APPENDIX B

SEDIMENT LOADING ANALYSIS

3 Sediment Loading Analysis

3.1 Approach

A sediment loading analysis was conducted for the Sausal Creek watershed. The loading analysis provided information on the amount of sediment that is being delivered to the creek from the watershed. Sediment is entering the creek from 5 basic sources; hillslope erosion from the open and developed landscape, mass wasting from landslides, erosion at culvert outlets, erosion from developed trails within the watershed, and observed channel bed and bank erosion. There is also a wind blown sediment contribution to the creek, but very little information is available to quantify that source.

The amount of sediment from each of the different sources is a function of land use and cover, surface soil types, topography, geology and culvert outlet conditions. The soils within the watershed are dominated by silty clay loams, gradually transitioning to a more sandier complex with decreasing elevation. These silty clay loams are easily eroded when exposed to weathering by rain or creek flow. The distribution of soil types was described in Section 2. The existing geology, dominated by numerous faults also influences hillslope stability and contributes to the sediment load. Figure 3-1 is a regional geologic map of the Oakland area. Figure 3-2 shows the geologic structure in the Sausal Watershed.

3.2 Hillslope Erosion

Hillslope erosion consists of surface erosion that originates from overland flow along vegetated or unvegetated hillslopes. Those areas of the watershed that are heavily developed will typically generate less sediment than open space vegetated areas. Also, the condition of the vegetated slope contributes significantly to the sediment load from the rainfall-runoff process.

The Revised Universal Soil Loss Equation (RUSLE) was used to develop an estimate of the hillslope erosion that is occurring within the watershed. The RUSLE is an improved implementation of the original USLE that has been used for many years across the country. The USLE and subsequent RUSLE were developed primarily for estimating the soil loss from agricultural areas. Through a selection of appropriate coefficients, the methodology has been used in urban and forested areas. Figure 3-3 is a schematic showing the basic mass balance approach to developing the surface erosion component to the creek sediment load.

For many years the RUSLE procedure has been used to guide conservation planning, inventory erosion rates and estimate sediment delivery. Values computed by RUSLE are supported by accepted scientific knowledge and technical judgment, are consistent with sound principles of conservation planning. and can be used to evaluate conservation plans. The RUSLE2 computer model (USDA 2002) was used for the analysis. The RUSLE 2 program is based on additional analysis and knowledge that were not available when the original RUSLE was developed. RUSLE2 is based on science and judgment that is considered superior to that of RUSLE.

