Figure 40

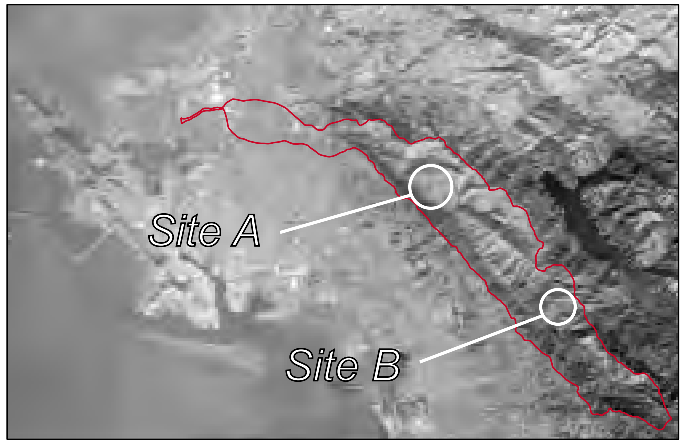


Photo Source:NASA, 1996

cattle grazing (Figure 41, A and B). Each photo pair shows landsliding at two dates, 1939 and 1999. Site A shows areas that have been grazed continuously since about 1817. Site B shows an area that was grazed from 1817 to 1939. We consider the geology of both sites to be Orinda Formation.

In both areas, there was a greater number and extent of active landslides in 1999 than in 1939. This might relate to the generally wetter conditions that have existed in the region since the late 1930s (page 9). However, the increase in landslide activity since 1939 was greater in the area that has been continuously grazed. Field inspections revealed that gullies and natural channels in this area have continued to incise and erode headward, removing the lateral hillslope support. This area also has many more slides that have merged since 1939 to form complex slides.

There has been a large increase in brush in the area of Site B following the removal of cattle. The cessation of grazing and continued fire suppression has allowed the encroachment of brush into the annual grasslands, with a concomitant increase in rainfall interception, rooting depth, root density, and rate of evapotranspiration. In the non-urbanized grass and brushlands, these changes have locally reduced shallow landslide activity and fluvial incision.

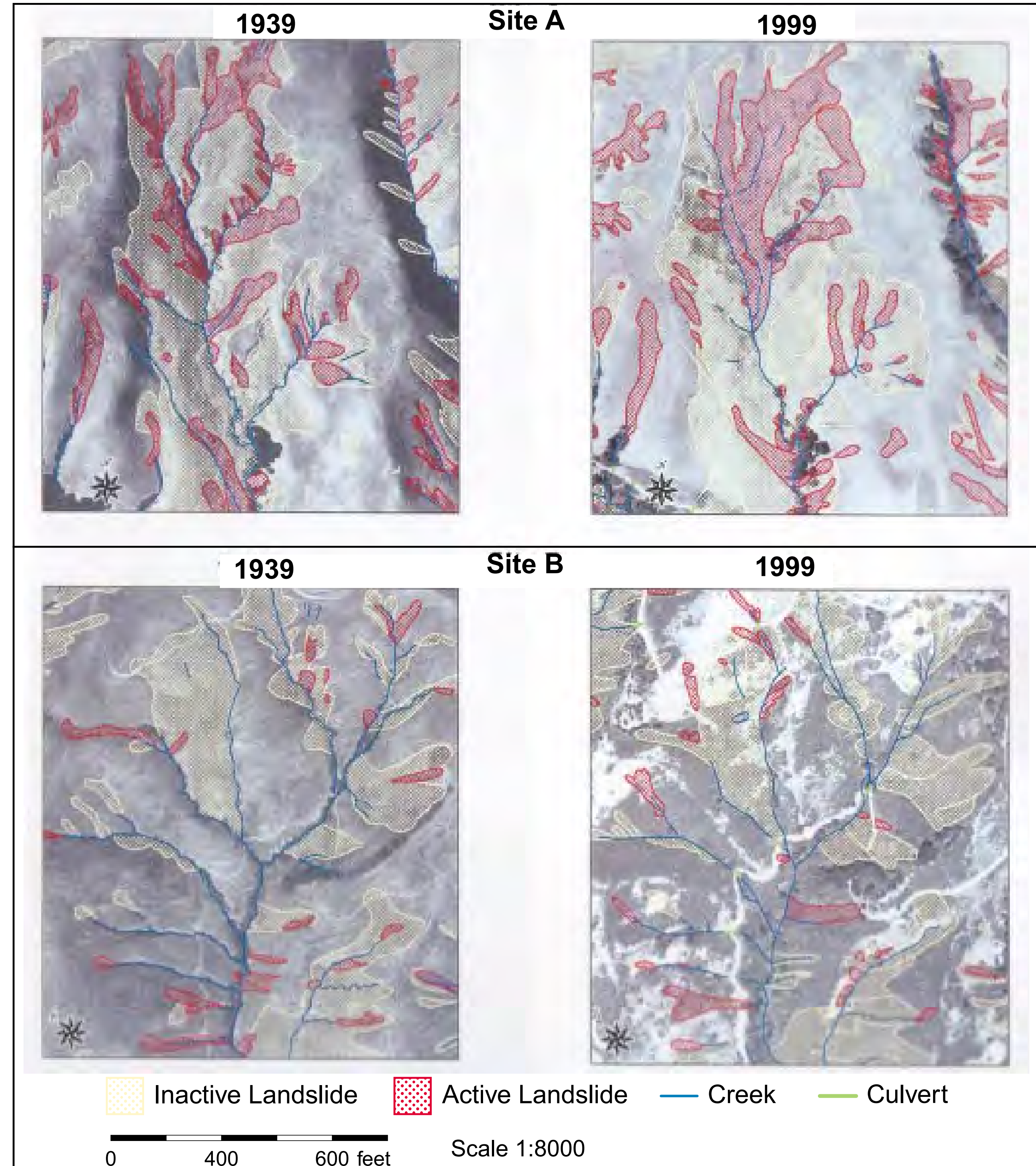
Climatic Effects

Examples of climatic control on earthflow activity are apparent near Point A (Figure 39). The activity of these landslides has been observed in the field by Laurel Collins (SFEI) for the last two decades. Analyses of historical aerial photos confirm the field observations.

Several very large, deep-seated earthflows have substantially increased in activity twice since the early 1980s. These slides have been most active during years of precipitation much greater than normal. Wet years of 1981-82 (150% of normal rainfall) and the 1997-98 ENSO (200% of normal rainfall) events reactivated very large deep-seated earthflows in this area. Some of the slides may not have previously moved for many centuries. One large earthflow severely damaged several homes situated at the ancient crown scarp. More landslide activity was actually associated with the earlier 1982-83 wet season than the later ENSO events of 1983 and 1998 because much of the rainfall occurred during a single storm that was very intense. Many debris slides also occurred at this time.

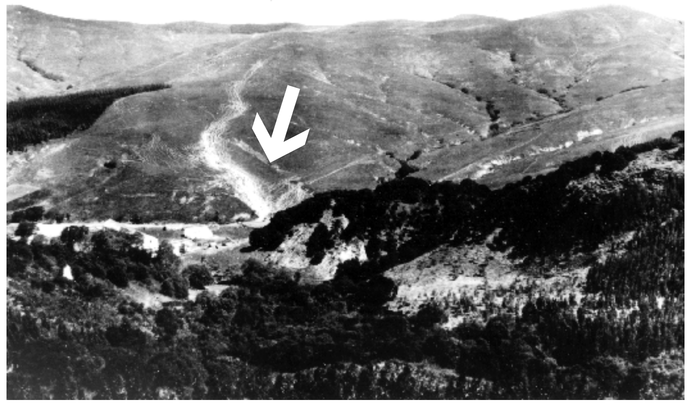
(Photo 17) February 1983, compound landsliding in the same area shown to the right, Site A.

Figure 41. Landslide Comparisons



Erosion That Could Not be Measured

A variety of historical sources of sediment could not be included in our long-term estimates of sediment supply. These are mostly localized sources relating to past land use practices. In most cases, the sources would have resulted in pulses of sediment that affected the short-term supply, more than the long-term average supply. Dairy ranches comprised an important exception becasue they were intensive operations that lasted many decades. Although not pictured, another source of sediment that we could not estimate was simply the amount that is generated by raindrop inpact and overland flow over the bare surfaces of soil with sparse thatch cover. How much sediment is entrained and whether it is delivered to the channel could not be ascertained within the scope of this project.



(Photo 18) Sweet Briar dairy in the Upper Canyon Segment, circa 1900. Consider the amount of sediment production from historic dairy ranches. The arrow indicates the extensive cattle trail network that has been gullied by surface runoff. Also observe the erosion scars occurring along the incising channels. Note the minimal riparian vegetation along the distant drainages. Source: photo from Louis Stein Collection, East Bay Regional Park District.

(Photo 19) Construction underway at Wildcat Reservoir (Jewel Lake) 1919. Consider the amount of sediment production and downstream impacts from these disturbed soils. Channel incision downstream of the dam and subsequent sediment production has been ongoing. Source: East Bay Regional Park District.

(Photo 20) Construction site erosion in disturbed soils. Soils that have been mechanically disturbed are more susceptible to erosion than soils that are bare but still have small rootlets intact. (Booker et al. 1993) Such a situation may occur after burning, grazing or application of herbicides.

(Photo 21) An example of rill erosion in soils prepared for sod in Alvarado Park. Consider the amount of sediment production during preparation of the Tilden golf course during the late 1930s.
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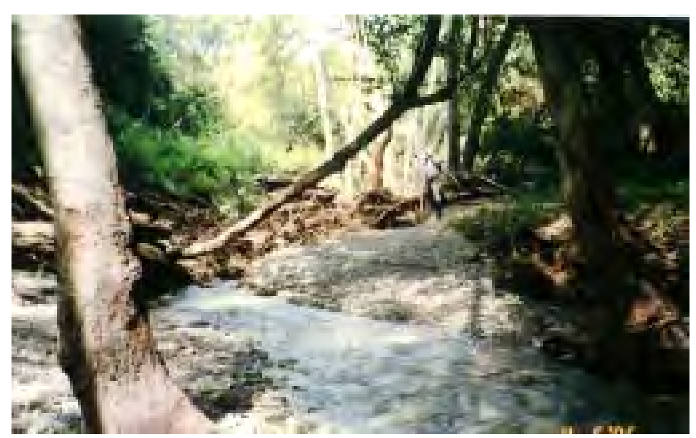
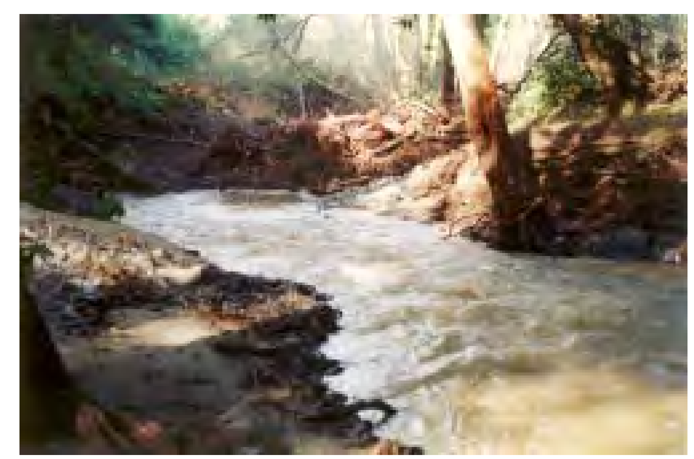
Local Short-Term Channel Changes

The four photos below illustrate typical changes in mainstem channel conditions within the Canyon over a 5 yr period from 1994 through 1999. Each photo is looking downstream from approximately the same left bank position. Peak annual flows had been moderately low for 7 years preceding photo 22 for 1994. Flows greater than 1000 cfs ocurred during 1995, 1996, 1997, and 1998.

