Fluvial Geomorphology Evaluation and Design
Bella Vista Ranch Reach on Steamboat Creek
Reno, Nevada

Prepared for:

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1 EXECUTIVE SUMMARY

The purpose of this report is the evaluation of a reach of Steamboat Creek at the site of the Bella Vista Ranch in Reno, Nevada. Centrex Homes has acquired the property and desires to construct a naturalistic channel through the property for the primary purpose of conveying normal and flood flows safely through the property while at the same time creating an attractive amenity within the development and enhancing both riparian and terrestrial habitat. It is further desired that the channel be largely self-maintaining and capable of achieving quasi-dynamic equilibrium from a fluvial geomorphology perspective. As part of the evaluation we have presented the measured characteristics of 21 transects in the area of the Bella Vista Ranch. Of the 21 transects provided, seven (7) are classified as C5 channels using the Rosgen classification system.

We believe the selection of a C5 channel type for the Bella Vista Ranch reach in Steamboat Creek is appropriate. Data derived from reference reaches within the Steamboat Creek channel upstream of the project as well as our own experience and professional judgment have been used in the selection of design parameters for the proposed low flow (bankfull) channel to be constructed at the base of the 100 year floodway. The recommended characteristics of the bankfull channel are as follows:

Qbf = 70 cfs
Wbf = 31 ft
Dbfmax = 2.0 ft
Dbfavg = 1.05 ft
W/D = 29.6
ER = 6.45

The proposed meander wavelength of 338 ft and constructed sinuosity of 1.38 will provide an appropriate initial planform geometry for the bankfull channel. Based on the results of sediment transport modeling and other considerations affecting the stability of the bed in profile, it would not appear that a regularly spaced program of grade control would be required for bed stability. Grade control should be used at the upstream entrance and downstream exit points to isolate the project from potential offsite impacts beyond the control of the developer. In addition, local grade control should be considered downstream from a proposed culvert facility near modeling station number 83. Armoring of the outside banks of the floodway will be required in the abrupt turns in floodway alignment in the upper half of the channel. In addition, armoring of the inside bank will be required in the first 2000 ft of channel on the upstream end of the project to resist the potential for bank attack caused by the potential for extension of the meander geometry (point bars and meander amplitude) as a response to local aggradation potential at the upstream boundary.

Successful establishment of stable vegetative cover on the floodplain and floodway banks is critical to the stability and self-maintenance aspects of the proposed channel. The newly constructed channel will be at greatest risk during the 2 to 5 year time period immediately after construction that is likely to be required for vegetation to mature.

Introduction and Project Description

The purpose of this report is the evaluation of a reach of Steamboat Creek at the site of the Bella Vista Ranch in Reno, Nevada. Centrex Homes has acquired the property and desires to construct a naturalistic channel through the property for the primary purpose of conveying normal and flood flows safely through the property while at the same time creating an attractive amenity within the development and enhancing both riparian and terrestrial habitat. It is further desired that the channel be largely self-maintaining and capable of achieving quasi-dynamic equilibrium from a fluvial geomorphology perspective. The proposed floodway and low flow channel has been designed by Quad Knopf. An independent review of the fluvial geomorphology aspects of the design has identified deficiencies in the justification for the floodway alignment and the proposed geometry of the low flow (bankfull) channel within the floodway. This report will attempt to address the comments and concerns expressed in the design review and provide a quantified justification for the final bankfull channel design.

Over a period of three (3) days in April 2006, personnel of Quad Knopf, under the supervision of the author, performed an inspection/field investigation of the Steamboat Creek channel and valley floor in an attempt to locate new reference reaches, suitable for the extraction of dimensionless ratios and other design guidance for the proposed channel reach in the Bella Vista Ranch Development. Attempts to find suitable examples of stable channel configurations with similar bedmaterials, channel gradients, and so on were unsuccessful. Therefore, the information presented in this report draws heavily from the experience of the author in the Steamboat Creek valley and associated tributaries over the last 10 to 15 years.

The Steamboat Creek Restoration Plan was ordered because Steamboat Creek has been classified as the largest nonpoint source of pollution to the Truckee River, resulting from bank erosion, geothermal mineral deposits and the cumulative impacts of human activities throughout the watershed. The land within the creek corridor is 98% privately owned. The creek originates at the outlet of Little Washoe Lake and meanders for 17.5 miles northeasterly to the Truckee River. The Restoration Plan was intended to identify opportunities and constraints along the creek based on existing and proposed land use conditions, coordinate between Washoe County and the City of Reno, recommend best management practices for specific reaches of the creek, provide design recommendations to establish continuity between restoration projects, increase public awareness and provide recommendations for public policies and implementation strategies which target implementation by developers and voluntary participation by private property owners.

Early in the planning process, the steering committee identified the following vision statement:

"The Steamboat Creek Restoration Project is a community-wide, cooperative effort to restore, enhance, and preserve Steamboat Creek."

In order to assess opportunities and constraints for stream restoration and determine a plan of action, the following project goals were identified and prioritized by the Steering Committee.

1. Improve the water quality of Steamboat Creek.
2. Restore Steamboat Creek to a sustainable condition.
3. Re-establish wildlife habitat appropriate for individual stream reaches.
4. Re-establish vegetation appropriate for individual stream reaches.
5. Combine stream restoration with recreation in areas designated for public access.

1.1 The Nature of Fluvial Channels and Stream Restoration

Basin and stream systems move rock, sediments and water, and exist to accomplish geomorphic work. Geomorphic work accomplished by a stream system consists of removing water from the basin area during rainfall and snowmelt and the transportation of sediment out of the basin. Every river and stream strives to establish an equilibrium relationship between a critical flow level, referred to as the mean-dominate discharge, and the sediment load produced by the basin. The mean dominant discharge is the magnitude of stream flow that, over the long run, moves the greatest amount of sediment and therefore has the greatest impact on the size, shape, and character of the channel. The stream accomplishes the search for equilibrium by adjusting its hydraulic variables (i.e., channel width and depth, velocity, roughness, slope, sinuosity, etc.). This normal fluvial condition is a state of dynamic equilibrium referred to as *quasi-equilibrium*. The interrelationship of these variables is extremely complex and the difficultly involved in understanding stream and river behavior is evident when one considers that the water discharge and the sediment load are in a continuous state of flux or change so that all of the hydraulic variables are always adjusting all of the time. Obviously a river or stream system will never ultimately reach a final steady-state permanent condition, thus the term quasi-equilibrium. However a stream system that is at any given time approaching this equilibrium state is said to be *in regime*. Some of the reaches in the upper portion of Steamboat Creek (just below the outlet at Little Washoe Lake) are near equilibrium and could be considered in regime.

This quasi-equilibrium state is periodically upset when the system is stressed beyond a *threshold*. The crossing of the threshold can be induced either by extreme events in the system or by the activities of man. Whatever the source, once a threshold is crossed the balance of the fragile equilibrium state is upset resulting in dramatic changes in the geometry and morphology of the system and setting off a new round of adjustments back toward some new quasi-equilibrium state. By definition once a threshold has been crossed the stream can never recover fully to its original equilibrium state. The removal of the Vista Reefs in the Truckee River represent an example of a threshold on Steamboat Creek. The resulting incision and head cutting in the lower Steamboat Creek channel is the physical manifestation of the geometry and morphology changes that accompany the adjustment toward a new equilibrium. The evaluation of basin and stream parameters (measurable characteristics or indicators) allow one to understand more clearly where the stream is with respect to the evolutionary history of the basin and how close the stream system may be to achieving a quasi-equilibrium state. This understanding can permit one to make both qualitative and quantitative predictions of stream system response to either expected or proposed changes and is the principal purpose for using the Rosgen classification system (see Appendix A).

The total effectiveness of a stream to do geomorphic work (i.e., to transport water and sediment) is a function of both the magnitude of the event and its duration. Although it is true that very large flow events are capable of transporting enormous amounts of sediment, they occur very infrequently and persist only over a very short duration. The vast majority of the geomorphic work and the events that shape the geometry of the channel are associated with the intermediate events that occur every one to two years. The event that controls the morphology of the channel is referred to as the *mean-dominant discharge.* This event is usually coincident with *bankfull discharge* which, in a natural and relatively undisturbed stream system that is near its quasi-dynamic equilibrium point, is the flow at which the water just fills the bed and banks of the main channel and is about to spill into the flood plain. In perennial streams this flow will have a typical recurrence interval on the order of 1.5 to 2 years. A frequent failing of modern drainage system planning and design is that most designers involved in the evaluation and design of drainage systems can deal effectively with the delivery of the water discharged through the system but often fail to consider the needs of the system to transport sediment. In a drainage channel that has the ability to change its boundaries (i.e., to either aggrade, degrade, or migrate laterally which is the definition of a fluvial system) it is absolutely critical that provisions be made for the transport of sediment as well as water in order to avoid upsetting the equilibrium of the channel.

A common way to circumvent the need to consider the movement of sediment in addition to water is to invoke the assumption of the *rigid boundary model* (which means to assume that the stream channel is incapable of changing its boundaries). The physical reality corresponding to this design assumption is the use of channel armoring such as concrete, riprap, or other forms of artificial erosion protection (in order to prevent degradation and erosion). The other physical manifestation of this assumption is maintenance (dredging) in order to remove the sediments associated with aggradation. When applied properly, the principals of fluvial geomorphology and the in-regime design can be used to create a more natural appearing and naturally functioning stream channel system with less need for hard lining forms of erosion protection, substantially reduced maintenance requirements, and improved aesthetics. Numerous opportunities exist along the Steamboat Creek channel to preserve, enhance, or restore the natural stream form and function. In general, the upper reaches involve more preservation and enhancement while the lower reaches require more aggressive restoration.

1.2 The Geomorphic Setting for Steamboat Creek

The first step in the evaluation and classification of any major channel network is to evaluate the broad morphological characteristics of the drainage basin in which it resides.

This level of investigation examines landforms, morphology, soils, climate, depositional history, basin relief, valley morphology, river profile morphology, and general river pattern (a Level 1 classification using the Rosgen classification system).

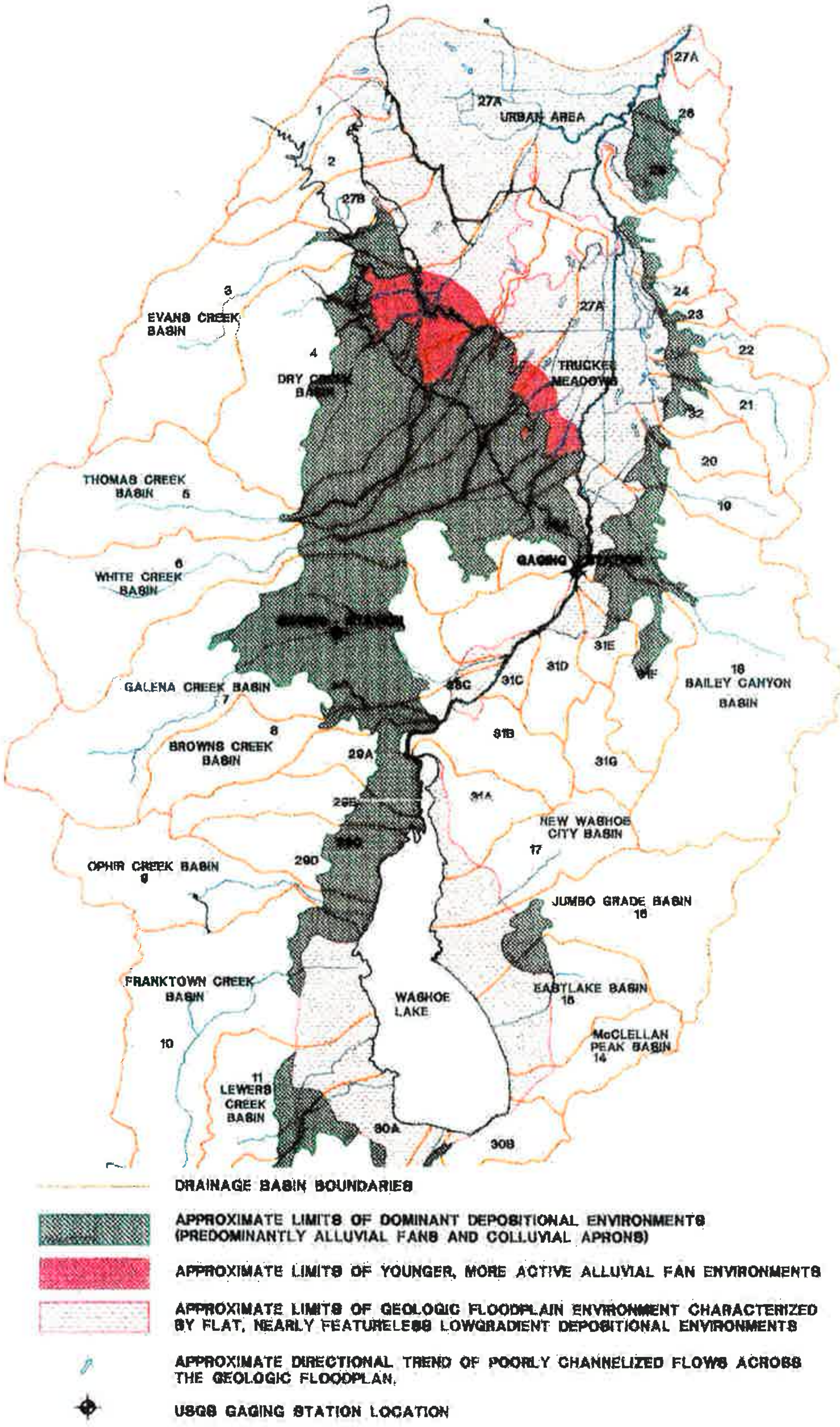
1.2.1 Geology and Basin Morphometry

The Steamboat Creek basin encompasses a total area on the order of 240 square miles. The Steamboat Creek valley (Truckee Meadows) does not fit neatly into the Rosgen Level 1 valley type configurations. It is most closely aligned with the Valley Type VI (fault line valley) classification but also bears some of the characteristics of a Valley Type VIII due to the width of the valley floor and the preponderance of alluvium in the center of the valley. The valley alignment is controlled, not by a single fault, but by a series of active range front faults that have produced a wide down-dropped block or "graben". A detailed discussion of the complex geology within the basin is beyond the scope of this report. However, major lithologies may be described by dividing the basin into 4 quadrants where the major north/south dividing line would be the Steamboat Creek main stem alignment including Washoe Lake and an arbitrary east/west line would pass through the outlet at Little Washoe Lake. Major lithologies in the headwaters of the north/west quadrant are predominately horneblende-pyroxene andesite and dacite flows of the Kate peak formation (Tertiary aged volcanic flows). The lower portions of the basin in this quadrant are dominated by glacial drift primarily associated with alluvial fans of the Thomas Creek, Whites Creek, and Galena Creek basins and at the very lowest elevations, the fluvial sediments of the Truckee Meadows. The headwaters of the south/west quadrant are dominated by horneblende biotite granodiorite (Cretaceous aged Igneous intrusive rocks). The lower elevations in the south/west quadrant contain alluvial fan type sediments and fine-grained lacustrine sediments associated with Washoe Lake. In the south/east quadrant of the basin complex volcanic rocks dominate the headwaters and include the Nine Hill, Eureka Canyon, and Crystal Tuffs (moderate to weakly welded Tertiary aged volcanic tuffs). It further includes metamorphosed tuffs, breccias and conglomerates and sporadic outcrops of the igneous intrusive rocks and volcanic flow rocks (horneblende-biotite granodiorite and the Kate peak formation as described above). The lower portions of the south/east quadrant are dominated by lacustrine sediments. In the north/east quadrant the headwaters contain virtually all of the complex volcanic rock types described in the south/east quadrant plus substantial exposures of the Kate peak formation, the pyroxene andesite flows, flow breccias, and laharic breccias of the Alta formation, and other various altered volcanic rocks including volcanic conglomerates and sandstones. Lower portions of the north/east quadrant are dominated by alluvial fan sediments and fluvial sediments of the Truckee Meadows.