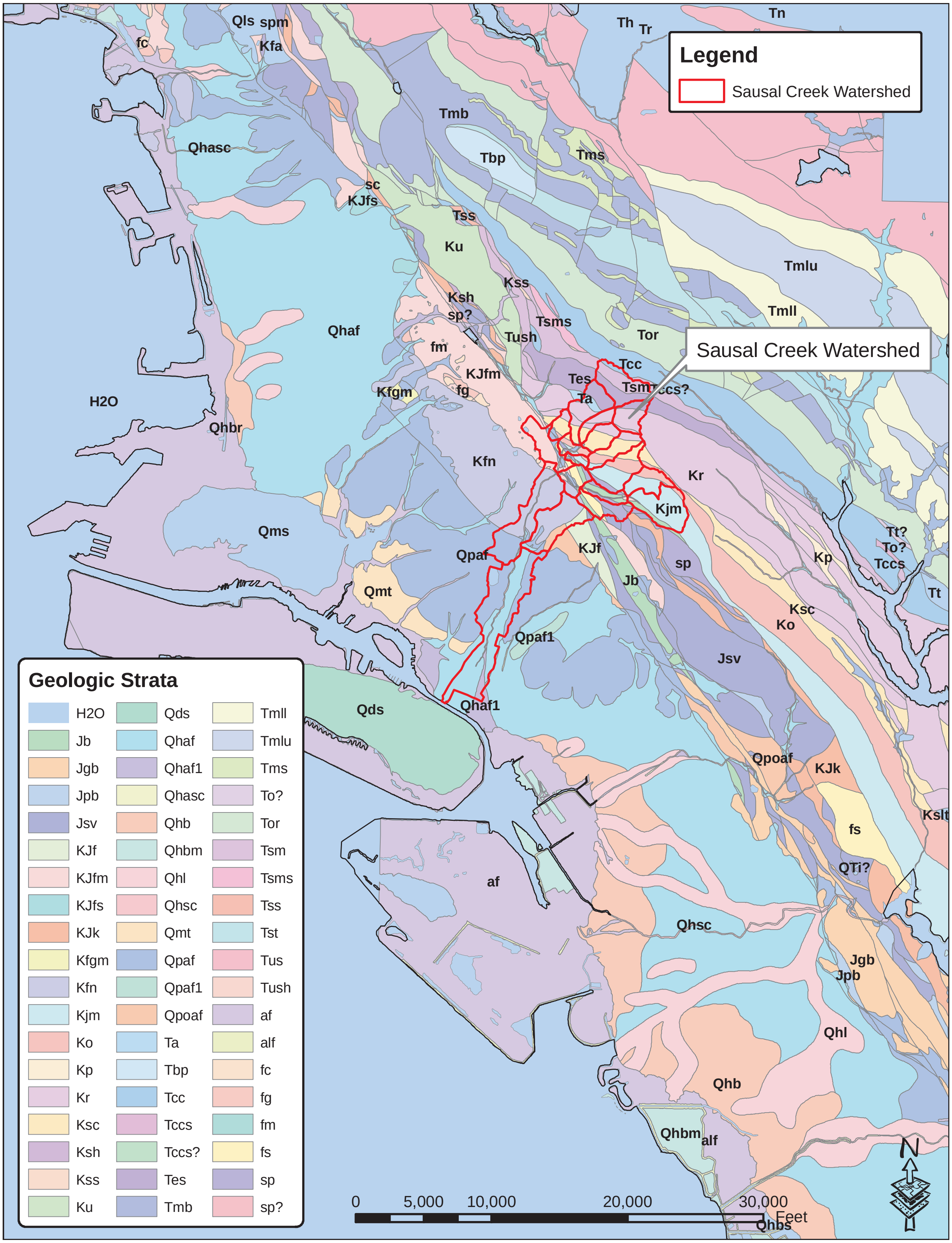

Figure 3-1 Oakland Regional Geology Map.

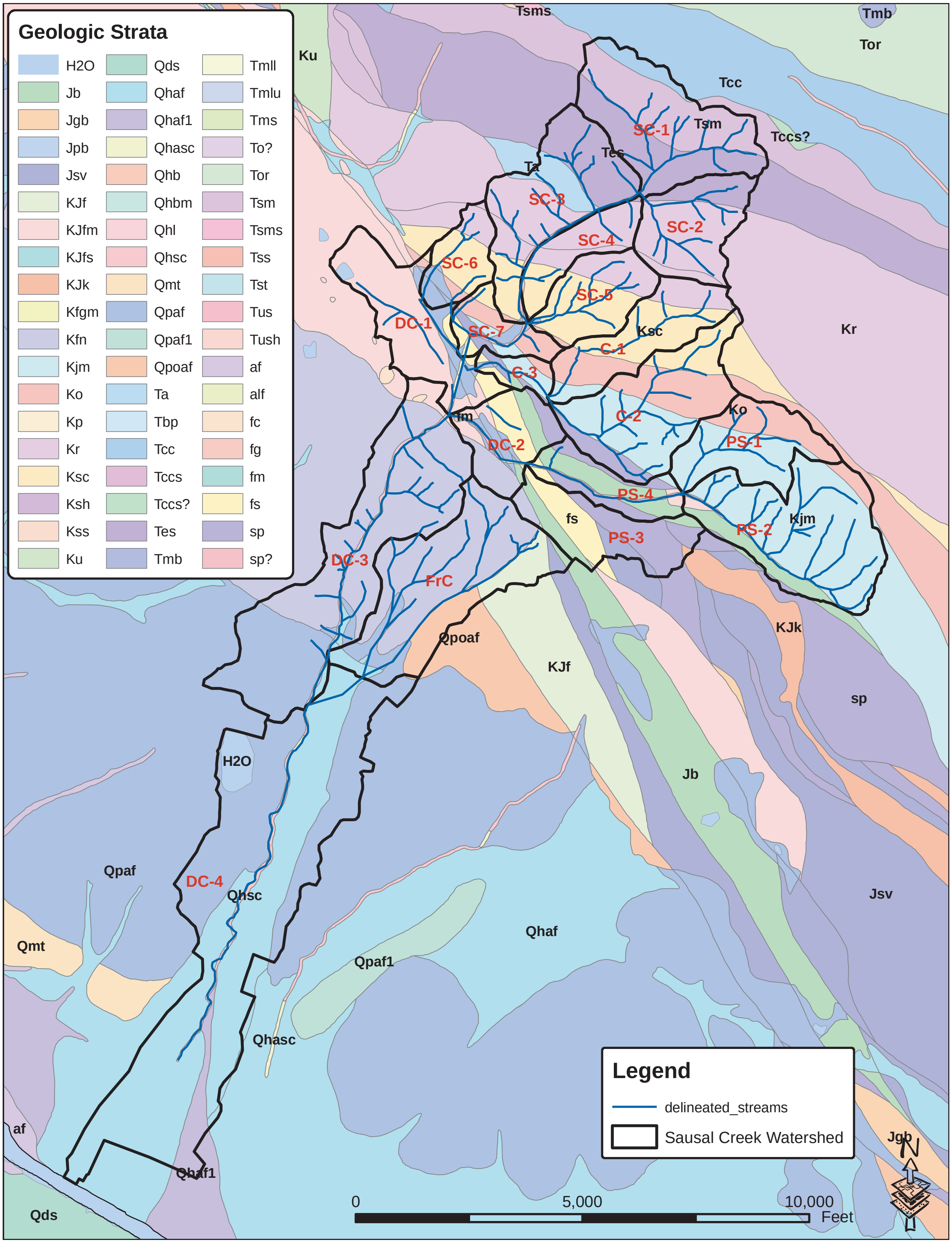

Figure 3-2 Sausal Creek Geology.

