Bank and Terrace Condition by Reach

Figure 55a

WILDCAT CREEK
Percent Length of Bank Condition per Reach
Upper Alluvial Plain Segment - 1998
(* Right and left banks and terraces combined)

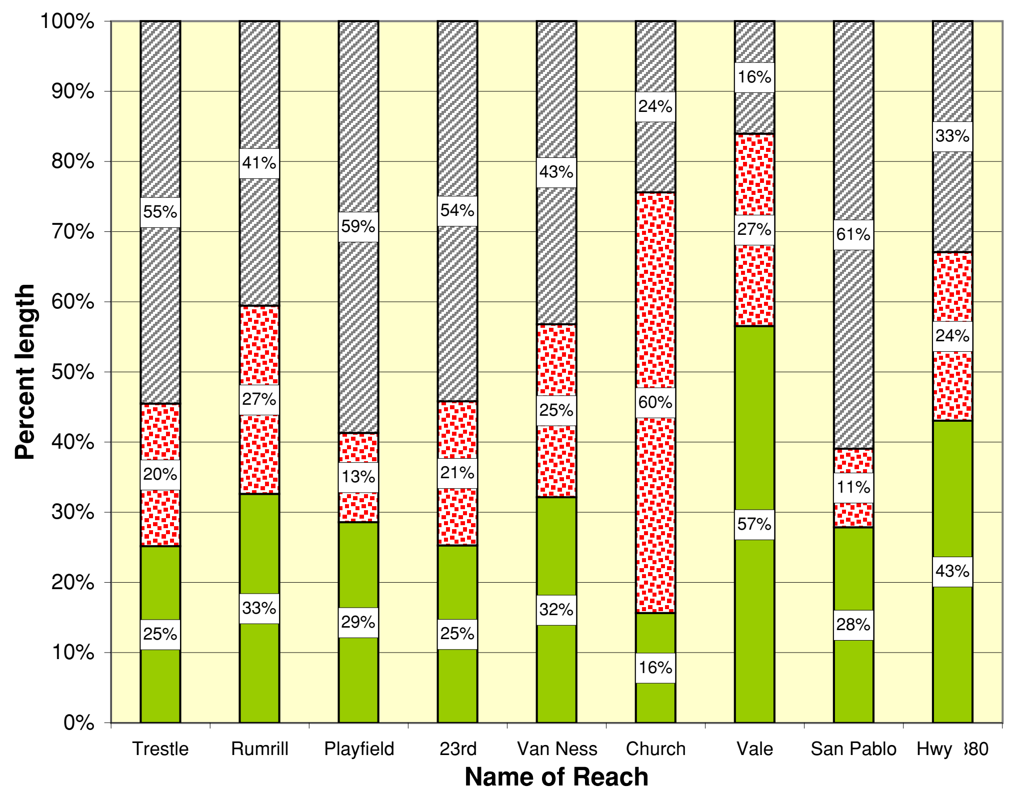


Figure 55b

Total Percent Length of Different Bank Conditions for Entire Upper Alluvial Plain Segment

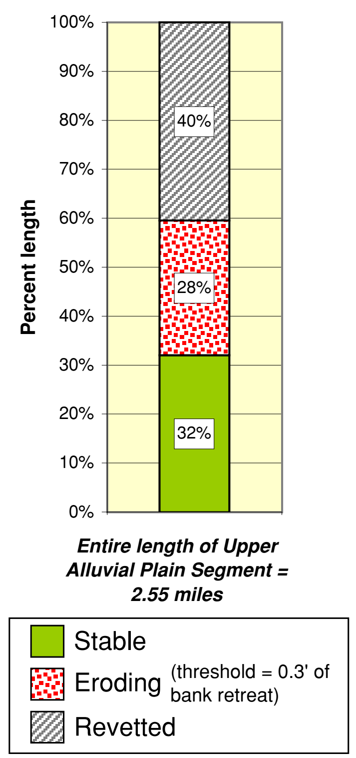


Figure 56a

WILDCAT CREEK
Percent Length of Bank Condition per Reach
Lower Canyon Segment - 1999
(* Right and left banks and terraces combined)

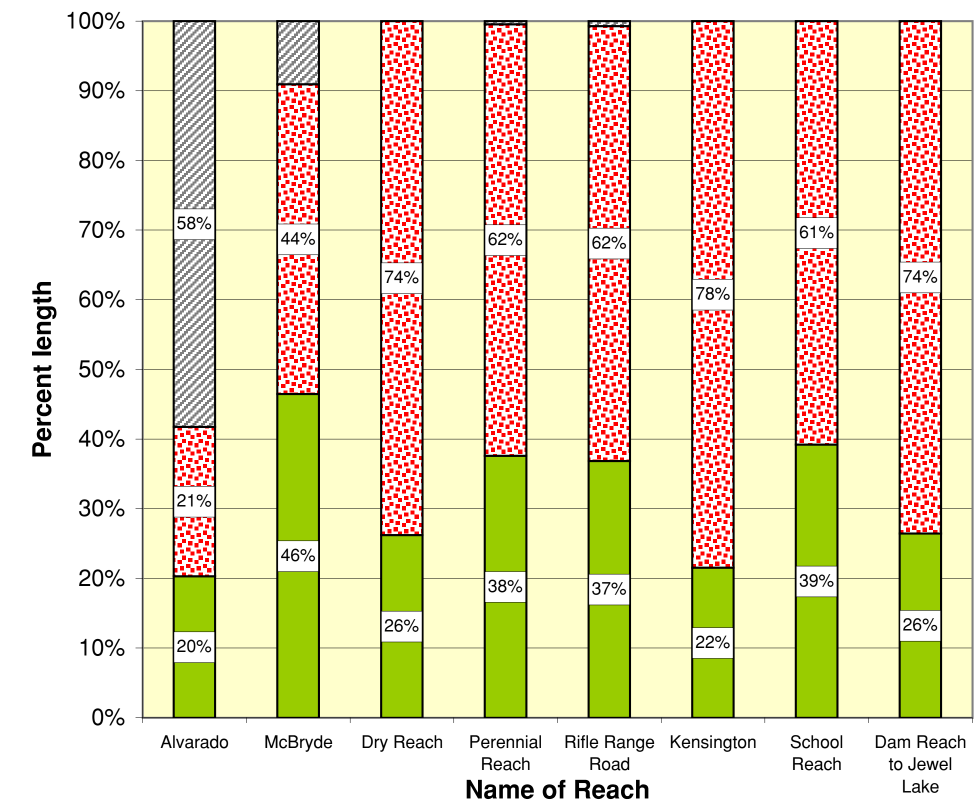
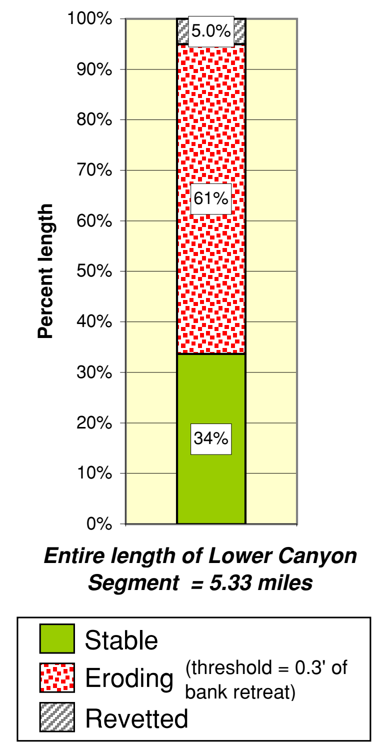


Figure 56b

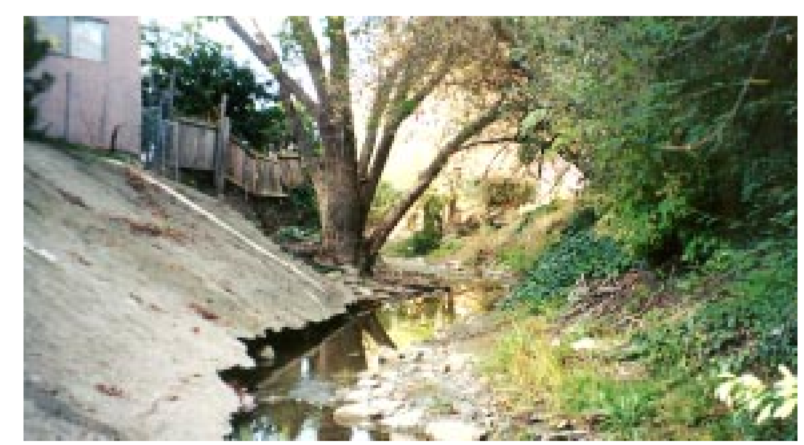
Total Percent Length of Different Bank Conditions for Entire Lower Canyon Segment



Amounts of eroding, revetted, and stable banks were measured and graphed for the Upper Alluvial Plain and Lower Canyon Segments. Bank erosion was measured wherever there was evidence of at least 0.25 ft of bank retreat, as indicated by exposed roots, the freshness of bank sediments, shape of the bank in plan view, and historical records. Note that even if the *banks* are shown as stable, the *channel* may be unstable if its bed is degrading or aggrading. The percents reported represent the total for four banks: right and left banks above and below bankful. Continuous bank conditions are shown in the Appendix Streamline Graphs. In Figures 55a and 56a, the data are summarized for individual reaches within each of the two respective segments. In graphs 55b and 56b, the percent length of bank erosion is totaled for each segment.

About 35% more revetments exist in the Upper Alluvial Plain than in the Lower Canyon, whereas the Canyon has 33% more length of eroding bank than the Upper Alluvial Plain. The Lower Canyon has 2% more stable banks than the Upper Alluvial Plain. If the areas that are now revetted in the Plain were assumed to be eroding in the past, then the relative amounts of stable and eroding bank are quite similar. The small percentage of stable natural bank is indicative of incising channels that are actively adjusting their hydraulic geometry.

The reach based analysis shows that Church Reach has twice the percentage of eroding banks of any other reach on the Upper Alluvial Plain and the least amount of stable natural bank. The erosion of its banks may relate to the change in gradient from Vale Reach to Church Reach (Figure 88, page 69). In the Canyon, Kensington Reach has the greatest proportion of eroding banks. The abundance of landslides along the banks in this reach might be a plausible explanation for its erosion. McBryde Reach has the greatest percentage of stable banks (46%).



(Photo 38) A revetted bank and a natural bank oppose each other along the Alluvial Plain. Bed incision within the last 50 years is apparent along the base of the concrete and at the exposed roots on the right bank.

Figure 57

WILDCAT CREEK

Percent Length Right and Left Bank Conditions

Upper Alluvial Plain Segment - 1998

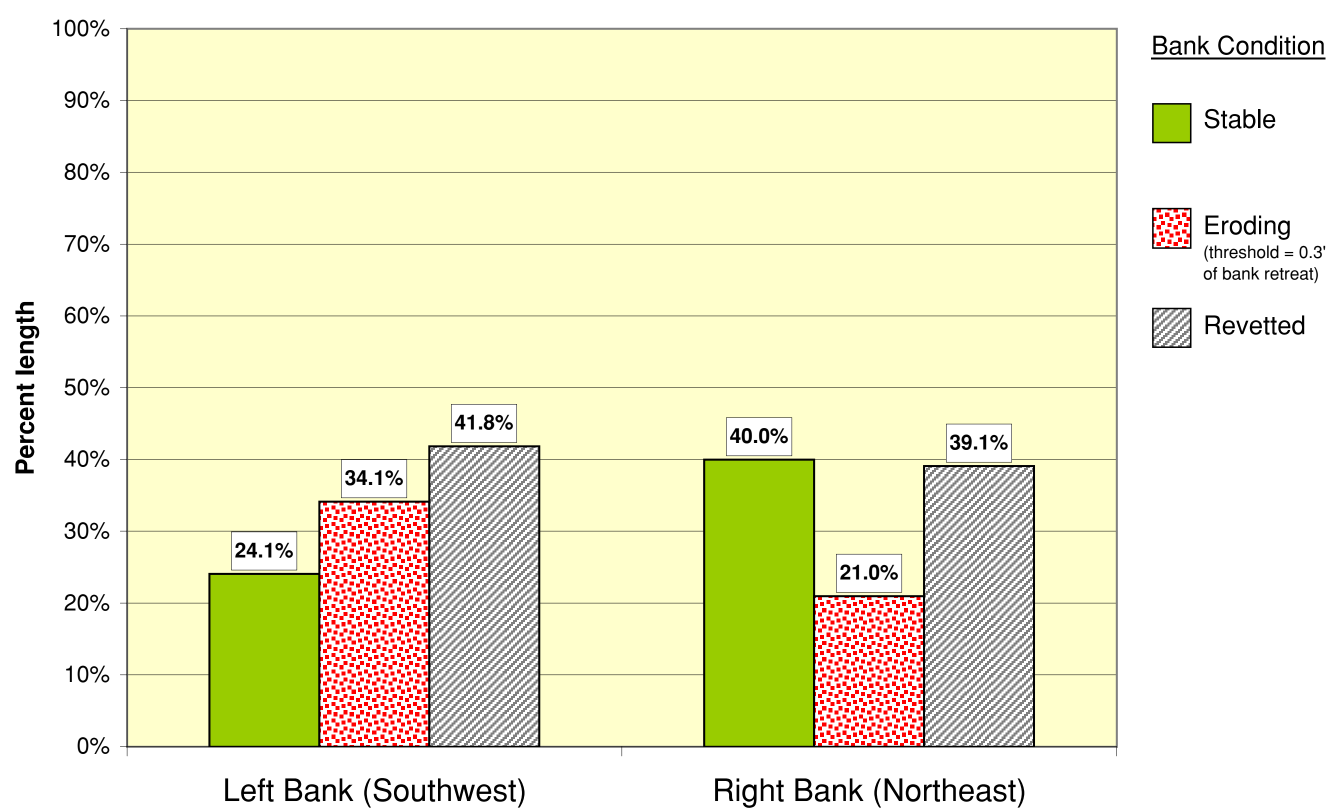
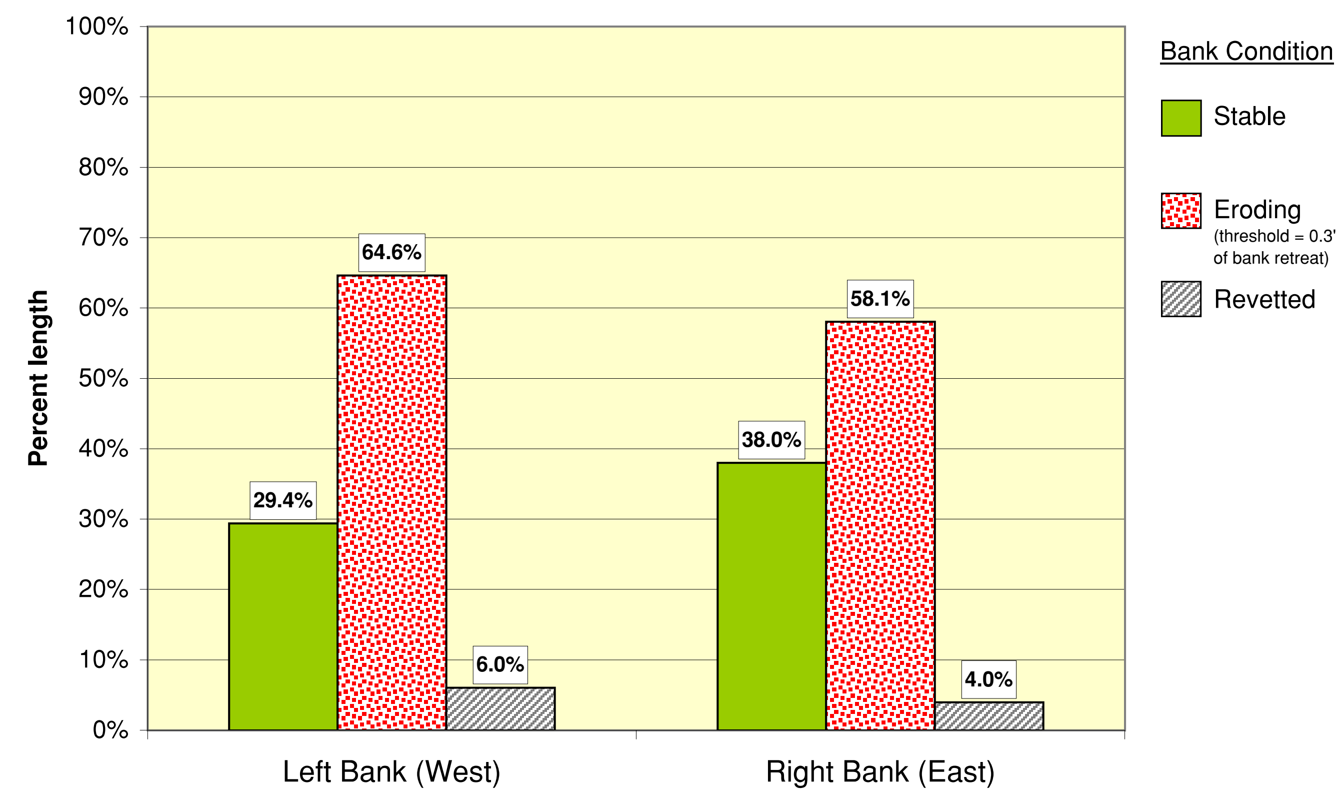


Figure 58

WILDCAT CREEK

Percent Length Right and Left Bank Conditions

Lower Canyon Segment - 1999



The percent lengths of eroding bank on the left side (south west) and right side (northeast) of the mainstem channel are plotted for the Upper Alluvial Plain and Lower Canyon Segments in Figures 57 and 58. For the Alluvial Plain Segment, the percent length of bank erosion is about 13% greater for the southwestern side than the northeastern side, even though there is a similar amount of revetment on both banks. We suggest that the greater length of eroding bank on the south side results from channel migration southward across its alluvial fan. Perhaps the northern portion of the fan is being tectonically tilted toward the south. Alternatively, right-lateral creep along the Hayward Fault could be moving the fan northward, against the westward creek flow, such that the south bank is eroding as it creeps into the creek.

In the Lower Canyon, about 6% more of the left bank (west side) is eroding than the right bank (east side). This slightly greater amount of erosion on the west side could be due to the greater abundance of large complex earthflows on the steeper Berkeley Hills.

(Photo 39) The waning flood flow of January 1997 exposes an eroding left terrace bank near Vale Road.

(Photo 40) Non-engineered revetment is failing into Wildcat Creek.

Types of Revetment by Reach

Figure 59a

WILDCAT CREEK
Length of Different Revetment Types per Reach
Upper Alluvial Plain Segment - 1998

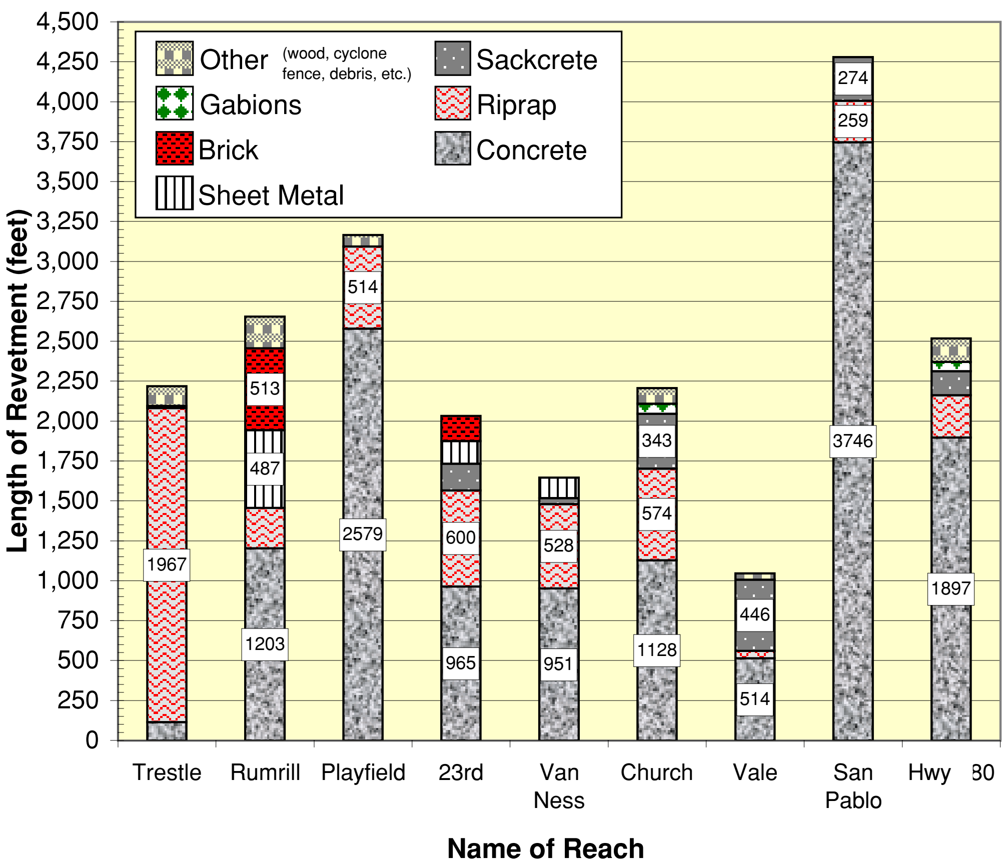
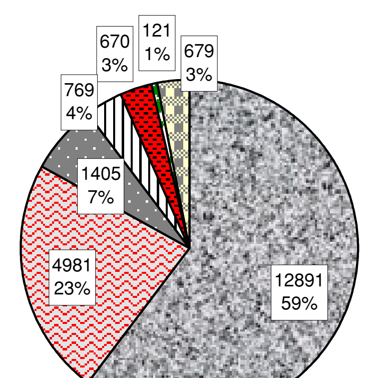


Figure 59b

Length of Different Revetment Types and Percent of Total Length of All Types for Entire Upper Alluvial Plain Segment

(In each white box, number on top is length of revetment (feet); number on bottom is the percent of total length)



Total length of revetments = about 40% of Upper Alluvial Plain Segment which totals 2.55 miles

Figure 60a

WILDCAT CREEK
Length of Different Revetment Types per Reach
Lower Canyon Segment - 1999

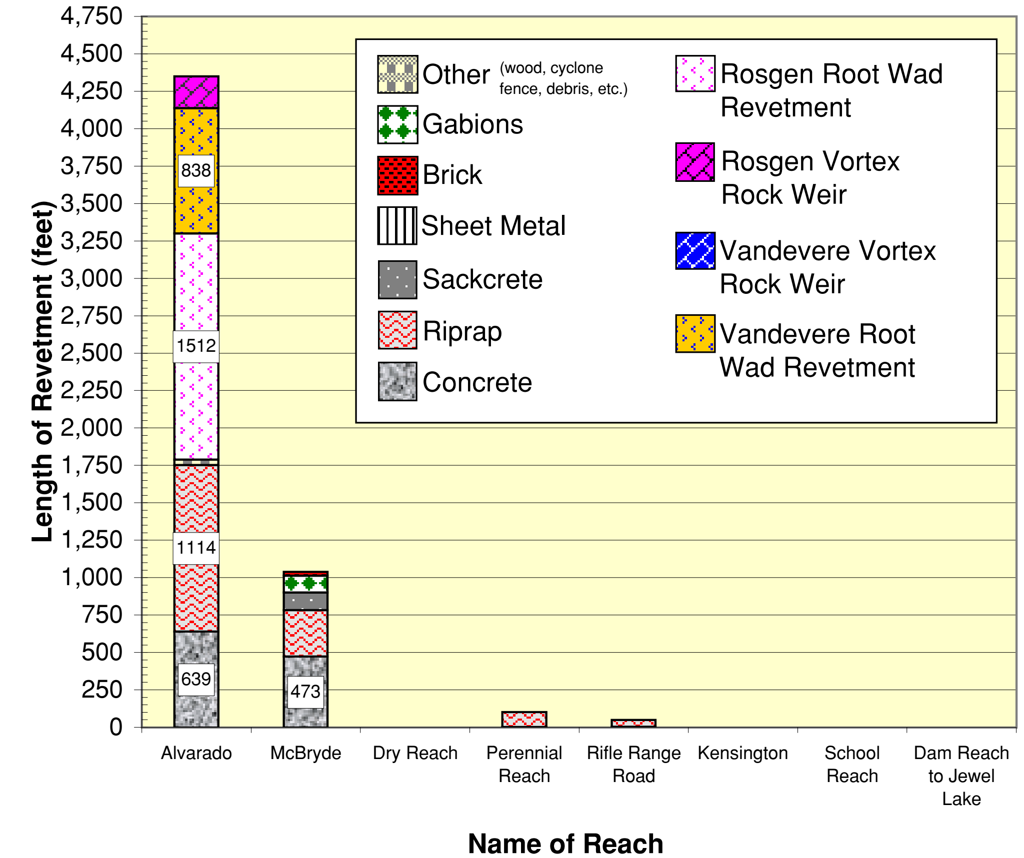
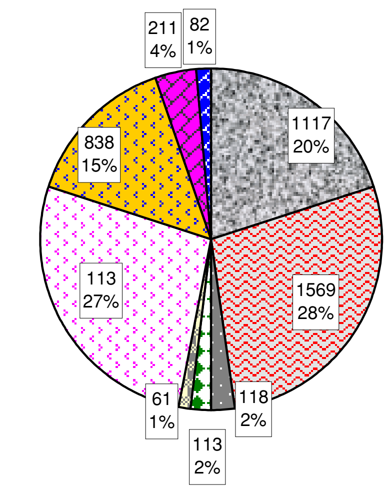


Figure 60b

Length of Different Revetment Types and Percent of Total Length of All Types for Entire Lower Canyon Segment

(In each white box, number on top is length of revetment (feet); number on bottom is the percent of total length)



Total length of revetments = 5% of Lower Canyon Segment which totals 5.33 miles

Figures 59a and 60a show the lengths of different types of revetment per reach along the Upper Alluvial Plain and the Lower Canyon. Note the difference in vertical scale of the two graphs. Figures 59b and 60b show the total length and percentage of each type of revetment per Segment. Concrete is the most common material used in Wildcat for bank revetment. Box culvert structures, poured concrete retaining walls, barriers that consisted of stacked fragments of broken concrete, and mortared banks are some of the ways that concrete is used to revet the banks of Wildcat Creek. In many cases these revetments have accelerated erosion at their downstream ends or on opposite banks.

Based upon Figure 55b on page 52,we know that 40% of the banks are revetted. From graph 59b, we can see that 59% of that revetment is concrete. From Figure 59a, we can see that nearly 3/4 of a mile (3,740 ft) of the banks in San Pablo Reach are covered with concrete. Riprap is the second most common form of revetment, as shown in Figure 59b. Trestle reach is the only reach where riprap exceeds concrete. About 1,000 ft of riprap has been applied to the banks near the railroad trestle (photo 29, page 46). Much of it is undersized and has been transported by high flows.

In the Lower Canyon, only 5% of the total length of the banks is revetted (Figure 56a, page 52). Riprap exceeds the amount of concrete by 8% (Figure 60b) in the Canyon. About 69% of this revetment is located in Alvarado Park (Figure 60a), where much was put in after a restoration project was conducted to remove two small dams. Additional amounts were constructed a few years later.

(Photo 41) A new wire basket gabion and apron revetment in McBryde Reach, January 1998.

