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Delineating the Spacial Variation of Sediment Yield Potential in the Upper Santa Ana River Basin

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산타아나강 상류 유역분지에서 잠재적 퇴적물 생산량의 공간적 분포에 관한 연구

성 효 현*

Abstract : The purpose of this investigation is to delineate spatial variation of long term sediment yield potential among 42 sub basins of the Upper Santa Ana River Basin. The rating of watershed for delineating spatial variation of long term sediment yield potential is based on the physical characteristics of the watershed to determine sediment yield: relief factor, area-shape factor, geology factor, and climatic factor. Among these properties of watersheds, watershed average slope(WSL), percentage of "soft rock" outcrop(GEOL), and hypsometric index(HAT), standard deviation from average stream gradient(SDS), and wet year annual rainfall are selected as the significant predictor variables for differentiation among the regions. The "K-means clustering of cases" and "Stepwise discriminant" analysis are selected as the most suitable techniques. The rating and classification exercise showed that the Region II is the part of the upper Santa Ana basin most prone to sediment aggradation. this is indicated by the lowest relief factors, the largest proportion(97.6%) of soft rock surface, and the lack of high elevation. Immediately upstream from the Region II are the watersheds with the highest potential for sediment yield. This region IV is characterized by highest relief, steepest slopes, high rainfall and large watershed size in addition to much more erodible sufaces and glaciation in the past. The fault separate the main depositional area region(region II) from the region of greatest potential sediment yield(region IV). The abrupt change of slope at the boundary would obviously encourage aggradation in region II.

Key Words : Upper Santa Ana River Basin, Sediment Yield, Spatial Variation, Watershed Management, GIS

요약 : 본 연구의 목적은 미국의 산타아나 강 상류 유역분지 내 잠재적 퇴적물 생산량의 공간적 분포 패턴을 고찰하는데 있다. 이를 위해 산타아나 강 상류지역을 42개의 하부 유역분지로 나눈 후에 각 유역분지의 퇴적물 생산량에 영향을 주는 지형 기복 요소, 면적-형태 요소, 지질 요소, 기후 요소와 관련하여 20개의 변수를 GIS를 이용하여 추출하였다. 이러한 20개의 변수들을 기초로 군집분석하여 42개 하부 유역분지들의 잠재적 퇴적물 생산량을 평가한 결과 4개의 지역으로 구분되었다. 평가 결과 '발톤'평지가 포함된 제2지역이 산타아나 상류 유역분지에서 가장 퇴적작용이 왕성한 지역으로 나타났다. 이 지역은 낮은 기복 및 고도와 미고화된 물질로 피복된 지역이 97%를 차지하고 있다. 잠재적 퇴적물 생산량이 가장 높은 지역은 제2지역의 상류부에 분포하는 유역분지들(제4지역)로서 높은 기복과 고도 뿐 아니라 침식 가능 면적이 넓으며, 과거의 빙하작용이 있었던 지역이다. 특히 단층선이 퇴적작용이 크게 이루어지고 있는 지역(제2지역)과 잠재적 퇴적물 생산량이 가장 높은 지역(제4지역) 사이에 분포하고 있어, 사면경사의 급변으로 제2지역의 퇴적작용은 더욱 가속화될 것이다.

주요어 : 산타아나 상류 유역분지, 퇴적물 생산량, 공간적 분포, 유역분지관리, 지리정보체계

1. Introduction

1) Research Scope and Purpose

The upper Santa Ana River Basin(latitude 34° 00′ and 34° 15′ north, longitude 116° 37′ 30′′ and 117° 07′ 30′′ west) is in the central San Bernardino Mountains, approximately 130km east of metropolitan Los Angeles, southern California (Figure 1). These mountains, like most of the

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Transverse Ranges, were elevated by interaction of the San Andreas Fault Zone and thrust fault systems.

Within the San Bernardino Mountains, the upper Santa Ana River runs between the Northern Plateau, an extensive old erosion surface to the north, and San Gorgonio Mountain to the south. San Gorgonio Mountain includes some of the highest peaks in southern California, stands more than a kilometer above the Northern Plateau, and was a site of Pleistocene glaciation (Sharp and others, 1959). The modern climate of the San Bernardino Mountains is mediterranean with mild, rainy winters and warm dry summers.

The upper Santa Ana River flows from east to west through a large irregularly shaped intramontane basin, of approximately 235 km^2. The basin is nearly 11 km wide and spans an east-west length of 29 km.

The upper Santa Ana River Basin originated as part of a late Tertiary alluviated valley; it is currently being dissected as a result of uplift to its modern altitude during the elevation of the neighboring mountain blocks(Dibblee, 1982; Sadler and Reeder, 1983; Sadler, 1990). In the modern time, the Upper Santa Ana River Basin has been developed as a resort area.

