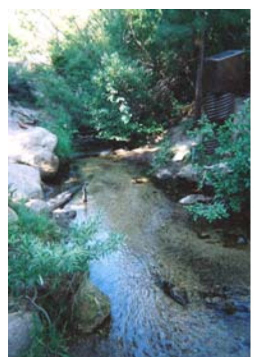
ENTRIX
ENVIRONMENTAL CONSULTANTS

GEOMORPHIC ASSESSMENT REPORT

THIRD, INCLINE, AND ROSEWOOD CREEK
SECTION 206 AQUATIC ECOSYSTEM RESTORATION PROJECT



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Under Section 206 of the Water Resources Development Act (1996) The U.S. Army Corps of Engineers, Sacramento District (ACOE) is authorized to restore the aquatic ecosystem conditions in the Third, Incline, and Rosewood Creek (TI&R) watersheds located on the north shore of Lake Tahoe in Washoe County, Nevada. ENTRIX, Inc. (ENTRIX) prepared this Geomorphic Assessment Report (GAR) under contract to the ACOE, who is joined by Washoe County and the Incline Village General Improvement District (IVGID) in the overall investigation. The geomorphic study was conducted to characterize fluvial processes and to identify impacts to stream channel, riparian, and wetland habitats resulting from historic and on-going land use activities. The GAR recommends activities to remedy impacts and frames the approach needed to restore geomorphic, riparian, and aquatic habitat conditions.

The GAR consists of a broad reconnaissance-level investigation of the entire TI&R watersheds, and a more detailed analysis for approximately 2.1 miles of specific project reaches. Most of the specific project reaches are downstream of SR 28. Study objectives included:

- Identify historic and present day channel geomorphic conditions
- Characterize the extent to which changes in historic geomorphic conditions affect aquatic habitat quality and water quality
- Qualitatively characterize sediment sources and sediment transport capacity
- Describe changes in channel stability
- Conduct a visual assessment of fish passage at road crossings
- Recommend restoration measures

Watershed Geology, Geomorphology, and Land-Use

Third Creek drains glaciated granitic uplands, which include glacial moraines and till deposits between its headwaters and near S.R. 431. Incline Creek drains strongly dissected granitic slopes with scattered volcanic deposits northeast of the Diamond Peak Ski area. Both streams are incised into a large alluvial fan downstream of SR 431 that extends to about SR 28. Below SR 28, Rosewood Creek joins Third Creek near the Incline Middle School. Third Creek and Incline Creek are entrenched into alluvial stream and lakeshore deposits from near Incline Way downstream to Lake Tahoe. Lake Tahoe functions as the base elevation control on vertical channel stability in the lowermost reaches of both

Third and Incline Creeks. As the lake fluctuates in elevation between cyclical wet and dry periods, the channels may incise or aggrade to adjust to the lake elevation. Both channels meet Lake Tahoe nearly at-grade today.

In the upper watersheds of Third and Incline Creeks, the channel includes steep gradient sections (often more than 10%), which are primarily zones of high sediment production and sediment transport. The channel is often confined in narrow, steep valleys and is deeply entrenched. Sediment production is derived primarily from hillslope processes, including landslides and debris flows, and these processes are not directly associated with human-induced impacts. Weathering of the granitic rocks in both basins dominantly produces sand-sized sediment, which were observed in the stream channel along upper watershed reaches. This sediment is ultimately transported downstream, where a portion is stored in the streambed, but all sediment is eventually delivered to Lake Tahoe. There are very few floodplain or riparian floodprone areas that function as long-term sediment storage sites. While of uncertain magnitude, it is likely that more opportunities for over-bank sediment storage existed under historic (pre-Comstock) conditions. Downstream from SR 28, stream gradients steadily decrease from about 4% to 2%, and the valley dramatically widens as the channels approach the lake across their alluvial/colluvial fans. Streambank erosion, incision, and road-related sediment production are the largest sources of sediment recruitment between about S.R. 431 and Lake Tahoe. All of these sediment sources have been accelerated by land use activities.

Between SR 28 to downstream of Incline Way, Third Creek is considered a G-type channel and Incline Creek appears to be characteristic of either a G or B-type channel. The G channel types may be found on alluvial fans, are well-entrenched, have a low width-depth ratio, typically have high rates of bank erosion and bedload transport rates, and are considered very unstable (Rosgen, 1996). The G-type channels are very sensitive to disturbance, with adverse adjustments occurring due to changes in the flow regime and sediment supply of the watershed (Rosgen, 1996).

The upper watersheds include forested sub-alpine canyons which are relatively undeveloped. The lower watershed areas are urbanized with residential and commercial developments. Urbanization, including development of Incline Village, began in earnest during the early 1960s. Approximately 22% of the total drainage area of Third Creek, 30% of Incline Creek, and nearly all of the Rosewood Creek drainage are within urbanized areas. The TI&R watershed has experienced a variety of historic land uses, including road building, logging, and water management in addition to the more recent urban development. A range of natural and human-induced changes in the flow and sediment regime have occurred over the past 100 to 150 years in response to these land uses. It is likely that even prior to historic logging in the late 1800's, the project study reaches exhibited changes in the position and dimension of the channel in response to large-scale sediment inputs from landslides and other sediment producing mechanisms in the watershed. These natural disturbances probably happened episodially.

It is difficult to assess the relative importance and the nature of changes associated with each factor (e.g., channel re-routing, logging and clearing, water fluming and export, road building, urban development) given the various potential combinations of direct and indirect effects. However, it is clear that there are ongoing adjustments of stream channel morphology in response to significant changes in the flow and sediment regime. These adjustments continue to have adverse consequences for aquatic and riparian habitats, and water quality.

Land-Use Impacts to Channel Morphology and Habitat Conditions

Channel Incision and Widening

In the reach between approximately Lakeshore Drive and SR 28 the Incline Creek and Third Creek channel morphology is presently not in equilibrium (except for a recently restored section of channel on Incline Creek), with some past evidence of incision and significant evidence of ongoing channel widening. Typically, runoff volumes and peak flows increase in urbanized areas primarily due to construction of impervious areas and to storm drainage facilities. On Third Creek, peak flows have also been increased by the addition of runoff from the Rosewood Creek basin. Rosewood Creek presently joins Third Creek just downstream of SR 28. However, the natural channel alignment did not join Third Creek, but rather flowed directly to Lake Tahoe.

Channel widening and incision has increased the flood conveyance capacity of the channels, reducing the frequency and extent of over-bank flows in the riparian floodprone area. As the channel widens and incises, the opportunity for deposition of sediments in floodprone areas is reduced, more sediment is delivered to Lake Tahoe (contributing to water clarity degradation), and excess sediment from the bed and bank erosion is deposited in the channel, degrading aquatic habitat. Sediment deposition of sand-sized material is nearly ubiquitous, but appears to be accelerated in most of the project reaches, and has adversely effected aquatic habitat by reducing the volume of pools and causing a fining of the channel bed.

In the Rosewood Creek project study reach between SR 28 and Northwood Blvd, the bed and banks are highly unstable, with significant active incision accompanied by initial channel widening. We anticipate continued channel incision and widening. The adjacent floodplain has been completely abandoned due to channel incision. Three nickpoints were identified in the lower segments of the project reach upstream from SR 28, indicating that the bed remains vertically unstable. Undercutting and bank collapse is common along the channel. Bank erosion was rated as continuous and severe. This reach of

Rosewood Creek represents an active source of anthropogenically accelerated sediment production to Third Creek and to Lake Tahoe. There are similar impacts to Rosewood Creek channel morphology in the project reaches further upstream, between Harold Drive and Driver Way.

Erosion of Streambanks

There is clear evidence of accelerated bank erosion due to heavy public use of informal footpaths and access trails that cross the streambanks. Many of the footpaths have resulted in a loss of ground cover leading to sloughing of the sandy bank material. This type of public use impact is most evident on Third Creek and Incline Creek between SR 28 and Lake Shore Drive.

Culverts Effects:

Straightened Channel Planform, Sediment Transport Rates and Potential Fish Barriers

Other adverse changes associated with urbanization are related to the development of roads and the associated need for culverts. Roads have previously been documented in other studies as a source of fine sediments in much of the TI&R watersheds. Culverts represent locations where the channel is “fixed” in position and cannot naturally migrate laterally across the valley flat. This reduces the channel sinuosity, and causes the channel to take a straighter flow path, with consequently higher energy during runoff events. This higher energy is also responsible for increased bed and bank erosion. The meanders associated with a sinuous channel tend to reduce the energy of flowing water. The extent to which the Third and Incline Creek channels may have naturally meandered prior to urbanization is not presently well-known. However, it is likely that the natural sinuosity of the channel would have increased where channel gradients are the lowest, from about Incline Way to the lake. Presently, both channels are very straight in this reach, and this may be due to the culvert crossings, and possibly to intentional re-alignment of the channels. No historic plans indicating that the natural channel alignments were in fact changed are known.

The culverts inspected along the specific project reaches have not significantly altered the overall volume of sediment transported in the watershed. Sand deposition was apparent at almost all inspected locations in the watershed, including at higher elevations upstream of developed areas. This indicates that there are large amounts of sand in transport, some of which is naturally derived in undeveloped areas. Sand is relatively easy to transport, unless flows have been reduced by diversions. However, local changes in sediment transport conditions were observed at some culvert inlets that have resulted in adjustments of the channel morphology upstream from the culvert. Most these changes are believed to be the result of the combined culvert and associated road-fill which together reduce the flow velocities at the road crossing.

The effect on channel morphology is particularly dramatic along Rosewood Creek, on the upstream side of the culvert crossing at Northwood Blvd and several other Rosewood Creek crossings further upstream. There is channel aggradation on the upstream side of the crossings due to sand deposition. The aggradation alters the channel configuration to a poorly entrenched, meandering channel with a sandy bed, and with an over-bank floodplain/wet meadow area. In stark contrast, immediately downstream from these culvert crossings, the channel is highly entrenched, with no connection to a floodplain. The dramatic difference in channel morphology between the upstream and downstream culvert crossings is due to the road fill and culvert. During high flow events, flow velocities are reduced and there is backwater in the channel at the crossings causing sand to deposit and the channel to adjust its form by aggrading. However, these changes in local sediment transport characteristics do not appreciably alter the total volume of sand delivered downstream. Although the transport of sand is moderated through the culvert, during the next storm event the deposited sediments are undoubtedly mobilized, pass through the culvert, and are eventually transported downstream. The total volume of sediment ultimately reaching downstream areas and the lake is not reduced since the sands deposited upstream of the culvert crossings are not long-term sediment storage sites. This is apparent due to the significant presence of sand in almost all stream reaches. The culverts themselves are not plugged with sand, although there was commonly found to be woody debris deposits at the culvert entrances which reduces the rate at which sediment will pass through the culverts and causes some deposition upstream of the culverts. All culverts should be regularly maintenance to eliminate clogging by woody debris and allow proper hydraulic functioning.

Several culvert crossings are barriers to fish migration due either to low depths, high velocities, excessive jump height into the culvert, or to a combination of any of these conditions. The following culverts are at least partial, if not complete barriers to migration. Incline Creek: concrete box culvert at Lakeshore Drive, USGS gage station upstream of Lakeshore Drive, double corrugated metal culverts at Incline Way and at SR 28; Third Creek: concrete box culvert at Lakeshore Drive, double corrugated metal culverts at Incline Way and at SR 28.

Restoration Recommendations

The recommended approach to erosion control and water quality improvement is to develop a comprehensive design solution for the reach of Third Creek between SR 28 and Lake Shore Drive. A comprehensive plan should identify a new, stable channel morphology that is appropriate for the existing sediment and flow regime. A stable morphology should provide capacity for up to a bankfull discharge that is equivalent to approximately the 1.5 year flood event. The existing channel appears to contain flows much greater than the 1.5 year flood. In addition, a higher sinuosity may be appropriate for a stable channel morphology. Higher sinuosity decreases the channel gradient and expends energy, reducing the overall shear stress on bed and banks. This restoration approach will foster some sediment deposition in floodplain areas, reducing excess deposition in the channel and delivery to the lake. By developing a stable channel morphology, this approach will also reduce the accelerated erosion associated with channel widening and incision.

Developing a stable morphology for channel segments entrenched into the alluvial fan presents some challenges, given the potential for episodic sediment inputs further upstream in the watershed. In addition, Incline Village General Improvement District (IVGID) plans to realign Rosewood Creek to its former channel in the near future. This will reduce peak flows and sediment inputs to Third Creek below SR 28. Channel adjustments within Third Creek may also be initiated as a result of this change. Therefore, it is recommended that a prudent restoration approach would include initiating a monitoring program on Third Creek to determine how the channel is responding, and contribute to a more comprehensive design solution. Likewise, monitoring of the recently restored section of Incline Creek between Incline Way and Lake Shore Drive would provide valuable information, since the performance of the channel in this reach may be a good analog for future restoration activities upstream.

It is likely that the prior to development, Rosewood Creek channel had some connection to an adjacent floodplain, providing an opportunity for overbank flows during flood events and thereby some water quality benefits. Stabilizing the channel and controlling excess sediment production from Rosewood Creek should be considered a restoration priority in the segment between Northwood Blvd and SR 28. If this section of Rosewood Creek is not stabilized, there will be continued incision, bank collapse, channel widening, and accelerated sediment production to the lower reaches of Third Creek and Lake Tahoe.

There are three basic approaches to consider for stabilizing this reach of Rosewood Creek, each with advantages and disadvantages:

(1) Reconstruct channel at higher, original elevation, with appropriate dimensions, geometry, and re-connect to former floodplain

(2) Construct channel with appropriate dimensions at elevation of existing bed, with an associated new floodplain or floodprone area, at lower elevation by excavating back streambank walls

(3) Stabilize channel in place using bioengineering techniques

A second project study reach on Rosewood Creek, Village Blvd between Driver Way and down to Harold Drive also shows evidence of bank erosion, although the extent of the erosion and bank instability is not as significant as the SR 28 to Northwood Blvd reach. This reach of Rosewood Creek may have been moved from its original channel alignment. There is evidence of a remnant channel to the west of the existing alignment along Village Blvd. It is likely that the present-day channel alignment was constructed in order to accommodate road and housing development. It appears from the remnant channel that Rosewood Creek may have functioned in conjunction with at least a small adjacent floodplain to provide hydraulic release during high flow events. Re-occupying this remnant channel section may be another option for restoration in addition to other erosion control methods including bio-engineering techniques.