Condition of Revetment by Reach

Figure 61

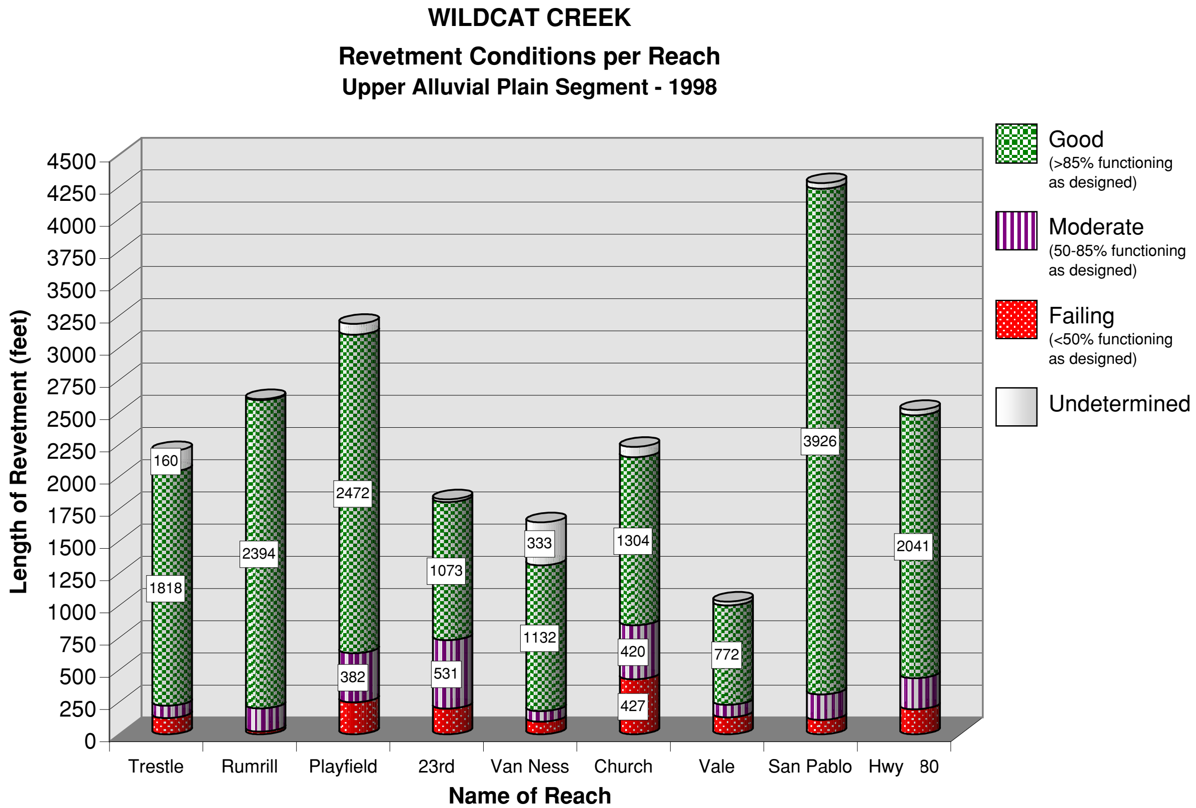
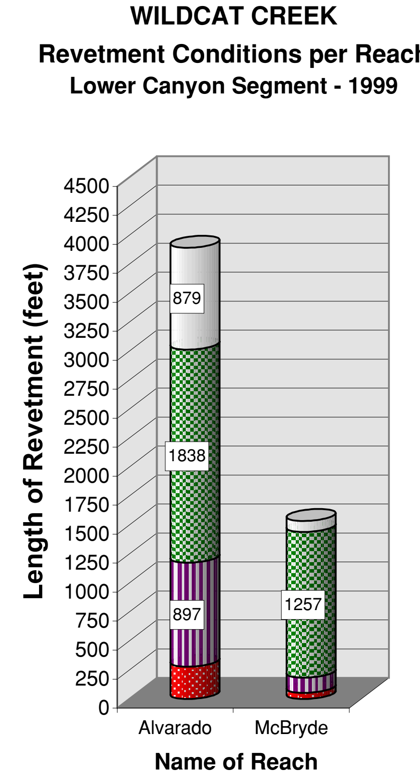


Figure 62



(42)

(43)

(Photo 42) 1997, root wad and boulder revetments were used in Alvarado Park for revision of the restoration project. Note the position of the boulder on the right bank tree stump at the arrow. Photo was taken shortly after construction.

(Photo 43) 1998, same view as photo 1, but one year later. Right bank revetment has slumped about 4 ft into channel. Note the position of the boulder on the stump at the arrow.

(Photo 44) August 1998, a concrete revetment collapses along the Upper Alluvial Plain.

The condition of individual bank revetments was evaluated for the Lower Canyon and Upper Alluvial Plain reaches. If greater than 85% of a structure was functioning as designed, it was rated as good. If only 50-85% was functioning, then it was rated as moderate. If less than 50% was functioning it was rated as failing. We disregarded box culverts for this analysis so that we could better compare individual structures that were not engineered as road crossings. To evaluate the revetments, we had to determine their functions. Almost all of the structures were designed to reduce fluvial erosion of the bank. In the Canyon a few were also designed to inhibit mass wasting.

Figures 61 and 62 show the rated condition of the various revetments per reach in the Upper Alluvial Plain and the Lower Canyon. Only the lower two reaches for the Canyon Segment are shown, since there were hardly any revetments in the rest of the Lower Canyon.

Most of the revetments in the Upper Alluvial Plain were in good condition. Church Reach had the greatest combined length of revetments that were failing (427 ft). It was also the reach that had the greatest percent length of eroding banks (page 52). It had the second greatest combined length of revetment that was moderately functioning (420 ft). The 23rd Street Reach exceeded Church with moderately performing revetment (531 ft). In all reaches, the revetment type that was consistently rated as good was concrete box culverts. Overall, riprap was the type of revetment that was failing most frequently.

In the Alvarado Reach of the Canyon, about 28% of the revetment length was in moderate to failing condition. During the 1993 fish barrier removal project, root wad revetments were placed along the channel banks to preserve the integrity of some historic rock walls along the creek bank that were being severely undermined. In 1997, four years after the project was completed, a 60 ft-long portion of one of the walls failed. Just across the Creek from the failed wall, a landslide slumped into the Creek that was caused by poor drainage problems from a newly constructed playfield. Later that same year, a new 400 ft-long creek restoration project was conducted within the boundaries of the previous project. It widened and deepened the channel where the walls had failed, and along the active toe of the landslide. Root wad revetments were constructed along nearly all the banks within the 1997 project. In 1998, we noted that most of the new root wad revetments were in moderate to failing condition. They were slumping into the channel. This was due to the excessive weight of the structures on the existing landslide deposits and post project bed incision. Our data set includes a series of longitudinal profiles of this project area dating back to 1987 (Figure 88, page 71).

Forms and Lengths of Streamside Erosion

Figure 63a

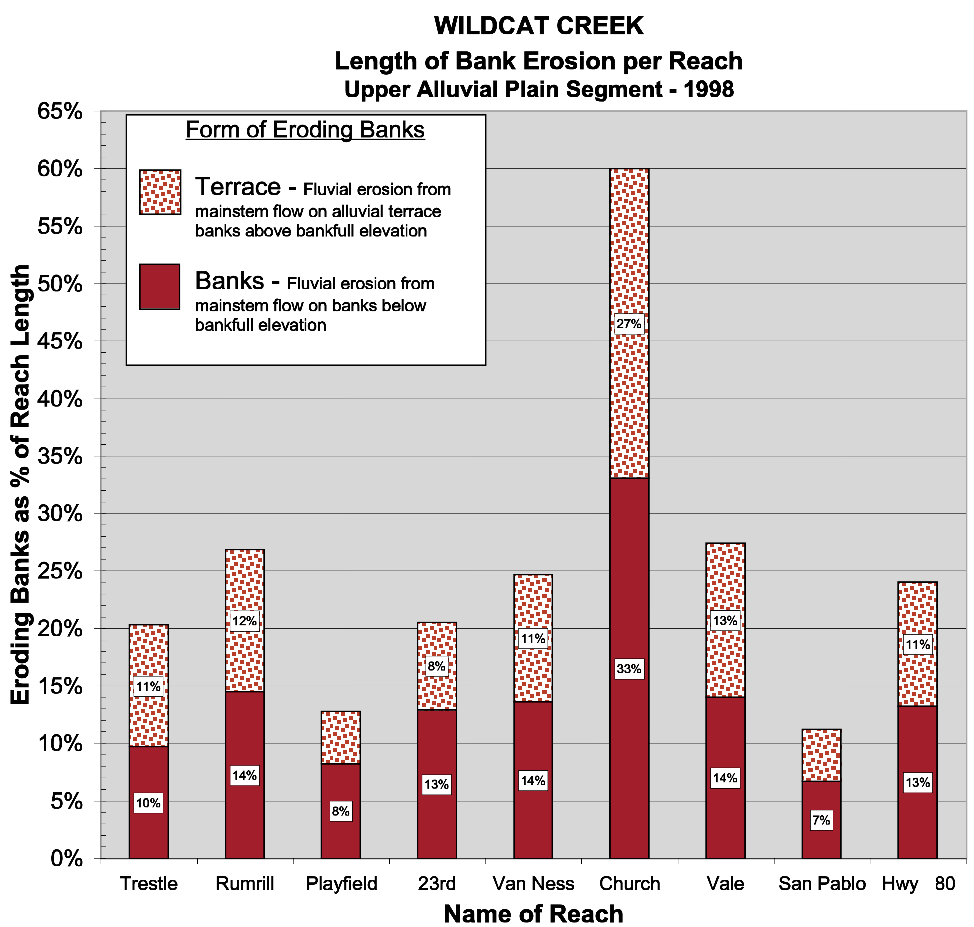


Figure 63b

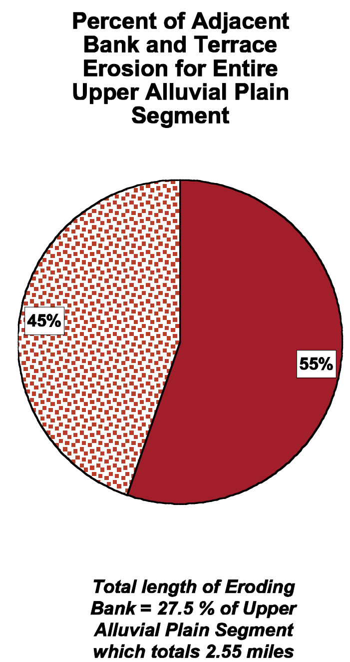


Figure 64a

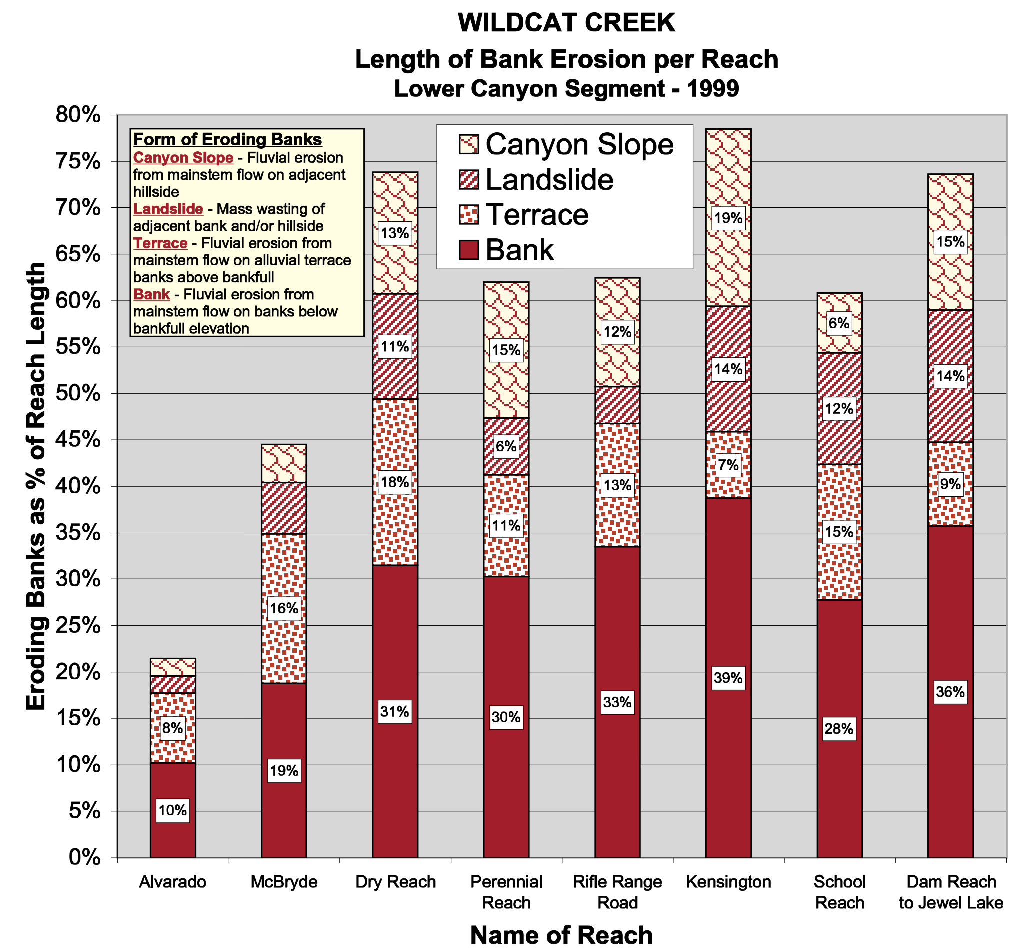
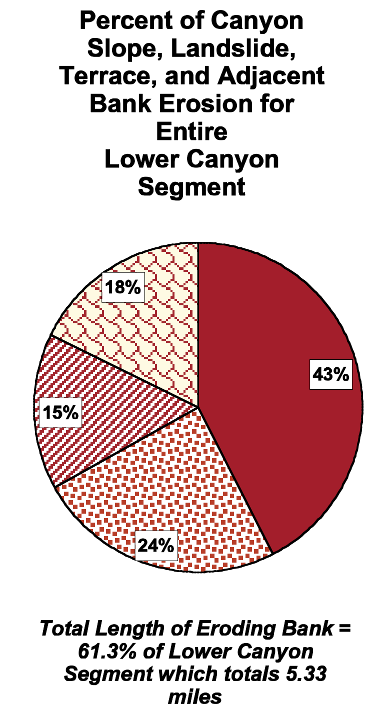


Figure 64b



Here we take a close look at the forms and lengths of streamside erosion for the reaches of the Alluvial Plain and Lower Canyon Segments. Figures 63 and 64 show the length of bank that is influenced by a particular process or form of erosion. For example, in Figure 63b the Upper Alluvial Plain has more length of bank below bankful elevation that is dominated by fluvial erosion (55%) than fluvial terrace erosion (45%). The Lower Canyon Segment in Figure 64b shows a similar pattern of 43% length of bank being dominated by fluvial erosion of alluvial banks below bankfull, but terrace erosion is only 24% of the length. This is because 18% of the bank length also has fluvial erosion on canyon slopes and 15% of the length is mass wasting processes from landslides.

In Figures 63a and 64a, all the reaches show the similar trend of most bank erosion being from fluvial processes below bankfull height. Length of terrace bank erosion is less important in the Lower Canyon reaches because terraces are discontinuous. This is partly due to their local destruction by landslides. All the mainstem reaches along the Lower Canyon Segment are receiving some amount of sediment from mostly earthflow-type slides. One particular exception is a large debris slide in Dry Reach that caused massive deposition of sediments and woody debris into the channel (see Figure 90, arrow at distance station 27,000, page 71).

(Photo 45) Direct sediment input to the channel from the reactivated toe of an earthflow, June 1999.

Volume of Streamside Erosion

Figure 65a

WILDCAT MAINSTEM CREEK
Bank Erosion Volume per Reach since ~1830's
Upper Alluvial Plain Segment - 1998
(volumes field measured)

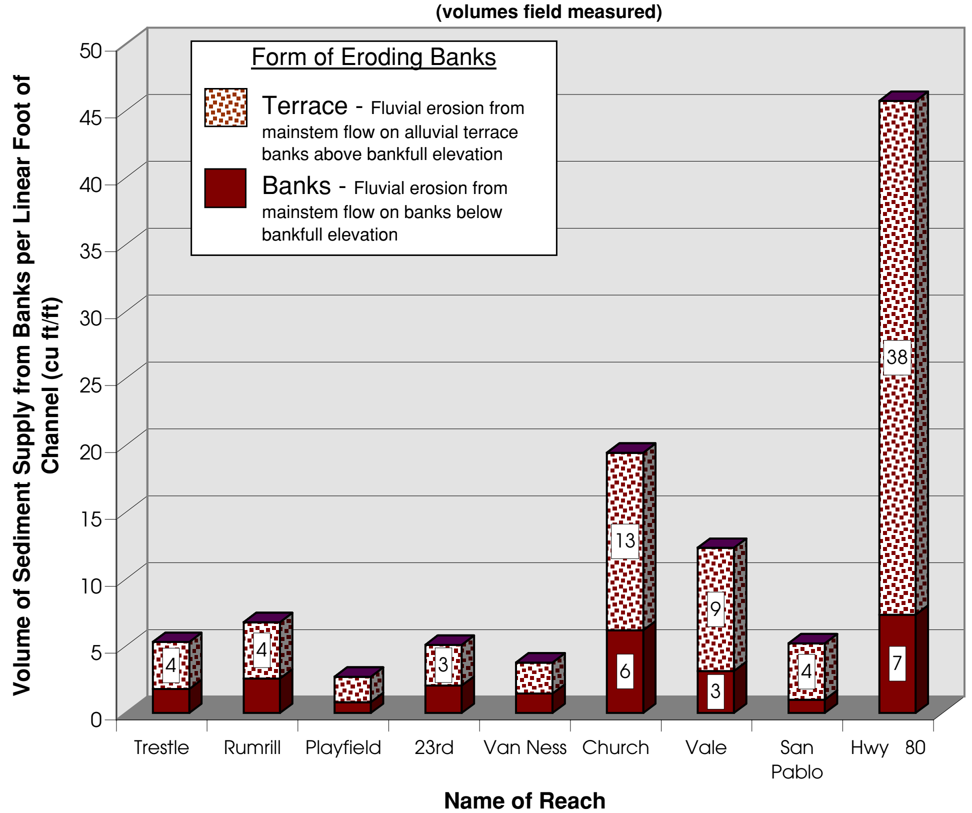
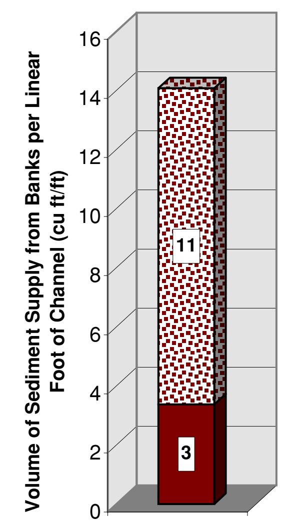


Figure 65b

Bank Erosion Volume per Foot of Channel for Upper Alluvial Plain Segment (cu ft/ft)



For the entire Upper Alluvial Plain Segment, there is about 14 cu ft of erosion per foot of bank length

Figure 66a

WILDCAT MAINSTEM CREEK
Bank Erosion Volume per Reach since ~ 1830's
Lower Canyon Segment - 1998
(volumes field measured)

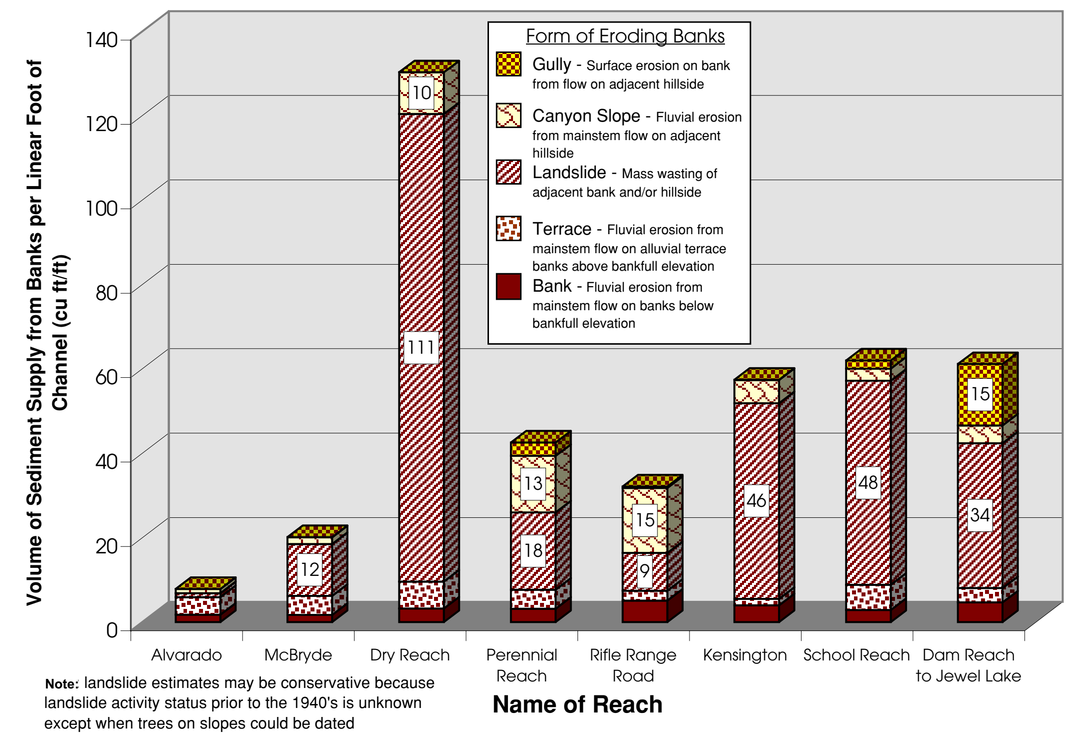
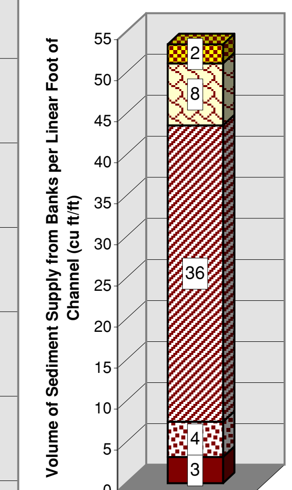


Figure 66b

Bank Erosion Volume per Foot of Channel for Entire Lower Canyon Segment (cu ft/ft)



For the entire Lower Canyon Segment, there is about 54 cu ft of erosion per foot of bank length

Length measurements of streamside erosion (see previous page) can be combined with measurements of height and depth of bank retreat to calculate the volume of sediment supply. The data for lengths of streamside landslides were combined with measures of their depth and height to estimate sediment supply from slides. The amount of sediment supplied by individual features is shown on the Streamline Charts in the Appendix.

Figures 65a and 66a show streamside erosion volumes for the individual reaches in the Upper Alluvial Plain and the Lower Canyon. To compare erosion volumes for reaches of different length, the total volume per reach was divided by reach length. Figures 65b and 66b show the total volumes per foot of channel for each Segment. These volumes do not include the calculated creep rates for soils or landslides, only the volumes measured in the field.

Streamside erosion near the apex of the alluvial fan involves coarse gravels at sharp meander bends occurring along traces of the Hayward Fault. It also involves the fan head, which is a geomorphic feature that can be prone to periodic natural entrenchment by over-steepening its gradient (Chorley *et al*, 1984). The Highway 880 Reach produces more than three times the volume of sediment than any other Alluvial Plain reach. It has produced about 45 cu ft/ft of streamside sediment supply. This is because the terrace banks extend more than 26 feet in height above the channel bed, such that any length of terrace erosion can supply large volumes of sediment. There has also been significant land use-related sediment supply from failure of a 15-ft diameter culvert (Photo 3, page 14). In contrast, Trestle Reach, which has a combination of artificial fill and terrace banks that are only 9 ft above the channel bed, has a supply rate of 4 ft/cu ft. Playfield Reach has the lowest supply, about 3 cu ft/ft.

The Lower Canyon has substantially less terrace erosion than the Upper Alluvial Plain, but it has very large volumes of sediment supply from landslides. This is because of their large size, and their high frequency of distribution and activity. Terraces are discontinuous in the Lower Canyon. This is partly due to their destruction by landslides. More than six terrace levels have been counted in some parts of the Lower Canyon. Such a high number may be caused by differential offsets along faults, activity of landslides, or backwater deposits from ancient debris jams when the creek was at a different elevations.

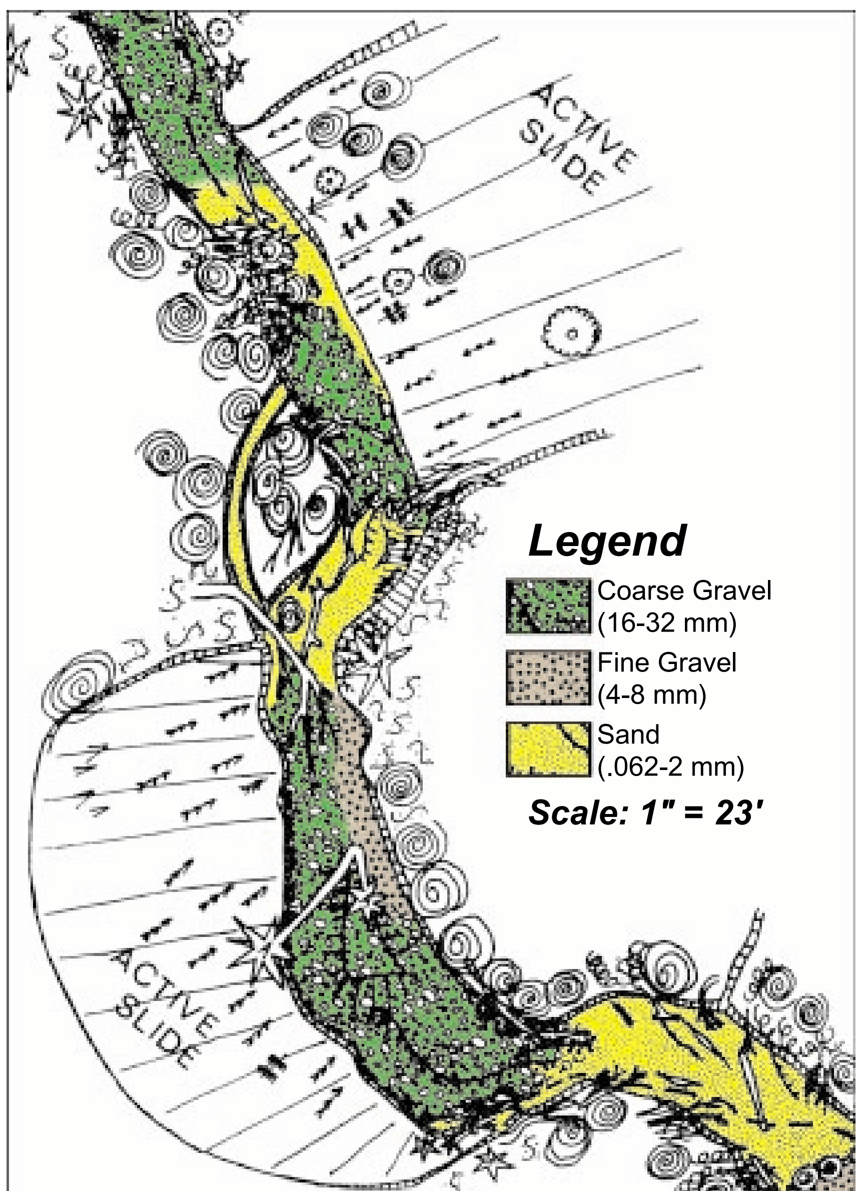
The Lower Canyon Reach with the greatest supply of bank-related sediment is Dry Reach. It has produced about 128 cu ft/ft. Fluvial erosion produces more sediment than landsliding in Perennial and Rifle Range Reaches.

Overall, the Lower Canyon has produced about 54 cu ft of sediment per foot of streamside, compared to 12 cu ft /ft in the Upper Alluvial Plain.

Average Size of Bed Material

This detailed Creek Map of Geomorphic Process (Figure 67) shows the anatomy of Wildcat Creek along a 215 ft-long reach of stream about one quarter mile downstream of Jewel Lake dam. The map accurately portrays the characteristics of planform, bankfull width, vegetation, and woody debris. In particular, it shows patches of sediment that have been sorted both laterally across the channel cross-section and longitudinally along the creek meanders. Patches of sediment that have been sorted into different size classes can be quantified by performing modified Wolman pebble counts (Wolman, 1954) where the average particle size (D50) is determined by statistical analysis. The method is modified by restricting the count to patches rather than averaging the entire bed. As can be seen from Figure 67, the channel bed is often characterized by different D50 size classes across its cross-section.