Sediment yield is the total sediment outflow from a watershed over a specified period of time. The amount of sediment transported by a river will be a function of the both hill slope and channel processes. Catchment erosion represents not only a loss of asset to agriculture and forestry, but also reservoir siltation and potential liability further downstream. Reservoir siltation reduces storage capacity and the life expectance of reservoirs, while the silting-up of rivers may affect navigation and increase the risk of flooding in lower reaches. Wash load transport has affect of more immediate relevance to stream behaviour and channel form

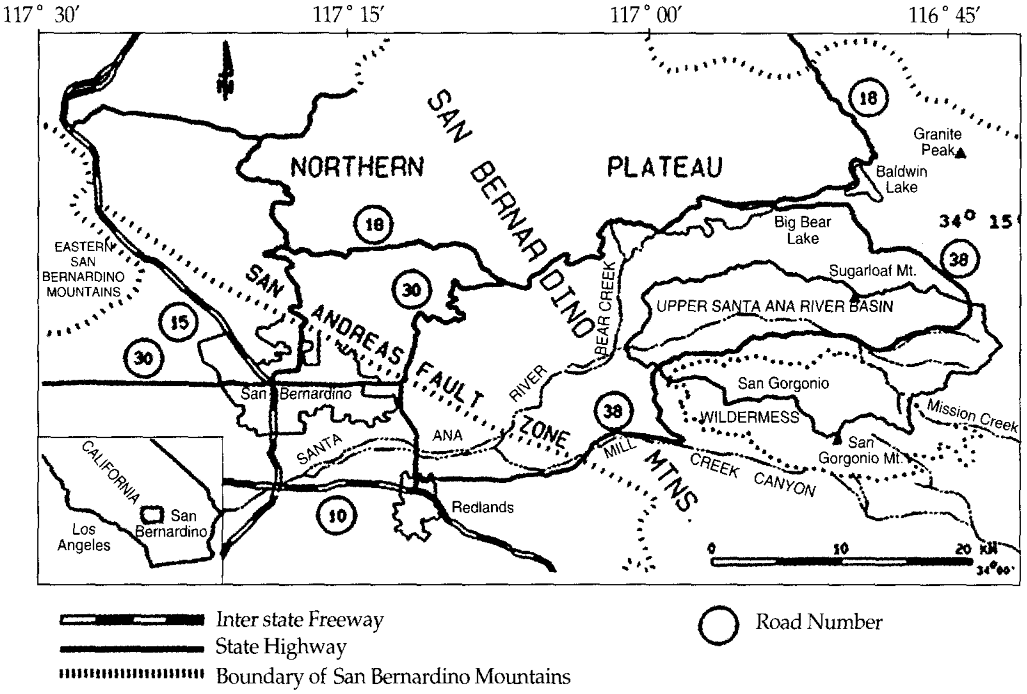


Figure 1. Location map of study area

adjustment. Very high concentrations damp down turbulence and alter the apparent viscosity of flow, enabling the transport of a slightly larger bed-load than would otherwise be the case. The erosion of watershed can significantly damage the terrestrial habitat. The transport of these materials from the watersheds to surface water bodies can also have serious environmental impacts.

It is very important to predict high potential sediment yield of watersheds, so it can be used as a planning tool for watershed management and water resource development. In this study the sediment yield in the upper Santa Ana River Basin is analyzed in the GIS environment.

The object of this study is to delineate spatial variation of long term sediment yield potential among sub-basins of the Upper Santa Ana River Basin. The purpose is to locate the dominant sediment sources. It is to delineate the relative sediment yield potential rather than to estimate accurately, the volume of sediment yield.

2) Previous Investigation of the Upper Santa Ana River Basin

Few studies deal specifically with the geomorphology of the upper Santa Ana River Basin. Vaughan(1922) suggested a generalized geomorphological history for the whole mountain range that includes four cycles of erosion, influenced by climatic changes and uplift, based on a cursory description of regional erosion surfaces. He attributed Santa Canyon, in which the main stream has cut into the sedimentary rock to a depth of nearly 150m, to the third cycle. Dibblee(1982) attributed the deep dissection in the Upper Santa Ana river basin to the uplift of the San Bernardino Mountains.

Sharp and others(1959) document the glacial geomorphology in the San Gorgonio Massif. They mapped seven glacial deposits and noticed that the principal products of glaciation are cirques and huge terminal embankments of coarse angular debris. Two separate episodes of Wisconsin glaciation are recognized.

Sadler(1990) reconstructed the Tertiary basin in the upper Santa Ana River Basin and tried to establish the pre-orogenic source areas of the Santa Ana Sandstone. In order to show possible regional reconstructions of deposits and their sources including the San Gabriel Mountains, Sadler presented four schematic paleogeographic maps in sequence from about 15 Myr to the present.

2. Strategy and Methods of Data Analysis

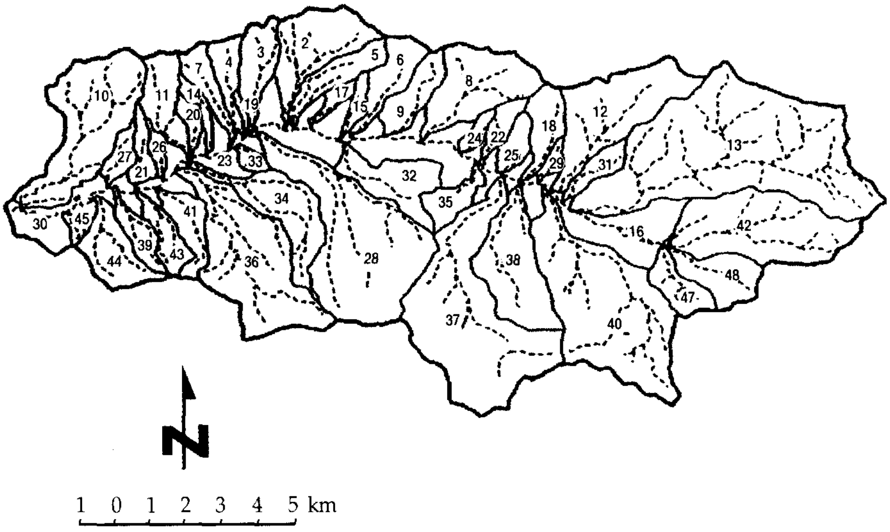
1) Data Analysis

The method is to classify all the watersheds in the uppermost Santa Ana River Basin according to differences in variables that affect sediment yield. The purpose of the classification exercise is to analyze the contribution of sediment from all parts of upper Santa Ana River Watershed in order to identify the dominant sediment sources.