1.0 INTRODUCTION

Under Section 206 of the Water Resources Development Act (1996) the U.S. Army Corps of Engineers, Sacramento District (ACOE) is authorized to restore the aquatic ecosystem of the Third, Incline, and Rosewood Creek watersheds located in Washoe County, Nevada. The purpose of this evaluation is to identify impacts to stream channel, riparian and wetland habitats associated with various historic and on-going land-use activities, and to develop measures to remedy those impacts. The ACOE is joined by Washoe County and the Incline Village General Improvement District (IVGID) in conducting this investigation.

Land-use activities such as road building, logging, residential and commercial development, and direct manipulation of stream channels often alter geomorphic processes by changing the equilibrium relationships between the hydrologic regime, sediment production, and sediment transport. Significant alteration of the equilibrium relationship will consequently alter channel morphology. Alterations may take the form of aggradation or degradation of the channel bed, lateral instability (bank erosion), and accelerated sediment production. The consequence for aquatic habitat and water quality may also be significant.

Accelerated sediment production to streams can adversely affect aquatic habitat and water quality. Excess fine sediment impairs successful reproduction of trout and salmon species by reducing adequate circulation of oxygenated water to incubating embryos and remove the water flow to their metabolic wastes (Cooper, 1965). Loss of pool depth and capacity reduces the availability of juvenile fish rearing habitat during the summer low-flow period (Bjornn et al, 1977). Macro-invertebrate production can also be impaired, reducing the fishery food base (Phillips, 1971). Excess sediment loading in channels may also cause aggradation, increased bank erosion, and an overall reduction in channel stability. Fine sediments, particularly clays, transported by Tahoe basin streams have been determined to be a significant cause in the decline of lake clarity (Jassby, 1999). Streambank erosion, linked to particulate Phosphorus (PP) loads, has been identified as the primary source of total suspended solids (TSS) in basin streams by numerous studies, including the recent work of Hatch and others (2001).

Land-use activities such as urbanization cause hydrologic changes in a watershed that can in turn result in adjustment of the channel morphology. Peak flow increases of two-to-three fold have been documented in areas with even relatively low-level suburban development (D. Booth, 1990). Generally, channel instability following urbanization will take the form of either channel incision or an increase in channel width and depth. As channels incise, they become disconnected from adjacent floodplain areas, reducing the frequency and extent of over-bank flows. As a consequence, the composition of floodplain vegetation may be altered, the nutrient stripping, sediment deposition, and other water quality benefits associated with floodplain inundation are limited, and additional sediment is delivered to the channel as the bed and banks are eroded.

ENTRIX, Inc., under contract to the ACOE, has performed this study in support of the Third, Incline, and Rosewood Creek Section 206 Aquatic Ecosystem Restoration Project. The following sections discuss the objectives, setting, methods, results, and restoration recommendations.

2.0 OBJECTIVES

The focus of this study was to perform a geomorphic assessment in order to characterize: fluvial processes at the watershed scale, impacts to aquatic habitat conditions, and water quality in the Third, Incline, and Rosewood Creek (TI&R) watersheds. Overall study objectives included:

- Identify historic and present-day channel geomorphic conditions
- Characterize the extent to which changes in historic geomorphic conditions affect aquatic habitat and water quality
- Qualitatively characterize sediment sources and sediment transport capacity
- Describe changes in channel stability
- Conduct a visual assessment of fish passage at road crossings
- Recommend geomorphic restoration measures

This geomorphic assessment consisted of two elements: (1) a broad reconnaissance-level investigation of the entire TI&R watersheds; and (2) a detailed analysis of specific project area reaches identified by the ACOE (Figure 2-1). The specific project area reaches total approximately 11,100 ft of combined channel length (Table 2-1).

Table 2-1. Project Study Reaches

Reach Location	River Station [1] from	to	Distance (ft)
Incline Creek from Lake Tahoe to USGS gage upstream of Lake Shore Drive	0	10+00	1,000
Incline Creek from Incline Way to SR 28	18+25	34+50	1,625
Third Creek from Lake Shore Drive to SR 28	5+04	38+50	3,250
Third Creek from SR 431 to Jennifer Court	137+30	162+30	2,500
Rosewood Creek from SR 28 to Northwood Blvd.	37+55	62+00	2,445
Rosewood Creek along Village Blvd., from Harold Drive to Driver Way	74+40	82+25	785
Study Total			11,605

[1] Channel stationing uses Lake Tahoe (elevation 6,229 ft) as the 0 station.

Figure 2-1. Third and Incline Creek Watershed Study Areas and Project Reaches

3.0 SETTING

The TI&R project watershed study area encompasses a total of approximately 13 mi^2 of steep mountainous terrain draining off the southwest side of the Carson Range towards Crystal Bay in Lake Tahoe (Figure 2-1). Maps showing the location of floodplains, terraces, severe bank erosion, and other geomorphic features in the study areas can be found at the back of the report.

3.1 WATERSHED AREAS AND TOPOGRAPHY

Third Creek has the highest headwater elevation of the study area and the greatest local relief of any other tributary to Lake Tahoe. The upper basin is rimmed by peaks ranging from 9,710 (Rose Knob Peak) to 10,340 ft (Relay Peak) on the west and north sides, with a lower ridgeline on the east side along Tahoe Meadows. Four small headwater lakes feed 8.3 mile long Third Creek.

The headwaters of Incline Creek are primarily located between 8,500 and 9,000 ft, with the maximum of 9,225 ft near the northeast corner of the watershed. Incline Creek flows 5.8 miles to Lake Tahoe.

Rosewood Creek is a 0.5 mi^2 tributary on the southwest side of the Third Creek basin. Rosewood Creek has a lower elevation headwaters, near 6,324 ft. A distinct 1.3 mi channel begins near State Route (SR) 431 and meets with Third Creek in Incline Village about 3300 ft upstream of the lake.

While Third and Incline creeks have similar total drainage areas, their area-altitude distributions are very different (Table 3-1). These differences can affect runoff relationships and sediment yield patterns. Annual runoff and peak discharges of Third Creek exceed that of Incline Creek, primarily because the drainage altitude distribution (Glancy, 1988).

Stream gradients for Third and Incline Creeks vary considerably between the upper and lower watersheds. Third Creek has three distinct profile portions: above 8,000 ft. between 8,000 ft and 6,400 ft. and below 6,000 ft. (Figure 3-1). The area above 8,000 ft has an undulating profile of lower gradient meadows and steeper bedrock-controlled sections. Between 8,000 ft and 6,400 ft elevation (between one mile to just under four miles upstream of the lake), the channel profile is more uniform and steep (ranging from 5 to 36 percent slopes). Below

Table 3-1. Drainage Areas and Altitude Distributions*

		Percent of Drainage in Altitude Zone				
	Total Area (mi^2)	< 7,000	7,000-7,999	8,000-8,999	9,000-9,999	> 10,000
Third	6.03	17	13	35	34	1
Incline	6.98	21	43	35	1	0

*Glancy, 1988

6,400 ft. the profile has a more gentle valley gradient, about 2 to 5 percent. Incline Creek also exhibits gradient changes throughout the watershed (Figure 3-2). A low gradient area of about 2 to 6 percent slopes extends for a little over one mile upstream. The remainder of the Incline Creek profile varies from moderate gradient 'steps' about 4 to 22 percent to steeper, bedrock-controlled areas with slopes from 17 to 46 percent. Rosewood Creek has a moderate to high gradient of about 6 percent, which is similar to that the corresponding portion of Third Creek (Figure 3-1).

Channel gradients within the project reaches (Table 3-2) reflect the portion of the watersheds represented. The study reach on Third Creek upstream of SR 431, has an average gradient of about 11 percent, while the reaches downstream of SR 28 have low to moderate gradients. The reaches on Rosewood Creek have intermediate slopes reflective of their watershed position.

Table 3-2. Project Reach Channel Gradients*

Reach Location	**Reach Gradient (ft/ft)**
Incline Creek from Lake Tahoe to the USGS gaging station upstream of Lake Shore Drive	.02
Incline Creek from Incline Way to State Route 28	.04
Third Creek from Lake Shore Drive to State Route 28	.03
Third Creek from State Route 431 to 2500 ft upstream	.11
Rosewood Creek from State Route 28 to Northwood Blvd	.06
Rosewood Creek along Village Blvd, from Driver Way to Harold Drive	.06

* Calculated from the most detailed map resource for each reach: Harding Assoc, CLD, and USGS 7.5 ' maps.