Figure 67. Geomorphic Map Detail of Wildcat Creek



As we walked along the channel in 1998 and 1999 measuring bank erosion, we also characterized the sorting pattern of sediment on the active channel bed. A graphical documentation of these patterns is shown in the Appendix. The average particle size (D50) on the channel bed was continuously estimated by eye for the length of the Upper Alluvial Plain and the Lower Canyon Segments. The visual estimation of D50 for sediment size classes was calibrated by occasionally performing pebble counts on different patches of sediment. The D50 estimates have an accuracy of +/- one standard size class. The range of particle size for the standard size classes is reported in the legend for Figures 68 and 69. We reported the D50 for all patches having a maximum width or length of at least a third of the bankfull width.

(Photo 46)

Figures 68a and 69a show the percent of D50 size classes on a reach basis for the Upper Alluvial Plain and Lower Canyon. Figures 68b and 69b show the percent of different size classes for each segment. The distribution of different sized sediment may be of particular interest to fishery biologists assessing availability of spawning gravel. Abundant sediment that is of sand and finer size classes (silt and clay) adversely affects fish habitat. Pools that scour during high flows can fill with fines during lower flows, effectively reducing potential pool volume. Spawning gravels that need good aeration between the interstitial grain spaces, fill with fines that suffocate eggs and/or entrap alevins.

Wildcat Creek has a greater percentage of sand and finer sediment upstream than it has downstream (32% compared to 24%). This is likely due to the abundance of active slides in the watershed that supply fine-grained sediment. Important to note is that the bed mapping was done after the 1998 ENSO event, which had 200% of normal rainfall. These conditions reactivate earthflows. Our data may reflect the large supply of sand that occurs following storms that activate landslides.

When gravels are analyzed for fish habitat, sand, and finer particles in excess of 30% in the subsurface is considered detrimental. Estimates of average particle size on the bed surface typically underestimate the amount of subsurface fines, so the surface D50 should be considered the minimum amount of fines for the subsurface. Hence, an estimate of 30% on the surface is an indication that conditions are not ideal for salmonids.

The bed material has a greater range of size classes in the Canyon than the Upper Alluvial Plain. Fine to medium-sized gravels are less abundant on the Canyon, while cobble and boulder are nearly absent on the Alluvial Plain. Very coarse gravels and small cobbles are generally more abundant upstream of Havey Creek (above Perennial Reach). The Dam Reach has more clay-sized bed surface sediment than any other reach in the Lower Canyon.

(Photo 46) A length of the mainstem Wildcat Creek in the Lower Canyon dominated by cobble-sized sediment.

(Photo 47) The trampled bed of a tributary channel in the east side grasslands shows a grain size of mostly silt.

When sediment supply is high, the bed tends to become finer in dominant grain size. When the sediment supply is low, the bed tends to coarsen. We have made these observations by comparing the 1987 maps to conditions observed during various reconnaissance surveys. Comparisons of earlier geomorphic maps of Wildcat Creek indicate that the high sediment supply from the years of 1882, 1983, and 1986 caused the bed to be patchier with more size classes and dominated by finer size classes. During the following years of low sediment supply, the bed coarsened and became less patchy. Following the wet season of 1998, the channel bed showed an increase in fines and patchiness again.

Figure 68a

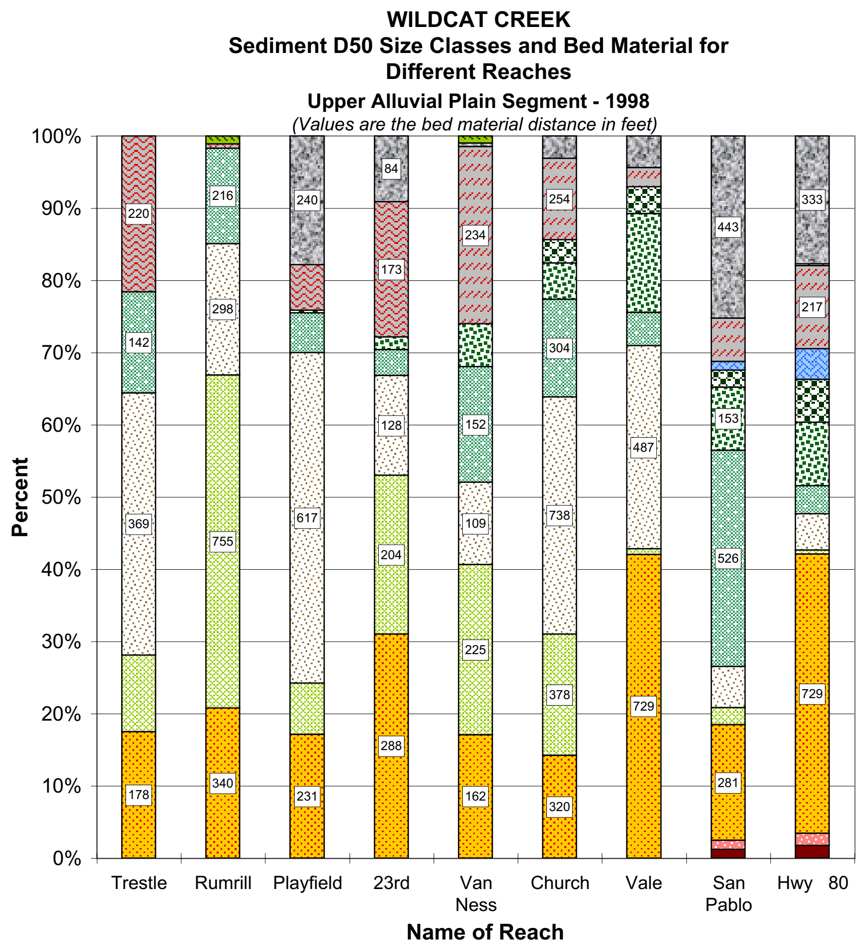
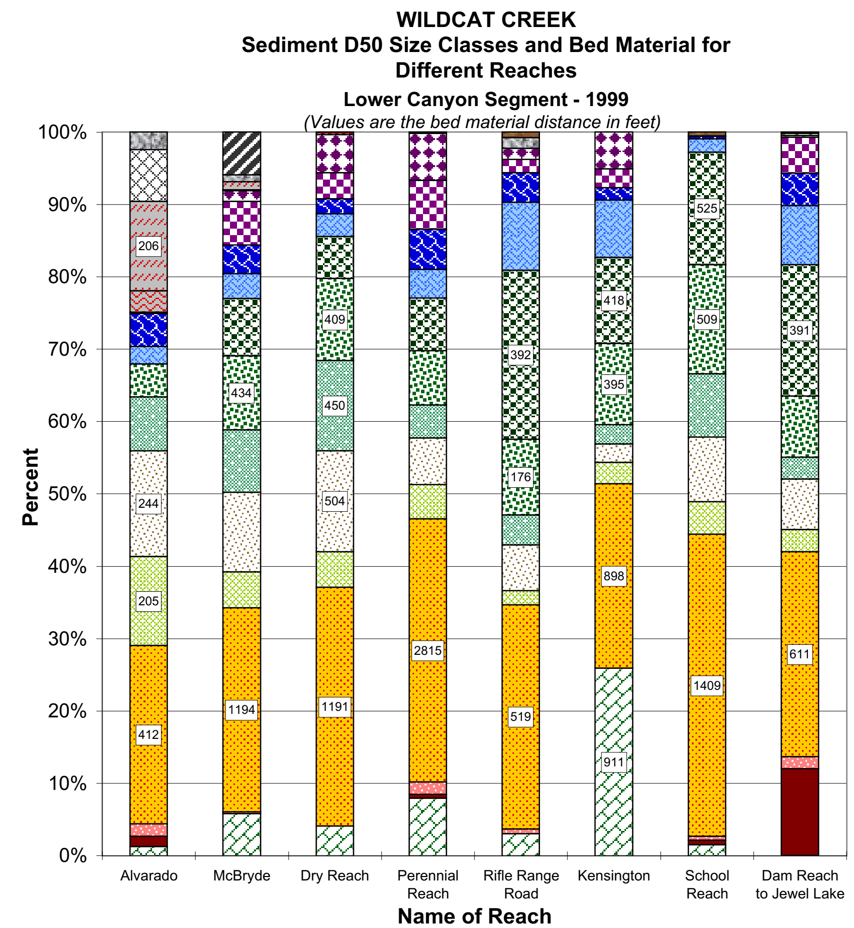


Figure 69a



Sediment and Bed Material

Figure 68b

Upper Alluvial Plain Percent of Sediment D50 Size Classes and Bed Material

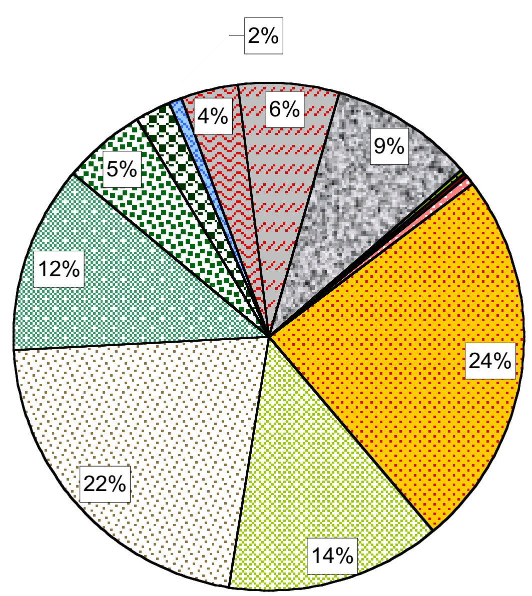
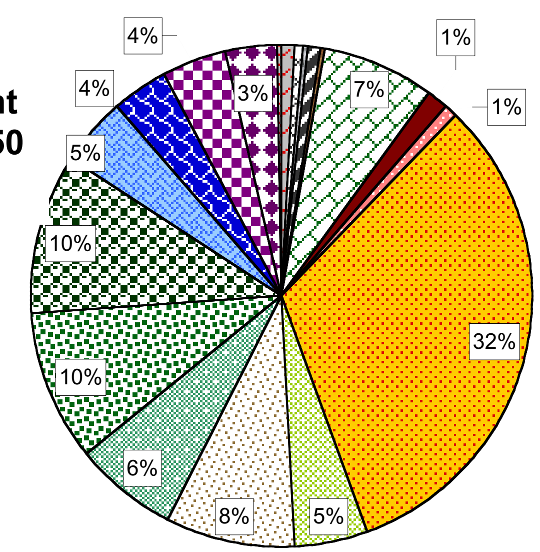


Figure 69b

Lower Canyon Segment Percent of Sediment D50 Size Classes and Bed Material



Size and Abundance of Pools by Reach

Figure 70a

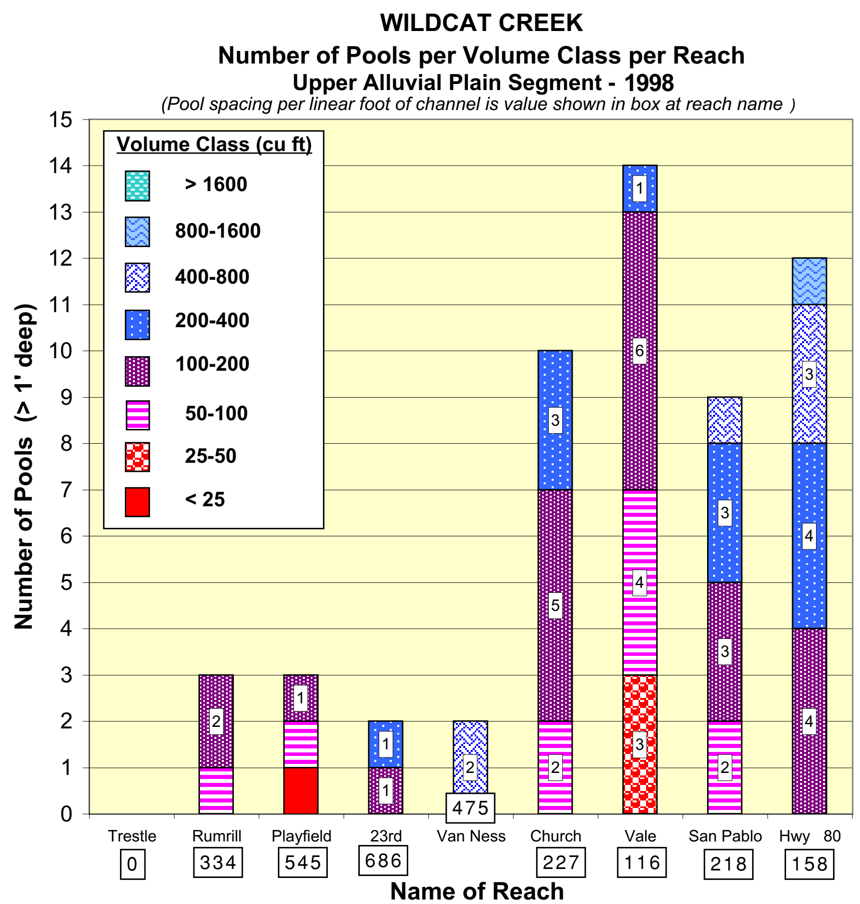


Figure 70b

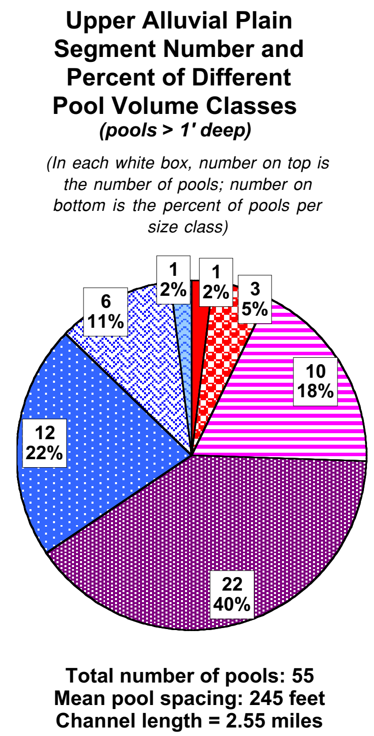


Figure 71a

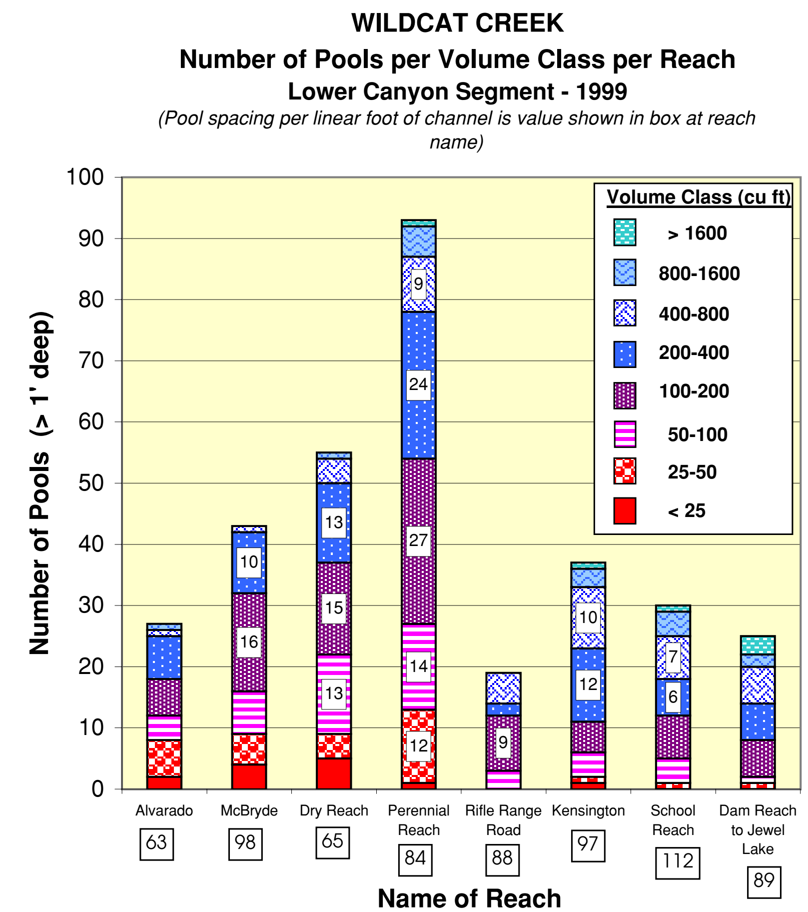
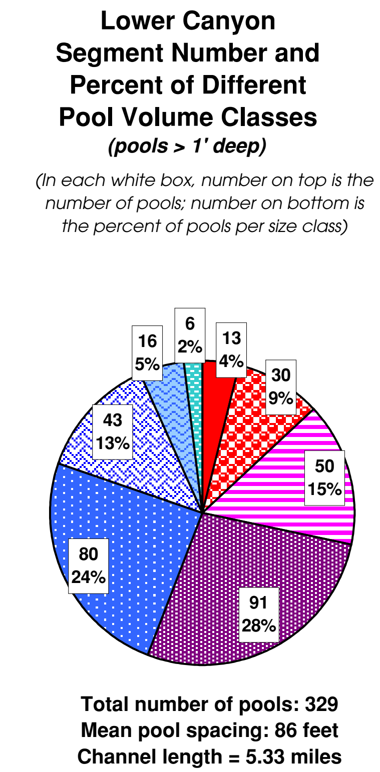


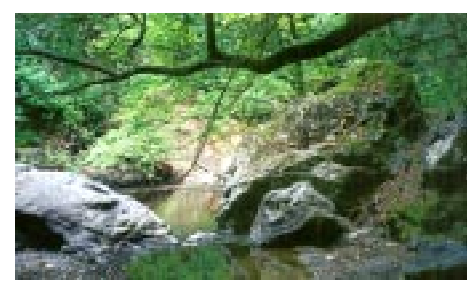
Figure 71b



Alternating pool-riffle morphology is expected in natural streams with coarse sand or larger bed material (Leopold, 1994). For these types of channels with well defined meanders, the expected pool spacing is 5 to 7 bankfull widths (Dunne and Leopold, 1978). This spacing is related to the meander wavelength, where scour and pool formation is found at the outside bend of meander curves.

There are other natural stream morphologies with different pool spacing. Step-pool channels for example, have a spacing of 2-4 bankfull widths. This morphology is not present in mainstem Wildcat Creek below Jewel Lake. Channels with sandy beds can also have plain-bed morphology, which generally lacks pools or topographic relief of the bed. We observed plain-bed morphology in the aggrading Rumrill Reach, where the bed was dominated by sand and fine gravels (see Photo 30, page 46).

For pools deeper than 1.0 ft, we measured mean width, length, maximum depth, and pool tail-out depth at riffle crests. The latter parameter was measured to determine minimum depth during summer drought. Pool volume was computed by subtracting water depth at the pool tail-out from maximum pool depth. Then the adjusted maximum depth for low flow was multiplied by 0.5 to approximate average depth. This was multiplied by length and mean width to estimate volume.



(Photo 48) A deep pool is formed by scour around boulders.

Figures 70a and 71a show the number of pools per volume class per reach in the Upper Alluvial Plain and Lower Canyon Segments. Note the large difference in vertical scales. Figures 70b and 71b summarize the data for the Segments. Individual pool locations are shown in the Streamline Graphs in the Appendix. The number of pools in the Alluvial Plain was observed to be greater than normal because of the previous El Niño winter.

Only two reaches had the expected pool spacing. Vale Reach had a spacing of 116 ft, or 5 bankfull widths, and Highway 880 Reach had a spacing of 158 ft or 7 bankfull widths. It also had the greatest number of large pools. The number of pools drops dramatically downstream of Church Reach. During years of normal rainfall some of these pools may dry completely.

The Lower Canyon has more pools and larger pools than the Alluvial Plain. Pool spacing is therefore much shorter. Average pool spacing in the Upper Alluvial Plain was 245 ft, while in the Lower Canyon it was 86 ft. Alvarado Park had the most pools.

Pool volumes tend to increase in the upstream direction, although discharge decreases significantly upstream of Havey Creek. The greater frequency and volume of pools upstream of Havey Creek is partly due to the incision caused by Jewel Lake dam, the low sediment supply, and plunge pool scouring from debris jams.

Causes, Volumes, and Depths of Pools

Figure 72

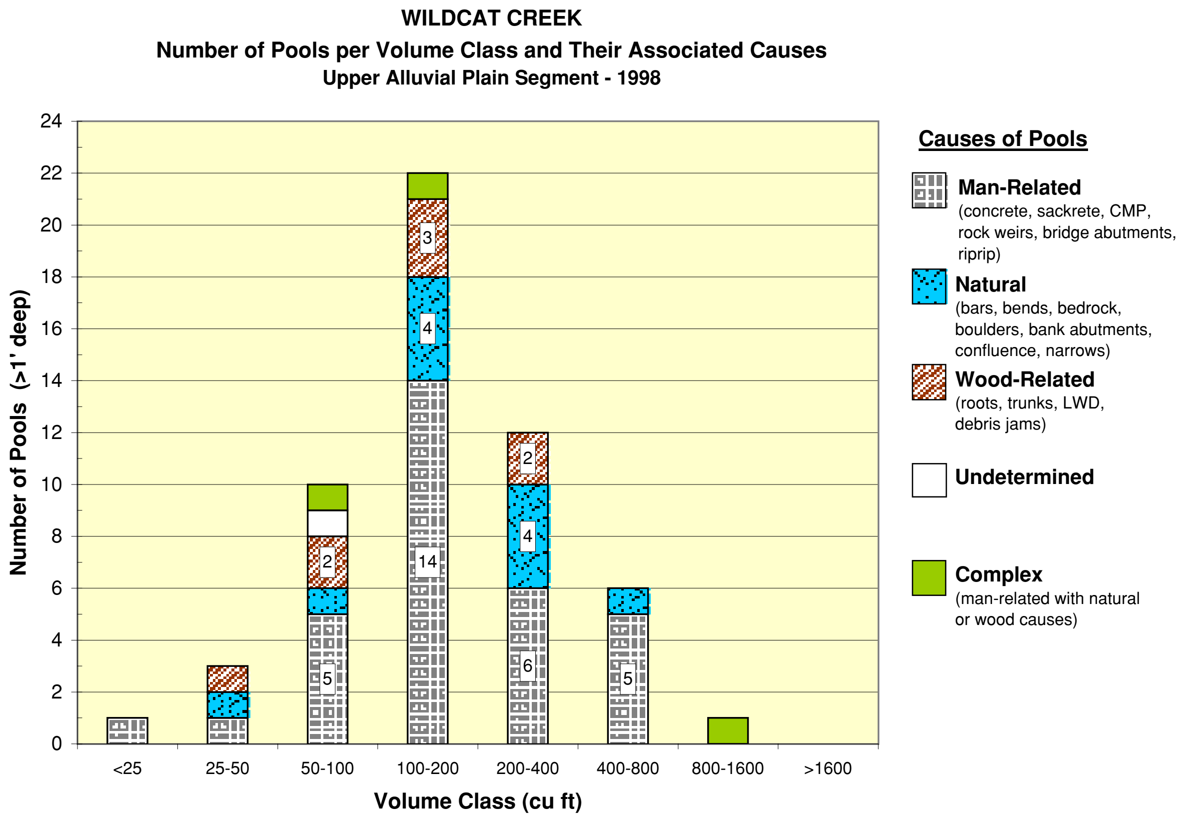


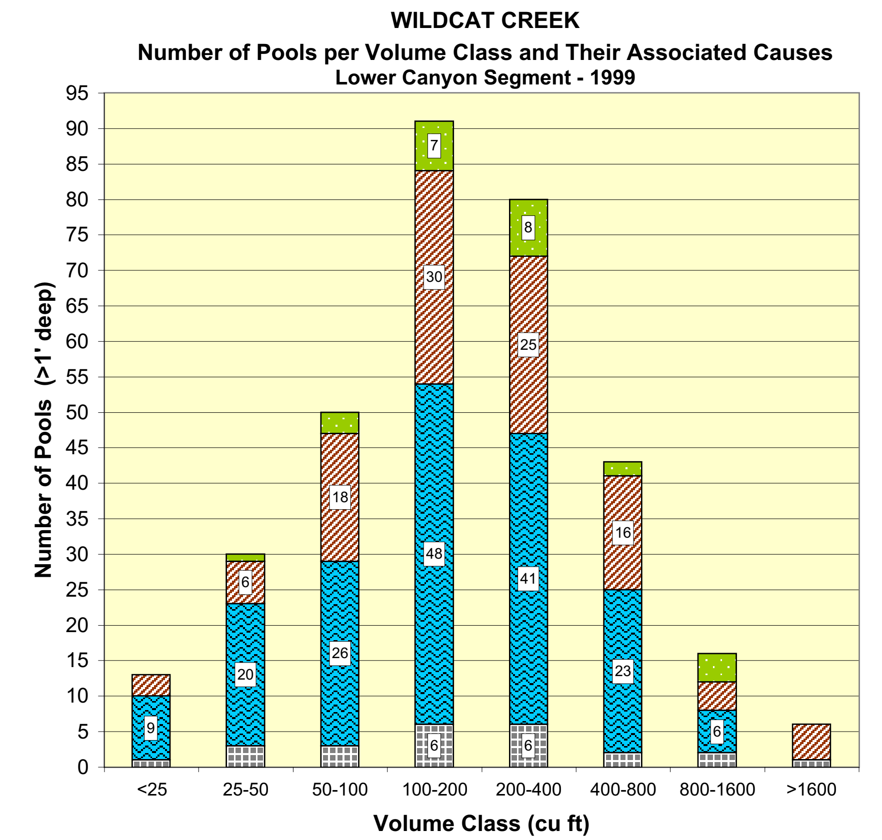
Table 14

Pool Depth Classes per Reach

(classes based on maximum depth for low flow)

	1' - 2'	2' - 3'	3' - 4'	4' - 5'	> 5'
Trestle	0	0	0	0	0
Rumrill	2	1	0	0	0
Playfield	3	0	0	0	0
23rd	2	0	0	0	0
Van Ness	1	0	1	0	0
Church	10	0	0	0	0
Vale	12	2	0	0	0
San Pablo	8	1	0	0	0
Hwy 880	5	5	1	1	0
Alvarado	21	5	1	0	0
McBryde	38	5	0	0	0
Dry Reach	42	12	1	0	0
Perennial Reach	68	22	2	1	0
Rifle Range Road	11	7	1	0	0
Kensington	23	14	0	0	0
School Reach	19	5	3	3	0
Dam Reach to Jewel Lake	12	7	4	1	1

Figure 73



Pools have a natural frequency of occurrence associated with their meander bends. Surface waters forced toward the out side bend of a channel create a scour pool, while sediment is transported toward the inside bend forming a point bar. When there is an abundance of pools with spacing less than the expected 5–7 bankfull channel widths, the "extra" pools are often created by scour from flow obstructions not associated with the meander. Large woody debris, boulders, and bedrock, are common pool-forming obstructions.

Figures 72a and 73a show the causes and numbers of pools per volume class for the Upper Alluvial Plain and Lower Canyon. Note the difference in vertical scales. Although individual causes were identified for each pool in the field, we have lumped them into 4 main categories: man-related, natural, wood-related, and "complex." These are further explained in the legend for the graphs.

The number of man-related pools (65%) exceeds the number of natural pools on the Upper Alluvial Plain. In the Canyon, the number of naturally caused pools is greater than the number of man-related pools. Pool spacing for natural and "complex" pools combined is 195 ft, within 7 average bankfull widths. By having wood in the channel, pool spacing is reduced to 4 bankfull widths. Wood accounts for 33% of the pools in the Canyon and 16% in the Upper Alluvial Plain. The most common volume class for both segments is the 100-200 cu ft.

Table 14 shows the maximum pool depth determined for low flow by subtracting the tail-out of the pool from the maximum water depth. Deeper pools were more abundant in the Lower Canyon and most deep pools were formed by wood. The Upper Alluvial Plain had 22 % of its pools deeper than 2 ft, whereas the Lower Canyon had 29%. Individual pool depths are noted in the Streamline Graphs in the Appendix.

(Photo 49) A pool is formed by scour over a debris jam.

Distribution and Type of Large Woody Debris

(Photo 50) An accumulation of different types of woody debris stores upstream sediment.

Large woody debris (LWD) plays a major role in the form and function of channels in Wildcat Watershed. It helps establish the distribution and abundance of pools, and creates places to store large amounts of sediment that slows its downstream delivery. It increases the risk of flooding by obstructing the flow of water at constrictions such as culverts and bridges.