The classification is based upon values for up to 20 variables determined for each of 42 sub-basins(Figure 2). Clearly this requires fairly sophisticated statistical methods and computer data handling.

The "K-means clustering of cases" and "stepwise discriminant" analysis were selected as the two most suitable techniques. The first is used to group the sub-basins into classes, the second is used to identify the most efficient set of predictor variables. The predictor variables are those that can be related to potential sediment yield. The ARC/INFO GIS, including the TIN(Triangulated Irregular Network) surfaces medelling subsystem is used to measure many of the sub-basin variables and to manage data tables for the maps of the spatial variation of expected sediment yield.

To identify the spatial variation of sediment yield, the following maps and related tabular data had to be created by using GIS: Watershed boundaries, Streams, Contours, A representation of a surface, consisting of a set of non-overlapping proximal triangles, Slope, Geology and structure, Mean annual precipitation, Mean annual rainfall, Mean annual rainfall for wet years (Five year recurrence interval flood), and Rainfall during the January, 1969 storm (100 year recurrence interval flood).



Watershed ID	Name of Watersheds	Watershed ID	Name of Watersheds
2	Converse Creek	26	East Clarks Grade
3	Hamilton Creek	27	West Clarks Grade
4	Grand	28	Barton Creek
5	West Converse Flat	29	East Sugarloaf Flat
6	Staircase Canyon	31	East Wildhorse
7	Clarks Summit	32	West Barton Flats
8	Rattlesnake Creek	33	Old Barton Flats
9	Sugarlump	34	Round Cienaga
10	Deer Creek	35	East Barton Flats
11	Mile Creek	36	Forsee Creek
12	WildHorse Creek	37	South Fork Creek
13	Cienaga Seca Creek	38	Lost Creek
14	Seven Oaks	39	Kilpecker Creek
15	West Burro Flat	40	Fish Creek
17	East Converse Flat	41	West Cedar Falls
18	Sugarloaf Mountain	42	Coon Creek
20	Sand Creek	43	Schneider Creek
21	Middle Clarks Grade	44	Cold Creek
22	Middle Sugarloaf Meadow	45	Helipork
24	West Sugarloaf Meadow	47	South West Hart Bar Watershed
25	East Sugarloaf Meadow	48	Hart Bar Creek

Figure 2. Watershed boundaries and streams

2) The Predictive Variables

Drainage basins serve as primary units for systematic analysis of geomorphology. Each basin is separated from its neighbor by a divide. Fluvial or other features, within a basin can be reasonably considered as an individual subsystem of the basin, having its own set of processes, geology and energy gains and losses. This study uses each tributary watershed as the basic areal unit. Characteristics of topography and climate are averaged out for each watershed. There are 42 tributary watersheds in the study area. The floodplain of the Santa Ana River and interbasin areas contributing directly to the Santa Ana River are not included for quantitative analysis (Figure 2).

In previous studies that have attempted to relate sediment yield to its causes, many meteorological and physiographic variables have been developed to describe watersheds.

The selection of variables was made in two steps. Following the logic and results of other studies (Anderson, 1957 Scott & William, 1978), and an appreciation that different data values can be created by measuring the same phenomenon in a different way, a long list of potentially useful variables was established. Secondly, statistical inferences were used to identify a short list of critical independent variables. The following list includes all variables initially considered, whether or not they were ultimately included in the analysis.

(1) The Relief Factors

The slopes of valley sides and channels, and the altitude range in a drainage basin must be among the significant factors controlling sediment yield. Steep slopes deliver water rapidly thereby decreasing lag time and increasing the peak discharge at any given frequency of flow, thus inducing high erosion rates. Steep slopes also lead to slope instability and mass wasting. In contrast, low relief and gentle slopes have greater lag times and retarded peak discharge, which reduce the sediment yield. These general rules vary with geology and climate. In this category, average slope of the watershed(WSL)[2], mean stream gradient (SG)[3], standard deviation of uniform slope(SDS)[4], altitude range(MRA)[5], relief ratio(RR)[6], ratio of surface area to planimetric area(RSP)[7], and hypsometric analysis index(HAI)[8] are included.

(2) The Area-Shape Factors

Sediment yield is a function of sediment availability. The area factors such as surface area and planimetric area are obviously positively associated with sediment availability. Drainage area(DA)[9], true surface area(SA)[10], sediment area (SED_A)[11], sediment movement factor(S_MOV)[12], total intermittent stream length (TIL)[13], frequency of intermittent streams(FI)[14], elongation ratio(ER)[15] and maximum basin length(UMWL)[16] and the dimensionless ratio of basin area to the square of basin length(Rf)[17] belong in this category.

(3) Geologic Factors

Unconsolidated surface materials are especially susceptible to erosion. In addition to this, the logic is established by the close association of extensive unconsolidated materials and transport rate and high erosion rates.

GEOL is the area occupied by soft rock units (landslides, colluvium, glacial deposits, Quaternary stream deposits, and poorly consolidated Teriary sedimentary rocks) expressed as a percentage of the total basin area.

