EQL Report No. 17-D

SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA MOUNTAINS, COASTAL PLAINS AND SHORELINE

PART D
SPECIAL INLAND STUDIES

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SPECIAL INLAND STUDIES

D1. INLAND CONTROL STRUCTURES

by William M. Brown III and Brent D. Taylor

William M. Brown III

D2. INLAND ARTIFICIAL SEDIMENT MOVEMENTS

by Oded C. Kolker

D3. ROLE OF VEGETATION IN SEDIMENT PROCESSES OF COASTAL SOUTHERN CALIFORNIA

by Wade G. Wells II and Nancy R. Palmer

D4. EFFECTS OF FIRE ON SEDIMENTATION PROCESSES

by Wade G. Wells II and William M. Brown III

Project directors:

Norman H. Brooks and Robert C.Y. Koh

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PREFACE

In southern California the natural environmental system involves the continual relocation of sedimentary materials. Particles are eroded from inland areas where there is sufficient relief and precipitation. Then, with reductions in hydraulic gradient along the stream course and at the shoreline, the velocity of surface runoff is reduced and there is deposition. Generally, coarse sand, gravel and larger particles are deposited near the base of the eroding surfaces (mountains and hills) and the finer sediments are deposited on floodplains, in bays or lagoons, and at the shoreline as delta deposits. Very fine silt and clay particles, which make up a significant part of the eroded material, are carried offshore where they eventually deposit in deeper areas. Sand deposited at the shoreline is gradually moved along the coast by waves and currents, and provides nourishment for local beaches. However, eventually much of this littoral material is also lost to offshore areas.

Human developments in the coastal region have substantially altered the natural sedimentary processes, through changes in land use; the harvesting of natural resources (logging, grazing, and sand and gravel mining); the construction and operation of water conservation facilities and flood control structures; and coastal developments.

In almost all cases these developments have grown out of recognized needs and have well served their primary purposes. At the time possible deleterious effects on the local or regional sediment balance were generally unforeseen or were felt to be of secondary importance.

In 1975 a large-scale study of inland and coastal sedimentation processes in southern California was initiated by the Environmental Quality Laboratory at the California Institute of Technology and the Center for Coastal Studies at Scripps Institution of Oceanography.

This volume is one of a series of reports from this study. Using existing data bases, this series attempts to define quantitatively inland and coastal sedimentation processes and identify the effects man has had on these processes. To resolve some issues related to long-term sediment management, additional research and data will be needed.

In the series there are four Caltech reports that provide supporting studies for the summary report (EQL Report No. 17). These reports include:

EQL Report 17-A -- Regional Geological History

EQL Report 17-B -- Inland Sediment Movements by Natural Processes

EQL Report 17-C -- Coastal Sediment Delivery by Major Rivers in Southern California

EQL Report 17-D -- Special Inland Studies

Additional supporting reports on coastal studies (shoreline sedimentation processes, control structures, dredging, etc.) are being published by the Center for Coastal Studies at Scripps Institution of Oceanography, La Jolla, California.

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SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA MOUNTAINS, COASTAL PLAINS AND SHORELINE

Section D1
(EQL Report 17-D)