To begin to understand the interactions between the riparian sources of LWD and fluvial processes, data were collected on number and species of LWD elements per stream reach. Individual elements of LWD and woody debris jam locations are shown in the Streamline Graphs in the Appendix. The distance location of each LWD element having an average diameter greater than 8 in was recorded. We also noted trees or brush that leaned or hung into the flow and caused local scour. They represented about 10% of the total LWD. Willows, in particular, commonly function this way.

Figures 74a and 75a show LWD distribution and species composition per reach. Figures 74b and 75b summarize the data per Segment.

In the Upper Alluvial Plain, the total number of LWD elements was 22, with an average spacing of 612 ft (about 24 bankfull widths). We know that 8 of these pools were caused by woody debris. Willows comprise most of the LWD in the Upper Alluvial Plain. As Figure 74b shows, they represent 50% and bays represent 18% of the total LWD. On the Alluvial Plain, the abundance of woody debris corresponds more to the volume of sediment provided by streamside erosion than the form of erosion or its length. If local streamside erosion delivered most of the LWD to the channel, then spatial correlation between erosion and LWD suggests that for conditions in 1998 there has been little transport from its place of origin. Hwy 880 Reach has the shortest spacing of LWD, Trestle, 23rd, and Rumrill reaches have no LWD. Much more wood may have previously existed in the stream along the Alluvial Plain when there was more mature riparian vegetation and there was little or no effort by people to remove wood.

In the Lower Canyon, the total number of LWD elements is 1,481. This represents an average spacing of about 19 ft, which is less than one bankfull width. The species that contribute most LWD are alder (44%), willow (31%), and bay (16%). The diversity of species that contribute to LWD is greater in the Lower Canyon than the Upper Alluvial Plain. (Figure 75b). The incidence of bay trees as LWD in the channel is much greater along the mainstem channel downstream of Havey Creek than upstream. Havey Creek is located at the upstream end of Perennial Reach. Live oak is commonly a source of LWD in the Lower Canyon. There does not seem to be any relationship between the amount of LWD in the Lower Canyon and length of volume of bank erosion, or the form of erosion. This is probably because much of LWD has been transported away from its point of origin.

Figure 74a

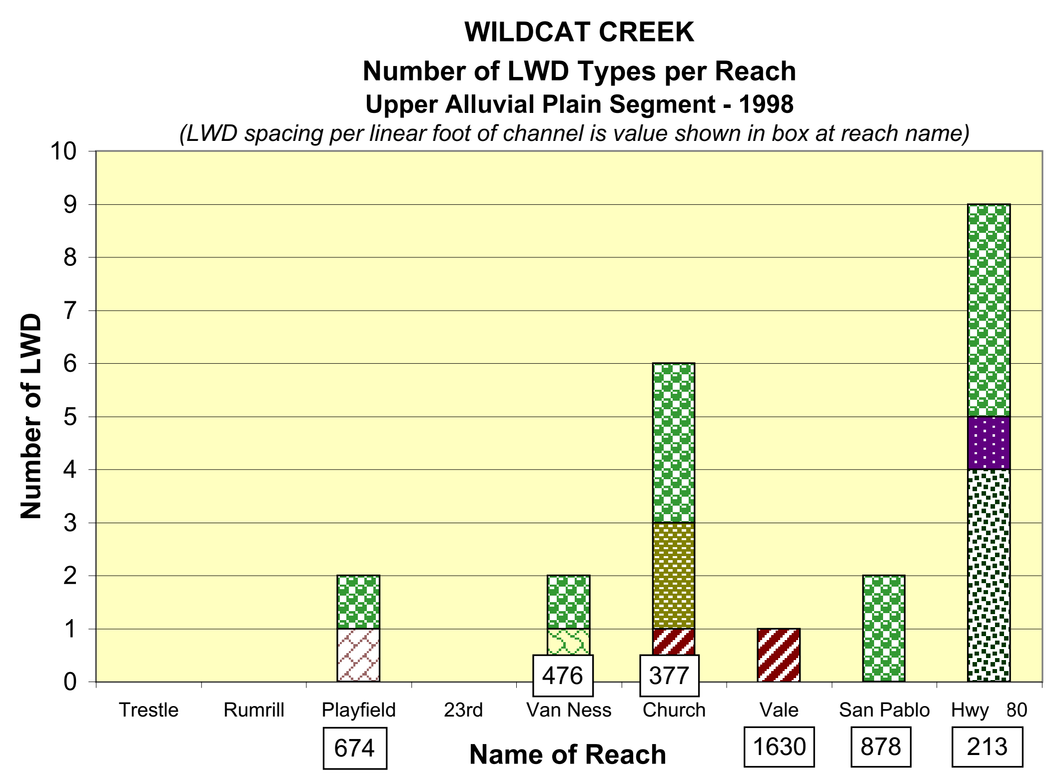
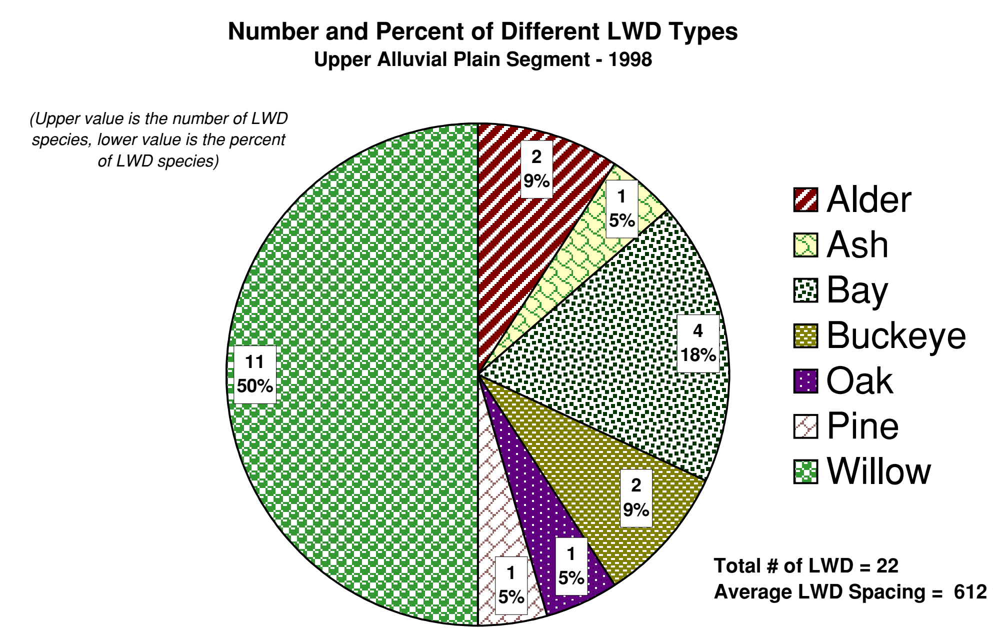


Figure 74b



Spacing of LWD is shortest in Rifle Range Reach and longest in Alvarado Reach. The difference in spacing in the Alvarado Reach is caused by two 6-ft diameter culverts at the upstream end that cause it to function as a bottleneck for LWD. Much of the wood in the Canyon is therefore not delivered to the Alluvial Plain. The next lowest spacing is in the McBryde Reach that may have occasional removal of LWD by EBRPD maintenance crews, and by private landowners along the urbanized McBryde Reach. During floods, large quantities of LWD can be transported great distances. Some standing trees in the Canyon that were tagged with distance markers during 1996 were subsequently ripped from their banks by large floating woody debris and transported more than 500 ft downstream during 1997 and 1998 floods.

Location and condition of large woody debris jams were also assessed. The deepest pools were often associated with debris jams. The debris jams were evaluated for sediment storage, flow obstruction, and management action. Figure 76 shows that a total of 47 debris jams completely spanned the creek, 33 were partly blown-out, 22 were remnants of the past, and 6 had been removed by maintenance crews. The total of 111 debris jams for 1999 represents a substantial increase from either 1987 or 1996 counts, when there were only 36 and 16 debris jams, respectively.

The LWD of debris jams can be redistributed rapidly during flood flows. The deep pools associated with debris jams may therefore be short-lived. On average, the debris jams in the Lower Canyon appeared to be storing less sediment during 1999 than after 1987, which still reflected catastrophic sediment supply from landslides associated with the record storm and flood event of 1982. These differences in sediment storage probably reflect differences in sediment supply among these years.

(Photo 51) A bay tree splits apart in 1996 summer after suffering severe rot from a fungal disease that attacked many trees. This was an important mechanism of woody debris recruitment of this species.

Figure 75a

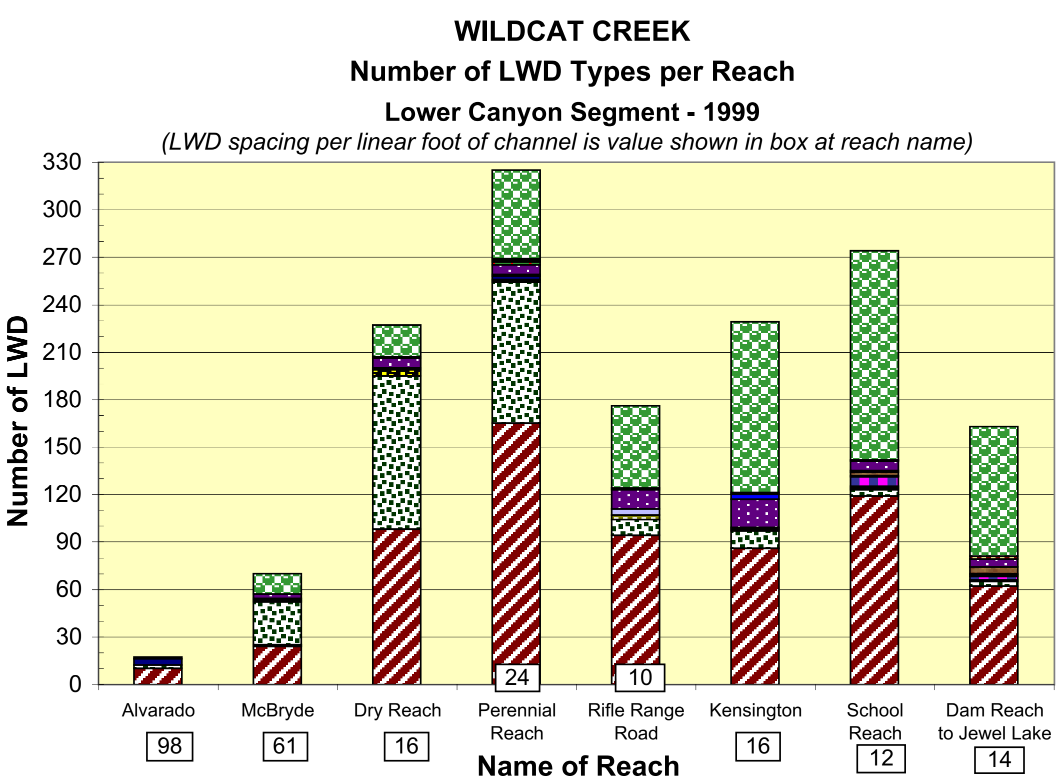


Figure 75b

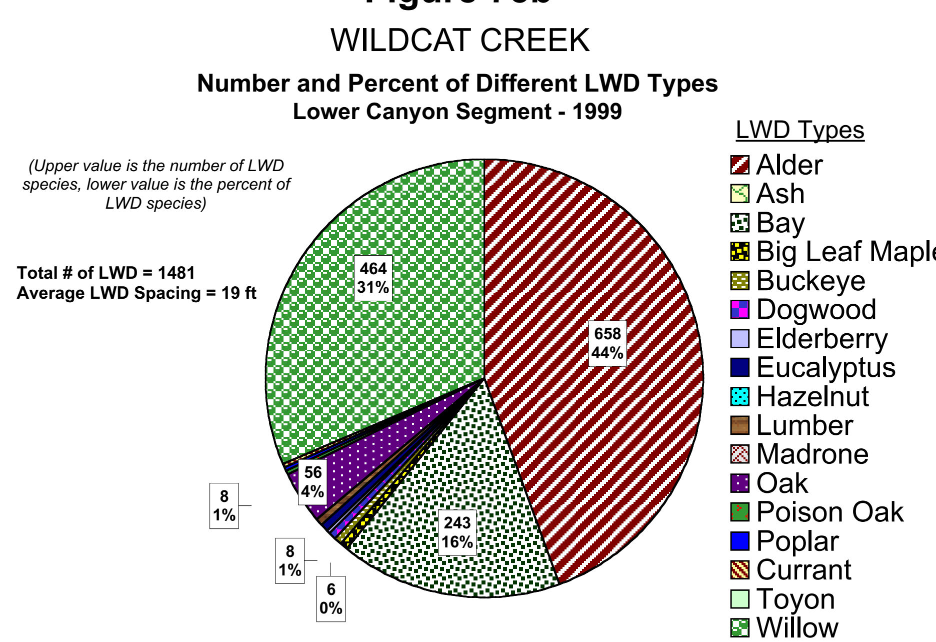
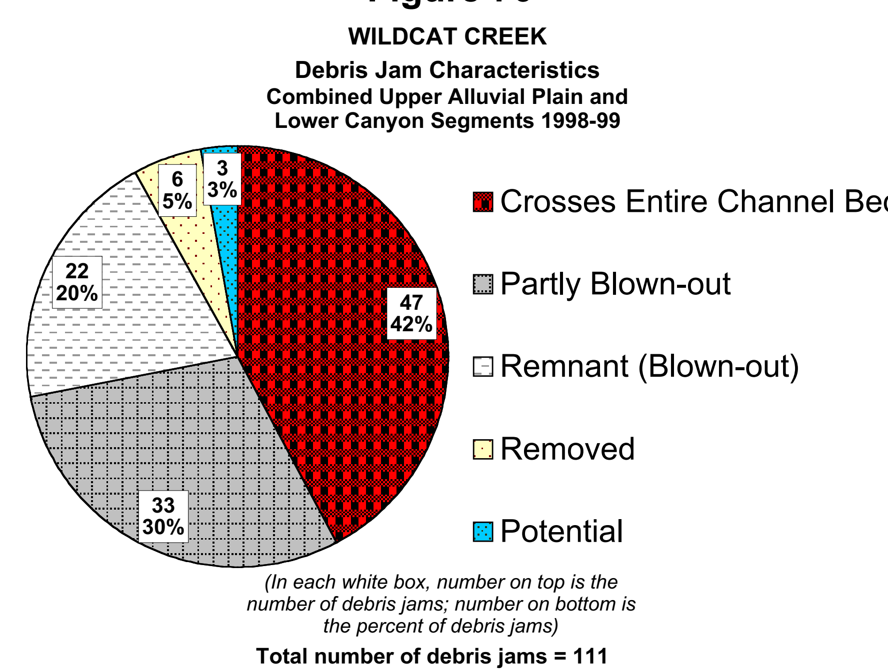


Figure 76



How Wood Enters Channels

The geomorphic and fluvial processes that supply wood to the channel need to be identified if an understanding of the recruitment and loss of wood to the system is desired. The location of LWD was recorded relative to its position along the centerline tape pulled in the field. How the wood was supplied to the channel was determined when possible. If it could not be determined, it was recorded as float, meaning that it floated to its present position. Several categories of LWD recruitment were devised that involved related processes. These include:

1. bank erosion (lateral migration and undermining);
2. landslides;
3. rammed (uprooted or ripped from the banks by large floating debris);
4. bent or leaning into the flow (functioning as large woody debris even though diameter may be less than 8 in);
5. gravity (falls from disease, windthrow, or is hit by another tree);
6. aggraded (deposited sediment fills around tree trunk incorporating it into the active bed); and
7. human-induced (for example, lumber or stumps discarded into creek bed).

Figures 77a and 78a show the number of LWD species plotted by recruitment process per reach for the Upper Alluvial Plain and the Lower Canyon. Figures 77b and 78b summarize the data by Segment.

The Upper Alluvial Plain receives most of its woody debris form bank erosion (45%), followed by gravitational processes (23%), and by human inputs (5%) (Figure 77b). About 27% of the LWD floated to their measured location, its original source could not be ascertained. Willows dominated the different recruitment processes on the Upper Alluvial Plain, yet more bay trees had been tallied as float (Figure 77a). This is probably because many bay trees were observed to have fallen in the stream during the summer of 1996.

Figure 78a for the Lower Canyon shows that the majority of woody debris (54%) had floated to its observed position. Alder species dominated the float category. Of the processes of recruitment that we could identify, landsliding exceeded the supply from bank erosion. Input from the categories of bank erosion (12%), landslides (13%), and leaning into flow (13%), were nearly equal (Figure 78b). Gravity and ramming each account for about 3% of the input. This means that 49 LWD elements

(Photo 52) Some alders are literally ripped from their beds when large floating debris rams into them during floods, May 1997.

Figure 77a

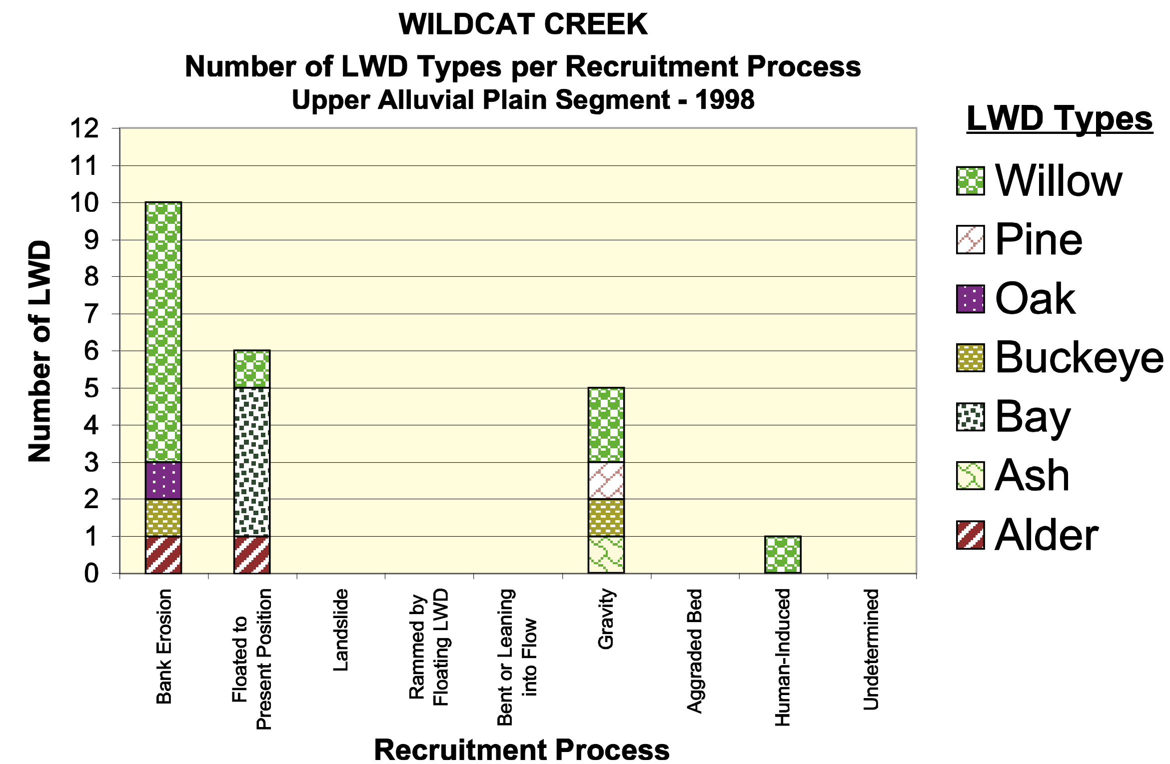
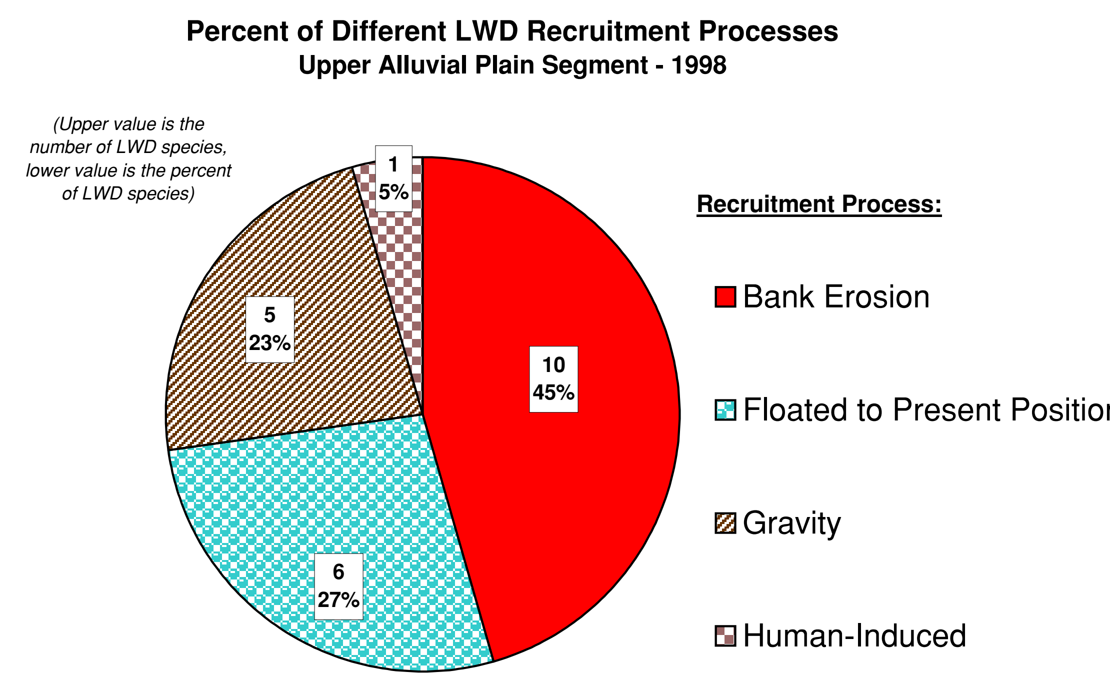


Figure 77b



were contributed to the channel by other large floating debris that literally ripped other trees from the banks. Most of the trees that were uprooted were alder that tend to grow near bankfull. Many of the oaks were supplied by landslide processes rather than by fluvial processes.

Amount of wood, its input, and spacing was quite different in the two years before 1999. Figure 79 shows the change in LWD over time. In 1996, 63 elements of LWD were counted as newly recruited to the channel in the Lower Canyon. How much wood was already in the channel in not known. Yet, if we assume that all the wood that was tallied as floated in 1997 had been in the channel in 1996, the spacing may have been about 158 ft. In 1996 the new types LWD were bay trees that had fallen during the summer and appeared to be suffering from a fungal rot, perhaps stressed from previous drought conditions of the late 1980s. Dominant recruitment processes for new LWD were landsliding (41%), followed by gravitational processes during the dry season (29%), and fluvial bank erosion (27%). In 1997 a total of 392 LWD elements were counted in the Lower Canyon that changed LWD spacing from the projected 158 ft from 1996 to 72 ft. The 1997 processes that dominated input were bank erosion (22%), followed by bent or leaning (15%), landsliding (13%), and gravity (14%). By 1999, LWD spacing changed from 72 ft to 19 ft.

These data provide a glimpse at the dynamic nature of how LWD comes into the channel, how it influences the recruitment of more wood, and how it effects sediment storage and bank erosion. The way wood is lost from the channel can also change. As entrenchment increases, the opportunity to float the wood to the high banks and remove it from frequent flow decreases. This means that the physical breaking and rotting of the wood within the channel becomes more important than its removal by floods. In addition, the removal of LWD by man increases as the number of culverts and bridges that it can obstruct increases.

(Photo 53) Large woody debris is recruited to the channel by fluvial erosion of the banks.

Figure 78a

WILDCAT CREEK
Number of LWD Types per Recruitment Process
Lower Canyon Segment - 1999

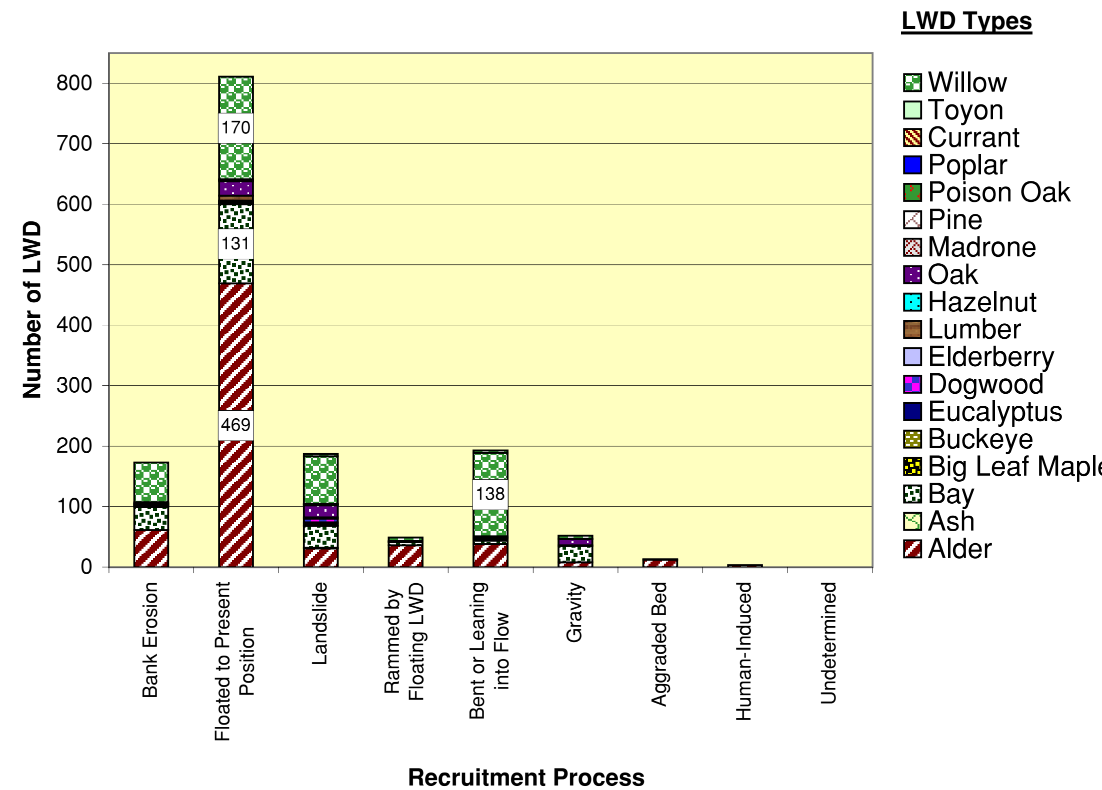


Figure 78b

Percent of Different LWD Recruitment Processes
Lower Canyon Segment - 1999

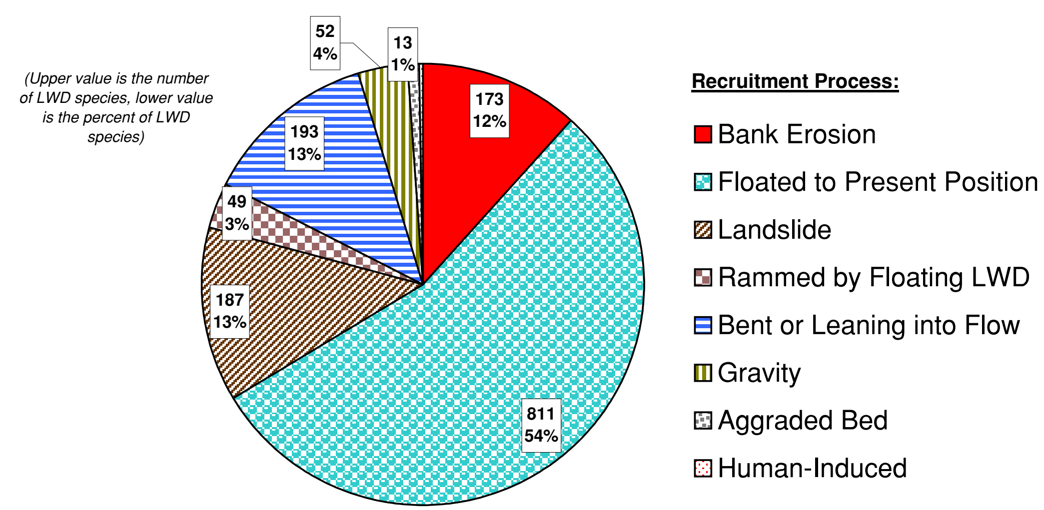
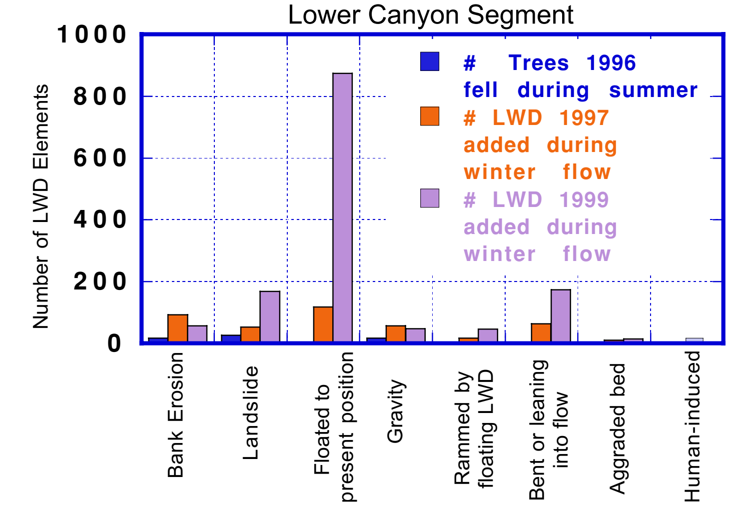


Figure 79

Change in Large Woody Debris over Time
Lower Canyon Segment



Flood Control Project Background

Intensive modern development in the flood-prone areas of Wildcat and San Pablo Creeks began in the 1940s. Contra Costa County started planning a flood control channel as early as the 1950s. In the 1970s, the Federal Goverment started the Model Cities Program. It sponsored community-based land use plans that called for protection against the 100-year flood. It also called for enhanced environmental, aesthetic, educational and recreational opportunities.