(Photo 22) (a) August 1994. A tree has fallen across the channel during the dry season. The bed is mostly coarse cobble due to a reduced supply of fine sediment during the previous 7 yrs. The banks are sharp-edged. The bed has been incising since 1986.(b) April 1995. Two significant flood flows occurred during January and March. The peak flow was the second highest in 33 yrs. Heavy rains activated landslides, providing large woody debris that were mobilized by floods. A debris jam has formed at the fallen tree (see photo a). The dominant bed material changed from cobble to sand. A gravel bar 4 ft high formed behind the jam. The standing alders are freshly scarred from being rammed by floating debris (see trunk left foreground).



(Photo 23) (b) April 1995. Two significant flood flows occurred during January and March. The peak flow was the second highest in 33 yrs. Heavy rains activated landslides, providing large woody debris that was mobilized by floods. A debris jam has formed at the fallen tree (see photo 22). The dominant bed material changed from cobble to sand. A gravel bar 4 ft high formed behind the jam. The standing alders are freshly scarred from being rammed by floating debris (see trunk left foreground).



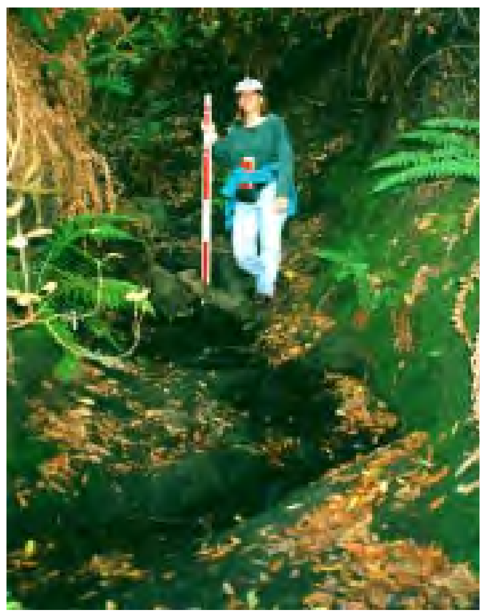
(Photo 24) (c) January 1997. The debris jam has collected more woody debris, but the channel has cut around the jam on the left, releasing the sediment that had deposited behind the jam. Much of the bar has eroded away. Sand from local landslides is beginning to cover remnants of the bar (see bar top left foreground).

(Photo 25) (d) June 1999. The debris jam has almost completely deteriorated. The gravel bar and its sandy cover have mostly washed away. The bed material is generally finer and the bed is higher than in 1994 (see photo 22). The banks are not as steep. The large alder (see left foreground photo 23) has been broken at its trunk and washed downstream.

Tributaries and Hillslopes

We developed a diagnostic tool for identifying and stratifying different sources of sediment and their causes in tributaries and hillslopes. The tool is called the Hillslope and Tributary Decision Tree (Figure 42). It defines sediment by sources and assigns it to natural, land use-related or uncertain categories of cause.

This Decision Tree was used in the hills and tributaries of the Lower Canyon Segment where we performed void measurements. A similar decision tree was used for the mainstem analysis of Wildcat Creek.



(Photo 26) An incised tributary channel in bedrock that drains the east-side grasslands.

We were conservative in attributing local erosion to land use. For example, there were situations where we could certainly relate landslide activity to a road cut or bed incision, but in the latter case we could not be certain that the flow causing the stream incision that initiated the slide was related to land use. In such situations, we did not rate the landslide as land use-related. Good use of this tool requires much discussion in the field among trained personnel.

Not all tributary erosion could be measured in the field (see page 41 and Table 6). Many channels on the western side of Wildcat Creek were covered by impenetrable vegetation. We were able to measure directly the conditions throughout 34% of the total tributary length of the Lower Canyon. For 19% of the field measured channels, we estimated conditions by extrapolating for short distances between points of access. We did not visit 47% of drainage network, so we conservatively estimated the amount of incision by viewing stereo photos and assuming similar conditions to nearby channels. The Middle and Upper Canyon Segments were not measured in this way because we decided to analyze sediment deposition in their reservoirs as an alternative for comparing yield.

The completed Decision Tree shows the long-term sediment supply rates of various sources in the Lower Canyon. The total rate of supply form field and map measurement techniques is 1,143 cu yd/yr. To estimate channel incision rates, we had to identify a time when incision started. Different starting times were used for different causes of incision. For example, incision of the channel downstream of Jewel Lake started after the dam was constructed in 1922. We decided that incision and channel extension caused by cattle began in about 1832, after the local herds were well established and the drought of the early 1800s had passed. We measured landslide activity since 1947 (the date of the earliest photographic record that was of sufficient quality to assess landsliding). This was the only way we could make reasonable estimates of long-term sediment supply rates as influenced by the settlement of non-native peoples.

The total amount of land use-related tributary incision is equal to the sum of the amounts that are directly attributed to various land uses plus the amount that is in excess of natural tectonically driven incision. We estimated the amount of downcutting that could be caused by tectonic uplift on the east side of the Hayward Fault (Figure 36). The expected incision was determined as the product of the bed surface area of the Lower Canyon tributary network and the 0.27 ft depth of incision that would occur over 167 ys assuming an uplift rate of 0.02 in/yr (0.5 mm/yr). We computed a tectonically driven sediment supply rate of about 31 cu yd/yr from tributary incision. The sums of the rates of various types of tributary incision that are not directly related to land uses are 402 cu yd/yr. If we subtract the tectonically driven rate from the total rate of measured incision, we have 372 cu yd/yr more than the natural tectonically driven supply. We suggest that this supply is also generated from land use activities, either indirectly or in a way that can no longer be measured.

Table 7 shows 11 categories of sediment sources based upon field measurements, calculations, and published studies and methods. Rates from just our field measurements are reported in the Hillslope and Tributary Decision Tree (Figure 42). The Decision Tree shows that the bulk of measured sediment comes from landslides (591 cu yd/yr) for which we cannot distinguish natural versus indirect effects of land use as a causative factor.

Table 6

Percent of Total Length of Tributaries Measured in Lower Canyon Segment		
	Lower Canyon Segment	**Eastern Side of Lower Canyon Segment**
Field measured	34%	41%
Field extrapolated	19%	23%
Estimated from aerial photos	47%	36%