As can be see in Figure 1 the Steamboat Creek basin is actually a complex network of smaller sub-basins. The headwaters of Steamboat Creek is made up of a series of 26 smaller basins lining the rim of the Steamboat Creek drainage area. The characteristics of these individual sub-basins have been evaluated using basin morphometry techniques, which describe the character of the drainage networks within each sub-basin. These techniques can be successfully applied to a true basin where the flows tend to converge on a single point. Morphometric relationships can become obscure when the drainage networks begin to diverge such as on the surface of an alluvial fan or when flows begin to spread out and become diffuse as is often the case on the flat terrain of the Truckee Meadows, therefore, the sub-basins designated 27 through 31 on Figure 1 represent groups of these minor sub-basins which line the main stem of Steamboat Creek and do not produce concentrated flows from a major tributary.

Basin morphometry was evaluated for each of the 26 principle sub-basins in the headwaters of the Steamboat Creek drainage area. Some significant differences were observed in the basin morphometry of those basins along the west side (the Carson Range/east front of the Sierras) and the east side (Virginia Range). Some of the parameters including the steam order, stream magnitude, bifurcation ratios and relief ratios were similar on both sides of the basin. However, substantial differences may be seen in the average area of the sub-basins, basin heights, basin lengths, texture ratio, drainage density, and ruggedness number. Sub-basins along the west side of the Steamboat Creek basin average more than twice the height and three times the length of basins on the east side. Drainage density (length of drainage per unit area) in the western sub-basins is only about one-third of the drainage density observed in the eastern sub-basins. This implies that the basins along the west side will have a stronger groundwater component of flow (and therefore have to carry less total volume on the surface). Basins on the east side in contrast must carry most of the flow on the surface and will have a very limited groundwater component (hence a greater number of drainages required per unit area to carry the surface flow). This means the eastern basins are likely to produce high-peak low-duration flows and quickly dry up becoming ephemeral since there is little groundwater component to support long-term base flow conditions. Basins on the west side however are likely to produce somewhat less flashy flows (for their relative size) and are more likely to be perennial having a base flow component supported by groundwater. The ruggedness number R which is the product of the drainage density and basin height is often used in relating morphometry to flood peak discharge. The lower ruggedness number for the western basins produced by the combination of low-drainage density and high-basin relief implies relatively low-peak discharge, long-duration floods on streams dominated by snowmelt. In contrast the higher ruggedness number for the eastern basins produced by the combination of high-drainage density and low-basin relief implies high-peak, short duration, and low volume floods associated with extreme precipitation events.

Figure 1 - Basin Map of the Northern Steamboat Creek Basin (WESTEC, 1994)



Floods in the western basins having a low-drainage density would be anticipated to carry less fine-grain sediment (wash load) producing relatively less sediment yield than an equivalent area in the high-drainage density basins along the east side. Not all of the sediments produced in the headwater sub-basins of Steamboat Creek will ultimately be delivered to Steamboat Creek. Many of these materials will be deposited on the surfaces of alluvial fans and aprons along the toe of the mountain front prior to reaching the main stem of Steamboat Creek. The location of these "dominant deposition environments" are shown on Figure 1 for the Steamboat Creek basin. It should be noted that the large alluvial fans associated with the Thomas Creek and Whites Creek basins represent special cases. These enormous alluvial fans were built during the Pleistocene under a much colder and wetter climatic condition where the flows in these two basins were dominated by glacial melt waters. In response to the change to the current warmer and dryer climate the main channels of these two creeks have incised into the surface of the old fan creating a long transportation section which currently delivers sediments well down the surface of the fan forming newer, younger and more active alluvial fan environments along the toe of the old pre-existing alluvial fans. These depositional environments do tend to filter out and store some of the sediments being transported out of the headwaters of the basin without delivering it to the main stem of Steamboat Creek for subsequent transport to the Truckee River. It should be noted, however, that these environments are inherently unstable because of the high levels of sediment transport and the tendency toward aggradation. Extreme events carrying large sediment loads are often the cause of channel avulsions where a channel suddenly abandons its old channel to find a new flow path. A good example of this type of activity can be seen along Whites Creek approximately halfway down the length of the older glacial fan. The position of Washoe Lake within the basin also has a major impact on the flow regime. For basins 9 through 17, Washoe Lake will act as a flood control structure, attenuating large flood peaks to much lower peak discharges and extending the duration of the flood flow. Further downstream as more tributaries enter Steamboat Creek below Washoe Lake the flow regime becomes more "flashy" (i.e., more high peak flows of short duration).

1.2.2 Flow Regime

High quality records of long-duration on the daily flows along Steamboat Creek and its tributaries are rather limited. The U.S. Geological Survey has maintained two gaging stations with 30+ years of record located on the main stem of Steamboat Creek near Steamboat, Nevada and on Galena Creek a considerable distance upstream from its confluence with Steamboat Creek. Flow records do exist at other locations including Thomas Creek, Whites Creek, Short Lane Road, and Kimlick Lane. However records at these locations tend to be incomplete and of short duration. For those records of adequate quality and length the exceedance probability of various flood discharges and their associated return intervals can be estimated by fitting a Log Pearson Type 3 probability distribution to the ranked observations of maximum annual flood flow. Such procedures applied to the maximum single flow observed in each year is said to be an "annual flood series." Were the same procedures applied to all flood peaks which exceeded a given threshold value (even if more than one were to occur in a single year) then the record would represent a "partial duration series." All of the flood records presented as part of this investigation represent an annual flood series.

Flood peaks can be associated with different types of events (i.e., a summer cloud burst event versus a winter snowmelt event). Records which do not distinguish between the source and type of event are said to be from a "mixed population." All the flood records utilized in the Bella Vista channel design represent values from a mixed population.

Figure 2 shows the average daily flow over the full water year (October 1 through September 30) for the U.S. gaging station at Steamboat, Nevada located on the main stem of Steamboat Creek. This plot represents the average over the full 30+ years of record. The flow regime of the Steamboat Creek channel is a highly regulated environment. The main characteristics which may be observed on this plot include the groundwater supported base flow of approximately 8 cfs over the months of September and October. Beginning in November the average flow begins to climb due to the relatively wet winter precipitation period reaching a peak at about 25 cfs during the month of March. The individual spikes on this portion of the record represent past extreme events, which were not completely averaged out over the 30-year period of record. Flows begin to decline over the month of April and then turn sharply starting on the first of May and climb rapidly peaking at a flow on the order of 40 cfs in late May and early June. Flows begin to fall off steadily from mid-June through late August back to the base flow level. This broad peak between May and August represents the snowmelt-dominated component the flow and artificial releases of irrigation water.

Figure 2

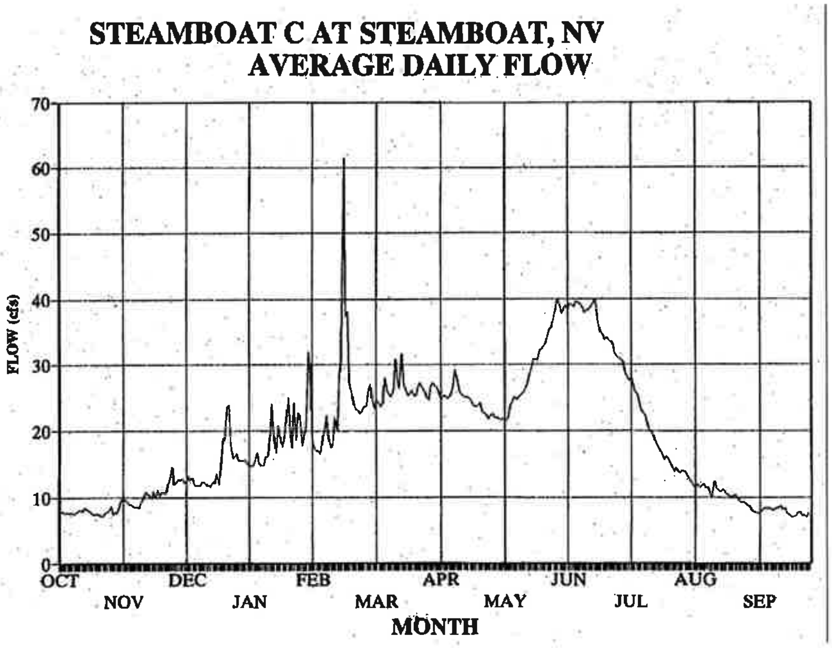
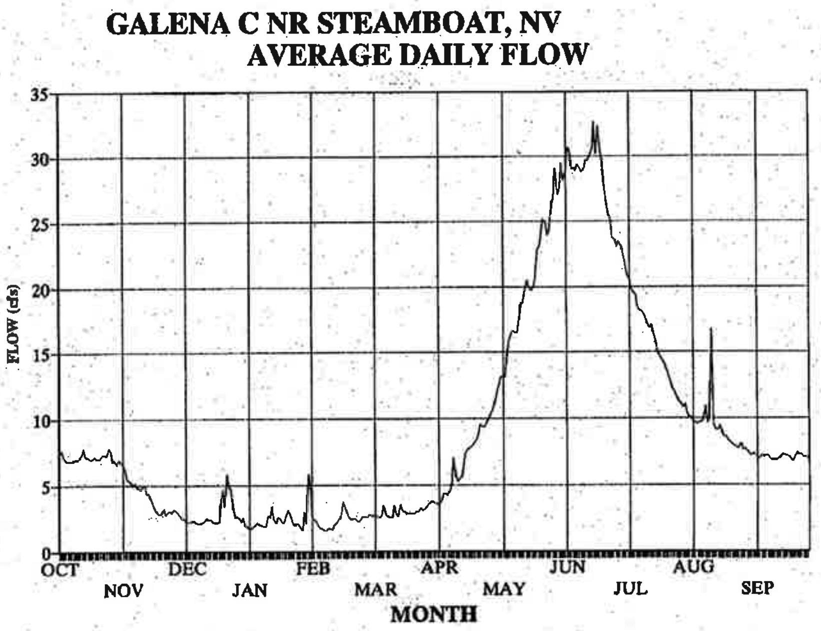


Figure 3 shows a similar plot for the average daily flow at the U.S.G.S. gaging station in Galena Creek. The same snowmelt dominated peak from April through August is evident on this plot, however it is also evident that the broad winter peak between November and April is missing. This is because the predominate precipitation in the Galena Creek basin over this period is snow rather than rain and because winter flows during the non-irrigation season are diverted near the County Park on Mount Rose Highway to Little Washoe Lake for storage and release as needed for the irrigation season.

Figure 3



The flow regime along the length of Steamboat Creek is highly complex with numerous importations and diversions of water associated with irrigation for agriculture. Perhaps the largest single artificial influx of water to Steamboat Creek comes from the Steamboat Ditch, which diverts water from the Truckee River near Floriston, California between the months of April and November and delivers it to the Steamboat Creek channel at a point upstream of the Steamboat Springs geothermal area. The peak summer delivery rate in this ditch averages approximately 100 cfs (see the average daily flow plot in Appendix A). This higher quality water from the Truckee River is intended strictly for agricultural irrigation use in lieu of the rather poor quality water available immediately below the Steamboat Hot Springs. This water travels only a short distance down the Steamboat Creek channel and is immediately diverted first by the Chandler Ditch and subsequently by the Crane Ditch, which carries this higher quality water to the east for irrigation of fields. These flows subsequently return to Steamboat Creek channel at points several miles downstream. Other points which deliver high agricultural return flows include the following (proceeding in a downstream direction): the Alexander Ditch and Rio Poco Drain, Boynton Slough, and the Yori Drain.

As more and more development replaces agricultural uses in the Truckee Meadows, the flow regime within Steamboat Creek will become less regulated and more "natural" over time with fewer drastic changes in discharge from reach to reach from the diversion and subsequent return (at some point well downstream of the diversion) of agricultural flows. The typical impact of development on surface water flow is to increase the magnitude of the flood flow (more imperviousness in the basin), shorten the time of concentration, and reduce the baseflow (more imperviousness results in less infiltration and therefore less groundwater support of the baseflow). However, these days most developers are required to attempt to offset these effects through the use of detention basins. Detention basins help attenuate flood flows by reducing the peak discharge and extending the duration of flow. They are also intended to promote infiltration to the groundwater system. Quantification of the specific impacts of the Bella Vista development on the flow regime is beyond the scope of this evaluation.

1.2.3 Channel Patterns

Relatively little of the Steamboat Creek channel is in its original pre-1850 state. Most of the original channel alignment was probably a meandering C5 channel. Some of the original planform geometry of the channel is preserved between Pembroke Drive and Clear Water Way and in the reach between Miraloma Lane and the Huffaker Hills. However, this "relic geometry" does not necessarily fit the new modern day flow regime and the channel is experiencing substantial damage, mainly in the form of deep incision. The planform channel geometry of Steamboat Creek has been substantially altered over time by the activities of man, again primarily associated with diversions and agricultural uses of water for irrigation. However, in the lower reaches, significant alteration has occurred in response to urban development as well as agricultural impacts. The altered channels have been converted to F, G, and D type channels. In both cases, whether related to agricultural or urban development, the most common type of impact results in straightening of the channel and loss of sinuosity. The indirect impact of such a change is also an increase in the slope of the channel bed profile and an increase in the sediment transport rate.

Amazingly a series of schematic maps dating back to 1863 showed the same very straight alignment present in the Steamboat Creek channel south of the Huffaker Hills today. A map of the Truckee Meadows, Washoe County, Nevada compiled by T.K. and R.M. Stewart in 1921 show the existence of the Crane Ditch and Chandler Ditch as well as the straightened alignment south of Huffaker Hills. A review of successive sets of aerial photography flown in 1946, 1956, 1966, 1974, and 1980 reveals numerous variations in the diversion of irrigation water in the fields south of Huffaker Hills. In the lower reaches of Steamboat Creek all maps prior to 1957 show a channel with relatively high sinuosity terminating in a short-straight section running the last half-mile to the Truckee River. Subsequent maps show additional straightening in this lower section associated with construction of the embankment fill and road leading to the current Waste Water Treatment Plant. More recently (i.e., in the late 1980s, early 1990s) development in the Hidden Valley, Rosewood Lakes Golf Course area has resulted in the widening and straightening of a portion of Steamboat Creek channel and in the creation of a section of impounded water.