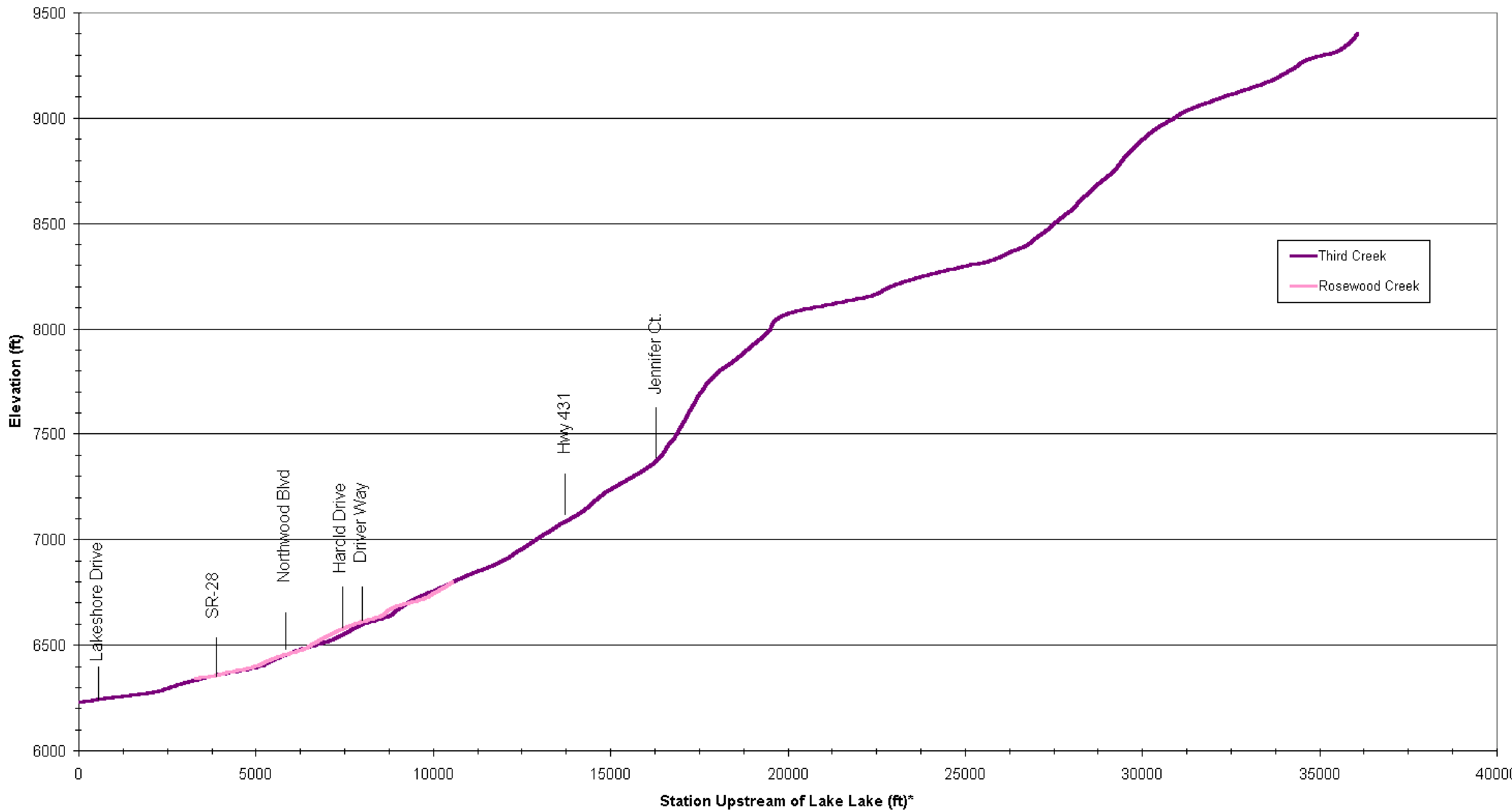

Figure 3-1 Third and Rosewood Channel Profile

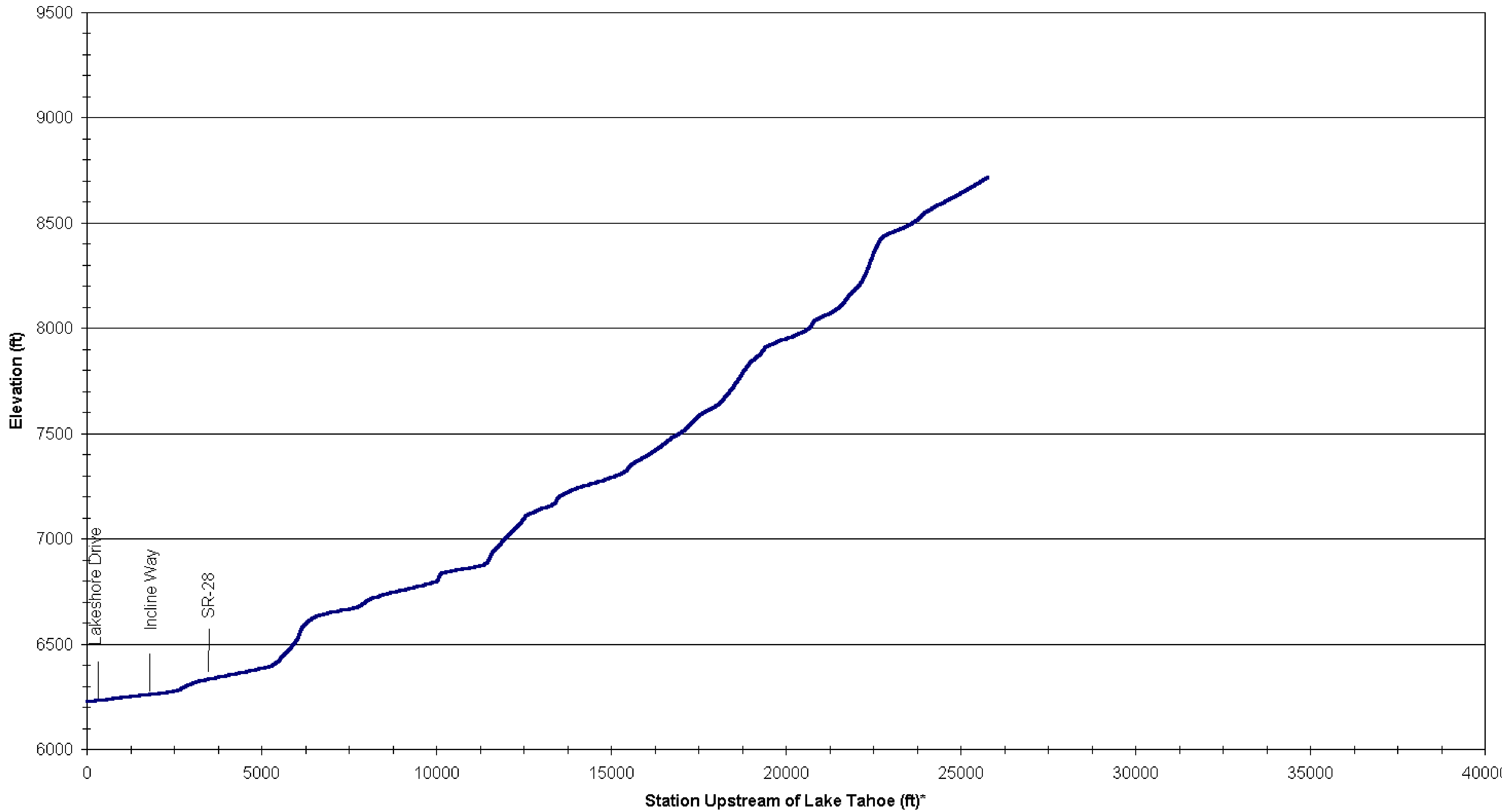

Figure 3-2 Incline Creek Channel Profile

3.2 GEOLOGY AND SOILS

The upper watershed geology of Incline and Third Creeks is composed of Cretaceous granitic rocks of the Sierra Nevada batholith and Tertiary and esitic volcanic rocks, along with Quaternary glacial till (Figure 3-3). The lower watershed surface geology is primarily derived from glacial outwash, alluvium, and lakeshore sediments of Quaternary age (Glancy, 1988). The major stream channels are lined throughout most of their courses by varying thicknesses of unconsolidated colluvium and alluvium. The basin fill deposits in the lower watersheds of Third and Incline creeks are over 1,000 ft thick (Thodal, 1997).

Third Creek drains glaciated granitic uplands of glacial moraines and till deposits between its headwaters and near SR 431. About 3,000 ft upstream from SR 431 the channel erodes through a large debris flow deposit in a narrow canyon. Several shallow landslides, in addition to the debris flow deposit, contribute a significant amount of sediment to Third Creek. Downstream of SR 431, the channel is incised into an alluvial fan that extends to about SR 28. Below SR 28 Rosewood Creek joins Third Creek near the Incline Middle School. Third Creek is entrenched into alluvial stream and lakeshore deposits between SR 28 and Lake Tahoe.

Incline Creek drains strongly dissected granitic slopes with scattered volcanic deposits northeast of the Diamond Peak Ski area. A zone of alluvial and lakeshore deposits extends about 6,000 feet upstream of the Lake.

Lower watershed soils of Third and Incline Creeks are similar, consisting of well drained to moderately well drained stony coarse sandy loams belonging to the Inville (IsC) soil series (Figure 3-4) (USDA Soil Conservation Service, 1974). These soils are deep to very deep over a hardpan, and are described as having a low potential for erosion, probably because they are generally found on flat slopes (2-9%).

Some of the mid-watershed soils in each basin are the same, while the upper watershed soils differ. Both watersheds have areas of Cagwin-Rock outcrop complex and Umpa very stony sandy loam, which have slight and high soil erosion hazard, respectively (Figure 3-4). Meeks very stony loamy coarse sand occurs on steep slopes between the two watersheds and has moderate to high erosion hazard. The upper watershed of Incline Creek includes large areas of Toem-Rock outcrop, characertized by rapid runoff, but slight erosion hazard. The soils of upper Third Creek include large areas of Rock Land (Ra), with low erosion hazard, as well as large areas of Rock Outcrop-Cagwin complex with a range of slopes and high to very high erosion hazards (Figure 3-4).

3-3 Geology of the Third & Incline Creek Watersheds

Figure 3-4 Soils of the Third and Incline Creek Watersheds

3.3 LAND-USE OVERVIEW

3.3.1 MODERN LAND USE

Present land uses of each study area are distinctly different between the upper and lower watersheds. The upper watersheds of Third and Incline Creeks are located in the Toiyabe National Forest and are undeveloped and uninhabited, while the lower watersheds are urbanized, with a range of residential, commercial, and public land uses in the Town of Incline Village.

The upper two-thirds of Incline Creek watershed is primarily undeveloped with steep forested slopes, while the lower third of the watershed is predominantly densely urbanized. The Diamond Peak Ski Resort is located within the Incline Creek watershed and includes lifts and runs upstream and southeast of the urban areas. The most densely urbanized area of Incline Creek basin extends from the Tyrolean Village downstream to the lakeshore for a length of 1.7 miles.

The watershed areas for Third (including Rosewood Creek) and Incline Creeks are shown in Table 3-3 along with the proportion of the drainage area that are within the general urban development boundaries. Approximately 22% of the Third Creek drainage and 30% of the Incline Creek drainage lie within the urban development boundaries. Most of the 0.5 mi^2 of Rosewood Creek drainage area is urbanized.

The upper half of the Third Creek watershed is primarily undeveloped with steep forested slopes and small glacial basins and meadows. SR 431 traverses along East Side of the basin and exits the watershed at the Mount Rose Summit (Figure 2-1).

Table 3-3. Watershed Urban Land Use Areas

	Total Area (mi^2)	Area within Urban Development Boundary (mi^2)	Area within Urban Development Boundary (%)
Third	6	1.3	22
Incline	7	2.1	30

source: Glancy, 1988

Most of Incline Village is fully developed as of 2001, with only about 250 lots still available for building (personal communication, Joe Borgerdine IVGID). In the early 1960s, Incline village was a small resort community with summer homes along Lakeshore Drive and the shorefront of Lake Tahoe. In 1962 the lower half of the community, including all infrastructure, was developed simultaneously. Boise Cascade began developing the rest of Incline Village in the late 1960s.

3.3.2 Historic Land Use

The following timeline outlines past occurrences of human land use in the Third, Rosewood, and Incline Creek area. The timeline was developed for the USFS Tahoe Basin Watershed Assessment (Susan Lindström, 2000), and is the most complete record of historical land-use available to-date. The information includes and expands upon that previously prepared by Lindström (1999) specifically for the Incline/Third Creeks Watershed Project.

3.3.3 Native American Use

Third and Incline Creek were valued by the Washoe as an important food gathering and hunting location. The Washoe's name for Third Creek meant "plunging into water." Both creeks were identified by the Washoe as one of the ten most valued fisheries in the Tahoe basin. Plants for traditional uses were also gathered in the watershed areas. This activity continued until recent decades.

Ma'goiyatwO'tha- Washoe camp near mouth of Incline Creek for collecting berries.

Wa'aba am ("plunging into water")-Washoe word for Third Creek. Recent interviews have provided information about the value of Third Creek to families from the Reno area and is ranked fifth out of ten streams in importance to the Washoe. Third Creek once watered an extensive wet meadowland, similar in the types of wildlife and vegetation to the Truckee River, but smaller in size (Bender, 1963 in George Wright papers).

Out of a list of 10 most desirable watersheds in descending order of resource value, Washoe testimony from Washoe land Claims Case ranks Incline/Third Creek as the fifth most valued fishery in the Tahoe basin (Bender, 1963 in George Wright papers).

Given the late period subdivision development, Washoe traditionalists continued to harvest plants around Incline Village up to the last several decades.

3.3.4 Transportation

The earliest route through the north shore was the Placer County Emigrant Road built between 1852-1855, which later became SR-28. The majority of the transportation infrastructure in the project study area was constructed with the development of the Crystal Bay Development in 1968. Limited road development continued after Boise Cascade Lands in the project watersheds were acquired by the IVGID in 1973.

1852-1855	Placer County Emigrant Road (SR-28) along north shore.
1891	First continuous road over Mt. Rose Pass connecting Reno area and Lake Tahoe (“The Road to Incline”/SR-27/SR-431).
1929	Highway 28 route between Spooner Summit and Incline is graded.
1930s	George Whittell acquires a continuous strip of property from the Bliss and Hobart estates that stretches from Crystal Bay south to Zephyr Cove.
1932	Grading of SR-27 between Incline and Mt Rose Pass.
1950-1960	Construction of SR-431 (replacing SR-27).
1959	9,000 acres of the Whittell estate are sold to Crystal Bay Development Company as Incline Village.
1968	Crystal Bay Development sells Incline Village to Boise Cascade Corporation.
1973	After limited logging, Boise Cascade lands are acquired by Incline Village General Improvement District for subsequent development.

3.3.5 LOGGING

Logging activities played a significant role in the Tahoe Basin, and had substantial effects on ecosystems of the study watersheds. Logging in the study watersheds was carried out by the Sierra Nevada Wood and Lumber Company (SNWLC) between 1878 – 1894. Historical discussions of logging activities in the study watersheds indicate that they were large-scale and intensive. Glancy (1988) demonstrates this by quoting Scott (1957); “By the summer of 1895 the mountain sides surrounding the [Crystal] bay were stripped clean." As a result of the intense, unrestricted logging activities, nearly all old growth pine and cedars were harvested by the turn of the century. Subsequent to Comstock era, second growth of trees covered the watersheds by the 1950s. This second growth was logged by Boise Cascade in the 1960s.

Heyvaert (1998) studied paleolimnological data taken from Lake Tahoe sediment cores in order to reconstruct the basin’s history of disturbance, particularly sediment production. His analysis revealed significant changes in mass sedimentation rates corresponding to two episodes of watershed disturbance over the last 150 years; rapid urbanization since the late 1950’s and clear-cut logging of virgin timber during the Comstock era (1870’s to 1890’s).

During the Comstock era logging, sediment deposition rates increased 7 to 12 fold over pre-disturbance era rates (Heyvaert, 1998). Logging roads were cited as one significant source of sediment production in this period. Watershed erosion and Lake Tahoe sediment deposition rates nearly recovered to baseline conditions soon after Comstock logging ended. The logging effects have been characterized as a “pulse” disturbance, which ceased when logging was discontinued. The implication of this finding is that most stream channels in the Lake Tahoe watershed have the capacity to transport much greater sediment loads than that supplied during un-disturbed periods. Since the beginning of recent urbanization in the late 1950’s, sedimentation rates have increased to about three to four times higher than the long-term pre-disturbance rates. Given the high transport capacity of basin streams, urbanization has the potential to be a chronic source of sediment and nutrients, limiting the clarity and degrading the water quality of the lake (Heyvaert, 1998).

1876-1898	Overall cutting, with intensive cutting lasting half that long.
CA. 1877	Construction of the North Flume by the Virginia and Gold Hill Water Company (VGHWC) to supply water to Virginia City; flume tapped waters of Third Creek and all intervening drainages south to the tunnel on Tunnel Creek; flume was in year round operation until 1944.
1878	SNWLC, probably the second largest lumbering and flume outfit in the Tahoe basin formally commences operations in the northeastern quadrant of the Tahoe Basin; the SNWLC also did considerable cutting in the southeastern quadrant of the basin, in partnership with its land-holding subsidiary, Nevada Lumber Company (NLC); SNWLC owned 55,000 acres in the basin, about 43,000 acres were logged in the Washoe and Douglas counties with the remaining 12,000 acres in placer county being traded away to the Truckee Lumber company (TLC) after SNWLC cutting ceased in the basin; the company operated a logging complex which included a narrow gage railroad, rafting on Lake Tahoe an inclined tramway, V-flumes, wagon haul roads, wood camps, and a mill at incline; initial cutting by SNWLC probably commences about one mile north of Crystal bay.
1879-1894	SNWLC Incline Mill operates at 75,000 feet a day.
1880-1890	SNWLC builds a 4000-foot-long tramway at their Incline mill; at the top, wood was dumped into a v-flume (built originally by VGHWC) and carried through a tunnel down to Washoe Valley to a storage yard served by the Virginia and Truckee Railroad (VTRR); a steamer rafted logs from the South Harbor, where logs were loaded onto a logging railroad.
1880-1890	Most intense period of timber harvest and engineering for water supply and wood transport.
1889	SNWLC initial cut is 8 million feet of lumber and 50,000 cords of fuel wood.
1881-1885	SNWLC peak cordwood production in Washoe County (around Incline).

1880	43,000 acres of SNWLC land in the Tahoe Basin stripped of trees.
1887	Incline Mill produces peak cut of 12 million feet of lumber.
1890-1891	SNWLC peak operations close down.
1894	Last major logging season for SNWLC.
1960s	Limited second growth logging around Incline by Boise Cascade.

3.3.6 GRAZING

Some grazing was likely to have occurred in the meadows of the upper Third Creek watershed in conjunction with the Comstock era logging. After logging, many cut over lands were leased to ranchers for grazing. Unrestricted grazing led to practices such as grazing too early in a season and using small fires to improve soil productivity. Restrictions on timing and location on grazing alottments were put in place in the 1930's to control overuse. (Lindstrom 2000).

1910s-1950s	With demise of logging, cutover lands are converted to grazing.

3.3.7 WATER MANAGEMENT

Water management in the study watersheds was most active during the Comstock era logging with water diverted to supply communities (out of basin) and to support lumbering operations (including out of basin fluming). The Virginia and Gold Hill Water Company (VGHWC) tapped Third Creek as a year round water supply for Virginia City between 1877-1944. During 1881 – 1890, intensive logging in the study watersheds required water to transport lumber into Washoe Valley for further distribution and into the Incline Mill for processing.

Incline Lake is a regulated reservoir in the in the headwaters of the east branch of Third Creek, to the west of Mount Rose Highway (SR 431). The reservoir is privately owned and operated by installing or removing flashboards. Operation of the flashboard control structure has apparently been identified as an occasional source of flow that surges into Third Creek, flushing accumulated organic material and sediments downstream (Swanson, 2000).