Figure 80

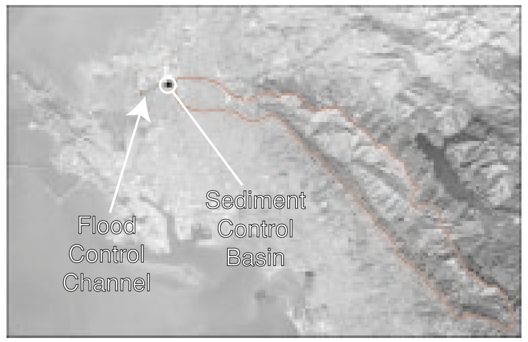


Photo Source: NASA 1996

In the 1970s, the USACE was invited through the Model cities Program to provide flood protection for both creeks. A channel modification project was proposed to extend from the tidal marshlands to Highway 880. A combination of severe channelization and environmental enhancement was proposed. The enhancements included a regional trail, a fishing pond, tree planting, and environmental facilities associated with Verde School.

In the early 1980s, when the proposed federally assisted project did not materialize, Contra Costa County Public Works (CCCPW) proposed low-cost conventional channelization for both creeks. This proposal featured a trapezoidal channel of dirt, riprap, and concrete with no environmental enhancements. Changes in environmental regulations and public protest prevented this proposal from advancing. The County then established an inter-agency, inter-disciplinary design team to develop and implement a new approach. Economic analyses by the USACE showed that extending a project upstream to Highway 880 would not be feasible (Riley, 1989). The new project boundaries extended from the tidal marshlands to the wooden Santa Fe railroad trestle. A consensus plan was completed in 1985 and construction began in both creeks in 1986. In 1996, a Federal project was authorized to modify the consensus plan to improve its environmental components.

Table 15

Records for Sediment Basin at Flood Control Channel			
	year	cu yd	cu yd/yr
Construction of Basin completed	1990		
Basin dredged	1995	6657	
Basin dredged	1996	7602	
Basin dredged	1997	14396	
Basin dredged	1998	10000	
Totals		*38655*	*4832*
Data Source: Tim Jensen, Contra Costa County Public Works			
Note: drainage area = 5.4 sq mi to Jewel Lake			

(Photo 54)The waning flood of January 1997 in the trapezoidal flood control channel divides between the constructed bankfull channel on the left and the constructed flood plain on the right. Debris has collectd at the entrance of the low flow channel.

Environmental Issues Associated with the Flood Damage Reduction Project

The consensus project as devised in 1986 was the first attempt in the country to use fluvial geomorphic design concepts. An equilibrium bankfull or active channel, a riparian reserve area, and a floodplain were designed within the trapezoidal banks of the project. Set-back berms and a regional trail were designed to accompany the new channel. A fish ladder was designed to allow anadromous fish to migrate through the sediment basin and the concrete channel at the railroad crossing. The project included marsh restoration along Wildcat Creek, with a sediment catchment basin to reduce the sediment load to Wildcat Marsh. The trapezoidal banks were designed to convey a flow 2,300 cfs, the projected 100 year flood. The 'inner' bankfull channel was designed to convey the 1.5-year flow of 300 cfs.

By 1996, the bankfull channel was evidently not self-maintaining and the fish ladder actually inhibited fish passage. Additionally, the low flow channel required for fish passage through the sediment basin had never been constructed. The Wildcat-San Pablo Creeks Watershed Council is now addressing the redesign of these features through the USACE Section 1135 authority. A meeting of Federal and state agencies and environmental experts are considering a bypass channel for fish as an alternative to the fish ladder.

In 1996, the Waterways Restoration Institute excavated a new channel through the riparian reserve from the Richmond Parkway up to Verde School. The natural meander pattern established by the creek was recreated in a channel that was made as deep as possible (up to 4 ft) at a width of 10-15 ft. Monitoring after winter storms indicated that the channel was efficiently transporting sediment and not filling (Waterways Restoration Institute, 1999). Unfortunately, during maintenance operations in 1998, the County excavated the bed of the inner floodplain below the bed level of the bankfull channel. Subsequently, bankfull flows were diverted from the constructed bankfull channel to the over-excavated floodplain. The bankfull channel filled with sediment. The undisturbed downstream sections of restored bankfull channel have had sufficient flows to maintain their designed geometry to date.

The designs for the fish ladder, channel grades, channel shape in cross-section, and sediment basin are under review for future modification. A report on alternative design modifications is expected to be provided to the Wildcat-San Pablo Creek Watershed Council by summer 20001.

Bedload Caught at the Sediment Catchment Basin

The USACE conducted a review of the project designs in 1999. Records of sediment removal from the sediment catchment basin in the Flood Control Project by the CCCPW were used to estimate sediment input. The analysis revealed that earlier estimates of sediment supply for the basin had been seriously underestimated. Table 15 shows the dredging records for the catchment basin and indicates a short-term bedload capture rate of 4832 cu yd/yr. The 8-year variability ranges from 1300-14,400 cu yd/yr. Sediment deposition has been occurring downstream of the basin as well, so the records do not account for 100% of the bedload.

The two largest floods occurring in Wildcat Creek this century occurred in 1955 and 1982. A new lobe of silt and sand was deposited across the backshore of Wildcat Marsh in 1982. Since 1988, all the flood flows have been contained within the flood control channel. However, none of the flows have been nearly as large as the 1982 flood. How the flood control channel and its sediment retention basin perform during future large floods and influence self-maintenance of the tidal marsh and its backshore remains to be seen.

The tidal baylands are transitional environments between Wildcat Watershed and San Pablo Bay. Both estuarine processes and fluvial processes influence them, and they have important natural attributes of their own. They include the tidal salt marsh of Wildcat Creek. The relative influence of fluvial processes increases landward through the intertidal zone, but most of the tidal zone is dominated by estuarine processes. The tidal baylands are therefore not strictly regarded as part of the watershed.

Figure 81

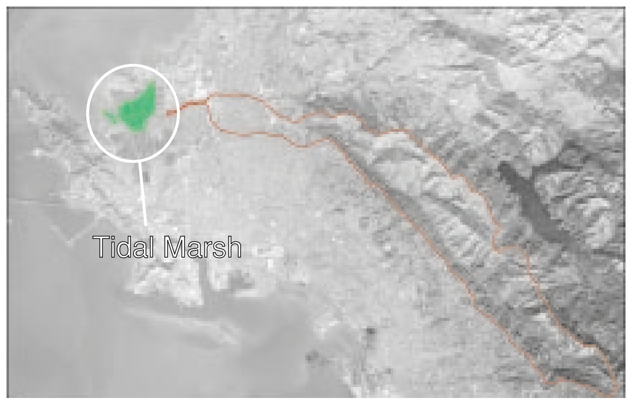


Photo Source: NASA 1996

Varieties of natural functions are attributed to tidal baylands. They trap and store sediment provided from the estuary and the uplands. They dissipate the energy of waves that cross San Pablo Bay and attack the shoreline, spread flood flows from terrestrial stream sources, provide nutrients to the bay ecosystem, and support species-rich communities of baylands plants and animals.

The baylands consist of mudflats, tidal sloughs, natural levees along the largest channels, the foreshore of the tidal marsh, the marsh plain, tidal marsh pannes, and the backshore of the marsh (Figure 82) (Goals Project, 1999). The mudflats gradually slope upwards from about mean lower low water to the vegetated foreshore. The elevation of the foreshore varies with plant species and wave height, but it generally approximates mean tide level at Wildcat Marsh. The mudflat innervates the marsh through the network of tidal channels. The largest channels have low levees. The elevation of the marsh plain varies slightly around mean high water. The plain slopes upwards at the backshore, where the marsh plain transitions into upland.

There are many kinds of tidal marsh pannes. A panne is an unvegetated area of the marsh that is poorly drained and therefore it tends to retain water on the marsh surface during low tide (Collins et al., 1984). Drainage divide pannes exist in the marsh interior, equidistant from neighboring channels. Transitional pannes exist along the backshore. Transitional pannes that form on alluvial sediments are called alluvial pannes (verbal communication Peter Baye, U.S. Fish and Wildlife Service). Drainage divide pannes tend to stay wetter longer than transitional pannes, which tend to desiccate during neap tides in the dry season.

The backshore near creeks is variable due to fluvial influences. At Wildcat Creek, floods from the uplands spread freshwater and fluvial sediments across the backshore, thus altering marsh elevations, soil texture, nutrient availability, and soil salinity. The rapid extension of the alluvial fan of Wildcat Creek over the marshland during the mid 1800s (page 68), and hence the transgression of marshland over the alluvial sediments, is a dramatic example of backshore dynamics.

Figure 82. A Detail of Wilcat Marsh

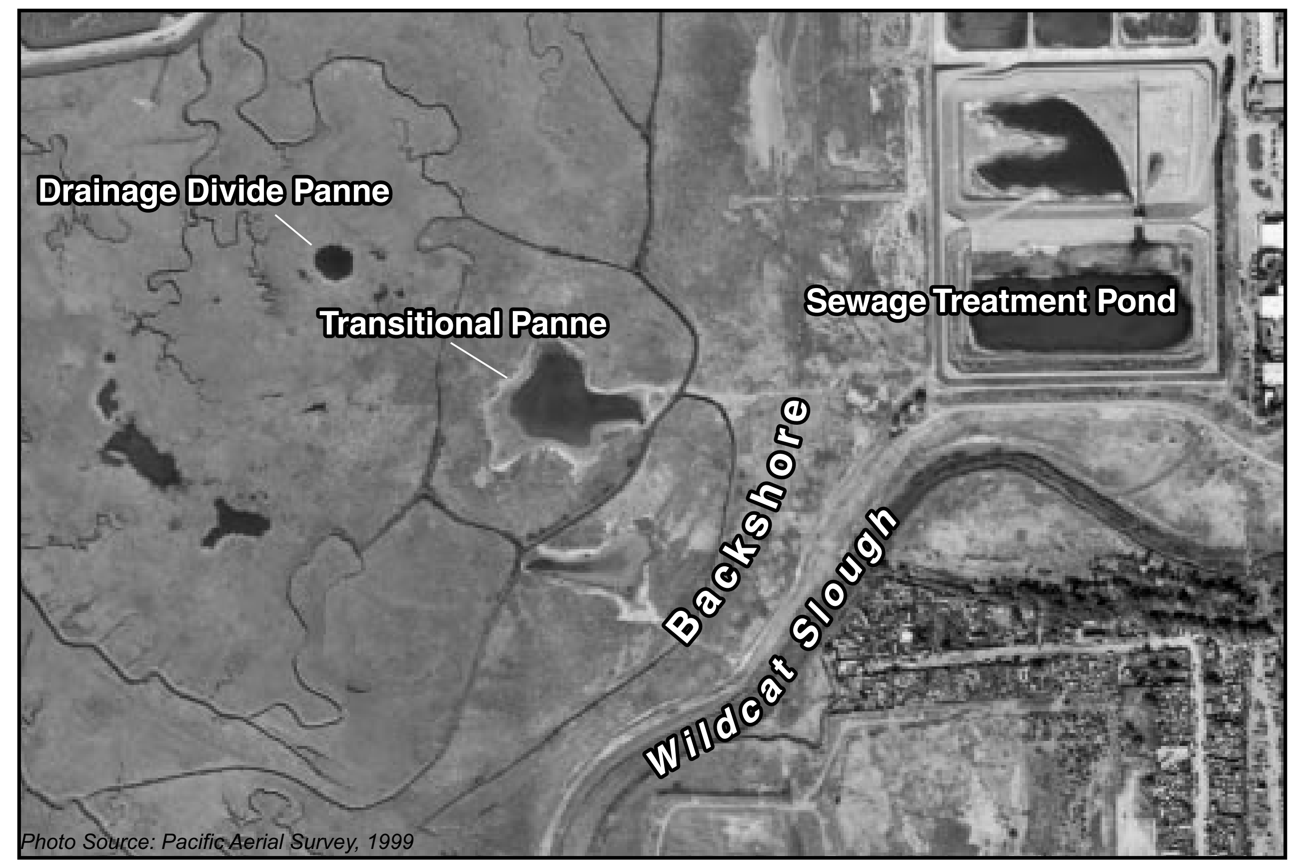


Photo Source: Pacific Aerial Survey, 1999

The evolution and natural maintenance of the tidal baylands require sediment deposition to keep pace with the average rate of sea level rise. Aggradation requires an adequate sediment supply in a depositional environment. For the Wildcat Creek baylands, the depositional environment is the quiet embayment in the northern lee of the Richmond Potrero. The needed sediment is provided in two ways. Each watershed of the Estuary contributes some sediment to the total amount that is distributed by the tides and estuarine currents. The estuarine sediments that are delivered to baylands by the tides contribute mostly to aggradation of the tidal flat, the backshore of the marsh, the tidal marsh channels, the natural levees, and the marsh plain near the tidal channels. The original source of the estuarine sediments might be any watershed of the estuary including the distant Sierra Mountains. Upward growth of the marsh surfaces in interior areas of Wildcat Marsh requires the formation of peat by marsh plants.

Our analysis of historical changes in the baylands shows that foreshore erosion has coincided with reductions in supplies of fluvial sediment from either Wildcat or San Pablo Creeks (page 22). The shape of the tidal slough in cross-section and profile are adjusted to the discharge of Wildcat Creek plus the tidal prism they convey.

For example, reclamation has reduced the flood capacity of sloughs in Wildcat Marsh by causing them to become narrower and more shallow (Haltner and Williams, 1987; Collins 1992; Siegel 1993). Castro Slough, the main channel leading from Wildcat Watershed to San Pablo Bay, is now less than half as wide and deep as it was before the surrounding marshlands were reclaimed. By diking the sloughs and containing floods flows within levees, especially at times of high tide, the backwater floods extend into areas that otherwise might not be affected.

A concrete-capped sewer line crosses Wildcat Creek downstream of the Richmond Parkway. It artificially raises the creek bed above the tides, restricting their upstream extent. The Creek has incised about 2 ft downstream of the sewer line since 1996. The concrete cap is preventing natural adjustment of the upstream gradient.

Plan View Changes of the Mainstem

Some of the most significant changes at the backshore of the Wildcat Marsh have been the result of processes that began far upstream in the Wildcat and San Pablo Watersheds. Of special interest are the dramatic aggradation of San Pablo Creek and the toe of the alluvial fan that expanded bayward onto tidal marshlands after 1817. The following scenario seems likely based upon all available evidence.

Just before European contact in the region. San Pablo Creek and Wildcat Creek were entirely separate. Each had its own way to San Pablo Bay (Figure 83). The Huchiun were most likely using fire to manage their food resources in their homeland including Wildcat Watershed. Based upon field notes from the DeAnza expedition of 1772 (Bolton 1930), Wildcat Creek at the apex of its alluvial fan was already entrenched, but not as deeply as it is today. Members of the expedition described a rather deep arroyo with a narrow riparian forest and little water near Alvarado Park.

Tree ring data from the West-Central Sierra indicates that a pronounced drought lasted in the Bay Area from about 1776-96 (Earl and Fritts, 1986). Sediment transport in Wildcat Creek would have been greatly reduced. Sediment may have started to accumulate in the upland tributary channels, while the lower mainstem channel may have started to incise because of the reduced sediment supply.

During 1798-99, severe rainstorms occurred in the Bay Area (Waananen *et al.*, 1977), whereas the early years following the 1800's were characterized by normal rainfall. Missionaries had removed almost all of the Huchiun from their homelands by this time. The major rainstorm of 1799 would have mobilized the sediment that accumulated in the upper drainage network during the previous years of drought. Aggradation of coarse sediments at the toe of the fan would have ensued while the finer load was transported through the tidal sloughs.

By the early 1800s, irreversible land use changes had begun. The missionaries had established a large herd of cattle in the watersheds in 1817. With abundant pasturage and without many predators, the cattle herd grew rapidly. An 1819 storm caused severe flooding in the north Bay Area (Montgomery, 1999) and it may have activated numerous landslides. With the introduction of cattle came shallow-rooted annual grasses from Europe. We hypothesize that the combined effects of grassland conversion to annual species and the reduced thatch cover from intensive cattle grazing greatly increased the runoff from rainstorms, and thereby initiated a cycle of channel incision and headward extension of tributaries. Channel adjustments to increased runoff increased sediment supply from fluvial sources. By the mid 1830s, cattle herds had grown too large for local consumption, so exportation of hides and tallow began (Purcell, 1944).

The changes in land use and related changes in water and sediment supplies in the Canyon and on the Alluvial Plain began to cause changes at the backshore of Wildcat Marsh. The toe of the alluvial fan began to expand across the backshore, as flows from both San Pablo and Wildcat Creeks became overwhelmed by sediment supply. New avulsion channels formed as the mainstem spread sands and fine gravels on the tidal marsh surface. Sediment cores from the toe of the fan verify the buried tidal marsh at the historical mouths of both creeks (Contra Costa Co, 1985). San Pablo and Wildcat Creeks converged through a tidal slough near the backshore of the marsh sometime between 1827 and 1830 (Figure 84).

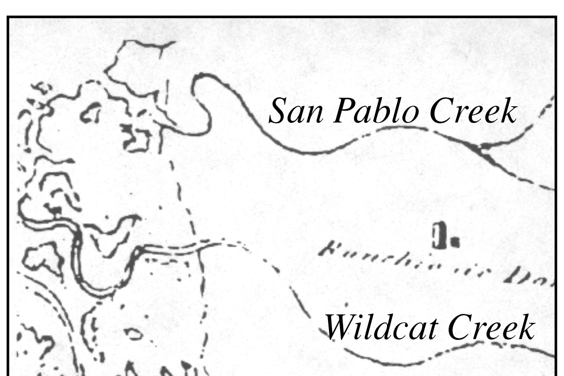
The early 1840's were marked by the onset of another drought. It probably reduced the supply of sediment supply from landslides. However, grazing continued to increase in intensity through the 1850s, until cattle were slaughtered to protect the pasturage (Paddison, 1999). With the increase in cattle, the riparian vegetation in the steep reaches of the drainage system may have also started to diminish as bank erosion and grazing pressures intensified. Until about 1856, San Pablo Creek maintained its tidal connection to Wildcat Creek through a channel along the previous backshore of the marsh. The channel was still deep enough at high tide for small boats and barges to regularly navigated the system. An embarcadero was developed on San Pablo Creek near the backshore of the tidal marsh (see Figure 85).

Creeks around San Pablo Bay flooded many times between 1850 and 1900. There must have been much landsliding and fluvial erosion in San Pablo and Wildcat Watersheds during these years. At some time in the 1860's, the tidal reaches of the creeks and their receiving sloughs began to downsize due to tidal marsh reclamation. Sediment supply from the Estuary also increased at this time from the great influx of hydraulic mining debris from the central Sierra Nevada Mountains and from land use disturbance of other local watersheds draining toward the bay. This contributed to the shoaling and loss of capacity of tidal sloughs in Wildcat Marsh, effectively increasing the base level for Wildcat Creek, and promoting aggradation near the backmarsh. The shoaling may have been particularly exacerbated by backwater effects of the 1861 flood when water from the Sacramento and San Joaquin Rivers flowed along both sides of the Potrero.

Railroads were built across both creeks. Debris jams beneath the trestles also increased backwater flooding. By 1893 (Figure 86) San Pablo and Wildcat Creeks were so choked with sediment in the tidal sloughs and backwater regions of the lower alluvial fan that numerous avulsion channels formed bayward of the channel that connected the two Creeks. Willows encroached onto the toe of the fan, where it had expanded over the salt marsh soils. Major flooding occurred again in 1895. This is about the time when San Pablo Creek abandoned its connection to Wildcat Creek. By 1898 (Figure 87), the two Creeks again flowed separately to San Pablo Bay. Local settlers placed a bulkhead across the old connecting channel to prevent its reuse by San Pablo Creek (State of California, 1893). Subsequently, a large willow grove grew through the abandoned connector channel.

Figure 83

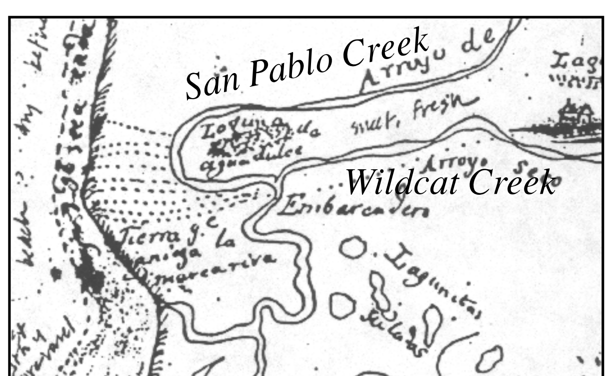
LOWER WILDCAT 1827-28



Source: Beechy, 1827-1828

Figure 84

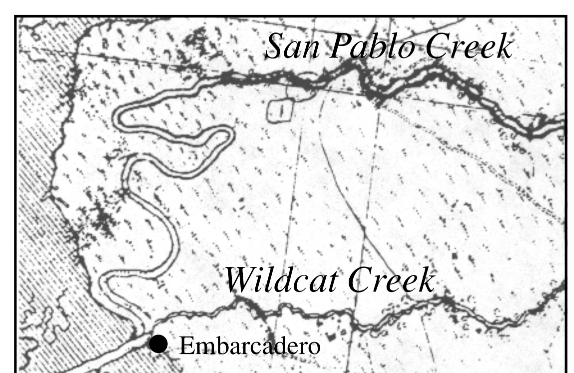
LOWER WILDCAT 1830



Source: Diseño del Rancho San Pablo

Figure 85

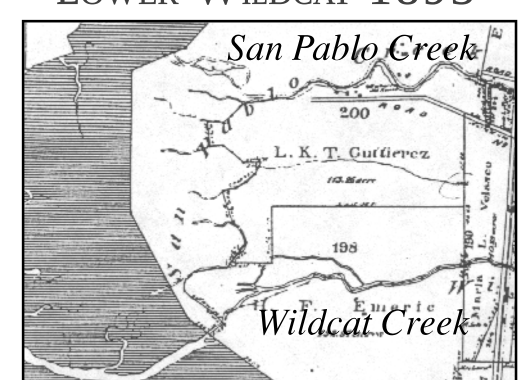
LOWER WILDCAT 1856



Source: United States Coast Survey

Figure 86

LOWER WILDCAT 1893



Source: Map of San Pablo Rancho

Figure 87

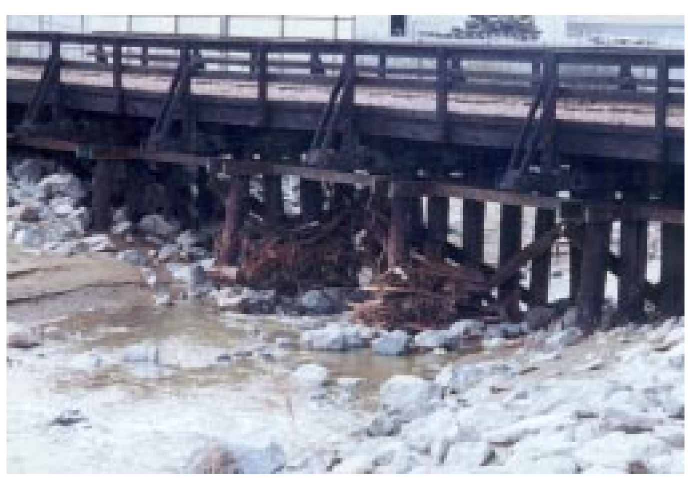
LOWER WILDCAT 1898

Source: United States Coast Survey

The Alluvial Fan Section

A longitudinal profile can be used to identify where a channel system shifts from an incision mode to an aggradational mode, and where pulses of sediment are moving through the system. A profile can also reveal sudden changes in grade that warrant investigation as headcuts or barriers to fish migration.

Figure 88 shows longitudinal bed profiles for three segments of the Alluvial Fan Section during 1817, 1830s, 1856, 1990, and 1998. The various profiles are based on numerous sources of information including field interpretation, field data, historical maps, as-built drawings for bridges, and USACE data for the flood control channel. The historical bed elevation of the early 1830s is indicated by the dashed red line, as determined from field indicators including the coring of riparian vegetation. The thin blue line is the 1998 bed profile as indicated by the elevations shown from as-builts drawings of engineered creek crossings and our recent measurements of terrace and bed heights at the locations of the as-built surveys. The thick blue line represents the as-built data for the flood control project, which has probably aggraded since the flood control channel was constructed, but recent elevation data were not available. The dashed orange line represents the average elevation of the high terrace banks that includes fill in Trestle Reach and the Flood Control Segment. The thin black line represents the probable bed elevation at Trestle and Rumrill Reaches during 1817, based on our findings that the rapid aggradation in that area began after the local introduction of cattle (page 68). The 1856 line is based upon historical evidence of tidal flow.



