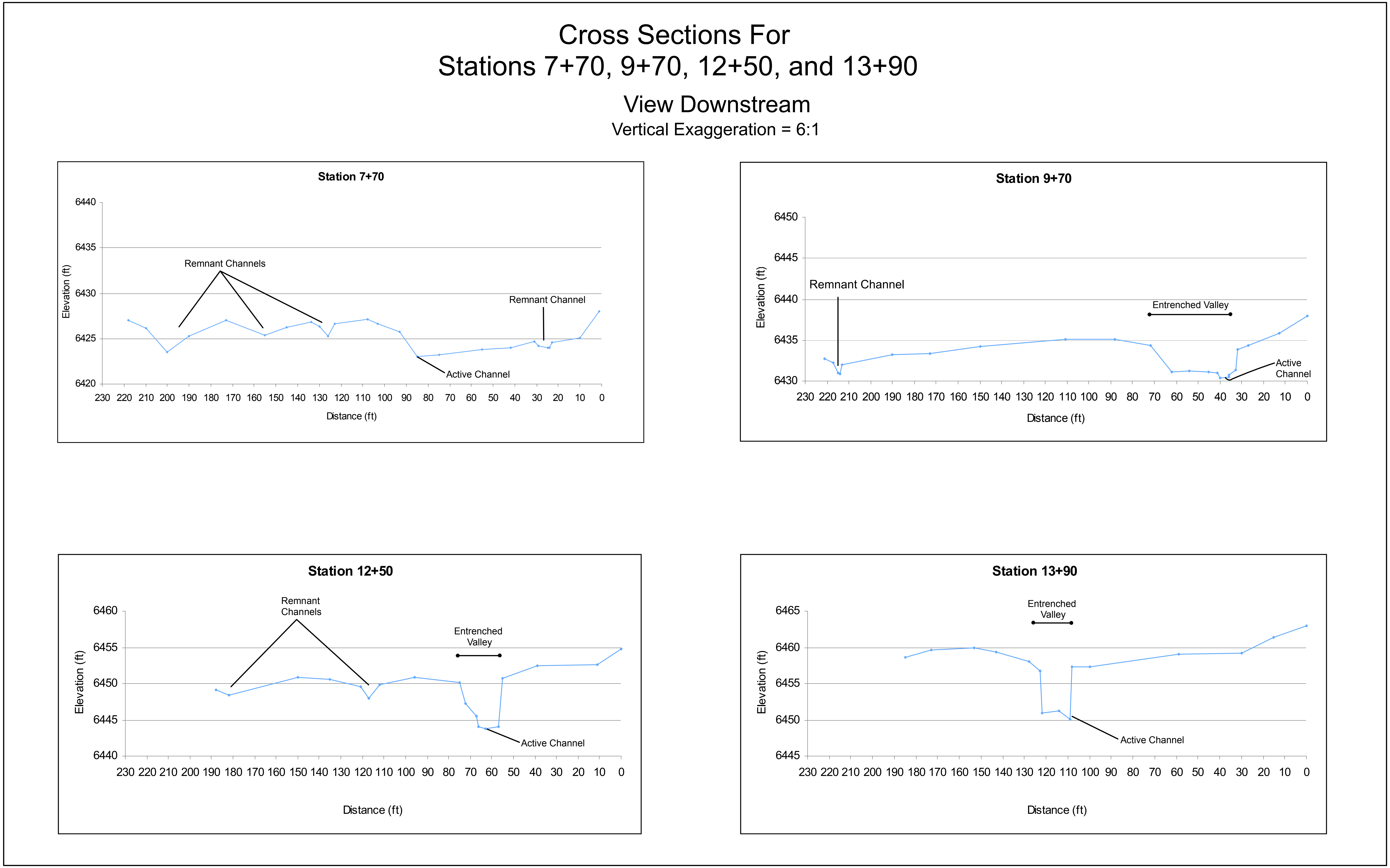


Figure 10B. Channal and Floodplain Cross-sections of Rosewood Creek

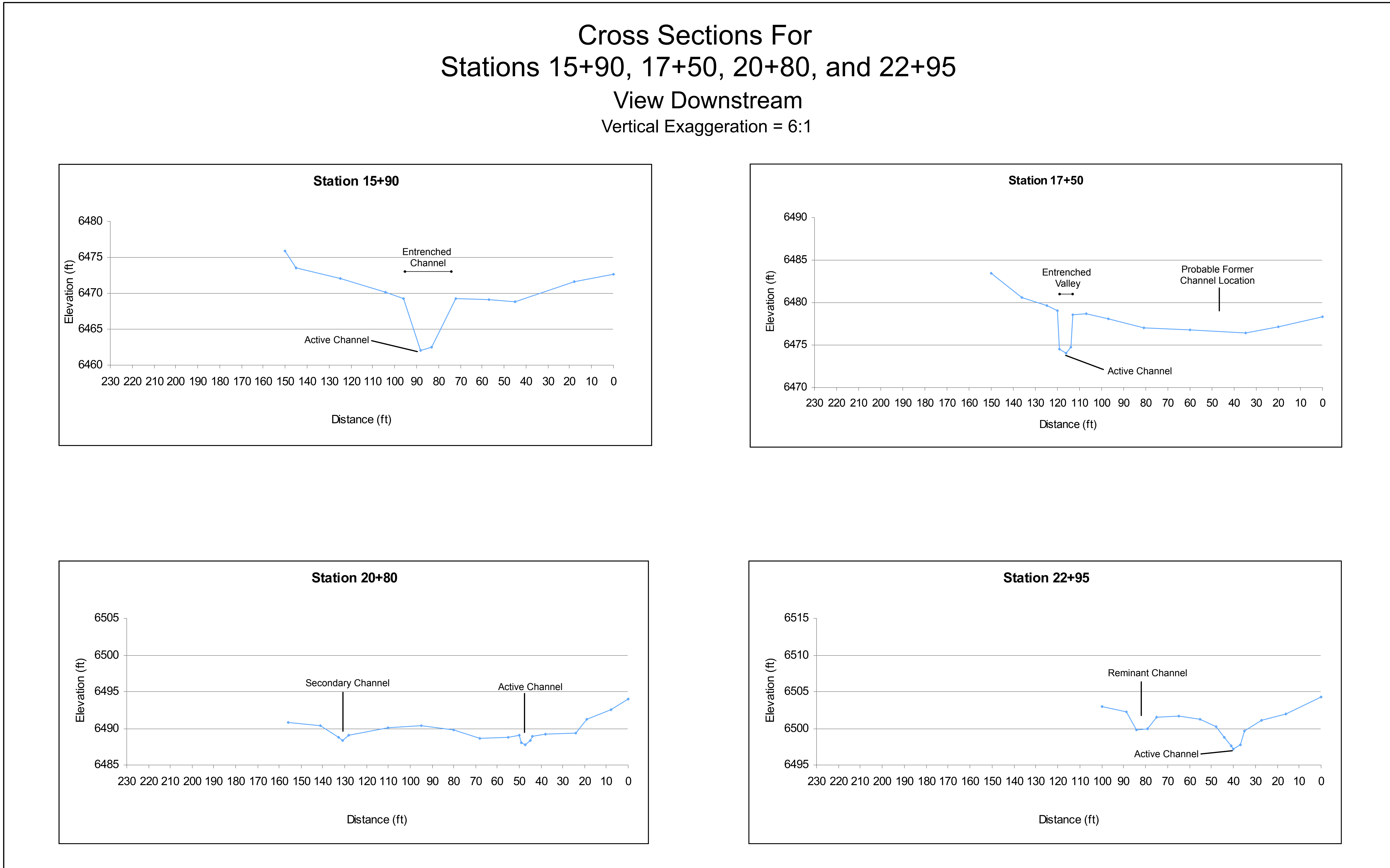


Figure 10C. Channal and Floodplain Cross-sections of Rosewood Creek

Cross Sections For
Stations 24+50, 26+25, 28+30, and 30+30

View Downstream

Vertical Exaggeration = 6:1

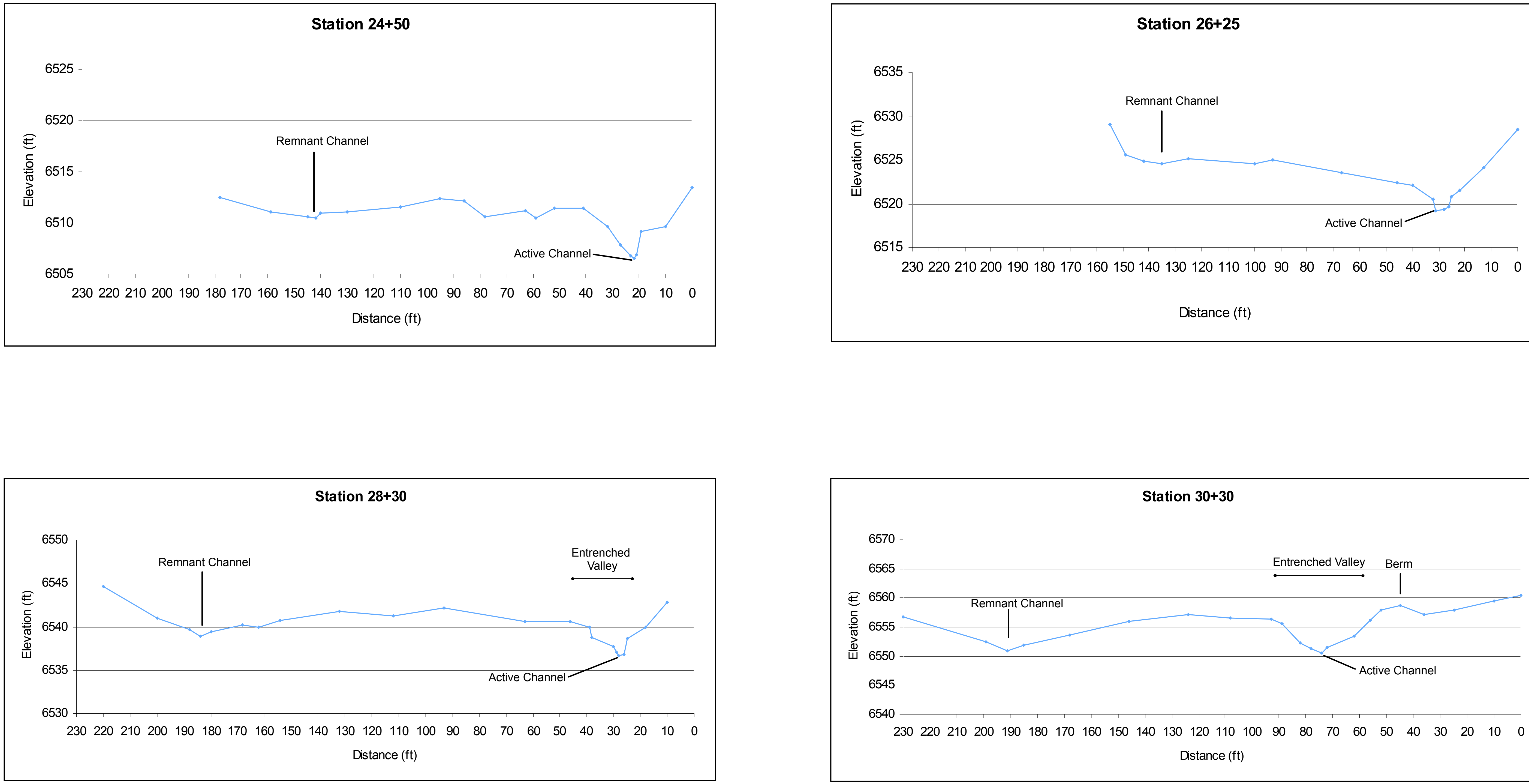


Figure 10D. Channal and Floodplain Cross-sections of Rosewood Creek

Cross Sections For
Stations 32+60, 34+05, 35+60, and 40+20

View Downstream

Vertical Exaggeration = 6:1

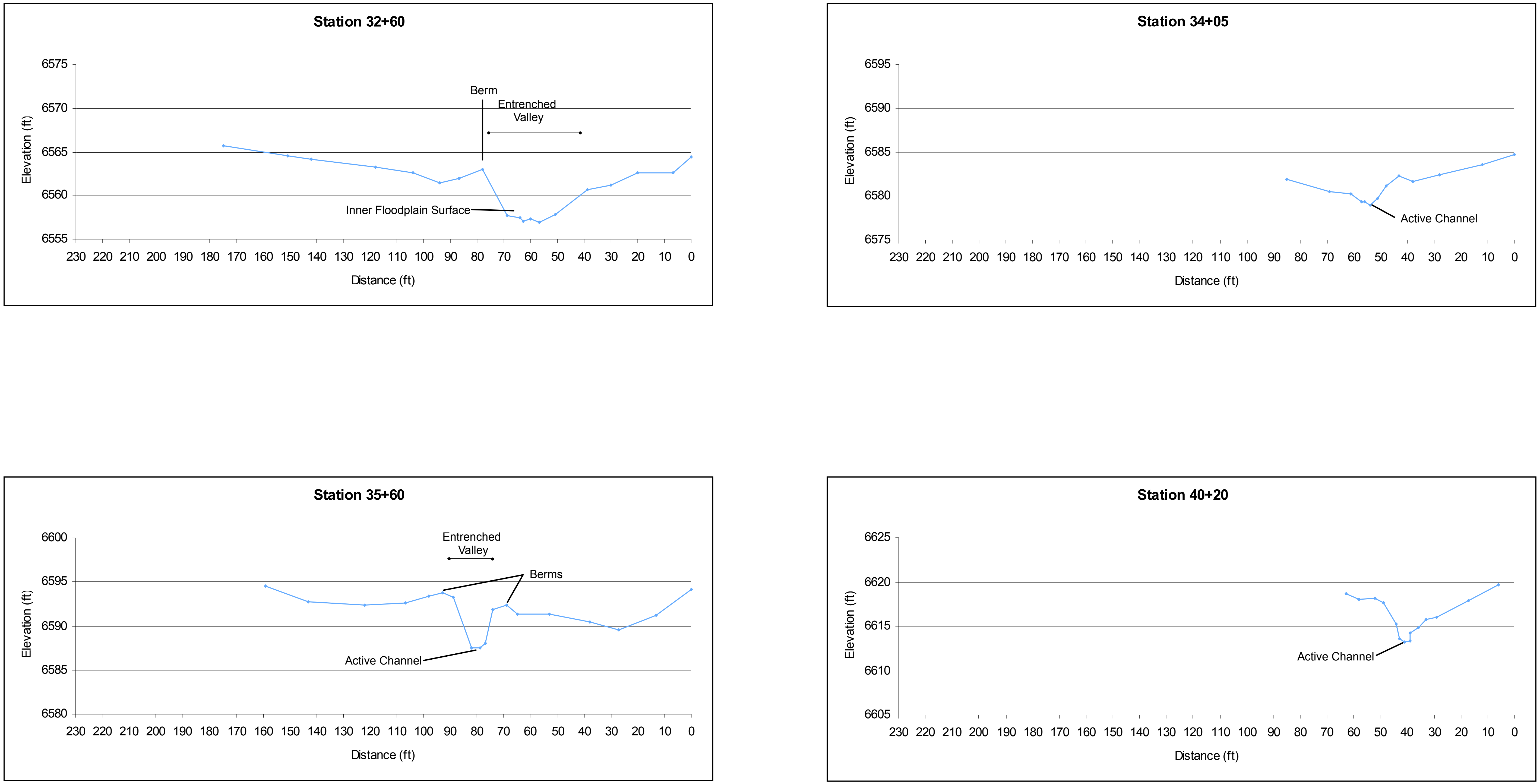


Figure 10E. Channal and Floodplain Cross-sections of Rosewood Creek

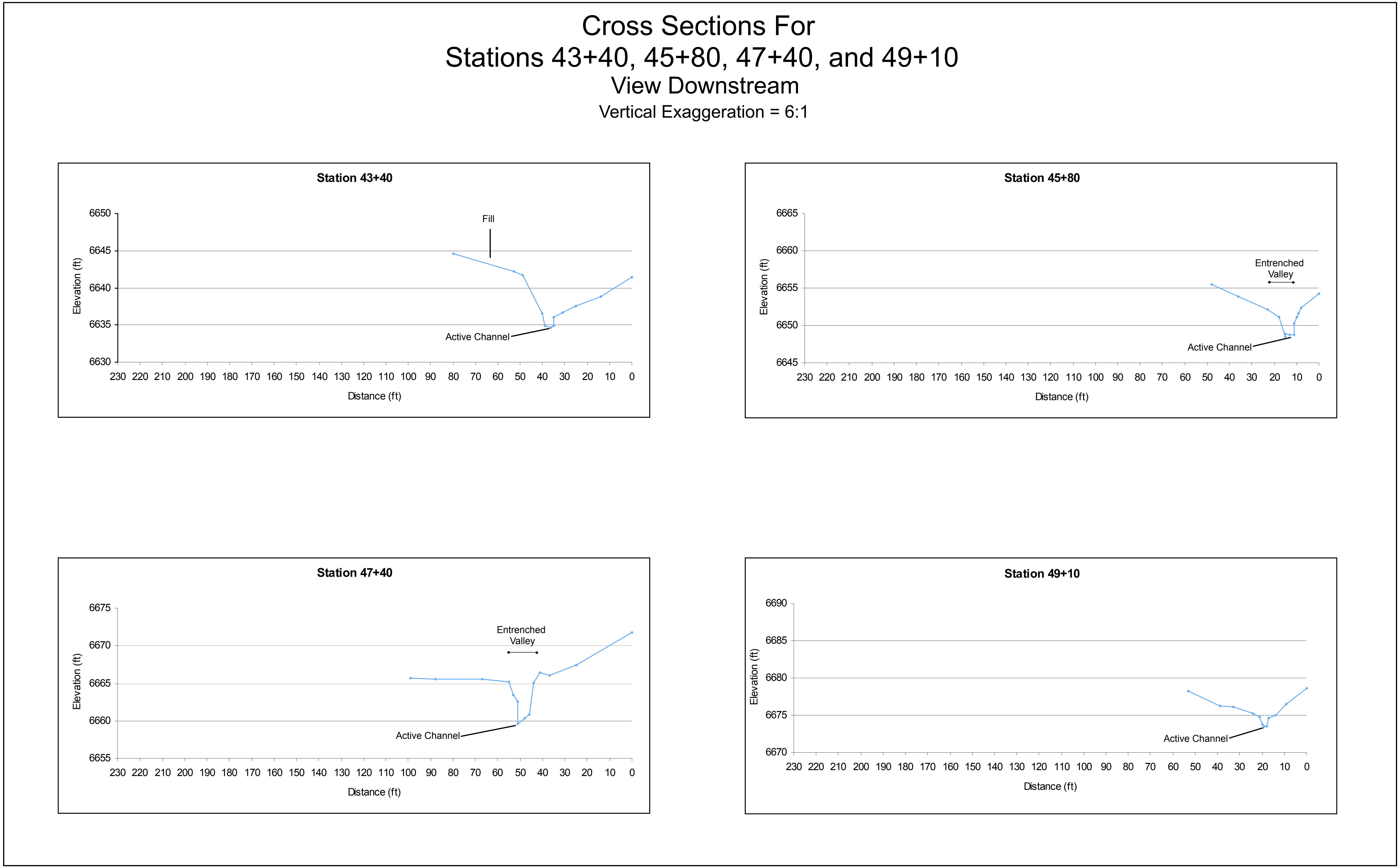


Figure 10F. Channal and Floodplain Cross-sections of Rosewood Creek

Cross Sections For
Stations 53+00, 56+00, 58+20, and 62+25
View Downstream
Vertical Exaggeration = 6:1

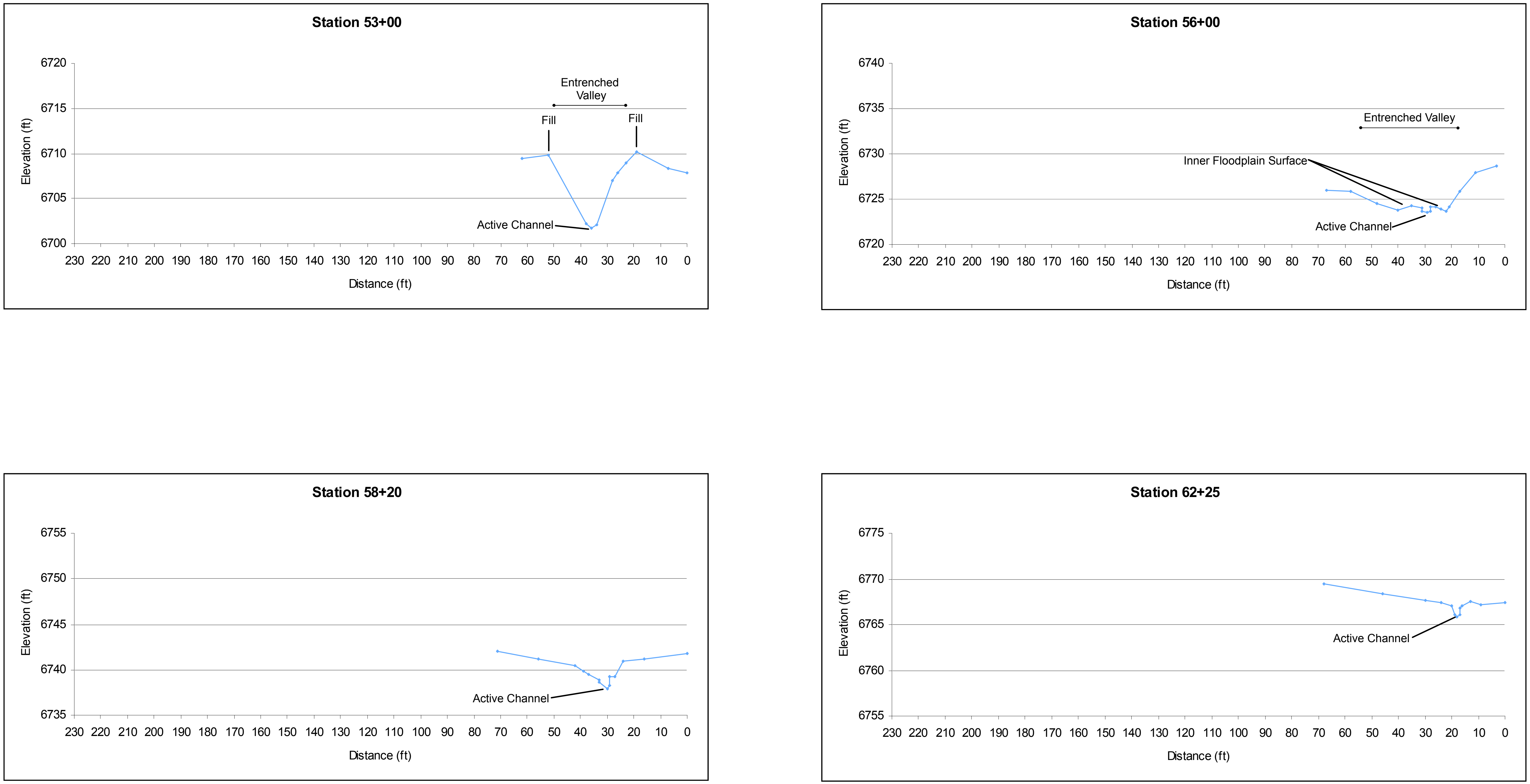


Figure 10G. Channal and Floodplain Cross-sections of Rosewood Creek

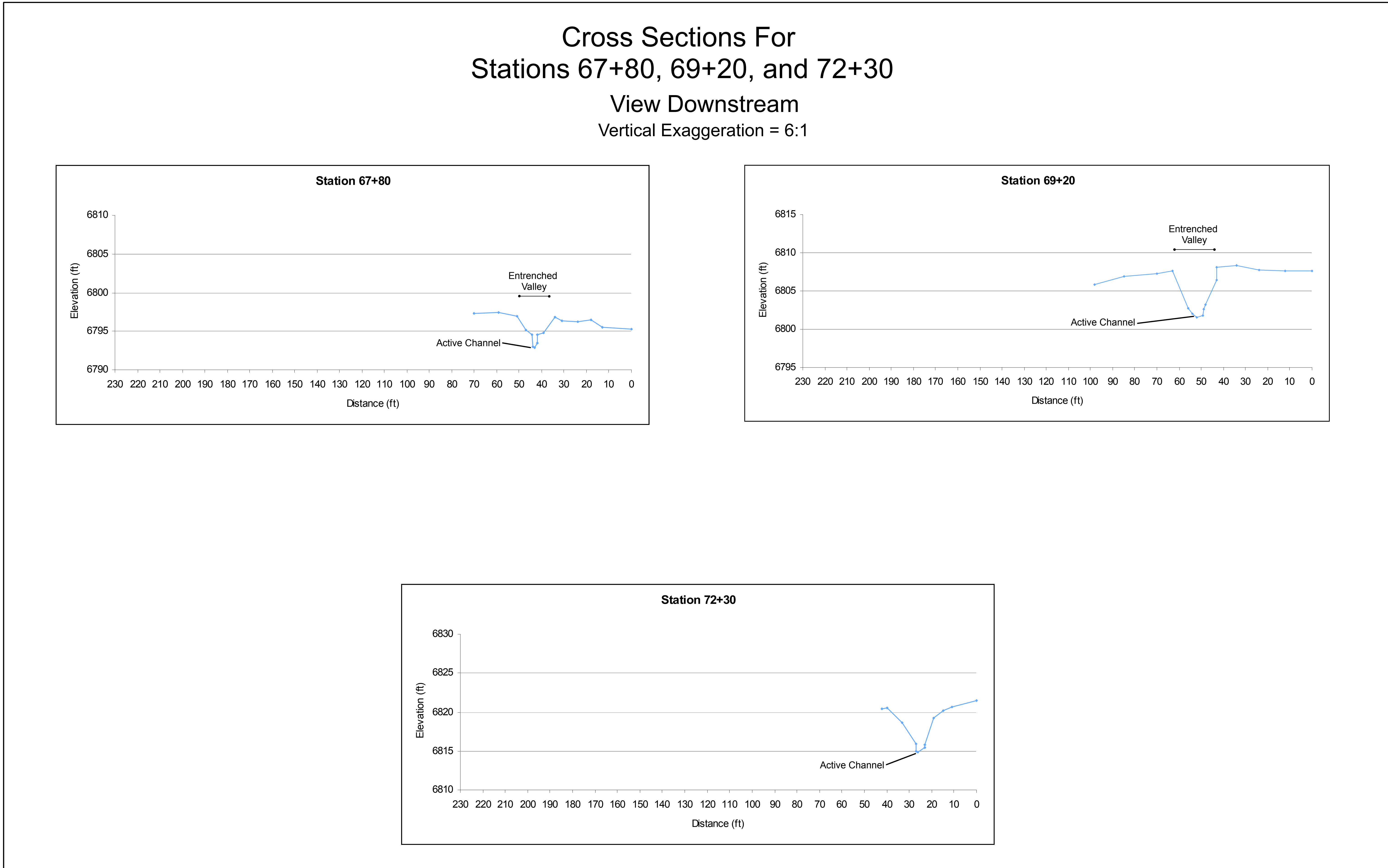


Figure 10H. Channal and Floodplain Cross-sections of Rosewood Creek

Sediment Transport and Supply

This study included an evaluation of the sediment delivered from Rosewood Creek to Lake Tahoe. The modeled hydraulic conditions of surveyed channel cross-sections were compared to the sediment sampled within the streambed to ascertain the mobility of the bed materials. The modeled bed material mobility can be compared to the results of the geomorphic assessment to further define reach stability. The channel dimensions of the incised reaches can also be used to estimate the amount of sediment that has thus far been eroded from Rosewood Creek. Using a projection of probable channel dimensions that would result over time if incision were left unchecked, the amount of sediment that might be further eroded from Rosewood Creek can then be calculated. This subsection provides the details of this sediment analysis.