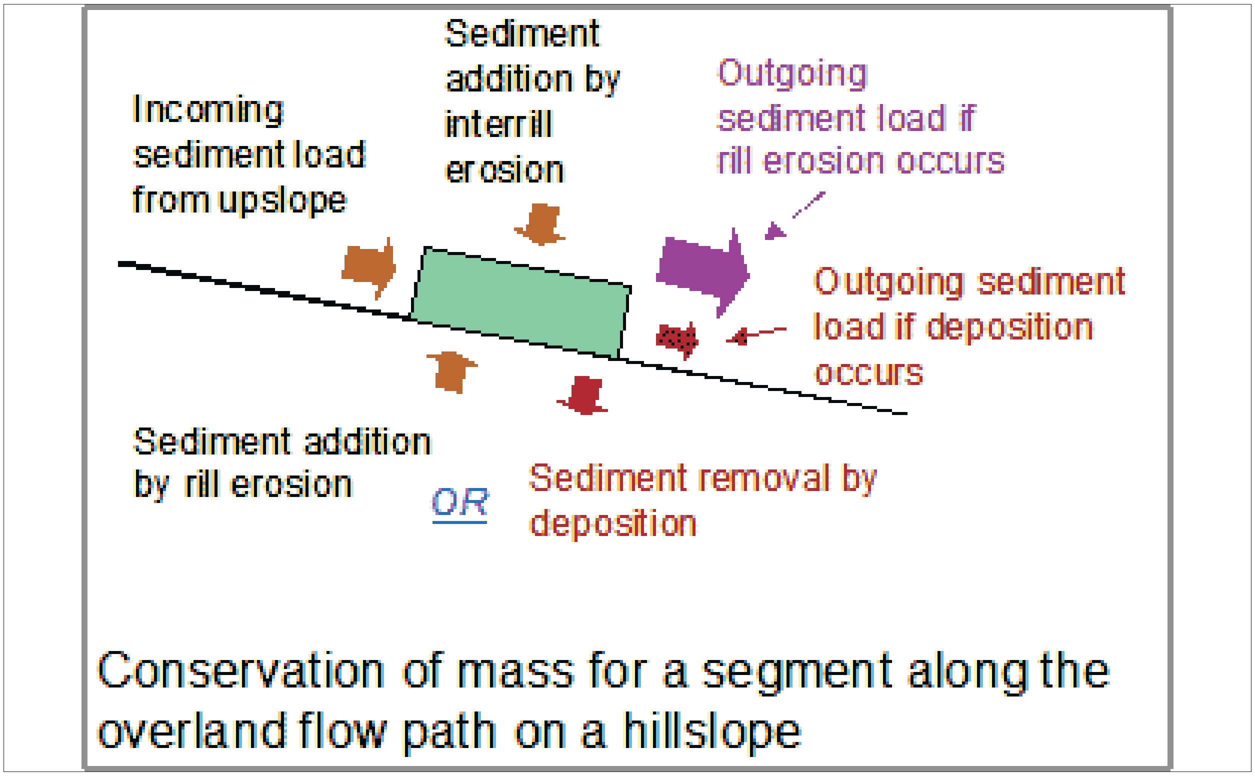

Figure 3-3 Soil Erosion Process.

RUSLE2 has evolved from a series of previous erosion prediction technologies. The USLE was entirely an empirically based equation and was limited in its application to conditions where experimental data were available for deriving factor values. A major advancement in RUSLE is the use of subfactor relationships to compute C factor values from basic features of land cover types. While RUSLE retained the basic structure of the USLE, process-based relationships were added where empirical data and relationships were inadequate, such as computing the effect of buffer strips and modern conservation tillage systems.

While RUSLE2 uses the RUSLE basic formulation of the unit plot, the mathematics of RUSLE2 are on a daily basis. Improved landcover-management subfactor relationships are used in RUSLE2, a new ridge subfactor has been added, and the deposition equations have been extended to consider sediment characteristics and how deposition changes these characteristics. It also includes new relationships for handling ground cover residue, including resurfacing of residue by implements like field cultivators.

The original USLE equation is shown below in Equation 3-1.

$$E = R \cdot K \cdot T \cdot C \cdot P \qquad \text{Eqn. 3-1}$$

Where: E = The soil loading in tons/acre/year
R = the soil erosivity index
K = the soil erodability factor
T = the watershed topographic factor
C = the crop management factor
P = a soil conservation practice factor

The erosivity index is a summation of the individual storm products kinetic energy of the rainfall and the maximum 30-minute rainfall intensity for all significant storms in a year. The remaining factors are specific to the land use, vegetation type, vegetation condition, and topography of the hillslope.