One of the most significant changes to impact the Steamboat Creek channel occurred not in Steamboat Creek but in the Truckee River immediately downstream of the Steamboat Creek confluence. In the early 1960s in an attempt to improve the flood flow efficiency in the Truckee, the U.S. Army Corps Engineers blasted and removed a volcanic dike within the Truckee River channel near Vista, Nevada (referred to as the Vista Reefs Project). This effort resulted in the straightening of a meander bend at that location and a significant lowering of the base level of the Truckee River. This initiated incision in the channel of the Truckee River and its major tributaries upstream of this location. The Steamboat Creek channel began to experience severe head cutting with associated extreme bed and bank erosion.

Along the east side of the Bella Vista Ranch are the remnants of a very old wetland and anastomosed channel system that has not been effectively wetted for over 100 years. A true stream restoration effort would probably attempt to re-wet the area and reconnect the complex network of channels that originally formed the anastomosed system. However, it is likely that much of the wetland value has degraded severely over time, and the wide drainage corridor and large general extent is not compatible with the proposed residential development use on the site. A more compatible stream type given the expected bedmaterial, channel slope, and climatic constraints on revegetation, would be the C5 channel type. The constructed channel from the DeMonte Ranch area, located along the south boundary of the Bella Vista property, enters the property near the existing irrigation ditch alignment. However, the historic valley floor lies approximately 3000 ft to the east. To minimize the risk of future avulsion, the main floodway channel alignment needs to occupy the historic valley floor. Therefore, the proposed alignment enters the site at the southern boundary and immediately turns east to follow the southern property boundary eastward the 3000+ feet to the valley floor at which point the alignment turns northward and remains in the historic valley floor to the north edge of the property. This proposed alignment also provides a relatively long path between the fixed entrance and exit points along the south and north borders respectively and therefore acts to minimize the energy slope acting on the very erodible fine grained sand that dominates the expected bedmaterial. If a more optimal alignment exists on the site, it is certainly not evident at this time.

1.2.4 History of Steamboat Creek and the Truckee Meadows

Steamboat Creek is the principle drainage feature of the long valley that runs between Carson City, Nevada and Reno, Nevada. The west side of the basin drains the Carson Range along the east slope of the Sierra Nevada Mountains. High elevations and a substantial winter snow pack in this portion are important to the flow regime in Steamboat Creek. The east side of the basin lies along the west slope of the Virginia Range. The valley is tectonically formed being a down-dropped "graben" bounded by active range front faults. At the extreme south end of the basin is Washoe Lake. Washoe

Lake is a shallow playa lake, which varies in size considerably with the season and with fluctuations in yield between water years. However, unlike most playas Washoe Lake has been able to cut an outlet to the north and discharge to the Truckee River. This drainage outlet at the north end of Washoe Lake forms the main stem of the Steamboat Creek channel.

Permanent occupation of the area began in the early 1850s with the introduction of agriculture to the Truckee Meadows. Stock raising was introduced in 1857 and by 1870 much of Pleasant Valley and Steamboat Valley in the upper Truckee Meadows was occupied by farms and ranches.

It was the opening of the Comstock Lode in 1859, which drove a great deal of the agriculture and stock raising activity in the upper Truckee Meadows. A toll road was built from Steamboat, Nevada to Virginia City in 1861. The hot springs at Steamboat would develop into a health and tourist resort in the early 1860s. The town of Steamboat, Nevada thrived until the completion of the railroad into Carson City in August of 1872 at which time it slowly began to fade. It did however, remain a tourist resort until about the turn of the century when the resort buildings burned and earthquakes reduced the vigor of the springs.

The maximum elevation along the rim of the basin is on the order of 10,800 feet to 7,400 feet, respectively, in the headwaters of Galena and Bailey Canyon Creeks. Climate on the mountainous west side is dry to sub-humid with an average annual precipitation on the order of 40 inches. The climate changes significantly on the valley floor becoming semi-arid with an average annual precipitation on the order of 7 inches. Summertime convective activity over the valley floor and mountains can produce high-intensity thunderstorms and flash flood potential. However, many of the longest duration floods are associated with the spring and early summer snowmelt.

Damaging floods have occurred 27 times since the winter of 1861-1862, or approximately once every four years on the average. Rain floods can occur anytime from October through March from prolonged heavy rainfall producing high peak flows of moderate duration. Severe localized flooding from cloudbursts centered over the tributary basins can occur from late spring to early fall but is most common during July and August. These events produce high-peak flows of short duration and low volume. Due to the small aerial extent of a moderate snow pack at high elevations on tributary steams, snowmelt usually does not constitute a major high-discharge flood hazard. It does produce low to moderate discharge long-duration flows, which are very important in the channel forming processes within Steamboat Creek.

The earliest documented wintertime flood occurred in December 1861 through January 1862. Similar floods occurred in the winter of 1867 and 1868, 1871, 1886, 1904, 1907, 1909, 1928, 1937, 1943, 1950, 1955, 1963, 1964, 1986, and most recently in January of 1997 and January of this year (2006). The earliest documented summer cloud burst flood occurred in July of 1869. Other cloud burst floods similar in nature occurred in 1878, 1911, 1913, 1927, 1941, 1952, 1956, 1960, 1965, 1966, and 1967. The most severe floods on Steamboat Creek to date have occurred in July of 1952, December of 1955, July of 1956, January through February 1963, August of 1965, February of 1986, and January of 1997.

The U.S. Army Corps of Engineers has predicted peak flood flows at various locations within the Steamboat Basin, which are summarized in **Table 1**. This table reports two categories of flooding describing as an "Intermediate Regional Flood" and the larger "Standard Project Flood." These predicted flood flows vary from as little as 200 to 400 cubic feet per second (cfs), respectively, at the outlet of Little Washoe Lake to as much as 8,100 cfs to 15,500 cfs, respectively, immediately downstream of Galena Creek on the main stem of Steamboat Creek.

Table 1 - Peak Flood Flows Predicted By The U.S. Corps Of Engineers

Location	Intermediate Regional Flood (cfs)	Standard Project Flood (cfs)
Short Lane Road	5400	11,000
Highway 17	7400	15,000
Rhodes Road	7600	15,000
Downstream from Galena Creek	8100	15,500
Highway 395	1700	3300
Little Washoe Outlet	200	400

2 Stream Classification (Level 2) and Data Collection for Reference Reaches Near Bella Vista Ranch

A Level 2 inventory compiles data relating to the site-specific channel geometry in cross section, profile, and planform. The parameters computed from this data (slope, entrenchment ratio, width-depth ratio, and sinuosity) are then used to characterize and classify the stream. Data for the Steamboat Creek channel were gathered at 22 transect locations between Geiger Grade and Short Lane (bracketing the proposed reach in Bella Vista Ranch). This data was collected in 1993 and 1994 as part of a field investigation for the Fluvial Geomorphology Study, Steamboat Creek Restoration Project (prepared by the author).

At each transect location, the bankfull depth, bankfull width, and flood prone width were measured for the channel cross section. The flood prone width is the width of the channel at a depth equal to twice the maximum bankfull depth. The cross sectional geometry (along with slope) is the primary determinant of the water flow and sediment transport characteristics of the channel.

Data on the profile geometry of Steamboat Creek was obtained by survey (1993 – 1994) using Washoe County personnel. Survey crews collected elevation data on the water surface and channel bed at intervals on the order of 100 to 200 feet on center. Although permission was originally granted for access to measure cross sectional geometry in transects on the Bella Vista Ranch, it was subsequently denied for the survey of the plan and profile geometry. Therefore, there is a substantial block of data missing from the database in this portion of the channel.

The profile geometry of Steamboat Creek channel does contain a readily identifiable riffle-pool structure. In a naturally functioning, stable stream environment, which is near its quasi-equilibrium state, there should exist a strong relationship between the profile geometry and the planform geometry. Pools should typically occur on the outside bends of meander loops while riffles should occur at the inflection points between the meander loops. Because of this relationship the profile geometry should experience two riffle-pool cycles for each full cycle of the meander planform geometry. Therefore, the wavelength of the meander planform geometry should be twice the wavelength of the riffle-pool profile geometry. The importance of this relationship in evaluating the equilibrium state of the channel will be discussed further in a subsequent section of this report.

In addition to measuring cross sectional geometry, samples of the channel bed materials were obtained at each transect location. A grain-size analysis was performed on these materials at approximately every other transect. The predominate particle size in Steamboat Creek is sand, although localized occurrences of gravel and even cobble size material are found within the channel.

The overwhelming majority of the Steamboat Creek alignment classifies as an F type stream. Since the dominant bed material type is sand, the most common classification is F5. Notable exceptions include the wide flat D5 section adjacent to the Rosewood Lakes golf course area and the C5 channels on portions of the DeMonte Ranch north of State Highway 341. In the middle section across the Bella Vista Ranch (from the Huffaker Hills south to the DeMonte Ranch area) stream classifications are highly erratic due to the artificial nature of the stream environment in this area, which is essentially a man-made irrigation ditch. F and G stream types dominate although one B type channel was identified. Bed material through this section again is predominately sand with sporadic areas of gravel bed channel delineated.

The characteristics of the Steamboat Creek channel vary considerably over its length with the major characteristics tending to cluster forming *characteristic reaches* that are sections of the channel having similar characteristics that would be expected to behave in a similar way. There have been 17 characteristic reaches identified along the 17.5-mile alignment of Steamboat Creek. CR1 begins at the confluence with the Truckee River at the extreme north end of the channel, and progressively increase in number sequence to the south (upstream). The Bella Vista Ranch occupies CR5 and CR6. The DeMonte Ranch occupies CR7 and CR8. Table 2 shows a summary of measured classification data and includes the CR number and the thalweg station (the distance upstream from the Truckee River confluence along the channel thalweg in hundreds of feet – i.e., Sta. 350 equals 35,000 ft upstream). Table 2 uses the following symbols and/or variables:

Wbf = Bankfull width
Dbfmax = Maximum bankfull depth
Dbfavg = Average (Mean) bankfull depth

Wfp = Active floodplain width
ER = Entrenchment ratio
W/D = Width/depth ratio
P = Sinuosity
S = Slope
D_{65} = Bedmaterial particle size at which 65% is finer (used as an index for bedmaterial size)

CR5 extends from Station 286 + 00 to Station 371 + 00. The main stem of Steamboat Creek through this reach is simply an irrigation ditch. Its most obvious characteristic in planform is its extremely low sinuosity (an average of 1.01). In other words it is straight as an arrow. The width-depth ratio is low, but artificially so. Stream types vary widely across this reach but there is little relation to the flow regime as they were created artificially by a backhoe. F and G stream types predominate with one transect (Transect 29) which actually classified as a B5c. Due to the denial of access to this area it was not possible to collect detailed information on the water surface and bed elevation profile. Bedmaterials in this reach were predominately sand with one transect (Transect No. 30) showing gravel to be dominant.

CR6 extends from Station 371 + 00 to Station 421 + 50. It is the southern extension of the irrigation ditch described under Characteristic Reach No. 5. However, unlike CR5, which appears very new and very straight, CR6 gives the impression of an older section of the irrigation ditch, which is attempting to re-establish a new planform and profile geometry. Small meanders are beginning to form along with a corresponding riffle pool structure in profile. This reach remains very straight with an average sinuosity of 1.04. The lateral migration associated with attempting to increase the meander belt-width of this ditch has increased the mean width-depth ratio from 10.84 to 19.18. Bed material in this reach is consistently sand sized, although the sands from CR5 on south have become increasingly coarse with maximum particle diameters on the order of 19 to 25 millimeters.

CR7 extends from Station 421 + 50 to 471 + 50. This section is a reach in transition. It has characteristics typical of a stream that is well into the channel metamorphosis process. The pre-development stream type in this area was again in all likelihood a C5 channel. It is apparent that this reach and the next reach upstream (CR8) were destabilized quite some time ago. Probably as early as the late 1800s. This destabilization caused a conversion from the C5 type to an F5 type. This disturbance is not believed to be related to the rejuvenation and head cutting described on the lower reaches of Steamboat Creek associated with base level changes in the Truckee River. It is more likely to be a result of changes in the flow regime associated with irrigation and/or grazing management practices. Whatever the reason, these reaches have experienced significant incision and entrenchment in the past. However, lateral bank migration has now proceeded far enough that it has created an adequate meander belt-width for the modern day stream to begin working a new C5 channel on the floor of the widened trench. This stream is regaining its sinuosity by building new active point bars and creating an active flood plain just like it had before the disturbance only now at a lower

Table 2 – Summary of Channel Characteristics on Steamboat Creek Between Short Lane and Geiger Grade

Characteristic Reach *	Transect No.*	Sta.*	Classification	Wbf (ft)	Dbfmax (ft)	Dbfavg (ft)	Wfp (ft)	ER	W/D	P	S ('/,)	D65 (mm)
CR4	25	277.7	F5	12.9	1.59	1.09	15.9	1.24	11.79	1.05	0.00333	1.3
CR5	26	294.5	G5c	5.1	1.25	1.05	7.9	1.55	4.86	1.00	0.00333	6
CR5	27	304.9	F5	16.3	1.80	0.97	17.9	1.10	16.80	1.01	0.00333	---
CR5	28	315.5	F5	7.3	1.03	0.88	10.5	1.45	8.24	1.01	0.00333	1.2
CR5	29	326.5	B5c	7.3	0.98	0.72	14.8	2.03	10.14	1.00	0.00333	---
CR5	30	342.4	F4	12.3	1.30	0.78	16.3	1.33	15.71	1.02	0.00333	30
CR5	31	359.4	G5c	10.1	1.52	1.09	---	---	9.27	1.00	0.00333	---
CR6	32	377	F5	12.9	0.80	0.59	18.0	1.40	21.86	1.01	0.00875	1.7
CR6	33	394.4	F5	14.5	1.16	0.88	16.1	1.11	16.48	1.06	0.00133	---
CR6	34	412.1	F5	12.4	0.95	0.67	16.6	1.34	18.51	1.05	0.00286	4.8
CR7	35	428.5	F5	13.7	1.24	1.13	16.2	1.18	12.12	1.16	0.00220	---
CR7	36	444	F5	11.3	1.12	0.84	12.1	1.07	13.45	1.13	0.00670	0.5
CR7	37	454.8	C5	10.9	1.22	0.82	26.4	2.42	13.29	1.24	0.00660	---
CR7	38	470	C5	10.5	0.85	0.60	32.6	3.10	17.50	1.50	0.00429	0.5
CR8	39	482.9	B5c	23.4	1.25	0.86	44.6	1.91	27.21	1.10	0.00861	---
CR8	40	499	C5	3.4	0.40	0.20	29.8	8.76	17.00	---	---	1.2
CR9	42	551.2	C5	14.9	1.10	0.55	34.2	2.30	27.09	1.10	0.00400	2
CR9	43	563.8	F5	26.1	0.85	0.75	31.3	1.20	34.80	1.41	0.00400	1.2
CR9	44	577.2	C5	26.8	1.15	0.89	46.0	1.72	30.11	1.23	0.00200	0.11
CR9	45	589.5	C5	6.9	0.85	0.61	62.5	9.06	11.31	1.08	0.00500	0.24
CR9	46	609.3	C5	13.5	1.75	1.27	35.4	2.62	10.63	1.25	0.00600	1.5

* - From 1994 Fluvial Geomorphology Study, Steamboat Creek Restoration Project

level. The mean sinuosity has increased from the 1.04 of CR6 to a mean sinuosity in CR7 of 1.25. Transect 38 now has a sinuosity of 1.5. The two transects in the downstream portions of CR7 still classify as F5, however, the two transects in the upstream portion of CR7 now classify as C5. The width-depth ratio is relatively low with an average of 14.09 and the average entrenchment ratio is 1.95.