(4) Climatic Factors

The climatic influence on sediment yield is described by average storm rainfall and snow/rain characteristics of the average precipitation. These climatic factors determine the characteristics of the run-off: total volume, peakedness, and intensity of run-off. The precipitation and rainfall variables consist average annual precipitation (AP)[18], mean annual rainfall (AV_AR)[19], 1969 flood rainfall (AV_69R)[20] and wet year rainfall (AV_WR).[21]

3. Results and Discussion

1) Classification Based on 20 Variables

The classification of watersheds in the Upper Santa Ana River Basin into geomorphic regions was initially based on all twenty variable described above. The results are presented in Figure 3. After inspecting Figure 3, and taking into account the cluster means matrix and data matrix based on each variable four major regions were distinguished.

The first, or western region includes north and south facing watersheds at the downstream end of the study area. They can be seen from Table 1, to be characterized by small to intermediate size, relatively steep mean watershed slope, high stream gradient, and a big range of relief. Since the data in Table 2 are z-scores, the negative values are below average and the positive values are above average.

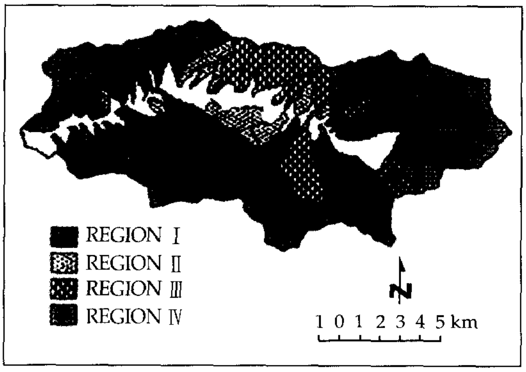


Figure 3. Classification of watersheds based on 20 variables

Table 1. Cluster Means based on 20 variables

GROUP / VARIABLE	CLASS 1	CLASS 2	CLASS 3	CLASS 4
RELIEF FACTOR				
WSL (°)	14.54	11.26	14.26	13.78
SG (°)	14.14	9.63	12.70	11.61
SDS	5.38	2.20	4.44	5.24
MRA (m)	932.55	549.32	842.77	1258.78
RR	0.28	0.22	0.25	0.16
RSP	2.77	3.44	2.19	1.40
HAI	0.47	0.41	0.45	0.53
AREA-SHAPE FACTOR				
DA (m^2)	3031875	15911534	3245055	16186153
SA (m^2)	7034040	4685107	6308803	22357514
SED_A (m^2)	3135185	1621191	3358635	16658968
S_MOV (m^2)	783582	301503	851271	3883530
TIL (m)	5127.68	2151.00	3797.10	19805.29
FI (m^2/m)	0.00184	0.00166	0.00132	0.00121
ER	0.51	0.52	0.56	0.57
UMWL(m)	3558.59	2604.17	3431.25	7875.00
GEOLOGY FACTOR				
GEOL(%)	32.25	76.66	41.10	30.14
CLIMATE FACTOR				
AP (cm)	75.51	62.66	56.11	61.04
AV_AR (cm)	51.02	42.22	26.50	21.68
AV_WR (cm)	108.86	89.86	62.82	52.23
AV_R69 (cm)	63.64	52.34	44.56	41.09

A negative number for the geologic factor indicates that a large portion of the area is covered by hard rock surfaces. Negative values for the area-shape dimensional variables indicate a relatively small watershed size.

The second or central region is an area of relatively low relief and low elevation. Unlike the other regions it is apparently dominated by depositional surfaces with very low relief factors, a high proportion of soft rock surfaces, and relatively low precipitation. Presumably deposition rates exceed erosion rates through most of this region.

There is no clear differentiation in terms of relief, geology, or climate factor between the third region, which encompasses south-facing watersheds in the middle of the Upper Santa Ana River Basin, and the fourth region, which occupies the south and south-east part of the Upper Santa Ana River Basin. These two regions are both characterized by lower relief factors than region one and are relatively dry.

The F-ratios in Table 2 represent the analysis of variance for each variable, comparing the between-cluster variance to the within-cluster variance. The size dimensional variables, which include surface area, planimetric area, sediment area, sediment movement, and maximum watershed length can be seen to have large F-ratio values, between 26.2 and 35.97. This implies that the size dimensional variables play a major role in maximizing the between-group variance relative to the within-group variance. Therefore, although the analysis uses 20 variables, it is predominantly controlled by factors relating to the size of the basins. The distinction between the third and fourth regions, is

Table 2. Cluster Means of Standardized Data (Z-score) and F-ratio based on 20 variables

		Relief Factors						
Class	Size	WSL	SG	SDS	MRA	RR	RSP	HAI
1	16	0.2980	0.5159	0.5162	0.1365	0.5192	0.2101	0.0748
2	9	-0.7811	-0.8277	-1.2511	-0.9275	-0.2497	0.8568	-0.5275
3	10	0.2049	0.0858	-0.0067	-0.1128	0.1210	-0.3391	-0.1121
4	7	0.0305	-0.2376	0.4394	1.0421	-1.0152	-1.0976	0.6756
F-Ratio		2.761	4.583	11.363	7.920	5.339	8.878	2.130
P-Value		0.055	0.008	0.000	0.000	0.004	0.000	0.112