RUSLE2 computes net detachment each day using a variation of the familiar USLE factors:

$$a = r \cdot k \cdot l \cdot S \cdot c \cdot p \qquad \text{Eqn 3-2}$$

where:

a = net detachment (mass/unit area)
r = erosivity factor,
k = soil erodability factor,
l = slope length factor,
S = slope steepness factor,
c = cover-management factor, and
p = supporting practices factor

Deposition is computed with the equation:

$$D = (Vf / q) \cdot (T_c - g) \qquad \text{Eqn 3-3}$$

where:

D = deposition rate (mass/unit area),
Vf = fall velocity of the sediment,
q = runoff rate,
Tc = transport capacity of the runoff, and
g = sediment load (mass/ unit width).

RUSLE2 divides the sediment load into five sediment classes: primary clay, silt, sand, small aggregates, and large aggregates. The difference between the different classes are based on grain size and density. Table 3-1 is a tabulation of the erosion for each of the subbasins in the watershed.

Table 3-1 Mean Annual Sediment Loading From Hillslope Erosion				
Basin Name	Area	Open Space	Mean Annual Erosion	
	(ac)	(%)	(tons)	(cy)
C-1	110.6	77%	2.5	3,709
C-2	172.3	83%	4.2	6,292
C-3	25.8	85%	0.6	963
Total	308.7		7.3	10,965
DC-1	132.8	64%	2.5	3,722
DC-2	82.2	74%	1.8	2,674
DC-3	332.0	76%	7.4	11,095
DC-4	592.9	73%	12.6	18,951
Total	1139.9		21.7	32,720
FrC	232.7	21%	1.4	2,139
PS-1	107.3	95%	3.0	4,476
PS-2	214.1	97%	6.0	9,053
PS-3	105.7	77%	2.4	3,550
PS-4	66.9	96%	1.9	2,827
Total	494.1		10.2	15,430
SC-1	182.7	75%	4.0	5,987
SC-2	104.1	71%	2.1	3,240
SC-3	163.6	78%	3.7	5,606
SC-4	61.5	78%	1.4	2,112
SC-5	86.1	77%	1.9	2,891
SC-6	56.7	75%	1.2	1,857
SC-7	50.2	83%	1.2	1,830
Total	704.9		4.4	6,578
Grand Total	2,880.2		44.9	67832