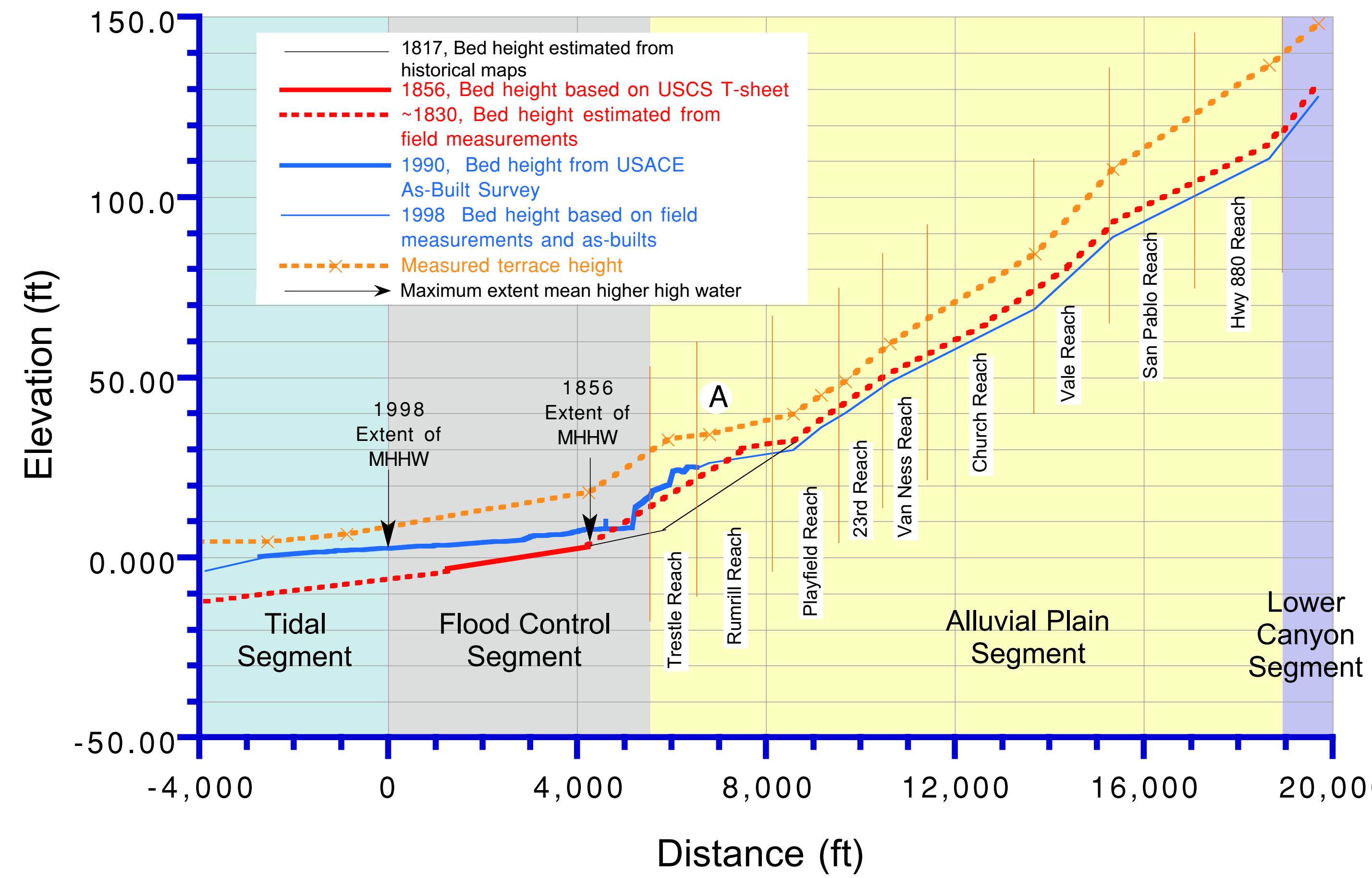
(Photo 55) Floating woody debris collects on the railroad trestle piers. The beams and the trestle impede the passage of flood flows and contribute to the formation of backwater floods. Flows have exceeded the top of the tracks.

The modern profile indicates that the channel is generally aggrading from about the upstream limit of Rumrill Reach through the Tidal Segment. The transition zone from aggradation to incision is near Davis Park in the Playfield Reach. This is shown at Point A in Figure 88 at the intersection of the red dashed line (1830s profile) and thin blue line (1998 profile). Although the flood control channel was excavated, its bed elevation is still above the historical bed of the early 1830s. The profile indicates considerable channel entrenchment into the terrace along the Highway 880 Reach near the fan apex. The distinct change in gradient near the apex and at the upstream end of Vale Reach approximates the position of strands of the Hayward Fault. The entrenchment of the upper fan may be driven by tectonic uplift through a series of steps east of the fault.

It seems possible that a stable channel system existed on the lower and middle alluvial fan before the 1800s. Flows at bankfull height and higher were sufficient to transport sediment through the alluvial fan and tidal sloughs that used to extend more than 4000 ft farther upstream than they do today (Figure 88). The sediment catchment basin in the flood control channel corresponds to the historical upstream extent of the tides. The transport of sediment at the historical tidal interface was complicated by the influence of the tides, storm surges, and flood flows from San Pablo and Wildcat Creeks. The rapid aggradation during the early 1800s occurred as back5water deposits upstream of the tides (see 1856 arrow, Figure 88).

Figure 88

Longitudinal Profile of Tidal, Flood Control, and Upper Alluvial Plain Segments



Channel aggradation is still occurring in the area of the historical backshore of the tidal marsh, although tidal influence has been stopped thousands of feet downstream. There are four obvious reasons for this aggradation. First, the flood control basin is much less steep than the local historical gradient of Wildcat Creek, so it lacks the power to convey as much sediment. Second, the basin of the Flood Control Project was designed

(Photo 56) A buried reinforced concrete pipe gives evidence of an aggraded bed. It is located near station 6200 on Figure A above.

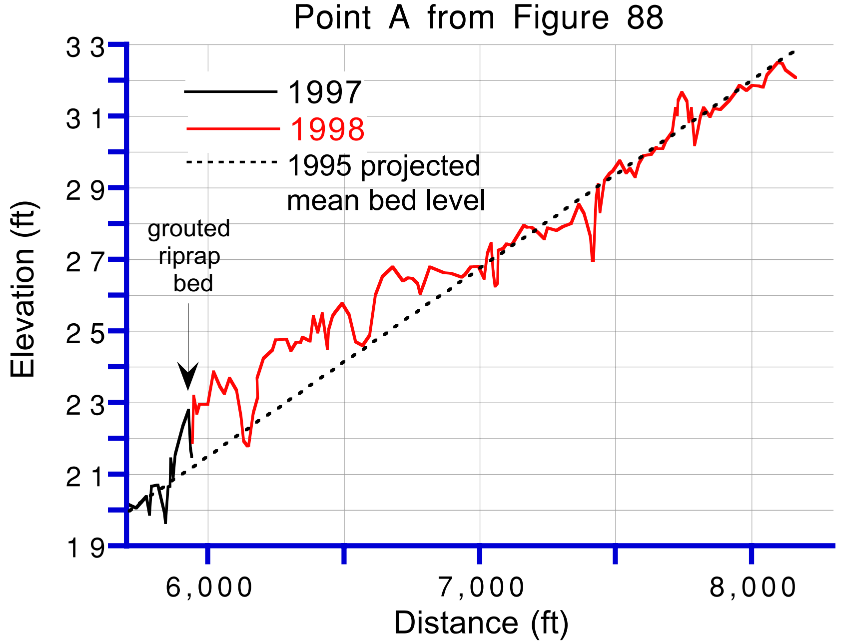
to trap sediment at its upstream end, at about station 5000 ft. Third, the Rumrill Reach is trapping bedload because of a grouted riprap structure that has artificially elevated the creek bed. Fourth, there is occasional aggradation in this reach from debris jams and flood flows that transport of water and sediment impeded by the railroad trestle.

Figure 89 shows a 1998 survey of the channel bed along Trestle and Rumrill Reaches near Point A of Figure 88. This profile extends between the box culverts of the Southern Pacific Railroad crossing and the box culvert at Davis Park. An aggradational lobe of sediment extends for more than 2000 ft upstream from approximately station 5800 ft. This aggradation began during the floods of 1995, when large amounts of woody debris accumulated under the railroad trestle, temporarily blocking downstream sediment transport. The dotted line on the graph shows the projected average bed level before the floods. Before the sediment could move downstream, grouted riprap was placed across the bed. The riprap has made permanent the aggraded bed. Aggradation now extends further upstream than the last date of survey. If the riprap were removed, the sediment would move downstream and the grade of the creek might be restored to its 1995 level. Yet occasional backwater floods and sediment deposition will still occur during future floods because of the effects of the trestle (see Photo 55, page 69). Floods have overtopped the trestle on several occasions.

Figure 89

Wildcat Thalweg Profile at Railroad Trestle

Point A from Figure 88



(Photo 57) Deposition of at least 3.5 ft has occurred behind a bay tree that slid into the channel, May 1999.

The Canyon Section

The long-term mode for Wildcat Creek in the Canyon has been degradation. This is evident from the numerous abandoned terraces. Nowhere were trees older than the last 170 years found within the height of twice bankfull depth, even where the banks were stable. This was verified by our coring of trees and counting growth rings. Figure 90 shows the bed profile (solid blue line) in 1987. Black dots along the blue line are bedrock outcrops within the thalweg. The red dashed line is the projected bed elevation of the 1830s. Note how this surveyed profile differs from the USGS 7.5' quadrangle profile (Figure 19, page 14), which is too general to reveal important local detail.

Distinct steps along the profile are apparent. The most pronounced is the steep step at the intersection of the creeping trace of the Hayward Fault in Alvarado Reach. We hypothesize that other significant changes in gradient are controlled by faults. The original geologic surveys of the water tunnel under the Canyon document several of them (EBMUD, 1921). Other smaller nick points are caused by local backwater deposits of sediment behind debris dams. The largest is shown at about distance station 27,000 ft, where sediment deposited behind a landslide-related debris jam has caused sediment deposition to extend more than 1,000 ft upstream.

(Photo 58) Exposed roots in 1996 indicate the amount of bed incision that has occurred since 1987 when this reach was previously surveyed.

(Photo 59) The same set of roots in 1999 show continued bed incision by at least another foot since 1996.

Portions of some Lower Canyon Reaches have been resurveyed at points A-D of Figure 90. These are shown in Figures 91-94.

Figure 91

Wildcat Thalweg Profile at Alvarado Park

Point A from Figure 90

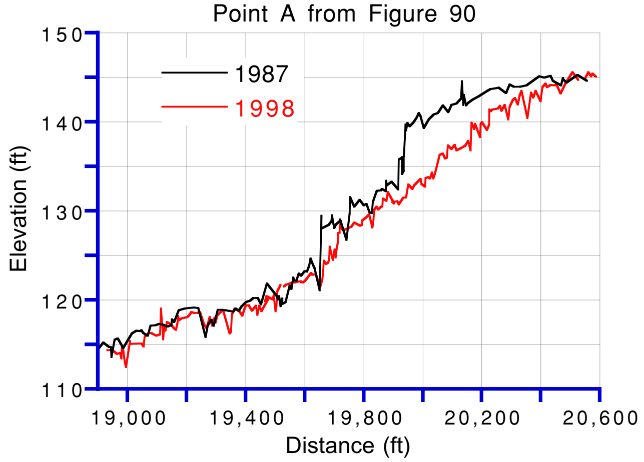


Figure 92

Wildcat Thalweg Profile at 117 Site

Point B from Figure 90

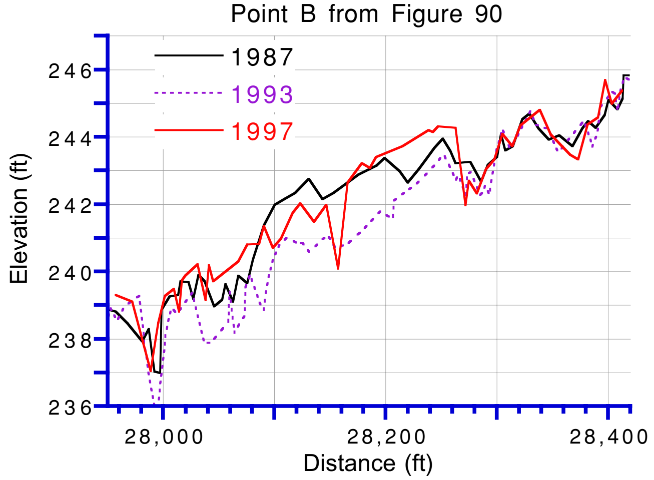


Figure 90

Thalweg Profile and Reaches for Lower Canyon Segment

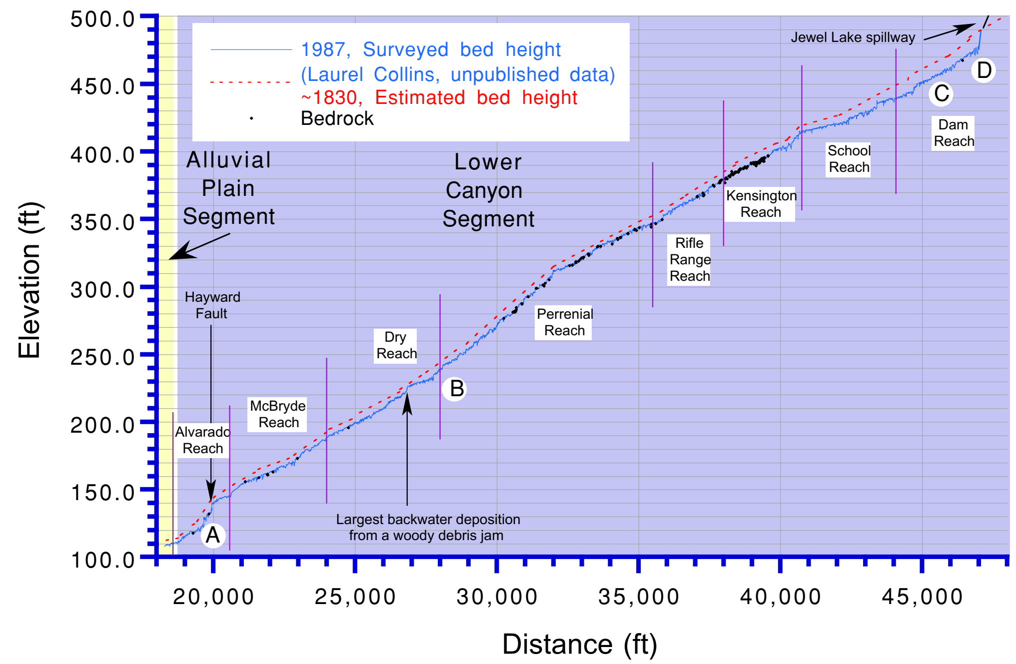


Figure 93

Wildcat Thalweg Profile
0.3 mi Downstream of Jewel Lake

Point C from Figure 90

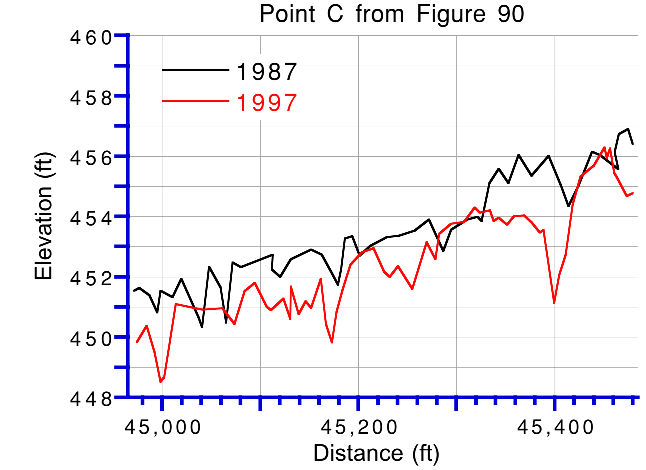


Figure 94

Wildcat Thalweg Profile at Jewel Lake

Point D from Figure 90

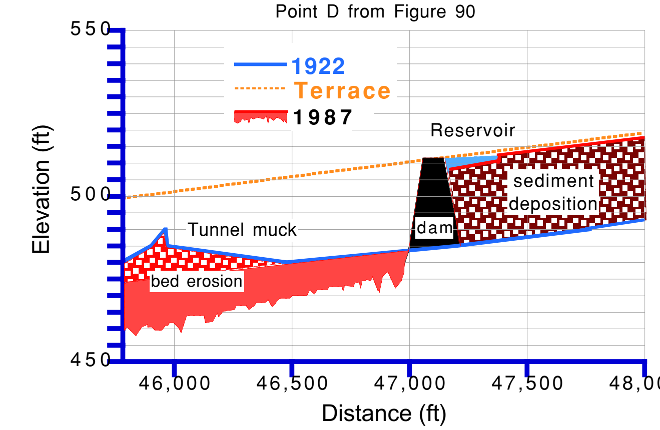


Figure 91 shows the section of Alvarado Park where the fish barrier removal project was performed to remove two small dams. There are considerable complexities of change that have evolved during this project, but the final differences between pre- and post-project profiles are shown. The net change has been incision.

Figure 92 shows surveys for 1987, 1993, and 1997 along a part of the Perennial Reach that has not been directly altered by people. Between 1987 and 1997 the channel had net erosion of about 1.0 - 1.5 ft. A small debris jam formed in 1986 at about station 28,100 ft. After it broke apart there was erosion that incised below the bed level that existed before the debris jam. In January 1997, two new debris jams formed, causing sediment deposition that is expected to last only as long as the debris jams persist. Photos 22 and 25 (page 41) show a portion of this survey reach.

Figure 93 shows a natural reach of channel that is located about 0.3 mi downstream of the Jewel Lake dam. During the last 10 years there has been net incision of about 1.5–2.0 ft. Deposition behind debris jams has not influenced this reach during the time span of these surveys. The small floodplain that existed in 1987, with 40-year old alders growing on it, has been abandoned.

Figure 94 shows the profile for the immediate vicinity of Jewel Lake and its dam. Downstream of the dam there has been net incision of at least 12 ft (Photos 36 and 37, page 51). The incision is represented in Figure 94 by the difference in height between the top and bottom of the area colored red. The bottom profile is from a 1987 survey. A 1922 survey, which is the solid blue line along the top of the bed downstream of the dam and at the bottom of the bed, shown in red, upstream of the dam, is from an early topographic survey of the proposed dam site (East Bay Water Company, 1919). The dotted red and white area below the dam represents material excavated from the vertical shaft used to divert water to the water tunnel 300 ft below. The brown and white dotted area upstream of the dam represents the combined sediment deposited since the reservoir was built and last dredged. The light blue area on top of the fill represents the present capacity of Jewel Lake. The length of aggraded channel upstream of the dam extends at least 2,100 ft.

Tectonics, natural droughts and deluges used to control the temporal patterns of degradation and aggradation in Wildcat Watershed. The impacts of land use are now over-riding these natural controls. Sediment retention by Jewel Lake has caused extreme scour below its spillway, while urbanization and grazing have increased runoff and consequently increasing drainage density and sediment supplies.

Mainstem Channel Condition Summaries

The measured characteristics of each Reach in the Upper Alluvial Plain and the Lower Canyon Segments are summarized in Table 16.

Some reaches in the Upper Alluvial Plain and Lower Canyon have important similarities. For example, in both Segments, the Reaches with the least percent length of eroding bank (San Pablo Reach and Alvarado Reach) also have the greatest percent length of revetted bank. People obviously view erosion as a problem in these reaches, that is why we observe so many revetments. Church and Kensington Reaches have the greatest length of eroding banks for their Segments, and both have the least percentage of sand and finer-sized sediments on the channel bed. This may indicate that bank erosion in these reaches is providing coarse gravels.

There are many interesting differences among the reaches. For example, for the Upper Alluvial Plain, the predominant wood recruiting processes, are bank erosion and "gravity", (trees drop limbs or the entire tree topples into the Creek from disease or windthrow). In the Lower Canyon, most of the LWD comes from landsliding and "leaning or bent vegetation," meaning that living willows or large trees are interfering with bankfull flows.

Kensington and Dam Reaches are both exposed to large inputs of sediment from landslides, but Kensington Reach has the most length of exposed bedrock in its bed and banks while Dam Reach has the least for the Lower Canyon. Dry reach has the greatest supply of terrace erosion, which may correspond to it having the greatest amount of "F" Rosgen Stream Class in the Lower Canyon Segment. The Upper Alluvial Plain reach that has the largest sediment supply is dominated by Rosgen Stream Class B and subordinately by G conditions. This indicates that much of the channel has started to become a stable B channel after it entrenched or that much of the sediment is coming from the shorter length of unstable G channel where the terrace height is large. The Streamline Graphs indicate the latter case.

Factors that effect runoff and sediment production for all the quantified Segments are compared in Table 17. The length of roads, amount of impervious area, and historical increases in drainage density are greater for the Upper Alluvial Plain than the Canyon, due to its more extensive urbanization. Yet, overall drainage density is much greater for the Canyon than the Alluvial Plain. This is because of the topography of the Canyon and that the alluvial fan has never had many natural tributaries feeding into the mainstem. Fans, by their nature tend to have distributary systems when they are aggrading. The very large increase in drainage density in the Upper Alluvial Plain is caused by storm drains. We have not attempted to account for paved road gutters that also function as ephemeral channels.

A comparison among just the Canyon Segments reveals that the Middle Canyon has been most influenced by urbanization. It has the largest increase in drainage density and the greatest amount of impervious area (Table 17). Subsequently, our field reconnaissance indicates that upstream of the backwater influence of Jewel Lake, the mainstem channel has incised, eroded its banks, filled the reservoir with bedload, and conveyed large loads of suspended sediment downstream.
The distribution of landslides among the Canyon Segments is proportional to the distribution of volcanic bedrock (Table 17). However, the ratio of inactive slide area to total slide area correlates to the total num-

Table 16

Facts Table for Reaches

	% length eroding banks	% length of stable banks	% length of revetted channel	**Total long-term rate of field measured sediment supply since 1940's	Dominant bank sediment supply process sediment supply process	% length of reach represented by sand and smaller D50 size classes	# pools > 1' deep	Pool spacing (ft)	# wood	Wood spacing (ft)	# debris jams	Dominant wood recruitment process (excluding float)	% length of Bedrock for Right and Left Banks	% length of Bedrock in the Bed	% length of Bedrock for Combined Bed and Banks	% length of landslides adjacent to banks	Dominant Rosgen Stream Class (%)	Second Dominant Rosgen Stream Class (%)
Trestle	20	26	59	200	terrace erosion	18	0	none	0	none	0	none	0	0	0	0	46, E	43, culvert
Rumrill	27	33	40	412	terrace erosion	21	3	546	0	none	0	none	0	0	0	0	74, E	12, E-G
Playfield	13	28	59	135	terrace erosion	17	3	450	2	674	1	gravity	0	0	0	0	56, E	22, B
23rd	21	31	49	177	terrace erosion	31	2	469	0	none	0	none	0	0	0	0	51, E-F	39, E-G
Van Ness	25	32	49	133	terrace erosion	17	2	476	2	476	0	gravity	0	0	0	0	47, E-G	42, G
Church	60	15	25	1629	terrace erosion	14	10	226	6	377	0	bank erosion	0	0	0	0	72, G	24, B-G
Vale	27	57	16	745	terrace erosion	45	14	116	1	1630	1	none	0	0	0	0	41, B	31, G
San Pablo	11	28	61	339	terrace erosion	19	9	195	2	878	0	bank erosion	0	0	0	0	51, culvert	41, B-G
Hwy 880	24	43	33	3242	terrace erosion	42	12	159	9	213	2	bank erosion	1	0	0	0	41, B	35, G
Alvarado	21	22	57	488	terrace erosion	28	27	62	17	98	1	landslide	9	1	5	2	46, ND *	30, B
McBryde	45	50	5	3163	landslide	28	43	99	70	61	6	landslide	16	6	11	5	80, B-G	6, culvert
Dry Reach	74	26	0	17417	landslide	33	55	66	227	16	17	bank erosion	18	4	11	11	31, F	22, B
Perennial	62	37	1	12298	landslide	38	93	84	325	24	21	lean/bent	24	8	16	6	84, B	5, F
Rifle Range	62	36	2	1998	canyon slope	32	19	88	176	10	14	lean/bent	11	3	7	4	87, B	7, B-G
Kensington	79	22	0	7582	landslide	25	37	96	229	16	17	lean/bent	28	26	27	14	65, B	34, G
School	61	39	0	7751	landslide	43	30	112	274	12	20	landslide	5	2	3	12	64, ND	27, B
Dam	74	26	0	5037	landslide	41	25	89	163	14	11	bank erosion	1	0	1	14	ND	ND

* not determined

** does not include soil and landslide creep calculations

Note: the time frame for the Alluvial Plain is 1998, and for the Lower Canyon, 1999 ber of years actively grazed. Rates of accelerated channel incision may require tens of years to diminish after the removal of cattle, especially if channel headcuts exist that will continue to propagate upslope.

Overall, sediment and water supplies in the Upper Canyon are less sensitive to land use changes. The mainstem channel gradient is steeper in the Upper Canyon, but stream discharge is less. The channel bed tends to be armored in some areas by coarse volcanic sediment that is transported by debris flows (Photo 33, page 37). This contrasts with channel conditions on the east slope where earthflows contribute mostly fine sediments. The west slope earthflows occasionally convey coarser sediments from the Franciscan bedrock that occurs at the top of the ridge. When armoring occurs, channel repsonsiveness to increased runoff from land use is reduced, especially if the banks are bedrock. The increased runoff from urbanization in the Upper Canyon is contributing to channel changes farther downstream in the more sensitive Segments of the watershed that are underlain by Orinda bedrock.

The Lower Canyon has more landslide activity per unit area than any other segment. Most of the grasslands on the southwest aspects

Table 17

Facts Table for Segments	Upper Alluvial Plain	Lower Canyon	Middle Canyon	Upper Canyon
Drainage area (sq mi)	1.13	4.38	1.71	1.46
1999 Drainage density since 1830's (ft/acre)*	46.9	80.0	86.9	72.4
% Increase in drainage density since 1830's	193	28	42	19
% Active slide area	0	13	4	<1
% Total slide area	1	37	22	10
% Impervious area	57	3	8	5
% Area volcanic rocks	NA	1	21	87
% Average hillslope	4	31	30	29
% Average channel gradient	0.5	1.6	3.9	8.1
Abandoned & currently used dirt road/trail density (mi/sq mi) (SFEI)	NA	9.5	14.6	13.2
Paved road and currently used dirt road density (mi/sq mi) (USGS GIS layer)	25.2	2.1	6.0	5.0
Number of years continuously grazed	~63	182**	119	119

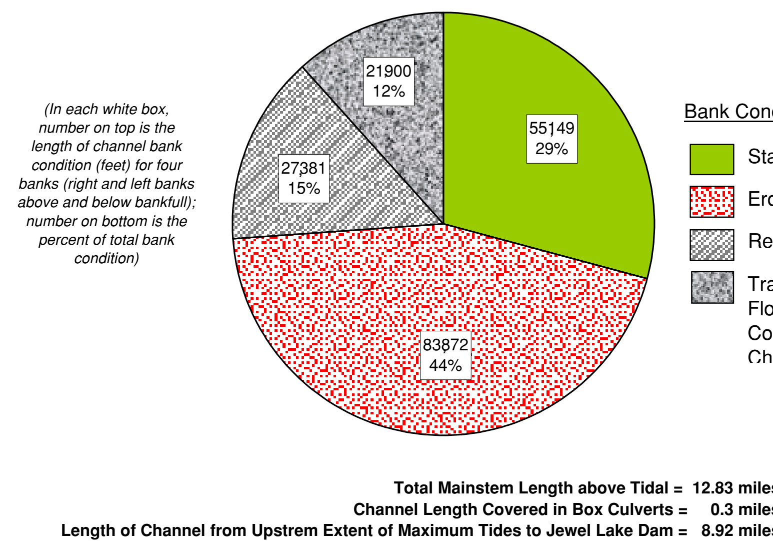
* includes storm drains, road ditches, headward extension

** pertains mostly to grassland on east side of Wildcat Creek

Figure 95

WILDCAT CREEK

Bank Conditions for the Upstream Extent of Maximum Tides to Jewel Lake - 1998-99



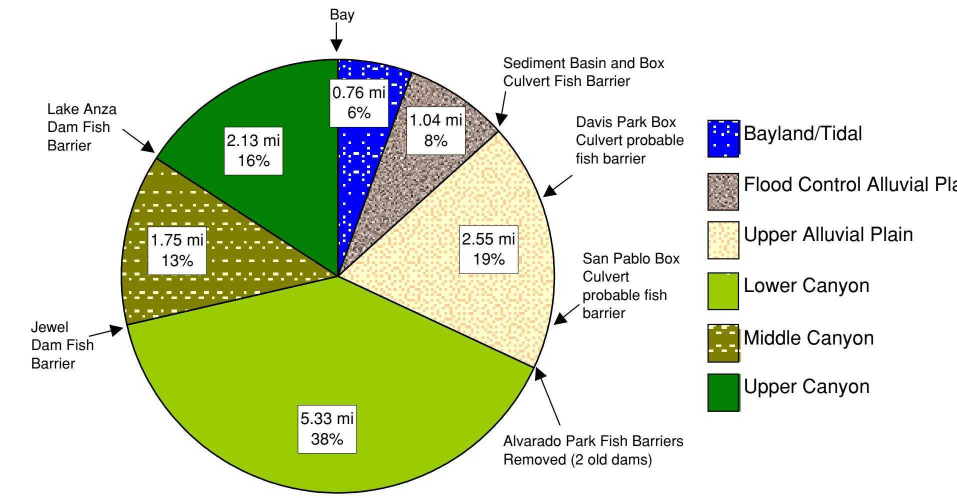
have been continuously grazed for about 182 years. The grasslands near the western ridge crest have also been intensively grazed, but for less time (Watershed View Map, page 23). Residential development covers only 3% of the total Lower Canyon Segment, yet it is concentrated at the top of steep tributary drainages that flow through numerous deep-seated earthflows. Runoff from these residential areas has accelerated fluvial erosion and mass wasting. Deep gullies have incised below most of the road drains. The combination of grazing, urbanization, and dam construction on the Orinda Formation accounts for much sediment production in the Lower Canyon.