Hydraulic Model Development and Application

Flowmaster® (Haestad Methods, Bentley Solutions, Inc.) is a 1-D (at-a-station) program for hydraulic analysis of open channels, pipes, weirs and orifices. The program is commonly used to analyze the hydraulic characteristics of stream channels. It can solve for discharge, normal depth, channel dimensions, slope, or roughness. Flowmaster® was used in this study to calculate the hydraulic conditions at the 2-, 5-, 10- and 100-yr recurrent flows. The surveyed cross-sections were to model each section; slope was calculated from the longitudinal profile. Given the variability of the profile, channel slope at the cross-sections was determined by using the bed elevations immediately upstream and downstream from the section (as opposed to the reach average).

The roughness coefficients (Manning's n values) used for each section in the hydraulic model were calculated, based on work by Jarrett (1984) and evaluations by Marcus et al. (1992) and Papanicolaou and Maxwell (2000). These researchers provided a means of calculating the roughness coefficient in small, high gradient mountain streams based on the hydraulic radius (cross-sectional area divided by wetted perimeter) and channel slope. A spreadsheet that further demonstrates this approach is included in the *Appendix 2 Hydraulic Modeling*.

The raw data from the hydraulic model are also contained in *Appendix 2 Hydraulic Modeling*. Of note are parameters that reflect water depth, velocity and shear stress.

Sediment Transport

Streambed Sampling and Analysis

Methods

Streambed sediment was sampled at seventeen locations within the study reach (Table 7). Sample sites were selected to represent conditions in riffles where an armor layer appeared to have developed. The samples included the surface armor layer to a depth of approximately twice the D_{50} (the mean particle diameter) (Bunte and Abt, 2001). Non-mobile bed material was not sampled. Samples were collected with a shovel and 5-gallon bucket. Samples were air-dried prior to sieving.

Bed material samples were sieved using a series of decreasing size square-hole wire screens and a mechanical shaker. Sieve sizes decreased from 64 mm as the coarsest sieve, to consecutively smaller sieves with mesh widths of 45.3, 32, 22.6, 16, 11.3, 8, 5.66, 4, 2.83 and 2 mm. Samples were sieved and weighed.

Table 7. Location of streambed sediment samples.

Streambed Sample No.	Station
1	3+00
2	4+20
3	5+90
4	8+70
5	10+60
6	12+70
7	16+85
8	23+20
9	24+90
10	26+15
11	29+20
12	30+90
13	40+20
14	45+70
15	48+00
16	49+15
17	47+30

Data quality assurance/quality control was performed for 10% of the streambed sediment samples. Field duplicates were collected in a location either immediately upstream or downstream from the original sample location. In the laboratory, 10% laboratory duplicates were run by first sieving a sample and then weighing. Then the sample was mixed in a container by hand shaking and re-sieved and weighed. Laboratory splits were run at 10%, where approximately half the sediment sample was sieved and weighed as Portion 1. Then the sample was mixed by hand in a container with the remaining un-sieved sample. Portion 2 was comprised of the mass differences between the mixture of the entire sample that was sieved and weighed minus the masses of Portion 1. Percent differences were calculated between the field duplicates with the original sample, between laboratory duplicate runs, and between laboratory splits.

Results

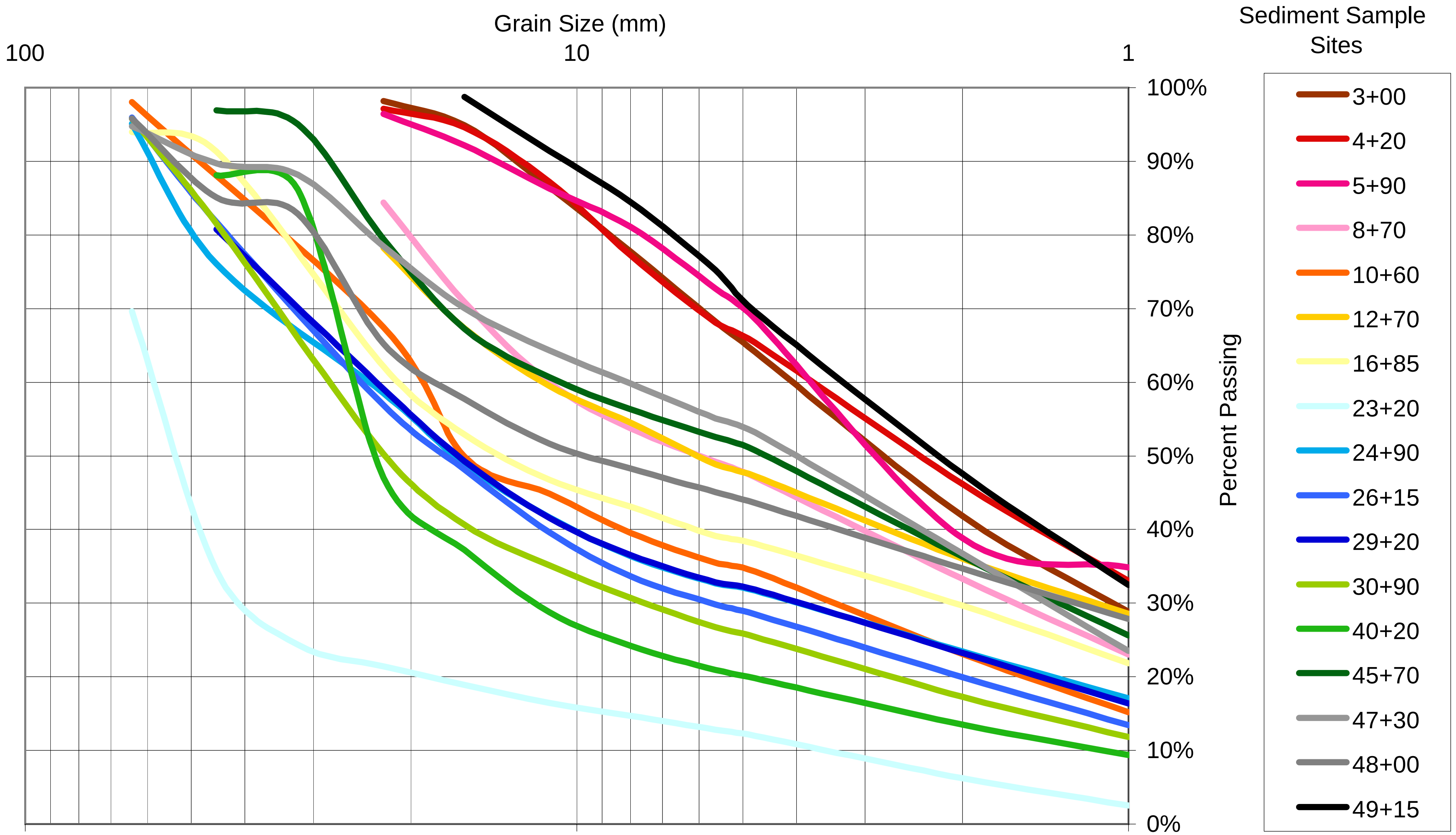
The particle size gradations (Figure 11) show that the median particle size of the samples ranged from about 2 to 50 mm (that is, from sand to gravel about 2.3 inches in diameter). The D_{16}, D_{50}, and D_{84} sediment sizes were calculated from the equation of a logarithmic line. Scatter plots of the duplicate run data were used to derive r^2 values, which varied from 0.93 to 1, indicating a high level of duplicity. The cumulative data for the streambed sediment sampling, including the D_{16}, D_{50} and D_{84} values, are located in *Appendix 3 Sediment Sampling*.

The data show that the streambed material generally becomes coarser in an upstream direction, with the three uppermost samples an exception (47+30, 48+00 and 49+15). Bed coarsening in an upstream direction is the condition typically exhibited in alluvial streams. The fact that the upper reaches have a high percentage of smaller material likely reflects that sediment supply is limited within the armored Reaches 15 through 18.

Sediment Mobility and Streambed Stability

In a stream in dynamic equilibrium, sediment transport continuity is maintained as sediment is gradually transported into and then out of a stream reach. Where discontinuity occurs, a channel aggrades with sediment or degrades as it erodes into the streambed. In conditions of dynamic equilibrium, the hydraulic forces exerted on the

Figure 11. Streambed sediment size gradation by sample.



streambed during the dominant discharge are roughly comparable to the resistance of the average bed materials. In other words, the particles of a streambed begin to become mobilized at the dominant discharge. The dominant discharge is commonly referred to as the bankfull discharge, and is generally comparable to the flows associated with recurrent intervals of 1.5 to 2 years.

For this study, the hydraulic conditions at the 2-yr flow were used to calculate the size of streambed material that would be mobilized. A relationship between shear stress on the streambed and particle size (Chen and Cotton, 1988) was used to estimate sediment mobility. The hydraulic model results for cross-sections near the sediment sample sites were used (Table 8). At all sample sites, the D_{50} material sampled in the field is smaller than the calculated size that would be mobilized by the 2-yr recurrence flow of 6 cfs. These data would seem to suggest that the channel should be actively degrading at a rapid rate. The field assessment, however, indicates that not all reaches are degrading. This inconsistency is probably due to several factors:

- There is a lack of precision inherent in calculating bed material mobility;
- The short duration of annual peak flow limits the time the channel is exposed to sediment mobilizing discharge; and
- Woody material within the channel serves to maintain the channel grade.

The results of the sediment mobility assessment, coupled with those of the geomorphic field investigation, suggest that active downcutting in the incised reaches of Rosewood Creek will continue to occur.

Table 8. Assessment of streambed sediment mobility at the 2-yr flow of 6-cfs. Sediment samples were compared to the hydraulic analysis of the nearest surveyed cross-section.

Station	Calculated Shear Stress at 2-yr Flow (lb/ft)	D_{50} Particle Size of Bed Material Sampled (mm)	D_{50} Particle Size Calculted to be Mobilized (mm)
1+00	1.1		85
3+00	1.8	2.6	141
4+50	1.6	2.3	122
5+60	1.9	2.3	148
7+70	0.6	5.2	44
9+70	0.6	10	42
12+50	1.2	5.1	92
13+90	0.8		65
15+90	1.5	8.4	113
17+50	3.2	8.4	246
20+80	0.7		50
22+95	0.9	47.7	69
24+50	1.7	11.6	130
26+25	2.2	12.2	169
28+30	3.0	13.1	230
30+30	1.1	12.2	86
32+60	1.9		141
34+05	1.9		143
35+60	1.4		103
40+20	1.1	8.3	85
43+40	1.7		132
45+80	2.1	4.5	162
47+40	3.5	4.4	268
49+10	4.0	2.1	303
53+00	3.2		245
56+00	0.5		36
58+20	1.6		120
62+25	1.5		117
67+80	2.1		160
69+20	1.5		116
72+30	1.9		145

Sediment Yield Resulting from Incision

Sediment supplied as bedload from upstream of the study area is likely limited. Conversely, there appears to be a larger quantity of sediment that is delivered from streambed and bank sources within the study area. The rate of within-reach sediment delivery is unknown. Delivery likely occurs sporadically (Susfalk, 2004), driven by spring snowmelt and late fall thunderstorms. Incised reaches of Rosewood Creek within the study area have likely contributed sediment over the last 40-50 years.

Sediment Volume Resulting From Incision

An effort was made to estimate the total amount of sediment that has been delivered to the downstream reach of Rosewood Creek, Third Creek and Lake Tahoe from the incised stream segments. The cross-sectional area of the entrenched valley at each surveyed cross-section was multiplied by the representative stream length (Table 9). The resulting volume of 12,000 cubic yards provides a gross estimate of the total amount of sediment that might have been eroded from Rosewood Creek within the study as a result of incision.

Future Sediment Supply

If left unmitigated, channel incision will likely continue to occur within the study area. The rate at which incision will occur is uncertain. It might take 50 or more years to progress to a stable, late stage incision condition, or it may take a much shorter time. The entire study area will not progress at the same rate. The rate is likely dependent on such factors as the magnitude of hydrologic events and the rate of riparian plant loss due to desiccation and land disturbance.

The maximum amount of sediment that would likely be produced if incision were left unchecked was estimated using the same method that was described previously to estimate the quantity of eroded materials to date. A cross-section of a ‘typical’ late-stage entrenched valley was compared to the dimensions of the existing entrenched valleys at the measured cross-sections. For this analysis, the cross-section for Station 3+00 was assumed to represent the conditions associated with an eventual end-result for the reach of stream between SR 28 and Northwood Blvd. A channel with dimensions of Station 30+30 was assumed to apply to upstream reaches. The upstream dimensions are assumed to be smaller due to the diminishing size of the watercourse. Overall, this is an imprecise method of estimating future entrenched valley conditions; nonetheless, it provides a rough estimate of potential future sediment delivery.

The results of this analysis, shown in Table 10 indicate that approximately 16,000 cubic yards of additional soil and subsoil could be eroded from Rosewood Creek as a result of incision. It was assumed that those reaches that are stabilized by riprap, grade controls and culverts would not incise. Only those reaches indicated in bold in Table 10 are those that were considered candidates for future sediment delivery resulting from incision. Again, this approach is a gross estimate—at best.

Recent research has shown that the clarity of Lake Tahoe is most affected by very fine clay particles (less than 20 microns, or 0.02 mm). In order to further determine the effects of the incision of Rosewood Creek on Lake Tahoe, the particle size distribution of stream bank material within the study area was evaluated. Nine grab samples of stream bank material were collected (Table 11). These samples were analyzed for size distribution using standard hydrometer methods (American Society for Testing and Materials, 2003).

Table 9. Estimated sediment volume resulting from channel incision, to date.

Reach No.	Cross-Section Station	Reach Station Begin		Reach Station End	Sub-Reach Station Begin		Sub-Reach Station End	Distance (ft)	Existing Entrenched Valley Area (ft^2)	Subtotal Volume Eroded (yds^3)	Total Reach Volume Eroded (yds^3)
1	1+00	0+00	to	2+90	0+00	to	2+90	290	157	1,688	1,688
2	3+00	2+90	to	4+15	2+90	to	4+15	125	239	1,106	1,106
3	4+50	4+15	to	6+00	4+15	to	4+90	75	35.5	99	297
	5+60				4+90	to	6+00	110	48.7	198	
4	7+70	6+00	to	8+80	6+00	to	8+80	280	52.6	545	545
5	9+70	8+80	to	17+75	8+80	to	10+90	210	92.5	719	2,864
	12+50				10+90	to	13+60	270	89.5	895	
	13+90				13+60	to	15+20	160	82.2	487	
	15+90				15+20	to	17+10	190	99.7	702	
	17+50				17+10	to	17+75	65	25.2	61	
6	20+80	18+50	to	22+10	18+50	to	22+10	360	4.5	60	60
7	22+95	22+10	to	28+50	22+10	to	23+50	140	7.9	41	223
	24+50				23+50	to	25+50	200	17.1	127	
	26+25				25+50	to	27+00	150	6.6	37	
	28+30				27+00	to	28+50	150	3.3	18	
8	30+30	28+50	to	31+00	28+50	to	31+00	250	91.7	849	849
9	32+60	31+00	to	32+90	31+00	to	33+25	225	33.0	275	275
10	34+05	33+30	to	34+50	33+25	to	34+50	125	0.9	4	4
11	35+60	34+50	to	37+00	34+50	to	37+00	250	37.9	351	351
12	35+60	37+72	to	41+20	34+50	to	37+00	250	37.9	351	351
13	43+40	43+20	to	50+15	43+25	to	44+50	125	5.7	26	388
	45+80				44+50	to	45+95	145	13.5	73	
	47+40				45+95	to	48+00	205	34.8	264	
	49+10				48+00	to	50+20	220	3.1	25	
14	53+00	51+70	to	58+90	51+50	to	54+50	300	103	1,140	1,353
	56+00				54+50	to	57+25	275	1.3	13	
	58+20				57+25	to	58+90	165	32.7	200	
15	62+25	58+90	to	65+50	58+90	to	65+50	660	5.5	134	134
16	67+80	66+15	to	72+30	66+15	to	68+50	235	27.8	242	1,306
	69+20				68+50	to	72+30	380	75.6	1,064	
17	72+30	72+30	to	74+70	72+30	to	74+70	240	26.7	237	237
Average								220	48.1	388	708
Total								6,825			12,033

Table 10. Estimated potential future delivery of eroded sediment after natural progression of incision. See text for a description of incision potential

Reach No.	Cross-Section Station	Reach Station Begin		Reach Station End	Sub-Reach Station Begin		Sub-Reach Station End	Distance (ft)	Potential Entrenched Valley Area (ft^2)	Actual Entrenched Valley Area (ft^2)	Subtotal Volume Eroded (yds^3)	Total Reach Volume Eroded (yds^3)
1	1+00	0+00	to	2+90	0+00	to	2+90	290	250.0	157	997	997
2	3+00	2+90	to	4+15	2+90	to	4+15	125	250.0	239	51	51
3	4+50	4+15	to	6+00	4+15	to	4+90	75	250.0	35.5	596	1,416
	5+60				4+90	to	6+00	110	250.0	48.7	820	
4	7+70	6+00	to	8+80	6+00	to	8+80	280	250.0	52.6	2,047	2,047
5	9+70	8+80	to	17+75	8+80	to	10+90	210	250.0	92.5	1,225	5,423
	12+50				10+90	to	13+60	270	250.0	89.5	1,605	
	13+90				13+60	to	15+20	160	250.0	82.2	994	
	15+90				15+20	to	17+10	190	250.0	99.7	1,058	
	17+50				17+10	to	17+75	65	250.0	25.2	541	
6	20+80	18+50	to	22+10	18+50	to	22+10	360	4.5	4.5	0	0
7	22+95	22+10	to	28+50	22+10	to	23+50	140	7.9	7.9	0	0
	24+50				23+50	to	25+50	200	17.1	17.1	0	
	26+25				25+50	to	27+00	150	6.6	6.6	0	
	28+30				27+00	to	28+50	150	3.3	3.3	0	
8	30+30	28+50	to	31+00	28+50	to	31+00	250	91.7	91.7	0	0
9	32+60	31+00	to	32+90	31+00	to	33+25	225	33.0	33	0	0
10	34+05	33+30	to	34+50	33+25	to	34+50	125	0.9	0.9	0	0
11	35+60	34+50	to	37+00	34+50	to	37+00	250	150.0	37.9	1,038	1,038
12	35+60	37+72	to	41+20	34+50	to	37+00	250	37.9	37.9	0	0
13	43+40	43+20	to	50+15	43+25	to	44+50	125	5.7	5.7	0	2,805
	45+80				44+50	to	45+95	145	150.0	13.5	733	
	47+40				45+95	to	48+00	205	150.0	34.8	875	
	49+10				48+00	to	50+20	220	150.0	3.1	1,197	
14	53+00	51+70	to	58+90	51+50	to	54+50	300	102.6	103	0	0
	56+00				54+50	to	57+25	275	1.3	1.3	0	
	58+20				57+25	to	58+90	165	32.7	32.7	0	
15	62+25	58+90	to	65+50	58+90	to	65+50	660	5.5	5.5	0	0
16	67+80	66+15	to	72+30	66+15	to	68+50	235	27.8	27.8	0	1,047
	69+20				68+50	to	72+30	380	150.0	75.6	1,047	
17	72+30	72+30	to	74+70	72+30	to	74+70	240	150.0	26.7	1,096	1,096
Average								220	121.9	48.1	514	936
Total								6,825				15,920

Table 11. Sample locations of stream bank materials.

Stream Bank Sample No.	Station
A	3+00
B	4+20
C	12+70
D	16+85
E	26+15
F	29+20
G	30+90
H	47+30
I	48+00

The stream bank particle size distribution is generally homogenous within the study area (Figure 12). The data show that the majority of the stream banks consist of sand-sized particles greater than half a millimeter. The percentage of fine clays (less than 20 microns or 0.02 mm) is 2.6% (range 0.4% to 8.9%). The cumulative data for the stream bank material sampling are located in *Appendix 3 Sediment Sampling*. While sample methods varied, this percent composition is lower than reported by Susfalk (2004), who found that bank sediment values of this size class varied between 5% and 20%. Nonetheless, it appears that future sediment volumes under an un-checked, fully incised scenario might include approximately 400 cubic yards of material in the size class that could affect Lake Tahoe clarity. These figures are rough approximations. Furthermore, potential future delivery of sand-sized materials may affect the conveyance or stability of lower Rosewood and Third Creeks. However, given that sand is readily mobilized, it is likely that this material would move rapidly through the system to the lake.

Riparian Vegetation Assessment

Assessment Methods

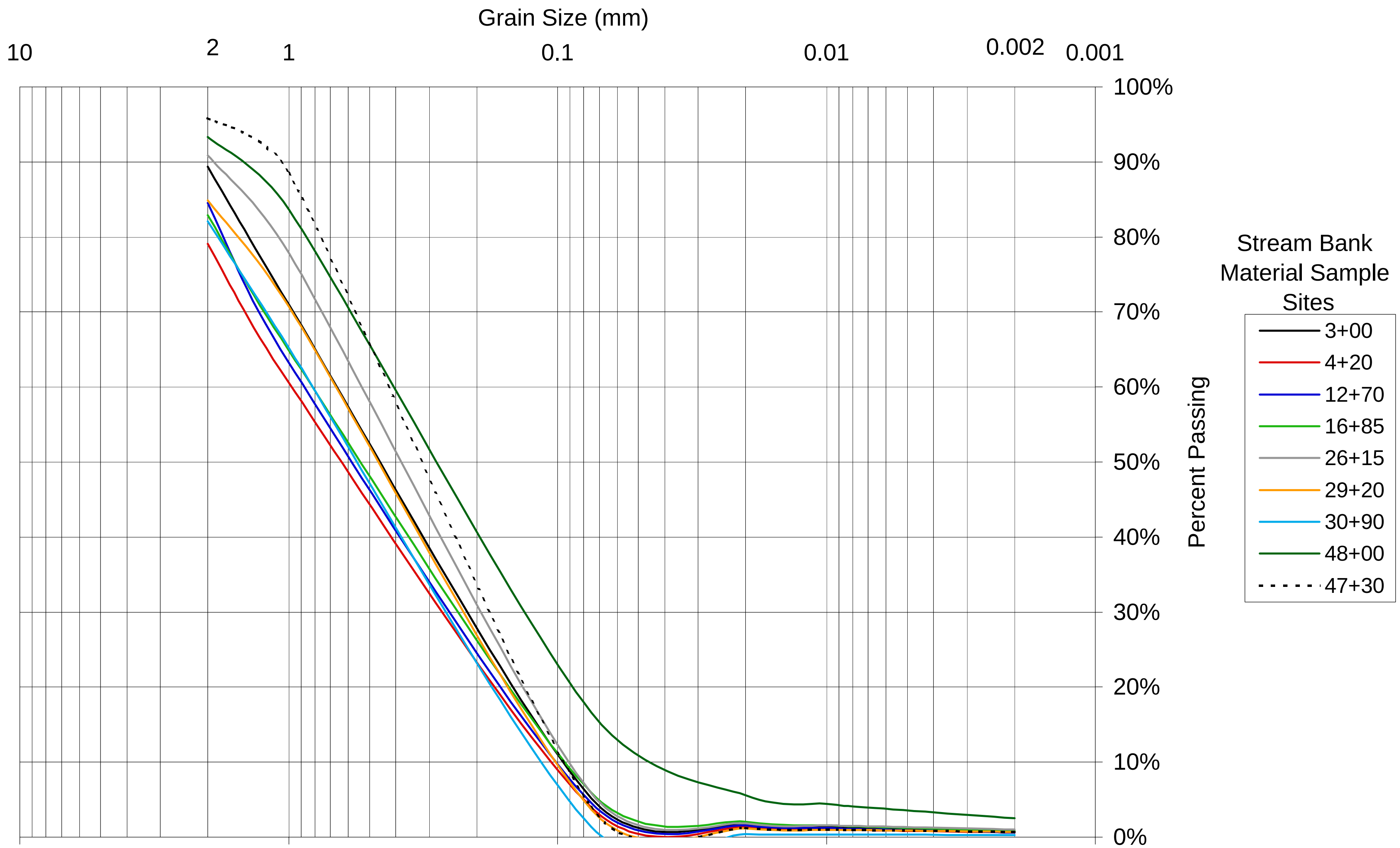
Pre-Field Investigation

During late April through mid May 2005, appropriate public agencies were contacted to obtain current documents that contain information that characterize Rosewood Creek with regards to its vegetation. These agencies include Nevada Division of State Lands, Tahoe Regional Planning Agency (TRPA), and the Nevada Tahoe Conservation District. The USFS Lake Tahoe Basin Management Unit (LTBMU) and the Nevada Natural Heritage Program (NNHP) were also contacted with regards to Special Status Plant Species and their habitats that may occur within the study area. Additionally, ecological references and floras were reviewed regarding riparian vegetation communities and their components that may occur within the study area.