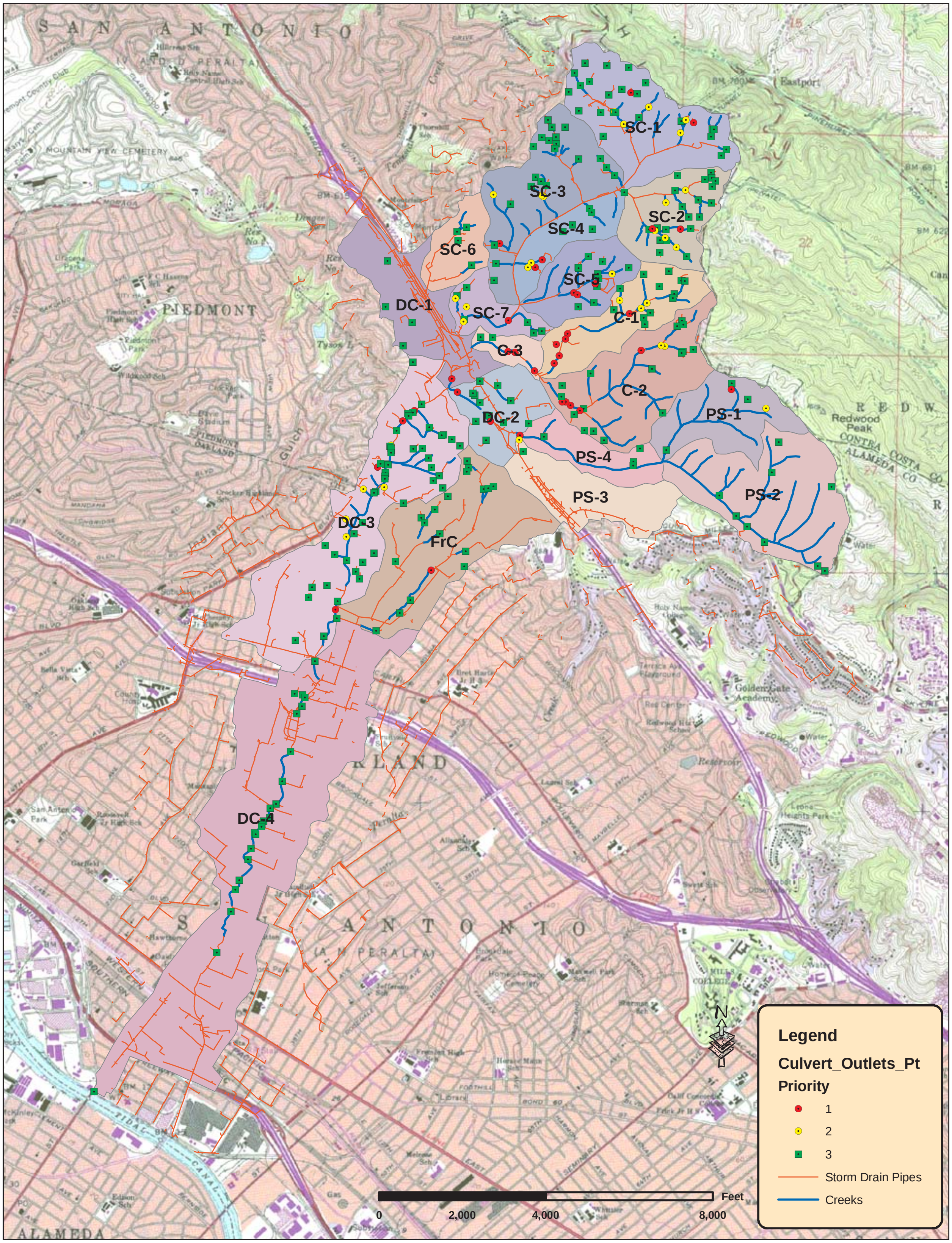

Figure 3-4 Sausal Creek - Culvert Outlet Map.

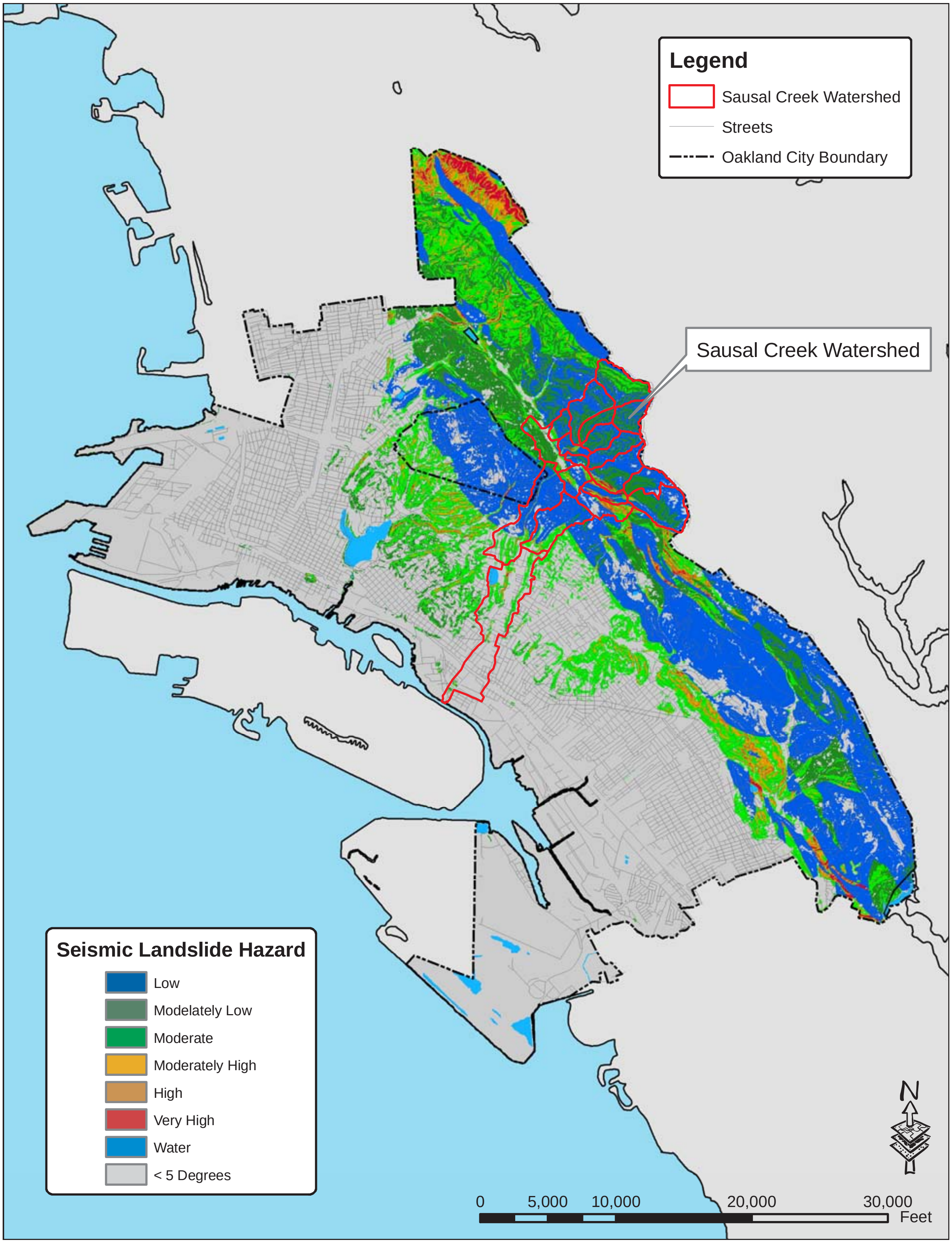

Figure 3-5 Oakland Area Landscape Hazard Map.