Inland Control Structures

by

William M. Brown III

and

Brent D. Taylor

D1: Inland Control Structures

by

William M. Brown III and Brent D. Taylor

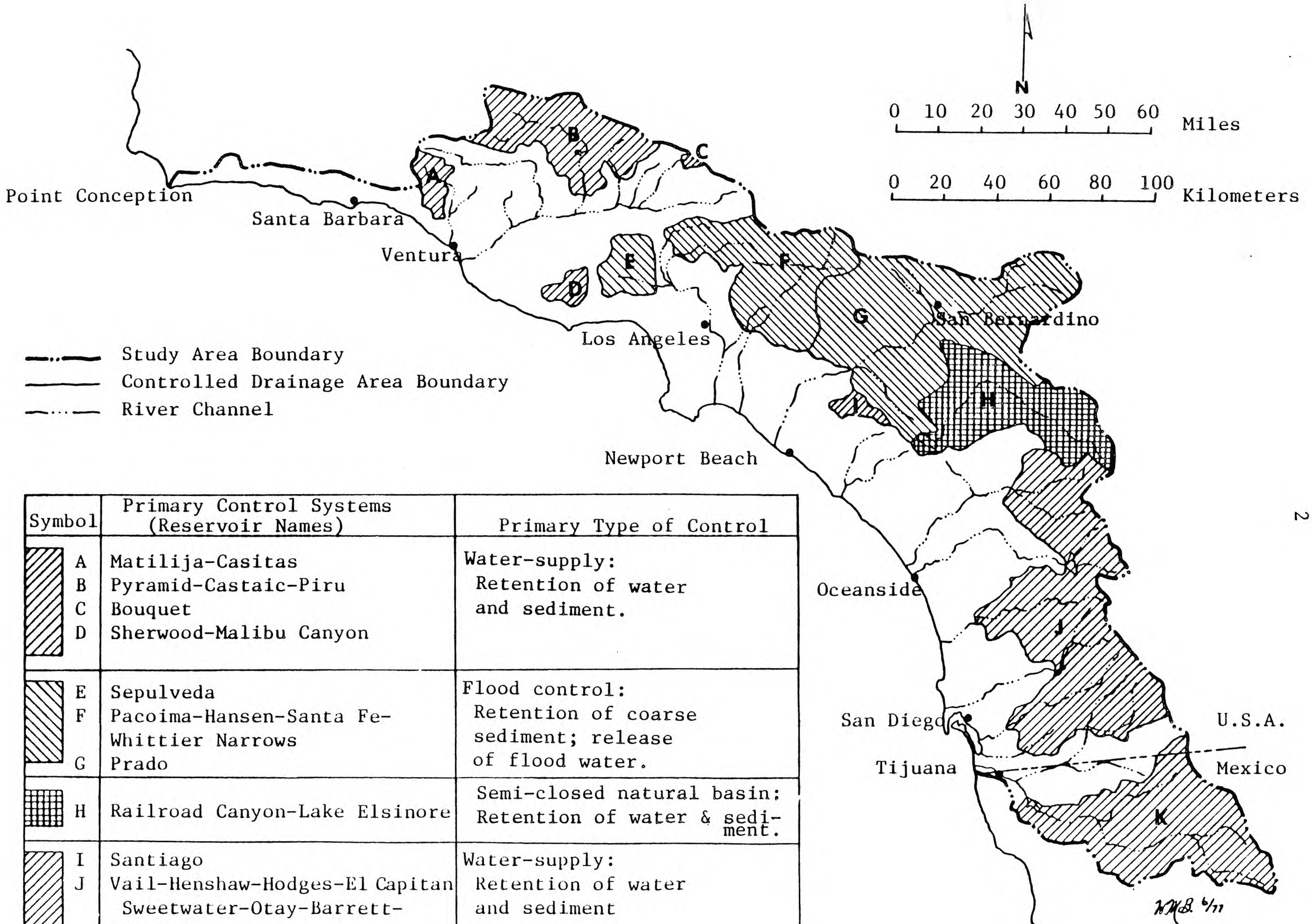
D1.1 Introduction

Between Point Conception and the USA/Mexico border the coastal drainage in southern California (Fig. D1-1) comprises 33,100 km^2 of inland area including 2,930 km^2 of drainage (Tijuana River) in Mexico. This coastal region has more than 450 km of shoreline, with varied geologic, topographic and climatic factors throughout. Thirteen million people who live between the mountains and the shoreline in this region are continually faced with several major problems involving their rivers and beaches. These problems relate to inundation of developed areas by water and debris during floods, water supply, construction needs for sand and gravel, and preservation and maintenance of natural areas including national forests and beaches. Dissimilar though they may seem, these problems are interrelated through common connectives of rivers and streams that originate in the mountains and typically cross inhabited areas enroute to the coast.

In dealing with these problems, the people of southern California have constructed extensive networks of debris basins, dams, canals, percolation basins (spreading grounds), lined channels, levees, mining pits, artificial fills and related structures and excavations, which affect natural stream mechanics.

The purpose of section D1 is to generally identify the types and geographic extent of inland structures that can affect the movement of water and sediment in coastal basins of southern California, as a basis for analysis of the extent to which human activity has altered inland sedimentation processes in southern California.

In the following sub-section, different types of control structures in use are described. Then in sub-sections D1.3 and D1.4 as an example, the Los Angeles River Basin, the most intensively controlled drainage basin in the study area, and perhaps in the U.S., is described



Symbol	Primary Control Systems (Reservoir Names)	Primary Type of Control
A B C D	Matilija-Casitas Pyramid-Castaic-Piru Bouquet Sherwood-Malibu Canyon	Water-supply: Retention of water and sediment.
E F G	Sepulveda Pacoima-Hansen-Santa Fe- Whittier Narrows Prado	Flood control: Retention of coarse sediment; release of flood water.
H	Railroad Canyon-Lake Elsinore	Semi-closed natural basin: Retention of water & sediment.
I J K	Santiago Vail-Henshaw-Hodges-El Capitan Sweetwater-Otay-Barrett- Morena Rodriguez	Water-supply: Retention of water and sediment

Figure D1-1: Major Drainage Areas controlled by downstream dams in Southern California Study Area.

in terms of natural conditions (D1.3) and present conditions (D1.4), to outline the effects of aggregate control systems or large drainages.

A comprehensive tabulation of public control structures throughout the study area is given in Table D1-1, and Plate D1-1 provides a general, synoptic view of the spatial distribution of these structures. Data for this tabulation and mapping were compiled primarily from published and unpublished reports, maps and data from seven county agencies and from topographic maps published by the U.S. Geological Survey. Contributing county agencies include:

-Los Angeles County Flood Control District
-Orange County Environmental Management Agency
-Riverside County Flood Control and Water Conservation District
-San Bernardino County Flood Control District
-San Diego County Department of Sanitation and Flood Control
-Santa Barbara County Flood Control and Water Conservation District
-Ventura County Flood Control District

D1.2 Regional Sedimentation Control Facilities

Check Dams

Check dams are smaller sediment retention structures intended to reduce the yield of debris from upland catchments. These structures are located along primary and secondary channels often well upstream from the mouth of the catchment. All of the check dams identified in Table D1-1 were designed and built by the U.S. Forest Service. Lesser check dams not included here but numbering in the hundreds throughout the study area have been built of a variety of materials such as wire-mesh and rock (gabion-type).

Forest Service check dams are concrete crib structures set on a reinforced concrete base. They are generally low structures (3-5 meters high), and are built in sequence along a channel to reduce the stream gradient between structures. In addition to reducing stream gradient these check dams are meant to raise and stabilize (vertically) the streambed (i.e. prevent down-cutting). Raising the streambed generally widens the flood channel in an upland catchment.

TABLE D1-1: STRUCTURES AFFECTING THE MOVEMENT OF WATER AND SEDIMENT IN COASTAL BASINS OF SOUTHERN CALIFORNIA

Santa Barbara County

Structure: Dams (Reservoir type)*	Drainage Area (km²)	Year**
Buell (WS)	.26	1927
Dos Pueblos (WS)	3.37	1946
Glenn Annie (WS-A)	NA	1953
La Patera (WS)	.67	1932
Lake Los Carneros (WS)	.67	1932
Lauro (WS-A)	NA	1952
Ortega (WS-A)	NA	1954
Rancho Del Ciervo (WS)	1.04	1938
Sheffield (WS-A)	NA	1925
Check Dams (Number)		
Arroyo Paredon (2)		1972
Carpintera Creek (1)		1972
Cieneguitas Creek (4)		NA
Cold Springs Canyon (1)		1965
Franklin Creek (3)		1972
Gobernador Creek (1)		1972
Highschool Creek (2)		1972
Hospital Creek (2)		1962
Mission Creek (2)		1965
Rattlesnake Canyon (1)		1965
Romero Creek (3)		1972
San Antonio Creek (1)		1965
San Roque Canyon (1)		1965
Santa Monica Creek (2)		1972
Sycamore Creek (2)		1977
Tecolito Creek (2)		1969
Tecolote Canyon (2)		1961
Toro Canyon (3)		1972

Ventura County

Structure: Dams (Reservoir type)	Drainage Area (km²)	Year
Anola (WS)	0.26	1924
Casitas (WS/R)	101.01	1959
Lake Eleanor (IA)	3.11	1881
Lake Sherwood (WS)	41.44	1904
Matilija (WS)	142.45	1949
Meiners Oaks (IA)	.26	1950
Robles Diversion (WS)	191.66	1958
Runkle (WS)	4.14	1949
Santa Felicia (WS/R)	1092.98	1955
Senior Canyon (WS)	.26	1964
Shell Oil Co. (IA)	.26	1946
Sinaloa Lake (R)	9.07	1925
Tapo Hills East (WS)	.52	1977
Taylor #2 (IA)	163.17	1954
Westlake (R)	2.33	1972
Wood Ranch (WS)	2.46	1965
Debris Basins		
Arundell Barranca	6.99	1970
Castro Williams	1.35	1957
Cavin Road	.36	1933
Coyote Canyon	18.41	1955
Crestview	.34	1934
Dent	.10	1950
Edgemore	.41	1955
Erringer	1.3	1957
Ferro	1.61	1933
Fox Barranca	12.54	1956
Franklin Barranca	1.35	1934
Gabbert Canyon	9.51	1963
Honda West	3.0	1955
Jepson Wash	3.16	1961
Los Posas Estates	.44	1956
Ramona	1.14	1961
Real Wash	.65	1964
Runkle Canyon	3.89	1950
St. Johns	.98	1957
Santa Rosa Rd. #1	1.35	1957