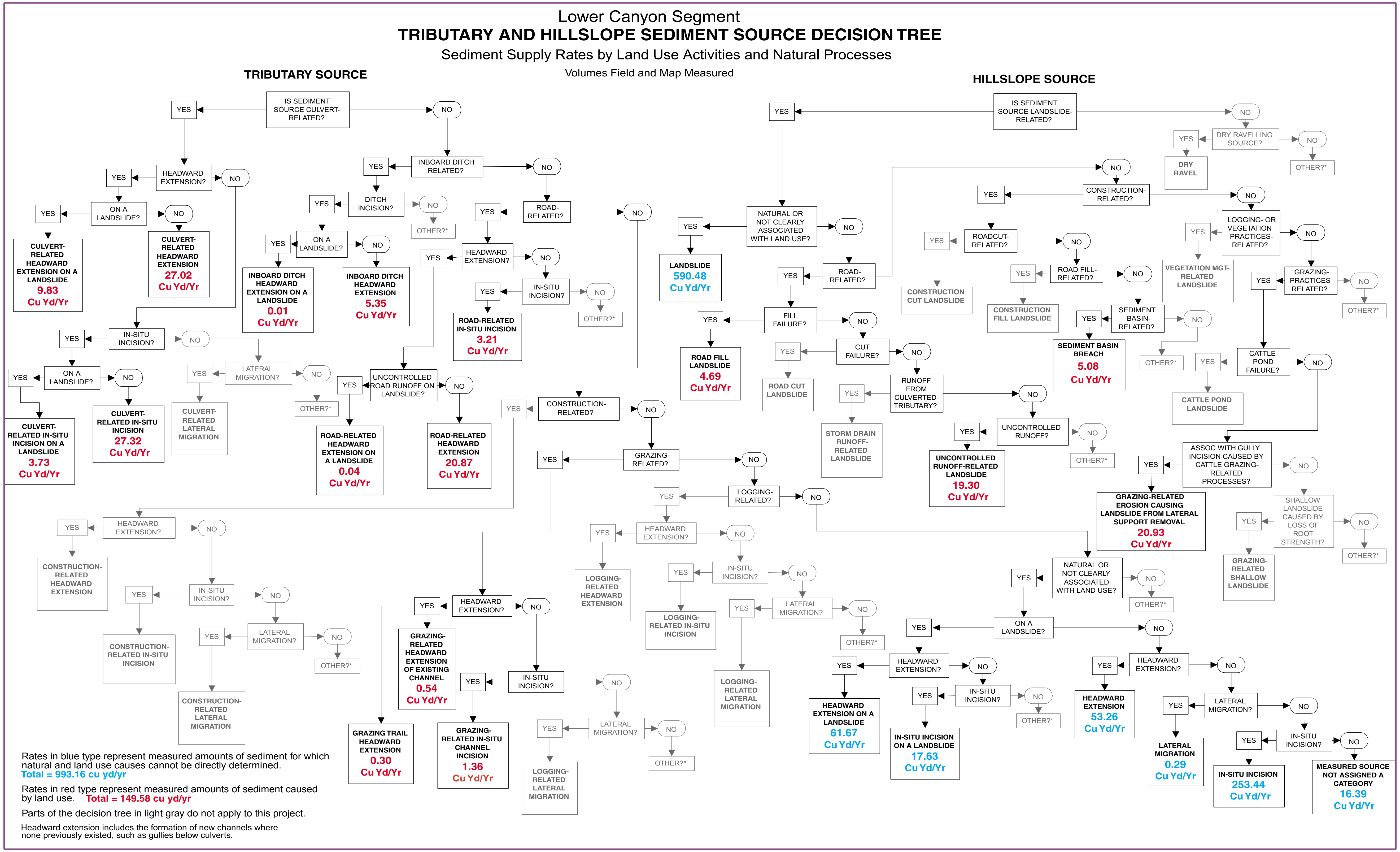
Table 7

Calculated and Measured Rates of Sediment Supply from Wildcat Canyon Hillslope and Tributary Sources, Lower Canyon Segment Applicable to the Last 167 Years		
Sources	**cu yd/yr**	**Percent of Total**
Field and map measured erosion directly related to land use or landslides	**149.6**	**4.1**
Grazing-related inner gorge slides and incision (from Decision Tree)	23.1	0.6
Culvert-related slides and incision (from Decision Tree)	67.9	1.9
Road-related slides and incision (from Decision Tree)	53.5	1.5
Construction-related (from Decision Tree)	5.1	0.1
Field and map measured landsliding natural and/or indirectly related to land use (from Decision Tree)	**590.5**	**16.3**
Field and map measured tributary incision, natural and/or indirectly related to land use (from Decision Tree)	**402.3**	**11.1**
Bed incision driven by tectonics (uplift rate = 0.5 mm/yr) (considered natural)	30.7	0.8
Bed incision in excess of the natural tectonic driven rate (402.3 - 30.7, natural and/or indirectly related to land use of which cattle grazing may account for at least 238.2 cu yd/yr; the remaining 133.4 cu yd/yr is from other combined indirect land use effects)	371.6	10.2
Lateral migration of tributaries (from Decision Tree)	**0.3**	**< 0.1**
Calculated	**2,488.6**	**168.5**
Dirt road tread surface erosion (WA State Forest Practices Method 1994)	187.6	5.2
Soil creep (WA State Forest Practices 1994) (soil creep rate = 5 mm/yr) (mean depth = 3 ft)	545.7	15.0
Landslide creep for active slides bordering channels (landslide creep rate = 30 mm/yr) (assume only 80% are earthflows) (mean depth = 3 ft)	581.3	16.0
Soil lowering (assume all goes to channel as suspended sediment) (0.05 mm/yr)	1,174.0	32.3
Totals	**3,631.3**	**100.0%**

When we incorporate calculations of sediment supply for erosion that we could not directly measure, the supply from landslides that includes slide creep and man-related causes exceeds 1,300 cu yd/yr. This is slightly higher than the calculated 1,174 cu yd/yr general lowering rate of the soil surface by raindrop impact and overland flow on the hillsides. We have used a conservative natural soil lowering rate of 0.05 mm/yr (verbal communication William Dietrich, Department of Geology and Geophysics, UC Berkeley) to try to account for the pervasive supply of sediment that cannot be measured in a short-term study. The proportion that actually is delivered to the channel is unclear, yet our estimate may be conservative if we consider the amount of accelerated supply from all the historical construction activities.

(Photo 27) The head of an extending channel in the east-side grasslands.

Figure 42



Lower Canyon Segment
TRIBUTARY AND HILLSLOPE SEDIMENT SOURCE DECISION TREE
Sediment Supply Rates by Land Use Activities and Natural Processes
Volumes Field and Map Measured
TRIBUTARY SOURCE
HILLSLOPE SOURCE
IS SEDIMENT SOURCE CULVERT-RELATED?
HEADWARD EXTENSION?
ON A LANDSLIDE?
CULVERT-RELATED HEADWARD EXTENSION ON A LANDSLIDE 9.83 Cu Yd/Yr
CULVERT-RELATED HEADWARD EXTENSION 27.02 Cu Yd/Yr
IN-SITU INCISION?
CULVERT-RELATED IN-SITU INCISION ON A LANDSLIDE 3.73 Cu Yd/Yr
CULVERT-RELATED IN-SITU INCISION 27.32 Cu Yd/Yr
LATERAL MIGRATION?
CULVERT-RELATED LATERAL MIGRATION
OTHER?*
INBOARD DITCH RELATED?
DITCH INCISION?
INBOARD DITCH HEADWARD EXTENSION ON A LANDSLIDE 0.01 Cu Yd/Yr
INBOARD DITCH HEADWARD EXTENSION 5.35 Cu Yd/Yr
ROAD-RELATED?
ROAD-RELATED IN-SITU INCISION 3.21 Cu Yd/Yr
UNCONTROLLED ROAD RUNOFF ON LANDSLIDE?
ROAD-RELATED HEADWARD EXTENSION ON A LANDSLIDE 0.04 Cu Yd/Yr
ROAD-RELATED HEADWARD EXTENSION 20.87 Cu Yd/Yr
CONSTRUCTION-RELATED?
CONSTRUCTION-RELATED HEADWARD EXTENSION
CONSTRUCTION-RELATED IN-SITU INCISION
CONSTRUCTION-RELATED LATERAL MIGRATION
GRAZING-RELATED?
GRAZING-RELATED HEADWARD EXTENSION OF EXISTING CHANNEL 0.54 Cu Yd/Yr
GRAZING TRAIL HEADWARD EXTENSION 0.30 Cu Yd/Yr
GRAZING-RELATED IN-SITU CHANNEL INCISION 1.36 Cu Yd/Yr
LOGGING-RELATED?
LOGGING-RELATED HEADWARD EXTENSION
LOGGING-RELATED IN-SITU INCISION
LOGGING-RELATED LATERAL MIGRATION
IS SEDIMENT SOURCE LANDSLIDE-RELATED?
DRY RAVELLING SOURCE?
DRY RAVEL
NATURAL OR NOT CLEARLY ASSOCIATED WITH LAND USE?
LANDSLIDE 590.48 Cu Yd/Yr
ROAD-RELATED?
FILL FAILURE?
ROAD FILL LANDSLIDE 4.69 Cu Yd/Yr
CUT FAILURE?
ROAD CUT LANDSLIDE
RUNOFF FROM CULVERTED TRIBUTARY?
STORM DRAIN RUNOFF-RELATED LANDSLIDE
UNCONTROLLED RUNOFF?
UNCONTROLLED RUNOFF-RELATED LANDSLIDE 19.30 Cu Yd/Yr
CONSTRUCTION-RELATED?
ROADCUT-RELATED?
CONSTRUCTION CUT LANDSLIDE
ROAD FILL-RELATED?
CONSTRUCTION FILL LANDSLIDE
SEDIMENT BASIN-RELATED?
SEDIMENT BASIN BREACH 5.08 Cu Yd/Yr
LOGGING- OR VEGETATION PRACTICES-RELATED?
VEGETATION MGT-RELATED LANDSLIDE
GRAZING-PRACTICES RELATED?
CATTLE POND FAILURE?
CATTLE POND LANDSLIDE
ASSOC WITH GULLY INCISION CAUSED BY CATTLE GRAZING-RELATED PROCESSES?
GRAZING-RELATED EROSION CAUSING LANDSLIDE FROM LATERAL SUPPORT REMOVAL 20.93 Cu Yd/Yr
SHALLOW LANDSLIDE CAUSED BY LOSS OF ROOT STRENGTH?
GRAZING-RELATED SHALLOW LANDSLIDE
NATURAL OR NOT CLEARLY ASSOCIATED WITH LAND USE?
ON A LANDSLIDE?
HEADWARD EXTENSION?
HEADWARD EXTENSION ON A LANDSLIDE 61.67 Cu Yd/Yr
IN-SITU INCISION ON A LANDSLIDE 17.63 Cu Yd/Yr
HEADWARD EXTENSION 53.26 Cu Yd/Yr
LATERAL MIGRATION 0.29 Cu Yd/Yr
IN-SITU INCISION 253.44 Cu Yd/Yr
MEASURED SOURCE NOT ASSIGNED A CATEGORY 16.39 Cu Yd/Yr
YES
NO
Rates in blue type represent measured amounts of sediment for which natural and land use causes cannot be directly determined.
Total = 993.16 cu yd/yr
Rates in red type represent measured amounts of sediment caused by land use. Total = 149.58 cu yd/yr
Parts of the decision tree in light gray do not apply to this project.
Headward extension includes the formation of new channels where none previously existed, such as gullies below culverts.

Example Subwatersheds

We used our intensive surveys of tributaries and hillslopes in the Lower Canyon Segment to examine the possible effects of slope and drainage area on sediment supply. We chose to focus on the subwatersheds of the northeast side of the Lower Canyon because of similar geology, vegetation, and land use history. Cattle grazing has been the predominant land use, although the basins differ in extent of time grazed. Other than some minor ranch roads, few additional impacts were observed. Impervious surfaces did not exist.

Figure 43 shows the boundaries of 24 subwatersheds, labeled A through X. Subwatersheds H through O comprise the Havey Creek tributary. The boundaries for subwatersheds A-G, P-X, and Havey Creek stop just upstream of the culvert inlets that cross under the main dirt road that parallels Wildcat Creek that we refer to as Wildcat Trail. Cattle were introduced into the entire area in1817, but were removed from subwatersheds A, B, and C in 1978, from W and X since 1956, and from a small portion of O and J in the mid-1990s. All other subwatersheds have been grazed continuously at varying intensities At least two dairies were located in the Canyon, one in the Lower Canyon at the base of watershed V in the Subwatershed Map (Figure 43).

Figure 44 shows the distribution of hillsides among slope classes for each of the subwatersheds. Subwatersheds A, M, N, and O are distinguished by having large areas that are not steep. Much of the Havey Creek watershed is less steep than the neighboring subwatersheds.

Figure 44

Subwatershed Slope Classes

Values below watershed names represent the average percent area for the slope classes.