		Area and Shape Factors							
Class	Size	DA	SA	SED_A	S_MOV	TIL	FI	ER	UMWL
1	16	-0.3229	-0.2507	-0.3222	-0.3012	-0.1957	0.4697	-0.3044	-0.2295
2	9	-0.5633	-0.5642	-0.5682	-0.6392	-0.5863	0.1549	-0.1889	-0.6816
3	10	-0.2873	-0.3475	-0.2859	-0.2537	-0.3703	-0.4449	0.3199	-0.2898
4	7	1.8727	1.7948	1.8754	1.8727	1.7303	-0.6277	0.4842	1.8153
F-Ratio		34.117	26.168	34.568	35.970	22.021	3.257	1.548	30.333
P-Value		0.000	0.000	0.000	0.000	0.000	0.032	0.218	0.000

		Geology Factor	Climate Factors			
Class	Size	Geol	AP	AV_AR	AV_R69	AV_WR
1	16	-0.3788	0.8755	0.8954	1.0137	0.9482
2	9	1.1167	-0.2746	0.2707	-0.0526	0.2115
3	10	-0.0808	-0.8604	-0.8442	-0.7866	-0.8366
4	7	-0.4497	-0.4189	-1.1857	-1.1137	-1.2468
F-Ratio		7.322	14.063	37.446	39.773	49.853
P-Value		0.001	0.001	0.000	0.000	0.000

essentially a matter of watershed size, not climate, geology, or relief. The fourth region includes all the very large watersheds; those in region three are smaller.

According to Anderson (1957), area is the "devil's own variable", since it trends to correlate with every other characteristic of a drainage basins. Size variables are one essential factor in determining total sediment yield; but other factors that influence the rate of erosion per unit area may have been occluded by the influence of total erosional surface area. To examine the role of other factors the size-related variables were excluded from the second statistical analysis, reducing the number of variables to 12.

2) Classification Based on 12 Variables

Using only twelve variables (topographic, geologic and climatic variables) (Figure 4) and excluding the size factors, we still find that four classes best explain the variance. Region Ⅰ does not change; region Ⅱ is somewhat more restricted; regions Ⅲ and Ⅳ are reconfigured. The results are summarized in the following tables: cluster means (Table 3); and standardized(z Score)cluster means (Table 4).

The western region (Ⅰ) is still characterized by relatively steep watershed slope(14.5 degrees) and stream gradients(14.1 degrees), and large range of relief (932 meters); high rainfall(51 to 109 cm) and precipitation(75.5 cm); and relatively small watersheds. Sixty-eight percent of the area is exposed hard-rock surface. For sediment yield, this region has high driving and high resisting forces. The high driving forces are defined as high relief and high precipitation. The resisting force is high due to the high proportion of hardrock surface. In addition to these, small watershed size exposes relatively small erodible surfaces.

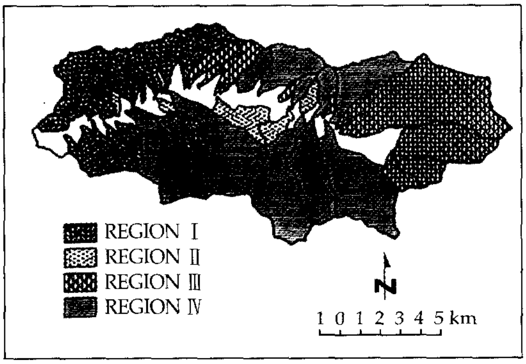


Figure 4. Classification of watersheds based on 12 variables

The second or central region has the lowest average value for the relief factor, reflecting the gentle slope of the watersheds (10.7 degrees), gentle stream gradients (9.9 degrees), and small range of relief(513 m). The geology value is high because 97.6 percent of the area is covered by soft rock. Annual precipitation(63.6 cm) is slightly below-average; however the rainfall data(43 to 93 cm) is slightly above average because the proportion of snow is relatively low. Ninety three percent of the area is located below the long-term mean snowline (2,300 m). This area has been dominated by depositional processes.

The third region now includes the eastern (west facing) watersheds, as well as watersheds transitional between regions Ⅰ and Ⅳ. The third region is characterized by relatively low relief factors (Table 3): 11.8 degree average watershed slope, 10.2 degree average stream gradient, and 631 meters of relief range. The region is also very dry with only 54.7 cm annual precipitation. Sixty eight percent of the area is exposed hard-rock. Even though some of the watersheds are large, this region must be one of relatively low sediment yield, because driving forces are low and resisting forces are high.

The fourth region, includes both north and south-facing watersheds in the middle reach of the Upper Santa Ana River Basin. They have relatively steep, average watershed slope (15.7 degrees), high average stream gradients (13.3 degrees) and an extremely large range of relief (1267 m). Also, 46 percent of this region exposes soft rock surfaces. Compared to the precipitation means of the total study area, this region has a precipitation z score of -0.21 (below average) and a rainfall z score between -0.78 and -0.98. This means most of the precipitation comes as snow, because a large proportion of this region is located at high elevation. Seventy-nine percent of the north-facing slopes in this region are located above the long-term mean snowline (2300 m). Therefore this region can be defined as having a relatively high potential erosion rate.

Futhermore, the south part of region Ⅳ consists of relatively large watersheds, whereas the north part has small watershed size. In the first classification, which is predominantly controlled by size-dimensional variables, these two parts were classified in different regions. The south (north facing) part of region Ⅳ is characterized by the highest sediment yield potential; it has the larger watersheds, greater altitude range, steeper gradients, more snow, and a relatively high potential erosion rate.