Ventura County

Structure: Debris Basins	Drainage Area (km²)	Year
Santa Rosa Rd. #2	3.89	1957
Stewart Canyon	5.13	1963
Tapo Hills #1	.36	1971
Warring Canyon	2.82	1952
W.Camarillo Hills, East	.36	NA
W.Camarillo Hills, West	.31	1955

Los Angeles County

Structure: Dams (Reservoir type)	Drainage Area (km²)	Year
Ascot (WS)	1.14	1926
Big Dalton (FC/WS)	11.66	1927
Big Santa Anita (FC/WS)	27.97	1924
Big Tujunga (FC/WS)	213.16	1930
Bouquet Canyon (WS-A)	35.22	1934
Brand Park (WS)	.26	1930
Browns Barrier (FC)	38.85	1942
Castaic (WS-A/R)	398.86	1973
Castaic Forebay (WS-A/R)	196.84	NA
Century (WS)	176.38	1913
Channel Diversion Dike (WS)	19.94	1940
Chatsworth (WS)	13.99	1918
Chevy Chase (WS)	1.50	1927
Chevy Chase 1290 (WS)	.26	1940
Cogswell (FC/WS)	101.53	1932
Devils Gate (FC/WS)	82.62	1919
Diederich (WS)	.26	1950
Drinkwater (WS)	.03	1946
Dry Canyon (WS)	11.66	1912
Eagle Rock (WS)	.26	1953
East Glorietta (WS-A)	NA	1932
Eaton Wash (DC/WS)	24.50	1936
Elysian (WS)	.26	1903
Encino (WS)	3.63	1924
Fairmont (WS)	6.73	1912
Garvey (WS)	.26	1954
Glenoaks (WS)	.26	1949
Green Verdugo (WS)	.26	1953
Greenleaf (WS)	.85	1921
Greystone (WS-A)	NA	1970
Hansen (FC)	381.00	1940
Highland (WS)	.10	1909
Ivanhoe (WS-A)	NA	1906
J.W. Wisda (WS)	.57	1958
Laguna Regulatory Basin (WS)	14.5	1970
Lake Van Norman Bypass (WS)	.26	1970
Lindero (WS)	12.95	1966
Live Oak (DC/WS)	5.96	1921
Lopez (FC)	88.06	1954
Los Angeles (WS)	33.67	NA
Lower Franklin (WS)	3.21	1922
Lower San Fernando (WS)	36.78	1918
Malibu Lake Club (WS)	165.76	1923
Morris (WS)	562.03	1935
Morris S. Jones (WS-A)	NA	1952
Mulholland (WS)	2.59	1924
Pacoima (FC/WS)	73.04	1925
Palos Verdes (WS)	2.59	1939
Porter Estate (WS)	2.23	1888
Portrero (WS)	74.85	1967
Puddingstone (FC/R)	57.24	1925
Puddingstone Diversion(FC/WS)	51.54	1927
Pyramid (WS-A)	758.87	1973
Reservoir #1 (WS)	.26	1928
Reservoir #4 (WS)	NA	1955
Reservoir #5 (WS-A)	NA	1949
Riviera (WS-A)	NA	1962
Rowena (WS)	.26	1911
Rubio Diversion (DC/WS)	7.61	1944
San Antonio (FC)	69.93	1956
San Dimas (FC/WS)	41.96	1920

TABLE D1-1: (Con't)

Los Angeles County

Structure: Dams (Reservoir type)	Drainage Area (km^2)	Year
San Gabriel #1 (FC/WS)	524.99	1932
Santa Fe (FC)	611.24	1949
Santa Ynez Canyon (WS)	.57	1968
Sawpit (FC/WS)	8.65	1926
Sawtelle (WS)	.85	1924
Sepulveda (FC)	393.68	1941
Sierra Madre (DC/WS)	6.19	1927
Silver Lake #1 (WS)	.39	1907
Silver Lake #2 (WS)	.34	NA
Stone Canyon (WS)	3.52	1924
10 Walteria (WS-A)	NA	1953
10th & Western (WS)	2.67	1924
Thompson Creek (FC/WS)	9.07	1925
Upper Franklin (WS)	1.37	1915
Upper Hollywood (WS)	.96	1933
Upper San Fernando (WS)	1.37	1921
Upper Stone Canyon (WS)	1.71	1954
Weymouth Memorial (WS-A)	NA	1966
Whittier Narrows (FC)	1434.86	1957
Whittier Reservoir #4 (WS)	.26	1931
Yarnell Debris Basin(WS)	.28	1963

Debris Basins

Debris Basins	Drainage Area (km^2)	Year
Afton	.16	1974
Aliso	7.17	1970
Altadena Golf Course	.52	1945
Arbor Dell	.28	1971
Auburn	.49	1954
Bailey	1.55	1945
Beatty	.70	1970
Bell Creek	18.13	1967
Big Dalton	6.79	1959
Blanchard	1.30	1968
Blue Gum	.49	1968
Brace	.75	1971
Bradbury	1.76	1954
Brand	2.67	1935
Carriage House	.08	1970
Carter	.31	1954
Cassara	.54	1976
Chamberlain	.10	1974
Childs	.80	1963
Cloud Creek	.05	1972
Cloud Croft	.54	1973
Cooks	1.50	1951
Deer	1.53	1954
Denivelle	.47	1976
Dunsmuir	2.18	1935
Eagle	1.24	1936
Elmwood	.80	1964
Emerald East	.83	1964
Englewild	1.04	1961
Fairoaks	.54	1935
Fern	.78	1935
Fieldbrook	.91	1974
Golf Club Drive	.83	1970
Gordon	.47	1973
Gould	1.22	1947
Haines	3.96	1935
Halls	2.75	1935
Harrow	1.11	1958
Haven Way	.57	1971
Hay	.52	1936
Hillcrest	.91	1962
Hog	.78	1969
Hook East	.47	1968
Hook West	.44	1970
Irving Drive	.08	1974
Kinneloa East	.52	1964
Kinneloa West	.41	1966
La Tuna	13.83	1955
Lannan	.65	1954
Las Flores	1.17	1935