1939	VGHWC deeds five inches of water from the North Flume to Norman Blitz at Incline Lake.
1950s	North Flume is abandoned.

4.0 METHODS

Our reconnaissance level assessment of watershed and project area geomorphic processes included a review of existing reports and maps and field observations. Existing maps and reports reviewed include county soil surveys, bedrock geology mapping (Tahoe Regional Planning Agency), streamflow and sediment transport data (Glancy, 1988), erosion and sedimentation studies (Swanson, 2000 and Watershed Restoration Associates, 1999), and other relevant sources of information, emphasizing those with specific information on the study watersheds.

Focussed field observations in the project reaches for this study include an evaluation of streambank stability, channel classification, streambed particle size composition, and indicators of erosion and sedimentation.

4.1 STREAMBANK STABILITY

Streambank stability was evaluated along the six project reaches. Stability was rated by considering the following streambank characteristics:

- Bank Height
- Bank Slope
- Bank Material
- Vegetation Density
- Vegetation Type
- Vegetation Rooting Depth

Bank stability was rated using each of the above characteristics and a procedure similar to that developed by Rosgen (1996). Overall bank erosion was classified into one of 5 categories: none, low, moderate, high, and severe. In addition, bank erosion was classified based on the frequency of occurrence ranging from none, infrequent, intermittent, and frequent or continuous.

Each of the above characteristics was rated using a field form (provided in Attachment A). The rating form was used for approximately every 500-700 ft along each of the channel project reaches, unless it was apparent that conditions had not changed, in which case longer segments of channel were rated. In addition to the assessment of bank stability, the type of existing bank failure(s) was also recorded.

4.2 CHANNEL CLASSIFICATION

In each of the six project reaches the channel was classified using the Montgomery–Buffington (1997) system and the Rosgen (1996) classification system. The Montgomery-Buffington and Rosgen channel types were determined in conjunction with bank stability ratings for approximately every 500 ft of channel, or larger intervals if it appeared that the channel type was consistent.

The Montgomery-Buffington classification synthesizes stream morphology into seven reach types based on distinctive bed morphology (Table 4-1). Associated with each channel type are additional diagnostic features that are based on typical bed material, dominant roughness elements, dominant sediment sources and storage elements, typical confinement, and typical pool spacing. The Montgomery-Buffington channel type is determined by visual observations, with no measurements necessary for classification.

The Montgomery-Buffington classification, developed for streams in the Pacific Northwest, is best suited to describe gravel, cobble, and boulder bed streams in mountainous terrain, from steep headwaters to low gradient valleys and plains. Each channel type in the Montgomery-Buffington system corresponds to differences in the ratio of transport capacity to sediment supply. Further, this allows identification of each channel type as predominantly a supply- or transport-limited segment. The sediment transport/sediment supply category associated with each channel type is shown in the last row of Table 4-1.

Table 4-1. Diagnostic Features of the Montgomery-Buffington Channel Types [1,2]

	Dune - Ripple	Pool -Riffle	Plane -Bed	Step -Pool	Cascade
Typical bed material	Sand	Gravel	Gravel- cobble	Cobble-boulder	Boulder
Bedform pattern	Multilayered	Laterally oscillatory	Featureless	Vertically oscillatory	Random
Roughness elements	Sinuosity, banks, grains, bedforms (dunes, ripples, bars)	Bedforms (bars, pools), sinuosity, banks, grains	Grains, banks	Grains, banks	Grains, banks
Sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure, debris flow	Fluvial, hillslope, debris flow	Fluvial, hillslope, debris flows

Table 4-1. Diagnostic Features of the Montgomery-Buffington Channel Types [1,2] (continued)

	Dune -Ripple	Pool -Riffle	Plane -Bed	Step -Pool	Cascade
Sediment storage	Overbank, bedforms	Overbank, bedforms	Overbank	Bedforms	Lee and stoss sides of obstructions
Confine ment	Unconfined	Unconfined	Variable	Confined	Confined
Pool spacing (channel widths)	5 to 7	5 to 7	none	1 to 4	<1
	Transport-limited	May have both Supply- and Transport-limited characteristics	May have both Supply- and Transport-limited characteristics	Supply-limited	Supply-limited

[1] Two non-alluvial channel types are not shown in this table, bedrock and colluvial. Bedrock is not an adjustable, alluvial stream type. Colluvial channels are small headwater streams that flow over colluvial valley fill and exhibit weak or ephemeral fluvial transport. Although these stream types may occur in the Incline and Third Creek watersheds as first order channels, none of the project reaches are located in the headwaters on colluvial slopes.

[2] based on Montgomery and Buffington, 1997

Preliminary identification of Rosgen Level 1 channel types was also made. Rosgen classification is based on morphometric parameters that distinguish channel types based on gradient (water surface slope at bankfull discharge), width-depth ratio (bankfull width/bankfull depth), sinuosity (channel length/valley length), and entrenchment ratio (floodprone width/bankfull depth) (Table 4-2). There are 8 basic channel types, which are each further subdivided into several additional categories based on bed particle size.

Typically, the Rosgen classification at a Level 2 resolution is determined based on detailed field measurements that require identification of the bankfull water surface elevation. Morphological features that were indicative of the bankfull elevation (for example, inside tops of point bars, tops of undercut banks, topographic flat adjacent to channel) were identified. However, we did not perform detailed measurements (using an engineers level) in order to quantify the width-depth ratio and entrenchment ratio needed to definitively identify channel type. Rather, these morphometric parameters were estimated by eye using a fiberglass tape and level rod. Channel gradient and sinuosity were determined from available topographic maps.

Table 4-2. Morphological characteristics of the Rosgen Level 1 stream types

Stream Type	Morphological Characteristics
A	Step-pool or cascading; plunge and scour pools, high gradient and high energy, low sediment storage, entrenched, low width-depth ratio, low sinuosity, stable
B	Riffles and rapids; some scour pools, bars occur but infrequent, moderate gradient, moderately entrenched, moderate width-depth ratio and sinuosity, stable
C	Pool-riffle; meandering, point bars, floodplain, high width-depth ratio, slightly entrenched, high sinuosity, low to moderate gradient, banks can be stable or unstable
D	Braided; multiple channels, shifting bars, deposition, high sediment supply, bank erosion, no entrenchment, high width-depth ratio, low sinuosity, and low gradient
DA	Anastomsing; multiple stable channels, pool-riffle, vegetated floodplain and bars, stable banks, high width-depth ratio, no entrenchment, low sinuosity, and low gradient
E	Meadow meanders; well-developed floodplain, pool-riffle, high sediment transport, low width-depth ratio, slightly entrenched, low to moderate gradient, high sinuosity
F	Valley/Canyon meanders; incised into valleys, small or no floodplain, pool-riffle, banks can be either stable or unstable, highly entrenched, moderate to high width-depth ratio, moderate to high sinuosity, moderate slope
G	Gully; incised into hillslopes, alluvial fans, and meadows, high sediment supply, unstable banks, step-pool, entrenched, low width-depth ratio, moderate sinuosity, moderate gradient

Source: Rosgen 1996.

4.3 PARTICLE SIZE ASSESSMENT

Bed particle size characteristics were evaluated at the same intervals and locations where channel classifications were performed (approximately every 500 ft, or more if channel type did not appear to change). Riffles were selected for the particle size characterization to provide consistency between sampling locations. However, this generally creates a bias for the overall characterization of particle sizes on the streambed, since riffle sites are typically composed of coarser particle sizes compared with pools or other morphological units. Therefore, visual observations, estimates of fine sediment depths, and photographs of the particle sizes associated with pools, debris jams, and other morphological units were also made.

Streambed particle sizes were characterized using three different methodologies: visual estimates, pebble counts, and bulk sampling. In addition, samples of streambank material were collected at two locations on Third Creek. The location of pebble counts, bulk samples, and bank samples are shown in Figure 4-1.

Embeddedness measures the extent to which larger particles are buried by fine sediment. Increasing embeddedness may reflect an increased input of fine sediments to the stream. Increased fine sediment as measured by embeddedness can be an indicator for reduced invertebrate production and reduced over-wintering habitat for salmonid fry. Chapman and McLeod (1987) noted lower aquatic insect densities when embeddedness exceeded 65-75% and salmonid densities declined with an embeddedness of 50% or more. Salmonid reproductive success can be adversely affected with excessive fine sediment due to a decrease in gravel permeability and intragravel dissolved oxygen. Embeddedness was visually estimated at each of the selected riffle locations for channel classification and bank stability rating. Embeddedness was recorded as the percentage of burial of coarser particle sizes (gravels and larger) by fines (sands, silts, clays).

Pebble counts were performed using standard techniques developed by Wolman (1954) in order to characterize bed surface particle sizes in the selected riffles. The pebble count data was reduced and plotted as cumulative particle size distributions (Attachment B).

Five bulk samples were collected to characterize bed subsurface material size. Three samples were collected within the designated project reaches (Rosewood Creek station 56+40, Incline Creek station 30+12, Third Creek station 26+75). Two additional samples were collected upstream of urban areas for comparison to the urbanized project reaches, including Incline Creek near the Diamond Peak Ski Area, and Third Creek above SR 431 near the fire station (Figure 4-1). Samples of bank material were also collected on Third Creek above Lake Shore Drive and above SR 431.

Bulk samples were collected using a modified McNeil sampler with a 12-inch diameter opening. For the three samples collected within the project reaches, pebble counts were first performed on the riffle unit, then the surface material was removed by hand over the bulk sample site. The sampler was sunk into the

Slip Page: (map from Tim Blewett)

Figure 4-1. Location of pebble counts, bed material samples, and bank material samples

bed and material removed to a depth of approximately 4-inches. For the samples collected from Third Creek and Incline Creek upstream of the project reaches, no pebble counts were performed. A combined bed surface and subsurface was sampled by removing materials to a depth of approximately 6-inches, so that the subsurface material was sampled to a depth of approximately 4-inches in each of the two samples. Samples were always collected near the head of a riffle at the selected sites.

Bank samples were collected from approximately the bankfull elevation using a hand trowel.

All bulk samples were transported from the collection site in 5-gallon plastic buckets for later sieving. The samples were spread on tarps to drain and air-dried for several days. When the fines in each sample appeared to be completely dry, the material was sieved using standard ASTM screens. For coarser material 16mm and larger, ½-phi size intervals were used for sieve screens. For finer material less than 16mm, whole phi size sieve screen intervals were used down to the 0.5mm size. Weights were recorded for each size fraction and graphed as cumulative particle size distribution curves and frequency histograms representing each particle size class. Bank samples were sieved in the same manner as the bed samples (Attachment B).

In the field, the commonly used “feel method” was employed to determine the texture and presence of sand, silt, and clay in bank samples. The “feel method” sampling procedure is to form a wetted soil ribbon by hand from a portion of the bank sample. A plastic or sticky feel in the ribbon, is associated with a higher clay content. Atalcum-powdery, smooth feel is associated with higher silt content. Sand is associated with a gritty feel.

In addition to the assessments described above, the following geomorphic and habitat characteristics of the project reaches were identified and noted on field maps:

- active floodplain and terrace surfaces adjacent to the project reaches
- location of remnant channels
- site-specific locations of significant, accelerated erosion
- existing bank erosion control treatment sites
- typical pool depths (randomly measured)
- indicators of bed aggradation, degradation (i.e., nickpoints), or equilibrium

- potential fish passage barriers, including culverts and grade control structures at streamflow gaging weirs

The watershed reconnaissance expanded on the project reach field assessment with observations of channel conditions throughout the Incline Creek and Third Creek watersheds. We selected locations along the mainstem of both streams between the project reach areas up to the headwaters, as access allowed. The watershed observations include a preliminary identification of channel type, estimate of dominant bed particle size, estimate of the extent of fines present on the bed, estimate of the relative magnitude of existing bank erosion, and consideration of likely sediment sources and contribution of land-uses to sediment production.

4.4 MAPPING

This study did not include new efforts to survey or map the stream reaches or watershed. Locations were described in the field using hip chain (in the study reaches), urban landscape features, and the available topographic maps at the time of the field assessment. Subsequently, river stationing for the entire watershed (stream profiles) was prepared from USGS 7.5 minute quadrangle data. Detailed AutoCAD files for most of the study reaches were used to refine stationing within the study areas for presentation in the report. Therefore, the stationing provided herein should be considered approximate.

5.0
RESULTS AND DISCUSSION

Channel geomorphic conditions are discussed separately for each of the project area reaches, by stream. Following the discussion of the project reaches, a summary of overall channel stability, and erosion/sedimentation conditions for each stream is provided. Results of the culvert inspections for potential fish migration barriers are discussed separately in Section 6.0. Figure 4-1 shows all sampling locations.

5.1 THIRD CREEK

There are two project study reaches on Third Creek, from Lake Shore Drive to about 100 ft upstream of SR 28 (stations 5+04 to 38+55), and upstream of SR 431 to about Jennifer Court (stations 137+31 to 162+31) (Figure 2-1).

Lake Shore Drive to State Route 28

While one channel type dominates this reach, a second distinct channel type occurs in the downstream portion of the reach (Figure 5-1). About 82 percent of this reach, from station 11+00, upstream of Lake Shore Drive, to station 38+55 at SR 28, has relatively similar geomorphic characteristics. An approximately 600 ft long segment of channel from station 5+04 (Lake Shore Drive) to upstream of the USGS gaging station (station 11+00) has a different channel type.

Stations 11+00 to 38+55

The dominant channel type in this Third Creek project reach is moderately well incised into unconsolidated Lake Tahoe shoreline sediments and alluvial fan deposits. The channel has narrow width relative to depth (low width/depth ratio), low sinuosity, moderate gradient, and moderate entrenchment (Table 5-1). The channel dimensions and planform pattern observed in the field are most indicative of a Rosgen G-type classification. The G stream types are usually observed in landform features such as alluvial fans, landslide debris, and incised headcut gullies (Rosgen, 1996). Soils are unconsolidated alluvial and colluvial material, as exemplified by the local Inville stony coarse sandy loam.