Vegetation

Few of the reports that have previously characterized and assessed Rosewood Creek provide detailed vegetation information. Generally, the presence of mountain alders is mentioned, and the lack of connectivity to the floodplain for much of this vegetation type (Entrix, 2001). Swanson (2000) measured rooting depth from the top of bank and percent root density of riparian vegetation to help develop the stream bank erosion potential for

Figure 12. Stream bank material size gradation by sample.



the stream (Rosgen, 1996). Specific riparian vegetation data including cover type, species, and location are not included in the report. Riparian vegetation is described in detail for the section of Rosewood Creek south of SR 28 in Picciani and Arsenault (2001); these researchers document the presence of mountain alder, willows and redosier dogwood. The Swanson (2000) and ENTRIX (2001) reports provide a historical overview of land use that explains the current ecological settings in terms of human induced impacts. Riparian community structure and potential successional trajectories are described by several researchers (Weixelman et al., 1999; Manning and Padgett, 1995 and Brunsfeld and Johnson, 1985). ALLREF.com (2005) provides species accounts of botanical and ecological characteristics regarding redosier dogwood, mountain alder, Pacific willow and Scouler's willow.

Special Status Plant Species

A list of special status plant species expected or known to occur within the Lake Tahoe Basin was obtained from the LTBMU prior to conducting the July, 2005 field survey. The list is a compilation of United States Fish and Wildlife Service (FWS), TRPA and LTBMU species receiving regulatory protections or interests by the various agencies. Additional agency consultation included a database request to the NNHP. Table 12 identifies the potential occurrence of special status plants and wildlife within the study area and vicinity. An "X" indicates that the study area contains suitable habitat, there is habitat within the vicinity of the study area or occurrences have been documented within the study area for that particular species.

Field Investigation

A preliminary field reconnaissance was conducted in early June, 2005 to visually assess the Rosewood Creek riparian corridor with regards to vegetation association/community types, their overall health and vigor, and preliminary vegetation type boundaries. The stream was directly accessed at roadways, and traversed north to south on the right bank and then surveyed south to north along the left bank of the stream.

A more comprehensive, in-depth characterization of riparian community types was performed in late June through mid July 2005. Differences in plant species composition, health and age class were noted and 15 vegetation cross-sections established at select locations to further document plant species composition and condition (Table 13). The vegetation association/community type boundaries identified during the preliminary reconnaissance were also verified. Concurrently, the study area was surveyed for Special Status Plant Species and their habitats that may occur within the study area.

The methods used to assess vegetation are both qualitative and quantitative in nature, and provide baseline data for identified stream reaches. The Proper Functioning Condition (PFC) assessment protocol developed by NRCS (1998a and 1999) recognizes that vegetative data are important to quantitatively support effects of vegetation on bank stability and succession. The cross-section composition quantitative method is recommended by NRCS as a means of developing that information. This method is described in the USDA Forest Service General Technical Report Monitoring the Vegetation Resources in Riparian Areas (Winward, 2000).

The vegetation cross-section composition sampling method was employed coincident with selected cross-sections sampled for the fluvial geomorphic assessment. This sampling method documents the riparian complex of community types present along the

Table 12. Special status plant species within the study area.

Common Name	Scientific Name	Suitable Habitat	Status[1]
Washoe tall rockcress	*Arabis rectissima* v. *simulans*	X	LSI
Galena Creek rockcress	*Arabis rigidissima* v. *demota*		SC, S
Tiehm rockcress	*Arabis tiehmii*		S
Upswept moonwort	*Botrychium ascendens*	X	SC, S
Scalloped moonwort	*Botrychium crenulatum*	X	SC, S
Slender moonwort	*Botrychium lineare*	X	C, S
Common moonwort	*Botrychium lunaria*	X	S
Mingan moonwort	*Botrychium minganense*	X	S
Western goblin	*Botrychium montanum*	X	S
Bolanders candle moss	*Bruchia bolanderi*	X	S
Tahoe draba	*Draba asterophora* v. *asterophora*		S, SI
Cup Lake draba	*Draba asterophora* v. *macrocarpa*		SC, S, SI
Subalpine fireweed	*Epilobium howellii*	X	S
Starved daisy	*Erigeron miser*		S
Donner Pass buckwheat	*Eriogonum umbellatum v. torreyanum*		SC, S
Blandow's helodium moss	*Helodium blandowii*	X	LSI
Shortleaf alpinegold	*Hulsea brevifolia*		S
Kellogg's lewisia	*Lewisia kelloggii* ssp. *hutchisonii*		LSI
Long-petaled lewisia	*Lewisia pygmaea* ssp. *longipetala*		SC, S, SI
Meesia moss	*Meesia longiseta*	X	LSI
Three-ranked hump-moss	*Meesia triquetra*		S
Broad-nerved hump-moss	*Meesia uliginosa*		S
Myurella moss	*Myurella julacea*		LSI
Orthotrichum moss	*Orthotrichum praemorsum*	X	LSI
Shevock's orthotrichum	*Orthotrichum shevockii*	X	LSI
Spjut's bristle moss	*Orthotrichum spjutii*	X	LSI
Felt lichen	*Peltigera hydrotheria*	X	S
Tundra pohlia moss	*Pohlia tundrae*		LSI
Tahoe yellow cress	*Rorippa subumbellata*		C, S, SI
Sphagnum moss	*Sphagnum* spp.		LSI

[1]Agency Codes:
(C) FWS Candidate Species
(E) FWS Endangered Species
(T) FWS Threatened Species
(PE) FWS Proposed Endangered Species
(PT) FWS Proposed Threatened Species
(S) LTBMU Sensitive Species, Regional Forester's Sensitive Species List
(SC) FWS Species of Concern
(SI) TRPA Special Interest Species, Regional Plan for the Lake Tahoe Basin: Code of Ordinances (1987)
(MI) LTBMU Management Indicator Species
(P) FWS Petitioned for Listing
(LSI) LTBMU Species of Interest

Table 13. Vegetation association and plant species observed at each vegetation sample cross-section.

Family	Scientific Name	Common Name	Vegetation Association[a] and Community Type per Vegetation Cross-section[b]																	
			Jeffrey pine-white fir 13	Jeffrey pine/ graminoids 13	Jeffrey pine/ western brackenfern 13	lodgepole pine 13	montane chaparral 2	Sierra currant 2	bittercherry 13	Scouler's willow/ conifer 9, 11	Scouler's willow/ mesic herbaceous 5	Scouler's willow/ disturbed herbaceous 6, 9	Scouler's willow/ mesic forb 11	Scouler's willow/ Sierra currant 7	mountain alder 1	mountain alder-Scouler's willow/ conifer 2, 7	mountain alder-mixed willow 3	mountain alder-Scouler's willow/ stinging nettle 6	mountain alder-Scouler's willow/ mesic forb 6	mountain alder-pacific willow/ stinging nettle 3
			RW1, RW2, RW3, RW4, RW5, RW6, RW7, RW8, RW9, RW10, RW11	RW13	RW2	RW14	RW13	RW13, RW14	RW15	RW2, RW6, RW13	RW2	RW3, RW13	RW14	RW6	RW5, RW11	RW6, RW7, RW8, RW14, RW15	RW1, RW6	RW6	RW14	RW1
Apiaceae	*Osmorhiza occidentalis*	sweetanise						X					X							
Asteraceae	*Cirsium andersonii*	Anderson's thistle											X						X	
	Cirsium sp.	thistle			X															
	Senecio triangularis	arrowleaf groundsel																		
	Taraxacum officinale	common dandelion																		
Betulacaeae	*Alnus incana* ssp. *tenuifolia*	mountain alder									X	X			X	X	X	X	X	X
Boraginaceae	*Hackelia* sp.	stickseed	X										X						X	
Brassicaceae	*Arabis* rectissima var. simulans	Washoe tall rockcress	X																	
Caprifoliaceae	*Symphoricarpos mollis*	creeping snowberry	X							X										
Cornaceae	*Cornus sericea*	redosier dogwood															X			X
Cupressacae	*Calocedrus decurrens*	incense cedar	X																	
Cyperaceae	Carex amplifolia	bigleaf sedge									X						X			
	Carex sp.	rhizomateous sedge			X								X							
	Carex deweyana	Dewey's sedge																		
	Carex fracta	fragile sheath sedge																		
	Scirpus microcarpus	small-fruit bulrush									X						X			
Dennstaedtiaceae	*Pteridium aquilinum*	western brackenfern	X		X	X			X	X		X	X	X		X	X			
Ericaceae	Arctostaphylos nevadensis	pinemat manzanita																		
	Arctostaphylos patula	greenleaf manzanita	X	X			X													
Equitaceae	*Equisetum arvense*	common horsetail									X									
Fabaceae	*Caragana arborescens*	Siberian peashrub															X			
	Vicia sp.	vetch	X		X					X									X	
Fagaceae	*Chrysolepis sempervirens*	Sierra chinquapin	X																	
Grossulariaceae	*Ribes cereum*	wax currant	X																	
	Ribes nevadense	Sierra currant	X					X		X			X	X						
	Ribes roezlii	Sierra gooseberry				X							X							
Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia																		
Juncacaceae	*Juncus* sp.	rush																		
Liliaceae	*Smilacina stellata*	starry false-Solomon's-seal				X													X	X
	Veratrum californicum	California false hellebore																	X	
Onagraceae	*Epilobium angustifolium*	fireweed														X				
	Epilobium sp.	willowherb																		
Pinaceae	*Abies concolor*	white fir	X							X						X			X	
	Pinus contorta	lodgepole pine				X				X										
	Pinus jeffreyi	Jeffrey pine	X	X	X					X						X				
Poaceae	*Agropyron* sp.	wheatgrass		X		X		X		X		X				X				
	Bromus sp.	brome		X		X		X		X		X				X				
	Elymus glaucus	blue wildrye			X															
	Poa pratensis	Kentucky bluegrass			X															
Ranunculaceae	*Aquilegia formosa*	crimson columbine																		
	Thalictrum fendleri	Fendler's meadowrue								X									X	
Rhamnaceae	*Ceonothus cordulatus*	whitethorn ceonothus	X				X			X										
	Ceonothus prostratus	squawcarpet	X		X															
	Ceonothus velutinus	snowbrush ceonothus								X										
Rosaceae	*Fragaria virginiana*	Virginia strawberry	X							X										
	Geum macrophyllum	largeleaf avens																		
	Potentilla gracilis	Northwest cinquefoil			X															
	Potentilla glandulosa	sticky cinquefoil												X						
	Prunus emarginata	bittercherry							X											
	Prunus virginiana	chokecherry																		
	Purshia tridentata	antelope bitterbrush	X																	
	Rosa woodsii	Woods rose	X		X															
	Rubus parviflorus	thimbleberry	X													X	X			
Rubiaceae	*Galium aparine*	catchweed bedstraw										X							X	
Salicaceae	*Salix lemmonii*	Lemmon's willow				X														
	Salix lucida ssp. *lasiandra*	Pacific willow									X						X			X
	Salix scouleriana	Scouler's willow	X							X	X	X	X	X		X	X	X	X	
Scrophulariaceae	*Veronica americana*	American speedwell																		
Urticaceae	*Urtica dioica*	stinging nettle										X						X		X

[a] Vegetation Association with which this community type was mapped. The community type may not fit with the vegetation association; this may reflect that some community types were too small to map as independent units.

1 mountain alder
2 mountain alder/conifer
3 mountain alder-mixed willow
4 mountain alder-mixed willow/conifer
5 mountain alder-mixed willow/mesic understory
6 mountain alder-Scouler's willow
7 mountain alder-Scouler's willow/conifer
8 mountain alder/mesic herbaceous
9 mixed willow/conifer
10 Scouler's willow
11 Scouler's willow/conifer
12 mesic graminoid
13 Jeffrey pine-white fir
14 mountain alder-Scouler's willow/mesic herbaceous

[b] Vegetation Cross-Sections RW1-RW15

Table 13. Vegetation association and plant species observed at each vegetation sample cross-section.

Family	Scientific Name	Common Name	Vegetation Association[a] and Community Type per Vegetation Cross-section[b]																		
			mountain alder-pacific willow/graminoids 3	mountain alder-pacific willow/small-fruit bulrush 5	mountain alder-Scouler's willow/small-fruit bulrush 14	mountain alder/conifer 2, 7	mountain alder/mesic herbaceous 8	mountain alder/common horsetail 1	mountain alder/small-fruit bulrush-western brackenfern 8	redosier dogwood 1, 3	redosier dogwood/bigleaf sedge 12	bigleaf sedge small-fruit bulrush 1	small-fruit bulrush 12	bigleaf sedge 12	sedge 3, 7	starry false-solomon's seal/common horsetail 5	western brackenfern 13	stinging nettle 6	mesic forb 11	disturbed herbaceous 4	graminoids 4
			RW12	RW4	RW7	RW4, RW10, RW11, RW13	RW4, RW10	RW13	RW4	RW1, RW5	RW1	RW5	RW9, RW11	RW1, RW11	RW12, RW15	RW2	RW3, RW9	RW6	RW14	RW12	RW12
Apiaceae	*Osmorhiza occidentalis*	sweetanise																			
Asteraceae	*Cirsium andersonii*	Anderson's thistle																	X		
	Cirsium sp.	thistle									X			X			X				
	Senecio triangularis	arrowleaf groundsel					X														
	Taraxacum officinale	common dandelion																		X	
Betulacaceae	*Alnus incana* ssp. *tenuifolia*	mountain alder	X	X	X	X	X	X	X												
Boraginaceae	*Hackelia* sp.	stickseed				X													X		
Brassicaceae	*Arabis* rectissima var. simulan	Washoe tall rockcress																			
Caprifoliaceae	*Symphoricarpos mollis*	creeping snowberry																			
Cornaceae	*Cornus sericea*	redosier dogwood								X	X										
Cupressacae	*Calocedrus decurrens*	incense cedar																			
Cyperaceae	Carex amplifolia	bigleaf sedge		X		X	X				X	X		X							
	Carex sp.	rhizomateous sedge	X																X		
	Carex deweyana	Dewey's sedge													X						
	Carex fracta	fragile sheath sedge													X						
	Scirpus microcarpus	small-fruit bulrush		X	X	X	X	X	X			X	X								
Dennstaedtiaceae	*Pteridium aquilinum*	western brackenfern				X			X	X							X		X		
Ericaceae	Arctostaphylos nevadensis	pinemat manzanita															X				
	Arctostaphylos patula	greenleaf manzanita															X				
Equitaceae	*Equisetum arvense*	common horsetail						X								X					
Fabaceae	*Caragana arborescens*	Siberian peashrub																			
	Vicia sp.	vetch																			
Fagaceae	*Chrysolepis sempervirens*	Sierra chinquapin																			
Grossulariaceae	*Ribes cereum*	wax currant																			
	Ribes nevadense	Sierra currant	X			X				X											
	Ribes roezlii	Sierra gooseberry																			
Hydrophyllaceae	*Phacelia hastata*	silverleaf phacelia															X				
Juncacaceae	*Juncus* sp.	rush					X														
Liliaceae	*Smilacina stellata*	starry false-Solomon's-seal														X					
	Veratrum californicum	California false hellebore																			
Onagraceae	*Epilobium angustifolium*	fireweed																			
	Epilobium sp.	willowherb									X			X	X						
Pinaceae	*Abies concolor*	white fir				X											X				
	Pinus contorta	lodgepole pine				X															
	Pinus jeffreyi	Jeffrey pine				X			X								X				
Poaceae	*Agropyron* sp.	wheatgrass	X			X													X		X
	Bromus sp.	brome	X			X		X											X		X
	Elymus glaucus	blue wildrye																			
	Poa pratensis	Kentucky bluegrass					X													X	
Ranunculaceae	*Aquilegia formosa*	crimson columbine				X															
	Thalictrum fendleri	Fendler's meadowrue				X													X		
Rhamnaceae	*Ceonothus cordulatus*	whitethorn ceonothus															X				
	Ceonothus prostratus	squawcarpet																			
	Ceonothus velutinus	snowbrush ceonothus																			
Rosaceae	*Fragaria virginiana*	Virginia strawberry																			
	Geum macrophyllum	largeleaf avens									X			X							
	Potentilla gracilis	Northwest cinquefoil																			
	Potentilla glandulosa	sticky cinquefoil																			
	Prunus emarginata	bittercherry																			
	Prunus virginiana	chokecherry																			
	Purshia tridentata	antelope bitterbrush																			
	Rosa woodsii	Woods rose								X											
	Rubus parviflorus	thimbleberry																			
Rubiaceae	*Galium aparine*	catchweed bedstraw																			
Salicaceae	*Salix lemmonii*	Lemmon's willow																			
	Salix lucida ssp. *lasiandra*	Pacific willow	X	X						X											
	Salix scouleriana	Scouler's willow			X																
Scrophulariaceae	*Veronica americana*	American speedwell									X		X	X							
Urticaceae	*Urtica dioica*	stinging nettle																X			

[a] Vegetation Association with which this community type was mapped. The community type may not fit with the vegetation association; this may reflect that some community types were too small to map as independent units.

1 mountain alder
2 mountain alder/conifer
3 mountain alder-mixed willow
4 mountain alder-mixed willow/conifer
5 mountain alder-mixed willow/mesic understory
6 mountain alder-Scouler's willow
7 mountain alder-Scouler's willow/conifer
8 mountain alder/mesic herbaceous
9 mixed willow/conifer
10 Scouler's willow
11 Scouler's willow/conifer
12 mesic graminoid
13 Jeffrey pine-white fir
14 mountain alder-Scouler's willow/mesic herbaceous

[b] Vegetation Cross-Sections RW1-RW15

elevational gradient of selected cross-sections. Community typing provides information regarding vertical and horizontal structure, plant species composition and potentially, successional status. Unknown plant species were collected, identified to species level, and verified with herbarium specimens when necessary. Plant species nomenclature follows the 1998b NRCS Nevada Plant List. Photographs of individual plant species can be found at www.plants.usda.gov.

Assessment Results

General

Throughout the Rosewood Creek study reaches, dominant, overstory riparian vegetation is provided by mountain alder, Scouler's willow and Pacific willow. Overstory health, canopy cover and age class are variable, with most of the reaches exhibiting some lack of riparian vegetation recruitment, senescence (aging of vegetation stands) and conifer encroachment. In general, mountain alder and willow species greater than 20 feet from the top of bank in incised reaches tend towards senescence, while well-established older trees' root systems on the bank proper are healthy because they are able to follow a lowered water table, a condition that often occurs with incision. A shrub layer is typically noncontiguous along the stream bank, except for discrete occurrences of redosier dogwood, Wood's rose (*Rosa woodsii*) and Lemmon's willow. The herbaceous understory varies from dense cover of mesic graminoids like small-fruit bulrush, bigleaf sedge, and common horsetail (*Equisetum arvense*), and dry graminoids like blue wildrye (*Elymus glaucus*) to that composed of forbs including western brackenfern (*Pteridium aquilinum*), stinging nettle, Anderson's thistle (*Cirsium andersonii*), and catchweed bedstraw (*Galium aparine*).

More detailed descriptions of the vegetation associations/community types, as they occur within each reach, are provided below. Vegetation transect cross-sections are indicated as RW1, RW2 and so on and are referenced in the following sections as such. These transects are shown on Plates 2 through 6.

Analysis of the 15 vegetation cross-sections provides a characterization of Rosewood Creek as an early seral (drying) riparian complex (Table 14). These results are based on approximately 30 percent of the vegetation rated as late seral. These interpretations of seral stage were derived from Winward (2000) successional status for riparian community types documented throughout the intermountain region, including the eastern Sierra Nevada Mountains. Assumptions include the presence of Scouler's willow and/or conifers are considered early seral, unless the dominant understory herbaceous components are rated as late seral.

A total of 15 vegetation associations were mapped (Plates 2 through 6). The vegetation association map units reflect the plant community types found within the study area. Given the scale of the aerial photography, it was not feasible to map and digitally survey each community type; rather, the similar community types were lumped into one association that reflects similar vegetation and environmental attributes. For example, the mesic graminoid map unit reflects communities dominated either singularly or in combination by the following plant species: small-fruit bulrush, bigleaf sedge and other sedge species. This vegetation association occurs on inner floodplains adjacent to Rosewood Creek. Mountain alder provides dominant or co-dominant overstory vegetative cover in nine map units, willows are the overstory dominants in three map units, and herbaceous plants are predominant in one association type.

Table 14. Analysis of 15 vegetation cross-sections by plant community type and successional status.

		RW1	RW2	RW3	RW4	RW5	RW6	RW7	RW8	RW9	RW10	RW11	RW12	RW13	RW14	RW15		Percent
Successional Status	Community Type	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Steps	Total	Composition
Late	mountain alder-mixed willow	21					2.6										23.6	2.2%
Late	mountain alder-Pacific willow/stinging nettle	54.6															54.6	5.1%
Late	redosier dogwood	37.8				15											52.8	4.9%
Late	redosier dogwood/bigleaf sedge	16.8															16.8	1.6%
Late	bigleaf sedge	6.3										13.8					20.1	1.9%
Early	Scouler's willow/conifer		44.6				57.2							4.5			106.3	9.9%
Early	Scouler's willow/mesic herbaceous		82.5														82.5	7.7%
Early	Scouler's willow/mesic forb														76.8		76.8	7.2%
Early	starry false/solomon's seal/common horesetatil		3.35														3.35	0.3%
Early	Scouler's willow/disturbed herbaceous			52.9										57.5			110.4	10.3%
Late	mountain alder-Pacific willow/small-fruit bulrush				25.85												25.85	2.4%
Early	mountain alder/conifer				9.4						19.2	16.1		55			99.7	9.3%
Late	mountain alder/mesic herbaceous				11.75						3.6						15.35	1.4%
Late	mountain alder/small-fruit bulrush-western brackenfern				14.1												14.1	1.3%
Early	mountain alder				12.5							11.5					24	2.2%
Late	bigleaf sedge-small-fruit bulrush				3.75												3.75	0.3%
Early	Scouler's willow/Sierra currant						18.2										18.2	1.7%
Early	mountain alder-Scouler's willow/conifer						7.8	12.5	16.2						8	27.5	72	6.7%
Early	mountain alder-Scouler's willow/mesic forb														44.8		44.8	4.2%
Late	mountain alder-Scouler's willow/stinging nettle						20.8										20.8	1.9%
Late	stinging nettle						23.4										23.4	2.2%
Late	mountain alder-Scouler's willow/small-fruit bulrush							25									25	2.3%
Late	small-fruit bulrush									1.3		9.2					10.5	1.0%
Early	mountain alder-Pacific willow/graminoids												10				10	0.9%
Late	sedge												2.5			2.5	5	0.5%
Early	mesic forb														22.4		22.4	2.1%
Early	disturbed herbaceous												5				5	0.5%
Early	graminoids												5				5	0.5%
Late	mountain alder/common horsetail													10			10	0.9%
Early	Sierra currant														25.6		25.6	2.4%
Early	Sierra currant/sweetanise													10			10	0.9%
Early	lodgepole pine														35.2		35.2	3.3%
Total		136.5	130.5	52.9	77.35	15	130	37.5	16.2	1.3	22.8	50.6	22.5	137	212.8	30	1072.9	100.0%

Steps = Distance measured by walking. Used to provide comparative extent of plant community type and successional status for each vegetative transect.

Total undisturbed types (%) = 30.0%

	0-15 = very early seral
X	16-40 = early seral
	41-60 = mid seral
	61-85 = late seral
	85+ = potential natural community

Vegetation Association/Community Type by Reach

This section provides a description of the vegetation associations found within each of the reaches identified and described in the geomorphic assessment.

Reaches 1 and 2

Mountain alder-mixed willow is the dominant vegetation association within these reaches and is located on the elevated floodplain. This map unit reflects variable dominance in the overstory by mountain alder, mostly in combination with Scouler's willow and/or Pacific willow. Mountain alder and Pacific willow provide co-dominant and continuous canopy cover, rooted at the top of the stream bank. Scouler's willow becomes more prevalent on elevated, drier topography located east of the main channel. The willows and mountain alder appear to be vigorous and multistemmed, although no recruitment of younger age classes was observed for the willow species. However, young, thin-stemmed, and vigorous mountain alder is present at the top of the right bank north of the mesic graminoid vegetation association and between stations 3+00 and 4+00. A vigorous stand of redosier dogwood is present at the top of the right bank by RW1 vegetation cross-section, and is also present as an understory component with the afore-mentioned willow species at the east edge of the riparian complex adjacent to a remnant channel. The inner floodplain is mapped as mesic graminoid and is co-dominated by young, vigorous redosier dogwood and bigleaf sedge. Ocular estimates of aerial cover of the stream bank resulted in 20 percent vegetated by herbaceous plants, including stinging nettle, 35 percent litter consisting of branches and leaves, and 45 percent bare soil. Large diameter Jeffrey pines provide sources of woody debris in proximity to the right stream bank. Note that the RW1 vegetation cross-section is applicable to both of these reaches and documents seven community types.

Reach 3

The floodplain in this reach is elevated above the stream channel by approximately four feet and supports the mountain alder-mixed willow vegetation association as described above. In this reach, the eastern third is drier and is dominated by Scouler's willow, often distributed adjacent to remnant stream channels. A few groupings of conifers are sporadically distributed within the mountain alder-mixed willow map unit east of the stream channel. A confined, somewhat incised reach by Station 5+00 exhibits a step-pool type stream, and redosier dogwood is present here as the understory shrub component within the mapped vegetation type.