3) The Classification Functions

Discriminant linear functions that serve to differentiate the four preferred regions were created in terms of the significant variables. The following summarizes four linear composites of the predictor variables in which the ratio of between-group to within-group variability is as large as possible:

REGION Ⅰ = 3.69WSL + 0.37 GEOL + 116.43 HAI - 10752.11FI + 4.82SDS + 0.86AV_WR - 111.46
REGION Ⅱ = .87WSL + 0.62GEOL + 156.7HAI - 13411.37FI + 0.95SDS + 0.80AV_WR - 111.95
REGION Ⅲ = 2.85WSL + 0.35GEOL + 101.30HAI - 6327.07FI + 2.89SDS + 0.55AV_WR - 64.44
REGION Ⅳ = 4.11WSL + 0.43GEOL + 114.26HAI - 10311.86FI + 4.53SDS + 0.57AV_WR -93.90

Watershed average slope(WSL), geology (GEOL), hypsometric index(HAI), standard deviations from average stream gradient(SDS), wet year annual rainfall (AV_WR), and the frequency of intermittent streams(FⅠ) were identified as the significant predictor variable for discriminating between the regions. They were selected for high F-value and high independence (i.e. low of correlation with one another), and represent topographic, geology, and climatic factors. The F-matrix(Table 5) created by using the most significant predictor variables indicates that evidently the classification is very robust.

Using the linear discriminant functions, additional watersheds can be assigned to one of the

Table 3. Cluster Means based on 12 variables

GROUP VARIABLE	CLASS 1	CLASS 2	CLASS 3	CLASS 4	ALL
WSL (°)	14.54	10.73	11.7	15.65	13.64
SG (°)	14.14	9.88	10.20	03.34	12.41
SDS	5.38	1.76	3.48	5.38	4.45
MRA (m)	932.55	513.28	631.41	1267.11	883.43
RR	0.28	0.22	0.19	0.24	0.24
HAI	0.47	0.44	0.44	0.48	0.46
FI (m/m^2)	0.00184	97.60	32.64	46.50	43.52
GEOL (%)	32.25	97.60	32.64	46.50	43.52
AP	75.51	63.62	54.65	63.31	65.72
AP_AR	51.02	43.97	29.65	25.06	38.41
AV_WR	108.86	93.27	67.63	59.22	84.39
AV_R69	63.64	53.54	44.62	44.58	52.92

Table 4. Cluster Means Standardized Data (z-score) and F-ratio based on 12 variables

Class	Relief Factors					
	WSC	SG	SDS	MRA	RP	HAI
1	0.2980	0.5159	0.5162	0.1365	0.5192	0.0748
2	-0.9437	-0.7542	-1.4956	-1.0275	-0.3159	-0.1682
3	-0.6034	-0.6589	-0.5390	-0.6996	-0.6023	-0.1801
4	0.6610	0.2765	0.5156	1.0653	0.0059	0.1682
F-Ratio	6.765	5.647	13.248	15.126	3.435	0.274
P-Value	0.001	0.003	0.000	0.000	0.026	0.844

Class	Size and Shape Factors	Geology Factors	Climate Factors			
	F I	Geol	AP	AV_AR	AV_WR	AV_R69
1	0.4697	-0.3788	0.8755	0.8954	0.9482	1.0137
2	-0.6451	1.8215	-0.1883	0.3949	0.3436	0.0608
3	0.2319	-0.3658	-0.9914	-0.6203	-0.6498	-0.7812
4	-0.6774	0.1010	-0.2160	-0.9458	-0.9760	-0.7846
F-Ratio	4.455	12.647	17.383	24.281	31.230	30.991
P-Value	0.009	0.000	0.000	0.000	0.000	0.000

Table 5. F-Matrix among Four Classes based on 6 Significant Predictors

Group	Class Ⅰ	Class Ⅱ	Class Ⅲ
Class Ⅱ	19.27	---	---
Class Ⅲ	17.66	15.40	---
Class Ⅳ	13.63	16.84	8.63

Note: Watershed Average Slope-WSL; Geology-GEOL; Hypsometric Index-HAI; Standard Deviation From Average Stream Gradient-SDS; Wet Year Annual Rainfall-AV_WR; Frequency of Intermittent Stream-FI

same four regional classes. The classification scores of any additional basin must be computed for each region (multiply the data by the coefficients and add the constant term) ; the basin is assigned to the region for which the classification score is highest. This classification function offers the opportunity for comparative studies in related areas.

4) Migration of Drainage Divides

Before completing a qualitative analysis of sediment source and sediment depositional areas in these regions, it is necessary to consider the probable migration history of the watershed divides and to evaluate the role of Pleistocene glaciation.

The probable migration history of the watershed divides was interpreted from the steepness and geological composition of adjoining watersheds. It was simply assumed that steeper slopes with softer rocks retreat faster than gentler slopes in resistant rocks. Faster retreating slopes are indicative of expanding basins. Applying this principle we conclude that the southeast and eastern parts of the Upper Santa Ana watershed have been shrinking, while the western and north-west parts of the divide have been expanding. The remaining portions of the watershed divide showed no striking asymmetry and may be in equilibrium in their current locations (Figure 5).

At the head of South Fork and Fish Creek basins we would reason that the divide is now migrating north, reducing the basin size. And yet the basins form an anomalous southward reentrant into the Mill Creek basin to the south. The reentrant is the site of Pleistocene cirques, so it may be that these basins tended to enlarge during glacial climates.