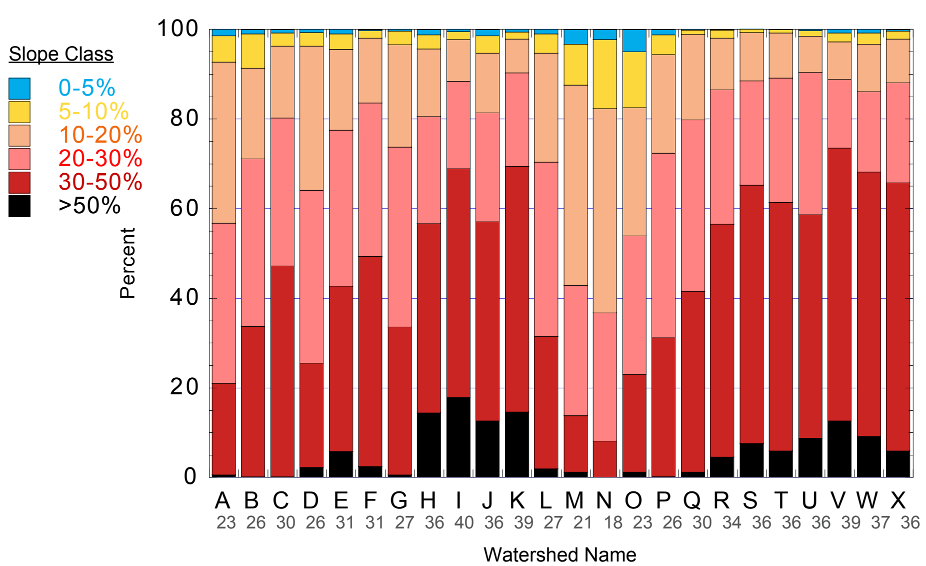


FIGURE 43. WILDCAT SUBWATERSHED MAP

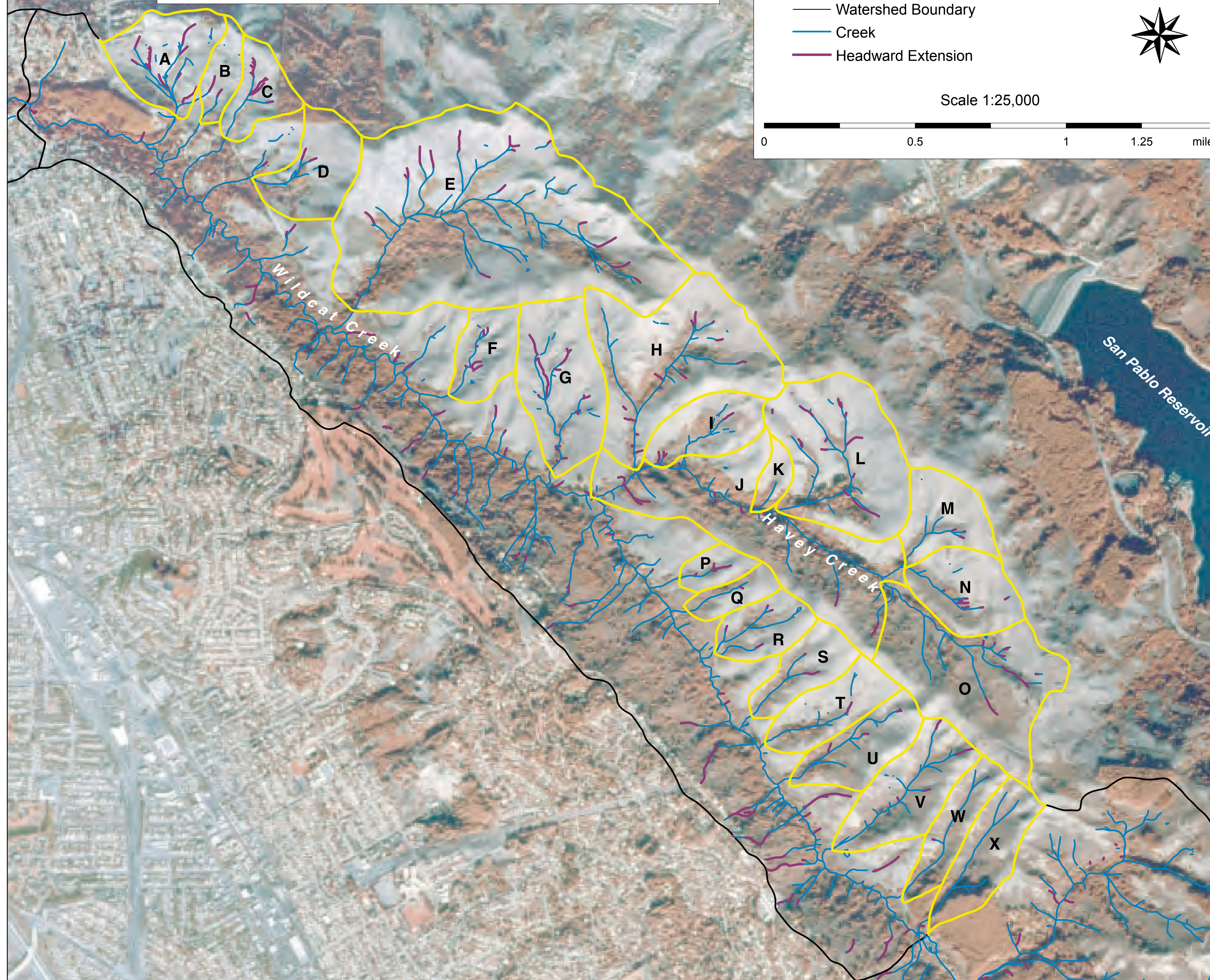


Figure 45

Percent Increase in Subwatershed Drainage Density from ~1830 to 1999

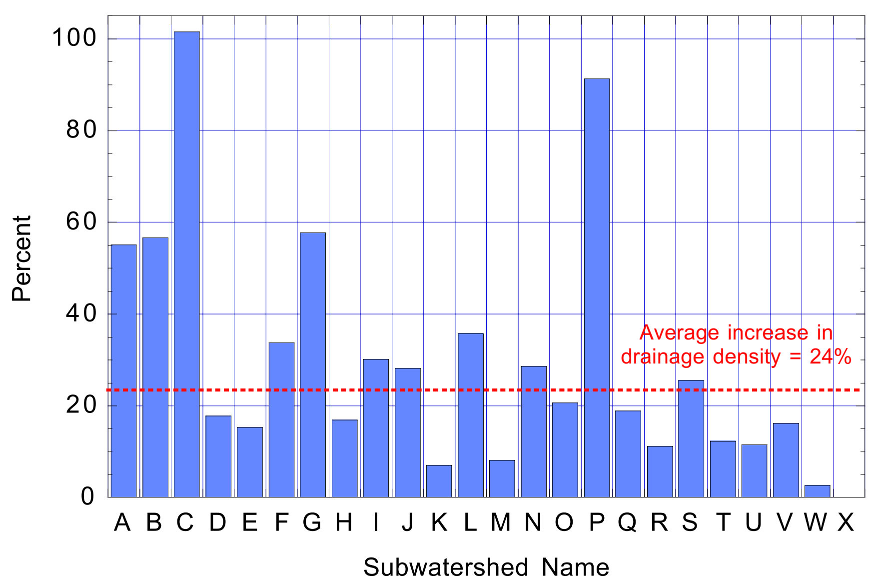


Figure 46

Percent of Field and Map Measured Sediment from Different Sources in Grassland Subwatersheds

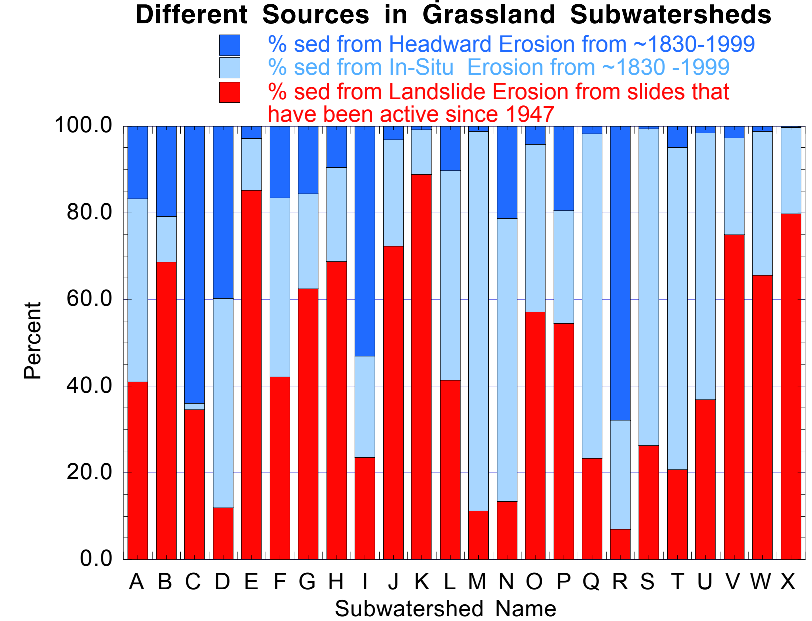
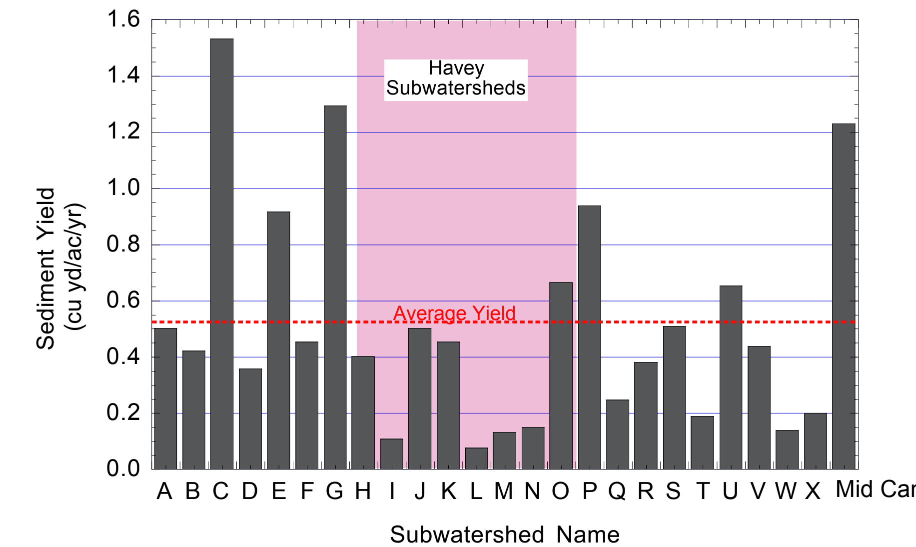


Figure 47

Long-term Sediment Yield from Subwatersheds from ~1830-1999



By comparing slope classes and landslides, we determined that steep slopes do not necessarily correlate with active earthflows. Watershed A, for example, has the third largest area of active landsliding, although it ranks 20th for area having slopes greater than 20%.

Figure 45 shows that since about 1830, average drainage density has increased by 24% within these 24 subwatersheds. Overall drainage density has increased from about 57 ft/acre to 72 ft/acre of watershed. For watersheds A, B, C, G, and P, drainage density has increased by more than 55%. These five subwatersheds are dominated by large, deep-seated complex earthflows that are particularly susceptible to gullying and headward extension from the reduced soil cohesion within the sheared slide deposits. As the landslide masses shift, they divert flow into other unconsolidated portions of the slide material that is also easily eroded. These subwatersheds were excessively grazed until cattle were removed about 21 years ago (verbal communication Neil Havlik, former EBRPD range manager). Watersheds G and P are still grazed and have large deep-seated complex earthflows. Watershed G is pictured as Photo Site A on Figure 41, and as Photo 17 on page 40.

Figure 46 shows the relative sediment contribution from landslides, in-situ channel erosion, and headward extension. Landsliding contributes about 46%, channel in-situ incision contributes 38%, and headward erosion contributes 16% of the total sediment supply from all 24 subwatersheds. For half of them, the main source of sediment is landslide erosion. In subwatersheds C, I, and R, the main source is headward extension of small channels, especially within landslide deposits. Although headward extension is not the dominant sediment source, it is a chronic form of erosion among these and other grazed subwatersheds in the Canyon.

By converting sediment rates to yields, we can compare sediment production among subwatersheds of different size. Figure 47 shows that the subwatersheds of Havey Creek have lower sediment yields than other subwatersheds. This is probably because hillsides are less steep in Havey basin (Figure 43, L-D). These subwatersheds only yield about 0.4 cu yd/ac/yr of sediment. Subwatersheds C and G have the highest yield, about 1.5 cu yd/ac/yr and 1.3 cu yd/ac/yr, respectively.