Reach 4

This reach exhibits a wide, accessible floodplain at grade that is saturated for much of the year, and supports the mountain alder-mixed willow/mesic understory vegetation association. Community types represented by this vegetation association map unit include the Scouler's willow/mesic herbaceous and the starry false-solomon's seal-common horsetail types. Note that at Station 7+00, a fallen Scouler's willow is present, currently providing grade control. A tree canopy composed variously of mountain alder, Pacific and Scouler's willow is underlain by a combination of mesic graminoids and forbs, including common horsetail, small-fruit bulrush, bigleaf sedge, starry false-solomon's seal and an unidentified opposite leaved forb (probably common large monkeyflower (*Mimulus guttatus*), which would have been immature at the time of the survey). Overall health and vigor of the tree canopy is good, with many of the mountain alders exhibiting young new stems. Recruitment of the willow species was not observed.

Adjacent to east of the floodplain, the mountain alder-mixed willow vegetation association exhibits a more open canopy, and differs in that the understory is composed of forbs that may include Fendler's meadowrue (*Thalictrum fendleri*), Anderson's thistle, and stickseed (*Hackelia sp.*). In contrast, the Scouler's willow/conifer and the mountain alder-Scouler's willow vegetation associations exhibit large stemmed Scouler's willow and mountain alder that are elevated above the floodplain. Although no recruitment was noted, the proximity of the mountain alder and Scouler's willow located adjacent to the right bank seems to provide adequate moisture for vigorous growth of these species. Large diameter Jeffrey pine are present here as sources for woody debris in this reach. The Scouler's willow/conifer vegetation association is located to the east of the floodplain and along a remnant stream channel. Greater than 20-inch diameter white fir and Jeffrey pine are present in this type, as well as white fir saplings and seedlings. The Scouler's willow is vigorous, although no recruitment was observed. The RW2 vegetation cross-section identifies six community types within this reach.

Reach 5

The abandoned floodplain supports both the mountain alder-Scouler's willow/conifer encroachment and mountain alder-Scouler's willow vegetation associations. The stream is variously incised from approximately 6 feet at Station 11+00 to 4 feet at Station 17+75, and to almost 15 feet by station 14+00. Pacific willow is no longer present in this section. The mountain alder-Scouler's willow vegetation association is located immediately adjacent to the stream at the top of bank, with semi-continuous canopy still present on the right stream bank. Community types represented by this vegetation association map unit include the Scouler's willow/disturbed herbaceous type that has mountain alder as a component. One portion of the left stream bank is lacking riparian vegetation. Senescent mountain alder exhibits older, large diameter stems dead or dying, and young 1-inch diameter stems replacing them. Scouler's willow appeared vigorous, although no recruitment was noted. The understory varies from primarily leaf litter to moderate cover of stinging nettle, western brackenfern and/or catchweed bedstraw. The mountain alder-Scouler's willow/conifer vegetation association is located adjacent to this type, both to the west and east of the stream. This type is characterized by the presence of white fir and Jeffrey pine saplings and some scattered large diameter Jeffrey pine and white fir individuals. Old, large, multi-stemmed Scouler's willow and mountain alder exhibit several dead limbs and appear as isolated individuals as opposed to continuous or semi-continuous canopy. A windthrown Scouler's willow was apparently cut and felled across the stream at RW3, and several mountain alders east of the stream channel are also windthrown, indicating defunct root systems. If greater than 20 to 30 feet from the stream, these species appear to be dying out and the area is transitioning to an upland, conifer-dominated vegetation type. Large diameter conifers are occasionally present, adjacent to the right bank until Station 11+00, and then again by Station 15+00 on the left bank. Jeffrey pine are present on the left bank just south of Northwood Blvd. These are a potential source of woody debris. RW3 documents four community types present in this reach.

Reach 6

Similar to Reach 4, this reach exhibits a wide, accessible, multi-channeled floodplain at grade that is saturated for much of the year, and supports the mountain alder-mixed willow/mesic understory vegetation association. The community types represented by this vegetation association map unit include the mountain alder-Pacific willow/small-fruit bulrush type, and the mountain alder-mixed willow/mesic herbaceous type. East of the floodplain, and somewhat elevated, the vegetation transitions to the mountain alder/mesic herbaceous vegetation association, characterized in this case by the presence of small-fruit bulrush, rush species (*Juncus spp.*) and Kentucky bluegrass (*Poa pratensis*) in the understory. The willow species and mountain alder exhibit healthy vigorous growth, although no active recruitment was observed. Directly east of this, a stand of Jeffrey pine-white fir occurs, ranging from seedlings to greater than 20-inch diameter mature trees. A secondary channel supports the mountain alder/conifer vegetation association adjacent to the upland edge of the abandoned floodplain. Vigorous mountain alder is rooted in the channel bottom with some willows also present, and Jeffrey pine occurs as saplings 6-10 inches in diameter. A large diameter Jeffrey pine is present on the left side of the stream bank (just south of the foot bridge) and provides a source of woody debris. The RW4 cross-section documents seven community types in this reach.

Reach 7

A narrow riparian corridor dominated by mountain alder occurs adjacent to the stream that incises from 1 to 3 feet below the top of bank. The mountain alder are vigorous and multi-stemmed, with some large- to medium-sized specimens present. The understory is negligible, with a thick duff layer present. In general, the shrub component is absent, but at Station 25+00 a stand of Lemmon's willow is present on the elevated floodplain. Most of the banks in this reach are unvegetated, but do not appear to be undercut and sloughing. South of Station 23+00, a fallen mountain alder provides grade control for the stream. The mountain alder-Scouler's willow/conifer vegetation association is east of and adjacent to the mountain alder vegetation association. This type is characterized by senescing mountain alder and Scouler's willow, and the presence of conifers including white fir, incense cedar and Jeffrey pine. On the eastern edge of the floodplain, a remnant channel supports a stand of Scouler's willow. Large diameter Jeffrey pine and white fir provide woody debris sources just north of the footbridge, south of Station 23+00 on the right bank and at Station 28+00 on the left bank. Note that at approximately Station 28+00, a fallen mountain alder has been removed from the channel. The RW5 cross-section documents six community types in this reach, mostly upland.

Reaches 8 and 9

The elevated floodplain supports the mountain alder-Scouler's willow vegetation association immediately adjacent to the incised stream, with some mountain alders exhibiting at least 25% dead limbs where the stream has deeply incised. The Scouler's willow are vigorous, with some young stems present. Although a few Pacific willow are present, they do not provide sufficient cover to justify calling this a mixed willow type. The RW6 vegetation cross-section documents a small inner floodplain that supports mountain alder, Scouler's and Pacific willow in the overstory, and an understory composed of small-fruit bulrush. East and west of the mountain alder-Scouler's willow vegetation association, the mountain alder-Scouler's willow/conifer vegetation association occurs. This type is characterized by its distance from the stream, the presence of senescent mountain alder and Scouler's willow, and the co-dominant cover provided by sapling and mature Jeffrey pine. A disjunct ribbon of Scouler's willow occupies a remnant channel adjacent to Village Blvd. Large diameter conifers located on the west side of the stream are a potential source of woody debris. The RW6 vegetation cross-section documents seven community types in this reach.

Reach 10

The gentle gradient floodplain and channel support the mountain alder-Scouler's willow/mesic herbaceous vegetation association, with the understory dominated by small-fruit bulrush. Overstory trees are vigorous and display young as well as older, mature stems. Adjacent to this type east and west of the channel, the mountain alder-Scouler's willow/conifer vegetation is present in a narrow band. The mountain alder and Scouler's willow are healthy and vigorous, and the conifers are represented by mature and sapling white fir. Some mature conifers are present in proximity to the channel and provide potential sources of woody debris. The RW7 vegetation cross-section documents four community types in this reach. Note that the Special Status Plant Species Survey documented the presence of Washoe tall rockcress on the northeast corner of Harold Drive and Village Blvd., just west of the stream on old fill material.

Reach 11

Riparian vegetation is lacking along most of this stream reach because the stream was relocated to flow within a stand of mature Jeffery Pine. A short segment of riparian vegetation occurs between Stations 36+20 and 37+00, where the mountain alder-Scouler's willow vegetation association exists, providing continuous, healthy and vigorous canopy cover. A remnant channel to the west of the active stream channel is vegetated by the mountain alder-Scouler's willow/conifer vegetation association. Most of the mountain alder appear to be healthy and vigorous, whereas the older, large-stemmed Scouler's willow are senescing. Jeffrey pine saplings provide the conifer element for this type, and western brackenfern and thimbleberry are present in the herbaceous layer. Large diameter Jeffrey pine adjacent to the left bank and large diameter Jeffrey pine and white fir on the right bank provide sources for woody debris for this reach. The banks of the incised stream exhibit primarily bare soil with pine needle duff present as the litter component. The RW8 vegetation cross-section documents four community types in this reach.

Reach 12

This reach is located on the west side of Village Blvd. and confined by the bike path road into a narrow, incised ditch. Riparian vegetation occurs on the west side of the channel, and is represented by the mountain alder/conifer vegetation association. This vegetation is characterized by young, vigorous mountain alder and the presence of co-dominant white fir. Sierra currant provides some vegetative cover on the stream bank, although the banks exhibit primarily bare soil.

Reach 13

Riparian vegetation in the southern portion of this reach is dominated by the mountain alder/conifer vegetation association relegated to a narrow, continuous band at the top of bank. At the south end of this type, a few Scouler's willow are present, but not enough to map as a separate vegetation unit. White fir is invading the mountain alder stands, with the mountain alders at the same elevation as mature and sapling conifers. The mountain alder is vigorous and healthy, although no recruitment was noted. Approximately at the midpoint of the reach, riparian vegetation is lacking, although a small patch of mesic graminoid characterized by small-fruit bulrush occurs adjacent to the right bank. North of this, the elevated floodplain vegetation is replaced by the mountain alder-Scouler's willow/conifer vegetation association. Mountain alder provide a fairly continuous canopy, sprinkled with a sporadic distribution of Scouler's willow. The health of both these species is vigorous within 15 feet of the stream and declines steadily as they become further removed from the stream. A remnant channel supports the Scouler's willow/conifer vegetation association, with the willow senescing and Jeffrey pine encroaching. A small inner floodplain located at the north end of this reach supports the mountain alder/mesic herbaceous vegetation association. This type is characterized by vigorous, mature mountain alder in the overstory underlain by dense cover of small-fruit bulrush, bigleaf sedge and arrowleaf groundsel (*Senecio triangularis*). Large diameter conifers are available as woody debris source throughout the reach, particularly on the west side of the stream. This is verified by the presence of a >20-inch diameter conifer above Station 49+00 that is currently providing grade control. The east side of the stream is generally shaded by the adjacent steep slope, whereas the west side of the stream gently slopes to the southeast and experiences more direct sunlight. The RW9 and 10 vegetation cross-sections document a total of six community types in this reach.

Reach 14

Riparian vegetation adjacent to the stream is mapped primarily as the mountain alder vegetation association in the lower 2/3 of the reach. This type is characterized by an almost continuous canopy of vigorous mountain alder rooted from the base to the top of bank, and generally within 15 feet of the stream. Sierra currant and thimbleberry (*Rubus parviflorus*) provide some understory shrub cover. A few Lemmon's willow are also present just north of College Drive. The mesic graminoid vegetation association is present at three locations, occurring on inner floodplains. These are characterized by the presence of small-fruit bulrush, sedge species (*Carex spp.*) and American speedwell (*Veronica americana*). The presence of mature Jeffrey pine and white fir intermixed with healthy, vigorous mountain alder provide the basis for the mountain alder/conifer vegetation association located west of the stream in the lower 2/3 of the reach, and on both sides of the stream in the upper third. Sierra currant is often present in the understory, and occasional Lemmon's willow are present on the western periphery of this map unit. A disjunct stand of Scouler's willow exhibiting conifer encroachment is present to the west of the stream near Station 58+50. Large diameter conifers are available as a woody debris source throughout the reach. The RW11 vegetation cross-section documents six community types in this reach.

Reach 15

The mountain alder-mixed willow vegetation association type dominates the lower half of this reach, primarily east of the stream. Pacific and Scouler's willow are variably co-dominant with mountain alder, and within 20 feet of the stream are healthy and vigorous. As distance from the stream increases, senescence of these species occurs. Between Stations 59+00 and 60+00, redosier dogwood provides some riparian shrub cover for approximately 35 feet, where otherwise riparian vegetation is lacking along the right bank. Also in this section, the horticultural shrub Siberian peashrub (*Caragana arborescens*) has naturalized and provides some spot riparian cover. The north portion of this reach exhibits the mountain alder-mixed willow/conifer vegetation association type. Similar to the mountain alder-mixed willow vegetation association type, within 15 feet of the stream the riparian vegetation is generally vigorous. Greater than this distance, health deteriorates and the distribution of these species becomes more sporadic. Mature and sapling Jeffrey pine are present, as well as mature white fir and lodgepole pine (*P.*

contorta). Occasional Lemmon's willow is also distributed throughout this type, adjacent to the stream. North of Station 63+00, the riparian canopy becomes discontinuous on both banks, and white fir and Jeffrey pine become more prevalent. The RW12 vegetation cross-section documents four community types in this reach.

Reach 16

Riparian vegetation in this reach reflects the altered vegetation landscape due to the re-routed stream. The mountain alder vegetation association is prevalent in the southern portion of this reach, located on and at the top of bank in a narrow, 5- to 10-foot wide strip where the stream is within two feet of the top of bank. Mountain alder are vigorous and multistemmed, and the herbaceous layer is variously dominated by common horsetail, graminoids and thick litter. The mountain alder/conifer vegetation association occurs adjacent to this type on the slightly more elevated floodplain, exhibiting seedling, sapling and mature white fir, and mature lodgepole pine. Therefore, a source of woody debris is present within this map unit. The understory consists of some shrubs including Sierra currant, and seeded grasses, stickseed and Fendler's meadowrue in the herbaceous layer. Mountain alder are healthy and vigorous. The mountain alder-Scouler's willow vegetation association is located just below the golf course, elevated above the floodplain and more or less disjunct from the stream. Thick herbaceous cover characterizes the understory, with vetch (*Vicia sp.*), false-solomon's seal, Fendler's meadowrue and various grasses present. Mountain alder occur in more shaded portions of this type, and both it and the Scouler's willow exhibit a range of sapling to old, multiple stemmed individuals, often re-sprouting from downed limbs. The mixed willow/conifer vegetation association is located to the west of the southern portion of the reach, exhibiting assorted willow species including Scouler's, Pacific and Lemmon's willow. These willow species vary from vigorous to senescent. A few dead and/or dying mountain alder are also present. Conifers include sapling and large diameter Jeffrey pine, and large diameter lodgepole pine and white fir. The understory consists of seeded grasses and western brackenfern in some areas. The Scouler's willow/conifer vegetation association occurs in a disjunct stand at about the midpoint of the reach, located within a series of old channels. Mesic forbs dominate the herbaceous understory, and Sierra currant and Sierra gooseberry (*R. roezlii*) are present in the shrub layer. Note that a few sections along the right bank, from Station 69+00 to 71+00, lack consistent riparian vegetation and are deeply incised. Occasional mountain alder and Scouler's willow provide intermittent riparian cover. The RW13 and 14 vegetation cross-sections document seven community types in this reach.

Reach 17

The mountain alder-Scouler's willow/conifer vegetation association prevails in this reach, relegated to a 12-foot wide strip on each bank. Scouler's willow and mountain alder are rooted from the base to the top of bank, and are healthy and vigorous. White fir seedlings and saplings represent the conifer element of this vegetation type. A stringer wetland vegetated by sedge species is intermittently present at the normal high water mark within this reach. The RW15 vegetation cross-section documents three community types for this reach.

Special Status Plant Species

Washoe tall rockcress, a LTBMU Species of Interest, was encountered at the northeast corner of Harold Drive and Village Blvd., just west of Rosewood Creek. Six individuals of this special status plant species were present in an open, somewhat disturbed area located approximately 10 feet from the roadway and within the Jeffrey pine-white fir vegetation association. Species identification was verified by Jim Morefield, NNHP botanist and a subsequent site visit verified identifiable vegetative characteristics.

6. Discussion

Riparian Plant Community Health

Role of Disturbance

Disturbance processes within the fluvial environment play an important role in the establishment and maintenance of riparian vegetation communities. Riparian vegetation communities develop as the result of elevation, climate, soils, and valley bottom gradient and width. Although these riparian area features are fairly stable over time, a continual physical adjustment occurs between a stream and the associated bank margins and floodplain. The regeneration of riparian plant species demonstrates co-evolution with these erosional and depositional fluvial processes. For example, the willow family (*Salicaceae*) regenerates on disturbed soils and in openings, taking advantage of little or no competition from other plant species for soil moisture, sunlight and nutrients. Table 15 presents vegetation attributes with regards to regeneration, site characteristics and general comments for the common riparian species encountered in the study area (Manning and Padgett, 1995; Brunsfeld and Johnson, 1985; Weixelman et al., 1999 and ALLREF.com, 2005).

Vegetation Associations and Ecological Ramifications

The main impact of the channel incision process to riparian vegetation has been, and will continue to be, the lowered water table. Reduced water availability to plants has resulted in a loss of wood recruitment, reduction of canopy cover and eventual plant senescence. Without inundation of the floodplain, the essential cycles of flooding, scouring and deposition are not present to regenerate riparian species. The existing vegetation exhibits a variety of responses to these altered conditions. The responses of vegetation, as categorized by plant association within the study area, are described in Table 16.

Influence of Vegetation and Woody Plants on Stream Geomorphic Character

There is no evidence available that would describe the pre-Comstock condition of small Lake Tahoe tributary streams like Rosewood Creek. It is hypothesized here that streams like Rosewood Creek probably flowed in small, multiple channels distributed throughout a narrow floodplain. It is likely that the channels were relatively small and the floodplains readily inundated, contained between adjacent high ground. Where boulders or bedrock were not present, large woody material and vegetation probably played a major role in determining channel condition. Large woody material probably maintained channels at grade. At the same time, wood and vegetation were likely responsible for rapid shifts in channel location. It is hypothesized here that decadent pines would fall from the adjacent higher ground into the floodplain, serving alternatively to control grade and to redirect short reaches of channel. Willow, dogwood and alder would grow prolifically along the channel margins and in adjacent low areas. Downed tree branches and trunks in the channel and shrubs on banks would slow flow, collect sediment and accumulate additional woody material. In some locations, this would serve to control grade, cause local aggradation and restrict the migration of the stream within the relatively narrow floodplain. In other locations, the woody debris would serve to dam and redirect flow, causing rapid shifts in channel location. The channel would flow through another part of the vegetated floodplain, its progress slowed by other woody

Table 15. Riparian plant species attributes of Rosewood Creek.

Plant Species	Regeneration Processes	Site Characteristics	Comments
Mountain alder	Wind and waterborne nutlets; re-sprouts from root crown following low severity fire; re-sprouts from cut stump or top removal by beaver	Seasonally flooded, water table within 3 feet of surface year round; scouring and deposition; shade to partial shade; most often occur adjacent to well-armored channels	Fixes nitrogen; early to mid seral; long-lived
Pacific willow	Windborne seed; re-sprouts from subterranean root crown following fire or cutting; brittle stems deposited on moist alluvium sprout	High water table year round	Early seral; repeated flooding allows persistence
Scouler's willow	Windborne seed; re-sprouts from subterranean root crown in response to fire, flood, mechanical damage	Seasonal flooding; depth to water table > 100cm; prefers open, sunny locations	Early to mid seral; often a response to clearcutting; can indicate transition from riparian to upland vegetation communities
Redosier dogwood	Seeds dispersed primarily by songbirds, and also bear, mice, grouse, quail, ducks, cutthroat trout; layering of lower stems; new shoots from roots and new branches from base of dying branches	Rich moist soils with high mineral component over 20 inches deep; sand, sandy loam, and loam preferred soils; tolerates flooding; moderate to full sun	Can tolerate extreme cold; when several years old can live with roots submerged for most of the growing season; early to mid seral
Lemmon's willow	Windborne seed	Depth to water table 44->100cm; coarse textured soils moist to wet during the growing season; abandoned channels and dry portions of riparian zone	

Table 16. Description of responses of vegetation by plant association to riparian impacts within the study area.

MOUNTAIN ALDER

Reach: 7, 13, 15 and 17

Landscape Position: Adjacent to the stream on slight- to moderately-elevated floodplain.

Hydrology: Water table accessible, some grade controls present, stream within 1-3 feet of the top of bank, seasonal flooding inconsistent.

Health/Regeneration: Vigorous and healthy, multi-stemmed, mature mountain alder, not consistent for riparian shrub species.

Explanation: Mature mountain alder are supported by the available hydrology that the fairly stable stream provides. Continuous riparian cover is present with the exception of Reach 13, where a younger age class of mountain alder indicates initial colonization of this reach. Variations in the understory include thick litter with/without some herbaceous growth (Reaches 7 and 17) to some understory shrub cover consisting of thimbleberry, Sierra currant and Lemmon's willow (Reaches 13 and 15).

Seral Stage: Early seral based on lack of understory shrub or herbaceous cover that would indicate a more advanced seral stage. This is most similar to the Manning and Padgett (1995) mountain alder/bench community type, which both they and Winward (2000) classify as early seral. The absence of redosier dogwood as a principle shrub component may be explained as a chance occurrence given that this vegetation association occupies sites similar to the mountain alder/redosier dogwood community type (Manning and Padgett 1995).

Long-term Prognosis: If adjacent stream reaches are stabilized, then consistent annual flooding, scouring and deposition may convert these to a longer lived, late seral community type that would support redosier dogwood, and also promote consistent regeneration of the mountain alder. Otherwise, this type may or may not persist dependent on up or downstream incision affecting hydrology for this vegetation type.

Function: Mountain alder root systems stabilize banks in these reaches.

MOUNTAIN ALDER/CONIFER

Reach: 6, 14, 15 and 17

Landscape Position: Elevated floodplain in Reach 6, this vegetation type in an abandoned stream channel laterally displaced from the existing stream; in Reach 14, channel is actively incising; in Reaches 15 and 17, channels are fairly stable.

Hydrology: Water table accessible, seasonal flooding inconsistent.

Health/Regeneration: Mountain alder healthy and vigorous, no recruitment observed.

Explanation: Incision, relocation of the stream through upland habitat, abandonment and/or lateral migration of prior stream channel system have resulted in elevational and/or lateral distance from the stream proper. Greater depth to the water table promotes the growth of conifers as opposed to riparian vegetation.

Seral Stage: Early seral type based on presence of conifers.

Long-term Prognosis: This type is characterized by the encroachment of Jeffrey pine and/or white fir into mountain alder stands, indicating transition towards an upland environment. Should the channel continue to incise in Reach 14, this type will continue its evolution to a conifer-dominated vegetation type, as will the occurrence in Reach 6. In Reaches 14, 15 and 17, this type may persist unless the mature conifer component is allowed to contribute woody debris to the system that may encourage an increased abundance of riparian vegetation.

Function: Adjacent to the stream, mountain alder stabilizes stream banks. This function will be lost in reaches that are incising, and become dominated by conifers. Mature conifers provide a source of woody debris for the stream.

MOUNTAIN ALDER-MIXED WILLOW

Reach: 1, 2, 3 and 16

Landscape Position: Floodplain in Reach 1; wide, inaccessible floodplain east of Reaches 2, 3 and 6.

Hydrology: Perennial and seasonal flooding in Reach 1; lowered water table in Reaches 2, 3 and 16.

Table 16. Description of responses of vegetation by plant association to riparian impacts within the study area.

Health/Regeneration: Riparian vegetation throughout Reaches 1-3 appear vigorous and healthy; in Reach 16, willow species and mountain alder health deteriorate if greater than 20 feet from the stream.

Explanation: In Reach 1 an inset floodplain provides perennial and seasonal flooding for immediately adjacent riparian species. One explanation for the healthy state of the riparian vegetation in Reaches 2 and 3 may be a combination of the age class of riparian vegetation, microtopography and the above normal precipitation received during the late fall of 2004 through spring of 2005. The mountain alder and willow species are mature and multi-stemmed with well-developed, deep root systems that can reach the lowered water table. Also, several relic channels convey surface runoff southward, and provide topographic lows that can continue to provide the riparian species with adequate soil moisture. More surface runoff than usual from surrounding development, a lateral charge from the both the stream and the upper, saturated floodplain in Reach 4, and the presence of the SR 28 roadbed effectively acting as a barrier to prevent soil water moving down-gradient of the highway serve to saturate the rooting zone during wet years. In Reach 16, a higher gradient channel may not permit sufficient lateral migration of soil water to charge the water table that would support a wider band of riparian vegetation. It appears that the stream channel may have migrated westward or was altered during urbanization, leaving the riparian vegetation to the east in this reach high and dry.

Seral Stage: Late seral type due to the dominant mesic understory herbaceous components that are rated as late seral. While this vegetation type is most similar to the Manning and Padgett (1995) mountain alder/bench community type, which both they and Winward (2000) classify as early seral, the differences in understory composition account for a different interpretation. According to this classification, cover contribution by mountain alder is typically 50-90%, sometimes only 20%; Pacific willow varies from 0-10%, and for Scouler's willow from 0-25%.

Long-term Prognosis: Riparian vegetation in Reach 16 will probably contract to a more confined strip along the east side of the stream. If the stream continues to incise in the lower reaches, riparian tree species may not be able to access the water table. Given that flooding, scouring and deposition are no longer active processes on most of these floodplains, regeneration of these species and hence viability seems unlikely. Therefore, it is probable that this vegetation type will contract, and the eastern edges convert to upland environments.

Function: The ability of mountain alder, Pacific and Scouler's willow to provide bank stabilization through rooting is compromised by continued incision. These species may also provide a source of woody debris.

MOUNTAIN ALDER-MIXED WILLOW/CONIFER

Reach: 16

Landscape Position: Elevated floodplain.

Hydrology: Water table accessible adjacent to stream; water table has lowered more than 20 feet.