CR9 extends from Station 610 + 00 downstream to Station 541 +00 at the crossing of State Highway 341 (Geiger Grade). At the top of CR9 between Transects 46 and 45 is the diversion point for the Crane Ditch. This portion of Steamboat Creek is also highly complex (in terms of the flow regime) and highly regulated. In general, however, due to the great volume of water diverted within and above CR9, the reach has experienced a significant reduction in the flow regime relative to what the historic relic channel apparently was able to carry. Although the majority of this reach still classifies as a C5 channel (with only the cross section at Transect 43 classifying as an F5 channel at this time) the majority of the channel is actively aggrading with silt and fine sand due to a decrease sediment transport capacity. The dewatering of the active channel and floodplain has also permitted vegetation encroachment that is slowly reducing the size of the active floodplain and even encroaching upon the narrow low-flow channel. Continued aggradation and vegetation encroachment will ultimately reduce the capacity of the channel with respect to large flood flow events with an increase, in the extent and magnitude of flooding during the passage of these large flood events.

3 Selection of Channel Design Parameters

Of the 21 transects shown in Table 2, seven (7) classify as C5 channels and have the potential to serve as reference reaches for the design of the proposed C5 low flow/bankfull channel on the Bella Vista site. All of these channels are located upstream of the Bella vista Ranch. The C5 channels have been extracted from the larger dataset in Table 2 and are summarized in Table 3. It should be noted that these channels are located in reaches that are in transition (believed to be recently converted from an F5 channel to a C5 channel) and do not necessarily represent stellar examples of quasi-dynamic stability under the existing climatic, sediment, and flow regime. However, that does not preclude their use for providing design guidance.

Table 3 – Summary of Channel Characteristics and Dimensionless Ratios for C5 Channel Reference Reaches

Characteristic Reach *	Transect No.*	Sta.*	Classification	Wbf (ft)	Dbfmax (ft)	Dbfavg (ft)	Wfp (ft)	ER	W/D	P	S ('/,)	D65 (mm)
CR7	37	454.8	C5	10.9	1.22	0.82	26.4	2.42	13.29	1.24	0.00660	---
CR7	38	470	C5	10.5	0.85	0.60	32.6	3.10	17.50	1.50	0.00429	0.50
CR8	40	499	C5	3.4	0.40	0.20	29.8	8.76	17.00	---	---	1.20
CR9	42	551.2	C5	14.9	1.10	0.55	34.2	2.30	27.09	1.10	0.00400	2.00
CR9	44	577.2	C5	26.8	1.15	0.89	46.0	1.72	30.11	1.23	0.00200	0.11
CR9	45	589.5	C5	6.9	0.85	0.61	62.5	9.06	11.31	1.08	0.00500	0.24
CR9	46	609.3	C5	13.5	1.75	1.27	35.4	2.62	10.63	1.25	0.00600	1.50
			Mean	**12.4**	**1.05**	**0.71**	**38.1**	**4.28**	**18.13**	**1.23**	**0.00465**	**0.93**
			Std. Dev.	**7.4**	**0.42**	**0.33**	**12.4**	**3.19**	**7.66**	**0.15**	**0.00163**	**0.76**
			Mean + 1 Std Dev						***25.79***			
			Mean + 2 Std Dev						***33.45***			

* - From 1994 Fluvial Geomorphology Study, Steamboat Creek Restoration Project

3.1 Cross Sectional Geometry

With regard to the selection of cross sectional dimensions, it is very important for long term equilibrium, that the bankfull channel remain connected to the active floodplain such that any discharge in excess of the bankfull flood immediately begins to spread across the active floodplain. In cross section, the important dimensions consist of the bankfull width (Wbf) and the bankfull depth (Dbf). The two key dimensionless ratios are the width/depth ratio (W/D) and the entrenchment ratio (ER). High W/D ratios indicate a wide and shallow channel (reduced sediment transport capacity, elevated water temperatures, poor connection with the groundwater table, etc.) while a low W/D ratio indicates a deep and narrow channel shape (increased sediment transport capacity, cooler water temperatures, good connection with the groundwater table). The ER measures the ability of the extreme flood events (larger than the bankfull flood) to spread out and dissipate energy across the active floodplain. Low values of ER indicate a narrow constrained floodplain, while large values of ER indicate wide, flat, unconstrained floodplains.

The C5 channels in Table 3 were observed to have a mean W/D ratio of 18.13 and a mean ER of 4.28. The Rosgen dataset for C5 channels shows a range of W/D ratios of 12 to 46 with an average of 27. There are several reasons why one would expect the observed W/D ratios for the C5 channels measured in Steamboat Creek to be somewhat depressed (low). All of the C5 channels sites are located upstream of the Bella Vista Ranch site. The bedmaterial is becoming progressively coarser upstream. This is confirmed by the observations where, using the D_{65} particle size as an index value, Table 3 shows the bedmaterial in the C5 reference reaches (mean D_{65} = 0.93 mm) to be significantly more coarse than the local bedmaterial observed on site in test pits (mean D_{65} = 0.39 mm). Finer grained sand bed channels tend to produce higher W/D ratios (wider and shallower) as the result of a feedback mechanism that attempts to limit sediment transport on the easily eroded bed. In addition, the sequence of stream type conversions that represent the kind of channel adjustments observed in the CR7, CR8, and CR9 reaches (in the context of the Rosgen classifications) would be as follows: The original C5 channel is destabilized due to a reduction in base level, loss of vegetation, etc. and converts to a G5 channel type that begins to incise (cut down). Once an equilibrium slope is established at the new base level and the channel can incise no further, it begins to attack the banks and widen, converting to a type F5 channel. Once the bottom width of the F channel is wide enough to allow the thalweg on the channel floor to begin to meander, the channel converts back to C5 channel and the cycle of change is complete. During the later stage of this process (the conversion from F5 back to C5) the transition channel would have a sinuosity lower than the final equilibrium condition (sinuosity would have an increasing trend as more of the banks are eroded and pushed back in the widening process) and the W/D ratio would also be lower than the equilibrium condition. W/D ratio would also have an increasing trend remaining low (narrow and deep with a high sediment transport capacity) in the early stages to remove the high volume of sediment generated from the eroding banks and becoming progressively higher (wider and shallower with les sediment transport capacity) as the channel floor widens and the bank erosion rate declines. Therefore, it is very likely that the sinuosity and W/D ratios measured in the DeMonte Ranch area (CR7, CR8, and CR9) are lower than the final expected equilibrium condition.

Given the indicated conditions (finer bed material and a channel in transition) it would be reasonable to use a W/D ratio and sinuosity higher than the measured mean as design guidance. However, the selected design target should not be so high as to represent an outlier in the distribution of measured values (i.e., the target design value should be at least equal to the mean plus one standard deviation but not greater than the mean plus two standard deviations). Applying these criteria, the expected W/D ratio should be in the range of 25.8 to 33.8 and the expected sinuosity should be in the range of 1.38 to 1.53. For purposes of cross section design of the bankfull channel we have selected a W/D ratio of 29.6.

The design of the bankfull channel cross section addresses the following considerations:

- The design channel must classify as C5 using the Rosgen classification system.
- The design W/D ratio should place the channel sufficiently close to a quasi-equilibrium condition to preclude channel type conversions or any other form of severe instability.
- To satisfy concerns of the Corps of Engineers, the constructed channel should not have a flat bottom, but a shallow "V" bottom with as much total depth as practical and a well-defined thalweg at flows less than the bankfull flood.

Using the above-described criteria and placing the bankfull channel within the floor of an extreme event floodway with a bottom width of 200 ft, we would recommend a bankfull channel with the following characteristics:

Wbf = 31 ft
Dbfmax = 2.0 ft
Dbfavg = 1.05 ft
W/D = 29.6
ER = 6.45

Using an assumed Manning's n value of 0.03 within the unvegetated limits of the bankfull channel and a water surface gradient of 0.001304 ft/ft (0.0018 ft/ft divided by a sinuosity of 1.38), the channel would be expected to have the following hydraulic characteristics (based on a normal flow depth model):

Qbf = 70 cfs
Vbf = 1.97 ft/s
Unit Stream Power = 0.19 (ft-lbs/s)/ft^2
Bed Shear Stress = 0.0939 psf
Froude No. = 0.32

Similarly, assuming an average Manning's n value of 0.04 and a water surface gradient of 0.0018 ft/ft the combined bankfull channel and floodway would have the following hydraulic characteristics:

Q_{100} = 6064 cfs
Maximum depth above the thalweg = 8.1 ft
Flow depth at the edge of the floodway (on the floodplain surface) = 4.1 ft
Maximum V = 6.5 ft/s (deepest part of the channel)
Mean V = 5.3 ft/s
Top Width = 225 ft
Unit Stream Power = 3.0 (ft-lbs/s)/ft^2
Bed Shear Stress = 0.5662 psf
Froude No. = 0.42

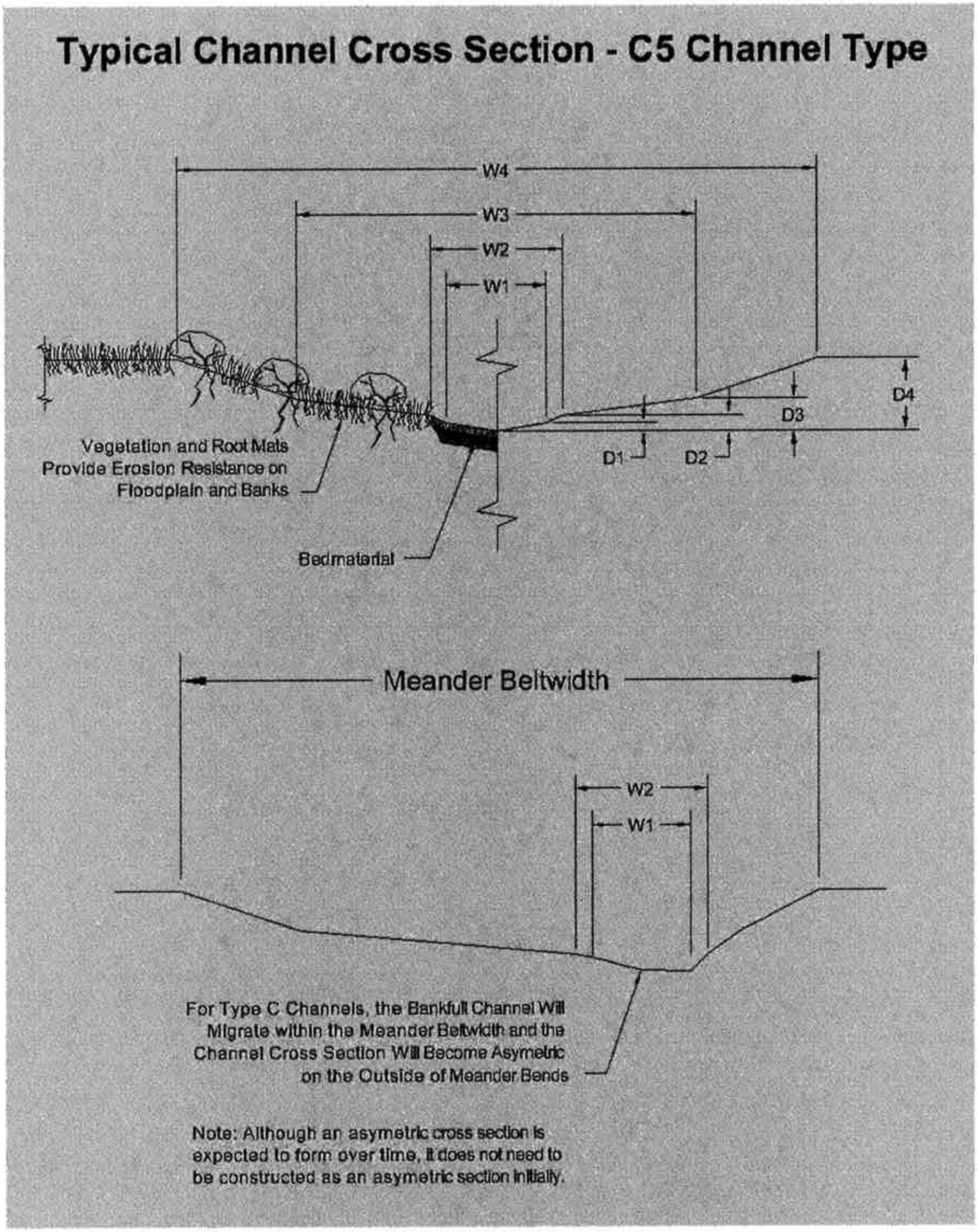
The recommended constructed bankfull channel dimensions are shown in Table 4 and Figure 4.

Table 4 – Summary of Constructed Channel Dimensions

Parameter	Dimension (ft)
W1	23.3
W2	31.0
W3	200
W4	Varies
D1	1.0
D2	2.0
D3	4.0
D4	Varies

As the channel enters the Bella Vista property, the floodway turns abruptly to the east, tracks parallel to the property line for some 3000 ft and then turns abruptly to the north again. Based on the ratio of the radius of curvature in those turns to the total channel width, the water surface will experience a superelevation on the outside of the channel bend on the order of 0.27 ft and the shear stress against the outer bank will increase by a factor of up to 1.8. The outer bank of the floodway must be armored through these turns to resist the increase in shear stress and the freeboard requirements must be checked to see that the modest increase in water surface elevation is accommodated.