What is causing all the channels to incise in the open grasslands?

The analysis of sediment supply among the subwatersheds leads us to ask what drives the headward extension and incision in the open grassland channels? Theory and experience would attribute this erosion to significant increases in runoff and reduction of vegetation resistance to surface erosion. Given that rainfall patterns have not changed (page 9), increases in runoff must be due to land use. The headward extension and incision on the southwest side of the Canyon is generated by urban roads, culverts, and impervious development. Since the subwatershed grasslands on the east side of the Canyon do not have these impacts, indirect effects of cattle grazing cause accelerated rates of channel incision.

The grazing has caused runoff to exceed historical amounts that occurred before modern settlement. While urban runoff can be measured as direct effects from ditches and culverts, erosion associated with grazing must be deduced as the indirect effect of diffuse changes in vegetation and soils. By subtracting the estimated rate of tectonically driven incision (11%) for all the subwatershed channels (27.7 cu yd/yr) from their total measured rate (330 cu yd/yr), we calculate that 92% of the sediment supply exceeds that which might be driven by tectonics. If we consider the data from Table 7 where about 64% of the sediment supply is associated with soil and landslide creep, an soil lowering that cannot be separated from natural versus land use-related supply, we can conservatively estimate that 36% (109 cu yd/yr) of the sediment supply from these subwatersheds is indirectly related to grazing.

The Mainstem Channel

Our analysis of sediment sources for the mainstem channel of Wildcat Creek has focused on the reaches of the Upper Alluvial Plain and Lower Canyon Segments. In addition, we have analyzed how the two reservoirs, Lake Anza and Jewel Lake, have responded to fluvial erosion and mass wasting in their catchment basins. To quantify erosion and assess the geomorphic processes that influence the mainstem channel, we applied a more detailed methodology than that which we developed for the tributaries.

(Photo 28) Looking downstream at the tidal reach that has old levees along its banks. This reach is represented in cross section "B" in Figure A (see facing page).

Table 8 lists a sample of cross-sections along the mainstem channel. The sections that are labeled alphabetically are also shown as cross-section sketches in Figure 49. Note that the vertical scale of the diagrams is twice the horizontal scale. The exaggerated vertical scale is needed to show fine relief of the channel banks. Locations of the sketched cross-sections are shown on the Locator Map, Figure 48.

(Photo 29) Looking downstream at Santa Fe Railroad trestle and rip rapped trapezoidal banks of the flood control project, as represented in cross section "F" in Figure A (see facing page). The grouted rip rap bed corresponds to the aggradation shown in Figure 89, page 69.

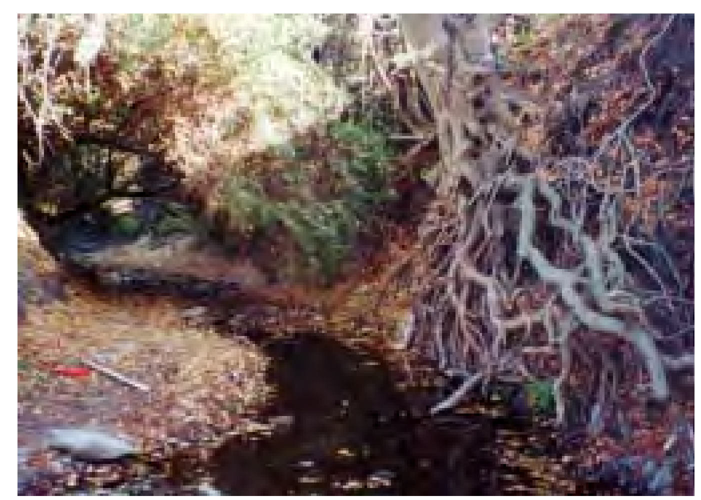
Cross-sections A and B are in the Tidal Segment, C-E are in the Flood Control Segment, F-R are in the Lower Canyon, S-X are in the Middle Canyon, and Y-Z3 are in the Upper Canyon. The cross-sections C-D show the maximum width of the trapezoidal-shaped flood control channel and the constructed berms on the banks. Starting at cross-section G, changes in the natural elevation of the valley flat (developed terrace) relative to the channel bed can be observed. As you travel up the alluvial fan to cross-sections Q and R, terrace bank height increases from 9 ft at section F to 25 ft at section Q.

(Photo 30) Looking upstream from the Rumrill box culvert at the plain bed of the creek that lacks topography. This reach is represented in cross section "I" (which is drawn looking downstream) in Figure 49.

(Photo 31) Looking downstream at revetted channel at Davis Park, which floods with flows that have a recurrence interval of less than 10 yrs. This area is represented by cross section "K" in Figure 49 (see facing page).

A channel that has an entrenchment ratio of less than 1.4 is considered highly entrenched. If the ratio is between 1.4 and 2.2 it is moderately entrenched, and only slightly entrenched if the ratio is greater than 2.2 (Rosgen 1996). By looking at Table 1, we can see that the entrenchment ratio for Wildcat Creek changes downstream through the Upper Alluvial Plain from highly entrenched to slightly entrenched. The significance of entrenchment is discussed on page 31. We note again that entrenchment confines flood flows between terraces so less entrenched reaches downstream on the Alluvial Plain are more likely to flood, especially upstream of poorly designed culverts.

Wildcat Creek tends to decrease in width downstream along the Upper Alluvial Plain Seg-



(Photo 32) Looking upstream at the exposed roots of a buckeye tree that indicates recent bank erosion, as represented by cross section "P" (which is drawn looking downstream) in Figure 49 (see facing page).

Table 8

Wildcat Creek Cross-Sections

Cross-Section Name	Adjusted Station Distance (ft)	Bankfull Width (ft)	Bankfull Depth (ft)	Entrench-ment Ratio	Width/ Depth Ratio	Rosgen Stream Class	Notes
	Tidal Segment						
A	-3836	NA	NA	NA	NA	NA	marsh
B	-3041	NA	NA	NA	NA	NA	marsh
	Flood Control Segment						
C	651	NA	NA	NA	NA	NA	channelized marsh
D	1289	NA	NA	NA	NA	NA	channelized creek
E	4239	NA	NA	NA	NA	NA	channelized creek
	Upper Alluvial Plain Segment						
	6030	28.0	3.5	1.1	8.1	E4	
	6123	31.4	3.5	2.6	9.0	E4	
	6991	24.5	3.5	2.5	7.1	E4	
	7207	29.0	3.2	2.1	9.0	E4	
	7997	24.6	3.7	2.8	6.7	E4-5	
	9037	29.5	3.6	3.3	8.1	E4-5	
F	9675	NA	NA	NA	NA	NA	trapezoidal w/ riprap
G	10026	21.0	2.7	1.3	7.8	G4	
	10103	22.0	4.7	1.4	4.7	G4-5	
H	10320	NA	NA	NA	NA	NA	box culvert
I 10398		21.5		not determined			
	10655	25.2	4.1	1.3	6.2	G4	
J	10910	22.0	2.7	1.5	8.1	G4	
	10977	26.1	3.5	1.2	7.4	G-E4	
K	11162	25.0	2.8	1.3	8.9	G4	
	11386	26.2	3.5	1.5	7.4	G4	
L	11735	19.0	2.7	1.3	7.0	G4	
M	12384	NA	NA	NA	NA	NA	box culvert
	12390	27.4	3.3	1.7	8.3	G-B4-5	
	12682	22.6	4.1	1.6	5.5	G-B4	
N	12847	18.0	2.4	1.4	7.5	G3	
	13354	20.2	4.1	1.6	5.0	B4	
O	13674	24.0	3.5	1.3	6.8	G4	
	14047	28.2	3.3	1.8	8.6	G-B5	
	16292	22.8	3.7	1.6	6.1	G-B4	
	16598	23.3	3.7	1.4	6.3	B-G4	
P	16835	17.8	2.4	1.0	7.4	G4	
	17942	31.0	2.6	2.1	11.1	B4	
	18618	22.4	3.6	1.4	6.2	G4	
Q	18733	15.0	2.7	1.3	5.5	G4	
	18913	39.2	2.1	1.4	18.6	B4	
	21275	28.0	1.8	1.2	16.0	F4	
R	21602	25.3	2.1	1.4	12.1	B4	
	Lower Canyon Segment						
S	22184	22.0	1.8	1.0	12.2	G3	
	22379	26.3	2.3	1.3	11.1	B-G4	
T	22414	27.0	1.2	1.3	22.5	B3	
	24097	26.0	2.3	1.2	11.1	F4	
U	26941	22.5	1.7	1.1	13.2	F3	
V	28854	21.7	2.0	1.2	10.8	B3-5	
	28951	25.0	2.2	1.5	11.3	B-4	
	30413	23.7	2.2	1.6	10.7	B-G3	
W	31686	19.4	1.7	1.2	11.4	B3-5	
X	35774	15.3	1.7	1.3	9.0	B1	
	36103	18.8	2.4	1.4	7.8	B-G4	
2	39291	38.5	2.2	1.4	7.9	B-G	
1	42280	20.3	2.1	1.2	9.6	G4	
	Upper Canyon Segment						
Y		16.0	1.1	1.3	14.5	F3	
Z1		6.3	1.5	1.9	4.2	A3	
Z2		6.0	1.5	1.6	4.0	A4	
Z3		3.8	2.1	4.2	1.8	A3	