Health/Regeneration: Senescence of mature willows and mountain alder greater than 20 feet from the stream; recruitment not observed.

Explanation: The senescence of mature willows and mountain alder greater than 20 feet from the stream coupled with the encroachment of conifers suggests a contraction of the riparian corridor is in progress. Possibly either a multiple, defined, shallow channel system or a spreading, shallow floodplain associated with a single channel has been converted to a confined channel system through urbanization.

Seral Stage: Early seral type given the presence of conifers.

Long-term Prognosis: Perennial water is present, so the existing riparian vegetation within 15-20 feet of the channel should persist. Where greater than this distance from stream, vegetation will eventually transition to an upland environment.

Function: Riparian plant species including mountain alder and willows stabilize stream banks by extensive, deep rooting, and may also be a source for woody debris. Conversion to uplands will lose this function. Mature conifers provide a source of woody debris for the stream.

Table 16. Description of responses of vegetation by plant association to riparian impacts within the study area.

MOUNTAIN ALDER-MIXED WILLOW/MESIC UNDERSTORY

Reach: 4 and 6

Landscape Position: Floodplain.

Hydrology: Perennial and seasonal flooding.

Health/Regeneration: Vigorous, mature mountain alder, Pacific and Scouler's willow; new stems and some saplings observed.

Explanation: In Reach 4 grade control is provided by a downed willow near Station 7+00, allowing water to back up and spread upstream. In Reach 6, presence of this vegetation type upstream from the culvert suggests that the culvert is undersized for high flows or was placed above grade, causing sediment deposition and the subsequent development of multiple channels that result in a spreading area.

Seral Stage: Late seral type, given the presence of stabilizing, later seral herbaceous components.

Long-term Prognosis: This type has elements common to Manning and Padgett (1995) mountain alder/mesic forb and mountain alder/mesic graminoid community types, which Winward (2000) would tend to classify as late seral given that 20-25% of the understory are later successional species. This vegetation type should regenerate and persist.

Function: The overstory composed of mountain alder and willows stabilize the banks and provide a source of woody debris, while small-fruit bulrush and sedges act as sediment stabilizers.

MOUNTAIN ALDER-SCOULER'S WILLOW

Reach: 4, 5, 6, 8, 11 and 17

Landscape Position: Slightly elevated floodplain of Reaches 4 and 6; top of bank on elevated, inaccessible floodplain adjacent to incised Reaches 5, 8 and 11; displaced laterally on elevated floodplain of Reach 17.

Hydrology: Seasonal flooding Reaches 4 and 6; lowered water table Reaches 5, 8, 11 and 17.

Health/Regeneration: Riparian vegetation healthy and regenerating in Reaches 4 and 6; healthy, regeneration not observed in Reaches 5, 8 and 11; healthy and regenerating Reach 17.

Explanation: Mature mountain alder and Scouler's willow have deep reaching root systems that can reach the lowered water table resulting from incision in Reaches 5, 8 and 11. In Reach 17, this vegetation type represents a disjunct remnant of the riparian zone that has been separated from the stream proper due to stream relocation. It is postulated that the continued health of these riparian species at this location is dependent on the lateral migration of stream water charging the water table and supplemental runoff from the adjacent golf course to the north.

Seral Stage: Early seral type, given the presence Scouler's willow and disturbance at these locations.

Long-term Prognosis: Long-term viability of mountain alder adjacent to the incised stream is not probable without the cycles of flooding, deposition and scouring. Scouler's willow has a wider ecological amplitude than mountain alder, and generally occurs on drier sites in the riparian zone. It is shade intolerant, and has been noted in forest openings that are transitioning to upland habitats. Therefore, it may persist longer than the mountain alder in this setting. Continued incision will convert this type to the mountain alder-Scouler's willow/conifer type. Viability of this type in Reach 4 and 6 is better as the channel is not deeply incised these reaches.

Function: Bank stabilization provided by mountain alder and Scouler's willow is at risk in Reaches 5, 8 and 11. This function is viable in Reaches 4 and 6. This vegetation type as disjunct riparian in Reach 17, and is a source for riparian plant materials, and possibly ameliorates occasional floodwaters from the stream, and surface runoff from the golf course.

MOUNTAIN ALDER-SCOULER'S WILLOW/CONIFER

Reach: 5, 7 through 11, 14, 17 and 18

Landscape Position: On elevated floodplain displaced laterally from the stream channel in Reaches 5 and 7 through 11; on elevated floodplain adjacent to stream in portion of Reach 8, and Reaches 14, 17 and 18.

Hydrology: Lowered water table in Reaches 5, 7 through 11 and 14; water table accessible Reaches 17 and 18.

Table 16. Description of responses of vegetation by plant association to riparian impacts within the study area.

Health/Regeneration: Scouler's willow and some mountain alder senescing in Reaches 5, 7 through 11 and 14; willow healthy in Reaches 17 and 18.

Explanation: Increased depth to water table attributable to alteration of original flow patterns and hydrology as indicated by presence of old channels, berms and disjunct riparian vegetation in Reaches 5, 7 through 11 and 14, with stream incision as the result. In the upper portion of Reach 17 and all of 18 the channel is confined and stable, allowing these riparian species to access the water table.

Seral Stage: Early seral type based on presence of conifers and Scouler's willow as dominants.

Long-term Prognosis: Conifers are present as both mature and sapling Jeffrey pine and white fir for the most part, indicating eventual conversion to an upland environment dominated by conifers in Reaches 5, 7 through 11 and 14 as riparian area contracts.

Function: The ability of mountain alder and Scouler's willow to stabilize stream banks is declining in Reaches 8 and 14 where the stream is actively incising, and is at risk in Reaches 17 and 18 by incision downstream. Mature conifers provide a source of woody debris for the stream.

MOUNTAIN ALDER/MESIC HERBACEOUS

Reach: 6 and 14

Landscape Position: Adjacent to or within floodplains located at channel grade.

Hydrology: Permanent and/or seasonal flooding.

Health/Regeneration: Healthy, viable mountain alder.

Explanation: For mountain alder to persist in this seemingly flooded environment, well-drained soils and sufficient gradient must be present to maintain aerobic conditions.

Seral Stage: Late seral type due to presence of mesic graminoids. This type is most similar to the mountain alder/mesic graminoid community type described by Manning and Padgett (1995) and also classified as late seral by Winward (2000) given the high percent cover of small-fruit bulrush present.

Long-term Prognosis: While it is likely that the annual dynamics of flooding, scouring and deposition will alter the understory composition, mountain alder will remain rooted in the lower banks and continue to stabilize the stream channel.

Function: Mountain alder stabilize the stream banks and provide a source of woody debris, while the mesic graminoid component acts as sediment stabilizers.

MIXED WILLOW/CONIFER

Reach: 17

Landscape Position: Elevated floodplain laterally displaced from stream.

Hydrology: Accessible to inaccessible water table.

Health/Regeneration: Highly variable.

Explanation: This highly altered area no longer has the hydrology to support consistent riparian vegetation due to relocation of the stream.

Seral Stage: Early seral type given the dominance of conifers and Scouler's willow, and past disturbance at this location.

Long-term Prognosis: The drier portions of this type that are farthest from the water table will eventually convert to conifer-dominated uplands, while topographic lows, areas adjacent to roadways that receive enhanced runoff and that are nearer the stream and hence experience a higher water table will persist as mixed willow riparian vegetation.

Function: Disjunct riparian vegetation is a source of planting stock.

SCOULER'S WILLOW

Reach: 7 and 9

Landscape Position: In abandoned channels on elevated floodplains displaced laterally from stream channel.

Hydrology: Water table accessible

Health/Regeneration: Healthy and regenerating.

Explanation: This type indicates an altered landscape due to clearcutting, and stream migration or rerouting. The microtopography provided by the topographic lows allows capture of surface runoff, and subsequent development of deep root systems that can access the water table. This species' ability to colonize marginal riparian habitat that is drier, open, and sunny is accommodated by the timber harvest practiced until the 1970s in this area.

Seral Stage: Early seral type based on willow species habitat preferences.

Long-term Prognosis: This vegetation type may indicate a transition from a riparian to an upland environment, and may eventually convert to Scouler's willow/conifer vegetation type.

Function: None for Rosewood Creek. May be a source for revegetation plant materials.

SCOULER'S WILLOW/CONIFER

Reach: 4, 5, 14, and 17

Landscape Position: On elevated floodplains displaced laterally from stream channel.

Hydrology: water table accessible in Reaches 4, 5, and 17; water table inaccessible in Reach 14

Health/Regeneration: Healthy in Reaches 4, 5 and 17; senescing in Reach 14.

Explanation: In Reach 4 and 5, this vegetation association occurs adjacent to the floodplain and in an abandoned channel. The water table is laterally charged by the floodplain seasonal waters, and surface runoff and snow pack are concentrated in the abandoned channel. Depth to the water table is beyond the reach of the Scouler's willow rooting system in Reach 14. This is likely due to relocation and/or channel migration in Reach 14. In Reach 17, this type occurs in abandoned channels but apparently these topographic lows hold snow pack and receive enough surface runoff to sustain healthy willows.

Seral Stage: Early seral type given the co-dominance of conifers and Scouler's willow.

Long-term Prognosis: Eventually this type will convert to a conifer dominated upland environment.

Function: Mature conifers provide a source of woody debris for the stream in Reaches 4, 5 and 14.

MESIC GRAMINOID

Reach: 1, 2 and 15

Landscape Position: Inset floodplain.

Hydrology: Permanent and seasonal flooding.

Health/Regeneration: Continual flooding, scouring and deposition allow the continued regeneration of these species.

Explanation: The low gradient spreading areas allow the accumulation of sediments that can become colonized by mesic graminoid plant species.

Seral Stage: Late seral type given the late seral ratings of bigleaf sedge and small-fruit bulrush.

Long-term Prognosis: In Reaches 1 and 2, higher elevations of the inset floodplain are vegetated by redosier dogwood, suggesting conversion to a riparian instead of wetland habitat.

Function: The root systems of mesic graminoids stabilize sediments.

MOUNTAIN ALDER-SCOULER'S WILLOW/MESIC HERBACEOUS

Reach: 10

Landscape Position: Floodplain.

Hydrology: Perennial and seasonal flooding.

Health/Regeneration: Healthy and viable riparian species.

Explanation: The presence of this vegetation type upstream from the culvert suggests that the culvert is undersized for high flows or that the culvert was installed above grade, and that deposited sediment and the subsequent development of multiple channels support this vegetation type.

Seral Stage: Late seral type given late seral ratings of the herbaceous understory.

Long-term Prognosis: Stability of this vegetation type at this location is unknown. High flow may scour the understory and remove the mesic forb component. The overstory mountain alder and Scouler's willow

Function: Mountain alder and Scouler's willow stabilize stream banks through extensive rooting, and also provide a source of woody debris. The root systems of the mesic graminoid component stabilize sediments.

debris littering the floodplain. These channel adjustments would be relatively rapid but small-scale shifts in channel location. The new channel might be locally unstable, but this instability would not persist for long. In a short period of time, the flowing water would shape the channel dimensions. In essence, then, the single and multiple threads of channel flowing across the floodplain were both controlled by and caused by large woody materials and shrubby vegetation.

If this were the dominant channel forming process, it would have been dramatically altered by timber harvest and land use. Harvest of large trees has reduced the potential for regular recruitment of downed trees in the floodplain; these trees would otherwise persist for decades. Furthermore, the clearing of brushy vegetation by property owners, in order to improve aesthetic values, has diminished the potential geomorphic function of this vegetation. Lastly, incised channels often exhibit reduced groundwater levels in adjacent riparian areas, which in turn diminish the vigor of riparian plant communities. The resulting changes in riparian plant condition may adversely affect the geomorphic role of plants and woody material.

Channel Stability Trends

Channels in dynamic equilibrium are those that exhibit a balance of flow conveyance and sediment continuity with channel geometry and floodplain connectivity. Such streams exhibit varying degrees of spatial and temporal changes in planform, profile and cross-section in response to hydrologic events and natural watershed events (such as fire). As a consequence, streams in equilibrium may show evidence of small to moderate scale adjustments (such as bank erosion and sediment deposition) as well as periodic large-scale adjustments (such as channel avulsion). Channels in dynamic equilibrium tend to return to an equilibrium state (that is, a background level of channel adjustment) following large-scale events.

Much of Rosewood Creek within the study area is not in dynamic equilibrium. Changes in land use in the last 50 years have increased the amount of impervious surface and focused overland flow patterns. As a result, the hydrology of Rosewood Creek exhibits higher peak flows, more frequent peak flows and more flashy flows. This altered hydrologic regime has, in turn, affected the channel processes by increasing the magnitude and frequency of erosional forces.

Concurrently, land use had reduced the recruitment of both large woody material (that is, large trees falling into the floodplain) and the composition and vigor of the riparian plant community. Prior to human disturbance, large woody material and riparian vegetation served to resist the erosional forces of flowing water and contributed to maintaining conditions of dynamic channel equilibrium. Without the resistant function of wood and plants, coupled with an increase in peak flow frequency and magnitude, reaches of Rosewood Creek have incised.

Channel incision has been described as the evolutionary process of channel downcutting, widening and eventual re-establishment of a channel within an inner floodplain. The re-established channel commonly exhibits dimensions similar to those of the pre-incision state, although the re-established floodplain is typically narrower than previously exhibited. The process of channel incision and subsequent stabilization is complex. The rate and magnitude of adjustment and re-established stable conditions may proceed rapidly (numbers of years) to slowly (hundreds of years), depending on climate and geology (both of which affect plant re-establishment, which is a key driver). The rate of adjustment of Rosewood Creek is likely measured on the order of decades.

Non-incised reaches of Rosewood Creek generally exhibit stable planform and cross-section dimensions, largely because these reaches have been locked into place by rock riprap along stream banks and rock grade controls spanning the channel. These reaches have lost varying degrees of geomorphic function (e.g., channel adjustment and frequent floodplain inundation). Some are also at risk of catastrophic adjustment (avulsion and incision) should reaches of rock-controlled channel fail during a high flow event.

Thus, the potential future instability of reaches of Rosewood Creek within the study area fall into two categories: 1) continued progression of channel incision and 2) potential catastrophic adjustment resulting from a high flow. Those reaches identified as exhibiting incision and those with the potential for rapid adjustment are listed in Table 17. The stream reaches have been be qualitatively ranked according to potential for future adjustment and instability. Those in the early stages of incision are ranked the highest potential whereas those with rigid boundaries are ranked lower. The potential for adjustment has been assigned based on the stage of incision (relative to the channel evolution model), the potential for upstream incision migration (for incised reaches) and the apparent integrity of bank protection and the potential for avulsion (for rigid boundary reaches).

SEZ restoration planning should take into account the potential for future instability. Assuming that the primary objective of restoration planning is to minimize adverse impacts to Lake Tahoe water quality (and secondarily SEZ health and function), then SEZ restoration should focus on reaches with the highest potential for sediment delivery. Thus, stream reaches with a high potential for instability should be addressed first, acknowledging that some more stable contiguous reaches may need to be addressed to provide for continuity within an SEZ restoration plan. Table 18 provides a grouping of stream reaches according to the potential for instability (based on the data within Table 17).

Table 17. Stream reaches within the study area and the potential for future instability.

Reach No.	Station			Reach Characteristics			
	Begin		End	Distance (ft)	Potential for Continued Future Incision	Potential for Catastrophic Adjustment	Basis
1	0+00	to	2+90	290	Moderate	Low	Active incision
2	2+90	to	4+15	125	Moderate	Low	Active incision
3	4+15	to	6+00	185	Very High	Low	Active early stage incision
4	6+00	to	8+80	280	Very High	Low	High potential to be affected from upstream migrating incision
5	8+80	to	17+75	895	Very High	Low	Active early stage incision and high potential to be affected from upstream migrating incision
6	18+50	to	22+10	360	Low	Low	Aggraded but confined reach
7	22+10	to	28+50	640	Low	Low	Stable reach with bed stability controlled by colluvial rock in channel
8	28+50	to	31+00	250	Low	Low	Stable reach
9	31+00	to	32+90	190	Low	Low	Stable reach
10	33+30	to	34+50	120	Low	Low	Stable reach
11	34+50	to	37+00	250	High	Moderate	Active early stage incision and high potential for avulsion to former channel
12	37+72	to	41+20	348	Low	Low	Confined by road
13	43+20	to	50+15	695	Very High	Low	Active early stage incision
14	51+70	to	58+90	720	Low	Low	Bed controlled by stable rock grade controls
15	58+90	to	65+50	660	Moderate	High	Riprapped; channel location is forced, riparian vegetation has been removed with risk of avulsion and incision
16	66+15	to	72+30	615	Moderate	Moderate to High	Riprapped; channel location is forced and incision has occurred in some subreaches
17	72+30	to	74+70	240	Low	Moderate	Riprapped; potential for avulsion to valley low point (in golf course)

Table 18. Stream reaches grouped by potential for adjustment.

Reach No.	Station			Reach Characteristics				
	Begin		End	Distance (ft)	Potential for Continued Future Incision	Potential for Catastrophic Adjustment	Highest Ranking	Subtotal Channel Length (ft)
3	4+15	to	6+00	185	Very High	Low		
4	6+00	to	8+80	280	Very High	Low		
5	8+80	to	17+75	895	Very High	Low		
13	43+20	to	50+15	695	Very High	Low	Very High	2,055
11	34+50	to	37+00	250	High	Moderate		
15	58+90	to	65+50	660	Moderate	High		
16	66+15	to	72+30	615	Moderate	Moderate to High	High	1,525
1	0+00	to	2+90	290	Moderate	Low		
2	2+90	to	4+15	125	Moderate	Low		
17	72+30	to	74+70	240	Low	Moderate	Moderate	655
6	18+50	to	22+10	360	Low	Low		
7	22+10	to	28+50	640	Low	Low		
8	28+50	to	31+00	250	Low	Low		
9	31+00	to	32+90	190	Low	Low		
10	33+30	to	34+50	120	Low	Low		
12	37+72	to	41+20	348	Low	Low		
14	51+70	to	58+90	720	Low	Low	Low	2,628

7. SEZ Restoration Opportunities

Prior Restoration Plans for Study Area

Previous assessments of Rosewood Creek have included generalized recommendations for improving channel stability upstream of SR 28 (US. Army Corps of Engineers, 2004; ENTRIX, 2001 and Swanson 2000). The U.S. Fish and Wildlife Service undertook a rapid bio-assessment of most of the present study area of Rosewood Creek and provided some reach-based recommendations (US. Army Corps of Engineers, 2004). Although the reaches were not mapped, the written description allowed a comparison of their reaches with those of the current study (Table 19). The assessment reflected marginal to suboptimal channel conditions throughout the study area. Conceptual stream restoration recommendations included:

- Widen the channel by laying back banks;
- Reconnect the stream to the floodplain; and
- Return the stream to its original channel.

Although these concepts may be valid, the recommendations did not account for the ongoing geomorphic processes (e.g., incision).

ENTRIX (2001) provided the most thorough recommendations for stream restoration to date. Three approaches to restoration were addressed:

1. Reconstruct the channel at a pre-incision elevation in order to provide a hydrologic reconnection of the stream with the pre-incision floodplain;
2. Create an inner floodplain around a reconstructed channel; and
3. Stabilize the channel in place.

The advantages of these approaches included the various levels of channel and floodplain stability and ecological function that could be provided. The disadvantages included potential flooding of buildings, impacts to existing vegetation and the degree of earthwork required. All of the approaches included the placement of rock grade controls extending across a portion of the valley width to provide vertical channel stability. No single approach was recommended.

In an earlier assessment (Swanson, 2000), recommended stabilization measures for Rosewood Creek upstream of SR 28 included:

- Installation of rock weirs to control gradient;
- Regrading and revegatating stream banks; and
- Installation of rock slope protection and retaining structures.

A valley-wide grade control and drop structure was recommended for Rosewood Creek at the lower end of the study area (likely near Station 3+00).

Suggested Restoration Philosophy

Based on the goal of this study, the primary objective of SEZ restoration within this reach of Rosewood Creek is to address sediment issues in order to improve water quality. Optimally, satisfying this primary objective will achieve a several secondary objectives including, but not limited to:

Table 19. Results of rapid bio-assessment and restoration recommendations, prepared by others (from US. Army Corps of Engineers, 2004). Reach locations are compared to those of the current study.

Reach No.	Station Begin		Station End	Distance (ft)	USACOE/USFWS Reach No.	USFWS Reach Score (of 200 Possible)[1]	USACOE/USFWS Restoration Recommendations
1	0+00	to	2+90	290	RC-1	67	Clear non-native vegetation. Widen channel at D/S by laying back banks.
2	2+90	to	4+15	125	RC-1	67	
3	4+15	to	6+00	185	RC-1	67	
4	6+00	to	8+80	280	RC-2A	92	Plant vegetation and clear woody debris from channel.
5	8+80	to	17+75	895	RC-2A and -2B	92 and 94	Reconnect stream to floodplain and remove encroached conifers.
6	18+50	to	22+10	360	RC-2B	94	
7	22+10	to	28+50	640	RC-2C and -2D	141 and 113	Maintain culverts and limit public use. Plant vegetation.
8	28+50	to	31+00	250	RC-2D	113	Limit public use. Plant vegetation.
9	31+00	to	32+90	190	RC-2D	113	
10	33+30	to	34+50	120	RC-3A	111	Return stream to original channel.
11	34+50	to	37+00	250	RC-3A	111	
12	37+72	to	41+20	348	RC-3B, -3C and -3D	49, 105 and 106	No Recommendations
13	43+20	to	50+15	695	RC-3E	98	Maintain culverts and clear woody debris from channel.
14	51+70	to	58+90	720	N/A	N/A	N/A
15	58+90	to	65+50	660	N/A	N/A	N/A
16	66+15	to	72+30	615	N/A	N/A	N/A
17	72+30	to	74+70	240	N/A	N/A	N/A

[1]Ranking:

Optimal = >160

Suboptimal = 110 to 159

Marginal = 56 to 109

Poor = 0 to 55

- Improve the quality of the riparian plant communities;
- Raise the potentiometric surface adjacent to the stream;
- Improve aesthetics and recreational opportunities; and
- Reduce maintenance.

SEZ restoration should provide some functional stabilization to the reaches of Rosewood Creek that are now unstable. Functional stabilization means establishing conditions to provide the following:

- Channel conveyance of flow and sediment;
- Frequency of floodplain inundation to support riparian plant communities; and
- Disturbance-induced conditions so that riparian plants that depend on such processes can regenerate.

SEZ restoration should also address providing stabilization of stream reaches that are at risk, but that do not presently show evidence of erosion. These reaches are those in the upper portion of the study area that are susceptible to avulsion.

Finally, SEZ restoration should also address the problems that have caused the reach-wide incision. This assessment suggests that incision is largely a result of altered watershed hydrology and the removal of woody vegetation from within the floodplain. Solutions to these impacts would largely focus on:

- Managing, from onsite, the impervious surface stormwater runoff (to reduce the unnatural hydrologic regime); and
- Reestablishing and maintaining vigorous and functional riparian plant communities (through replanting, removal of encroaching vegetation, and implementation of riparian land use management plans).

Restoration Opportunities

This section provides descriptions of a variety of floodplain and channel restoration measures that might be applicable to portions of Rosewood Creek. These descriptions are conceptual in nature and are written to describe objectives, techniques, methods and programs that might be used within various reaches of the study area. These measures are not site- or reach-specific; rather, recommended actions for specific locations are addressed in a subsequent section.

Reconnect Floodplain

Streams in dynamic equilibrium are those that exhibit balanced channel geometry and floodplain connectivity. Flow in streams in equilibrium tends to overtop the banks and inundate floodplains on a frequent basis. Most undisturbed high elevation streams with a snowmelt-driven hydrology have channel bankfull capacities with recurrence intervals of about 2 years and flow exceedances of about 2 percent (7 to 10 days per year). It is this periodic inundation that serves to maintain floodplain functionality, supporting a variety of hydrologic, geomorphic and biologic processes.

High flow and floodplain inundation serve to recharge the groundwater adjacent to the stream. Water is stored in the stream banks; the water that is gradually released serves to maintain base flow (Rorabaugh, 1963; Rorabaugh and Simons, 1966 and Rorabaugh et al., 1966). Floodplain inundation also promotes and maintains the hyporheic zone, the zone of surface water influenced groundwater.

Periodic floodplain inundation also involves several geomorphic processes. Fine sediments are deposited by flowing water on the floodplain surfaces, bringing both nutrients and growing surfaces to plants. Disturbance of stream banks and floodplain surfaces redistributes sediments, providing a growing medium for plants whose reproduction and distribution occur by seed germination or rhizome growth keyed to disturbed conditions. Cottonwoods are an example of plants that regenerate by seed germination on disturbed surfaces, whereas willows have evolved to tolerate disturbance conditions that other plants cannot.

These hydrologic, geomorphic and biologic floodplain processes are intricately linked. One of the primary objectives of the restoration of incised channels, therefore, is to re-establish these processes and re-create a functional floodplain and riparian ecosystem.

The physical process of reconnecting an incised stream to its floodplain typically takes one of three forms:

1. Filling the incised channel to raise the bed so it is nearer to the elevation of the existing floodplain;
2. Lowering the surrounding floodplain surface so it is nearer to the elevation of the stream channel; or
3. A combination of filling the channel and cutting the floodplain surface.

In all of these scenarios, reconstruction or stabilization of the channel (described below) is typically warranted. Reconnection of the channel to the original floodplain surface is the most desirable course of action when it is culturally and ecologically feasible (Fischenich and Morrow, 2000), as well as economically justifiable. There are obvious conflicts that can potentially arise with allowing the full recovery of incised streams, such as channel migration, overbank flooding, loss of streamside property, and damage to buildings and infrastructure (from flooding or channel migration).

The choice to fill an incised channel or excavate a floodplain, so some combination of the two, typically depends on the stage of incision. Streams that are in the later stages of the incised channel evolution model are typically wide and filling them would require major effort. Furthermore, streams in the later stages of incision have often affected adjacent tributaries (by lowering base level), and returning an entire system to pre-incision conditions would be impractical. These advanced stage incised channels benefit the most from either excavating adjacent high ground (former floodplain) or developing an inner floodplain.