Los Angeles County

Structure: Debris Basins	Drainage Area (km^2)	Year
Limekiln	9.56	1963
Lincoln	1.30	1935
Linda Vista	.96	1970
Little Dalton	8.57	1959
Maddock	2.17	1954
May #1	1.81	1953
May #2	.23	1953
Morgan	1.55	1964
Mull	.39	1973
Mullally	.88	1974
Nichols	2.43	1937
Oak	.13	1975
Oakglade	.16	1974
Pickens	3.89	1935
Pinelawn	.05	1973
Rowley	.70	1953
Rowley Upper	.80	1976
Rubio	3.26	1943
Ruby Lower	.73	1955
Santa Anita	4.40	1959
Sawpit	7.36	1954
School	1.71	1945
Schoolhouse	.73	1962
Shields	.08	1937
Sierra Madre	6.19	1927
Sierra Madre Villa	3.78	1957
Snover	.60	1936
Sombrero	2.75	1969
Spinks	1.14	1958
Starfall	.34	1973
Stetson	.75	1969
Stough	4.27	1940
Sturtevant	.08	1967
Sullivan	6.16	1970
Sunnyside	.05	1970
Sunset Lower	1.68	1963
Sunset Upper	1.14	1928
Turnbull	2.56	1952
Upper Shields	.52	1976
Verdugo	24.35	1935
Ward	.26	1956
West Ravine	.65	1935
Wilbur	15.18	1942
Wildwood	1.68	1967
Wilson	6.68	1962
Wining	.47	1968
Zachau	.91	1956

Check Dams (Number)

Check Dams (Number)	Year
Allen Reservoir (2)	1968
Arroyo Seco (15)	1965
Barn Canyon (1)	1970
Bear (1)	1970
Beatty Canyon (3)	1970
Beckley Canyon (11)	1965
Blanchard Canyon (8)	1969
Browns (4)	1971
Clamshell Canyon (1)	1959
Cooks Canyon (9)	1956
Coon Canyon (23)	1948
Dunsmore Canyon (9)	1963
El Prieto Canyon (18)	1968
Englewild Canyon (1)	1970
Fern Canyon (9)	1967
Girl Scout Canyon (3)	1970
Glencoe Canyon (5)	1969
Gooseberry Canyon (5)	1967
Goss Canyon (6)	1968
Haines Canyon (14)	1971
Harding (1)	1970
Harrow Canyon (5)	1970
Hay Canyon (3)	1968
Hillcrest Canyon (2)	1970
Hilltop Canyon (3)	1970

TABLE D1-1: (Con't)

Los Angeles County

Structure: Check Dams (Number)	Drainage Area (km^2)	Year
Hook East Canyon (1)		1970
Hook West Canyon (3)		1970
Hyman Canyon (2)		1970
Iron (1)		1970
Las Flores Canyon (3)		1966
Leaming (1)		1971
Lost Mine Canyon (1)		1970
Monrovia Canyon (7)		1958
Mullally Canyon (5)		1965
Nino Canyon (3)		1948
Nursery Canyon (3)		1970
Oak Canyon (2)		1963
Pennsylvania Canyon (1)		1970
Pickens Canyon (20)		1964
Rainbow Canyon (4)		1970
Ruby Canyon (4)		1966
Sand (1)		1970
Santa Anita Canyon (53)		1958
Sawpit Canyon (35)		1960
Schoolhouse Canyon (8)		1967
Shields Canyon (4)		1968
Sombrero Canyon (5)		1962
Spanish Canyon (14)		1964
Towsley (1)		1971
Ward Canyon (3)		1963
Wilson Canyon (8)		1966
Winery Canyon (3)		1964
Winifred (2)		1970
Spreading Grounds		
Arroyo Seco		1948
Ben Lomond		1958
Big Dalton		1931
Branford		1956
Buena Vista		1954
Citrus		1960
City of Pomona		NA
Dominguez Gap		1957
Eaton Basin		1956
Eaton Wash		1947
Fish Creek		ca. 1917
Forbes		1964
Hansen		1944
Irwindale		1958
Laguna		1962
Little Dalton		1931
Live Oak		1961
Lopez		1956
L.A. City - Headworks		1938
L.A. City - Tujunga		1931
Pacoima		1932
Peck Road		1959
Rio Hondo Coastal		1937
San Antonio		1921
San Dimas Canyon		1965
San Gabriel Canyon		ca. 1917
San Gabriel Coastal		1938
San Gabriel River Lower		1954
San Gabriel River Upper		1965
Santa Anita		1944
Santa Fe		1953
Sawpit		1946
Sierra Madre		ca. 1933
Thompson Creek		ca. 1928
Walnut Creek		1962
Walteria		1962