*note: combination stream classes are transitional between classes

Figure 48. Cross-Sectional Locator Map

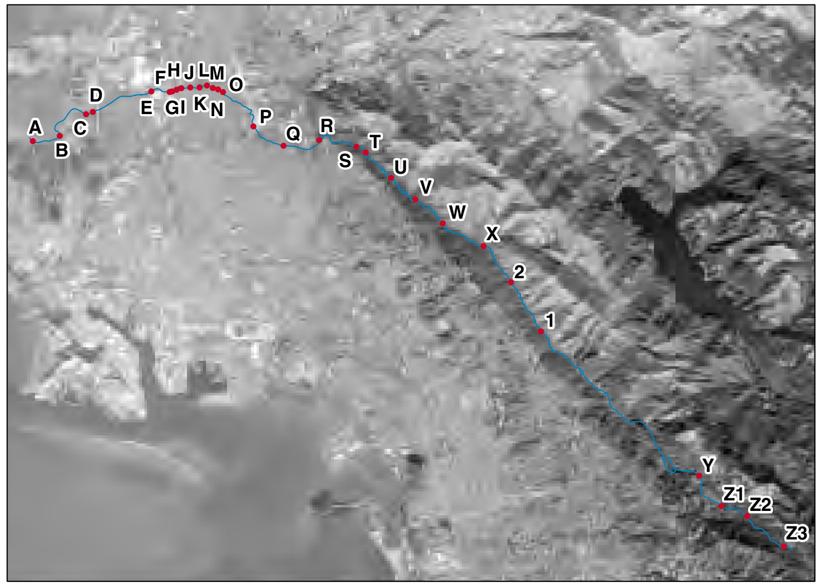
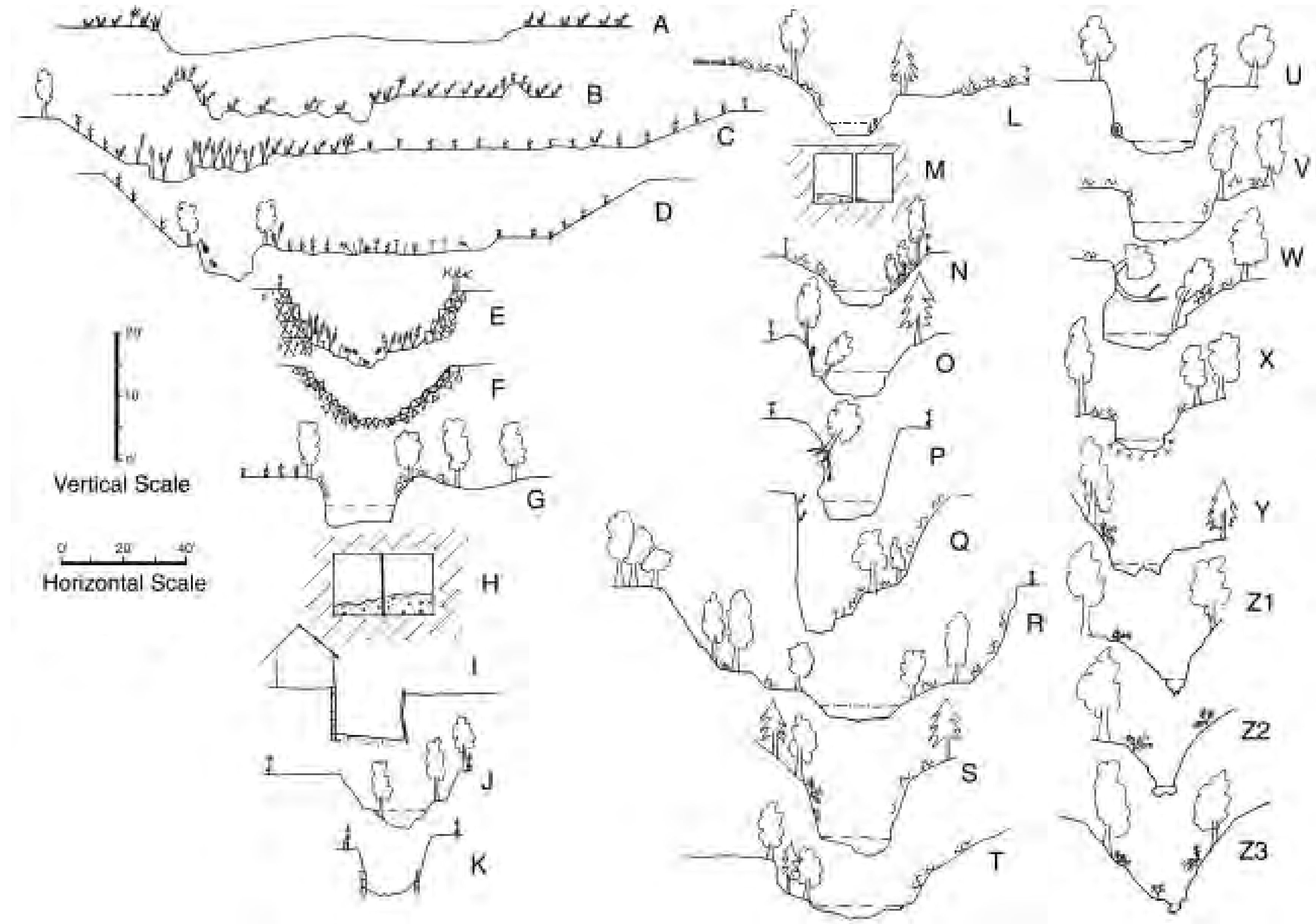


Photo Source: NASA, 1996

Figure 49. Wildcat Cross-Sections



(Photo 33) Looking downstream at mainstem Wildcat Creek between cross sections Z1 and Z2 (Figure 49). The channel is dominated by volcanic cobble from debris flow deposits that armor the bed.

ment. Table 8 shows that the width/depth ratio also decreases in the downstream direction. This differs from the typical expected pattern for most streams, which get wider as they pass through more catchment and receive more runoff. Increased amounts of urban runoff from the developed alluvial fan are added to Wildcat Creek through storm drains. However, the creek does not widen as predicted to accommodate this runoff. Table 8 shows that the mainstem channel is wider in the downstream half of the Lower Canyon Reach than the downstream reaches of the Upper Alluvial Plain. The wider Canyon reaches might be caused by the influence of large woody debris (LWD) and landslides, while the narrower downstream reaches may be associated with the increased bank cohesion from higher clay content. The historical natural channel that existed before urbanization also decreased in width downstream of the Canyon as can be seen on the 1856 Coast Survey maps.

We have used the Rosgen Stream Classification System (Rosgen, 1996) on the Upper Alluvial Plain and Lower Canyon Segments of Wildcat Creek. An example of the system is in the Appendix. We have found that the Rosgen system works better for streams in this region, if we change the threshold for width/depth ratios to 10 ± 3, rather than 12 ± 2. Reaches that could not be easily distinguished as one particular type were labeled as transitional.

Figure 50

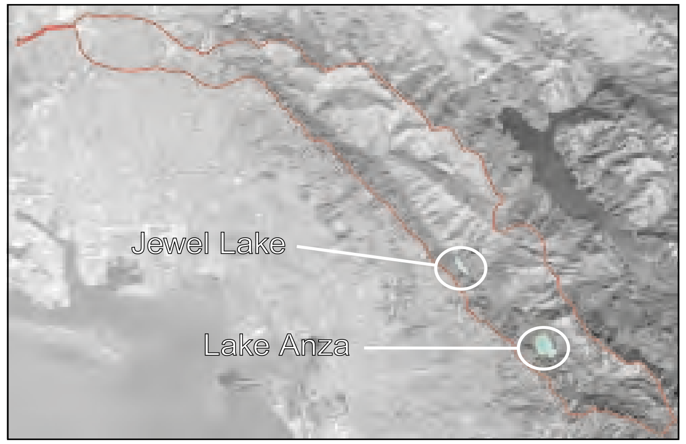


Photo Source: NASA, 1996

Two reservoirs in Wildcat Watershed, Lake Anza and Jewel Lake impound the mainstem channel in Wildcat Canyon. They capture the bed load and most of the sands that comprise the suspended portion of the bedload. They have captured varying proportions of silt and clay that comprise the wash load portion of the total load that flows over the spillways during the wet season. Lake Anza may be large enough to capture some portion of the washload from the Upper Canyon. Sedimentation in the reservoirs is mostly due to bedload input and its suspended fraction.

We have used changes in reservoir capacity, records of dredging and artificial fill to estimate the supply of bed load coming from the Middle and Upper Canyon Segments. For both reservoirs, historical bathymetric maps show filling over time. Jewel Lake has been periodically dredged by the EBRPD. They have kept good records of the amounts removed. To use Jewel Lake as a measure of bedload sediment supply from the Middle Canyon, we had to account for changes in the trap efficiency (Brune 1953) and survey the elevation of the backwater fan at the Lake's upstream end. We plotted the height and width of the fan on the original as-built profile of the Lake to estimate the volume of sediment that has accumulated in the fan since the Lake was constructed. This fan has risen above the original level of the Lake.

During the fall of 1999, we resurveyed the bathymetry of both reservoirs. Frequent soundings were taken with a weighted tape measure along numerous transects located on our photo base map. We tried to match the methods previously used by others for these reservoirs to produce new maps comparable to the older maps. Yet, we were unable to compare our maps to some of the others because shorelines were inaccurately depicted. This reduced the number of time intervals for which filling of the reservoirs could be computed.

(Photo 34) Looking toward the dam at Lake Anza.

Figure 51 shows both reservoirs as they have changed through time. Lake Anza was completed in 1938 for recreational purposes and golf course irrigation. Jewel Lake was completed in 1922. It was used for drinking water supply until 1933. Table 9 shows the major influences of sedimentation in these reservoirs.

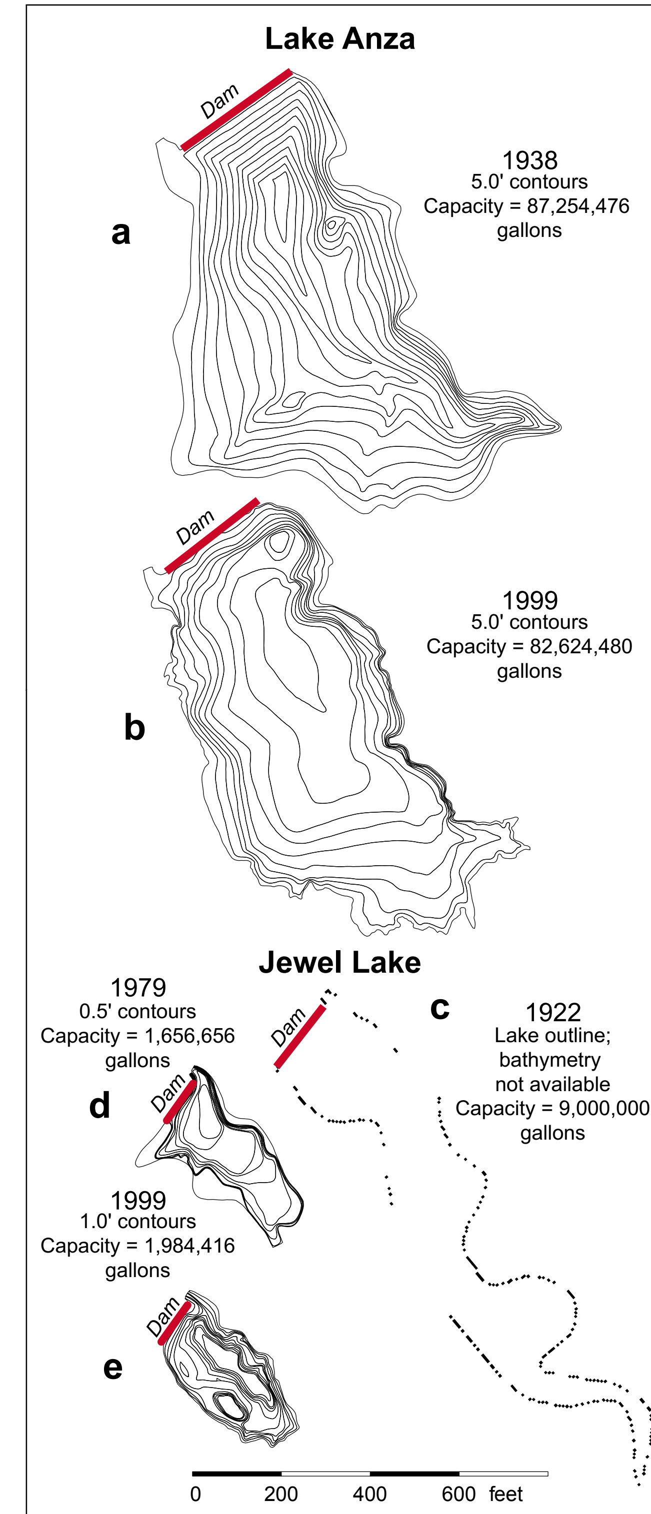
Table 9

LAKE ANZA HISTORY		
Date	**Capacity (gal)**	
1938	87,254,476	Lake Anza completed
1962		landslide deposition, 7,404 cu yd *
1965		imported beach sand, 9,976 cu yd **
1984		golf course sediment basin built ***
1999	82,624,480	bathymetric survey, SFEI