Conversely, streams that are in the initial stages of incision, those that are very narrow and deep, are the best candidates for filling. The relative volume of material required to fill an early stage incised channel is small. Although there may be issues with minimizing floodplain disturbance (as there exists within middle Rosewood Creek), the biggest risks are preventing conditions that would allow the stream to revert back to an incised condition. Where newly modified floodplain surfaces are steep, there is a greater risk of channel avulsion and subsequent downcutting. It is suggested that filled floodplain areas be stabilized with accumulations of large and small woody debris in order to replicate former floodplain processes. Design of floodplain placement of woody debris will need to address size variability, density, location and methods of securing.

Projects that involve filling of incised channels or restoration of floodplains in general often include provisions to prevent subsequent channel downcutting. These provisions may include valley-wide rock grade controls. Such structures might prevent downcutting, but they may also limit appropriate meander migration or may act as drains which subsequently lower stream or ground water levels or redistribute subsurface flow. Thus, the effects of different design solutions need to be adequately considered.

Reconstruct Channel

Channel reconstruction involves re-establishing a channel geometry that balances water and sediment delivery, using bed materials that are appropriately mobile, and incorporating bank stabilization measures that promote the long-term establishment of riparian vegetation. Channel reconstruction typically involves reach-level and site-level variability in slope, appropriate sinuosity and variable meander configurations. It is important to address whether it is acceptable to allow the channel to slowly migrate within its corridor, or whether it is preferable to maintain the channel in a single location. The reconstructed channel may rely largely on rock as a base to maintain bed stability, it may include the use of substrate that is partially mobile, or it may include the use of bioengineered stream banks that might be rigid or flexible.

For reference, the restored reach of Rosewood Creek between SR28 and Lakeshore Blvd utilized a largely immobile streambed (large rock in steep reaches and smaller cobbles in flat reaches) with stream banks constructed of gravel and topsoil that would be essentially rigid but would be able to deform somewhat over time after vegetation has become established (Miller, 2003).

Stabilize Channel

In contrast to channel reconstruction, channel stabilization (as used for this study) refers to stabilizing the banks and/or bed of a stream channel in its present location. There is a wide range of bank and bed stabilization measures available (see, for example, Washington State Aquatic Habitat Guidelines Program, 2003). Stabilization measures may include:

- Structural techniques such as bank riprap or large woody material;
- Biotechnical techniques consisting of hard elements (such as rock) or biodegradable materials (such as coir erosion control fabric) with vegetation;
- In-stream structures that redirect flow (for example, those made of wood or rocks); and
- Techniques that limit bed degradation (such as rock grade controls spanning the channel) or the potential for avulsion (measures typically employed on the floodplain).

Relocate Channel

Channel relocation is a variation of channel reconstruction and involves the reconstruction of the channel in another location. Intentional channel relocation is most likely warranted under the following conditions:

- Where infrastructure (a building or road) is too close to the channel;
- Where the channel is not flowing within the adjacent topographic low point and where there is a risk of avulsion; and

- Where there is no defined floodplain and overbank flows might flow in some undesirable direction other than down the channel.

Where the channel flows within a reach lacking a defined floodplain, there may be options for either relocating the channel or for constructing a floodplain by lowering the adjacent ground surface (as might be done with an advanced stage incised channel). Creating an inner floodplain offers many benefits, including flood control and the eventual establishment of more appropriate riparian plant communities.

Improve Riparian Vegetation

The overall objective for improving riparian vegetation along Rosewood Creek is to have in place continuous, healthy and regenerating vegetation along the stream banks and floodplain surfaces. Such vegetation would represent the species and plant community structure that would normally persist within the soils, groundwater and inundation conditions found along the stream. Revegetation of stream reaches where the channel is at grade with a high water table will focus on increasing plant density and health through direct planting techniques. Those reaches that are unstable and incising should be physically repaired in order to improve the frequency of floodplain inundation and the proximity to the water table. Revegetation could include a wide range of measures, including planting a variety of life forms (seed, cuttings and bare rooted stock). Revegetation measures that will likely be most effective along Rosewood Creek include planting rooted, live stock and the use of native seed. Irrigation for some period following construction will also likely be necessary.

Develop Riparian Management Guidelines for Landowners

A program should be formulated with the stakeholders along Rosewood Creek to develop plans for riparian land use. Although such plans should address limits to placing structures in the floodplain (such as footbridges and bank stabilization), the primary focus should be the long-term maintenance of healthy riparian plant communities. Plans should address (and limit as appropriate) such activities as tree cutting, vegetation clearing and removal of downed vegetation from the floodplain and from within the stream channel. Plans should establish footpaths that are located and maintained to have no impact on the floodplain function.

Reach-Based Restoration Recommendations

This section provides preliminary concepts for SEZ restoration by stream reach. Each reach is addressed separately, except where a grouping of reaches is appropriate based on a common, contiguous treatment. These reach-based restoration measures are listed and summarily described in Table 20. Furthermore, reaches have been ranked according to relative need and benefit, resulting in a recommended priority for restoration. This information is also provided in Table 20.

No design analysis was undertaken to develop these concepts. Restoration design for any and all of these segments of Rosewood Creek should include an appropriate level of analysis and the concepts provided herein should be scrutinized accordingly.

Table 20. Recommended SEZ restoration actions by reach, with suggested prioritization.

Reach No.	Station Begin		Station End	Distance (ft)	Recommendations	Constraints	Need & Benefit	Recommended Priority
1	0+00	to	2+90	290	At lower end fill reach and activate old channel with limited modification; salvage woody vegetation to roughen floodplain; provide grade drop to culvert. In upper end, fill narrow incised channel to bring to floodplain grade.	Landowner has plans to develop property. Proximity to SR 28.	High	3
2	2+90	to	4+15	125				
3	4+15	to	6+00	185	Fill narrow incision channel to bring to floodplain grade	Condominium held property	High	1
4	6+00	to	8+80	280	*Restoration not required*	None	N/A	N/A
5	8+80	to	17+75	895	Fill narrow incision channel to bring to floodplain grade	Condominium held property	High	2
6	18+50	to	22+10	360	Replace culvert at Northwood Blvd. with outlet to the former channel location at floodplain grade.	Northwood Blvd. and condominiums on right side of floodplain	Low	N/A
7	22+10	to	28+50	640	Minimal bank protection coupled with trail development and footpath obliteration		Low	8
8	28+50	to	31+00	250	Remove berms, widen to create an inset floodplain		High	6
9	31+00	to	32+90	190				
10	33+30	to	34+50	120	*Restoration not required*	None	N/A	N/A
11	34+50	to	37+00	250	Remove berms, relocate channel to new location	Mature firs adjacent to channel; proximity to Village Blvd.	High	5
12	37+72	to	41+20	348	Confinement precludes substantial restoration	Proximity to Village Blvd. and residences	Low	N/A
13	43+20	to	50+15	695	Fill narrow incision channel to bring to floodplain grade	Privately held land parcels	High	4
14	51+70	to	58+90	720	Remove fill in floodplain margins	Ongoing Incline Creek Estates development	Low	10
15	58+90	to	65+50	660	Create floodplain with soft margins	Condominium held property	Low	9
16	66+15	to	72+30	615	Repair failing banks, create floodplain, remove berms	Privately held land parcels	Moderate	7
17	72+30	to	74+70	240	*Restoration not required*	Proximity to Titlist Dr. and golf course	N/A	N/A

Reaches 1, 2 and 3

The landowner of Reaches 1 and 2 has plans to eventually develop the property. In contrast, Reach 3 is commonly held property as part of the Third Creek Condominiums. These three reaches, which total 600 feet in length, are ranked as high in need and recommended restoration priority.

The restoration of Reaches 1, 2 and 3 should be considered collectively because of the need to provide an appropriate channel grade that extends through these reaches (there are currently several nickpoints in Reaches 2 and 3). This grade should connect with that of Reach 4, which is one of the few reaches at grade with its floodplain. A finished channel gradient through Reaches 1, 2 and 3 would likely be one of two configurations. The first would be a constant grade from the downstream end of Reach 4 to the culvert invert at SR 28. The second would be a similarly constant but gentler grade through this reach, with some form of drop structure at the downstream end that would bring the grade down to the SR 28 culvert.

In Reach 3, restoration would involve filling the incised channel to bring it to grade with its floodplain. In Reaches 1 and 2, restoration could involve re-activating the remnant floodplain channel and filling the existing eroded, incised segments. Conversely, the restoration solution for Reaches 1 and 2 could involve some filling of the incised areas and reconstruction of the channel within the same location but at a higher grade. Selection of a preferred option for Reaches 1 and 2 should incorporate the future development plans for the property.

Note that whatever option is selected for Reaches 1 and 2, woody material could be harvested from within these incised segments. This material could be used for stabilization of the margins of Rosewood Creek and the adjacent floodplain surfaces. Revegetation of the restored stream segments would likely involve planting native, rooted riparian species where disturbed by construction.

Reach 4

No restoration actions are recommended for Reach 4. Although this reach is susceptible to incision resulting from upstream-migrating grade imbalances (nickpoints), it is currently stable. If restoration is undertaken in the reaches downstream from Reach 4, then no restoration in this reach is required.

Reach 5

Reach 5 is a fairly long reach (almost 900 feet) downstream of Northwood Blvd., within common property held by the Third Creek Condominiums. This reach has been ranked high in terms of need and priority. The primary problem is that of channel incision, although there are secondary considerations of adjacent land use (buildings, footpaths and vegetation clearing by landowners). Restoration would involve filling the incised channel to bring it to grade with its floodplain. Because there is low ground to the east along the condominiums, there is potential for the channel to eventually shift in that direction. Restoration will need to address this issue. Solutions might involve selective filling of the eastern floodplain to restrict flow from this area. Solutions would also need to address the vegetation clearing practices that are currently undertaken by the property owners in this reach. In addition to revegetation of restored channel margins and floodplain surfaces with the planting of native, rooted riparian species (where disturbed by construction), a revegetation plan would need to be developed for portions of the floodplain where vegetation has been manually cleared.

Reach 6

Reach 6 is primarily comprised of an aggraded channel within a confined floodplain, where no restoration actions are necessary. The short segment of Rosewood Creek adjacent to and under Northwood Blvd. is included in this reach, however, because some restoration potential exists. The need for this restoration is low, and as such it is not ranked as a recommended priority. Nonetheless, restoration would involve the removal of fill placed on the upstream (north) side of Northwood Blvd., and the replacement of the culvert to re-orient a short reach of Rosewood Creek to the topographic low point in the valley cross-section. This low point is to the west of the current creek orientation and would involve just a couple of hundred feet of stream channel. While these restoration activities are not a priority, were the culvert under Northwood Blvd. ever to be replaced, this would be an ideal opportunity to implement these activities.

Reach 7

Reach 7 is generally stable throughout this fairly long reach (more than 600 feet). The need and ranking for restoration is low. This reach is primarily located within property that is under the management of the U.S. Forest Service. Two types of restoration activities could be undertaken within this reach. The first would involve providing defined, single footpaths along the creek and floodplain, while obliterating the extensive series of trails that have been formed. Path obliteration would require de-compacting soils, planting vegetation, and providing physical restraints to foot traffic (either with fences or collections of woody material). Furthermore, there are several locations where the stream bank is sloughing (largely due to foot traffic). Revegetation would be provided in these spot locations. Overall, existing riparian vegetation would also be supplemented by planting Lemmon’s willow and redosier dogwood rooted stock.

Reaches 8 and 9

These stream reaches are also within U.S. Forest Service property. The stream channel within Reaches 8 and 9 is generally stable, but the floodplain shows evidence of former incision and modification with berms. Restoration of these two reaches would involve removal of these berms and further lowering of the adjacent ground in order to create a functional floodplain. This solution would also serve to limit high flows from accessing the remnant channel along the east boundary of the valley bottom. Revegetation would consist of salvaging woody material removed in order to create an inner floodplain and aggressively planting the new floodplain surface to restore a riparian plant community.

Reach 10

No restoration actions are recommended for Reach 10, which is short (just over 100 feet) stable stream segment.

Reach 11

Restoration of Reach 11 is somewhat problematic due to the limited available space to create a functional floodplain and the very large trees by which the stream currently flows. There is insufficient space to create a floodplain and riparian plant community along the existing channel without removing mature pines. Therefore, the most viable option appears to be relocating the majority of stream channel within this reach to the west, into topographic low ground (and apparent former channel). Relocation to this orientation would place the channel closer to Village Blvd.; however, it would also provide conditions that would support a riparian plant community. The berms along the existing channel would be used to fill that portion of abandoned channel. Revegetation of both higher ground (in the current channel location) and newly created floodplain would be implemented using seed and rooted stock. This reach was rated high in terms of need and benefit and ranked highest after all of the identified incised reaches.

Reach 12

Reach 12 provides little opportunity for restoration because of the confinement of the stream along Village Blvd. and the associated bike path. These reaches are ranked low in terms of need and are not prioritized. There are a few short segments (tens of feet long) where former rock stabilization measures are compromised. These segments could be repaired with bioengineered bank stabilization measures, although the bike path limits available space. The riparian plant community is sparse through this reach, due in part to the road encroachment and clearing that occurred with development of the adjacent residential properties. Thus, revegetation efforts within this reach would involve planting the low areas with suitable riparian brushy species and seeding the road shoulders and top of bank along the bike path with an upland mix. Additionally, a small asphalt berm along the margin of the bike path could be installed to prohibit runoff from the path from entering the stream.

Reach 13

Reach 13 consists of a fairly long (almost 700 feet) stream segment with varying degrees of incision and a narrow floodplain dominated by alder communities. The lower- and uppermost portions of this reach are less incised and may not require restoration by channel filling. Nonetheless, this reach is ranked high in terms of need and benefit and fourth in priority (after the incising reaches between SR 28 and Northwood Blvd.). Restoration of the severely incised portion of this reach would involve filling the existing channel to reconnect the grade to the floodplain. There is an extensive amount of woody material that might be utilized in reconstructing the channel and providing a roughened floodplain surface. This woody material ranges in size from mature alder (6 to 8 inches in diameter) to downed mature conifers (to 3 feet in diameter). In fact, this was the only reach where downed conifers of any size were observed. Revegetation would involve planting native, rooted riparian species on along stream banks, on ground disturbed by construction, and where riparian cover is lacking.

Reach 14

The stream channel within Reach 14 is currently stabilized by a series of rock drops. Although the floodplain is limited in width (due to encroachment resulting from prior land development activities), the riparian plant community has become re-established along this reach. Restoration actions are not required and this site was not rated as a priority.

Reach 15

Reach 15 has been affected by the land development in this area. The channel has been straightened in some places, and in others it has been laterally confined with riprap.

Former multiple-thread channels have been confined to a single channel. Floodplain vegetation is generally lacking. Although this reach is currently stable, some segments are at risk of shifts in location resulting from avulsion.

Restoration actions for this reach are considered a low priority. Restoration would involve evaluating potential overbank flow paths and working with the landowners to develop and implement a riparian revegetation and management plan for the area. Restoration would also involve reconfiguring the channel geometry in location where it is unnaturally contrived, and replacing the rock bank armor with bioengineered bank stabilization measures. Revegetation would involve planting riparian shrub and mountain alder stock along any newly created stream banks and on the floodplain surfaces currently devoid of vegetation.

Reach 16

Reach 16 suffers from a variety of human-induced modifications, including encroachment, relocation, armoring, and berming and resulting incision and bank failure. These issues led to this 600-foot long reach being ranked as having a moderate need and benefit and an identified priority for restoration. Although the reach flows through a variety of private landownership, there appears to be adequate space for restoration. Building development precludes use of the observed remnant channel. Rather, restoration would primarily involve the creation of an inner floodplain (and the removal of berms and riprap, where they occur). Restoration at the upper end of the reach will need to account for flood protection of a residence on the immediate right bank. Given that overbank flows from the upstream reach might circumvent the channel and flow across the golf course, some ground contouring might be undertaken to ensure that high flows are redirected into the Rosewood Creek channel at this location.

There is an extensive quantity of alder and some conifer available in the area to the west of the channel at Titlist Drive that could be used for roughening a newly created floodplain surface. Revegetation would involve planting native, rooted riparian species on the newly created floodplain, where ground is disturbed by construction, and where the stream is currently devoid of riparian cover.

Reach 17

The channel in Reach 17 is currently stable. It is bounded by a narrow but dense corridor of riparian vegetation. This channel, however, is perched along the contour between Titlist Drive and a golf cart path for the Incline Village Mountain Golf Course. No restoration actions are recommended for this reach due to the constraints imposed by the golf course.

Restoration Constraints

There are several constraints that may hinder or limit development of an SEZ restoration program for Rosewood Creek within the study area. These constraints do not appear to be obstacles to project implementation; rather, they are merely issues that need to be addressed as restoration efforts proceed through the planning, design, implementation and monitoring phases. Some of the constraints identified during this study include:

- Potential limitations to collaborative project development resulting from differing agendas and restrictions of regulatory agencies (e.g., TRPA), funding organizations (e.g., Bureau of Reclamation, Nevada Division of State Lands) and conservation organizations (NTCD) that would likely be involved in the project;

- The varied type of property ownership along the SEZ, including privately held parcels, commonly-held land (by condominiums), Washoe County land (along roadways) and Federal land (U.S. Forest Service);
- Limited opportunity for allocating responsibility for post-implementation monitoring and maintenance, both short-term (such as irrigation) and long-term (such as vegetation management);
- Differing land use objectives along the study area, including both private and public open space, residences, rights-of-way and ongoing and future land development (e.g., one development project is ongoing and another is planned);
- Risk of flooding to buildings and roadways; and
- The physical limitations imposed by topography and existing vegetation (both deciduous riparian species and adjacent large pines) on equipment and material access and the space to undertake restoration while minimizing environmental impacts.

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Plates

Site Plan Maps

Appendix 1 Reach Photographs

Appendix 2 Hydraulic Modeling

Method of Calculation of Roughness in a Small, High Gradient Mountain Stream

Hydraulic Modeling Results

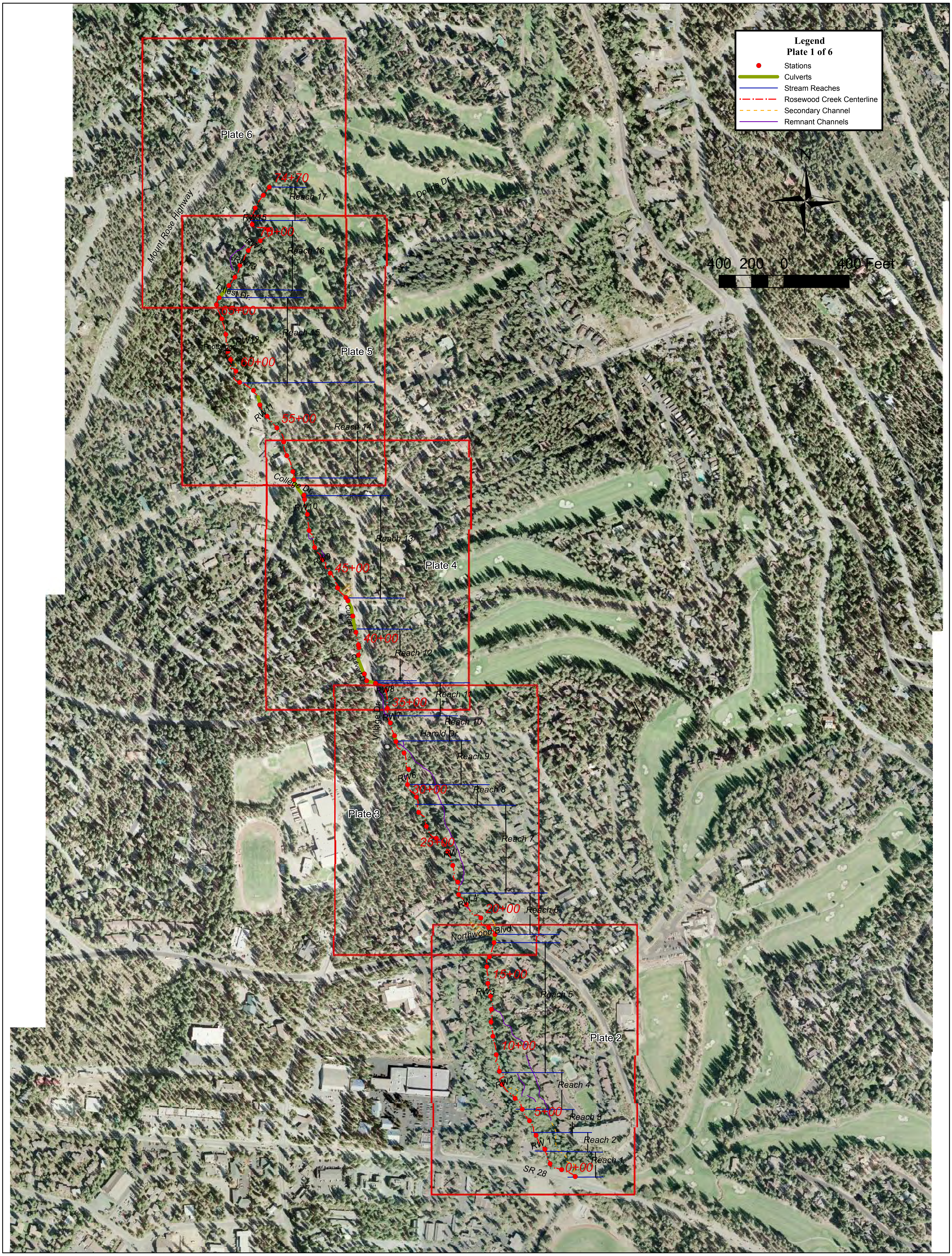
Appendix 3 Sediment Sampling

Sieve Data

Particle Size Data

PLATES

SITE PLAN MAPS



Legend
Plate 1 of 6
Stations
Culverts
Stream Reaches
Rosewood Creek Centerline
Secondary Channel
Remnant Channels
N
400 200 0 400 Feet
Plate 6
Plate 5
Plate 4
Plate 3
Plate 2
Mount Rose Highway
Dorla Dr
College Dr
Harold Dr
Northwood Blvd
SR 28
74+70
70+00
65+00
60+00
55+00
45+00
40+00
35+00
30+00
25+00
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5+00
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Reach 17
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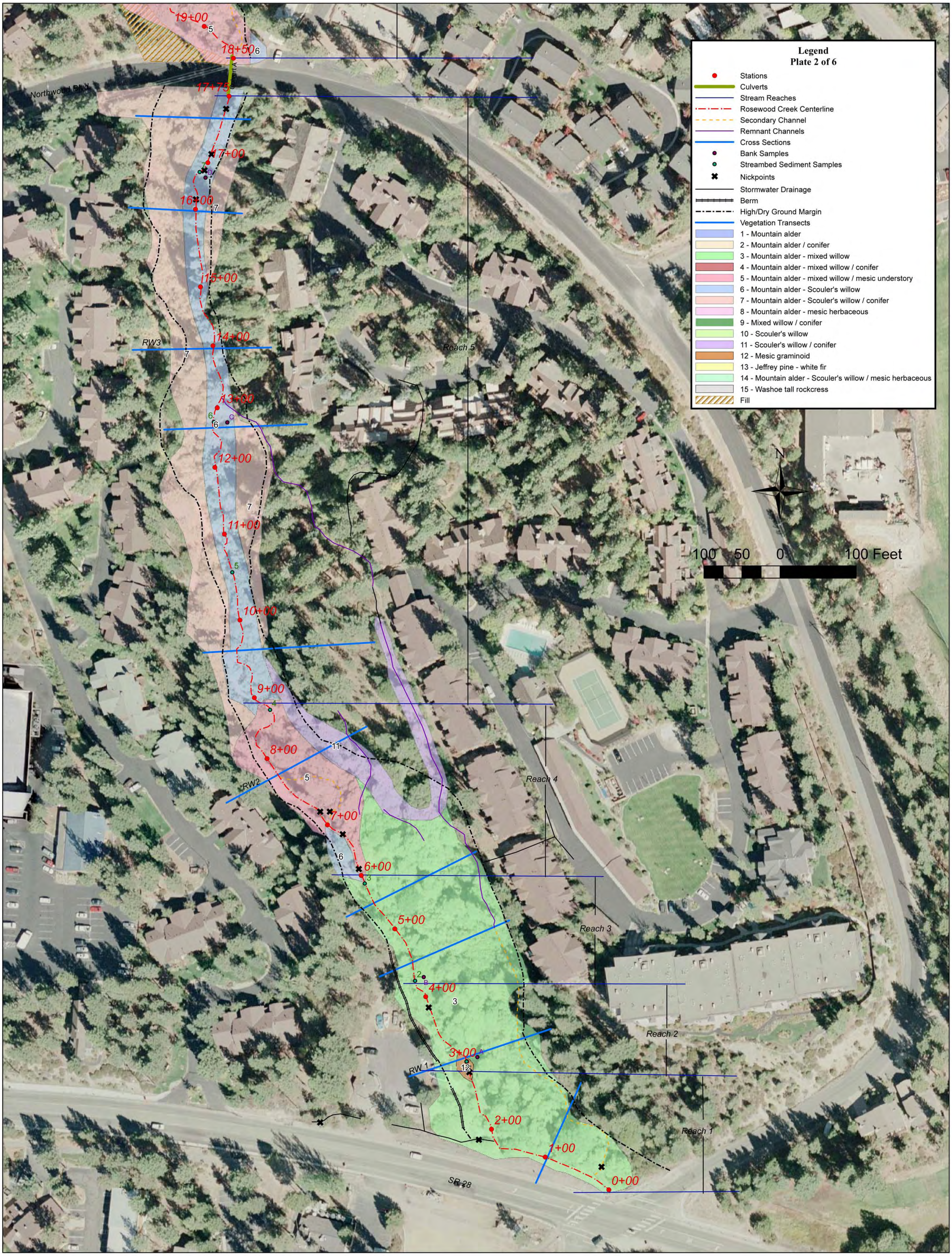
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Plate 2 of 6
Stations
Culverts
Stream Reaches
Rosewood Creek Centerline
Secondary Channel
Remnant Channels
Cross Sections
Bank Samples
Streambed Sediment Samples
Nickpoints
Stormwater Drainage
Berm
High/Dry Ground Margin
Vegetation Transects
1 - Mountain alder
2 - Mountain alder / conifer
3 - Mountain alder - mixed willow
4 - Mountain alder - mixed willow / conifer
5 - Mountain alder - mixed willow / mesic understory
6 - Mountain alder - Scouler's willow
7 - Mountain alder - Scouler's willow / conifer
8 - Mountain alder - mesic herbaceous
9 - Mixed willow / conifer
10 - Scouler's willow
11 - Scouler's willow / conifer
12 - Mesic graminoid
13 - Jeffrey pine - white fir
14 - Mountain alder - Scouler's willow / mesic herbaceous
15 - Washoe tall rockcress
Fill
N
100 50 0 100 Feet
Northwood Blvd
SR 28
Reach 1
Reach 2
Reach 3
Reach 4
Reach 5
RW 1
RW2
RW3
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
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17+75
18+50
19+00