G channels typically have high bank erosion and bedload transport rates and are considered very unstable (Rosgen, 1996). The ratio of bedload to total sediment load often exceeds 50% (Rosgen, 1996). These sediment supply characteristics

Figure 5-1. Channel Types Third Creek and Incline Creek Downstream of SR 28

are supported by a USGS study (Glancy, 1988) conducted in 1972 and 1973 that found suspended loads were about one-fourth of total sediment loads measured at the gaging station just upstream from Lake Shore Drive.

Table 5-1. Representative Channel Characteristics: Third Creek, Stations 11+00 to 38+55

	Station 19+04	Station 23+52	Station 30+31
Slope (ft/ft)	.035	.035	.035
Sinuosity (channel length/valley distance)	1.0	1.0	1.0
Width/Depth Ratio (bankfull width/bankfull depth)	6.5	5.8	6.3
Entrenchment Ratio (floodprone width/bankfull width)	2.0	1.6	2.2
Riffle D_{50} (mm)	28	--	45

Based on the Montgomery-Buffington classification system, this reach of Third Creek corresponds most closely to an intermediate morphology incorporating characteristics of both a Pool-Riffle stream type and a Step-Pool stream type. Montgomery and Buffington (1997) acknowledge that their description of channel types may be considered as identifiable members along a continuum that includes intermediate morphological types.

The pool-riffle channel is characterized by an undulating bed that defines a sequence of bars, pools, and riffles (Montgomery and Buffington, 1997). This type of bedform is apparent in Third Creek, although the point and alternate bars are both infrequent and of a relatively small-scale. Although the channel in this reach does not have unconfined well established flood plains like a type of pool-riffle. The channel is mostly confined (i.e., moderate entrenchment ratio), and the adjacent "floodplain" does not appear to be subject to frequent flows (defined here as about twice out of every three years). This is based on the fact that indicators for modern bankfull are well below the top of bank, and there are no indicators of recent flood flows (i.e., trash lines, sediment deposits) at or above the top of bank. Rather, flows much larger than bankfull are necessary to flood the adjacent valley flat, which is therefore functionally a terrace, rather than a floodplain. According to Montgomery Buffington (1997) step-pool morphology is generally associated with steep gradients, small width-to-depth ratios, and pronounced confinement by valley walls. The step-pool channels have slopes of 3% to 6.5%, which is within the range of this reach. Accordingly, a "riffle step" (pool riffle-step pool) may be the best way to describe this intermediate channel classification.

Over most of the Lake Shore Drive to SR 28 reach, riffles are primarily heterogeneous mixtures of gravel with some cobble and sand. The median particle size (D50) ranges from 28 mm to 45 mm, based on pebble counts in the riffle sampling sites (see Table 5-1). Embeddedness is consistently 25% in all sampling sites. It is significant that except for riffles, sand is the dominant particle size on the bed and on most bars. Small woody debris jams typically impound sand (Figure 5-2). Sand is also the dominant particle size in pools. These are all indicators of significant amounts of sand material in transport.

A bank sample from Third Creek at Station 6+00 (Figure 4-1) has a D50 about 1mm (Attachment B, Station 6+00). Using the "feel method", very little silt or clays are present in the portion of the sample less than 0.5 mm.

A bed subsurface material sample collected downstream of SR 28 (station 30+31) has a median particle size (D50) of 19mm, which is finer than the 45 mm D50 of the surface pebble count data (Attachment B, Station 30+31). This vertical increase of fines with depth is consistent with typical geomorphic conditions (Everest et al, 1986).

Although excessive levels of fine sediment are commonly acknowledged to limit spawning success, there is no single particle size statistic that adequately relates fine sediment composition to survival. Kondolf (2000), based on a review of laboratory and field studies suggests that sediments finer than 1mm can reduce gravel permeability affecting dissolved oxygen content and removal of metabolic wastes from the redd (the nest). Larger sediments in the 1 to 10 mm size range are generally considered to be responsible for inhibiting fry emergence through interstitial gravel spaces. Based on Kondolf's (2000) compilation of laboratory and field studies, the following maximum percentages for allowable fine sediment content of sampled gravels are used:

- Maximum percentage finer than 1mm is 14%
- Maximum percentage finer than 3 mm is 30%

The percent finer than 3mm was 16%, percent finer than 2mm (i.e., sands and smaller) was 11%, and the percent finer than 1mm was 6%. The percent finer than 1mm and the percent finer than 3 mm are not exceeded in this sample based on the above criteria. Although the bed material sampling sites were not selected for their suitability as spawning sites, the sediment levels suggest that spawning gravels are not adversely affected by fines.

(use photo #57)

Figure 5-2. Photograph of sand impounded behind a woody debris jam on Third Creek. This site is located about 600 ft downstream of Incline Way. Station B+50

Small plunge pools occur in association with woody debris jams in the reach, although most pools were freely formed rather than forced. Maximum pool depths at the time of the survey were never greater than 1.5 ft and were typically about 1-ft depth. The pools have a very small total volume and rarely exceeded one bankfull width in length (10-15 ft length).

Overall, bank erosion in this reach is moderate, occurring intermittently. There are distinct, but isolated locations where bank erosion is high. These locations were noted on the field topographic maps and added to the electronic AutoCAD files. The erosion potential is high, due to the fine-grained, sandy, non-cohesive nature of the bank material, and top-of-bank heights greater than the bankfull elevation. However, dense vegetation with rooting depths equal to or greater than the top of banks is an important counter-balancing element that helps to maintain bank stability. Streambank erosion potential was rated as high, with some smaller segments rated as very high and extreme in a previous bank erosion survey (Swanson, 2000). However, the two studies are not strictly comparable given the different classification categories and different rating procedures.

This reach has channel morphology that is not in equilibrium, with evidence of past incision and ongoing channel widening. Past incision is inferred from root exposures of trees perched at the top of channel banks, abandoned remnant channel fragments on low terraces, and vegetation patterns. It is not likely that incision is presently occurring. This is due to three factors: (1) the culvert crossings at Lake Shore Drive, Incline Way, and SR 28 act as grade controls, (2) there were no channel nick-points observed, and (3) the channel is actively widening, which reduces shear stress on the bed. In addition to the grade control provided by the culvert crossings, Lake Tahoe also provides some local base-level control, as fluctuations in the lake's water surface elevation can influence the channel conditions downstream of this reach.

The channel is widening by a process of cutting at the toe of the bank. Random field measurements indicate 2 to 5 ft of undercutting in this reach. Figure 5-3 is an example of a section of bank that is undercut approximately 5 ft, located about 700 ft upstream of Lake Shore Blvd. Once the undercut extends far enough into the bank, the bank collapses. Interestingly, collapse does not always result in mass-failure or complete washout of the bank soil. We often observed sections of streambank that collapsed as a cohesive, integral unit. In these instances the bank section appeared to cantilever down along a hinge axis parallel to the channel, corresponding roughly to the depth of the undercut, so that the bank came to rest at a new, lower angle of repose. Figure 5-4 shows a section of bank after undercutting and collapsing as an integral unit. The dense riparian vegetation and associated root-mass is undoubtedly an important component holding the surface bank soil together, and allowing the upper portion of the bank to fail as an integral unit rather than always completely washing out.

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Use photo #47

Figure 5-3. Bank undercutting to a depth of 5 ft on Third Creek (station 12+00)

Use photo #53

Figure 5-4. Bank collapse as an integral unit on Third Creek (station Station 17+74). The survey rod indicates the new bank angle of repose.

It is notable that although undercutting leads to bank collapse, erosion, and channel widening, there is a habitat benefit for fish. The undercut banks provide excellent cover from predators, particularly during low-flow periods, and high-flow refuge during flood events. This may be a very important component of fish habitat given the lack of deep pools on Third Creek.

Two additional erosion mechanisms were observed on this reach of Third Creek. Direct surface scour by high flows intermittently along the streambank and footpaths and access trails crossing the banks. Surface scour is probably not as significant in terms of either sediment production or channel widening as undercutting. Of greater importance is the influence of footpaths and foot traffic near the channel (Figure 5-5). Many of these footpaths and access points have resulted in loss of the ground cover, leading to sloughing of sandy bank material directly into the channel. Erosion associated with foot traffic along informal trails is a direct accelerated form of sediment production, although surface scour may be affected buy human influences on peak flows.

Stations 5+04 to 11+00

The most downstream 600 ft of the project reach exhibits different geomorphic characteristics from the remainder of the reach. While the channel still exhibits low sinuosity, it is noticeably less entrenched. Based on the channel geomorphic characteristics (Table 5-2), a Rosgen C type channel is probably most representative. The most distinguishing feature of this portion of the channel is the adjacent floodplain (about 60 ft wide) on the Right Bank, which provides for over-bank flows and hydraulic release during floods. The Montgomery Buffington classification is Pool-Riffle.

The median riffle particle size, based on pebble count, of 40 mm, embeddedness of 20%, and moderate, intermittent bank erosion are very similar to the characteristics of the remaining, upstream portion of this reach.

Table 5-2. Representative Channel Conditions: Third Creek, Stations 5+04 to 11+00

	Station 10+04
Slope (ft/ft)	.015
Sinuosity (channel length/valley distance)	1.0
Width/Depth Ratio (bankfull width/bankfull depth)	10
Entrenchment Ratio (floodprone width/bankfull width)	3.0
Riffle D_{50} (mm)	40

Slip Page: Use photo # 65

Figure 5-5. Example of streambank erosion caused by foot-traffic along Third Creek. Near (22+00)

Third Creek Upstream of SR 431 to Jennifer Court

The 2,500 ft study reach on Third Creek upstream of SR 431 exhibits a channel incised into, and confined by narrow depositional slopes associated with glacial till and landslide debris. Steep gradients, over 10% are typical (Table 5-3). The D50 riffle bed particle size of 128 mm, based on pebble counts, reflects the coarse substrate (see Attachment B, station 146+38). Bed surface material is dominated by cobble and small boulders, although sand is present. Sand deposition is evident behind a woody debris jam near the upstream boundary of this project reach. The active channel dimensions and bed material are typical of a Rosgen A3 stream type (Figure 5-6). The A3 channel type usually has a step-pool or cascade bed form (Rosgen, 1996), which is exemplified by the Cascade channel type (Montgomery and Buffington, 1997) within this project reach (Figure 5-7).

Table 5-3. Representative Channel Conditions: Third Creek, Stations 137+31 to 162+31

	Station 145+38
Slope (ft/ft)	.11
Sinuosity (channel length/valley distance)	1.0
Width/Depth Ratio (bankfull width/bankfull depth)	6.0
Entrenchment Ratio (floodprone width/bankfull width)	1.3
Riffle D_{50} (mm)	128

The A and Cascade stream types are typically high gradient systems with a correspondingly high sediment transport rate (Rosgen, 1996, and Montgomery and Buffington, 1997). Generally, A and Cascade type channels have sediment transport capacity that exceeds sediment supply. However, the local valley fill in this vicinity is comprised of shallow landslide and debris flow deposits, with poorly vegetated side slope surface soils. Sediment sources from upstream reaches also appear abundant. The valley cross section shape indicates that the modern A channel is inset within a gully that has partially, but not entirely, eroded through older alluvial and colluvial material. Field observations indicate that sediment supply is derived from the reworking of the landslide and debris flow materials, and lateral bank scour during high flow events (Figure 5-8). During periods where sediment supply to the channel through slope processes exceeds the runoff required for transport, this reach is expected to have excess sediment until such time as the normal excess transport capacity relationship is re-established.

Slip Page: (Tim Blewett Map)

Figure 5-6. Channel Types Third Creek Above SR 431

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Figure 5-7. Entrenched, confined channel with cascade bedform, Third Creek upstream of SR 431 (station 157+00).

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Figure 5-8. Shallow landslide on Third Creek upstream of SR 431 (station 150+00).

A sample of bank material obtained near the upstream end of the project reach (Attachment B, station 153+18) has a D50 of 1 mm. Nearly 39% of the sample was less than 0.5 mm and 40% of the sample was between 0.5 and 2 mm in size. The portion of the bank material less than 0.5 mm is estimated to be predominantly fine sands (>0.0625mm) based on the "feel method", with very little silt or clay present. This particle size distribution is very similar to the bank material composition collected from a sample upstream of LSD (Station 6+00).

A bulk sample of combined surface and subsurface bed material has a D50 of 58 mm (Attachment B, station 137+82). The much higher stream gradients and combined surface/subsurface sampling upstream of SR 431 (11%) would be expected to result in coarser bed material. The percentage finer than 1mm was 4% and the percent finer than 3mm was 12%, both within the criteria for spawning gravels (14% and 30%, respectively). The percent of fine sediments within this sample were slightly less than that obtained downstream (below SR 28, station 30+31).

5.1.1 Third Creek Channel Stability, Erosion & Sedimentation

The upstream half of Third Creek, approximately 4 miles, drains a relatively non-urbanized portion of the watershed upstream of SR 431 (Figure 2-1). This steep gradient upper watershed is best characterized as a high sediment recruitment and transport reach. While sediment transport capacity is generally greater than sediment supply, this does not mean the sediment load generated is small. In fact, a large proportion of the total sediment load in the Third Creek watershed is probably generated from the hillslope and channel erosion processes in this non-urbanized half of the drainage basin. The observed large-scale sediment sources associated with debris flows, landslides, and other hillslope process that deliver sediments directly to the channel upstream of SR 431 do not occur downstream. Minor streambank erosion, incision, and road-related sediment production are the largest sources of sediment recruitment between SR 431 and Lake Tahoe.

The hillslope sediment generating processes in the upstream half of the watershed, particularly debris flows and landslides, tend to occur on an episodic basis. Debris flows and landslides are activated by infrequent but significant storm events (rain-on-snow, snow avalanches, 20-100 year recurrence interval storms). Following such a storm event, a debris flow or landslide will nearly instantaneously deliver a large volume of sediment to the channel. A portion of this sediment may be stored in a section of the channel for a period of time buffering the impact of sediment delivery to the reaches further downstream, but causing long-term disequilibrium and channel changes such as aggradation where the sediment is deposited and stored. Streams in steep mountainous terrain store little sediment for relatively short periods of time, but rivers in broad alluvial valleys store larger quantities of sediment in features such as bars for periods of years, and on floodplains for perhaps hundreds or thousands of years.