In addition to gradual migration of the divides,

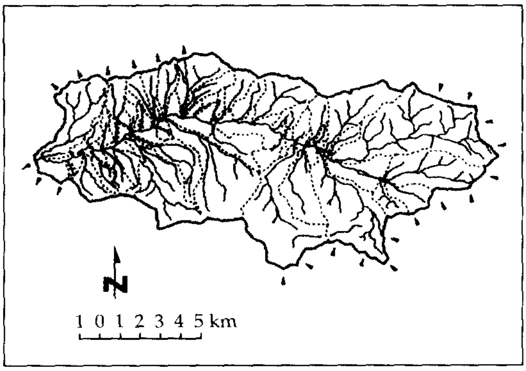


Figure 5. Direction of migration of watershed divides

Note: Arrows denote direction of watershed migration.

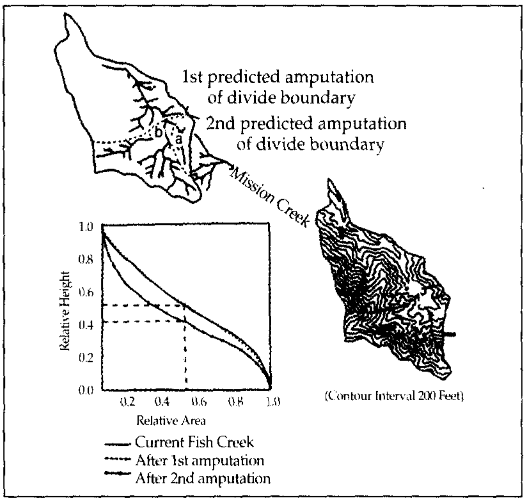


Figure 6. Future migration in Fish Creek watershed divide

stream capture may lead to abrupt loss of whole sub-basins. This occurs when part of a high order stream is captured. A textbook example is Coon Creek Jumpoff. One mile downstream from its source, the former headwater course of Coon Creek now turns abruptly south and cascades down the steep, rapidly retreating slopes at the head of Mission Creek.

Since the rate of lowering of the basin surface is probably much slower than the rate of loss of area during capture, and because capture selectively amputates upstream portions, the hypsometric analysis index should be significantly reduced following capture. Figure 6 is an attempt to predict the future of the Fish Creek watershed. At point a, a trunk stream is likely to be captured by Mission Creek; its sub-basin will be lost. If capture extends to point b, almost one-third of the area of the watershed will be lost. Eventually, due to the loss of high elevating and steep slope portions, the current hysometric index of 0.52 will decrease to 0.41 (after capture of point b).

As a result of stream capture, the erosion rate within the amputee watershed will be reduced. For example, having concluded that Fish Creek watershed has been shrinking, we should infer that it once had more area with relatively high elevation and steep slopes, and therefore that the erosion rate and sediment yield was formerly higher than at present. As this watershed continues to shrink sediment yield will fall.

Watersheds in region I are expanding; this implies that in the past, the region yielded less sediment than at present. The eastern divide of region Ⅲ and the southern divide of the north-facing slope in region Ⅳ has been encroaching, even though the current size of the watershed in these areas are relatively large. The shrinking of these watersheds implies that more erodible, steep upstream surfaces were available in the past.

5) The Role of Pleistocene Glaciation

In addition to qualitative analysis of the migration of the watershed divides, it is clear that an evaluation of Pleistocene glaciation must be included in this study. Sharp and others(1959) recognized at least six cirques and valley glaciers at elevations between 3100 and 3450 meters in the north-facing San Gorgonio Mountain area. San Gorgonio Mountain (3,505 m), the highest point in southern California, is located in the southern part of region Ⅳ of which 79 percent is above 2,300meters, the long-term mean snowline. Under present conditions, snow is persistent until July in protected, high places on north facing slopes. Snow fields persist year to year after abnormally wet winters (Minnich, 1984). Two episodes of glaciation have been distinguished at all sites in the San Gorgonio area.

The older deposits have an age at least twice and possibly several times as great as the younger episodes. Both are considered to be of Wisconsin age.

Thick deposits of boulder-rich, poorly sorted debris covering the Barton Flats region, down stream area of the glaciated area may be fluvio-glacial, in the sense that they are deposits of stream fed by melting glaciers. This distinction concerns the pattern of flood events capable of producing debris flows. In a simple fluvial regime, debris floods can be expected to follow immediately after rare storm events. In a fluvio-glacial regime, precipitation is stored as ice until melt season; there is a potential for annual debris flow events.

Glacial times were presumably characterized by higher precipitation totals. For a given glacial episode (Firnlines vary form episode to episode), whether or not the precipitation was stored as ice depends upon the altitude of the watershed. We know that parts of region Ⅳ were high enough during the last two glacials. In earlier glacial episodes the region may not yet have been sufficiently elevated to form glaciers, but would have experience enhanced precipitation.

We must also consider the possibility of accelerated mass wasting of the north-facing slope of region Ⅳ; and the ability of glacial ice masses to support oversteepened valley sides which fail upon retreat of the ice.

4. Conclusion

The purpose of this investigation is to delineate spatial variation of long term sediment yield potential among 42 sub-basins of the Upper Santa Ana River Basin. The rating of watershed for delineating spatial variation of long term sediment yield potential is based on the physical characteristics of the watershed to determine sediment yield: relief factor, area-shape factor, geology factor, and climatic factor. Among these properties of watersheds, watershed average slope(WSL), percentage of "soft rock" outcrop (GEOL), hypsometric index(HAT), standard deviation from average stream gradient(SDS), and wet year annual rainfall are selected as the significant predictor variables for differentiation among the regions. The "K-means clustering of cases" and " Stepwise discriminant" analysis are selected as the most suitable techniques.