* East Bay Regional Park District
** Buffler *In* : Saffell, A.
*** Superintendent, Tilden Golf Course

The as-built survey for Lake Anza is shown as Figure 51a. This bathymetric map shows the maximum capacity of the reservoir before any filling. By 1999 (Figure 51b), only 5% of the original capacity had been lost by sedimentation. The depositional history of Lake Anza includes beach construction (verbal communication Jerry Kent, EBRPD) that had to be subtracted from the calculation of filling by bed load. The volumes of fans from small tributaries entering the reservoir were included in the calculations as well as landslides (Buffler, 1964 in Saffell, 1980). Zuckswart (1953) reported a filling rate of 13.8 cu yd/yr during the first thirteen years after Lake Anza dam was constructed. This information was combined with the data derived from the apparent changes in bathymetry. In 1984, a small settling basin was constructed upstream of Lake Anza in Tilden Golf Course. According to our interview of the Tilden Golf Course Supervisor, about 2.5 cu yd of sediment accumulate in this basin each year. The basin is occasionally dredged.

Figure 51. Historical and Modern Reservoir Contours



(Photo 35) Dredging Jewel Lake in 1991.

Jewel Lake (Figure 51c) has a more complicated history than Lake Anza (Table 10). We are not certain that all its history has been recorded. Some dewatering or dredging was observed by long-time residents in the early 1950s (verbal communication Dean Bacon). Nevertheless, by comparing Figures 51c and 51d, we can see that the aerial extent of Jewel Lake decreased by about 82% between 1921 and 1979. Dredging of Jewel Lake in 1967 achieved about 37% of its original capacity. There are accurate bathymetric surveys for 1982, 1984, 1991, and 1999 (this study). Figure 51e shows the condition for 1999.

Figure 52 and Table 11 have been prepared to show changes in sedimentation rates and the long-term average rates of sedimentation for the two reservoirs and the small settling basin in the golf course. Lake Anza has a much slower rate of sedimentation than Jewel Lake. The rates for Anza and for Jewel Lake, following the construction of Lake Anza, are 375 cu yd/yr and 1,272 cu yd/yr, respectively. Their representative bedload yields are 257 cu yd/sq mi/yr and 744 cu yd/sq mi/yr. The erosion-resistant volcanic bedrock that has few landslides in the Upper Canyon is responsible for low sedimentation rates in Lake Anza. About 87% of the Upper Canyon is comprised of volcanic rocks. Although the rate of sediment supply to Lake Anza is slow compared to other supply rates in Wildcat Canyon, it was most accelerated during times of road, home, golf course, and reservoir construction. Only about 5% of the surface area of the watershed above Lake Anza is impervious due to roads or other development (Table 17, page 73). There is a high density of dirt roads and trails; however, drainage density has increased by 19% from headward extension of channels, creation of storm drains, and inboard road ditches.

Table 10

JEWEL LAKE HISTORY

Date	Capacity (gal)	
1919		tunnel muck deposited in channel ***
1921	9,000,000	Jewel Lake completed
1933		Jewel Lake diversion discontinued
1938		Lake Anza completed
1967	1,466,329	estimate*
1967		dredging, 9,450 cu yd **
1979	1,656,656	bathymetric survey**
1982	1,109,658	bathymetric survey**
1984	929,075	bathymetric survey**
1991		dredging, 10,404 cu yd **
1991	2,205,669	bathymetric survey**
1999	1,984,816	bathymetric survey, SFEI

* Department of Water Resources, 1977
** East Bay Regional Park District
*** EBMUD map

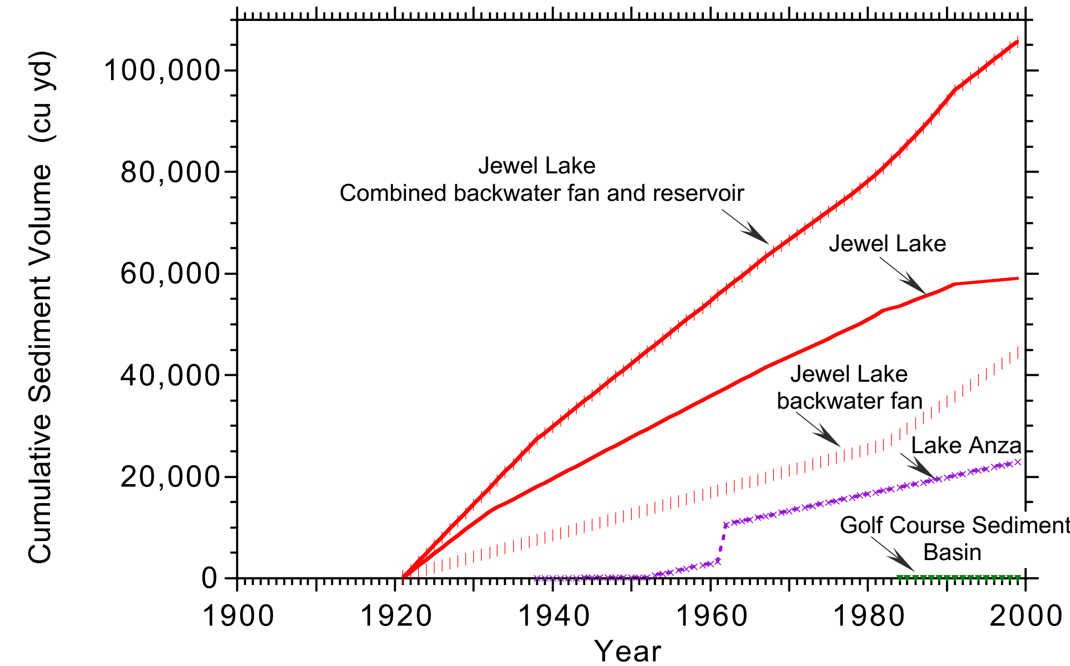
Table 11

Long-Term Average Rates of Sedimentation
(construction dates in parentheses)

	Cu Yd/Yr
Jewel Lake Reservoir (1921)	787
Jewel Lake Backwater Fan	558
Jewel Lake Combined Reservoir and Fan	1345
Jewel Lake Combined Reservoir and Fan*	1272
Anza Reservoir (1938)	375
Golf Course Sediment Basin (1984)	2.5

* Rate of filling following construction of Anza Reservoir

Figure 52
Jewel Lake and Lake Anza Sedimentation
1921-1999



Jewel Lake sediment volumes are based upon reservoir bathymetry, and survey of the backwater fan upstream of the reservoir. Changes in trap efficiency and the effects caused by Lake Anza (1938) are taken into account.

The long-term sedimentation rate for Jewel Lake in the Middle Canyon is high because of there is a greater amount of Orinda Formation (with its associated large number of earthflows) than volcanic bedrock. The Middle Canyon also has a higher percentage of impervious surface area, vegetation maintenance for fuel breaks, and greater drainage density increase (42%) than the Upper Canyon Segment (see Table 17, page 73). Deposition rates in Jewel Lake are slowing down as trapping efficiency on the backwater fan increases, and perhaps, as construction activities have slowed. The backwater fan has developed a stand of willows as it has built upwards. As the willows have aged, they provide woody debris that helps slow water velocity and entrap sediment.

(Photo 36) Some sediment is deposited in the Tilden Golf Course upstream of the mainstem sediment basin.

Lower Canyon and Upper Alluvial Plain Segments and Reaches

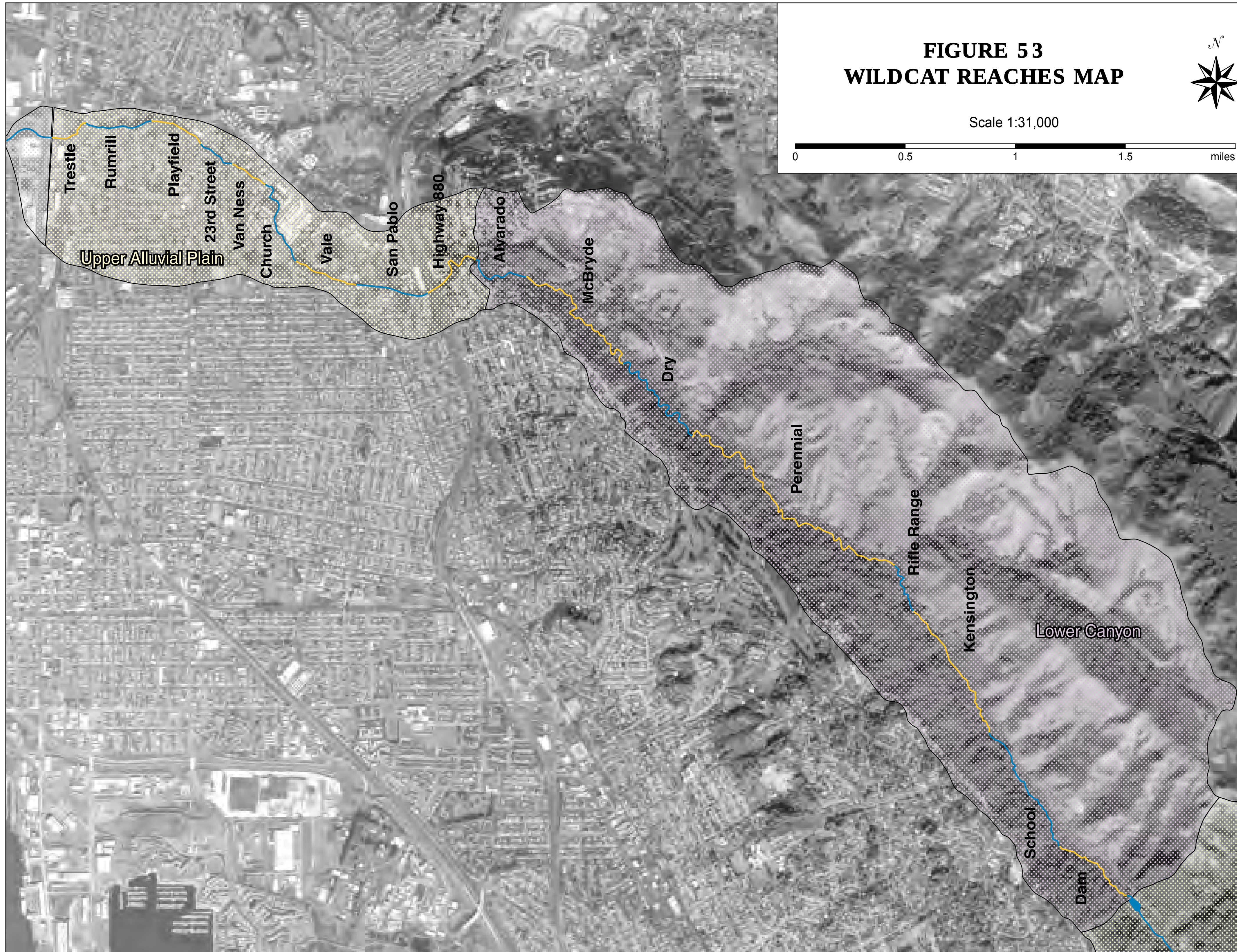
The mainstem channel is subject to more kinds of stresses and management practices in the Lower Canyon and Upper Alluvial Plain than elsewhere in the watershed. Sediment sources vary significantly over short distances. To understand this variability, and to develop a comprehensive baseline assessment against which various sampling strategies could be tested in the future, we measured most sediment sources continuously throughout both segments. To maximize the relevance of the baseline survey, we collected baseline information about infrastructure and channel form that relates to flood control, pollution control, and wildlife conservation. Channel conditions are summarized by Reaches, which are shown in Figure 53. The length of each reach is listed in Table 12. The details of field conditions are documented in the streamline graphs located in the Appendix.