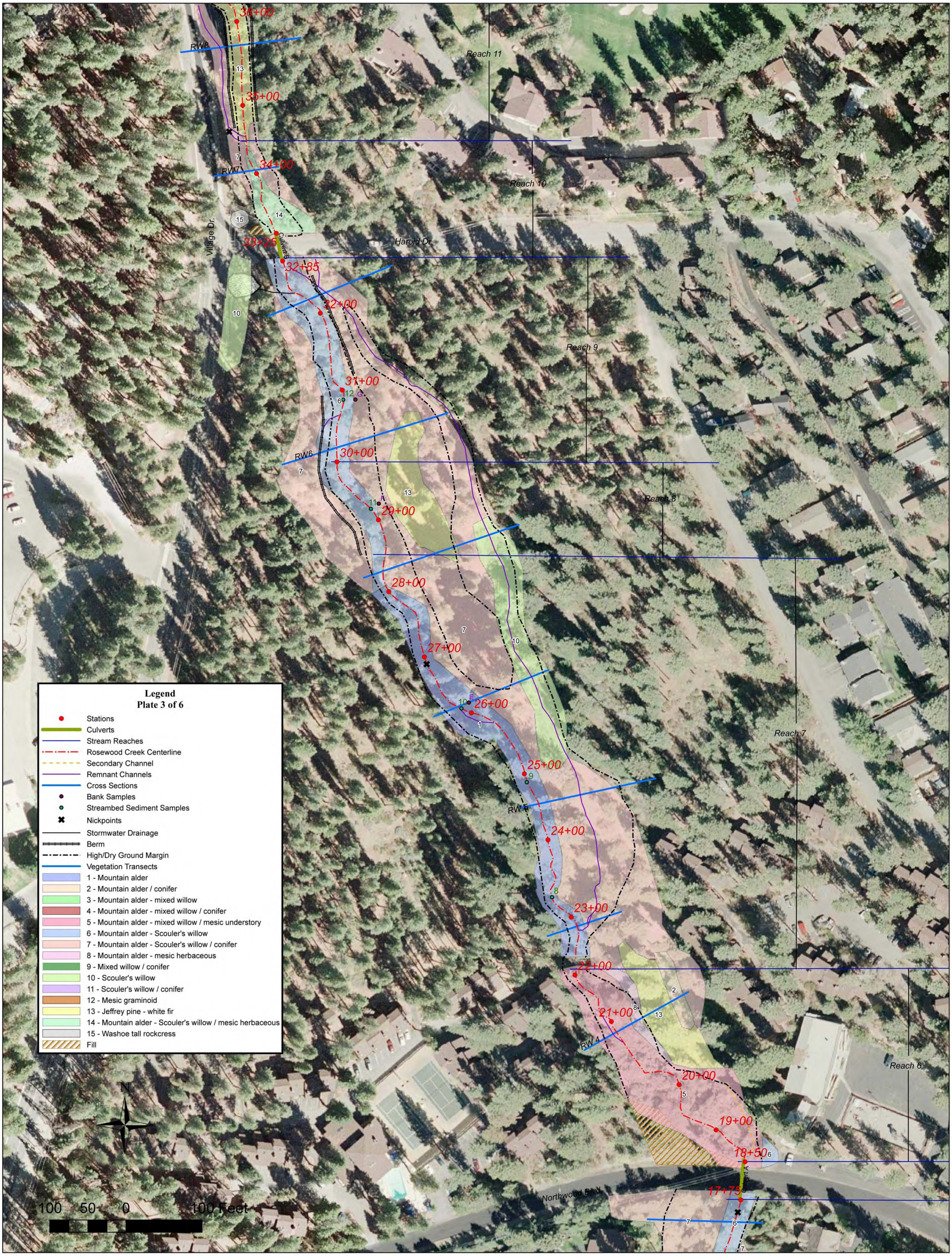
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Plate 3 of 6
Stations
Culverts
Stream Reaches
Rosewood Creek Centerline
Secondary Channel
Remnant Channels
Cross Sections
Bank Samples
Streambed Sediment Samples
Nickpoints
Stormwater Drainage
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15 - Washoe tall rockcress
Fill
Reach 11
Reach 10
Reach 9
Reach 8
Reach 7
Reach 6
Harold Dr.
Village Dr.
Northwood Blvd
Culverts
RW8
RW7
RW6
RW 5
RW 4
36+00
35+00
34+00
33+25
32+85
32+00
31+00
30+00
29+00
28+00
27+00
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17+75
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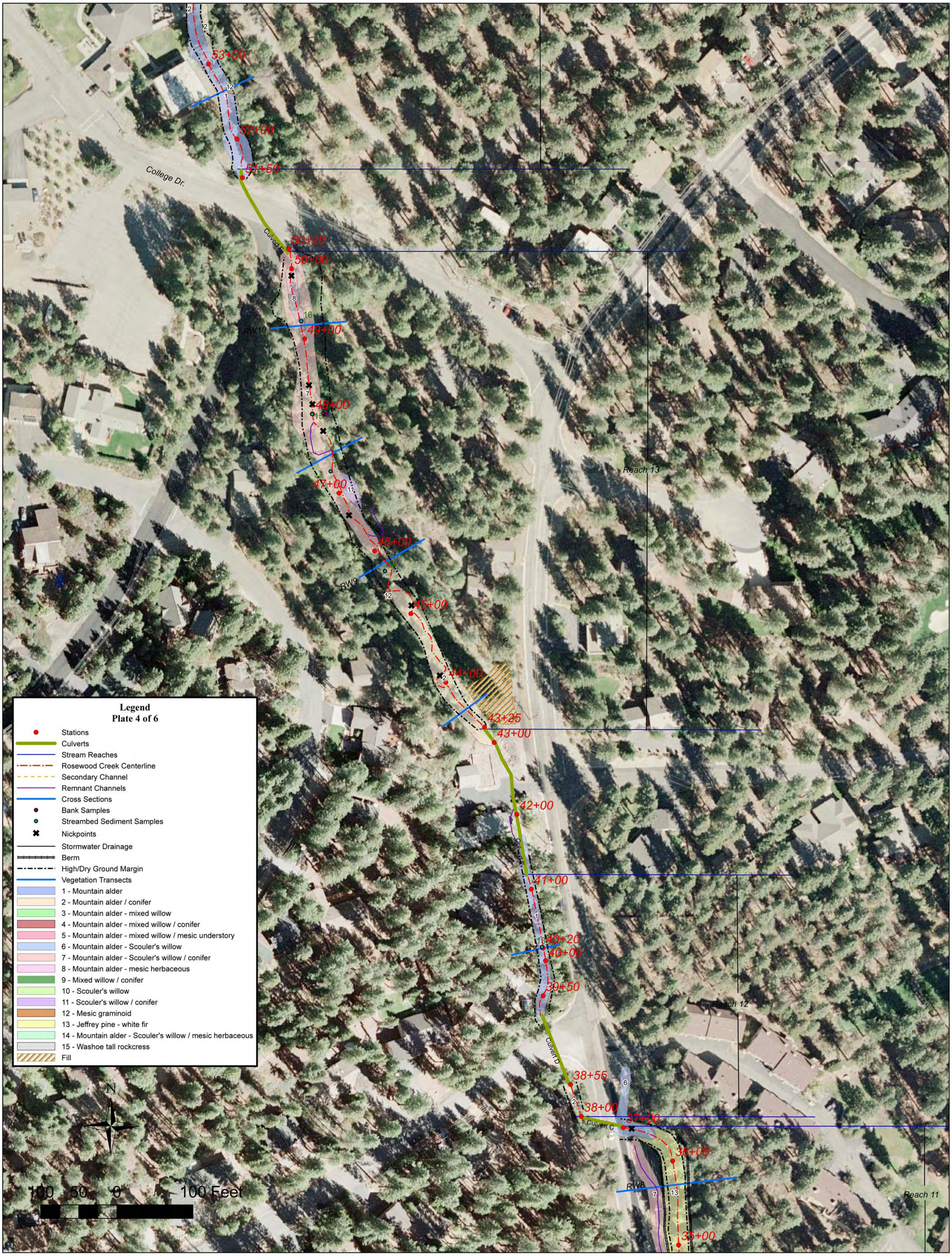
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52+00
51+50
50+20
50+00
RW10
49+00
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47+00
46+00
RW9
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44+00
43+25
43+00
42+00
41+00
40+20
40+00
39+50
38+55
38+00
37+00
36+00
RW8
35+00
Reach 13
Reach 12
Reach 11
Legend
Plate 4 of 6
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Stream Reaches
Rosewood Creek Centerline
Secondary Channel
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Streambed Sediment Samples
Nickpoints
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15 - Washoe tall rockcress
Fill
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100 50 0 100 Feet

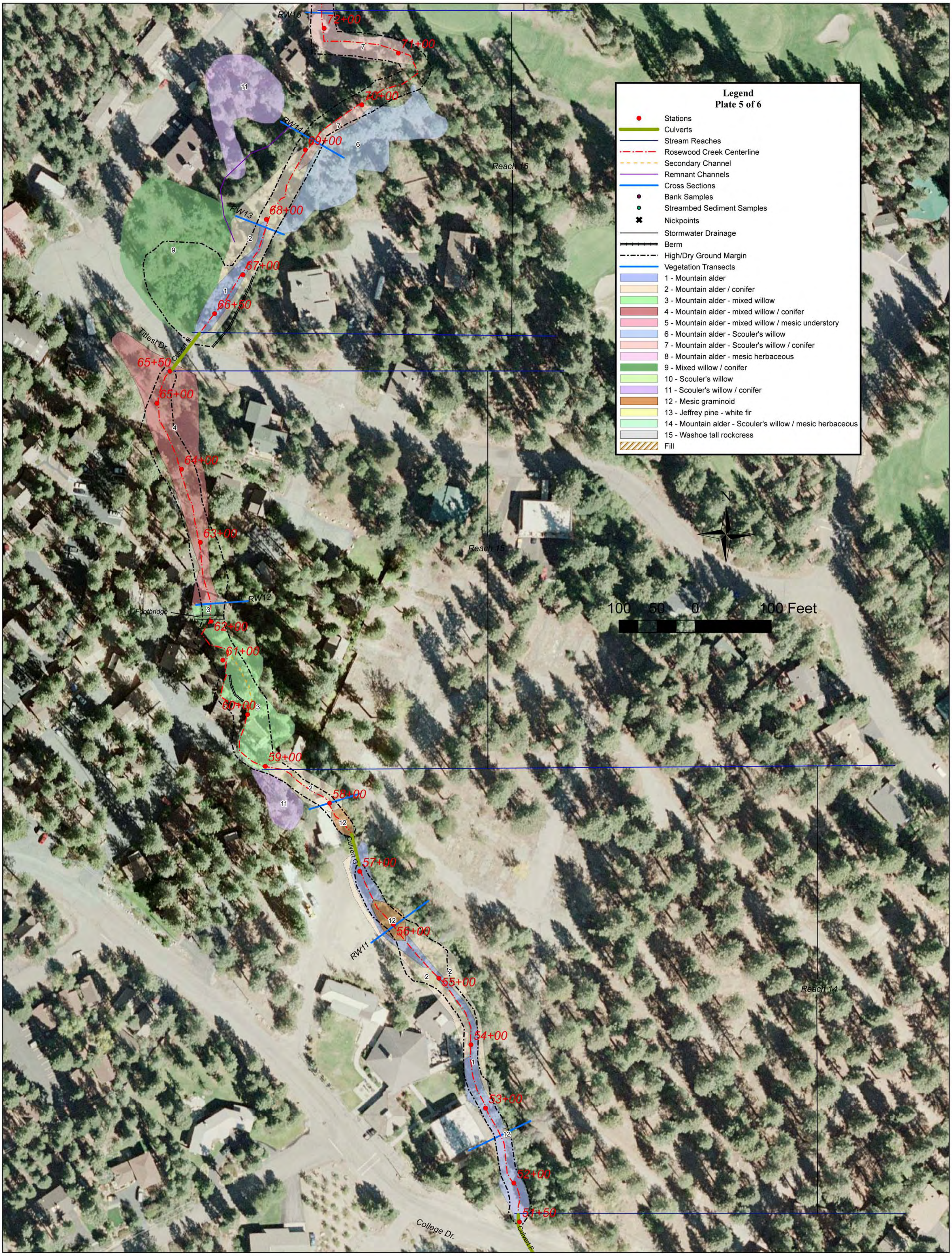
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Plate 5 of 6
Stations
Culverts
Stream Reaches
Rosewood Creek Centerline
Secondary Channel
Remnant Channels
Cross Sections
Bank Samples
Streambed Sediment Samples
Nickpoints
Stormwater Drainage
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15 - Washoe tall rockcress
Fill
N
100 50 0 100 Feet
Reach 16
Reach 15
Reach 14
RW15
RW14
RW13
RW12
RW11
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71+00
70+00
69+00
68+00
67+00
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65+50
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59+00
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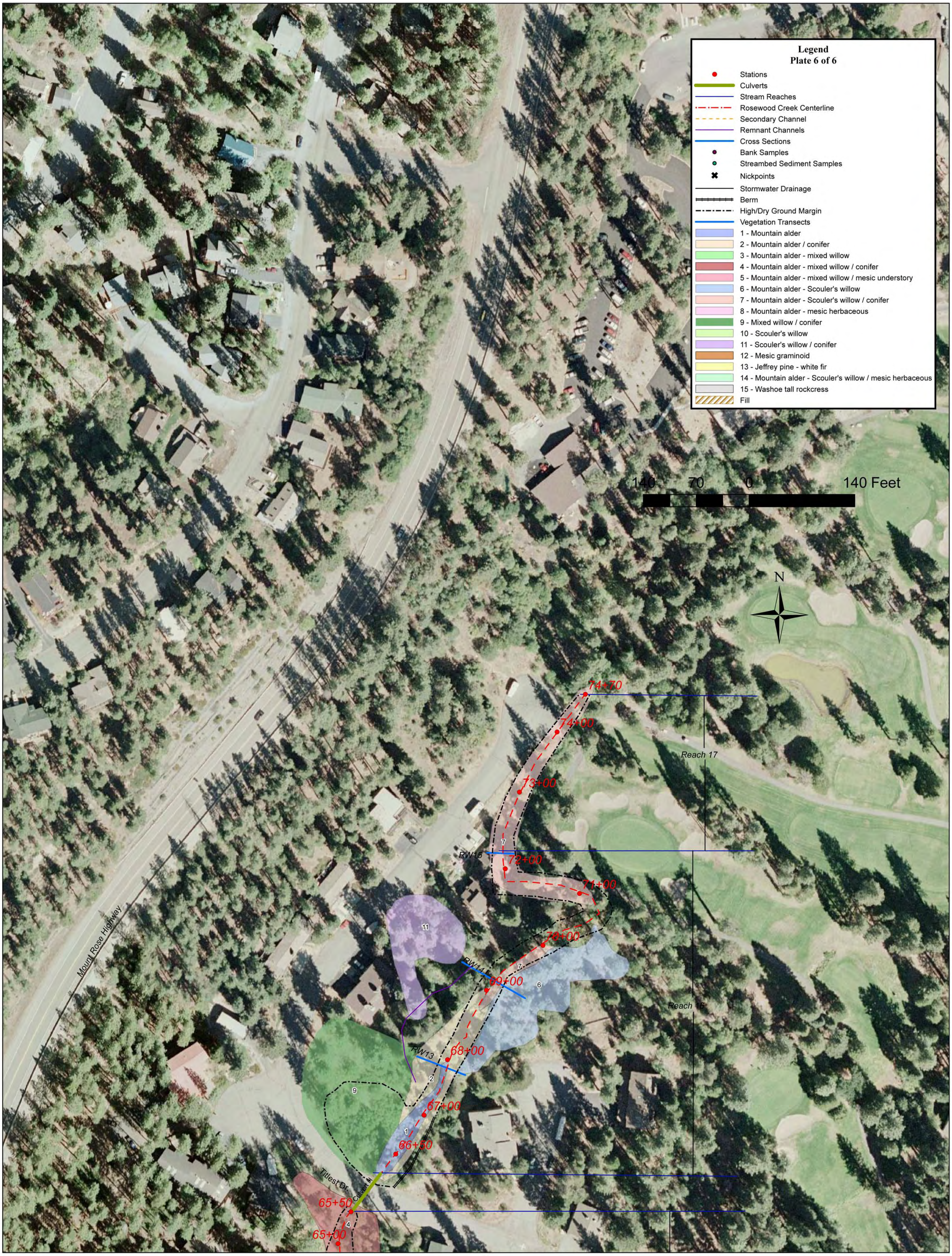
53+00
52+00
51+50
Tiltest Dr.
Footbridge
College Dr.



Legend
Plate 6 of 6
Stations
Culverts
Stream Reaches
Rosewood Creek Centerline
Secondary Channel
Remnant Channels
Cross Sections
Bank Samples
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Nickpoints
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11 - Scouler's willow / conifer
12 - Mesic graminoid
13 - Jeffrey pine - white fir
14 - Mountain alder - Scouler's willow / mesic herbaceous
15 - Washoe tall rockcress
Fill
140 70 0 140 Feet
N
Mount Rose Highway
Reach 17
Reach 16
74+70
74+00
73+00
72+00
71+00
70+00
69+00
68+00
67+00
66+50
65+50
65+00
RW15
RW14
RW13
Tiller Dr.

APPENDIX 1
PHOTOGRAPHS

Reach 1

Reach 2

Reach 2


Reach 3

Reach 4

Reach 5

Reach 6

Reach 7

Reach 8

Reach 9

Reach 10

Reach 11

 

Reach 12

Reach 13

Reach 14

Reach 15

Reach 16

Reach 17

APPENDIX 2
HYDRAULIC MODELING

Method of Estimating Manning's Equation Roughness Coefficient Using Channel Dimensions

Cross-Section No.	Recurrent Interval (yrs)	Estimated Q at RI (cfs) from Table 1	Channel Characteristics								Flow Characteristics		Sediment Characteristics	
			Bottom Width	Side Slope	Water Depth	Friction Slope	Manning n*	Area	Wetted Perimeter	Hydraulic Radius	Velocity	Discharge	Shear Stress	Particle Mobilized (D_{50})
			(ft)	(ft / ft)	(ft)	(ft / ft)		(ft^2)	(ft)	(ft)	(fps)	(cfs)	(lb/ft^2)	(mm)
Average	**2**	**6**	**4.0**	**0.5**	**0.69**	**0.0670**	0.127	3.0	5.543	0.5409	2.0	6.06	2.26	172
	5	**16**	**4.0**	**0.5**	**1.26**	**0.0670**	0.118	5.8	6.817	0.8557	2.7	16.01	3.58	273
	10	**23**	**4.0**	**0.5**	**1.58**	**0.0670**	0.115	7.6	7.533	1.0047	3.1	23.1	4.20	320
	100	**40**	**4.0**	**0.5**	**2.22**	**0.0670**	0.111	11.3	8.964	1.2655	3.6	40.4	5.29	403
	100	**60**	**4.0**	**0.5**	**2.81**	**0.0670**	0.108	15.2	10.283	1.4770	3.9	60.0	6.17	471
Average							0.116							

Bold = input variables

* Manning's n roughness coefficient is calculated from hydraulic parameters according to research regarding roughness in small, high gradient mountain streams (Jarret 1984, Marcus et al. 1992 and Papanicolaou and Maxwell 2000) using the following formula:

n = 0.39*(Sf^0.38)*(R*0.3048)^-0.16*0.68

where:

n = roughness coefficient
Sf = friction slope
R = hydraulic radius (ft) = A/Wp
A = area (ft^2)
Wp = wetted perimeter (ft)
0.68 = adjustment to formula based on Marcus et al. 1992

Hydraulic results for the 2-yr recurrent flow of 6 cfs.

Station	Manning's Coefficient	Channel Slope (ft/ft)	Water Surface Elevation (ft)	Discharge (cfs)	Flow Area (ft^2)	Wetted Perimeter (ft)	Top Width (ft)	Actual Depth (ft)	Critical Slope (ft/ft)	Velocity (ft/s)	Velocity Head (ft)	Froude Number	Shear Stress (lb/ft)
1+00	0.104	0.040	6,377.23	6	3.6	8.1	6.6	1.8	0.329	1.67	0.04	0.40	1.1
3+00	0.142	0.091	6,386.60	6	4.0	12.3	12.1	0.6	0.492	1.50	0.03	0.46	1.8
4+50	0.110	0.046	6,399.36	6	3.1	5.6	4.7	0.8	0.281	1.95	0.06	0.42	1.6
5+60	0.130	0.072	6,407.84	6	3.4	7.9	7.7	0.8	0.374	1.76	0.05	0.46	1.9
7+70	0.100	0.036	6,423.47	6	5.3	20.5	20.4	0.5	0.263	1.14	0.02	0.40	0.6
9+70	0.101	0.037	6,431.20	6	5.4	22.4	21.8	0.8	0.228	1.10	0.02	0.39	0.6
12+50	0.112	0.049	6,444.30	6	3.8	9.6	9.3	0.6	0.300	1.58	0.04	0.44	1.2
13+90	0.108	0.044	6,451.29	6	4.5	14.4	12.9	1.2	0.307	1.33	0.03	0.39	0.8
15+90	0.113	0.050	6,462.88	6	3.3	6.9	6.5	0.8	0.288	1.80	0.05	0.44	1.5
17+50	0.148	0.102	6,474.89	6	2.9	5.7	5.1	0.9	0.480	2.05	0.07	0.48	3.2
20+80	0.107	0.043	6,488.76	6	5.4	22.1	21.5	1.1	0.246	1.12	0.02	0.40	0.7
22+95	0.090	0.028	6,498.15	6	3.3	6.3	5.9	1.0	0.176	1.80	0.05	0.42	0.9
24+50	0.116	0.053	6,507.60	6	3.1	6.0	5.5	1.0	0.293	1.91	0.06	0.45	1.7
26+25	0.131	0.074	6,519.95	6	3.1	6.4	5.9	0.8	0.390	1.91	0.06	0.46	2.2
28+30	0.139	0.086	6,537.58	6	2.8	5.0	4.3	0.9	0.428	2.14	0.07	0.47	3.0
30+30	0.117	0.054	6,551.42	6	4.2	12.5	12.2	0.8	0.329	1.43	0.03	0.43	1.1
32+60	0.146	0.097	6,557.60	6	4.2	13.7	13.5	0.6	0.516	1.44	0.03	0.46	1.9
34+05	0.129	0.070	6,579.80	6	3.5	8.2	8.0	0.8	0.369	1.73	0.05	0.46	1.9
35+60	0.106	0.042	6,588.19	6	3.3	6.4	6.0	0.7	0.246	1.84	0.05	0.44	1.4
40+20	0.094	0.031	6,614.10	6	3.1	5.3	4.3	0.9	0.204	1.93	0.06	0.40	1.1
43+40	0.112	0.048	6,635.49	6	3.0	5.2	4.3	0.9	0.285	2.01	0.06	0.42	1.7
45+80	0.128	0.069	6,649.46	6	3.2	6.5	5.1	1.0	0.432	1.89	0.06	0.42	2.1
47+40	0.157	0.118	6,660.79	6	3.0	6.3	5.0	1.2	0.640	1.99	0.06	0.45	3.5
49+10	0.151	0.106	6,674.50	6	2.7	4.5	3.7	1.0	0.514	2.26	0.08	0.47	4.0
53+00	0.148	0.101	6,702.59	6	2.9	5.7	5.3	0.9	0.470	2.05	0.07	0.49	3.2
56+00	0.095	0.031	6,724.21	6	5.5	22.5	21.5	0.7	0.241	1.08	0.02	0.38	0.5
58+20	0.110	0.046	6,738.99	6	3.1	5.7	4.7	1.1	0.276	1.94	0.06	0.42	1.6
62+25	0.118	0.055	6,767.15	6	3.4	7.6	6.4	1.4	0.350	1.74	0.05	0.42	1.5
67+80	0.118	0.055	6,794.49	6	2.8	4.6	2.1	1.6	0.422	2.14	0.07	0.32	2.1
69+20	0.112	0.048	6,802.32	6	3.3	6.5	5.9	0.8	0.280	1.84	0.05	0.44	1.5
72+30	0.117	0.054	6,815.88	6	3.0	5.3	4.2	1.0	0.323	2.01	0.06	0.42	1.9

Hydraulic results for the 5-yr recurrent flow of 16 cfs.