San Bernardino County

Structure: Dams (Reservoir type)	Drainage Area (km^2)	Year
Alta Loma Basin #1(DC)	5.44	1964
Alta Loma Basin #2(DC)	1.40	1971
Bear Valley (WS/R)	98.42	1911
Cedar Lake (WS)	1.3	1928
Chino Ranch #1 (WS)	4.66	1918
Desilting Basin #3 (DC)	33.67	1934
Desilting Basin #6 (DC)	33.67	1937
Devils Canyon Dyke #1 (FC)	15.54	1934
East Highlands (WS-A)	NA	1885
Glen Martin (WS)	.78	1950
Little Mountain (FC)	13.52	1958
Mineral Hot Springs Lake(WS)	.26	1967
Perris Hill (WS-A)	NA	1962
Rancho Cielito (WS)	2.07	1912
Small Canyon (FC)	2.28	1957
Wiggins #2 (FC)	.39	1957
Debris Basins (Number)		
Banana (1)	NA	1944
Baseline (2)	NA	1941
Basin #3 (1)	NA	1964
Beryl (1)	NA	1950
Brush Canyon (1)	NA	1956
Cactus (2)	NA	1965&69
Cherbak (1)	NA	1971
Church Street (1)	NA	1958
College Heights (4)	NA	1958
Cook Canyon (1)	NA	1971
Cucamonga (3)	NA	1930's
Cucamonga Cross Walls (13)	NA	1930
Daley (1)	NA	1953
Day Creek (2)	NA	1975
Demens Basin #1 (1)	NA	1958
Devil Canyon (7)	NA	1930's&70's
Diversion Gate (1)	NA	1934
Dynamite (1)	NA	1949
East Badger (1)	NA	1957
8th Street (3)	NA	1938
Elder Creek (1)	NA	1971
Ely (3)	NA	1950
Etiwanda Conservation (1)	NA	1954
15th Street (1)	NA	1935
Frankish (7)	NA	1961
Gray (1)	NA	1961
Harrison (1)	NA	1948
Hickory (1)	NA	NA
Jurupa (1)	NA	NA
Lee Hill Canyon (1)	NA	1964
Lemon (1)	NA	1966
Linden (1)	NA	1960
Little Sand Canyon (1)	NA	1970
Lynwood (4)	NA	1963
Loma Linda (3)	NA	1959
Macy (1)	NA	1946
Marble (1)	NA	1960's
McQuiddy Basin #4 (1)	NA	1962
Merrill (1)	NA	1960
Meryl (1)	NA	1961
Mill (1)	NA	1957
Montclair (4)	NA	1954
North Badger (1)	NA	1957
Oak Creek (1)	NA	1971
Patton (1)	NA	1961
Pepper (3)	NA	1958
Redhill (1)	NA	1938
Rich (1)	NA	1955
Riverside (1)	NA	1971
San Antonio (5)	NA	1920's
San Canyon (1)	NA	1971
San Sevaine (5)	NA	1960&76
Scott Canyon #1 (1)	NA	1975
South Badger (1)	NA	1957
Sweetwater (1)	NA	1955
Sycamore (1)	NA	1957
13th Street (1)	NA	1954
Turner (9)	NA	1971&76
29th Street (3)	NA	1953
Twin Creek (1)	NA	1942
Victoria (1)	NA	1975

TABLE D1-1: (Con't)

San Bernardino County

Structure: Debris Basins (Number)	Drainage Area (km^2)	Year
Warm Creek Conservation (4)	NA	1976
Waterman (4)	NA	1940
West Badger (1)	NA	1957
West Frankish (1)	NA	1971
Wiggins Basin #1 (1)	NA	1958
Wilson Creek (4)	NA	1959
Wineville (1)	NA	1945

Riverside County

Structure: Dams (Reservoir type)	Drainage Area (km^2)	Year
Allesandro (WS)	13.47	1956
Box Springs (WS)	10.62	1960
El Casco (WS)	2.59	1879
Fairmont Park (WS)	56.98	1923
Foster (WS)	2.33	1945
Hall Mill (WS)	3.89	1949
Harrison St. (WS)	5.18	1954
Hole (WS)	90.65	1922
Lake Hemet (WS/R)	173.53	1895
Lee Lake (WS)	139.86	1923
Little Lake (WS)	.31	1891
Mabey Canyon (WS)	3.89	1974
Matthews (WS-A)	103.60	1938
Mockingbird Canyon (WS)	31.08	1914
Perris (WS)	25.9	1973
Pigeon Pass (WS)	20.98	1958
Prado (FC/R)	5775.70	1941
Prenda (WS)	5.18	1954
Quail Valley (WS)	4.14	1959
Railroad Canyon (WS/R)	1859.62	1928
Robert A. Skinner (WS/R)	132.09	1973
San Jacinto (WS-A)	NA	1946
Sycamore (WS)	38.85	1956
Vail (WS/R)	826.21	1949
Woodcrest (WS)	14.50	1954

Orange County

Structure: Dams (Reservoir type)	Drainage Area (km^2)	Year
Big Canyon (WS-A)	NA	1959
Bonita Canyon (WS)	10.36	1938
Brea (FC/WS)	56.98	1942
Carbon Canyon (FC/WS)	49.99	1961
Diemer (WS-A)	NA	1963
Diemer #8 (WS-A)	NA	1958
El Toro (WS)	.26	1967
Fullerton (FC/WS)	12.95	1941
Harbor View (WS)	1.01	1964
Harvill #1 (WS)	.26	1942
Harvill #2 (WS)	1.14	1941
Laguna (WS)	2.59	1938
Lake Mission Viejo (R)	9.32	NA
Lambert (WS)	.52	1929
Olive Hills (WS-A)	NA	1962
Orange County (WS-A)	NA	1941
Palisades (WS)	.26	1963
Peters Canyon (WS)	4.40	1932
Rattlesnake Canyon (WS)	5.18	1959
Rossmoor #1 (WS)	.60	1964
San Joaquin (WS)	.91	1966
Sand Canyon (FC/WS)	16.58	1941
Santiago Creek (WS/R)	163.17	1933
Settling Basin (WS)	.26	1947
Sulphur Creek (WS)	11.91	1966
Syphon Canyon (WS)	.75	1949
30 Central (WS-A)	NA	1924
Trampas Canyon (WS)	1.81	1975
Tri-City Park (WS)	.26	1900
Veeh (WS)	5.44	1936
Villa Park (WS)	214.97	1963
Walnut Canyon (WS)	.85	1968
Yorba Linda (WS)	2.85	1907

Orange County

Structure: Spreading Grounds	Drainage Area (km^2)	Year
Anaheim Lake or Crill Basin		NA
Burris Pit		1975
Santa Ana River		NA
Warner Basin		1975

San Diego County

Structure: Dams (Reservoir type)	Drainage Area (km^2)	Year
Alvarado Regulatory (WS-A)	NA	1950
Aqua Tibia (WS)	.26	1947
Barret (FC/WS)	644.91	1922
Bernardo (WS-A)	NA	1964
Blossom Valley (WS-A)	NA	1962
Calavera (WS)	9.32	1940
Campo Lake (WS)	199.43	1948
Chet Harrit (WS)	4.4	1962
Chollas (WS)	.26	1901
Corte Madera (WS)	6.48	1919
Cottonwood (WS)	.26	1971
Cuyamaca (FC/WS)	31.08	1887
Dixon (WS)	9.58	1970
Earl Thomas (WS-A	NA	1958
El Capitan (FC/WS)	492.1	1934
Grossmont (WS)	.54	1890
Henry Jr. (WS)	24.09	1929
Henshaw (FC/WS)	530.95	1923
Lake Hodges (FC/WS)	784.77	1918
Lake Loveland (FC/WS)	253.82	1945
Lake Wohlford (FC/WS)	20.98	1924
Mary Jo (WS)	23.57	1930
Matthews (WS)	.39	1967
Miramar (WS)	2.69	1960
Morena (FC/WS)	295.26	1895
Mt. Helix (WS)	.41	1927
Mt. Woodson (WS-A)	NA	1958
Murray (WS)	9.32	1918
Palo Verde (WS)	139.86	1970
Pechstein (WS)	.26	1926
Poway (WS)	6.48	1971
Red Mountain (WS)	.60	1949
San Dieguito (WS)	4.14	1918
San Marcos (WS)	1.14	1958
San Marcos (WS)	75.11	1946
San Vicente (FC/WS)	194.25	1943
Savage (FC/WS)	255.37	1919
Squires (WS)	.26	1963
Sutherland (FC/WS)	139.86	1954
Sweetwater Main (FC/WS)	471.38	1888
Thing Valley (WS)	26.94	1961
Turner (WS)	26.94	1971
Upper 45 (WS)	4.92	1927
Upper Otay (WS)	32.63	1901