We show a simplified Mainstem Sediment Source Decision Tree (Figure 54) that shows our field measured sediment supplies stratified by process based locations and whether the supply was directly related to land use practices. Bank features were categorized as alluvial banks below bankful elevation, terrace banks, landslides, gullies and canyon slopes. Bed incision (1,146 cu yd/yr) and landslides (724 cu yd/yr) have contributed the greatest local supply of sediment along

Table 12

Length of Wildcat Creek by Reach

	length (mi)		length (mi)
Trestle	0.19	Alvarado	0.32
Rumrill	0.31	McBryde	0.80
Playfield	0.26	Dry Reach	0.68
23rd	0.18	Perennial	1.48
Van Ness	0.18	Rifle Range	0.32
Church	0.43	Kensington	0.68
Vale	0.31	School	0.64
San Pablo	0.33	Dam	0.42
Hwy 880	0.36		



the mainstem since the time of non-native settlement. The amount of alluvial bank and terrace erosion from lateral migration (76 cu yd/yr) is minor compared to bed incision and slides. The total field measured sediment supply rate that is directly related to land use is 458 cu yd/yr. Another 1,580 cu yd/yr comes from sources that cannot be readily differentiated from natural and indirect land use effects.

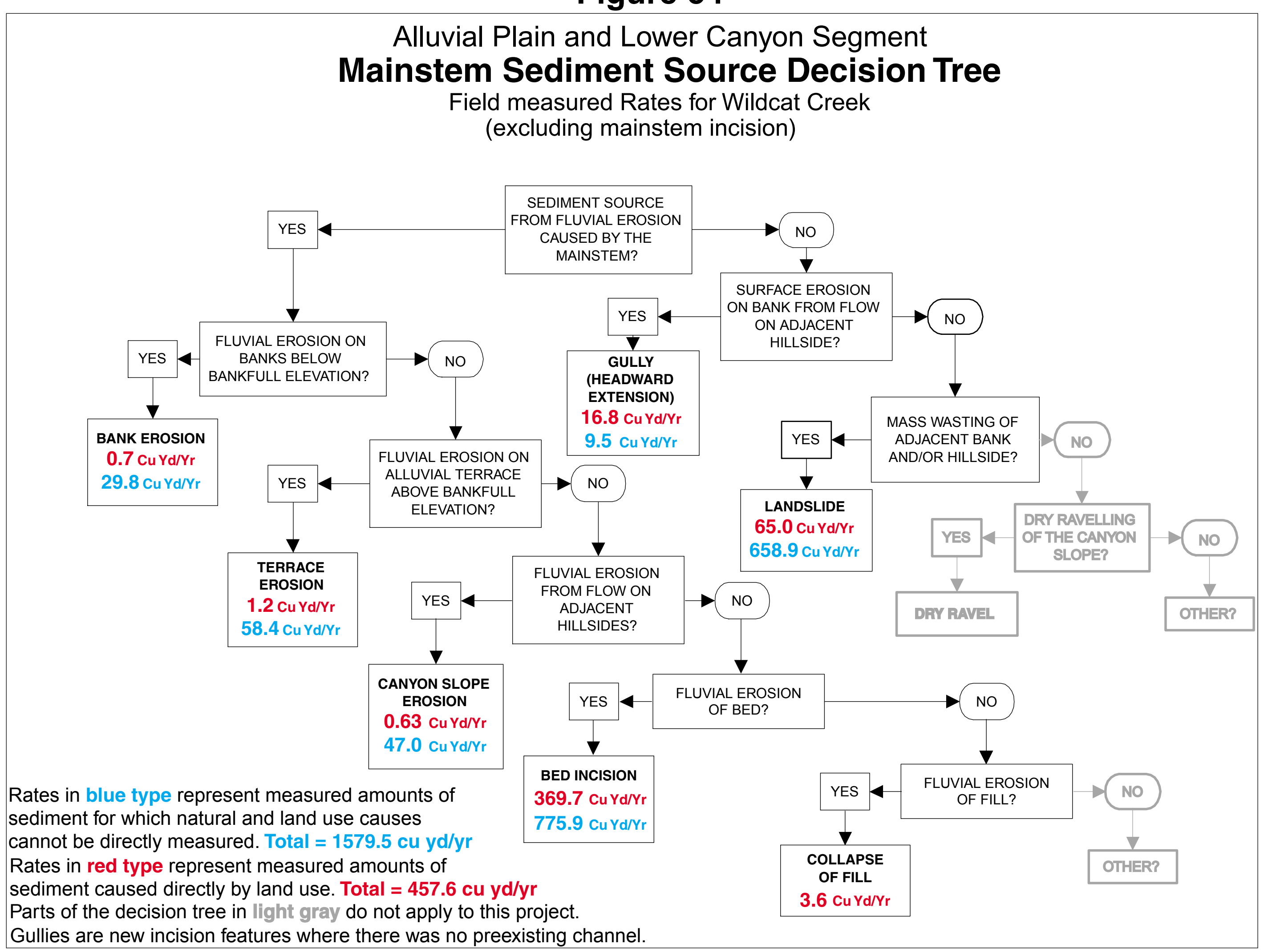
Table 13 shows categories of calculated and field measured sediment supply along the mainstem channel of both the Upper Alluvial Plain and Lower Canyon. We have further divided the sources of bed incision to exemplify our estimate of the contribution of sediment supplied by downcutting below Jewel Lake dam. This estimate may be conservative because we did not calculate its potential influence beyond Havey Creek confluence, which is the first substantial tributary that supplies significant bedload downstream of the dam. A substantial amount of incision is caused by the withholding of sediment by the reservoir. The channel below the spillway has incised 12 ft from the time it was constructed in 1922 (Photos 36 and 37). We have calculated the bed incision supply from the effects of the dam to be 233 cu yd/yr (Table 13).

Historical data and field evidence indicates that the mainstem channel has incised at least 1 ft since the 1940s when runoff increased from rapid urbanization. We considered 136 cu yd/yr a conservative estimate of direct urban influences to downcutting.

If we calculate the amount of sediment that would be generated from erosion keeping pace with the tectonic uplift (0.5 mm/yr), then the rate of supply for the mainstem in the Lower Canyon east of the Hayward Fault would only be 36 cu yd/yr. The rate of sediment supply from bed incision in the Lower Canyon that we have measured that cannot be explained by either tectonics or direct land use effects is 559 cu yd/yr, 49% of the total bed incision supply. Much of this supply may be from the adjustments that the mainstem channel has had to make to accommodate the increased runoff from the tributaries. The overall average increase in drainage density for the entire watershed upstream of the Flood Control Channel is 35%.

Soil creep and landslide creep rates are also reported in Table 13. These were calculated by the same methods discussed for Tributaries and Hillslopes (page 42), with some changes in depth and creep rates. The mainstem channel supplies 23% of the combined total for all soil and landslide creep in the Lower Canyon Segment.

Figure 54



(Photo 36a) The edge of the newly constructed dam at Jewel Lake, 1922. Note there is about 2.5 ft of fall.

(Photo 36b) The edge of the spillway in 1999 has over 14 ft of fall.

Table 13

Calculated and Measured Long-Term Rates of Sediment Supply from Wildcat Creek Mainstem Bed and Adjacent Bank Sources along the Alluvial Plain and Lower Canyon Segments Applicable to Last 167 Years		
Sources	**cu yd/yr**	**Percent of Total**
Field measured mainstem bed erosion estimated as directly related to land use	**369.7**	**15.3**
Canyon bed incision from fan to Havey Creek confluence related to effects of sediment retention at Jewel Lake Dam since 1922	233.3	9.7
Mainstem bed incision related to increased runoff from urban impacts since 1940's	136.4	5.7
Field measured mainstem bed incision (natural and/or indirectly) related to land use	**777.9**	**32.3**
Bed incision driven by tectonics for mainstem east of Hayward fault (uplift rate = 0.5 mm/yr) (considered natural)	35.5	1.5
Bed incision in excess of the natural-tectonicly driven rate (777.9 - 35.5 - 183.3)	559.1	23.2
Alluvial Plain bed incision (natural and/or indirectly related to land use)	183.3	7.6
Calculated	**374.5**	**15.5**
Soil creep at Canyon slopes (WA State Forest Practices 1994, soil creep rate = 5 mm/yr) (mean depth = 4 ft)	82.0	4.6
Soil creep at terraces (Upper Alluvial mainstem) (soil creep rate = 3 mm/yr) (soil depth = 3 ft)	29.9	1.2
Landslide creep for active slides bordering channel (landslide creep rate = 65 mm/yr) (assume 100% earthflows) (mean depth = 5 ft)	262.6	10.9
Field measured along banks (directly related to land use)	**87.9**	**3.6**
Gully erosion on mainstem banks	16.8	0.7
Landslides	65.0	2.7
Canyon slope	0.6	< 0.1
Terrace banks	1.2	< 0.1
Bankfull banks	0.7	< 0.1
Culvert fill / collapsed and washed out along mainstem	3.6	0.1
Field measured along banks (natural and/or indirectly related to land use)	**803.6**	**33.3**
Gully erosion on mainstem banks	9.5	0.4
Landslides	658.9	27.3
Canyon slope	47.0	1.9
Terrace banks	58.4	2.4
Bankfull banks	29.8	1.2
Totals	**2,413.6**	**100.0%**