The total percent of impervious surface for the entire watershed above the flood control channel has only increased by 11% since the time of non-native settlement. As a rule, this amount of impervious area is expected to increase peak flows by 1.1 times (Waananan, 1977). We hypothesize that there are at least four very important reasons why peak flows have likely increased much more than predicted by this general rule. First, the amount of impervious area varies among the Segments. For example, we know that the amount of impervious area in just the Upper Alluvial Plain Segment has increased by 57%, which would increase peak flows by 50% (Waananen et al., 1977). Second, we know that drainage density for the whole watershed has increased by a minimum of 35%. This means that more runoff can enter the

Figure 96

WILDCAT CREEK

Percent Length of Segments and Fish Barrier Locations



mainstem more rapidly. Third, the replacement of perennial grasses with annual grasses, plus the concomitant reduction in thatch and perennial grasses has increased runoff in the grasslands. Runoff coefficients can be as much as 70% during large storms. Fourth, the replacement of natural banks and floodplains with concrete walls and flood control berms has decreased the lag time between rainfall and peak flow by decreasing roughness and increasing water velocity.

Figure 95 Summarizes bank conditions from the tides to Jewel Lake, this includes the trapezoidal channel banks. In total, 27% of the bank length has been artificially altered, and 29% remains in relatively natural, stable condition.

Figure 96 summarizes the percent length of all geomorphically distinct segments for the entire mainstem channel and the partitioning of the watershed by migration barriers for steelhead. This diagram allows us to visualize the potential increase in habitat if these barriers were removed or modified. Presently, fish can only swim up stream through 14% of the mainstem, of which no portion can be used for rearing habitat because tidal slough comprises 6% and the remaining 8% within the Flood Control Project has poor habitat. At the upstream end of the sediment basin, a nonfunctional fish ladder is under consideration for redesign by the USACE. Even if this structure is improved, two additional barriers in the Upper Alluvial Plain greatly diminish opportunities for steelhead to reach the perennial flow and viable habitat in the Lower Canyon.

Long-Term Sediment Supply Estimates

In this part of the report we make some estimates of the total amount of sediment supplied by the Watershed and then itemize the processes of input. We then provide a context for Wildcat Watershed by comparing its supply to other watersheds and by developing a picture of landscape response to land practices. We emphasize that these numbers do not constitute a sediment budget because storage and output measurements were not a component of our study. To approximate the total sediment supply to the channel, we had to make some broad assumptions by estimating proportions of suspended sediment and erosion that could not be field measured.

Figure 97 shows the measured and estimated sediment supply rates for all segments above the flood control channel. The values shown for the Upper and Middle Segments are for the bedload that was captured behind Jewel Lake and Lake Anza (Table 11, page 48).

Suspended load over the dams was not measured. It had to be estimatedusing the following guidelines. First, we used a rule of thumb that bedload usually represents about 10-20% of the total sediment load (personal communications, Bill Dietrich, University of California at Berkeley, 2000; Bill Firth, USACE, 2000). Table 18 shows that the USACE (1999) calculated the percent sand and gravel caught in sediment catchment basin of the Flood Control Project to be 19% of the total load. We applied this same percentage to the sediment caught at Jewel Lake. For Lake Anza, which is a bigger reservoir, we assumed that the captured load represented about 30% of the total.

Table 18

Army Corps of Engineers Estimate of Total Annual Load of Wildcat Creek 1989-1996 (determined for the concrete channel above the flood control basin)			
Bed material	Amount (cu yd/yr)	Where it goes	Percent of Total
Clay	20,800	100% goes to the bay	48
Silt	14,150	99% goes to the bay, 1% goes to sediment basin	33
Sand and gravel	8,350	25% goes to the bay, 75% goes to the sediment basin	19
TOTAL	**43,300**		**100**

Second, to determine the relative influence of one segment to another, we needed to compute yields for each Segment per square mile (Figure 98). The combined yield of both suspended and captured bedload of the Middle Canyon Segment is compared to the sediment supplied by voids (both bedload and suspended load) in the Lower Canyon. Third, we considered that just the yield from void measurements in the Lower Canyon was too low, because a large component of existing and historical sediment sources could not be easily measured or calculated. These important sediment sources include:

- banks that had less 0.25 ft retreat and banks that have revetment where amount of erosion could not be easily assessed;
- extensive bare, inner gorge stream banks in the grasslands that are exposed to raindrop impact and overland flow;
- bare soil from construction of road fills of Wildcat trail, some are more than 80 ft in height;.
- bare soils from construction of thousands of homes and tens of miles of paved roads;
- bare soil from construction of Jewel Lake reservoir;
- bare soil from construction of two golf courses and numerous recreational playfields;
- sparsely vegetated soils upstream of channel heads and along cattle terracettes that convey saturated overland flow;
- channel sediment that was in storage before the 1830s (in our estimates of incision we had to assume the bed was level which does not account for bars; and
- gullies that may have been obscured beneath the dense vegetative cover on the western slope where access could not be attained and features may not be visible in stereo photos.

Fourth, we considered that the yield from the Lower Canyon should not be as high as the Middle Canyon because the values of drainage density, impervious surface and road conditions (Table 17) were not as great. Based upon the latter two assumptions, we conservatively assummed that the total yield for the Lower Canyon should be about half of the yield of Jewel Lake. This assumption allowed us to back-calculate an estimated yield for the sediment sources that could not be measured. The result is a plausible picture of minimum expected long-term sediment supply rates and yields.

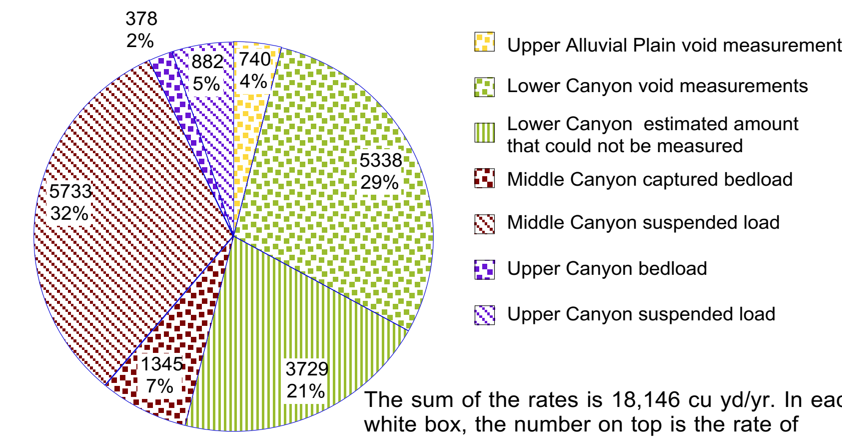
Given these guidelines, the Middle Canyon has the highest yield of 4,140 cu yd/sq mi/yr compared to the Lower Canyon, which has a minimum of 2,070 cu yd/sq mi/yr. The overall yield for the watershed above the flood control channel is 2085 cu yd/sq mi/yr.

If we convert the estimated yield from cubic yards to tons, we can compare the long-term yield of sediment sources in Wildcat to yield estimates determined by different methods for other Northwestern California streams (Figure 99). Some estimates are based upon sediment transport measurements or models (e.g. USACE), not sediment supply. We used a bulk density value of 1.63 tons/cu yd to convert cubic yards to tons for Wildcat Creek and Corte Madera Creek. The sediment source/transport yields from Wildcat Watershed are comparatively large for a drainage area that is so small. Some watersheds that are more than a hundred times larger than Wildcat generate lesser yields of sediment. From the perspective of watershed management, the very large sediment yield from Wildcat Watershed raises two questions: what causes the large sediment yield, and how much of it can be managed?

Figure 100 shows the rate of sediment supply stratified by the major geomorphic processes for just the Upper Alluvia Plain and the Lower Canyon. The

Figure 97

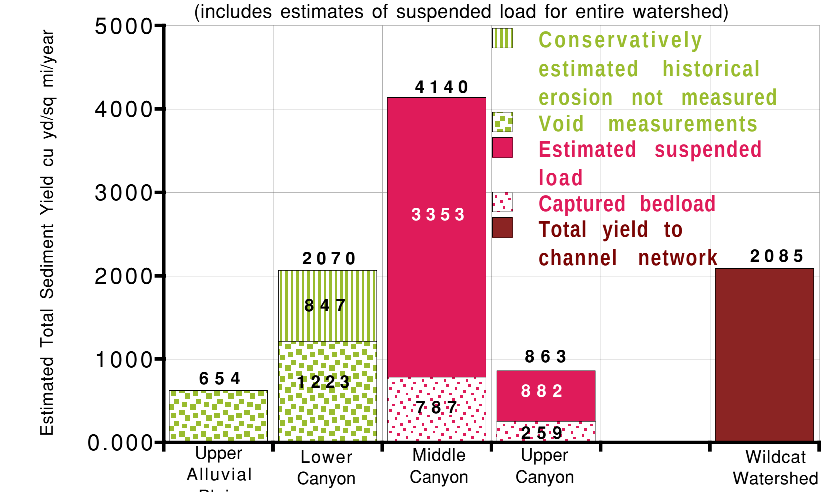
Measured Sediment Supply Rate for Each Segment
(does not include suspended load)



The sum of the rates is 18,146 cu yd/yr. In each white box, the number on top is the rate of sediment supply in cu yd/yr; number on the bottom is the percent of total estimated volume.

Figure 98

Conservative Estimate of Long-term Sediment Yield to Wildcat Channel
(includes estimates of suspended load for entire watershed)



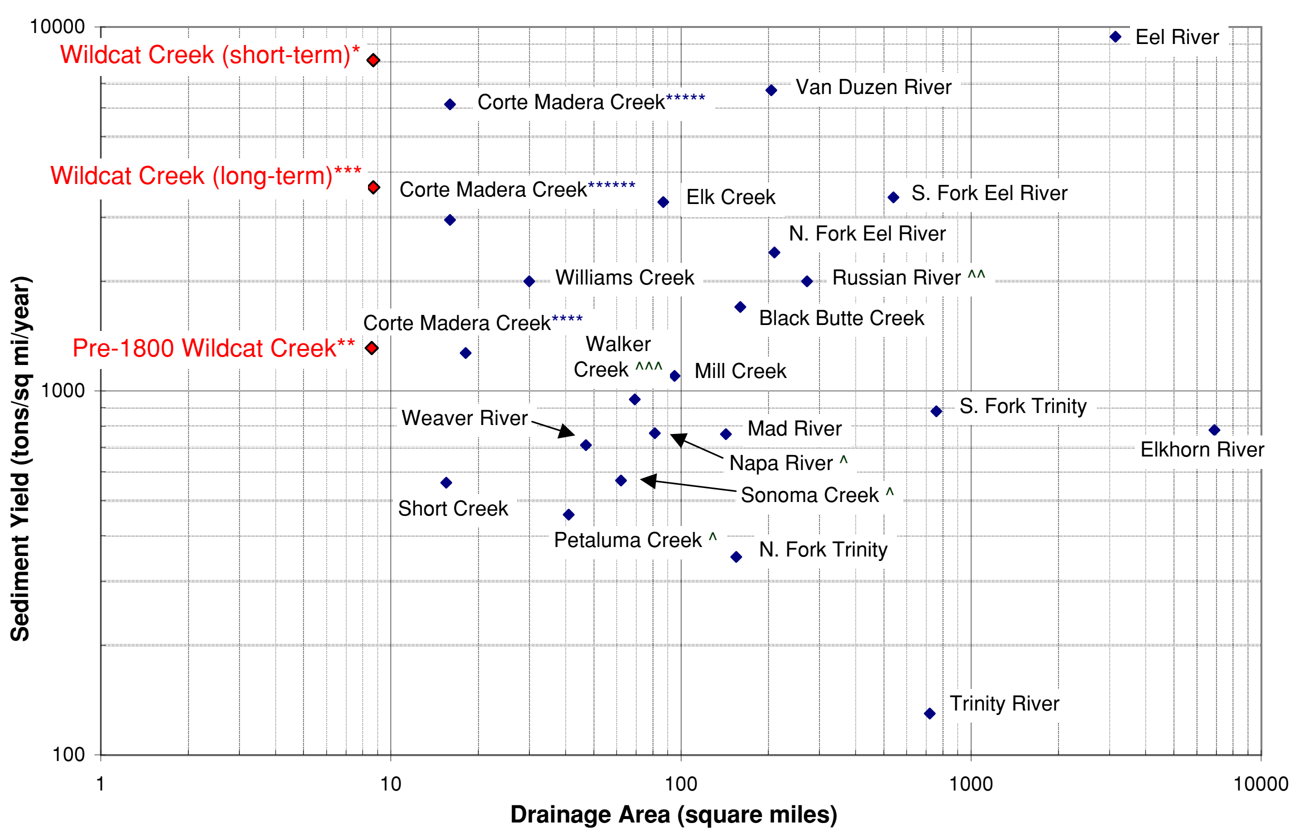
Note: For banks that had not retreated more than 0.25 ft or were revetted, we estimated an addtional input of 34 cu yd/yr for terraces and banks along the Upper Alluvial Plain and 17 cu yd/yr for the Lower Canyon. These rates were added into each segment.

red striped lines represent mass wasting processes, the blue striped lines represent fluvial processes. The dotted and circular patterns represent the calculated sediment supply rates from road tread erosion and soil creep. The green striped pattern shows our estimated rate from natural soil lowering. The gray color shows estimated supply from sources that could not be field measured. Fluvial erosion (18%) and landsliding (22%) account for nearly equal parts of the total measured sediment supply. However, tributaries receive most of their sediment from landslides, whereas mainstem sediment input is nearly equal for both processes. The supply of 38% (3763 cu yd/yr) of the sediment for the "gray area" may be dominated by overland flow processes on disturbed or bare soils as listed above. We expect that a large proportion of the gray area may be land use-related. Yet, a natural component would be the lateral migration of the channel.

Figure 101 shows the sediment supply stratified by natural and land use-related causes for the Lower Canyon and Upper Alluvial Plain. We are

Figure 99

Sediment Yield for Selected California Watersheds

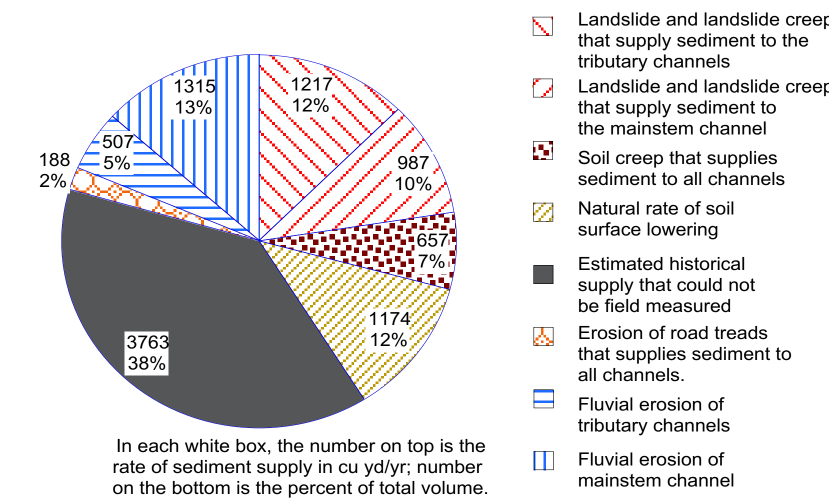


Data points without asterisk from William Dietrich, UC Berkeley Department of Geology and Geophysics, personal communication, 1988
* *Bill Firth, USACE, personal communication, sediment transport yield above flood control basin 1989-1996 (does not include captured load at Jewel And Anza dams)*
** *This study, SFEI, estimated total sediment source yield to channel network before European contact*
*** *This study, SFEI, estimated total sediment source yield to channel network since European contact*
**** *Bill Firth, USACE, personal communication*
***** *Stetson Engineers, P-K shear values; uncalibrated estimates*
****** *Stetson Engineers, USDA FS shear values; uncalibrated estimates*
^ *USGS Water Resources Investigations 80-64*
^^ *Kondolf and Matthews*
^^^ *Daetwyler (1950) as cited in Haible (1980:252)*

confident that at least 20% of the supply is indirectly attributable to land use. We are also confident that least 19% is part of the natural supply. The gray area (61%) represents the same estimated amount of sediment for the "gray area" in Figure 100, plus the proportion of sediment that could not be attributed to either natural or other causes, but was measured as fluvial or landslide input. From our subwatershed analysis (page 42) we were able to deduce that at least 36% of the sediment supply was probably indirectly caused by grazing impacts (page 45). Thus, perhaps another 22% (2,160 cu yd/yr) of the overall total might be attributed to grazing. This is consistent with the findings of Cooke and Reeves (1976). They found that soil disturbance and vegetation conversion by intensive use of livestock throughout southern coastal California resulted in entrenchment of channels (arroyo formation), extension of channel networks, aggradation of low gradient valley bottoms, and increased sediment supply. We also expect that another proportion of the gray area is sediment supply that is indirectly related to recent and historical urban effects. Therefore, a conservative approximation of the total proportion of the gray area in Figure 101 that is land use-related (both urban and grazing effects) is 40%. Adding to this the 20% that is in the "red area", we hypothesize that as much as 60% of the supply in the Lower Canyon and Upper Alluvial Plain is land use-related.

Figure 100

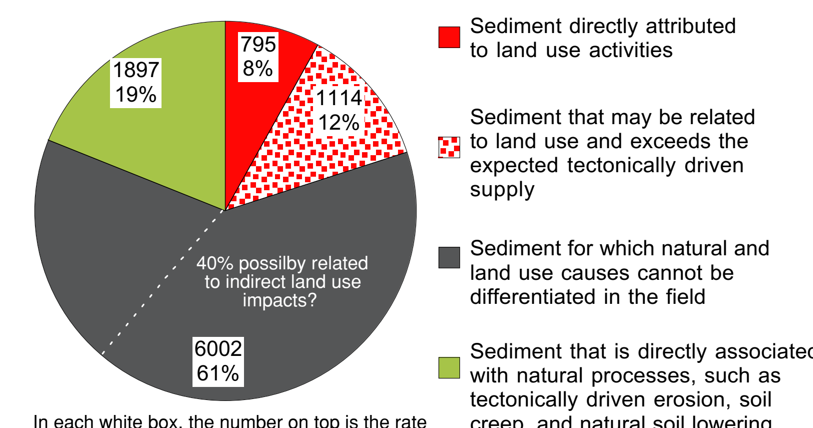
Percent of Sediment from Different Processes Flood Control Channel to Jewel Lake



In each white box, the number on top is the rate of sediment supply in cu yd/yr; number on the bottom is the percent of total volume.

Figure 101

Percent of Measured Sediment Caused by Land Use Flood Control Channel to Jewel Lake



In each white box, the number on top is the rate of sediment supply in cu yd/yr; number on the bottom is the percent of total volume . Total rate of sediment supply is 9808 cu yd/yr.

In Figure 97, we reported the total natural sediment supply rate for the entire Wildcat Watershed to be 18,146 cu yd/yr. If we assume that 60% of this total rate for the entire watershed is land use-related, then the historic natural rate would have been 7,258 cu yd/yr, or 40% of the modern supply.

We can compare these values to the total amount of erosion that would be required to compensate for uniform uplift and erosion of the entire Canyon (Table 19). (Other estimates of erosion driven by tectonics were for the amount caused by fluvial incision of the channel bed at a similar uplift rate.) At a maximum rate of 0.02 in/yr (0.5 mm/yr), the tectoni-

Table 19

Estimates of Sediment Supply and Annual Load to Flood Control Segment

	cu yd/yr
Estimated maximum natural sediment supply to entire channel network before 1800's (40% of long-term load)	7,258
Estimated maximum sediment supply, if erosion in the Canyon kept pace with tectonic uplift of 0.5 mm/yr	12,845
Estimated long-term supply to channel network 1832 - 1999, SFEI	18,146
Estimated long-term sediment supply to channel network between Jewel Lake and Flood Control Project	16,423
Modeled (Hec-6) load for short-term 1989 -1996, Army Corps of Engineers (1999)	43,000

Data Source: Tim Jensen, Contra Costa County Public Works

cally driven supply would be 12,845 cu yd/yr. Our estimate of natural historical supply (7,258 cu yd/yr) therefore seems reasonable, given that the natural rate should be less than the maximum tectonically-driven rate, otherwise uplift would not be apparent.

The differnce between the historical and the modern long-term sediment supply rates cannot logically be attributed to causes other than changes in land use. The regional climate during the last two centuries has not had any major shifts, only short-term droughts and deluges that represent a usual pattern for the region. The lower reaches of the channel system have aggraded, not degraded, so there is no pervasive headward erosion of the mainstem due to a change in base level.

It follows that if 60% of the total sediment load from Wildcat Watershed is related to land use, some of this supply can be mitigated by improved land practices. For example, if this supply was decreased by half, sediment supply might be reduced by 5,400 cu yd/yr.

These assumptions and calculations allow some conclusions about the influence of Jewel Lake dam for modern versus historical rates of sediment supply. People generally think that dams reduce total sediment supply because they withhold bedload. If we consider the total sediment load that would have occurred at Jewel Lake before non-native settlement, we would have 504 cu yd/yr, which is 40% of the modern supply. Based upon the ratio of bedload to suspended load (from Table 1), 81% of the total load would be flowing over the dam (403 cu yd/yr) and 19% (101 cu yd/yr) would be captured bedload. The amount of long-term sediment supply from channel incision below the dam was determined to be at least 233 cu yd/yr (from Table 13), which is more than twice the amount that would have been captured historically. The yeild of sediment by bed incision downstream of the dam has more than compensated for loss of sediment trapped behind the dam.

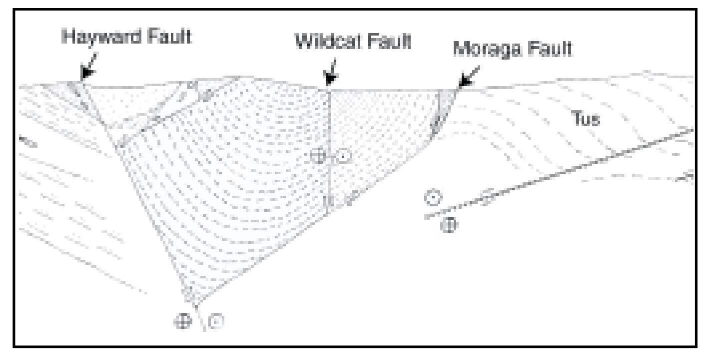
Conceptual Models

These word models integrate among qualitative and quantitative observations of watershed form and function to produce simple statements of possible cause and effect relations that could be tested through field experiments.

Tectonics and Seismicity

Tectonic processes can be slow and incremental or punctuated by sudden seismic events. Thus watershed structure and form is influenced over very different scales of time. In practical terms, local rates of tectonic uplift and down-dropping provide a basis to calculate natural, background rates of landscape erosion and estuarine or fluvial deposition. In general, the uplift of hills around the Estuary provides a gradient for erosion, whereas the down-dropping of the basins of the Estuary and adjacent alluvial plains provides places to deposit sediments conveyed by streams and the tides. Right-lateral offset along active faults can help explain the plan form of streams and differential rates of erosion from one bank to another, whereas vertical offset can help explain breaks in stream gradient that control headward erosion. The history of seismicity can explain temporal variations in water and sediment supplies, especially as related to the productivity of springs and activation of landslides. A basic understanding of tectonic and seismic processes in relation to watershed management requires detailed investigations, including longitudinal profiles of streams, distribution of bedrock and fault traces, and compilations of all available evidence of local seismicity and tectonic motion.

Figure 102



Geologic cross-section of the Berkeley Hills. Source: Russ Graymer, USGS.

(Photo 60) Curious cattle peer over the incised channel banks.

Grazing

Grazing practices indirectly effect sediment and water supply through direct effects on vegetation and soil that causes increased runoff. Grazing effects must be deduced from an understanding of the mechanisms relating runoff to stream flow, mass wasting, and fluvial erosion. Cattle grazing can have the following direct impacts:

1. conversion of dominant perennial grassland to dominant annual grassland;
2. trampling of banks and spring areas;
3. reduction in riparian growth of willows;
4. reduction in grass cover;
5. compaction of soils;
6. creation of extensive trail networks that function as ephemeral channels; and
7. reduction in water quality.

The combination of impacts 1-3 leads directly to increased sediment production. More sediment will aggrade the channel bed. The aggradation leads to increased bank erosion and/or flooding. The combination of impacts 4-6 leads directly to increased runoff. The following processes caused by more runoff will indirectly increase sediment production as well:

1. bed incision, which can lead to increased shallow landslides along the inner gorge, increased deep-seated landslides due to removal of lateral hillslope support, and subsequent gully formation associated with the deep-seated slides;
2. bank erosion, which can also lead to the loss of riparian vegetation leading to more bank erosion;
3. increased headward extension, which leads to increased drainage density, which increases runoff and flooding; and
4. increased frequency and magnitude of flooding.

The individual or combined effects of more sediment and runoff require an adjustment of hydraulic geometry of receiving channels. Within the grasslands and downstream, grazing has lead to destabilization of the entire channel network. The effects of entrenchment upon the long-term fluctuations in the water table in Wildcat Watershed are not immediately obvious through this study, although we can say that riparian vegetation has less probability of creating mature stands in an unstable and entrenched system.

Where grazing has been discontinued, there is more brush, more winter thatch cover, and there appears to be a greater proportion of perennial rather than annual grasses. Runoff coefficients should therefore be less in ungrazed area. The decrease in runoff reduces sediment transport capacity, thereby increasing sediment storage in tributary channels. Small woody debris dams and more overhanging vegetation help trap sediment and decrease water velocity. Sediment storage was observed to be greater and active landsliding to be less in areas removed from grazing.

(Photo 61) March 1995 Wildcat Creek near peak flood in Alvarado Park.

Drought and Deluge

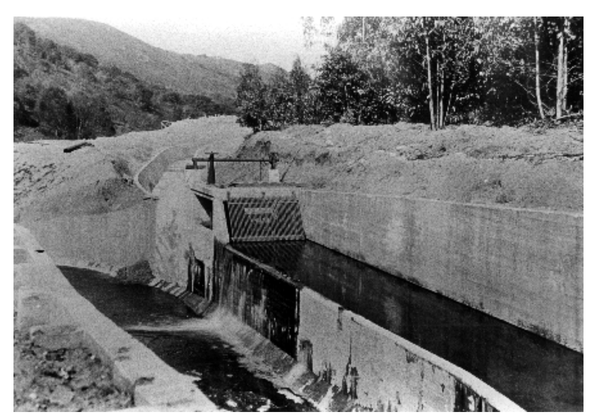
Periodic drought and deluge influence production of sediment on the hillslopes, and erosion and sediment storage in the channel. The timing of one relative to the other, their magnitude and duration all have important geomorphic consequences. If either one is extreme for an extended period of time, the hydraulic geometry of channels will change, base flow and ground water will rise or fall, riparian vegetation will respond to changes in ground water, and a scenario of aggradation or degradation may occur in either the uplands or the lowlands.

Short-term droughts might be expected to cause the following responses in an earthflow-dominated landscape:

1. a decrease in active earthflow-type landslides, which would cause a substantial overall reduction in sediment supply;
2. a decrease in flow, which would cause a reduction in sediment transport and in sediment load;
3. possibly an increase in supply of woody debris from stressed vegetation, which might lead to increased sediment storage behind debris dams;
4. coarsening of the particle sizes on the bed as the fine materials winnow from the system; and
5. aggradation in places that were previously incising, and scouring of sediments in places that were previously aggrading.