Given the large-scale, episodic sediment delivery processes present in the upper half of the Third Creek watershed, it can be expected that there will always be some periods when sediment delivery and bedload transport is dramatically increased. However, it is difficult to predict how and where the channel downstream will respond when such events occur, and what the rate of recovery may be. In general, sediment deposition and storage is greatest in reaches having large valley widths and gentle channel gradients (Madej, 1992). Therefore, it is most likely that downstream of SR 28 to the lake, the channel will be most affected. Between SR 431 and SR 28, the channel is a transport zone, and gradients are between 3%-6%, so potential changes in channel morphology will not be as great as further downstream. Storage and deposition of sediments is most likely to affect the channel below SR 28 where the gradients decrease to less than 3%. The nature of channel changes due to increased sediment inputs are likely to include increased lateral instability, bank erosion, and deposition of sediments in pools and riffles. Probably the best way to moderate potential effects of episodic sediment inputs to this section of Third Creek is to provide more opportunities for long-term sediment storage in floodplain areas.

Inspection of Third Creek between SR 431 and Village Blvd indicate that the channel has Cascade and Step-Pool bedforms, with cobble and gravels as the dominant particle size. Thus, this section of channel is also a sediment transport zone. A little further downstream, below Driver Way at the Championship Golf Course, sand size particles begin to become more prevalent on the bed as gradients decrease to less than 6%. Below SR 28 the stream begins to transition to a Pool-Riffle channel type, and gradients further decrease to less than 3%.

As a G stream type below SR 28, Third Creek is considered to be very sensitive to disturbance, with adverse adjustments occurring due to changes in the flow regime and sediment supply of the watershed (Rosgen, 1996). Third Creek has experienced a range of natural and human-induced changes in the flow and sediment regime over the past 100 to 150 years. It is difficult to assess the relative importance of each factor, given the combinations of direct and indirect effects (e.g. channel rerouting/ bank stabilization, water fluming and export, logging/clearing (multiple periods), road building and drainage changes (repeated), urban development), natural climatic cycles, and the complex process-response of streams.

Recent channel widening and incision are probably related to urbanization in the watershed, which accounts for approximately 22% of the total drainage area. The increased impervious surface area from parking lots, roads, commercial and residential buildings and related infrastructure reduce infiltration and increase peak flows. Storm drains and roadside ditches typically reduce travel times and have low roughness, which accelerates runoff and increasing peak storm flow. Increased peak flows and velocities create higher shear stress on bed materials. Once downcutting is initiated, the process tends to be self-reinforcing, and will persist until a new equilibrium slope and channel width is achieved.

Runoff volumes and peak flows on Third Creek have also been increased directly by the prior (uncertain year) rerouting of Rosewood Creek. Rosewood Creek currently joins Third Creek about 450 ft downstream of SR 28 (about station 33+00). However, the natural (i.e., pre-development but not necessarily pre-Comstock era) channel alignment did not join Third Creek, but rather flowed directly to Lake Tahoe (Joe Borgerding, 2001). A remnant channel of Rosewood Creek is apparent downstream of Incline Way, west of Third Creek. A restoration plan by IVGID will route Rosewood Creek into this remnant channel, although it will still join Third Creek upstream of the Lake Shore Drive culvert. By re-occupying its former channel, Rosewood Creek will no longer contribute additional flows to Third Creek near SR 28, reducing peak flows on Third Creek between stations 33+00 and the lake.

5.2 ROSEWOOD CREEK

The two project reaches on Rosewood Creek are between SR 28 and Northwood Blvd (stations 44+00 to 62+00) and along Village Blvd between Harold Drive and Driver Way (stations 74+40 to 82+25) (Figure 2-1).

5.2.1 ROSEWOOD CREEK BETWEEN SR 28 AND NORTHWOOD BLVD

Stations 44+00 to 62+00

Most of this 0.4 mi reach is steep, deeply entrenched, low sinuosity channel with a low width-to-depth ratio (Table 5-4). Based on these geomorphic characteristics, the channel is classified as a Rosgen A-type (Figure 5-9). The median riffle particle size, from pebble counts, is 22 mm, with 40% embeddedness. The median bed subsurface particle diameter is 8 mm (Attachment B, station 56+40). The percent finer than 1mm is 12% and the percent finer than 3mm is 30%. This site has the greatest amount of fine sediment for any of the bed material samples, and is consistent with visual observations of bed conditions. These percentages nearly exceed the upper limit for fine sediment content of spawning gravels.

Table 5-4. Representative Channel Conditions: Rosewood Creek, Stations 44+00 to 62+00

	Station 56+40
Slope (ft/ft)	.06
Sinuosity (channel length/valley distance)	1.1
Width/Depth Ratio (bankfull width/bankfull depth)	4.5
Entrenchment Ratio (floodprone width/bankfull width)	1.3
Riffle D_{50} (mm)	22

The Montgomery-Buffington stream classification is best described as intermediate between Plane-bed and Step-pool. The reach slope is characteristic of a step-pool, but the lack of distrinct “steps” or bar formations are indicative of a flume bed channel. The plane-bed channel typically exhibits armored bed surfaces, although accelerated sediment loading can result in fining of the bed (Montgomery and Buffington, 1997). This is the case for Rosewood Creek. The plane-bed channel is considered to be transitional between supply-limited and transport-limited morphologies.

The bed and banks of Rosewood Creek are highly unstable, with significant, active channel incision and widening. Undercutting and bank collapse is common throughout the reach. Bank erosion was rated as continuous and severe over almost the entire reach. An example of channel incision is shown in Figure 5-10. The adjacent floodplain has been abandoned due to the extent of channel incision. The exception is a 250 ft-long section of channel (~ Station 51+00 to 53+50) that has aggraded to within 2.5 ft of the top of bank, and is connected to a vegetated wet meadow that functions as a floodplain. However, this section has multiple thread channels and is not stable. It is immediately upstream of three nickpoints, from one to two feet high, between stations 47+00 and 51+50 (Figure 5-9), indicating ongoing vertical adjustment. Swanson (2000) reports that this reach incised 3 to 8 feet since the 1997 winter storms.

Randomly measured bank heights range from 5 ft to 8 ft throughout the reach, with top and bottom widths up to 15 ft. Based on observations at a few select locations where the banks had not yet collapsed, it seems likely that the channel width was about 4 ft prior to incision and bank erosion.

Slip Page: Tim Blewett Map

Figure 5-9 Channel Classification Rosewood Creek between SR 28 and Northwood Blvd

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Figure 5-10. Channel incision and bank erosion on Rosewood Creek. Bank height is over 7 ft (Station 52+40).

5.2.2 Rosewood Creek between Driver Way and Harold Drive

Stations 74+40 to 82+25

This reach has two distinct sub reaches, a portion that's highly confined along Village Blvd (stations 78+75 to 82+25) and another section with more natural lateral control (stations 74+40 to 78+75). Both have morphologic characteristics of a Rosgen A channel, with Step-pool bedform (Figure 5-11).

Downstream of Driver Way there is a 350 ft reach of channel adjacent to Village Blvd (stations 78+75 to 82+25), including an 80 ft culverted section under Donna Drive. This sub-reach has homes and yards adjacent to the west bank, and a sidewalk along the east bank. This short segment of stream is a Step-pool channel type (Montgomery and Buffington, 1997), indicative of a supply-limited, transport reach. The bed material is a bi-modal distribution of cobble and sand, with occasional boulders.

Bank erosion is moderate to severe, with surface scour, undercutting and bank collapse evident. Up to 2 ft of bank undercutting was measured along the channel banks. Rip-rap protection has been placed along the channel, specifically near the culvert outlets and inlets. The rip-rap has encroached on the channel area and is exacerbating erosion, particularly on the right (west) bank upstream of Donna Drive. Figure 5-12 shows a section of undercut bank and rip-rap placement.

The subreach between stations 74+40 to 78+75 crosses Village Blvd in a 60 ft long culvert, and flows 375 ft downstream to Harold Drive. This reach has a high gradient, low sinuosity, low width-to-depth ratio, and is moderately entrenched (Table 5-5). There is limited connection to a floodplain, except for an 80 ft-long section of channel at the lower end of this reach, immediately upstream from Harold Drive. The channel best fits a Rosgen A-type, although it is not as deeply entrenched. The Montgomery and Buffington classification is a step-pool channel type. Evidence of vertical downcutting and undercut banks occur, and the bank height increases to about 4-5 ft in some areas. The reach is supply-limited, although it is apparent that local bank erosion has caused a fining of the

Figure 5-11. Channel types Rosewood Creek from Donna Drive to Harold Drive

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Figure 5-12. Undercut bank (approximately 1.5 ft) on Rosewood Creek along Village Blvd. Rip-rap placement on left bank is likely accelerating erosion on right bank.

channel bed. The median bed particle size of 16 mm by pebble count (Attachment B, station 75+82) integrates the effect of a sand and cobble dominated bed.

Table 5-5. Representative Channel Conditions: Rosewood Creek, Stations 74+40 to 79+32

	Station 75+82
Slope (ft/ft)	.06
Sinuosity (channel length/valley distance)	1.0
Width/Depth Ratio (bankfull width/bankfull depth)	3.0
Entrenchment Ratio (floodprone width/bankfull width)	1.8
Riffle D_{50} (mm)	16

Bank erosion was rated as intermittent in frequency and moderate in magnitude. There is evidence of bank undercutting, approximately 0.5 to 1.0 ft. There is also local surface scour against the banks, particularly at locations where there is no vegetative protection. Unconsolidated, sandy material is likely to enter the channel from these bare banks due to direct rainfall, snowmelt, informal public use, and high-flow events.

This reach of Rosewood Creek may have been moved from its original channel alignment. There is evidence of a remnant channel to the west of the existing alignment along Village Blvd (stations 74+50 to 78+00) and spoils or a small artificial levee in short sections near station 75+00. The present-day channel alignment is likely one of the sections of Rosewood Creek have been altered (in alignment, cross section, and/or grade) to accommodate road and housing development. The channel bed may be currently stable, as no nickpoints were noted during field surveys. However, the degree of entrenchment and bare banks increase the potential for accelerated erosion. The remnant channel is on a low terrace about two feet above the present channel, suggesting that it functioned in conjunction with a small floodplain that provided hydraulic release during high flow events.

5.2.3 Rosewood Creek Channel Stability, Erosion & Sedimentation

The channel geomorphic conditions in the study reaches of Rosewood Creek have different channel types and display considerable instability, compared to the areas upstream and downstream.

Between Northwood Blvd and Harold Drive (stations 62+00 to 74+40) the channel is sinuous and connected to a floodplain, with low entrenchment. The Ushaped channel is approximately 1.5 ft deep, with a 5 ft top and bottom width. Immediately upstream from Northwood Blvd the adjacent wetland meadow functions as a floodplain (Figure 5-13). The channel dimensions and pattern are most indicative of a Rosgen E-type. The E-type channel has moderate sinuosity, gentle to moderately steep gradient, low width-to-depth ratio, and low entrenchment (Rosgen, 1996).

Rosewood Creek is also an E-type channel upstream of Driver Way to its headwaters near SR 431 (stations 83+00 to 106+00). The channel has a sand bed with some cobble, well-vegetated banks with minimal erosion. It has low entrenchment with an overbank floodplain area. Due to limited headwater and sand-sized particles must be derived from golf course roadways. The sand is likely transported as suspended sediment load during high flow events through both project reaches, and delivered to Third Creek downstream of SR 28.

The Rosewood Creek restoration plans proposed by IVGID (Joe Borgerding, 2001) would modify the alignment downstream of SR 28. Rosewood Creek would be routed west of Third Creek along Rosewood's natural alignment through a series of detention ponds. Implementation would be expected to decrease the total sediment load delivered to Third Creek, along with reducing the volume and peak flows through the section of Third Creek between stations 33+00 and 6+00.

It is not certain whether an E-type channel is an appropriate and accurate model for an undisturbed Rosewood Creek. Aside from the difficulty of determining site-specific pre-development (especially pre-Comstock era) conditions, it is also possible that some channel adjustments to the numerous road crossings in place for over 40 years have supported E-type channels in some sub-reaches. Reduced conveyance capacity at culvert during flood events alters velocities and sediment transport. The culverts and cross-valley roadway fill may reduce energy gradients upstream of the crossings. This could facilitate overbank and in-channel deposition upstream. This may account for the locally sandy bed for example, upstream of Northwood Blvd, and upstream of Harold Dr.

Use Photo #68

Figure 5-13. Rosewood Creek immediately upstream from Northwood Blvd. Channel is approximately 5 ft wide and 1.5 ft deep.

5.3 INCLINE CREEK

The two project reaches on Incline Creek are from Lake Tahoe to the USGS gage upstream of Lake Shore Drive (stations 0+00 to 10+00) and from Incline Way to SR 28 (stations 19+25 to 34+75) (Figure 2-1).

5.3.1 LAKE TAHOE TO THE USGS GAGE

Stations 0+00 to 10+00

This 1000 ft-long reach exhibits three different channel types

From Lake Tahoe to the first pedestrian bridge crossing (Stations 0+00 to 3+00), the channel is a Rosgen B-type stream. The channel is moderately entrenched, has a moderately low width-to-depth ratio, and low sinuosity (Table 5-6). The depositional bar forms, pools, and riffles indicate a Montgomery-Buffington Pool-riffle classification. Some of the pools are forced by woody debris or by boulders. However, pool depths never exceed 1.5 ft. The median riffle bed particle size is 16 mm with a low embeddedness of 10-20%. (Attachment B, station 2+00). The bed surface material is predominantly sand in the pools and on the bars. These indications of a transport-limited reach are consistent with the position near the mouth of the stream.

Incline Creek enters Lake Tahoe at-grade and no nickpoints occur in the reach, which indicates no local bed incision. Although the project reach is not incised, there has been fill encroachment on the floodplain, probably associated with construction of the road and beach parking lot adjacent to the west (right) bank. Watershed Restoration Associates (1999) state that the mouths of both Third and Incline Creeks have been straightened to protect beaches, reduce flooding, and provide year-round fish access. The probable natural mouth conditions are described as having small lagoon and barrier beach systems.

Large boulders have been placed along both banks near the confluence with Lake Tahoe, possibly to control erosion and to limit flooding. No bank erosion is evident on the west bank (adjacent to the floodplain), but moderate and frequent bank erosion is occurring on the east bank. Unlike either Third Creek or the reaches of Incline Creek further upstream, bank erosion is limited to minor surface scour associated with high flows, not undercutting and bank collapse. Alders line the channel near the top of bank, and large pines are growing at slightly higher elevations.