The rating and classification exercise showed that the Region Ⅱ is the part of the upper Santa Ana basin most prone to sediment aggradation. This is indicated by the lowest relief factors, the largest proportion(97.6%) of soft rock surface, and the lack of high elevation.

Immediately upstream from the Region Ⅱ are the watersheds with the highest potential for sediment yield. These watersheds are characterized by highest relief, steepest slopes, high rainfall and large watershed size in addition to much more erodible sufaces and glaciation in the past.

The high elevation north-facing slopes in the southern part of the region Ⅳ (between Forsee Creek watershed and the Fish Creek watershed) have the highest potential sediment yield, and are suitably located to be the main source area for region II. The inferred migration of the watershed divide implies that more, rather than less, erodible surface was probably available in the past. Only this region contains obvious Pleistocene glacial geomorphology. It includes the highest elevation and north-facing slopes, which retain snow and ice in the leeside of the prevailing storm winds. It is reasonable to infer that during the last two glacial episodes, region Ⅱ downstream had a fluvio-glacial sediment transport regime i.e., one with a spring-summer melt. In interglacial episodes sediment transport would be dominated by rare storm events.

Therefore, we should expect the course of the west-flowing Santa Ana River to show some perturbation where it encounters the more prolific sediment and runoff from source on the north flank of San Gorgonio. Futhermore, brief consideration of the Climate and tectonic history reveals ample reason for complexity and change in the relationship between the dominate source area, the main depositional area, and the trunk stream of the Santa Ana River.

Notes

2) $WSL = \frac{\Sigma_i (D_i X A_i)}{\Sigma_i A_i}$

D_i = slope (in degrees) of the ith triangle within a watershed.

A_i = true surface area of the ith triangle within a watershed.

3) $SG = \frac{\Sigma_i (D_i X L_i)}{\Sigma_i L_i}$

D_i = slope (in degrees) of the ith triangle within a watershed.

L_i = true surface length of the stream segment in the ith triangle within a watershed.

4) $SDS = [\frac{\Sigma_i (SD_i - SG)^2}{N}]^{\frac{1}{2}}$

SD_i = slope degree of the ith segment in stream channel.

SG = mean stream gradient.

N = number of segments in stream channel.

5) ALTITUDE RANGE(MRA-units: meters)

MRA is measured as the difference between the maximum elevation and minimum elevation within a watershed as depicted on 1:24000-scale USGS topographic maps.

6) $RR = \frac{MRA}{UMWL}$

MRA = altitude range

UMWL = maximum watershed length (from basin mouth to drainage divide)

7) $RSP = \frac{SA}{DA}$

SA = the summation of the true surface area of individual triangles within a watershed (m^2).

DA = the planimetric area of a watershed (m^2).

8) HAI is defined by the relative height (altitude of a given contour above basin outlet/basin relief) at the point where relative area (area in basin above a given contour/total drainage area)=0.5.

9) DA is the planimetric area contained within the watershed boundaries, as resolvable on a USGS 1:24000-scale topographic map.

10) SA is determined from the TIN surface model (Appendix A). The summation of the individual triangles within each watershed is the total surface area of the watershed.

11) SED_A is defined by following formula:

SED_A = DA + COS(WSL)

DA = drainage area (m^2)

WSL = average slope of watershed

12) S_MOV = SED_A × SIN(WSL)

SED_A = sediment area (m^2)

WSL = average slope of watershed

13) TIL is the total length of all intermittent streams as depicted by blue lines on the 1:24,000-scale USGS topographic maps.

14) FI = TIL ÷ DA

TLL = total intermittent stream length (m)

DA = drainge area (m^2)

15) $ER = 2 \times [(DA \div \pi)^{1/2}] \div UMWL$

DA = drainage area (m^2)

UMWL = maximum basin length (m)

16) UMWL is the distance measured from the mouth of the basin to the upstream basin divide following the main channel.

17) $Rf = Au \div Lb^2$

Au: basin area

Lb : basin length

18) $AP = \frac{\Sigma_i(a_i \times p_i)}{\Sigma_i a_i}$

a_i = the area between ith and (i+1)th isohyetal lines in mean annual precipitation map.

p_i = mean value of precipitation between ith and (i+1)th isohyetal lines in mean annual precipitation map .

19) $AV\_AR = \frac{\Sigma_i(a_i \times Ra_i)}{\Sigma_i a_i}$

a_i = area between ith and (i+1)th isohyetal lines in the isohyetal map of the mean annual rainfall.

RA_i = mean value between ith and (i+1)th isohyetal lines in the isohyetal map of the mean annual rainfall.

20) $AV\_69R = \frac{\Sigma_i(a_i \times 69R_i)}{\Sigma_i a_i}$

a_i = the area between ith and (i+1)th isohyeta lines in the isohyetal map of rainfall during 9 days of the January 1969 storm(100 years recurrence interval).

$69R_i$ = the mean value between ith and (i+1)th isohyetal lines in the isohyetal map of rainfall during 9 days of the January 1969 storm.

21) $AV\_WR = \frac{\Sigma_i(a_i \times WR_i)}{\Sigma_i a_i}$

a_i = area between ith and (i+1)th isohyetal lines in the isohyetal map of mean annual rainfall for wet year (5 years recurrence interval flood).

WR_i = mean value between ith and (i+1)th isohtetal lines in the isohtetal map of mean annual rainfall wet year.

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