Channel response to deluge depends on whether storms produce extensive landslides and flooding, or just flooding. Floods with landslides will generate more sediment and finer-grained sediments on the bed surface than those without slides. High gradient channels will likely scour. In low gradient areas, an overall depositional mode will likely be associated with storm events that produce both floods and landslides, such as ENSO events, while scouring will be associated with floods that have limited sediment supply. High sediment loads occasionally associated with ENSO events could have cumulative downstream effects if frequency of ENSO is increasing. It took about 10 years for Wildcat Creek to rid itself of the massive amount of sediment associated with the 1982 and 1983 ENSO. The influence of accelerated rates of erosion from land use has increased ENSO impacts.

During droughts, riparian vegetation encroaches on point bars. When high flows return, the vegetated point bars push the flow against the outside banks of meander bends. The outside banks erode, releasing sediment to build more point bars.



(Photo 62) 1922 Water diversion at the old Wildcat Dam (Jewel Lake). Source: East Bay Municipal Utility District.

Dams, Bridges and Culverts

Engineered creek crossings, like dams, bridges, grade control structure, and culverts influence the amount and distribution of water and sediment in many ways. The dams and other grade control structures can have the following geomorphic consequences:

1. increased washload and sometimes gullying on disturbed soils at construction sites;
2. decreased flow during years of water diversion, allowing vegetation to encroach into channel bed downstream of the dam, and loss of power to convey inputs of sediment from downstream sources;
3. increased incision below dams during large floods, if flood flows are not reduced by diversions;
4. substantially increased incision and entrenchment below dams without diversions;
5. increased erosiveness of entrenched flows below dams that causes more bed incision and bank erosion that additionally increases sediment supply; and
6. increased aggradation in reservoirs resulting in loss of capacity and dredging.

Bridges and culverts mark intersections between the flow of people and the flow of water. They can have the following geomorphic consequences:

1. increased upstream flooding and bank erosion due to backwaters caused by woody debris jams in or under the crossing structure and/or by loss of its capacity due to aggradation;
2. increased deposition of sediments upstream due to backwater;
3. increased upstream bank erosion and property damages due to backwater:
4. increased downstream bed incision and bank erosion that contributes to loss of riparian vegetation due to acceleration of flow through smooth-walled structures;
5. increased bank erosion from eddies upstream and downstream of abutments;
6. in the case of culverts along dirt roads and trails, frequent clogging of the structures resulting in failure of road fills, and increased sediment supply; and
7. in the case of urban culverts, occasional failure of road fills due to structural deterioration of culvert, resulting in increased sediment supply and potential property loss.

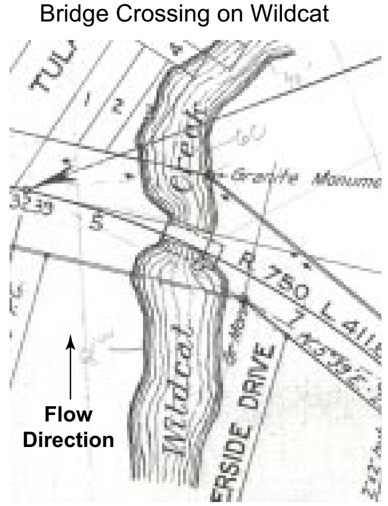
Urbanization

(Photo 63) 1947 Wildcat Creek and Upper Alluvial Plain. Source: Pacific Aerial Survey

Urbanization involves hardened horizontal surfaces that prevent infiltration; hardened banks and artificial channels that inhibit riparian plant growth; and roof drains, gutters, and storm drain systems that increase drainage density. In the early days of Richmond, urbanization included extensive ground water pumping, the impacts of which may have mostly passed. The effects of urbanization in Wildcat Watershed include:

1. increased urban runoff leading to increased rates of both channel incision and bank erosion from the first-order channels on the Canyon slopes, and to the mainstem channel on the Alluvial Plain; and increased sediment production due to bed and bank erosion;
2. increased runoff into landslide deposits and accelerated earthflow activity and their associated sediment production;
3. bed incision of steep tributary channels with increased inner gorge landslides along channels and gully walls;
4. increased drainage density due to storm drains and headward extension and gully formation at culvert outlets;
5. increased magnitude and frequency of flooding especially in reaches that are aggrading from the impacts of bridges and culverts.

Figure 103
Bridge Crossing on Wildcat



1927 early bridge across Wildcat Creek at San Pablo Road. Note the narrower width at bridge crossing. Source: City of San Pablo.

The following impacts are associated with channel banks that are hardened by revetments:

1. reduced lateral migration at the site of the revetment transfers erosion to opposite bank;
2. if revetments impinge on flow, erosion may be transferred to the opposite bank, and result in increased revetment on the opposite bank if erosion is initiated;
3. increased revetment upstream and downstream when erosion from erosive eddies occurs at the end points of the revetments;
4. increased flow velocities when bank roughness is decreased by smooth artificial structures;
5. increased bed incision from increased velocity; and
6. frequent undermining and failure of revetments due to bed incision.

(Photo 64) October 1991, fire in the Oakland Hills.

Fire

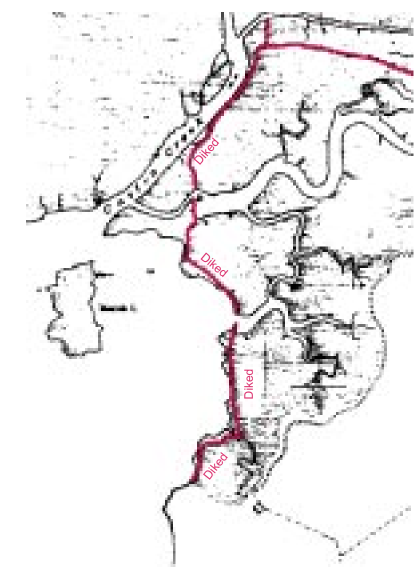
Intentional fires historically maintained vigorous grasslands and inhibited brush invasion. Even without fire, it may have been difficult for brush to successfully invade the deep-rooted perennial tussocks. In the woodlands, fires controlled the understory and maintained relatively little fuel.

Fires were not intense. Little soil erosion was associated with these cool fires. There is no evidence of ash deposits in the stratigraphy of streamside banks. Fire scars on trees are very rare. Recent monitoring of fire effects of the 1991 Tunnel Fire in the Berkeley and Oakland Hills showed that soils in this region do not develop strong water repellency or rill networks following fire, especially clay-rich soils that develop on the Orinda Formation (Collins and Johnston, 1995).

Controls on fire and fuels shifted from native fire management to cattle and fire suppression. As the population of Europeans increased, so did incidence of arson and accidental fire. With the advent of fire suppression in the 1900s and the reduction in grazing, the rate of brush invasion into the grasslands has increased. Wildfire now burns larger and hotter.

Bulldozer trails used as fire breaks mechanically disturb the soil and occasionally require culverts. Short-term pulses of sediment are associated with road construction and culvert placement. Vegetation management activities that disturb the soils also increase sediment production.

Figure 104
Detail of Wildcat Marsh



Dikes in southern Wildcat Marsh circa 1860. Source: US Coast Survey T2445 1898.

Channelization and Reclamation

Tidal marsh reclamation and channelization greatly influence the way sediment and water are conveyed through the lowermost reaches of Wildcat Creek. The impacts of diking and reclamation include:

1. reduced tidal prism causes tidal sloughs to narrow and shallow;
2. reduced cross-sectional area of the tidal sloughs causes increased flooding during terrestrial floods and reduced capacity to transport sediment;
3. increased containment of terrestrial floods between unnatural levees elevates flood waters and increases shear stress on the banks and levees and increases the potential for bank erosion and levee failure; and
4. increased flooding beyond the extent of tidal flow occurs when terrestrial flood flows, coinciding with high tides, cannot spread out over the tidal marsh.

The channelization of Wildcat Creek through a portion of the marsh and the toe of the alluvial fan was designed to reduce localized flooding. The following impacts are associated with the channelization:

1. increased water velocities convey the flood faster and increase the peak height of the flood flow to downstream points;
2. increased deposition of sediment through deepened and widened reaches due to lessened channel gradient requires dredging of sediment basin;
3. increased need to dredge beyond the boundaries of sediment control basin;
4. reduced deposition of sands on the remaining tidal marsh surface which slows the rate of marsh accretion and reduces diversity of the backshore; and
5. reduced rate of formation of new tidal mudflats and backshore pannes, and possible erosion of the foreshore of the tidal marsh.

Expected Trends

The Contra Costa County Clean Water Program has asked for a description of expected future trends in watershed conditions, assuming that there are no changes in watershed management. It must also be assumed, however, that average trends will be punctuated by extreme events, such as major landslides, large storm events, and fire, that cannot be predicted. Shifts in climate over decades or centuries will also affect the average trends. Within this framework of assumption and uncertainty, some simple pictures of future trends in hillslope and channel conditions have been developed for each of the major subregions of the watershed. These hypothesized forecasts could be tested with a program of channel and hillslope monitoring. The results of this study provide a baseline for testing these hypotheses.

Volcanic terrain above Lake Anza & Jewel Lake

The hillslopes of volcanic geology are not prone to landslides. Assuming that grazing is not reintroduced, that the extent or type of vegetation management for fuel break construction does not increase, and that there are no major increases in the amounts of trails, roads, or urban structures, then the average sediment yield from these slopes should eventually decrease as vegetation recovers from the intensive grazing of the past. Channel adjustment to the increased urban runoff should eventually diminish but the time frame is unknown. Brush may continue to encroach into annual grasslands, but the remaining grasslands may increase in relative percentage of perennial species. These ecological aspects are beyond the scope of this study, yet the ramifications of these changes on biological diversity may be important to consider. As brush increases and fire suppression practices continue, the potential for wildfire that will burn hotter will increase. Subsequently, containment may be more difficult and large fires have greater potential to generate sediment than small ones. Extreme sediment supply from water repellent soil conditions would not necessarily be expected, unless there was extensive soil disturbance by construction activities. The sediment yield to the channels from the hillsides should not increase, but the manicured turf in the golf course will maintain high rates of runoff.

Channel upstream of Lake Anza

As channels recover from past land use activities and adjust to present practices, the amount of net sediment storage in the channels may increase. Small headward channels not influenced by culverts or urban runoff should retain more sediment behind woody debris that will be provided by the recovery of riparian vegetation. The mainstem channel in its steeper reaches may continue to be armored by coarse bedload deposits from debris flows. The channel banks along the golf course that lack riparian vegetation, if they continue to be maintained in such condition, will continue to supply sediment from bank instability. Lack of riparian shade will continue to elevate water temperature. Old bridge crossings upstream of the Tilden Golf Course and culverts beneath road crossings will continue to trap debris and sediment, and this will continue to cause maintenance problems and unnaturally high rates of sediment supply.

Lake Anza

The overall rate of infilling should decline as the upper watershed recovers and as the depositional fan traps more sediment. Barring any major landslide on the lakeshore, the filling will continue to build the delta at the head of the lake, and will secondarily fill the deep areas north of the lake center. Drought and deluge will punctuate sediment supply rates. The Delta will grow above the elevation of the spillway. Fish habitat in the upstream perennial section of Wildcat Creek could improve.

Orinda hillslopes between Lake Anza & Jewel Lake

If grazing activities continue to be suppressed, runoff rates from the open grasslands should not increase above existing levels associated with the mixed native and non-native species. Runoff from road and trails will continue to maintain high drainage density and high runoff rates. Landslide activity on the eastern grasslands should not accelerate if stream incision rates are diminishing. On the western urbanized side, earthflow activity will continue to be exacerbated by urban runoff that discharges onto active and inactive slides along the ridgelands. If runoff infiltrates into the landslide deposits, it increases the potential for renewed instability. If it flows into channels that are on or along earthflows, it will continue to supply sediment from incision and potentially initiate landsliding by the removal of lateral support. Along Wildcat Canyon Drive, where vegetation management activities are expected to continue for fuel break maintenance, soil disturbance by goats, people, and equipment will continue to supply more sediment from surficial erosion processes than natural background rates. Most of the abandoned roads appear to be recovering, but yearly grading of roads used for fire fighting and maintenance purposes will continue to provide unnaturally higher rates of fine sediment supply.

Channels between Lake Anza & Jewel Lake

Small tributary channels may continue to recover from impacts associated with accelerated rates of runoff from the grazing period. They may continue to trap sediment as small woody debris accumulates and raw banks continue to stabilize from vegetation, yet natural instability within the Orinda bedrock will always persist. The mainstem channel downstream of Lake Anza flows through volcanic and then Orinda bedrock. Through the volcanic sections, there is evidence of incision associated with the capture of bedload in Lake Anza. However, the degree of incision and sediment production is not as great as the mainstem channel that flows through the Orinda Formation. Higher than natural rates of sediment supply form the hillsides will continue to be transported through most of the mainstem channel until it reaches the low gradient section that is influenced by backwater flooding from Jewel Lake (near the Tilden Educational Center parking lot). Within this low gradient and backwater zone, Laurel Creek (large eastern tributary just south of Jewel Lake) and the mainstem channel will continue to aggrade their beds during large floods and exacerbate the backwater flooding that occurs in this area. Bridge and culvert structures (at the end of the paved parking lot) contribute to the flooding.

Jewel Lake

If Jewel Lake continues as an educational resource for the EBRPD, it will require frequent dredging to offset sediment inputs from neighboring slides, road runoff, and fluvial processes. The channel will continue to aggrade around the boardwalk upstream of the open-water lake. The Dam and lake will continue to trap bedload and starve the channel downstream, at least as far as Havey Creek.

Hillslopes of the Lower Canyon

In the eastern grassland sections that continue to be grazed, landslides will continue to be exacerbated by channel incision that removes lateral support. The incision will be maintained by channels that are still adjusting to increased runoff from the grasslands. Runoff will remain higher than background rates because vegetation will remain sparse in some areas. Surface erosion of bare inner gorge banks and grasslands areas that have sparse thatch or vegetative cover will continue to supply large amounts of fine sediment from surficial erosion processes. Fire trails will continue to supply higher than background rates of runoff and sediment. Wildcat Trail will continue to have maintenance problems where it intersects active landslides. Along the western ridge, paved roads and urban structures will continue to increase runoff to channels and landslides, maintaining their instability. Structures along the western ridge will continue to be threatened by natural seismic, landslide, and fire hazards. The risk of landslides and fire will be exacerbated by the activities of people. Brush encroachment of the grasslands will be slower than in the ungrazed lands upstream of Jewel Lake.

Channel of the Lower Canyon

Incision downstream of the Jewel Lake spillway does not appear to be slowing during the last decade. The concrete structure at the end of the spillway is severely undermined. Its eventual failure will exacerbate downstream erosion and potentially initiate erosion at the foot of the dam. In tens of years from now, if this erosion proceeds unchecked, the results could be extremely damaging to downstream resources.

The mainstem channel is expected to continue its long-term down-cutting of unnatural rates. It will continue to have localized areas of temporary deposition and incision associated with debris jams and toes of landslides that impede flow. Sediment supply from bank erosion and loss of mature riparian forest will continue. Structures such as the Rifle Range Bridge and the two 6-ft diameter culverts at Alvarado Park will continue to require maintenance after floods deposit LWD at their inlets. Subsequently, backwater floods will create erosion and maintenance problems. Culvert structures beneath Wildcat Trail will continue to cause maintenance problems of road fills when the culverts become clogged by sediment and/or debris during storm events. Culverts will eventually require replacement as they corrode which means their condition, if left unchecked, could in tens of years lead to their complete failure. If this occurs at the eastern tributary that flows to the mainstem beneath an 80–ft high fill of Wildcat Trail (about 1 mi downstream of Havey confluence), the results could be very damaging to upstream resources. For places such as the two-6 ft culverts near Alvarado Park, damages would occur both upstream and downstream. The various revetment structures that have been placed along portions of the banks will continue to lose their functionality as they deteriorate and as the channel continues to adjust its geometry. Fish habitat is not expected to improve.

The extent of perennial flow will remain limited for two main reasons. First, land use impacts have caused the watershed to become dominated by overland flow processes because of the intersection of the water table by incised streams, reduced interception, increased drainage density, and increased impervious surfaces. Thus, base flow is limited during summer drought. Secondly, much of the natural spring flow that helped maintain perennial flow in the mainstem is now captured at Anza and Jewel Lakes. Some of this water is also lost by surface evaporation. The upstream extent of perennial flow in the Lower Canyon during summer drought will continue to depend upon flows from Havey Creek and a small western tributary north of Rifle Range Road, rather than upstream sources.

Channel of Upper Alluvial Fan

Our stream bank data indicate that the channel may be migrating toward the south. If this is true, sediment supplies from the south bank may exceed those from the north bank. Large floods within entrenched channel conditions will continue to decrease channel stability and longevity of riparian vegetation. Structures where significant erosion has already occurred will continue to be at risk. Continued deterioration of existing revetments is expected. Some structures have actually caused accelerated rates of erosion, while others have inhibited it. If artificial revetment of the 32% of eroding banks continues in the future, further loss of stream resources and further increases in velocity are likely. Increased velocity could lead to further need for grade control in the incising sections of the Creek, which depending on type of design, could lead to further loss of stream resources. Subsequent velocity increases could increase downstream flood frequency.

Many of the engineered stream crossings will continue to impede transport of water and sediment during floods. Associated backwater floods will continue to create problems for the people and infrastructure existing along the Creek. The lower reaches of the channel that currently have loss of capacity from deposition of sediments upstream of the railroad trestle will have increased flood frequency.

The fish habitat conditions and presence of perennial flow are not expected to improve along this reach. Fish migration barriers will still exist for various flow conditions in the Davis Park and San Pablo Avenue box culverts.

Flood Control Channel

Aggradation will continue, therefore maintenance dredging will always be required if the capacity of the flood control channel is to be maintained. If climatic conditions of the last ten years were to occur again, we would not expect to see a decrease in sediment deposition rates to the Flood Control Project. This is because the watershed recovery occurring upstream of Anza and Jewel Lakes will not influence deposition rates in the sediment catchment basin, because the suspended load over these dams, even if it decreases, will not settle in the sediment basin.

Tidal Reach

The tidal marsh will continue to receive sediments from the Estuary but its upland supply of fine gravels and sand will continue to be less than natural. Higher than natural loads of suspended sediments will continue to be transported through this system during winter flows. The tidal slough may continue to narrow as it adjusts to the reduced tidal prism from former diking of the marsh. Delta building on levee shoulders during extreme floods will occur at elevations above the average tides. Gradual tidal excursion into Wildcat Creek from sea level rise is anticipated. This will result in upward migration of the null zone and sediment entrapment zone, which will increase the tendency of the Tidal Reach of the Creek to aggrade, which will, in turn, increase the risk of local flooding and increase the need for maintenance dredging.

The Estuary

The downstream extent of the Tidal Reach of the Creek is strongly influenced by estuarine processes. It is difficult to project the effects of local watershed processes into the estuary. However, it can be expected that the load of fine sediments from the watershed into the Estuary will continue to be greater than natural rates. Some of these sediments will be deposited on the floor of the Estuary as a submerged delta near the mouth of the Creek. Additional development of mudflats can also be expected, mostly on the "up-estuary" side of the Creek mouth, where fine sediments from the Creek can be deposited by flood tides. Reworking of these sediments by wave action will re-distribute some of the sediments onto the nearby tidal marshes and into the tidal sloughs, including the Tidal Reach of Wildcat Creek.

Final Note

Successful watershed management requires knowing how watersheds respond to land use. The basic responses are geomorphic – changes in land use cause changes in water supply and sediment supply that in turn affect changes in stream channels. The science of geomorphology provides the tools to describe the relationships between land use and landscape.

This study of Wildcat Watershed shows that sediment sources, water sources, woody debris, and many other parameters of watershed condition can be quantified by process and causation. This quantitative analysis reveals the relative effects of natural processes and land use on landscape form and function. It therefore provides a scientific basis for restoration and/or management strategies.

Some details of the study approach are especially noteworthy.

The comparison of sediment supply estimates, based on void measurements with deposition in reservoirs, is a useful method to check the void estimates, but it requires information about suspended sediment loads that cannot be easily measured. Similarly, empirical evidence of background or natural erosion rates is seldom complete. The estimates of sediment supply are very sensitive to the assumptions required to fill these data gaps.

We have shown large differences between short-term estimates of sediment supply based on transport models or studies (i.e., the USACE study for the flood control channel) and long-term estimates based upon geomorphic analyses. Watershed managers should consider that average rates of sediment and water supply are punctuated by extreme episodes. The degree to which short-term data sets represent long-term trends should be considered when the data sets are used in engineering designs and management decisions. However, a relatively short study of the history of change in major sediment sources in the context of land use can provide estimates of long-term trends and serve to forecast future conditions. The magnitude of change can be put into context by comparing long-term supply rates other watersheds.

Bed incision is an important cause of large sediment supplies in Wildcat Watershed and probably in many other Bay Area watersheds, but most watershed studies have ignored this important parameter.

Some watershed problems can be solved on-site, and for others, the solutions are off-site. For example, if a culvert is preventing fish passage, then the onsite solution is removal or modification of the culvert. But if the culvert is failing due to chronic incision, then the solution could be modification of land use practices far upstream. Managers could benefit by maps of problems, and their on-site or off-site solutions. Managers are asking for a set of diagnostics that can be used to assess watershed conditions.

This study indicates that baseline watershed assessments might focus on parameters that inlcude: 1) drainage system extension; 2) landsliding as influenced by geology; 3) bank/terrace erosion and changes in bed elevation at the heads of alluvial fans and at engineered stream crossings (including dams); and 4) hydraulic geometry and bedload particle size distribution at references reaches of the mainstem channel. All of these diagnostics are greatly enhanced by an understanding of major historical trends in land use and landscape change. In all cases, sound study designs and the interpretation of the data require special training and much experience.

Our ability to diagnose watershed problems and recommend remedies could be greatly improved through a program of coordinated research. Much could be accomplished by conducting this kind of baseline study in other watersheds, followed by monitoring of key processes and research to fill data gaps. Some of the questions that need to be answered to improve watershed diagnostics are listed below.

How much sediment is supplied from the hillsides into the heads of first-order channels? This could be answered by developing a field sampling program in different geologic terrains with different intensities of land use.

How much do changes in drainage density from the headward extension of first-order channels and the addition of storm drains change the downstream flood frequency? This could be answered by modeling a watershed that has intensive field measurements of flood frequency, storm drain size and distribution, headward channel extension, and impervious surfaces.

What are the realistic rates of sediment supply from landslides caused by creep, and how does this vary with landslide type and position in the watershed? This could be answered by long-term monitoring of landslide-dominated hillsides.

What are the practical restoration strategies for reducing runoff into first-order channels in grazed grasslands where sediment supply from channel incision and its cumulative effects dominate the landscape? This would require field experiments and monitoring of grazed and ungrazed watersheds.

These kinds of questions point to the need for a regional watershed monitoring and research program. A regional network of watersheds like Wildcat that are used as monitoring stations and study sites could be very beneficial for developing diagnostic tools, training personnel, calibrating models, and developing best management practices. A program of watershed science is needed to meet the managers' requirements for basic information about watershed responses to management actions.

Glossary

A

Aggradation
The long-term process of building up a surface by deposition of sediment.

Alluvial fan
An outspread cone-shaped, gently sloping mass of alluvium deposited by a stream due to a rapid change in slope or valley width.

Alluvium
Stream deposits made by streams on riverbeds, flood plains, or fans that may include boulders, gravels, sands, silts, and clays.

B

Bankfull
The incipient elevation of the water surface of a stream as it begins to flow onto its floodplain. The flow may have a recurrence interval of about 1.3 to 1.7 years.

Bathymetry
The depth of water body relative to the elevation of the water surface.

C

Colluvial hollow
A bedrock depression, typically at the headward end of first-order channels that is filled with colluvium. These are commonly the source areas for debris-type slides. Sometimes referred to as a zero-order basin.

Colluvium
Deposits of soil or rock that have been transported by gravitational processes at the foot of a slope or into a bedrock hollow.

Confinement
The relationship between valley width and bankfull width.

Cross-section
The geometry of a river channel or other fluvial feature usually measured at right angles to the bankfull flow.

D

D50
Median grain sizes of sediment that can be measured by pebble count methods, sieving, or visual estimation. The particle size is measured along the intermediate axis. 50% of the grains are finer than the reported D50 value.

Debris flow
A moving mass of rock fragments, soil or mud, more than half of the particles being greater than sand size. The rate of movement can range from slow 1 ft/yr to fast 100 mi/hr.

Degradation/denudation
The long-term lowering of a surface by erosive processes, especially by flowing water.

Deposition
The short-term laying down of material previously entrained in flowing water because of a decrease in the energy needed for transport.

Dike
A fabricated levee often built along wetlands to eliminate tidal waters.

Drainage density
The ratio of the total length of all streams within a drainage basin to the area of that basin.

E

Earthflow
Downslope sliding of soil and weathered rock of low fluidity over a discrete basal shear surface with well-defined lateral boundaries. Complex earthflows may have multiple failure surfaces that involve both translational and rotational movement.

Effective discharge
The discharge which is responsible for the most sediment transport over the long-term. Effective discharge tends to be greater than bankfull discharge in entrenched channels.

Entrenchment
The down-cutting of a stream into its floodplain that causes its abandonment and results in greater containment of flood waters.

Entrenchment ratio
The floodprone width divided by the bankfull width. Highly entrenched channels have a width/depth ratio > 1.4 while moderately entrenched channels have a ratio between 1.4-2.2.

Equilibrium
A stream channel in a state of balance between erosion and deposition; with relatively stable cross-sectional geometry during a particular climatic regime.

F

Fault
A fracture along the earth's surface where there has been tectonic displacement of one side relative to another either in the vertical, horizontal, or combination of the two directions.

Flood control channel
A constructed channel designed to transmit floodwaters and sediment and reduce the chance of inundation of the floodprone areas. Banks are often trapezoidal or rectangular and may be earthen or concrete.

Flood frequency curve
Graph that describes the recurrence interval of a flooding of a given magnitude, over a period of years.

Floodplain
A flat bench or plain at the edge of the banks that floods an average of every 1.3-1.7 years.

Floodprone area
Description of an area that is likely to be inundated during flood stage above the floodplain.

Floodprone width
Floodprone width is the measured width between the banks at twice the maximum bankfull depth.

G

Grade control
Stabilization of the channel gradient with structures such as check dams or weirs.

H

Headward extension
The lengthening of a channel by erosion of its bed and banks in an upslope direction at the point of inception.

I

Incision
The short-term process of down-cutting which, if occurring at a faster rate than deposition, may eventually lead to permanent degradation of a channel bed.

L

Lateral migration
The action of a stream eroding its banks so that in time, it may move across its valley.

Longitudinal profile
The elevation of the stream bed relative to its distance along its valley.

P

Planform
The outline of a shape viewed from above.

R

Revetment
Any type of retaining structure along a bank that is intended to increase bank stability or protect it from erosion, i.e., riprap, concrete, or wire mesh.

Rosgen Stream Classification
A system of defining streams based upon their morphology.

Rosgen stream class
A system of stream classification that defines streams by their morphology. It requires measurement of width/depth ratio, entrenchment ratios, sinuosity, and stream gradient.

S

Sediment budget
The quantitative description of sources, sinks and riverine transport of sediment. Taking into account the errors associated with the definition and quantification of each of the terms, the sum of all the terms will add to zero. This represents the conservation of mass.

Sediment control basin
A basin constructed to widen and flatten a stream and thus cause the retention of sediments. The basin will usually require maintenance dredging.

Sediment rate
Transport, accumulation, or erosion of a volume or mass of sediment expressed per unit time.

Sediment yield
Transport, accumulation, or erosion of a volume or mass of sediment expressed per unit area.

Strath terrace
Remnant valley floor that has undergone dissection and may have a veneer of alluvial deposits.

Stream order
A system of ordering channels where two channels of the same order converge, they create a channel of the next higher order.

T

Tectonic uplift
The rising of a land surface because of pressure resulting from the movement of the Earth's crustal plates.

Terrace
A relatively level bench or step-like surface that was constructed by a river and represents an abandoned floodplain.

Thalweg
The deepest point of a channel at any given cross-section. A thalweg profile is a survey of the deepest point in the channel bed.

Tidal datum
The average height of a phase of the tide, such as high or low tide, during the 19-yr tidal epoch.

Trap efficiency
The relative ability of a basin or reservoir to retain sediment expressed as a percentage of the input.

W

Watershed
Area defined by a topographic drainage divide within which water from rainfall flows toward a common point.

Width/depth ratio
The relationship between the width of the channel and the depth of the channel at bankfull stage.

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