Table 5-6. Representative Channel Conditions: Incline Creek, Stations 0+00 to 10+00

	Station 2+00	Station 4+80
Slope (ft/ft)	.015	.015
Sinuosity (channel length/valley distance)	1.0	1.0
Width/Depth Ratio (bankfull width/bankfull depth)	9.0	9.6
Entrenchment Ratio (floodprone width/bankfull width)	2.4	1.6
Riffle D_{50} (mm)	16	--

Between station 3+00 (the first pedestrian bridge) and Lake Shore Drive, the channel becomes more entrenched and has lower sinuosity (Table 5-6). This reach is indicative of a Rosgen G-type, with less potential for overbank flow than the B-type channel downstream. Stream bank erosion is similar the sub-reach downstream of the pedestrian bridge, with large cobble to boulder bed material near the toe of banks that resist undercutting and rooted alders lining the upper bank.

From Lake Shore Drive to the USGS gage (stations 5+75 to 10+00) a recent stream restoration project has created a side-channel floodplain along the West Bank. In this restored reach, entrenchment is low (no measurements were made), which provides an opportunity for high flows to spread over a wide floodplain area at low velocity. Return flows from the restored floodplain re-enter the main channel upstream of Lake Shore Drive, so some of the previous hydrograph magnitude and shape is retained downstream. As part of the restoration, both banks have been protected from erosion by rip-rap installations.

5.3.2 Incline Creek from Incline Way to SR 28

This reach extends 1900 ft from Incline Way upstream to SR 28 (stations 19+25 to 34+75). The channel is moderately entrenched, has a very low width-to-depth ratio, and a low sinuosity (Table 5-7).

The very low width-to-depth ratio is most representative of a Rosgen G type channel. However the moderate entrenchment ratio is most representative of a Rosgen B type channel. The sinuosity and slope conditions are indicative of either channel type.

Table 5-7. Representative Channel Conditions: Incline Creek, Stations 17+64 to 35+29

	Station 28+39	Station 33+92
Slope (ft/ft)	.04	.04
Sinuosity (channel length/valley distance)	1.1	1.1
Width/Depth Ratio (bankfull width/bankfull depth)	5.0	4.0
Entrenchment Ratio (floodprone width/bankfull width)	2.0	2.0
Riffle D_{50} (mm)	22	--

Based on the Montgomery-Buffington classification system, this reach of Incline Creek incorporates characteristics of both a Pool-riffle stream type and a Step-pool stream type. Accordingly, a “riffle step” (pool riffle-step pool) may be the best way to describe this channel.

The median riffle bed particle size, based on pebble count, is 22 mm (Table 5-7), with 40-50% embeddedness. Bed subsurface material at the same site has a median surface particle size of 22 mm (Attachment B, station 28+39). The subsurface material sample percentage finer than 1mm of 10%, and the percentage finer than 3mm of 22% are both under the criteria for spawning gravels.

Moderate bank erosion occurs intermittently to frequently through the reach. Bank undercutting was the most significant and commonly observed failure process, with some surface scour. The bank erosion potential was considered moderate due to bank heights much greater than the bankfull depth, sandy soils with poor cohesiveness and lack of significant toe rock content to provide erosion protection. Offsetting these potentially highly erosive conditions, dense alders with rooting depths greater than the bank height line the channel. It is likely that the bank undercutting, collapse, and erosion is slowly producing channel widening.

A remnant meander of a former Incline Creek channel was identified near station 30+00. The meander is perched on a low terrace about 3.0 ft above the present-day channel, indicating prior down cutting of the bed and a previously more sinuous channel (Figure 5-14). The bed may now be vertically stable, as no nickpoints were identified.

A definitive evolution of channel geomorphology is not easily determined, based on the complex natural and human alterations over the last 100 to 150 years (see discussion for Third Creek). However, the general valley slope, confinement, and remnant channel sinuosity suggest that Incline Creek may have had a B-type Rosgen channel. Initial bed degradation processes would result in a deeper, narrower, and entrenched channel, probably with a lower bankfull width-to-depth ratio than today (G-Type channel). However, as the entrenched channel experienced bank undercutting and collapse, channel widening occurred, often widening more at the top than at the bottom (for example, see Figure 5-4 on Third Creek which is the same process). This would eventually result in a low bankfull width-to-depth ratio, but a slightly less entrenched channel (i.e., higher entrenchment ratio), as the banks are "laid-back". Thus, the entrenchment ratio approaches the Rosgen B-type, as is seen today, but the width-depth ratio remains low as in a G-type channel. However, the channel is now at a lower bed elevation than it was before incision, and the former floodplain is abandoned as a low terrace.

Another channel-altering process that has likely occurred as development proceeded in Incline Village is a reduction in channel sinuosity. The lateral position of the channel is essentially "locked in" place as it passes through the three sets of culverts at SR 28, Incline Way, and Lake Shore Drive, reducing the opportunity for meandering. In addition, increased peak flows and resulting channel incision reduces sinuosity and may even cut-off meanders, resulting in a straighter, steeper and less sinuous channel planform.

5.3.3 Incline Creek Channel Stability, Erosion & Sedimentation

Channel and watershed conditions towards the headwaters of Incline Creek were inspected to above the Diamond Peak Ski area. At Tyrolian Village, the channel bed is overwhelmingly dominated by sand, with occasional cobbles and boulders (Figure 5-1). Further downstream below the Diamond Peak Ski area, near Ski Way, the channel gradient is steep, with a step-pool bedform, yet sand was still obvious in large patches on the bed. Thus, sand is a significant proportion of the total sediment load, and is clearly being transported to the downstream project reaches from headwater source areas.

A combined bed surface and subsurface bulk sample was obtained from a riffle near the Tyrolian Village USGS gage. The median particle size was 22 mm (Attachment B, station 112+45), with about 16% of the sample within the sand-sized range (<2mm). The percentage finer than 1mm of 9% and the percentage finer than 3mm of 19% are both less than the criteria for spawning gravels. The percentage of fine sediment is very similar to the sample taken further downstream, above Incline Way (station 23+39). These bed conditions, the lack of local sediment sources in the project reaches, and visible areas of exposed soils in the upper watershed (upstream of Tyrolian Village) all indicate that fine sediment load begins in the upper watershed. Additional sediment sources upstream of the project reach include streambed incision and streambank erosion through alluvial deposits downstream of Diamond Peak.

Slip Page: see Amanda for photograph (she has edited the photo with lines and text)

Figure 5-14. Remnant Incline Creek meander channel (near station 30+00)

6.0
RECOMMENDED RESTORATION PROJECTS

Previous studies have recommended various restoration projects for erosion control, channel restoration, habitat enhancement, and water quality protection/improvement in the TI&R watersheds (Watershed Restoration Associates 1999 and Swansonk 2000). The following description of ENTRIX's recommended restoration projects for the TI&R study reaches are identified primarily based on their potential to provide water quality benefits and to improve aquatic habitat (including the fish passage).

As an overall approach, greater emphasis is placed on projects that provide control of accelerated sediment production at the source, rather than capturing sediment in detention basins or on floodplains at locations downstream from the source. Capture of excess sediments during flood flows by promoting deposition overbank in floodplain areas provides storage for only a portion of the transported sediments. Most of the finer-grained sediments carried during flood flows will remain in suspension within the channel and will be carried to Lake Tahoe. Only the portion of the suspended sediment load that is overbank and experience velocity reductions will be deposited on floodplains with an opportunity for stabilization. Sediment within the channel system (from all source areas) has the potential to adversely affect aquatic habitat.

The watershed position of the study reaches limits the degree to which some of the watershed-wide source erosion can be addressed by projects in these reaches. However, projects that promote bed and bank stability, thereby reducing sediment production from unstable stream bed and bank sources, deserve high priority. Swanson (2000) recently identified road shoulders, roadside drainage ditches, road cut slopes, and some reaches of Rosewood, Deer, Incline and Third Creeks as significant sediment sources in the watersheds. While the focus of our study is on stream corridor projects, Swanson's (2000) list of priorities for erosion control and water quality features/practices in road-related areas is certainly important for reducing urban pollutant loading.

The following sections describe potential stream restoration treatments for the project study reaches, including discussion of specific projects requested by the ACOE. In addition, a discussion of culvert crossings and other potential fish migration barriers is provided in Section 6.7.

6.1 STABILIZE ROSEWOOD CREEK BETWEEN HIGHWAY 28 AND NORTHWOOD BLVD

This reach of Rosewood Creek is highly unstable, with active vertical incision and channel widening. Incision is occurring at almost all locations between SR 28 and Northwood Blvd. Incision depth is estimated to be 4 to 6 ft below the original channel bed. Widening is also occurring, but is not as prevalent, and where it occurs is estimated to be 2 to 4 times the original channel width. Three nickpoints were identified in the lower reach (Figure 5-9), indicating that vertical instability will probably continue. This section of Rosewood Creek represents an active source of accelerated (human-induced) sediment production to Third Creek and to Lake Tahoe. It is likely that the undisturbed Rosewood Creek channel was vertically and laterally more stable and had connection to an adjacent floodplain, providing an opportunity for overbank flows during flood events, and thereby some water quality benefits. Stabilizing the channel and controlling associated sediment production should be considered a restoration priority. Stabilization of Rosewood Creek was also identified in previous studies as an important erosion control priority (Watershed Restoration Associates 1999 and Swanson 2000).

There are three basic approaches to stabilizing this reach of Rosewood Creek, each with advantages and disadvantages:

(1) Reconstruct channel at higher, original elevation, with appropriate dimensions, geometry, and re-connect to former floodplain;

(2) Construct channel with appropriate dimensions at elevation of existing bed, with an associated new floodplain or floodprone area, at lower elevation by laying back present streambanks; or

(3) Stabilize channel in place.

The advantages of the first approach is that it re-establishes a connection with the former floodplain, provides stable bed and banks, raises the local water table, and may produce water quality benefits from overbank flows. This approach also raises the local water table. A stable Rosewood Creek channel would be sized to accommodate a new design discharge under the present-day flow regime as part of the restoration design.

Disadvantages of the first approach include the need to develop a very careful design in order to ensure no flooding of nearby homes. Most of the housing development and infrastructure appears to be set back sufficiently to allow for construction of a new channel and some overbank flow area. Another disadvantage is the need for some type of grade control in order to connect the new channel to the elevation of the previous channel at the downstream end (i.e., culvert at SR 28). Connecting at-grade to the existing channel could be accomplished with one grade control structure near the downstream end, requiring a large drop in elevation, or could be accomplished with smaller drops spread over the restored channel length. The grade control structures would need to be stable under peak flow conditions in order to prevent future head-cutting, and might well be an impediment to fish passage. However, it is reasonable to assume that the 6% gradient in this reach of Rosewood Creek is likely to be too high to support suitable habitat for migrating fish species.

An optional approach to completely filling the old channel and constructing a new channel is to fill a portion of the existing channel depth, and layback the banks providing connection to the existing floodplain. This option would likely reduce the amount of earthwork needed.

It should be anticipated that the construction for this approach could destroy much of the dense riparian vegetation, primarily alders. A construction footprint would probably be at least 20 ft in width. Until riparian vegetation becomes re-established, the newly constructed channel is likely to be very unstable during high flows. Therefore, a two-phase construction process should be used whereby the existing incised channel remains open, providing high-flow relief until vegetation matures along the new channel. Once vegetation is well established along the new channel, the old channel can be filled.

The second approach uses the existing channel alignment and bed elevation, but channel dimensions and patterns are adjusted to an appropriate stream type. A new floodplain or floodprone area is created at a lower elevation to reduce shear stress on bed and banks during high flows. The existing channel walls are excavated back in order to create a small floodplain or floodprone width. A portion of the currently abandoned floodplain (i.e., terrace) may remain above the floodprone area. This second approach can provide stable bed and banks, and the tie-in to the existing channel at the downstream end is simpler, since the channel should connect at-grade. However, grade controls would still be required at intervals along the channel length in order to prevent ongoing incision. Grade control structures, as in the first approach, could be constructed as short cascades, probably utilizing rock 150-300 mm diameter. The grade control structures would need to be well keyed through the banks, and extend across a portion of the valley width in order to prevent lateral erosion (end-running).

A disadvantage of the second approach is that it does not raise the floodplain to the original elevation, and therefore the water table does not also rise. There are also no options to use a “high-flow relief channel” during the vegetation establishment period along the newly constructed channel. This makes the restored channel vulnerable to erosion until vegetation can mature.

The third approach is to stabilize the existing channel in-place. This would require similar grade controls as under the second treatment approach to prevent progressive incision, and significant effort to harden the bed and banks. Although bio-technical treatments can be considered to improve bank stability, hard rock structures are most likely to be needed in order to provide stability on Rosewood Creek. Such hardened structures could include cellular confinement grids and geotextiles at the toe of the bank and on bank slopes. Existing riparian vegetation is already dense, and well established along the channel, with rooting depths of alders extending to the elevation of the bed. This vegetation is an important component of maintaining some resistance to bank erosion, but is ultimately insufficient in itself and does little to prevent further channel incision. Thus, it is not expected that vegetative treatments alone could foster the stability needed in this highly entrenched channel.

The advantage of the third approach is that earthwork is significantly reduced, additional land needed to act as a floodplain or floodprone area is not necessary, and connection at-grade near SR 28 is not an issue. However, no connection to a floodplain is established, so that shear stress on the bed and banks remains high, presenting some risk of failure of bank stabilization treatments. Aquatic habitat is likely to be limited under these conditions, particularly since there is no refuge from high flows. Without connection to a floodplain, there is no opportunity for overbank flows and for water quality benefits associated with filtering of sediments. However, bank stabilization would prevent the erosion of local streambank sediments.

6.2 STABILIZE ROSEWOOD CREEK BETWEEN VILLAGE BLVD AND HAROLD DRIVE

This short segment of Rosewood Creek is in a similar unstable condition as between SR 28 and Northwood Blvd. All three of the stabilization approaches discussed above would be feasible and appropriate for further consideration. There appears to be sufficient land and setback from existing housing to function as a floodplain or floodprone area.