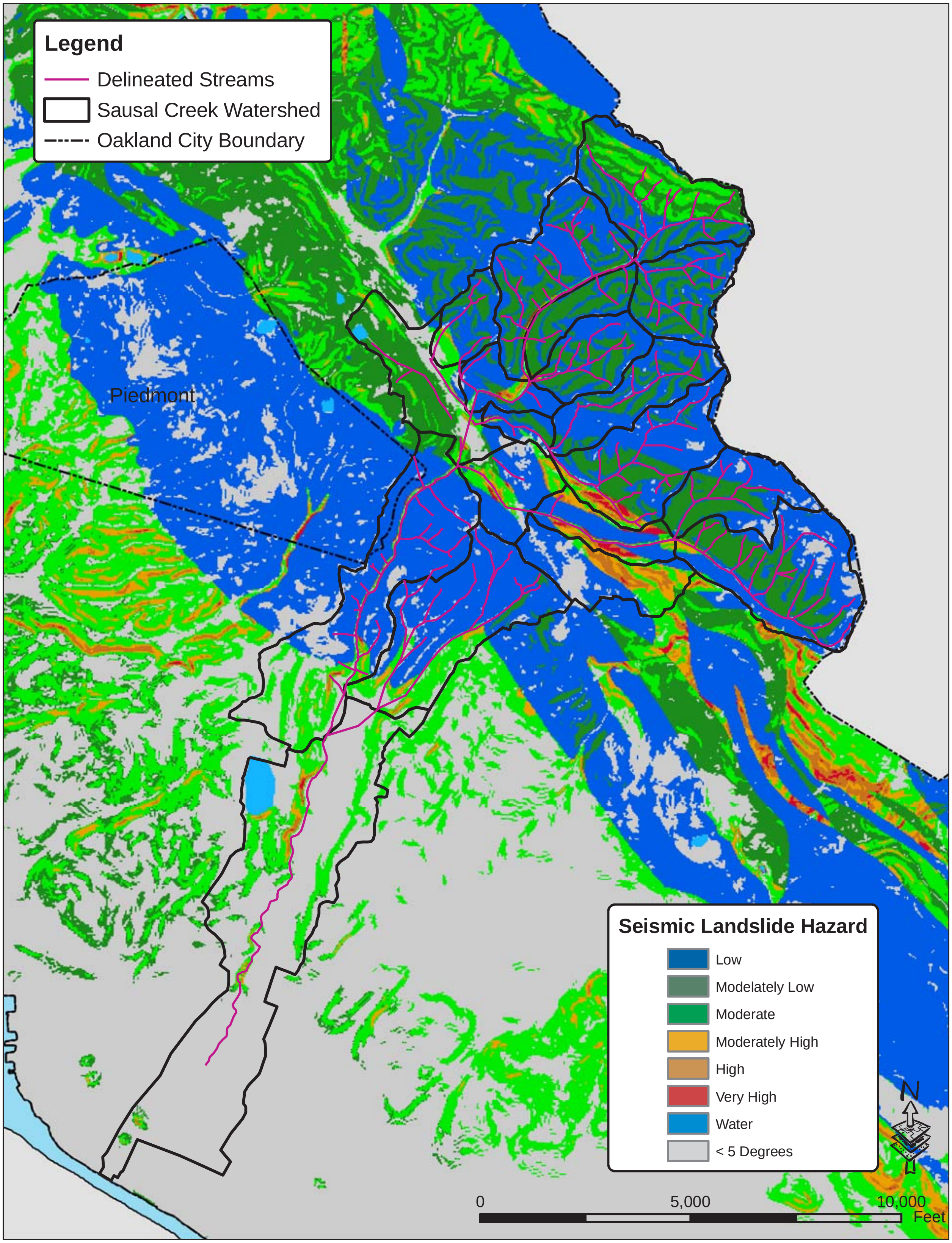

Figure 3-6 Sausal Creek - Landslide Hazard Map.

3.3 Culvert Outlet Erosion

Erosion generated from the scour at the downstream ends of culverts within the existing drainage system are a significant source of loading to Sausal Creek. A field survey was conducted of culvert outlets within the watershed. The culvert outlets were identified and classified into high, medium and low erosion potential. The erosion potential was based on channel slope and watershed area upstream of the outlet. Culvert outlets within the high and medium priority sites were surveyed and the existing erosion at the culvert outlet and downstream of the culvert was identified.

The documented erosion was used to estimate the erosion at the remaining culvert locations. Table 3-2 is a tabulation of the culvert outlet erosion tabulated for each of the subbasins in the watershed.

Table 3-2 Average Annual Sediment Loading From Scour at Culvert Outlets

Basin	Area	No of	Ave Erosion Rate	Erosion		
	(ac)	Culverts	(ft3/yr/culvert)	(ft3)	(tons)	(cy)
C-1	111	20	11	228	0.15	8.46
C-2	172	23	11	263	0.17	9.73
C-3	26	5	11	57	0.04	2.12
Total	309	48		548	0.36	20.30
DC-1	133	5	1,981	9,906	6.56	366.89
DC-2	82	0	1,981	0	0.00	0.00
DC-3	332	56	1,981	110,947	73.50	4,109.16
DC-4	593	21	1,981	41,605	27.56	1,540.93
Total	1,140	77		152,552	107.63	6,016.98
FrC	233	20	0	0	0.00	0.00
Total	233	20		0	0.00	0.00
PS-1	107	0	81	0	0.00	0.00
PS-2	214	6	81	486	0.32	18.00
PS-3	106	2	81	162	0.11	6.00
PS-4	67	2	81	162	0.11	6.00