Station	Mannings Coefficient	Channel Slope (ft/ft)	Water Surface Elevation (ft)	Discharge (cfs)	Flow Area (ft^2)	Wetted Perimeter (ft)	Top Width (ft)	Actual Depth (ft)	Critical Slope (ft/ft)	Velocity (ft/s)	Velocity Head (ft)	Froude Number	Shear Stress (lb/ft)
1+00	0.097	0.040	6,377.67	16	7.8	14.2	12.6	2.3	0.218	2.05	0.07	0.46	1.4
3+00	0.132	0.091	6,386.87	16	7.7	15.9	15.6	0.9	0.364	2.09	0.07	0.53	2.8
4+50	0.102	0.046	6,399.90	16	5.7	6.8	5.2	1.3	0.219	2.80	0.12	0.47	2.4
5+60	0.121	0.072	6,408.19	16	6.6	10.5	10.2	1.2	0.280	2.42	0.09	0.53	2.8
7+70	0.093	0.036	6,423.68	16	10.6	30.0	29.8	0.7	0.198	1.51	0.04	0.45	0.8
9+70	0.094	0.037	6,431.39	16	10.9	32.7	32.0	1.0	0.212	1.46	0.03	0.44	0.8
12+50	0.105	0.049	6,444.62	16	6.8	10.3	9.6	0.9	0.221	2.37	0.09	0.50	2.0
13+90	0.100	0.044	6,451.55	16	8.0	15.3	13.3	1.5	0.238	2.01	0.06	0.46	1.4
15+90	0.105	0.050	6,463.28	16	6.2	8.3	7.6	1.2	0.213	2.59	0.10	0.51	2.3
17+50	0.138	0.102	6,475.36	16	5.4	6.7	5.3	1.4	0.379	2.98	0.14	0.52	5.1
20+80	0.099	0.043	6,488.97	16	11.0	34.6	33.9	1.3	0.235	1.45	0.03	0.45	0.9
22+95	0.084	0.028	6,498.61	16	6.4	8.2	7.5	1.4	0.134	2.50	0.10	0.48	1.3
24+50	0.108	0.053	6,508.06	16	6.2	8.3	7.5	1.5	0.225	2.60	0.11	0.51	2.5
26+25	0.122	0.074	6,520.38	16	5.8	7.5	6.6	1.2	0.293	2.77	0.12	0.52	3.6
28+30	0.129	0.086	6,538.15	16	6.2	9.2	8.1	1.5	0.334	2.59	0.10	0.52	3.6
30+30	0.108	0.054	6,551.71	16	8.4	18.2	17.8	1.1	0.247	1.91	0.06	0.49	1.6
32+60	0.135	0.097	6,557.84	16	8.0	18.0	17.8	0.8	0.391	2.00	0.06	0.52	2.7
34+05	0.120	0.070	6,580.15	16	6.6	10.5	10.2	1.2	0.277	2.41	0.09	0.53	2.7
35+60	0.098	0.042	6,588.62	16	6.0	7.6	6.9	1.1	0.183	2.66	0.11	0.50	2.1
40+20	0.088	0.031	6,614.74	16	6.5	8.5	6.9	1.5	0.167	2.47	0.09	0.45	1.5
43+40	0.104	0.048	6,636.07	16	5.6	6.5	4.7	1.5	0.231	2.85	0.13	0.46	2.6
45+80	0.119	0.069	6,649.96	16	5.9	7.8	5.7	1.5	0.330	2.73	0.12	0.47	3.3
47+40	0.146	0.118	6,661.28	16	5.5	7.3	5.3	1.7	0.491	2.89	0.13	0.50	5.5
49+10	0.140	0.106	6,675.10	16	6.4	10.4	9.4	1.6	0.404	2.50	0.10	0.53	4.1
53+00	0.138	0.101	6,703.03	16	5.6	7.3	6.7	1.3	0.358	2.86	0.13	0.55	4.8
56+00	0.088	0.031	6,724.40	16	10.3	27.4	26.4	0.9	0.188	1.55	0.04	0.44	0.7
58+20	0.102	0.046	6,739.53	16	7.2	11.8	10.5	1.6	0.223	2.23	0.08	0.48	1.7
62+25	0.109	0.055	6,767.53	16	10.0	28.0	26.7	1.7	0.278	1.61	0.04	0.46	1.2
67+80	0.109	0.055	6,795.21	16	7.1	12.1	9.3	2.3	0.431	2.24	0.08	0.45	2.0
69+20	0.104	0.048	6,802.77	16	6.2	8.4	7.4	1.3	0.214	2.57	0.10	0.49	2.2
72+30	0.108	0.054	6,816.45	16	5.9	7.5	6.1	1.6	0.256	2.71	0.11	0.49	2.6

Hydraulic results for the 10-yr recurrent flow of 23 cfs.

Station	Mannings Coefficient	Channel Slope (ft/ft)	Water Surface Elevation (ft)	Discharge (cfs)	Flow Area (ft²)	Wetted Perimeter (ft)	Top Width (ft)	Actual Depth (ft)	Critical Slope (ft/ft)	Velocity (ft/s)	Velocity Head (ft)	Froude Number	Shear Stress (lb/ft)
1+00	0.094	0.040	6,377.84	23	10.0	15.9	14.2	2.4	0.191	2.31	0.08	0.49	1.6
3+00	0.129	0.091	6,387.00	23	9.8	17.6	17.3	1.0	0.328	2.35	0.09	0.55	3.2
4+50	0.099	0.046	6,400.19	23	7.2	7.4	5.4	1.6	0.202	3.18	0.16	0.48	2.8
5+60	0.118	0.072	6,408.37	23	8.5	11.8	11.4	1.4	0.253	2.72	0.11	0.55	3.3
7+70	0.091	0.036	6,423.78	23	13.7	34.5	34.3	0.8	0.181	1.68	0.04	0.47	0.9
9+70	0.091	0.037	6,431.47	23	13.4	33.4	32.5	1.1	0.195	1.71	0.05	0.47	0.9
12+50	0.102	0.049	6,444.78	23	8.4	10.7	9.7	1.1	0.197	2.74	0.12	0.52	2.4
13+90	0.097	0.044	6,451.68	23	9.8	15.5	13.4	1.6	0.210	2.35	0.09	0.48	1.7
15+90	0.102	0.050	6,463.48	23	7.8	9.0	8.2	1.4	0.190	2.95	0.14	0.53	2.7
17+50	0.134	0.102	6,475.62	23	6.8	7.2	5.5	1.6	0.352	3.40	0.18	0.54	6.0
20+80	0.097	0.043	6,489.06	23	14.3	39.8	39.0	1.4	0.216	1.61	0.04	0.47	1.0
22+95	0.082	0.028	6,498.84	23	8.2	9.1	8.3	1.6	0.121	2.80	0.12	0.50	1.5
24+50	0.105	0.053	6,508.28	23	7.9	9.2	8.3	1.7	0.204	2.93	0.13	0.53	2.8
26+25	0.119	0.074	6,520.62	23	7.5	8.6	7.5	1.4	0.267	3.08	0.15	0.54	4.0
28+30	0.126	0.086	6,538.38	23	8.2	11.0	9.8	1.7	0.309	2.82	0.12	0.54	4.0
30+30	0.106	0.054	6,551.84	23	10.9	21.0	20.5	1.2	0.227	2.11	0.07	0.51	1.7
32+60	0.132	0.097	6,557.95	23	10.0	18.9	18.6	1.0	0.354	2.30	0.08	0.55	3.2
34+05	0.117	0.070	6,580.39	23	9.5	15.5	15.1	1.4	0.249	2.42	0.09	0.54	2.7
35+60	0.096	0.042	6,588.85	23	7.6	8.3	7.3	1.4	0.168	3.01	0.14	0.52	2.4
40+20	0.085	0.031	6,614.99	23	8.4	10.0	8.2	1.8	0.153	2.73	0.12	0.48	1.6
43+40	0.101	0.048	6,636.47	23	8.0	9.5	7.4	1.9	0.216	2.88	0.13	0.49	2.5
45+80	0.116	0.069	6,650.22	23	7.4	8.4	6.0	1.7	0.302	3.10	0.15	0.49	3.8
47+40	0.142	0.118	6,661.54	23	7.0	7.9	5.4	1.9	0.455	3.30	0.17	0.51	6.5
49+10	0.137	0.106	6,675.29	23	8.3	12.0	10.9	1.8	0.370	2.77	0.12	0.56	4.6
53+00	0.134	0.101	6,703.25	23	7.1	8.1	7.3	1.6	0.323	3.23	0.16	0.58	5.5
56+00	0.086	0.031	6,724.50	23	12.9	28.7	27.7	1.0	0.169	1.78	0.05	0.46	0.9
58+20	0.099	0.046	6,739.70	23	9.1	13.1	11.7	1.8	0.202	2.53	0.10	0.51	2.0
62+25	0.106	0.055	6,767.63	23	12.5	30.0	28.5	1.8	0.259	1.84	0.05	0.49	1.4
67+80	0.106	0.055	6,795.53	23	12.0	27.2	23.9	2.6	0.285	1.91	0.06	0.48	1.5
69+20	0.101	0.048	6,802.99	23	7.9	9.2	8.1	1.5	0.195	2.92	0.13	0.52	2.6
72+30	0.106	0.054	6,816.72	23	7.6	8.6	7.0	1.8	0.233	3.01	0.14	0.51	3.0

Hydraulic results for the low estimate of the 100-yr recurrent flow (40 cfs). Refer to the report text for a discussion of the basis for using a low and high 100-yr recurrent flow estimate.

Station	Mannings Coefficient	Channel Slope (ft/ft)	Water Surface Elevation (ft)	Discharge (cfs)	Flow Area (ft^2)	Wetted Perimeter (ft)	Top Width (ft)	Actual Depth (ft)	Critical Slope (ft/ft)	Velocity (ft/s)	Velocity Head (ft)	Froude Number	Shear Stress (lb/ft)
1+00	0.091	0.040	6,378.13	40	14.6	19.1	17.2	2.7	0.163	2.74	0.12	0.52	1.9
3+00	0.124	0.091	6,387.24	40	14.5	21.8	21.3	1.2	0.280	2.76	0.12	0.59	3.8
4+50	0.096	0.046	6,400.77	40	10.6	8.7	6.0	2.2	0.185	3.78	0.22	0.50	3.5
5+60	0.114	0.072	6,408.66	40	12.0	12.9	12.2	1.7	0.219	3.34	0.17	0.59	4.2
7+70	0.087	0.036	6,423.97	40	21.3	48.3	48.1	1.0	0.155	1.88	0.05	0.50	1.0
9+70	0.088	0.037	6,431.63	40	18.6	34.6	33.5	1.2	0.163	2.15	0.07	0.51	1.2
12+50	0.098	0.049	6,445.12	40	11.7	11.4	10.1	1.4	0.169	3.41	0.18	0.56	3.1
13+90	0.094	0.044	6,451.97	40	13.6	16.1	13.4	1.9	0.180	2.94	0.13	0.52	2.3
15+90	0.099	0.050	6,463.89	40	11.3	10.4	9.3	1.8	0.166	3.54	0.19	0.57	3.4
17+50	0.129	0.102	6,476.73	40	17.7	36.7	33.2	2.7	0.325	2.26	0.08	0.55	3.1
20+80	0.093	0.043	6,489.22	40	21.5	51.1	50.3	1.5	0.186	1.86	0.05	0.50	1.1
22+95	0.079	0.028	6,499.26	40	12.1	11.0	10.0	2.1	0.105	3.32	0.17	0.53	1.9
24+50	0.101	0.053	6,508.68	40	11.5	11.0	9.8	2.1	0.176	3.48	0.19	0.57	3.5
26+25	0.115	0.074	6,521.10	40	11.9	12.6	11.3	1.9	0.235	3.37	0.18	0.58	4.3
28+30	0.121	0.086	6,538.76	40	12.5	14.9	13.5	2.1	0.268	3.20	0.16	0.59	4.5
30+30	0.102	0.054	6,552.07	40	16.4	26.7	26.1	1.5	0.196	2.45	0.09	0.54	2.1
32+60	0.127	0.097	6,558.15	40	14.0	20.2	19.9	1.2	0.297	2.85	0.13	0.60	4.2
34+05	0.112	0.070	6,580.67	40	14.9	22.4	21.9	1.7	0.211	2.68	0.11	0.57	2.9
35+60	0.093	0.042	6,589.29	40	11.1	9.5	8.2	1.8	0.148	3.62	0.20	0.55	3.0
40+20	0.082	0.031	6,615.44	40	12.6	12.6	10.5	2.2	0.130	3.18	0.16	0.51	1.9
43+40	0.098	0.048	6,636.98	40	12.8	14.1	11.7	2.4	0.197	3.13	0.15	0.53	2.7
45+80	0.112	0.069	6,650.74	40	10.8	10.0	7.2	2.2	0.270	3.69	0.21	0.53	4.7
47+40	0.137	0.118	6,662.10	40	10.0	9.1	5.7	2.5	0.417	3.99	0.25	0.53	8.1
49+10	0.132	0.106	6,675.65	40	13.1	17.2	16.1	2.2	0.316	3.06	0.15	0.60	5.0
53+00	0.129	0.101	6,703.66	40	10.4	9.6	8.6	2.0	0.280	3.85	0.23	0.62	6.8
56+00	0.083	0.031	6,724.68	40	18.0	30.6	29.6	1.2	0.142	2.22	0.08	0.50	1.1
58+20	0.096	0.046	6,740.03	40	13.3	15.6	14.1	2.1	0.173	3.00	0.14	0.54	2.5
62+25	0.103	0.055	6,767.81	40	18.1	34.1	32.5	2.0	0.223	2.21	0.08	0.52	1.8
67+80	0.103	0.055	6,795.73	40	17.0	29.4	25.9	2.8	0.235	2.35	0.09	0.51	2.0
69+20	0.097	0.048	6,803.39	40	11.4	10.6	9.3	1.9	0.166	3.51	0.19	0.56	3.2
72+30	0.102	0.054	6,817.18	40	11.2	10.4	8.5	2.3	0.198	3.56	0.20	0.55	3.6

Hydraulic results for the low estimate of the 100-yr recurrent flow (60 cfs). Refer to the report text for a discussion of the basis for using a low and high 100-yr recurrent flow estimate.

Station	Mannings Coefficient	Channel Slope (ft/ft)	Water Surface Elevation (ft)	Discharge (cfs)	Flow Area (ft²)	Wetted Perimeter (ft)	Top Width (ft)	Actual Depth (ft)	Critical Slope (ft/ft)	Velocity (ft/s)	Velocity Head (ft)	Froude Number	Shear Stress (lb/ft)
1+00	0.089	0.040	6,378.39	60	19.4	21.8	19.8	3.0	0.145	3.09	0.15	0.55	2.2
3+00	0.121	0.091	6,387.47	60	19.8	26.6	26.0	1.5	0.253	3.04	0.14	0.61	4.2
4+50	0.094	0.046	6,401.33	60	14.0	9.9	6.5	2.7	0.176	4.27	0.28	0.51	4.1
5+60	0.111	0.072	6,408.94	60	15.5	13.8	12.9	1.9	0.196	3.88	0.23	0.62	5.1
7+70	0.085	0.036	6,424.11	60	28.7	57.2	56.8	1.1	0.142	2.09	0.07	0.52	1.1
9+70	0.086	0.037	6,431.78	60	23.7	35.7	34.4	1.4	0.144	2.53	0.10	0.54	1.5
12+50	0.096	0.049	6,445.46	60	15.2	12.2	10.4	1.8	0.154	3.96	0.24	0.58	3.8
13+90	0.092	0.044	6,452.24	60	17.4	16.7	13.5	2.1	0.162	3.46	0.19	0.54	2.8
15+90	0.096	0.050	6,464.24	60	14.8	11.6	10.3	2.1	0.149	4.06	0.26	0.60	4.0
17+50	0.126	0.102	6,476.95	60	27.3	61.3	57.4	3.0	0.314	2.19	0.07	0.56	2.8
20+80	0.091	0.043	6,489.37	60	30.1	66.5	65.6	1.7	0.168	2.00	0.06	0.52	1.2
22+95	0.077	0.028	6,499.64	60	16.1	12.9	11.6	2.4	0.095	3.72	0.21	0.56	2.1
24+50	0.099	0.053	6,509.04	60	15.3	12.6	11.2	2.4	0.160	3.93	0.24	0.59	4.0
26+25	0.112	0.074	6,521.45	60	16.4	15.9	14.5	2.3	0.212	3.67	0.21	0.61	4.7
28+30	0.118	0.086	6,539.09	60	17.6	19.7	18.1	2.4	0.242	3.41	0.18	0.61	4.8
30+30	0.099	0.054	6,552.27	60	21.9	31.4	30.7	1.7	0.176	2.74	0.12	0.57	2.4
32+60	0.124	0.097	6,558.35	60	18.1	21.4	21.0	1.4	0.262	3.32	0.17	0.63	5.1
34+05	0.110	0.070	6,580.88	60	19.8	25.2	24.7	1.9	0.211	3.04	0.14	0.60	3.4
35+60	0.090	0.042	6,589.93	60	18.5	19.7	17.8	2.4	0.133	3.24	0.16	0.56	2.5
40+20	0.080	0.031	6,615.87	60	17.8	16.8	14.7	2.7	0.116	3.38	0.18	0.54	2.0
43+40	0.095	0.048	6,637.32	60	17.4	17.4	15.0	2.7	0.170	3.44	0.18	0.56	3.0
45+80	0.109	0.069	6,651.23	60	14.7	12.1	8.9	2.7	0.245	4.09	0.26	0.56	5.3
47+40	0.134	0.118	6,662.66	60	13.3	10.4	6.1	3.1	0.401	4.51	0.32	0.54	9.5
49+10	0.128	0.106	6,675.91	60	17.8	21.0	19.9	2.4	0.283	3.38	0.18	0.63	5.6
53+00	0.126	0.101	6,704.03	60	13.8	11.0	9.7	2.3	0.255	4.36	0.30	0.65	7.9
56+00	0.080	0.031	6,724.84	60	23.0	32.3	31.2	1.3	0.122	2.61	0.11	0.54	1.4
58+20	0.094	0.046	6,740.32	60	17.8	17.9	16.4	2.4	0.155	3.37	0.18	0.57	2.8
62+25	0.100	0.055	6,767.97	60	23.6	38.0	36.2	2.2	0.196	2.54	0.10	0.55	2.1
67+80	0.100	0.055	6,795.91	60	21.9	31.4	27.7	3.0	0.208	2.74	0.12	0.54	2.4
69+20	0.095	0.048	6,803.76	60	15.0	11.9	10.4	2.3	0.151	3.99	0.25	0.59	3.8
72+30	0.099	0.054	6,817.58	60	14.9	12.0	9.9	2.7	0.175	4.03	0.25	0.58	4.2

APPENDIX 3
SEDIMENT SAMPLING

Streambed Sediment Data

Station	3+00		4+20		5+90		8+70	
Sample No.	1		2		3		4	
Grain Diam. (mm)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)
64	-----	-----	-----	-----	-----	-----	-----	-----
45	-----	-----	-----	-----	-----	-----	-----	-----
32	-----	-----	-----	-----	-----	-----	-----	-----
22.4	98.2%	150	97.1%	198	96.4%	332	84.4%	1558
16	94.9%	222	94.6%	172	92.2%	363	70.9%	1347
11.2	86.5%	548	87.2%	486	86.3%	495	59.9%	1097
8	77.8%	566	77.2%	652	81.1%	444	53.7%	623
5.6	68.2%	618	68.1%	599	72.7%	704	49.2%	460
4.75	64.1%	274	65.3%	189	68.5%	355	47.1%	220
2	41.8%	1431	46.2%	1241	38.8%	2466	33.3%	1378
1	28.8%	838	33.1%	854	34.8%	342	23.0%	1033
0.075	-----	1726	-----	2037	-----	2768	-----	2192
Percentiles*								
D_{16}	-----		-----		-----		-----	
D_{50}	2.6		2.3		2.3		5.2	
D_{84}	10.9		10.9		10.7		33.0	

**Percentiles derived from the equation of the logarithmic trend line .*

Streambed Sediment Data

Station	10+60		12+70		16+85		23+20	
Sample No.	5		6		7		8	
Grain Diam. (mm)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)
64	98.0%	185	-----		94.0%	430	69.6%	2859
45	-----	-----	-----		91.3%	199	34.5%	3310
32	-----	-----	-----		-----	-----	24.4%	959
22.4	67.5%	2735	78.2%	1462	62.1%	2058	21.4%	290
16	49.9%	1562	67.3%	729	52.9%	655	18.9%	249
11.2	44.9%	456	59.5%	523	46.8%	439	16.4%	242
8	39.5%	484	54.5%	339	43.1%	264	14.7%	172
5.6	35.5%	367	48.9%	382	39.1%	290	12.8%	191
4.75	34.3%	120	47.3%	118	38.1%	86	12.0%	89
2	23.1%	1002	36.0%	747	29.6%	600	6.3%	548
1	15.2%	705	28.5%	504	21.8%	557	2.5%	361
0.075	-----	1223	-----	1763	-----	1400	-----	118
Percentiles*								
D_{16}	-----		-----		-----		2.5	
D_{50}	10.0		5.1		8.4		47.7	
D_{84}	60.8		48.0		57.9		-----	

**Percentiles derived from the equation of the logarithmic trend line .*

Streambed Sediment Data

Station	24+90		26+15		29+20		30+90	
Sample No.	9		10		11		12	
Grain Diam. (mm)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)
64	95.1%	477	95.9%	468	-----	-----	95.8%	425
45	76.0%	1824	81.7%	1598	80.8%	2126	81.5%	1415
32	-----	-----	-----	-----	-----	-----	-----	-----
22.4	58.5%	1678	56.9%	2781	59.1%	2389	50.2%	3092
16	48.9%	925	48.1%	990	49.3%	1087	40.6%	953
11.2	41.6%	705	39.6%	967	41.6%	852	35.1%	551
8	36.4%	509	33.7%	673	36.5%	564	30.7%	449
5.6	32.7%	362	29.8%	442	32.8%	416	26.7%	400
4.75	31.7%	110	28.4%	163	31.8%	121	25.4%	142
2	23.4%	795	20.0%	960	23.2%	947	17.3%	813
1	17.1%	614	13.5%	737	16.4%	764	11.8%	545
0.075	-----	1517	-----	1394	-----	1667	-----	1040
Percentiles*								
D_{16}	-----		-----		-----		-----	
D_{50}	11.6		12.2		13.1		12.2	
D_{84}	80.0		71.3		-----		71.0	

**Percentiles derived from the equation of the logarithmic trend line .*

Streambed Sediment Data

Station	40+20		45+70		47+3		48+00	
Sample No.	13		14		15		16	
Grain Diam. (mm)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)
64	-----	-----	-----	-----	94.7%	461	95.8%	348
45	88.1%	1468	96.9%	319	89.7%	442	85.1%	867
32	86.1%	256	95.1%	201	88.2%	140	82.9%	187
22.4	47.1%	4807	79.5%	1575	78.4%	843	65.2%	1418
16	37.2%	1217	67.3%	1234	70.1%	726	57.8%	608
11.2	28.8%	1049	60.6%	676	64.3%	504	51.6%	500
8	24.2%	572	56.3%	447	59.9%	389	48.3%	280
5.6	20.9%	417	52.6%	388	55.1%	418	45.1%	267
4.75	19.8%	149	50.7%	196	53.2%	178	43.6%	131
2	13.5%	784	36.3%	1453	36.8%	1408	34.7%	721
1	9.4%	521	25.6%	1088	23.5%	1140	27.8%	559
0.075	-----	1040	-----	2459	-----	1886	-----	2098
Percentiles*								
D_{16}	1.6		-----		-----		-----	
D_{50}	8.3		4.5		4.4		6.4	
D_{84}	43.9		27.8		31.6		51.8	

**Percentiles derived from the equation of the logarithmic trend line .*

Streambed Sediment Data

Station	49+15	
Sample No.	17	
Grain Diam. (mm)	% Passing	Mass (g)
64	-----	-----
45	-----	-----
32	-----	-----
22.4	-----	-----
16	98.8%	151
11.2	91.4%	631
8	84.5%	596
5.6	75.2%	787
4.75	69.5%	490
2	47.6%	1858
1	32.5%	1280
0.075	-----	2622
Percentiles*		
D_{16}	-----	
D_{50}	2.1	
D_{84}	8.4	

**Percentiles derived from the equation of the logarithmic trend line .*

Stream Bank Material Data

Station No.	3+00		4+20		12+70		16+85	
Sample No.	A		B		C		D	
Grain Diam. (mm)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)
2	89.4%	340	79.1%	331.6	84.5%	302.6	82.9%	293.6
1	71.0%	1192	60.6%	1183.6	63.2%	924.6	64.9%	960.6
0.075	5.1%	101	4.0%	92.6	4.5%	64.6	5.9%	96.6
0.020	1.744%	60.93	1.359%	42.65	1.563%	53.26	2.052%	63.00
0.010	1.354%	7.08	1.062%	4.80	1.196%	7.38	1.569%	7.92
0.008	1.248%	1.92	0.981%	1.31	1.098%	1.81	1.439%	2.13
0.002*	0.753%	9.00	0.599%	6.17	0.643%	8.35	0.841%	9.79

0.002 mm is the limit of the analysis procedure and thus data should be used with caution

Stream Bank Material Data

Station No.	26+15		29+20		30+90		47+30		48+00	
Sample No.	E		F		G		H		I	
Grain Diam. (mm)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)	% Passing	Mass (g)
2	90.2%	101.6	84.9%	163.6	82.1%	248	95.9%	112.6	93.3%	51.6
1	76.6%	523.6	70.7%	773.6	65.2%	939.8	88.5%	394.6	83.6%	356.6
0.075	6.8%	50.6	3.7%	42.6	1.4%	20.1	3.9%	37.6	16.6%	88.6
0.020	8.853%	84.40	1.156%	29.29	0.432%	13.89	1.229%	25.75	5.583%	58.80
0.010	7.482%	1.27	0.973%	2.11	0.367%	0.93	1.027%	1.95	4.403%	6.30
0.008	7.089%	0.36	0.920%	0.61	0.349%	0.27	0.969%	0.56	4.078%	1.73
0.002*	5.079%	1.86	0.651%	3.10	0.252%	1.39	0.675%	2.83	2.536%	8.23

0.002 mm is the limit of the analysis procedure and thus data should be used with caution