One specific option relative to reconstructing the channel at the original floodplain elevation in this reach is to re-occupy an older remnant channel to the west of the existing alignment. This remnant channel is associated with the adjacent floodplain surface. This option would need to be further investigated to ensure that the channel has the appropriate dimensions and that the alignment reconnects in a hydraulically efficient manner to the culvert crossing at Harold Drive. It was noted during field surveys that the most downstream 80 ft section of this reach is not incised, so that the bed is within 2 ft of the top of banks, and the adjacent land surface is functioning as a floodplain. The riparian vegetation is predominantly alders rather than the scattered pines that dominate the abandoned floodplain just upstream. It may be that the culvert crossing at Harold Drive is providing some limited grade control, preventing local incision.

6.3 STABILIZE ROSEWOOD CREEK ALONG VILLAGE BLVD TO DRIVER WAY

This section of Rosewood Creek is parallel to the sidewalk on the west bank along Village Blvd. It passes under a long culvert at the upstream end, a second culvert at Donna Drive, and a third culvert under Village Blvd. There is approximately 75 ft of rip-rap against the west bank upstream from Donna Drive (where it emerges from the first culvert), probably placed to control erosion. Inspection of the channel revealed that opposite the rip-rap the right bank is undercut by up to 2 ft, and this section of bank is near collapse. It appears that the large rip-rap placed here has encroached on the channel cross-sectional area, forcing flow to cut against the right bank and thereby accelerating bank under cutting. Undercutting is also occurring just before the culvert at Donna Drive, but is less pronounced with no imminent signs of bank collapse.

Bank stabilization measures should be employed between the culvert outlet at Donna Drive and the upstream end of the reach. There are probably several stabilization design options that would be appropriate here, such as the use of willow-brush mattresses in combination with a rock toe on the right bank. It is important not to use excessively large rip-rap material in order to avoid significantly reducing the channel cross-sectional area. Another option is to reshape and enlarge the channel, providing adequate flood capacity, which would require removing the existing large rip-rap.

6.4 STABILIZE THIRD CREEK AND ADDRESS FOOT-TRAFFIC IMPACTS BETWEEN LAKESHORE DRIVE AND SR 28

Beginning about 600 ft upstream of Lakeshore Drive to SR 28, Third Creek has been subject to incision and channel widening. As with Rosewood Creek, channel instability is probably linked to changes in the flow and sediment regime that are related to urbanization, possibly to straightening and channelization, and the rerouting of Rosewood Creek. Part of the increase in peak flows is undoubtedly attributable to the linking of the Rosewood Creek drainage area to Third Creek just downstream of SR 28.

The extent of incision on Third Creek is not as dramatic as on Rosewood Creek, and it is not clear if incision is ongoing. However, channel widening is still occurring. As a result of these geomorphic changes, there is accelerated bank erosion and high flows do not spread over a floodprone area, reducing water quality benefits and increasing shear stress on the bed and banks. It appears that excess sediments generated in the watershed have resulted in sand deposition in pools, reducing summer rearing habitat for fish species.

Treating isolated areas of severe bank erosion along Third Creek as a long-term solution is not recommended. Such treatments would require at least hardening the base of the bank slope using rip-rap, gabions, or other structures to control undercutting and bank collapse. If the channel continues to incise, structures hardening the base of the bank slopes would fail, unless they are keyed well below grade and any potential future bed incision. Additionally, hardening the banks does not restore opportunities for overbank flows.

A better approach to erosion control and water quality improvement is to develop a comprehensive design solution for longer reaches of Third Creek. A comprehensive plan should identify a new, stable channel morphology that is appropriate for the existing sediment and flow regime. A stable morphology should provide capacity for up to a bankfull discharge that is equivalent to approximately the 1.5-year flood event. The existing channel appears to contain flows much greater than the 1.5-year flood. In addition, a higher sinuosity is most likely to be appropriate for a stable channel morphology given the valley gradients. Higher sinuosity decreases the channel gradient and expends energy, reducing the overall shear stress on bed and banks.

IVGID plans to realign Rosewood Creek to its former channel in the near future. This will reduce peak flows and sediment inputs to Third Creek below SR 28. A new channel equilibrium may be initiated as a result of this change. Therefore, it is recommended that monitoring be initiated on Third Creek for a period of several years to determine how the Third Creek channel responds to this change. Monitoring should include establishing permanent cross-sections to determine changes in bed elevation and channel width. Erosion pins should also be installed at select locations to monitor bank erosion. During the monitoring period, change in peak flows can be determined using the USGS gaging station above Lakeshore Drive. The data gathered would provide an improved basis for design of a restored, stable Third Creek channel with suitable dimensions and planform between stations 6+00 and 33+00.

The ACOE requested ENTRIX, Inc. to consider the feasibility of creating a small floodplain area or “pocket wetland” on Third Creek immediately upstream of the culvert at Incline Way. Developing a floodplain area at this location is feasible, and would require moving some existing boulders and a small amount of earthwork on the left bank. The floodplain area would have to be initially protected from erosion following construction by using a treatment such as sod or geotextile grid. The channel shape would need to allow flow to enter the culvert efficiently, which would limit the extent of the overbank area that could be developed, probably too less than 100 ft in length. The culvert hydraulics during moderate to high flows would need to be considered in order to construct a floodplain area that is functional since the culvert controls water surface elevation.

Overall, the water quality benefit gained by creating a limited and isolated floodplain area is likely to be very minimal. The potential area for sediment deposition and filtering is very small, and therefore unlikely to function as a good sediment trap. Since this site itself is not eroding and contributing sediment, there is no benefit to be gained from controlling erosion at the source. A more significant benefit might be gained by the resulting wet riparian area that could be utilized as habitat by amphibians. Overall, if the ACOE decides to foster a restoration project over the entire project reach from Lakeshore Drive to SR 28, then isolated projects such as this should be considered at a later date and incorporated as part of the larger restoration program.

Foot-traffic along the banks and crossing Third Creek is a source of accelerated sediment production to the channel. The non-cohesive bank soils are readily subject to erosion with the loss of understory vegetation. The most heavily worn areas were observed downstream of Incline Way, although there are informal trails and bank erosion evident upstream as well. Re-directing public use to defined areas along the channel will reduce this source of erosion. One approach would be to develop formal trails that are set back from the top of banks, and by developing bridge crossings. Trails could be developed using logs, wood-chips, crushed gravel, or more permanent material such as asphalt. It is recommended that patterns of foot-traffic in the area be assessed in order to develop pathways that will provide public circulation but avoid erosion of banks. In addition to directing foot-traffic to defined areas, public information dissemination such as kiosks describing the effects of foot-traffic on restoration efforts may be valuable.

6.5 THIRD CREEK UPSTREAM FROM SR 431

Shallow landslides and debris flows adjacent to Third Creek are evident upstream from SR 431. It does not appear that these erosion sources represent accelerated sediment production, but are associated with natural processes. We expect this reach to continue to periodically produce high sediment concentrations and load. The very steep slopes and relatively large scale of these sediment sources make erosion control infeasible. Third Creek has a very high transport rate in this reach due to the steep channel gradient (11%) and highly entrenched condition. As a result, fine sediments are not likely to overwhelm the bed, except during specific flood, debris flows or other mass movement episodes. Although fine sediments are present, they are transported as suspended and bed-load to downstream reaches.

6.6 STABILIZE INCLINE CREEK AND ADDRESS FOOT-TRAFFIC IMPACTS

The same type of channel stability issues and, therefore, restoration scenarios described for Third Creek are applicable to Incline Creek between Incline Way and SR 28. Since there are no known plans to alter tributary drainage patterns to Incline Creek, the monitoring program suggested for Third Creek would not be necessary. The existing restoration work implemented between Incline Way and Lake Shore Drive may provide a suitable model for a comprehensive geomorphic restoration upstream. The bankfull design capacity for Incline Creek should be approximately 30 cfs, based on the 1.5-yr peak flow data at the USGS gaging station (Watershed Restoration Associates 1999). Some additional data collection on the performance of the restored reach could be very informative for restoration planning upstream of Incline Way.

Although there are informal foot-trails and related bank erosion on Incline Creek, it does not appear to be as intensive as on Third Creek below Incline Way. Therefore, addressing foot-traffic related erosion should be a higher priority on Third Creek.

Immediately upstream from SR 28, Incline Creek crosses through the Incline Championship Golf Course. The ACOE requested ENTRIX, Inc. to consider potential development of a pocket wetland in this area. This is technically feasible, however, the effort required would probably be significant given that the channel is entrenched over 10 ft below the top of banks. The bank slopes are steep and would need to be laid-back or terraced-back in order to provide a floodprone, riparian wetland area. The construction process would temporarily eliminate riparian vegetation currently growing along the channel, and would require earthwork into the golf-course fairway. The wet riparian area that could be created would provide additional riparian habitat, but it is doubtful that the small size of the area available would provide any water quality benefits.

Downstream of Lakeshore Drive the channel is not incised, although construction of the parking lot has encroached on the former floodplain, probably reducing the previous extent of flooding. There were virtually no indicators of bank undercutting and the channel enters Lake Tahoe at-grade. Therefore, any restoration work undertaken in this reach would not be needed to address bank stability issues. The ACOE did request that ENTRIX determine if water quality benefits could be achieved by creating a floodplain for overbank flows downstream of Lakeshore Drive. Although it is technically feasible to construct a floodplain in this reach, it is not likely to provide significant water quality improvement benefits. This is due to the limited floodplain width that can be developed without imposing on the road and parking lot area, and to the relatively short length of channel available, approximately 500 ft. It should be noted that the lowermost 250 ft of channel already functions as a B type channel, with a small floodplain area providing opportunity for overbank flows on the right bank. Other habitat benefits, potentially for amphibians, may be derived by creating a more extensive, wet riparian area. Developing a floodplain in this reach would result in converting existing pines to riparian species such as alders, willows, and grasses. A complicating factor is that any plans to develop a floodplain would necessitate determination of flood-stage changes that will occur with different water levels in Lake Tahoe. There may also be fluctuations in bed elevations over periods of time that are coincident with changes in Lake Tahoe.

6.7 CULVERTS AND OTHER FISH BARRIERS

ENTRIX, Inc. inspected the entrance and exit conditions at 6 culverts on Incline and Third Creeks to determine if they are potential fish migration barriers. Fish passage has not been identified as an issue on Rosewood Creek. Therefore, no observations were made at those culverts. In addition, the USGS gaging stations above Lakeshore Drive were inspected on both streams to determine if they were migration barriers. A description of the nature and extent of the problem at each site, and recommended improvements are provided below. The ACOE has indicated that they will be conducting hydraulic modelling at each of the culverts to confirm the type and magnitude of the passage problem.

6.7.1 INCLINE CREEK

Concrete Box Culvert at Lakeshore Drive

The 37 ft-long concrete box culvert at Lakeshore Drive has been retrofitted with offset-style baffles in order to improve fish passage. The outlet of the culvert flows over a wide concrete apron. It likely has velocity problems during moderate to high flows and does not provide sufficient depths for entrance. Boulder wiers downstream would create a backwater and modify entrance conditions to reduce velocities and increase depth. During visual inspections, the culvert inlet only had a minor amount of small woody debris collected in the first set of baffles. All the baffles appeared to be functioning efficiently for transport of water and sediments.

Incline Creek USGS Gaging Station at Lake Shore Drive

At the USGS gage there is a broad-crested concrete weir that forms a 2.7 ft high jump (Figure 6-1). While the height of the jump is not likely an impediment to fish passage, the width of the concrete wier (3 ft.) and the lack of a jump pool at the wier base are passage impediments. Boulder weirs added to the downstream channel would create a backwater that increase depth and provide a jump pool at the base of the concrete wier. The jump pool depth should ideally be about 1.5 times the height of the jump, or about 4.5 ft depth (Flosi et al 1998). In addition, the 3 ft wide concrete weir should be sloped back into the channel bed, reducing the width from 3 ft to about 0.5 ft.

Incline Creek at Incline Way

There are double corrugated metal culverts at Incline Way, with the right barrel carrying most of the streamflow. While the holding pool downstream of the culvert is adequate for fish, the entrance velocity may be too high and should be measured or modelled. A resting area upstream at the culvert inlet should be created by installing a boulder weir. The woody debris observed at the culvert entrance should be cleared.

Incline Creek at SR 28

Double corrugated metal culverts cross SR 28 to the golf course. Both outlets are perched 3 ft above the channel bed, forming a migration barrier. Providing access into the culverts might be accomplished by a pool-and-weir fishway. However, fine sediments transported through the culverts could represent a significant problem for the function of a fishway. Another option is to consider a bridge crossing in place of the culverts. Either solution would be very costly and should be justified based on an investigation of the availability of suitable habitat upstream that is presently not accessible. In addition, velocities in the culvert during migration flows are unknown and should be modelled or monitored.

6.7.2 THIRD CREEK

Third Creek Culvert at Lakeshore Drive

The concrete box culvert at Lakeshore Drive should be checked for depth and velocity under fish migration conditions.

Third Creek at USGS Gage Upstream from Lake Shore Drive

The small boulder step-pool just downstream from the USGS gaging station at Lakeshore Drive was inspected and determined not to be a passage barrier. Passage would be enhanced by creating a backwater to increase depth during low flows.

Third Creek Culvert at Incline Way

There are double corrugated metal culverts at the Incline Way crossing. Jump height and velocities at the culvert outlet may be a problem for migration and need to be modelled. The culvert entrance is also blocked with debris and sediment. The sand deposit at the inlet is unlikely to be related to a lack of flow capacity at the culvert, but is much more likely due to the woody debris blockage. Such impoundments of sand were commonly observed at locations on both Third and Incline Creeks wherever there are woody debris jams that span the channel. Maintenance annually is necessary, preferably following large storm events, in order to keep the culvert debris free. Trash racks or single fence posts can either capture or turn woody debris parallel to the culvert to keep debris from being caught at the entrance. Annual maintenance should be a standard best management practice at all culvert crossings.

Third Creek at SR 28

There are double corrugated metal culverts at the Tahoe Blvd crossing, with the right barrel higher than the left barrel. Most of the flow is through the right culvert. Small boulders step-up from the bed to the culvert outlet. The right culvert only functions adequately to pass adults at high flows. To improve passage during low flows, a backwater can be created at the left barrel outlet with boulders. Velocities in the culvert should be checked to ensure it is not a barrier. Woody debris was observed blocking the culvert inlet, which should be cleared.

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ATTACHMENT A

Field Rating Form for Channel Classification and Erosion

ATTACHMENT B

Particle Size Distribution Data from Pebble Counts, Bulk Samples, and Bank Samples