Figure 4 – Typical Channel Cross Sections



Vegetation and Root Mats Provide Erosion Resistance on Floodplain and Banks

Bedmaterial

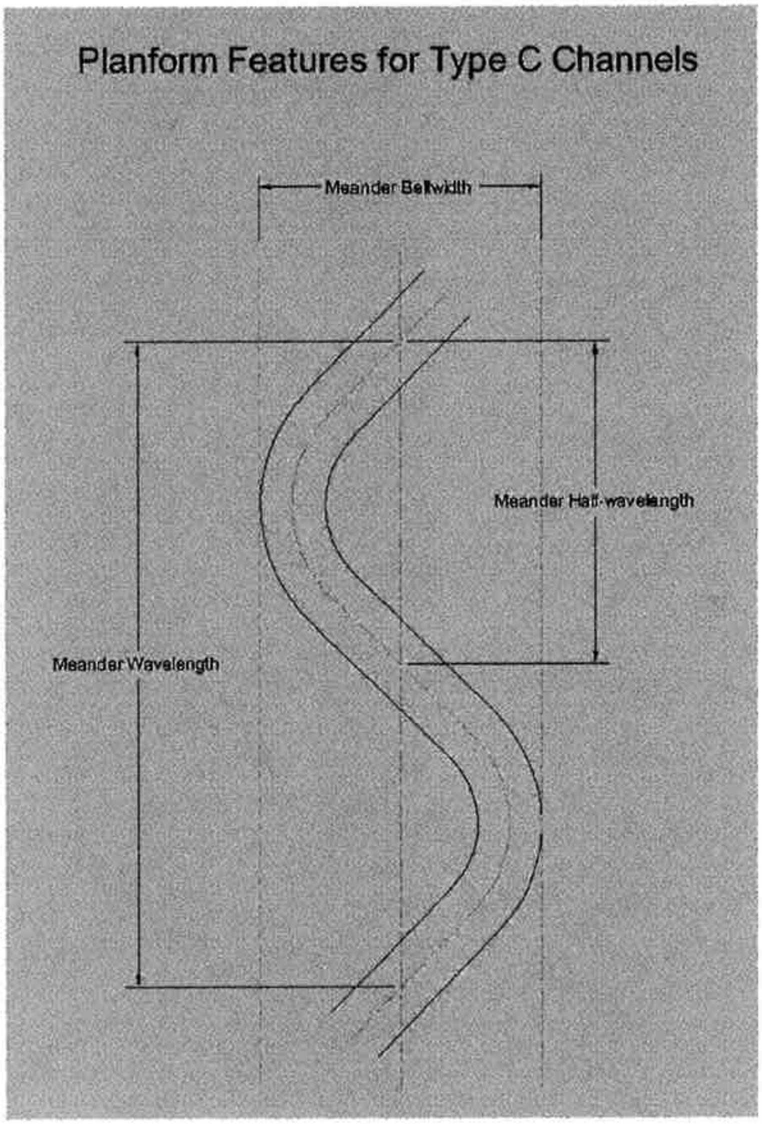
For Type C Channels, the Bankfull Channel Will Migrate within the Meander Beltwidth and the Channel Cross Section Will Become Asymetric on the Outside of Meander Bends

Note: Although an asymetric cross section is expected to form over time, it does not need to be constructed as an asymetric section initially.

3.2 Planform Geometry

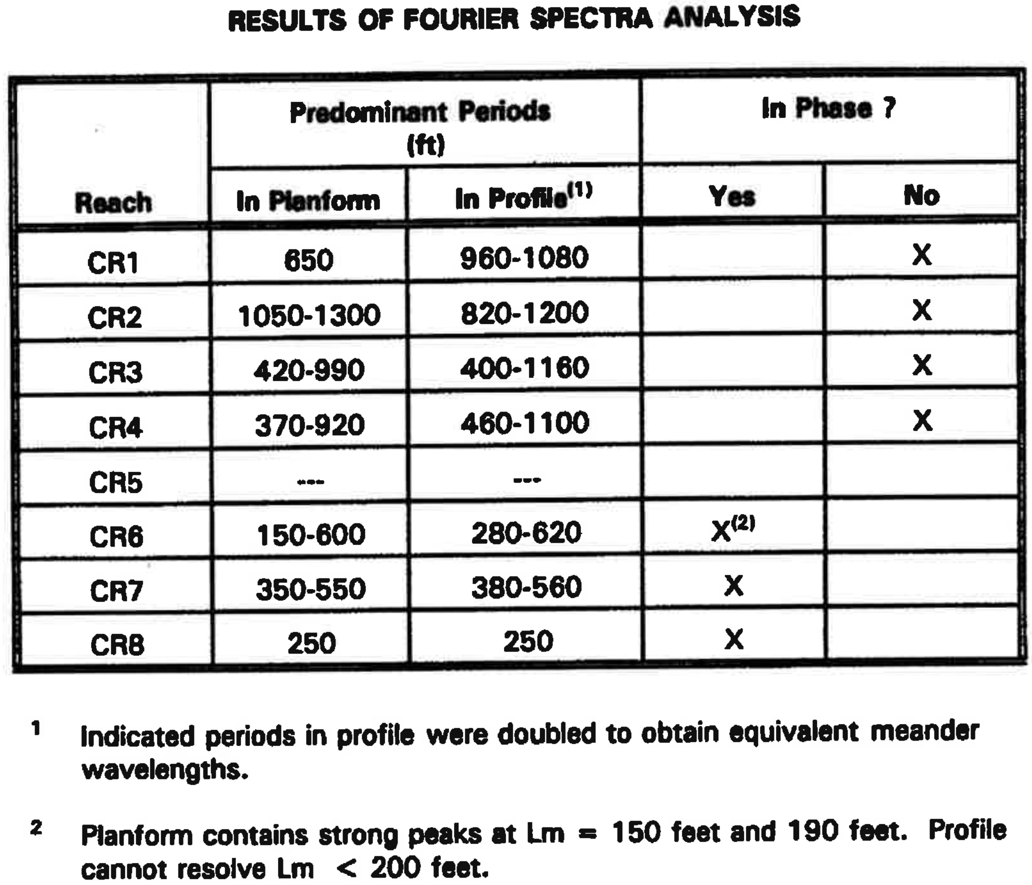
The C5 channel type is a meandering channel with a riffle-pool type of profile. The profile features (pools and riffles) are coordinated with the meander planform geometry. Pools occur consistently at the outside of meander bends, point bars build on the inside of meander bends, and riffles occur consistently at the crossover points between meander bends. Meanders are typically described as a simplified waveform with a quantified wavelength and amplitude (see Figure 5). The meander beltwidth is the minimum amount of space (floodplain width) required to completely contain the meanders without hindering their development.

Figure 5 – Planform Features



When systems are near equilibrium these relationships between pools and riffles in the planform and profile will be *in phase*. When systems are undergoing rapid change they will sometimes get *out of phase*. This occurs because channels may be abandoning older relic geometry and trying to superimpose a new geometry based on a different flow regime. The 1994 study in Steamboat Creek evaluated planform geometry (meanders) and profile geometry (spacing of riffles and pools) using Fourier spectra analysis (WESTEC, 1994). In general, within the channel reaches where the reference channels were selected (CR7, CR8, and CR9) the sequence of riffles and pools within the profile geometry would appear to be in phase with the major planform geometry (although minor planform geometry may not be reflected clearly in the profile geometry). A summary table of the WESTEC results is shown as Table 5.

Table 5 – Summary of Fourier Spectra analysis from WESTEC, 1994



RESULTS OF FOURIER SPECTRA ANALYSIS

Reach	Predominant Periods (ft)		In Phase ?	
	In Planform	In Profile(1)	Yes	No
CR1	650	960-1080		X
CR2	1050-1300	820-1200		X
CR3	420-990	400-1160		X
CR4	370-920	460-1100		X
CR5	---	---		
CR6	150-600	280-620	X(2)	
CR7	350-550	380-560	X	
CR8	250	250	X	

[1] **Indicated periods in profile were doubled to obtain equivalent meander wavelengths.**

[2] **Planform contains strong peaks at Lm = 150 feet and 190 feet. Profile cannot resolve Lm < 200 feet.**

A number of relationships have been developed over the years to predict the stable meander patterns, usually as a function of bankfull width or bankfull discharge. Two of those in common use are the equation of Dury (1976), and Leopold (1960).

Using the estimate of bankfull flow and a hydraulic geometry relationship from Dury 1976, the expected range of the meander wavelength can be estimated using the equation:

$$\mathbf{Lm = 59(Qbf)^{0.48}}$$

where the discharge is in cubic meters per second and the meander wavelength will be in units of meters. This equation is estimated to have a standard error of plus or minus 37 percent. Using the estimated bankfull discharge of 70 cfs, (1.98 m^3/s) the expected meander wavelength Lm = 269 ft (81.9 m) with a range of 196 ft to 368 ft.

Leopold's equation estimates meander wavelength as a function of bankfull width as follows:

$$\mathbf{Lm = 10.9(Wbf)^{1.01}}$$

Using Leopold's equation and a bankfull width of 31 ft, the expected meander wavelength Lm = 350 ft. Leopold does not provide confidence limits or an error range for his relationship.

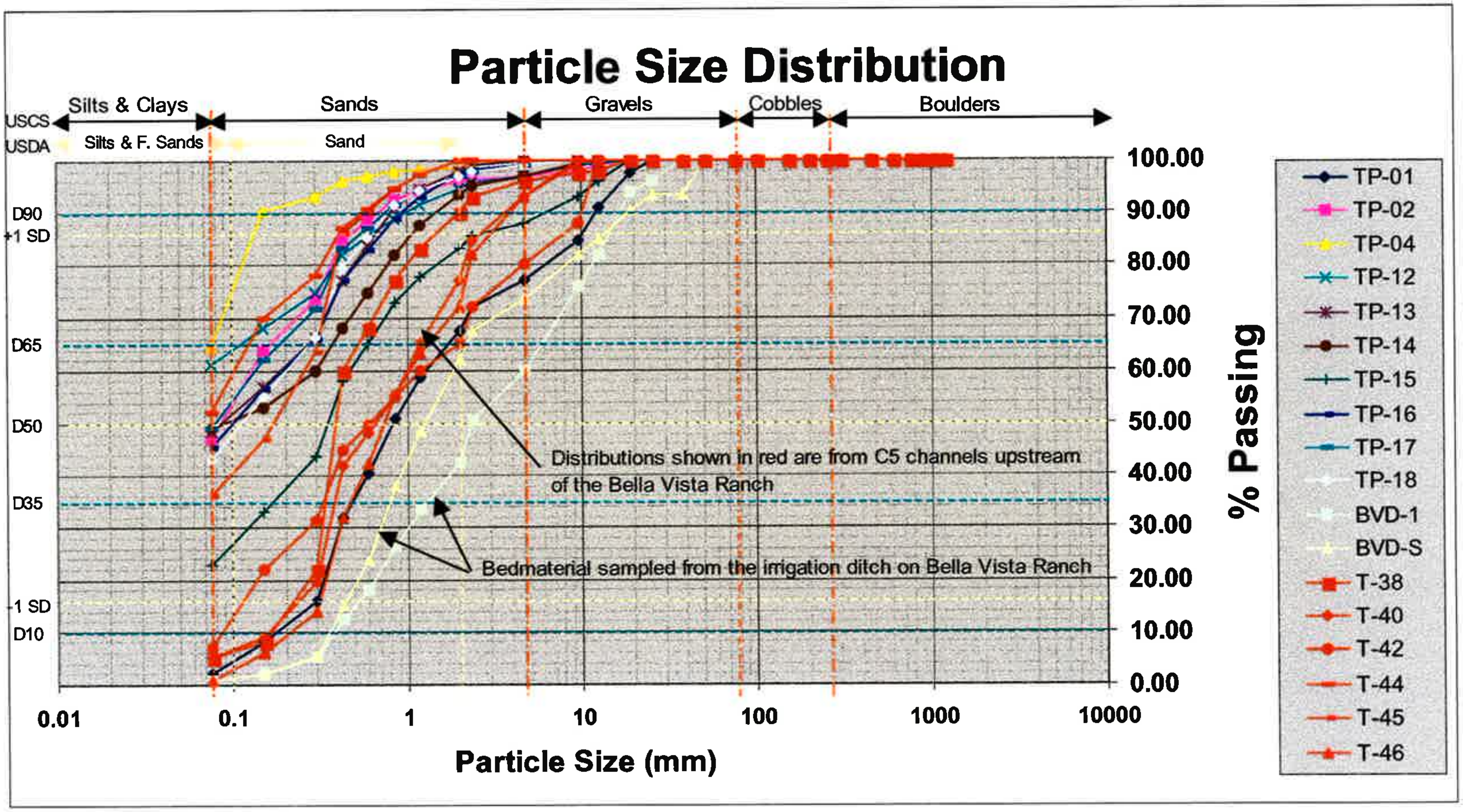
The current design meander wavelength proposed by Quad Knopf is 338 ft. This value lies between the estimates of Dury and Leopold and is well within Dury's error range. It also lies within the observed range of values in Steamboat Creek from the 1994 WESTEC study. Therefore, the proposed initial (constructed) planform geometry should be acceptable.

It should be noted that the final planform geometry and cross sectional geometry will change over time as the channel seeks and adjusts to the final quasi-dynamic equilibrium condition. Meander bends may migrate and vary in both length and amplitude. Pools will form at the outside of meander bends, and the symmetrical constructed cross sections will become asymmetric. However, these changes should be local adjustments and not massive changes throughout the channel system or conversions to other stream types.

3.3 Profile Geometry

As mentioned previously, a C5 channel type will have a sequence of shallow riffles and deeper pools that are coordinated with the planform geometry (pools on the outside of meander bends and riffles at the crossover points). The overall stability of the bed is controlled largely by the particle size distribution of the bedmaterial and the tractive force or bed shear dictated by the channel hydraulics. Characteristics of the bedmaterial expected in the proposed channel have been determined by sampling in test pits along the proposed channel alignment, and subsequent laboratory testing to obtain a particle size distribution. The data obtained from sampling on the Bella Vista site are shown in Figure 6. Figure 6 also shows the particle size distributions for the C5 channel reference sections (shown in red) and for samples of point bar materials obtained in the existing irrigation

Figure 6 – Summary of Particle Size Distributions



Distributions shown in red are from C5 channels upstream of the Bella Vista Ranch

Bedmaterial sampled from the irrigation ditch on Bella Vista Ranch ditch on the Bella Vista Ranch, one sample from the north end (BVD-1) and one from the south end (BVD-2).

Although the Bella Vista Ranch test pit samples and the 1994 Steamboat Creek samples cover a similar range, the test pit samples tend to cluster on the finer side of the range while the 1994 samples cluster of the coarser side of the range. The samples from the Bella Vista irrigation ditch are significantly coarser than either the test pit samples or the 1994 samples and represent the size of the material that could potentially be transported through the reach over time and be available to armor the channel bed and deposit in point bars.

The stability of the channel profile depends on the particle sizes exposed on the channel bed, the ability of the channel to form an armor layer of coarser particles, and on changes in sediment transport capacity from section to section along the channel alignment. For any isolated reach (or control volume) within a channel bounded by a section at the upstream end and a section at the downstream end, the channel bed profile between the sections will remain stable if the sediment volume entering the reach on the upstream end is equal to the sediment volume exiting the reach on the downstream end. If the sediment volume entering the reach exceeds the sediment volume exiting the reach, then the channel bed will tend to aggrade (fill). If the sediment volume exiting the reach exceeds the sediment volume entering the reach, then the opposite occurs and the reach will degrade (scour). Whenever there is a local deficit in the sediment load vs. the sediment transport capacity of the flow, the channel will always attempt to satisfy the deficit by recruiting sediment from its bed and banks. There are several different channel responses that can occur to resolve this condition.

- If the sediment is available and can be accessed by the flow, then it will simply scour the bed and banks to satisfy the deficit.
- In the process of scouring the bed, the channel can also reduce the slope of the bed (and ultimately the water surface slope) causing a reduction in the sediment transport capacity, which eliminates the deficit.
- If the bedmaterial contains a sufficient amount of coarse material (coarse enough that it cannot be transported by the flow), then it can concentrate the coarse fraction on the channel bed to form an armor that will resist further degradation and allow the flow to pass through the reach without fully satisfying the deficit.