*Key to reservoir types:
WS = water supply; WS-A = water supply from aquaduct bringing water from outside study area; WS/R = water supply and recreation; R = recreation; IA = inactive, may serve as sediment trap; FC = flood control; FC/WS = flood control & water supply; FC/R = flood control and recreation; DC/WS = debris control and water supply; WS-A/R = water supply from aquaduct and recreation

**Year in which the structure was completed.

Reduction of the net stream gradient tends to reduce the streams' competence to transport debris, and thus may reduce sediment yield. However, field experience (Ruby, 1973a,b) suggests that the Forest Service check dams have not been effective in accomplishing this objective. The volume of debris and the mechanics of its movement in the mountain canyons are such that the check dams appear to be at best only temporarily effective. Once the channels behind the check dams have filled, debris movements down the canyons seem to proceed as if the check dams were not present. Check dams are intended for one-time filling, and periodic removal of accumulated debris behind them is not a design condition. A more complete description of the design, construction and effectiveness of the Forest Service check dams is presented in reports by Ruby (1973a,b).

Debris Basins

The basic purpose of debris basins is to trap boulders, gravel and other coarse debris, while allowing through-flow of water and fine sediment during storm events (Fig. D1-2). Debris basins are significantly larger than check dams and are located near the mouths of the catchments, just upstream from where flood flows enter developed areas. As shown in Fig. D1-3, in some cases debris basins have been installed downstream from check dams. While individual check dams may retain hundreds or thousands of cubic meters of debris, a debris basin is generally built with a storage capacity one or two orders of magnitude larger than this, i.e. tens of thousands up to hundreds of thousands of cubic meters of debris storage capacity.

A debris basin is created by construction of a concrete or earth-fill dam including an overflow spillway for the largest flood flows. Inside a typical basin, a large vertical pipe with many orifices allows passage of moderate flows with fine sediments to the downstream channel, typically lined. The riser pipe drains the accumulated sediments after storm events, as no water storage is intended. Periodically, debris is removed from the basins and transported to a disposal site in the area.

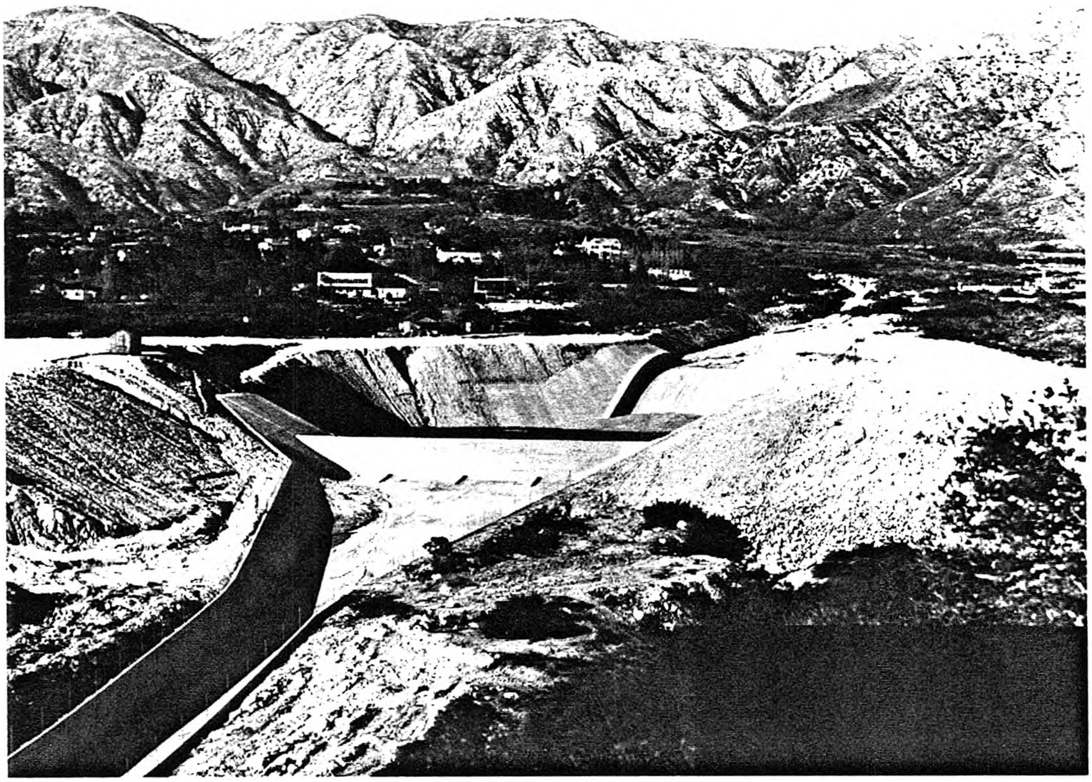


Figure D1-2: Pickens Debris Basin, La Crescenta, when first constructed, 1936 (photo by Los Angeles County Flood Control District). Inflow is from upper left, outflow is into a lined channel, lower left. Basin was first filled completely in the 1938 floods.