Table 3-2 Average Annual Sediment Loading From Scour at Culvert Outlets						
Basin	Area	No of	Ave Erosion Rate	Erosion		
	(ac)	Culverts	(ft3/yr/culvert)	(ft3)	(tons)	(cy)
Total	494	10		810	0.54	30.00
SC-1	183	30	92	2,771	1.84	102.64
SC-2	104	24	92	2,217	1.47	82.11
SC-3	164	25	92	2,309	1.53	85.53
SC-4	62	7	92	647	0.43	23.95
SC-5	86	10	92	924	0.61	34.21
SC-6	57	4	92	370	0.24	13.69
SC-7	50	10	92	924	0.61	34.21
Total	705	24		10,161	6.73	376.34
Total	2,880	179		164,072	115.26	6,443.62

3.4 Trail Erosion

Erosion along existing trails contributes sediment to the creek. A field survey was conducted of existing trails in various locations within the watershed. From this reconnaissance, a mean erosion rate was developed for the trails throughout the watershed. A total of 22.8 miles of trails were identified within the watershed. A summary of the trail erosion within each subbasin is provided in Table 3-3.

Table 3-3 Average Annual Sediment Loading From Trail Erosion					
Basin	Area	Length	Erosion		
	(ac)		(ft3)	(tons)	(cy)
C-1	110.61	750	75.01	0.05	2.78
C-2	172.27	4,047	404.67	0.27	14.99
C-3	25.81	0	0.00	0.00	0.00
Total	308.69	4,797	479.68	0.32	17.77

Table 3-3 Average Annual Sediment Loading From Trail Erosion					
Basin	Area	Length	Erosion		
	(ac)		(ft3)	(tons)	(cy)
DC-1	132.82	400	39.99	0.03	1.48
DC-2	82.19	2,881	288.10	0.19	10.67
DC-3	331.97	16,251	1,625.10	1.08	60.19
DC-4	592.87	2	0.17	0.00	0.01
Total	1,139.86	19,534	1,953.36	1.29	72.35
FrC	232.71	1,754	175.36	0.12	6.49
Total	232.71	1,754	175.36	0.12	6.49
PS-1	107.28	19,268	1,926.84	1.28	71.36
PS-2	214.13	42,315	4,231.45	2.80	156.72
PS-3	105.73	6,090	608.98	0.40	22.55
PS-4	66.94	11,873	1,187.29	0.79	43.97
Total	494.08	79,546	7,954.56	5.27	294.61
SC-1	182.67	0	0.00	0.00	0.00
SC-2	104.08	8	0.82	0.00	0.03
SC-3	163.63	6,457	645.72	0.43	23.92
SC-4	61.55	1,316	131.56	0.09	4.87
SC-5	86.10	2,902	290.18	0.19	10.75
SC-6	56.65	1,702	170.21	0.11	6.30
SC-7	50.19	2,569	256.92	0.17	9.52
Total	704.87	14,954	1,495.42	0.99	55.39
Total	2,880.20	120,584	12,058.38	7.99	446.61

3.5 Landslide Erosion

The Oakland Hills area is known for numerous landslides. A combination of soils, geology and numerous active faults contributes to very unstable hillslopes. Figure 3-5 is a map of the Oakland area showing the location of areas that are susceptible to landslides. Figure 3-6 is map of the landslide hazard through the Sausal Creek Watershed. A survey of existing landslides was developed from the Sausal Creek Watershed Management Plan developed by the City of Oakland. The location of the known landslides was compared to the landslide potential map. From this comparison, an estimate of an annual landslide rate was developed. Table 3-4 is a tabulation of the sediment loading from landslides for each of the subbasins in the watershed. The estimate assumes that 5% of the landslide mass is transported to the river.

Table 3-4 Average Annual Sediment Loading From Landslides

Basin	Area	Area Susceptible to Landslides	Probability of Slide	Erosion		
	(ac)	(ft2)		(ft3)	(tons)	(cy)
C-1	110.6	0	0.05	0	0.00	0.0
C-2	172.3	858,714	0.05	8,587	5.69	318.0
C-3	25.8	89,973	0.05	900	0.60	33.3
Total	308.7	948,688		9,487	6.29	351.4
DC-1	132.8	1,071,161	0.05	10,712	7.10	396.7
DC-2	82.2	1,081,128	0.05	10,811	7.16	400.4
DC-3	332.0	2,697,759	0.05	26,978	17.87	999.2
DC-4	592.9	4,855,067	0.05	48,551	32.16	1,798.2
Total	1,139.9	9,705,116		97,051	64.30	3,594.5
FrC	232.7	1,872,412	0.05	18,724	12.40	693.5
PS-1	107.3	987	0.05	10	0.01	0.4
PS-2	214.1	276,014	0.05	2,760	1.83	102.2
PS-3	105.7	1,808,472	0.05	18,085	11.98	669.8
PS-4	66.9	1,279,644	0.05	12,796	8.48	473.9
Total	494.1	3,365,116		33,651	22.29	1,246.3
SC-1	182.7	1,925,636	0.05	19,256	12.76	713.2