The potential for long term aggradation or degradation of the channel (using only the locally derived bedmaterial soils) will be addressed in the next section of the report dealing with sediment transport modeling. More localized impacts will be addressed in this section. The equilibrium slope (also referred to as the limiting slope) for the channel is the slope at which the sediment transport potential drops to near zero and it varies with the nature of the bedmaterial and the magnitude of the discharge. It is also dependent on the method used to establish incipient motion criteria for the particle size distribution involved (Shields, Meyer Peter & Muller, etc.) Table 6 shows estimates of the equilibrium slope, using the Shields criteria for incipient motion, for both the bankfull flood and the 100-year flood and for each of the three (3) representative particle size distributions (on site test pits, DeMonte Ranch bedmaterial (CR7, CR8, and CR9), and the coarsest observed bedmaterial from the Bella Vista irrigation ditch – BVD). As the results show, the equilibrium or limiting slopes are all well below both the thalweg gradient of 0.001304 ft/ft and the overall floodway gradient of 0.0018 ft/ft. The equilibrium slope can be used to estimate the maximum amount of local channel incision impact (degradation) that might be expected from sediment depleted flow at any point along the channel alignment and to evaluate the potential need for grade control.

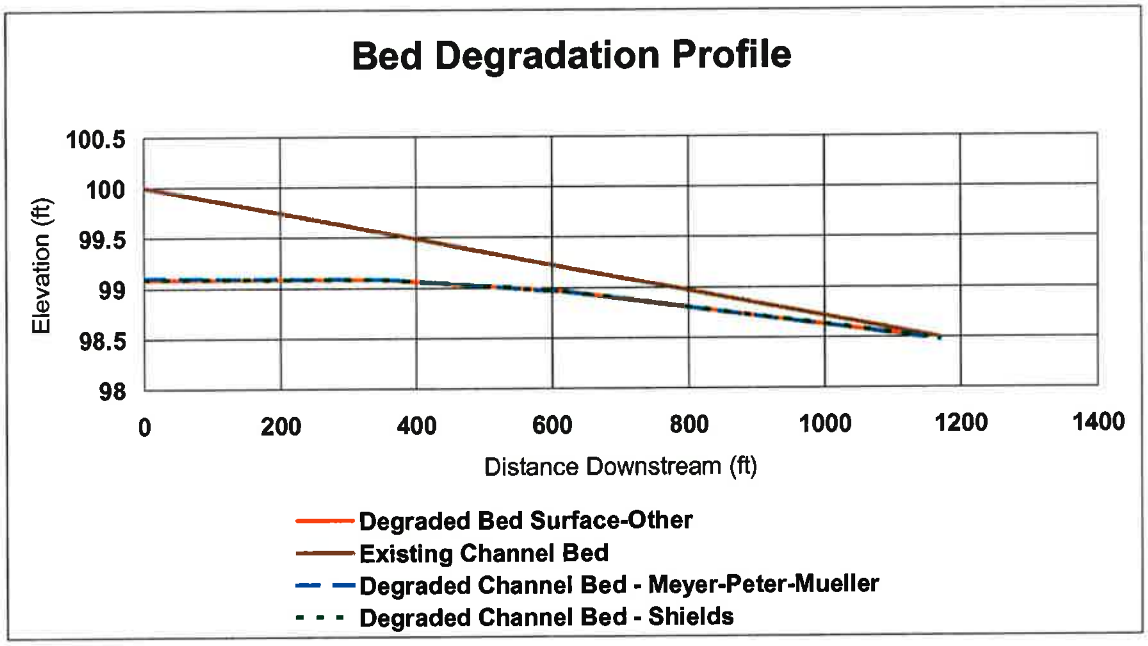
Table 6 – Estimates of Equilibrium Slope (Limiting Slope)

Discharge	Test Pit Soils	DeMonte Ranch Soils	BVD Soils
Bankfull Flood	0.0000106 ft/ft	0.000128 ft/ft	0.000389 ft/ft
100 Year Flood	0.00000182 ft/ft	0.0000350 ft/ft	0.0000989 ft/ft

When there is an insufficient amount of coarse material to develop an armoring layer, degradation can be computed using the *stable slope method*, developed by the U.S. Bureau of Reclamation, 1987 (also called the *three slope method*) and used primarily to evaluate channel degradation from clear water releases in the tailwater areas below major dams. The procedure calculates the maximum depth of degradation below the dam (or any other sediment trapping feature), the length of the transition back to the original channel slope, and the intervening degradation profile. In addition to estimates of the equilibrium slope, it requires an estimate of the total volume of sediment trapped or removed from the flow upstream over the time period of interest.

For example, section 83 in the sediment transport model is immediately downstream of a culvert structure. Changes in the energy grade line across this structure create circumstances that trap sediment on the upstream side and release sediment depleted flow on the downstream side. Over an extended period of time at the mean dominant discharge or bankfull flow, the sediment transport model shows a deficit of 20 tons per day (t/d) (26 t/d upstream of the structure and 46 t/d downstream). The cumulative impact over 30 model days at the bankfull flow (representing at least 45 years of elapsed time) would be the storage of approximately 600 tons of sediment upstream of the structure. The resulting degradation profile downstream of the structure is shown in Figure 7. This analysis shows a maximum degradation depth of 0.9 ft and a degradation profile extending nearly 1200 ft downstream of the structure. At a distance of 600 ft below the structure, the expected degradation depth would be reduced to less than 0.3 ft. The depth of degradation below the structure can be reduced using grade control structures. In a C5 channel, grade control structures should be placed at the crossover points (riffles) between meander bends. For the planform geometry proposed, the acceptable spacing of grade control structures (along the floodway centerline) would be 169 ft, 338 ft, 507 ft, 676 ft, and so on in increments of half the meander wavelength (169 ft). The degradation profile for the example shown indicates that grade control structure spacings greater than 338 ft would have no benefit (i.e., the reduction in the degradation depth would be no greater than the expected degradation on the transition profile). Therefore, it would be recommended that three (3) grade control structures be placed in the channel immediately downstream of the culvert structure at a spacing of 169 ft (half the meander wavelength). This would limit the degradation depth to approximately 0.22 ft and reduce the potential for instability in the bankfull channel. Alternatively two (2) grade control structures could be placed at a spacing of 338 ft (one meander wavelength) but the degradation depth would be limited to approximately 0.43 ft.

Figure 7 – Estimated Bed Degradation Profile at Section 83



If grade control structures are used in the Steamboat Creek channel, it is recommended that they be constructed as rock vortex weirs and securely embedded well into the stable, vegetated floodplain adjacent to the bankfull channel. The crest of the weir should have the same cross sectional shape as the bankfull channel. Typical details for rock vortex weirs are provided in Figure 8 and Figure 9. Nominal crest rock diameter should be 12 inches (in). Nominal Footer rock diameter should be 18 in. The depth of embedment of the footer rock below the channel invert should be at least 3 ft. The wings of the weir structure should extend no less than 5 ft into the vegetated floodplain and must not project above the floodplain surface. The surface of these wings must also be revegetated with the same seed mix as the floodplain itself.

Figure 8 – Rock Vortex Weir, Typical Detail 1

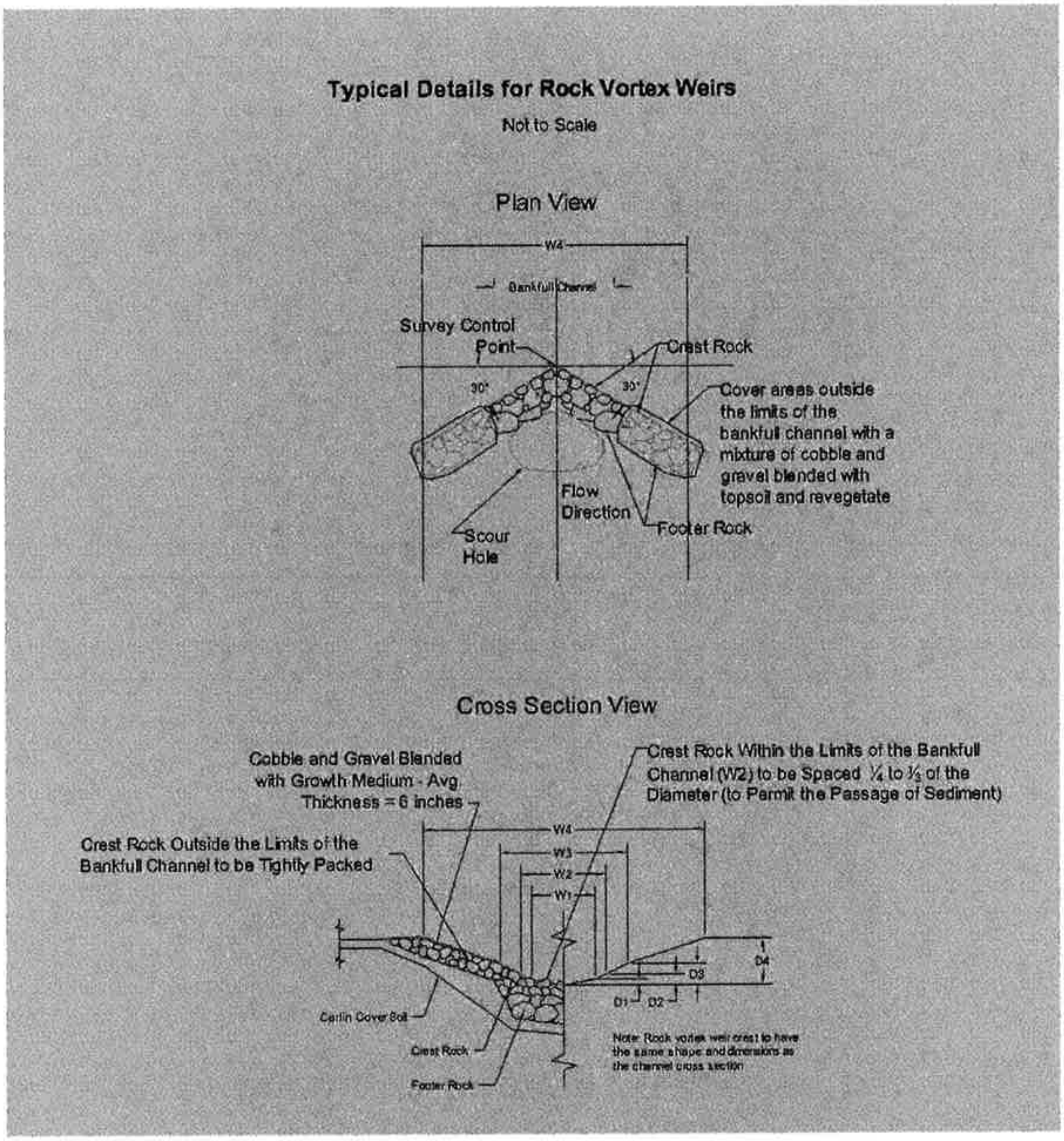
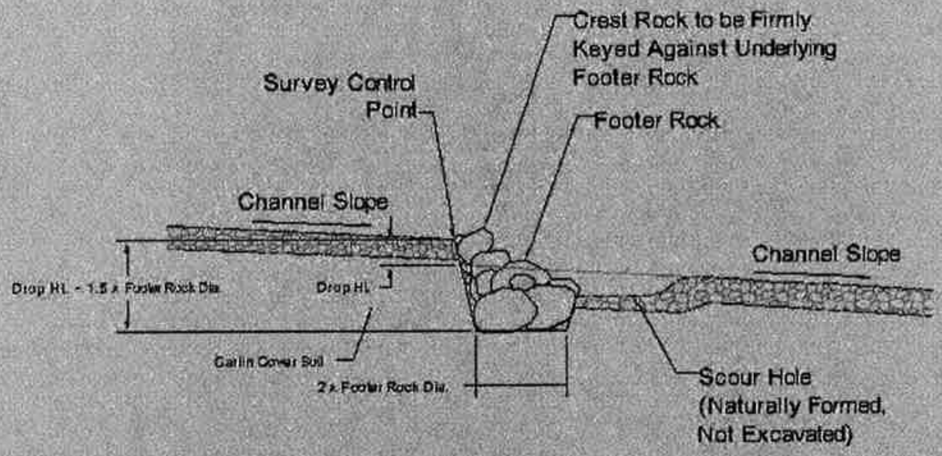


Figure 9 - Rock Vortex Weir, Typical Detail 2

Profile View



Notes on Construction:

1. Stake the location of each structure on the centerline of the channel alignment.
2. Excavate the rough grade of the channel including the drop (step) in the channel grade at the staked location of each weir structure and establish channel cross sectional shape, prior to beginning construction of the weir structures.
3. Excavate a trench for the placement of the footer rock that establishes the upstream pointing chevron shape of the weir.
4. Place the footer rock in the base of the trench.
5. Place the crest rock against the upstream side of the trench, keying the rock against the back of the footer rock. Take care to establish the required spacing between crest rock within the limits of the bankfull channel and preserve the cross sectional shape of the bankfull channel. Outside the limits of the bankfull channel, the crest rock should be tightly packed.
6. Backfill any large voids with small rock and gravel.
7. Cover exposed rock outside the limits of the bankfull channel with a mixture of cobble, gravel and growth medium (topsoil if available) to permit revegetation of the surface. The thickness of the cover mixture should average approximately 6 inches.

Although the stable slope method can only address degradation in the channel, an excessive sediment supply leading to local aggradation of the channel bed is essentially a mirror image of the degradation profile. Channel slopes increase above the original bed slope in an attempt to increase the sediment transport rate out of the area and then transition back to the original slope over some distance. The stable slope method cannot predict an aggradation profile, however since it is highly dependent on the redistribution of the sediment volume, it can provide a rough estimate of the length of channel impacted by a local aggradation of sediment. The average channel gradient in the DeMonte Ranch channel immediately upstream of the Bella Vista Ranch channel is 0.003 ft/ft, significantly steeper than the 0.0018 ft/ft gradient in the Bella Vista floodway. The bedmaterial soils are not significantly different at the boundary. Therefore, it is likely that local aggradation will occur near the boundary over time. Using estimates of the change in sediment transport rate at mean dominant discharge over a period equivalent to an elapsed time on the order of 100 years, the sediment volume is estimated to be approximately 41,500 ft^3. This volume is likely to impact the channel over a distance of up to 2200 ft. The kinds of channel responses that are likely to accompany such a local influx of sediment would include the accelerated growth of point bars in the area leading to an extension of both the wavelength and amplitude of the meanders. In a floodway that just contains the stable meander geometry, these impacts could result in a more aggressive attack of the floodway channel banks (both sides). There are two (2) potential solutions to the mitigation of this problem. One is to increase the floodway width to accommodate the growth of the point bars and extension of the meander geometry. The second is to armor the floodway banks to resist this more aggressive attack of the banks and constrain the meander geometry. Since the primary use of the property is residential development and the magnitude of the change in meander geometry cannot be accurately predicted, the second approach is probably the preferable alternative. The armoring should be placed on both banks and should extend not less than 2000 ft down the channel alignment from the property boundary. Bank armor should be embedded not less than four (4) feet below the floodplain surface.

4 Sediment Transport Modeling

At our request, Quad Knopf personnel were asked to modify the sediment transport model to address what we perceived as problems with the model performance. The original sediment transport model covered only the limits of the Bella Vista Ranch development, beginning at the upstream boundary with the DeMonte Ranch project. The assumed incoming sediment load was based on a single measured value of suspended sediment only (ignoring the important bedload component). This produced numerical instability in the model and a high sensitivity to the assumed incoming sediment load. Therefore, the model was amended to include the first mile of the channel within the DeMonte Ranch project. This permitted the model make adjustments to the sediment load prior to reaching the property boundary so that sections near the property boundary are at or near equilibrium and changes between sections downstream of the boundary no longer represent spurious numerical adjustments within the model itself. We also recommended changing the sediment transport relationship to the Yang method. Yang's procedure is a relatively current and robust procedure based on unit stream power as the dependent variable and has validity across the full range of particle sizes represented by the expected bedmaterial particle size distributions on the Bella Vista Ranch project. For a detailed discussion of the sediment transport modeling, the reader is referred to the sediment transport modeling section of the main Quad Knopf report. However, summaries of the modeling results will be reviewed here in light of the potential long-term impacts to channel stability.