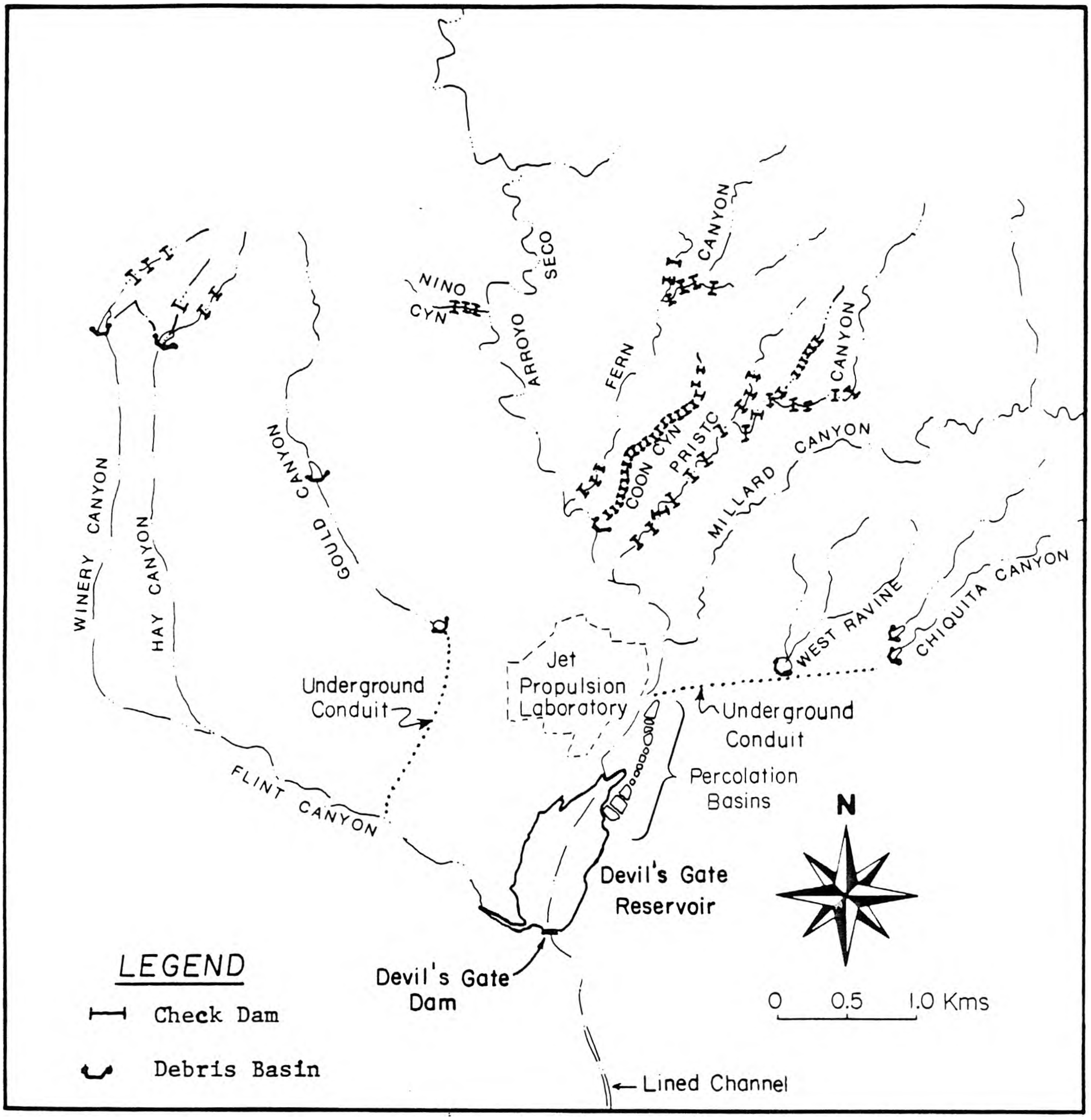


Figure D1-3. System of check dams, debris basins and percolation basins in Arroyo Seco drainage above Devils Gate Reservoir. The Arroyo Seco is a tributary to the Los Angeles River and is located near Pasadena in the western San Gabriel mountains.

The periods between cleanouts are dependent upon intervening flood events, basin capacity, and the level to which debris may accumulate before the basin is deemed unsafe with respect to potential storms. Most basins are excavated every three to five years, but basins on recently burned drainages may be excavated two or three times during a single season and longer basins may be allowed to accumulate debris for a decade or more.

Flood-Control, Water Conservation and Multipurpose Reservoirs

Floodwater control and water conservation are important in semiarid southern California, and thus an extensive system of reservoirs and transfer facilities have evolved with growth in population. Many of these reservoirs originally constructed for either flood control or municipal and agricultural water supply, now serve multiple purposes including recreation.

The majority of these reservoirs are intended to store runoff from local hills and mountains; however, some reservoirs store imported water brought in by aqueducts from northern California, Owens Valley, and the Colorado River. Numerous small private reservoirs that might be classified as stock ponds are not listed in Table D1-1 or shown on Plate D1-1. These are primarily earthen structures built to trap local runoff and have very small capacities and drainage areas.

Flood-control basins are large structures whose primary function is the storage of floodwater for gradual release at safe discharges. During the winter flood season, such basins are kept at low storage levels or dry so that design flood flows may be accommodated. Therefore, water conservation is limited when water storage could interfere with flood-control operations. Despite storage restrictions, efforts are made to release storm flows such that they can be conserved by groundwater recharge through spreading grounds and natural channels. The reservoir floors of larger basins, such as Whittier Narrows and Sepulveda, are developed for multiple recreational uses during the dry season.

Percolation Basins

Percolation basins, or spreading grounds, are shallow excavations into which water is diverted for percolation into underlying alluvium. The water is thereby effectively stored in natural ground water reservoirs with negligible evaporative losses.

Most percolation basins are built near stream channels so that surplus water can be easily diverted. In some cases, such as along the San Gabriel and lower Santa Ana rivers, the channel itself is maintained to act as a series of percolation basins through the use of earthen baffles or barriers. These baffles operate effectively during periods of low and moderate flow, but wash out with high flows and must be periodically rebuilt. Percolation areas are also located in flood control basins and sand-and-gravel mining pits.

Sand and Gravel Mining Pits

Sand and gravel mining pits are sizeable excavations from which basic materials for construction and road building are derived. These excavations are located in stream channels, on flood plains adjacent to stream channels, on alluvial fans, and in poorly consolidated bedrock in off-stream locations. Excavations in stream channels can lead to sediment entrapment during floods, roughly similar to that which takes place in debris basins. In fact, coarse sediments excavated from the channels during dry periods may be in part replaced by the streams during periods of flood flow. As suggested in EQL Report 17-B, the natural replacement of material may be accompanied by significant channel changes upstream and downstream as the natural stream adjusts to this artificial perturbation.

D1.3 The Los Angeles River Drainage: A Case Study

Prior to human alterations, the channels of the Los Angeles River (Fig. D1-4) delivered both water and sediment from numerous geologically erosional upland catchments* to alluvial fans and coastal plains areas.

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*The geologically erosional area is approximately 1200 km^2 out of the total drainage area of 2155 km^2.