Table 3-4 Average Annual Sediment Loading From Landslides						
Basin	Area	Area Susceptible to Landslides	Probability of Slide	Erosion		
	(ac)	(ft2)		(ft3)	(tons)	(cy)
SC-2	104.1	0	0.05	0	0.00	0.0
SC-3	163.6	240,786	0.05	2,408	1.60	89.2
SC-4	61.5	45,269	0.05	453	0.30	16.8
SC-5	86.1	32,132	0.05	321	0.21	11.9
SC-6	56.7	329,642	0.05	3,296	2.18	122.1
SC-7	50.2	286,173	0.05	2,862	1.90	106.0
Total	704.9	2,859,638		28,596	18.95	1,059.1
Total	2,880.2	18,750,969		187,510	124.23	6,944.8

3.6 Creek Erosion

Creek bed and bank scour is occurring through many areas of the watershed. The scour that has occurred historically has been a combination of bed scour with the channel downcutting through the bed material, and bank erosion. Many areas of the creek have downcut to bedrock material, resulting in a reduction in bed erosion and an increase in bank erosion. Field surveys were conducted to identify where ongoing erosion is occurring. From this survey, average erosion rates were established for each of the individual watersheds. Table 3-5 is a summary of the average annual sediment load from each of the subbasins.

Table 3-5 Average Annual Sediment Loading From Creek Erosion					
Basin Name	Area	Length	Erosion		
	(ac)	(ft)	(ft3)	(tons)	(cy)
C-1	110.6	750	840	0.56	31.1
C-2	172.3	4,047	4,532	3.00	167.9
C-3	25.8	0	0	0.00	0.0
Total	308.7	4,797	5,372	3.56	199.0
DC-1	132.8	400	868	0.57	32.1
DC-2	82.2	2,881	6,252	4.14	231.5
DC-3	332.0	16,251	35,265	23.36	1,306.1

Table 3-5 Average Annual Sediment Loading From Creek Erosion					
Basin Name	Area	Length	Erosion		
	(ac)	(ft)	(ft3)	(tons)	(cy)
DC-4	592.9	2	4	0.00	0.1
Total	1,139.9	19,134	41,520	28.08	1,537.8
FrC	232.7	1,754	1,964	1.30	72.7
Total	232.7	20,887	43,484	1.30	1,610.5
PS-1	107.3	19,268	28,325	18.76	1,049.1
PS-2	214.1	42,315	62,202	41.21	2,303.8
PS-3	105.7	6,090	11,083	7.34	410.5
PS-4	66.9	11,873	21,609	14.32	800.3
Total	494.1	60,277	94,894	81.63	3,514.6
SC-1	182.7	0	0	0.00	0.0
SC-2	104.1	8	9	0.01	0.3
SC-3	163.6	6,457	7,232	4.79	267.9
SC-4	61.5	1,316	1,473	0.98	54.6
SC-5	86.1	2,902	3,250	2.15	120.4
SC-6	56.7	1,702	1,906	1.26	70.6
SC-7	50.2	2,569	2,878	1.91	106.6
Total	704.9	7,173	8,034	11.10	297.6
Total	2,880.2	112,268	193,305	125.67	7,159.5

The sum of the individual components to the total sediment load on the is shown in Table 3-6. For the entire watershed, the sediment load to the creek averages 0.15 tons/acre. This is an average for the watershed, with some areas contributing much more and some areas contributing much less. It should also be noted that this is an average annual load based on observed scour and erosion that has occurred historically. For any particular year, this rate will vary considerably depending on rainfall, construction in the watershed, earthquakes, and disturbance of the creek system.

Table 3-6 Sum of the Average Annual Sediment From All Sources

Basin Name	Area	Erosion	Erosion
	(ac)	(cy)	(tons)
C-1	110.6	3,751.4	3.2
C-2	172.3	6,803.0	13.3
C-3	25.8	998.8	1.3
Total	308.7	11,553.3	17.8
DC-1	132.8	4,519.6	16.7
DC-2	82.2	3,316.9	13.3
DC-3	332.0	17,569.6	123.2
DC-4	592.9	22,290.3	72.3
Total	1,139.9	43,941.9	223.0
FrC	232.7	2,911.9	15.2
PS-1	107.3	5,596.9	23.0
PS-2	214.1	11,634.1	52.2
PS-3	105.7	4,658.5	22.2
PS-4	66.9	4,151.5	25.6
Total	494.1	20,515.9	120.0
SC-1	182.7	6,802.4	18.6
SC-2	104.1	3,322.6	3.6
SC-3	163.6	6,073.0	12.1
SC-4	61.5	2,212.6	3.2
SC-5	86.1	3,067.9	5.1
SC-6	56.7	2,069.7	5.0
SC-7	50.2	2,086.5	5.8
Total	704.9	8,366.3	42.1
Total	2,880.2	88,827.0	418.1