Sediment transport modeling was performed using the Corps of Engineers HEC-6 model which is a simple one-dimensional model that predicts general aggradation and degradation in a moveable boundary (fluvial) channel system. As such it has important limitations. Calculated changes in sediment transport capacity across channel sections are resolved by either recruiting the sediment deficit by scouring the bed or depositing the excess sediment load on the bed. The sediment volume is uniformly distributed across the width of the channel and along the length of the reach between sections. The model is not capable of resolving local changes in aggradation or bed scour. It produces estimates of long-term averaged trends in bed change and is most useful in predicting the long-term direction of change.

Table 7 shows the results of a sensitivity analysis using an extended period of bankfull flow. Sediment input load was varied using the measured suspended sediment load, 150% of the measured load, 50% of the measured load and zero (0) sediment inflow. Results showed minimal differences resulting from any of the assumed loadings. The amended model is now insensitive to the assumed sediment input loading.

Table 7 – Sensitivity Analysis Results

Section #	Bed Change (ft) after 30 days using Bankfull discharge (Q=70cfs)			
NUMBER	Measured Sed. Inflow	150% Measured Sed. Inflow	50% Measured Sed. Inflow	Zero Sed. Inflow
89	-0.12	-0.14	-0.14	-0.14
87.64	0.16	0.19	0.19	0.19
87.28	0.01	0.01	0.01	0.01
85.63	0.09	0.1	0.1	0.1
83	-0.28	-0.23	-0.23	-0.23
79	0.02	0.02	0.02	0.02
73	0.02	0.02	0.02	0.02
67	0.02	0.02	0.02	0.02
63	0.02	0.02	0.02	0.02
59	0.02	0.02	0.02	0.02
55	0.03	0.05	0.05	0.05
52	0.04	0.03	0.03	0.03
49	0.05	0.03	0.03	0.03
45	-0.06	-0.15	-0.16	-0.18
40	0.02	0.02	0.02	0.02
37	-0.1	-0.09	-0.09	-0.11
29	0.01	0.01	0.01	0.02
25	0.02	0.02	0.02	0.02
22	0.02	0.02	0.02	0.02
19	-0.12	-0.09	-0.09	-0.1
18	0.2	0.2	0.2	0.2

Table 8 shows bed changes over a one-year duration using a dry year hydrograph (the actual flow record from 2001). It shows the channel to be in equilibrium with negligible bed changes between sections. If there is any trend to be seen at all in this data, it is a temporary, short-term tendency toward aggradation (the 7 day sediment loads are slightly higher in the upstream sections and progressively reducing in the downstream sections).

Table 8 – Calculated Bed Changes for a Dry Year Hydrograph

Section #	Bed Change (ft)			Sand transport rate through sections (tons/day)		
	after 7 days	after 195 days	after a year	after 7 days	after 195 days	after a year
89	-0.02	-0.02	-0.03	5	0	1
87.64	0.00	0.00	0.02	5	0	1
87.28	0.00	0.00	0.08	5	0	1
85.63	0.01	0.00	0.01	4	0	1
83	0.00	0.00	0.01	4	0	1
79	0.00	0.00	0.01	4	0	1
73	0.00	0.00	0.00	4	0	1
67	0.00	0.00	0.00	4	0	1
63	0.00	0.00	0.01	4	0	1
59	0.00	0.00	0.01	4	0	1
55	0.00	0.01	0.01	4	0	1
52	0.00	0.00	0.01	3	0	1
49	0.00	0.00	0.01	3	0	1
45	0.00	0.00	0.00	3	0	1
40	0.00	0.01	0.01	3	0	1
37	0.00	0.00	0.00	3	0	1
29	0.00	0.01	0.00	3	0	1
25	0.00	0.00	0.00	3	0	1
22	0.00	0.01	0.01	3	0	1
19	0.00	-0.01	0.00	3	0	1
18	0.00	-0.05	-0.05	3	0	1

Table 9 shows bed changes over a one-year duration using a wet year hydrograph (the actual flow record from 2002). It shows most of the channel to be in equilibrium with negligible bed changes between sections, but with local perturbations in the transport rate and bed change in a few isolated reaches, most notably at the channel entrance, in the vicinity of the culvert structure near section 83, and at the channel exit. Performance is variable over both distance and time and can be interpreted as slugs of sediment migrating through the system or migrating knickpoints in the channel. The changes at section 83 are as expected and discussed in the earlier section. The only extreme change seems to be focused at the channel exit where anomalous results over time vary from as much as 2.95 ft of scour to no change to as much as 0.92 feet of aggradation over the one year duration of the model run. Clearly, if this represents anything close to reality, some form of grade control is probably warranted near the channel exit (which we would typically want to do anyway in order to hydraulically isolate the project).

Table 9 – Calculated Bed Changes for a Wet Year Hydrograph

Section #	Bed Change (ft)			Sand transport rate through sections (tons/day)		
	after a day	after 86 days	after 172 days	after a day	after 86 days	after 172 days
89	-0.04	-0.29	-0.41	726	47	32
87.64	0.07	0.01	0.00	708	51	32
87.28	0.00	0.00	0.00	708	51	32
85.63	0.08	0.02	0.01	618	53	33
83	0.02	-0.44	-0.59	548	58	34
79	0.01	0.00	0.00	495	86	39
73	0.00	0.05	0.00	466	109	39
67	0.00	0.08	0.00	445	107	46
63	0.00	0.04	0.01	429	92	45
59	0.00	-0.05	-0.10	417	106	46
55	0.00	0.03	0.01	408	93	45
52	0.00	0.01	0.01	402	129	43
49	0.00	0.05	0.02	397	127	41
45	0.00	0.05	0.02	393	152	40
40	0.00	0.05	0.02	392	160	38
37	0.00	0.05	-0.01	390	146	39
29	0.00	-0.06	-0.06	388	222	47
25	0.00	0.24	-0.24	387	14	90
22	0.00	0.23	-0.05	386	0	87
19	0.00	0.16	-0.19	385	0	68
18	0.00	-2.95	0.92	385	1288	0

Table 10 shows the short-term impacts of the passage of the 100-year flood event. The bed remains quite stable through most of the event, but after 24 hours there is some modest scour near the channel entrance and in a few of the downstream sections (29 through 45). However, the dominant trend here seen in all time periods in both the bed change and the transport rates is a trend toward aggradation that is highest either at the upstream end or near the culvert structure at section 83 and diminishes with distance downstream.

Table 10 – Calculated Bed Changes for the 100 Year Flood

Section #	Bed Change (ft)			Sand transport rate through sections (tons/day)		
	after 11 hours	after 12 hours	after 24 hours	after 11 hours	after 12 hours	after 24 hours
89	-0.44	-0.23	-0.54	2544	2580	12800
87.64	0.06	0.01	0.02	2475	2930	12790
87.28	0.67	0.11	0.33	2311	3684	12742
85.63	0.11	0.02	0.04	2029	5007	12712
83	0.03	0.04	0.05	1819	4460	12850
79	0.01	0.02	0.03	1661	4018	13657
73	0.01	0.01	0.03	1543	3921	14013
67	0.01	0.01	0.06	1454	3699	15845
63	0.00	0.01	0.09	1425	3421	17714
59	0.01	0.01	0.37	1366	3254	17705
55	0.01	0.01	0.03	1322	3194	17120
52	0.00	0.01	0.03	1288	3094	16738
49	0.00	0.01	0.02	1263	2970	16505
45	0.00	0.00	-0.32	1256	2777	15657
40	0.00	0.00	0.01	1239	2688	15741
37	0.00	0.00	-0.14	1231	2574	14212
29	0.00	0.00	-0.12	1228	2451	12000
25	0.00	0.00	0.15	1218	2335	8424
22	0.02	0.05	0.12	1063	1254	6319
19	0.15	0.17	0.11	415	657	5066
18	0.09	0.11	0.12	316	551	4975

The final model just looks at the passage of the mean dominant discharge or bankfull flow through the channel over an extended period of time and is intended to disclose the long term trend, absent any short term fluctuations, for the event that moves the greatest amount of sediment through the system over the long-term. The results show only small changes in the bed over time in all time frames, confirm the local tendency toward scour below the culvert structure at section 83, and confirm the same trend seen in the other models showing a tendency toward aggradation in the upper portions of the channel that progressively dissipates in the downstream direction, below sections 79, 83, or 85.63.

Table 11 – Long-Term Trends Under Extended Mean Dominant Discharge (Bankfull) Flow

Section #	Flow, Q	Bed Change (ft)			Sand transport rate through sections (tons/day)		
	(cfs)	after a day	after a week	after a month	after a day	after a week	after a month
89	70	-0.07	-0.11	-0.12	182	96	28
87.64	70	0.06	0.07	0.16	174	94	28
87.28	70	0.00	0.00	0.01	174	94	28
85.63	70	0.09	0.05	0.09	156	90	26
83	70	0.01	0.01	-0.28	143	95	46
79	70	0.00	0.01	0.02	135	104	43
73	70	0.00	0.01	0.02	129	98	42
67	70	0.00	0.01	0.02	124	92	40
63	70	0.00	0.02	0.02	120	86	39
59	70	0.00	0.03	0.02	118	79	42
55	70	0.00	0.03	0.03	116	74	42
52	70	0.00	0.01	0.04	114	71	39
49	70	0.00	0.00	0.05	113	69	36
45	70	0.00	0.00	-0.06	113	67	36
40	70	0.00	0.00	0.02	112	68	34
37	70	0.00	0.00	-0.10	111	67	40
29	70	0.00	0.00	0.01	111	65	37
25	70	0.00	0.00	0.02	111	64	35
22	70	0.00	0.00	0.02	111	62	34
19	70	0.00	0.01	-0.12	111	61	39
18	70	0.00	0.02	0.20	110	60	37

Based on an interpretation of these results, it would appear that there is no need for regularly spaced grade control along the full length of the channel since the long-term trend seems to be aggradation in the upper portion of the channel transitioning toward an equilibrium condition downstream. Local grade control below the culvert structure at section 83 is probably appropriate as discussed in the earlier section. Grade control structures should also be placed at both the upstream entrance and the downstream exit. The model did occasionally show anomalous changes in the bed and sediment transport rate in these areas, however, even if there were no such anomalies, it is important in an urban setting to isolate your project from potential impacts on adjacent properties that are outside of your control. Although not evident in the data reviewed thus far, grade control should be considered in any other areas where there might be a rapid change in the energy grade line (sudden constrictions or expansions for example).

5 Revegetation

Revegetation of the floodplain (floor of the 100 year floodway) and the floodway banks is beyond the scope of this report and outside of my area of expertise. However, a general discussion of the role of vegetation in maintaining the stability of the channel is appropriate. Type C channel systems are extremely dependent on vegetation for their stability. Due to the erodability of the fine sand bed, it is the establishment of mature, stable vegetative cover on the floodplain and banks that allows the C5 channel type to be self-maintaining. The channel is at greatest risk over the 2 to 5 year time period immediately after construction typically required for the vegetation to mature. In the interim, erosion control mats can be considered to reduce the risk. If the vegetation is absent or lost, it is very likely that the C5 channel will rapidly convert to a D5 channel type (a braided channel with very high W/D ratio and multiple thalweg channels amongst numerous mid-channel bars). Braided channels tend to be very unstable with frequent avulsions (sudden changes in the location and direction of the thalweg channel in response to a flood event) and provide very little habitat value.

For Steamboat Creek and a C5 reach the vegetation mix should probably be a combination of herbaceous species such as sedges, rushes and various grasses with occasional willow species on the bar depositions and scoured banks. Tree species, such as cottonwood, are desirable, but not critical to channel stability. It is important that any species considered for use in Steamboat Creek/Truckee Meadows be locally derived and capable of adapting to the high boron, arsenic, and phosphorous conditions that often dominate the soil and water chemistry in the area. Text extracted from a letter prepared by botanical consultant Lynda S. Nelson in 1994 regarding revegetation in Steamboat Creek is included in Appendix B.

6 Conclusions and Recommendations

We believe the selection of a C5 channel type for the Bella Vista Ranch reach in Steamboat Creek is appropriate. Data derived from reference reaches within the Steamboat Creek channel upstream of the project as well as our own experience and professional judgment have been used in the selection of design parameters for the proposed low flow (bankfull) channel to be constructed at the base of the 100 year floodway. The recommended characteristics of the bankfull channel are as follows:

Qbf = 70 cfs
Wbf = 31 ft
Dbfmax = 2.0 ft
Dbfavg = 1.05 ft
W/D = 29.6
ER = 6.45

The proposed meander wavelength of 338 ft and constructed sinuosity of 1.38 will provide an appropriate initial planform geometry for the bankfull channel. Based on the results of sediment transport modeling and other considerations affecting the stability of the bed in profile, it would not appear that a regularly spaced program of grade control would be required for bed stability. Grade control should be used at the upstream entrance and downstream exit points to isolate the project from potential offsite impacts beyond the control of the developer. In addition, local grade control should be considered downstream from a proposed culvert facility near modeling station number 83. Armoring of the outside banks of the floodway will be required in the abrupt turns in floodway alignment in the upper half of the channel. In addition, armoring of the inside bank will be required in the first 2000 ft of channel on the upstream end of the project to resist the potential for bank attack caused by the potential for extension of the meander geometry (point bars and meander amplitude) as a response to local aggradation potential at the upstream boundary.

Successful establishment of stable vegetative cover on the floodplain and floodway banks is critical to the stability and self-maintenance aspects of the proposed channel. The newly constructed channel will be at greatest risk during the 2 to 5 year time period immediately after construction that is likely to be required for vegetation to mature.

Appendix A
The Rosgen Classification System

David Rosgen is a hydrologist who spent nearly 30 years with the U.S. Forest Service. In that time he has amassed a tremendous knowledge of the behavior of natural stream systems and compiled a substantial database of nearly 500 different stream systems of varying character from which he derived numerous empirical relationships which formed the basis for his various classifications. As discussed above the resulting physical appearance and character of the stream is a product of adjustments of its boundaries to the current stream flow and sediment regime. Stream form and fluvial process evolves simultaneously and operate through mutual adjustments toward quasi equilibrium or self-stabilization.

The Rosgen Stream Classification System is an effort to categorize river systems by channel morphology in order to better

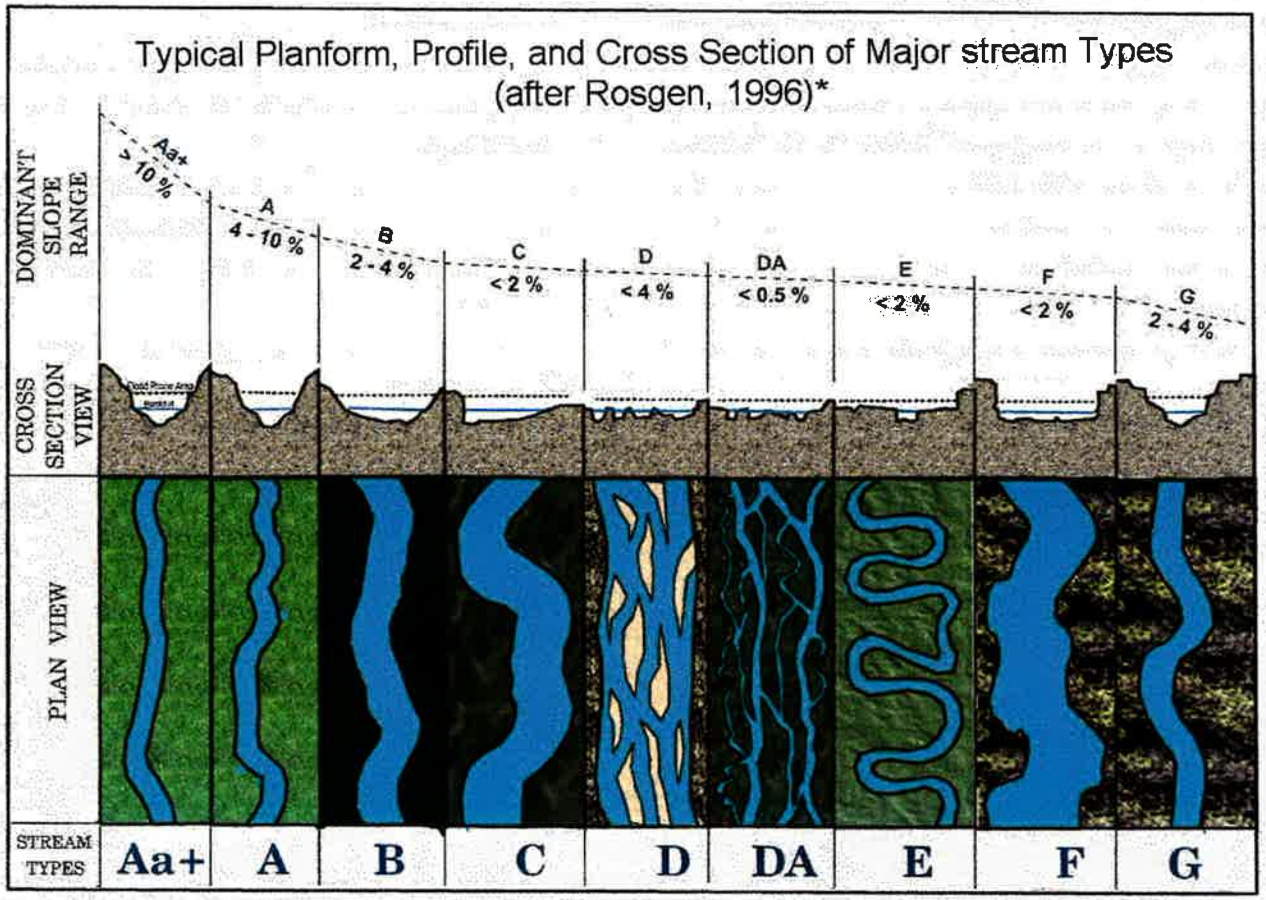
1. Predict a river's behavior from its appearance,
2. Develop specific hydraulic and sediment relations for a given morphological channel type and state,
3. Provide a mechanism to extrapolate site-specific data collected on a given stream reach to those of similar character, and
4. Provide a consistent and reproducible frame of reference of communication for those working with river systems in a variety of professional disciplines.

None of the principles utilized in the Rosgen Stream Classification System are particularly new; in fact the earliest observations of the importance of mean dominant discharge or bankfull discharge were published by Leopold and Wolman in 1957. Stream classification systems are nothing new either with the earliest classifications dating back to Davis in 1899 where he first divided streams into three classes based on relative stages of adjustment, which he described as youthful, mature, and old-age. Subsequent classification systems based on qualitative and descriptive delineations were developed by Melton in 1936 and Matthes in 1956. Systems based on channel patterns (described as straight, meandering and braided) were developed by Leopold and Wolman in 1957 and by Lane in the same year. A system proposed by Schumm in 1963 involved delineation partly based on channel stability (stable, eroding, or depositing) and mode of sediment transport (mixed load, suspended load, and bedload). Numerous investigators in the 1960s and 1970s began to develop descriptive classifications that utilized depositional features, vegetation, braiding patterns, sinuosity, meander scrolls, bank heights, levee formations, and flood plain types to discriminate various stream systems.

Many of these classifications systems are rather academic in nature as might be expected since their use was primarily for research. One of the most compelling characteristics of the Rosgen Stream Classification System is that it was developed by an individual that was not directly involved in the academic role of research but from one who spent most of his career dealing with practical problems in the river environment and finding practical solutions to those problems. Because of its origin, this particular classification system is better suited to design oriented problems and the application of in-regime design.

A schematic of the classification system is provided in Figure A1 and Figure A2. The system is based on morphological characteristics of the channel leading to a letter designation A through G and determined by characteristics such as entrenchment, width-depth ratio, sinuosity, and slope and by bed material types leading to a number designation ranging from 1 (for bedrock) to 6 (for silt and clay). An F5 stream for example would be expected to be a single thread channel, well entrenched, with moderate to high width to depth ratio, high sinuosity, and flat slope flowing on channel bed materials made up predominately of sand.

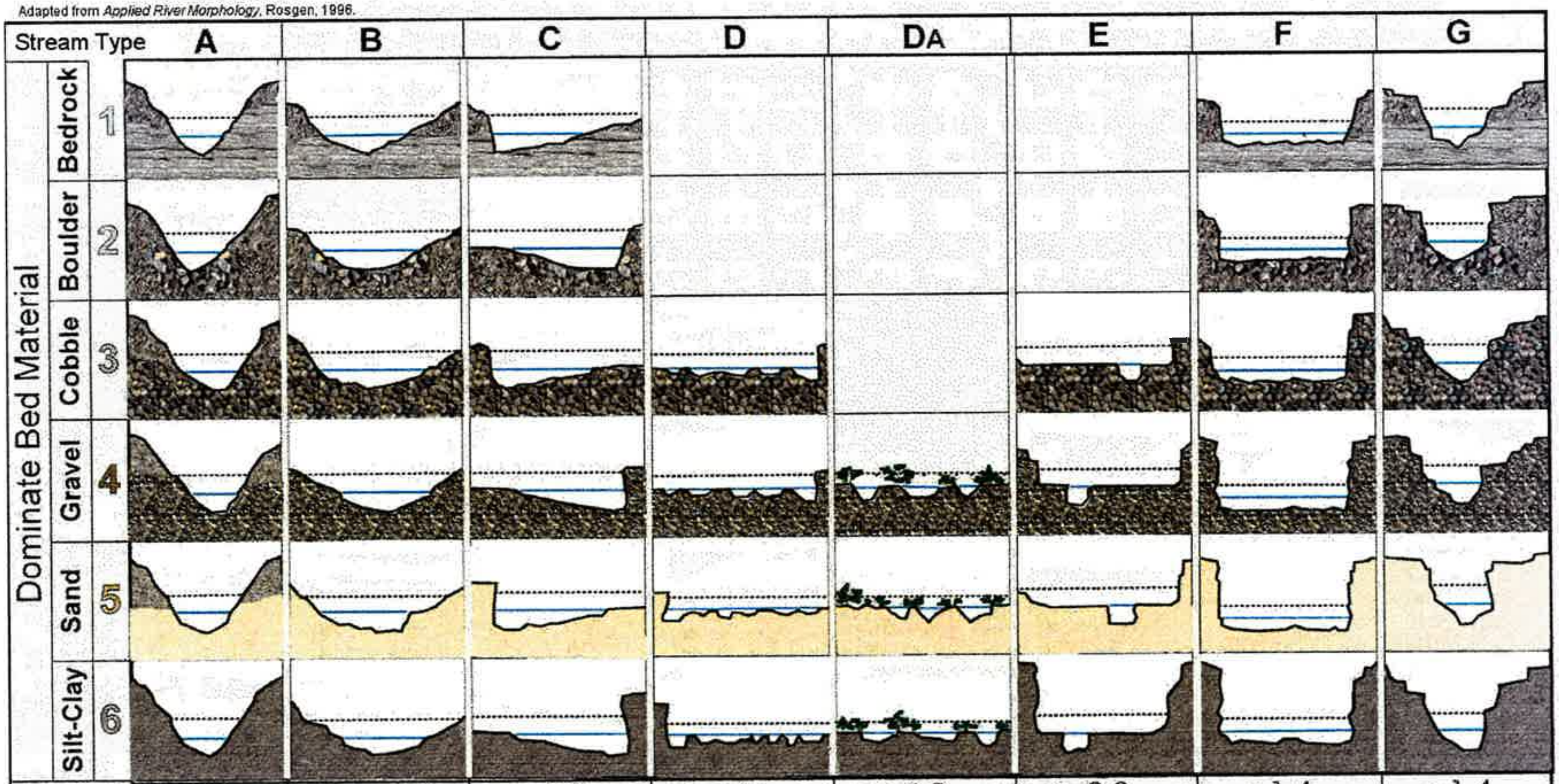
Figure 6-1 – Rosgen Classification System



Adapted from *Applied River Morphology*, Rosgen, 1996.

Figure 6-2 - Rosgen Classification System

Adapted from *Applied River Morphology*, Rosgen, 1996.



Stream Type	A	B	C	D	DA	E	F	G
Entrchmnt	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	>1.5	> 1.2	>1.2
Slope	.04-.099	.02-.039	< .02	< .04	< .005	< .02	< .02	.02-.039

Appendix B
Revegetation Recommendations from Lynda Nelson, 1994

“Enclosed you will find a recommended plant species list for revegetation along sections of Steamboat Creek. Also, I've written some general planting guidelines as well as some potential sources for the plant material. All of the recommended plant species are considered to be native wetland species and considered somewhat tolerant of boron. Based on the history of Steamboat Creek and considering the fact that the creek was more than likely a "C" type channel according to Rosgen's classification along much of it's reach through the Truckee Meadows, tree overstory did not play an important role. Much of the creek was occupied by obligate and facultative herbaceous species such as sedges, rushes and various grasses with occasional willow species on the bar depositions and scoured banks.

If you are considering various tree species for revegetation for increasing shade and lowering the temperature of the water for fisheries purposes several species are recommended, Populus fremontii, Fremont cottonwood, Populus anoustifolia, Narrow-leaf cottonwood, and Populus trichocarpa, Black Cottonwood. All three of these species are native and considered middle elevation riverine species. Black Cottonwood is found occurring mid-to high elevation but will grow in the Truckee Meadows. Aspen, Populus tremuloides, is also a native species but primarily found in higher elevation ecosystems. One of the main problems in re-establishment of cottonwood species is that they do need seasonal flooding along the course of the channel for scarification of the seed as well as providing the needed moisture for growing seedlings. Along the Truckee River for example, no to very little cottonwood regeneration is occurring because of the fact that flood control plays an important role now. Also, cottonwoods are susceptible to a disease known as Cytospora, which will kill many immature cottonwoods prior to reaching maturity. The other option for tree establishment along Steamboat Creek would be introduced species tolerant of Boron.

Some of the recommended willow species native to the Truckee Meadows are Salix exigua, coyote willow, Salix lutea, yellow willow, Salix lasiolepis, arroyo willow and Salix lasiandra, Pacific Tree Willow. All of the willow species require bare soil or depositional bars for establishment and seasonal flooding at least until their root systems are developed enough to tap into the water table. Many other willow species exist, however, they would not be considered native to the Steamboat Creek ecosystem.

Other native shrubs that would be compatible are Rosa woodsii, Wood's Rose, Prunus virginiana, Chokecherry, and Alnus incana var. tenuifolia, Mtn. alder (if it were established along the water course).

Some of the recommended sedge, rush and grass species for Steamboat Creek are listed ranging from wettest to least wet habitat requirements. Scirpus acutus, Hardstem bulrush, Scirpus americanus, Olney threesquare, Scirpus maritimus, Alkali bulrush, Eleocharis palustris, and Eleocharis pauciflora, spikerush, Juncus nevadensis, Nevada rush, Juncus ensifolius, swordleaf rush, Juncus balticus var. mexicanus and Juncus balticus, wiregrass or Baltic rush. Some of the sedges are, Carex nebrascensis, Nebraska Sedge, Carex lanuginosa, Wooly sedge, Carex rostrata, Beaked sedge, Carex vesicaria, Carex retrorsa, and Carex lenticularis. Recommended grass species are Distichlis spicata, saltgrass, Elymus triticoides, creeping wildrye, Glyceria grandis, American mannagrass, Agropyron trachycaulum, slender wheatgrass, Hordeum brachyantherum, meadow foxtail, Agrostis stolonifera, redtop, Puccinellia sp. and Poa pratensis, Kentucky bluegrass (an introduced species).

PLANTING GUIDELINES

It is recommended to purchase fairly good size trees (5 to 7 gallon) if possible for planting along Steamboat Creek. There will be less predation problems (rabbits, deer, etc.) and a

quicker establishment of bank cover. Trees should be planted along the cut bank of steamboat creek with the idea that eventually they will receive some seasonal flooding for regeneration. Trees should be planted at a minimum of 15-20' centers and should receive supplemental irrigation until the trees are established and can tap into the water table.

Willow establishment is best achieved by planting "willow poles" usually in the Spring when the water table is higher and the willows can grow throughout the season. Willow poles are long branches or cuttings taken from already established shrubs. They are augured into the stream banks or depositional bars, 2/3 of the pole needs to be below ground and also at or near ground water for the majority of the growing season. No supplemental irrigation is required if the willows are augured into or very near the water table. Spacing of willows can be 1012' apart.

Establishment of other species of shrubs, rose, chokecherry, and alder can be accomplished with small tubling size or containers obtained from local growers. Wire cages or fencing may be required to protect smaller plants from predation by deer, rabbits, and cattle. Supplemental irrigation may be required for these species for several years until they have become established.

One of the most successful methods for establishment of sedges and rushes has been a sodding method. If there are known areas of sedge and rush which will be impacted from development, you can with the use of a Front loader, go in and pick up huge pads of existing sedges and rushes 12-14" thick and actually transplant them as is into a prepared area. This is one of the quickest methods for re-establishing sedges and rushes. Another method would be to obtain tubling size containers of sedges, rushes and bulrush and plant them directly into the floodplain or channel on 1' centers. Since many of the sedges and rushes are obligate species, they need a guaranteed water supply throughout the majority of the growing season they also establish quicker in areas of slower water where sediment has a chance to accumulate.

Establishment of grasses along Steamboat Creek will be best accomplished from a fall seeding or hydromulching of native species. The seeding rate should be approximately 30 lbs/acre dependent on the species selected. The seed should be broadcast or applied first with the wood fiber hydromulch applied over the seed. This will help keep the seed hydrated and also allows the seed to be in closer contact with the soil. No supplemental irrigation will be required if the seeding is done late in the fall and if a normal winter of precipitation follows , if the seeding is done earlier in the season supplemental irrigation may be required for establishment of the grasses prior to the onset of winter.”