On the fans and coastal plains, much of the water percolated into the thick layers of alluvium, and consequently much of the sediment was deposited along the channel. With sufficiently large discharge from the mountain catchments some water and sediment flowed across the coastal plains to nearshore marshes and lagoons which were separated from the ocean by narrow barriers of sand. During especially high flows, these sand barriers must have been breached, allowing water and sediment to flow directly into the ocean. In such cases most of this sediment (primarily silt and clay particles) was transported to offshore areas, while coarser material (sand) was deposited at the shoreline providing beach nourishment.

Quantitative details of the processes described above are only partially understood for the coastal plains and nearshore environment, and while many of the mountain channels remain essentially uncontrolled, and their natural behavior may be observed today, stream channels on coastal plains and through nearshore marshes and lagoons have been severely altered by human activities. Therefore, the only information available on the character of natural riverine sediment movement in these areas comes from early maps and reports, and geologic strata underlying developed areas.

Figure D1-4 identifies active and antecedent downstream channels of the Los Angeles, San Gabriel, and Santa Ana rivers in 1917, prior to most human alterations. Tributaries of the Los Angeles River emanate from the western San Gabriel Mountains and spread across the San Fernando Valley floor before funneling into a single channel near Glendale. Thence, the channel was confined as far as Los Angeles where the river is shown to have taken two alternate courses that converge about 10 km north of Long Beach. The channel then divided again before entering the lagoon just west of the City of Long Beach. Prior to a large flood in 1825, the Los Angeles River flowed westerly from a point just south of Los Angeles into a coastal lagoon southeast of Santa Monica (Troxell and others, 1942). The approximate course of the river before 1825 is shown as a dashed line.

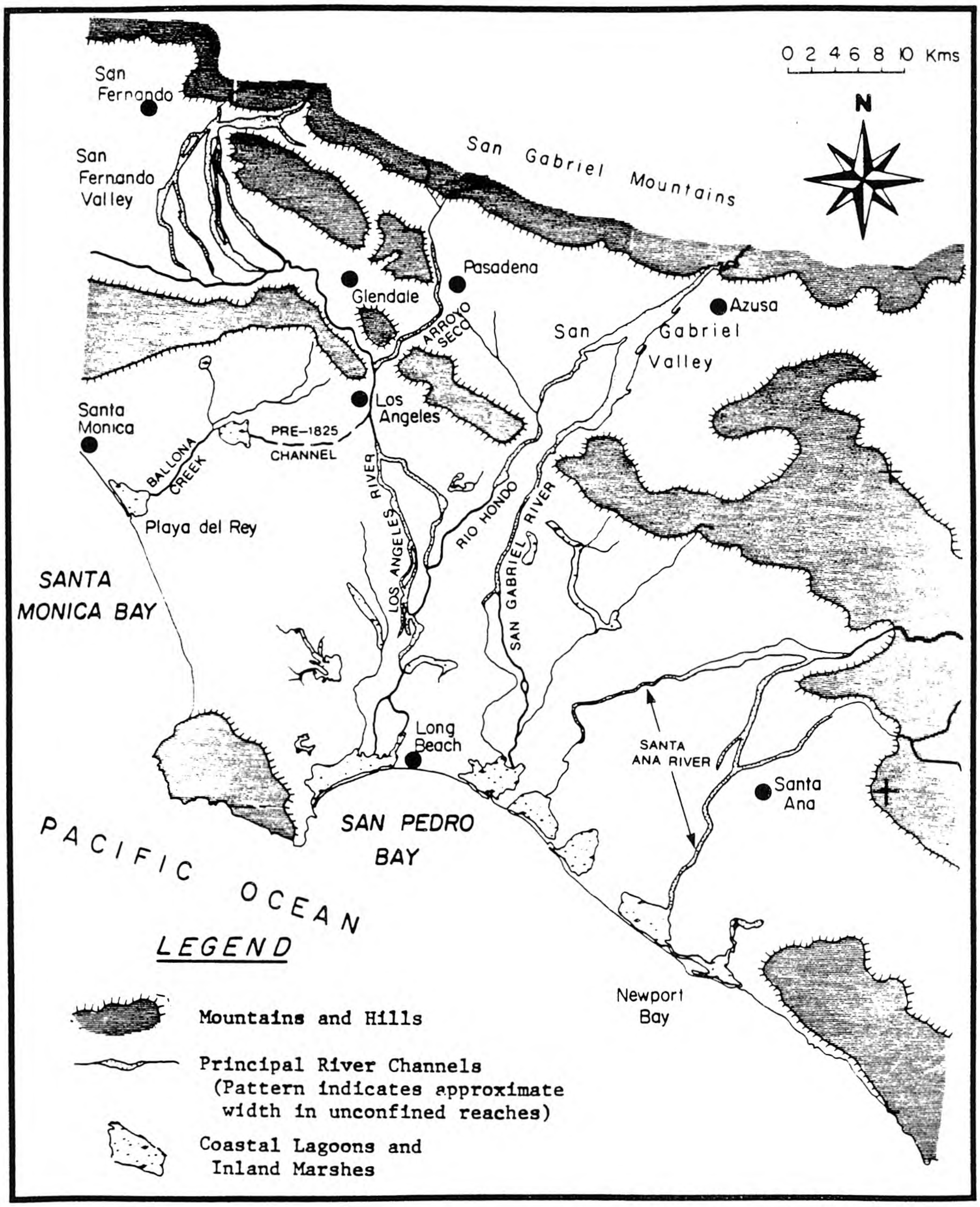

Figure D1-4. Natural river channels on the Los Angeles flood plains in 1917 prior to extensive development. (Tributary mountain watersheds not shown.)

The San Gabriel river channel is shown divided near Azusa, forming the Rio Hondo and the San Gabriel River. The former ultimately connected with a Los Angeles River channel southeast of central Los Angeles, while the latter discharged into a coastal lagoon southeast of Long Beach.

Under natural conditions, water and sediment discharges were such that simple, stable channels could not be formed by these rivers. Historical records give little detailed information or understanding of how and why the natural shifting of river courses took place.

D1.4 Artificial Controls on the Los Angeles River

At present, tributaries of the Los Angeles River deliver water and sediment to a number of debris basins and reservoirs built in upland areas (see Fig. D1-5). The water is released into channels downstream or diverted through artificial conveyance systems for various uses or groundwater recharge. Entrapped sediments reduce reservoir capacities and are excavated occasionally when capacities are seriously depleted. In order to control flood flows in downstream channels and retain for future use as much as possible of the flood water that cannot be stored in the mountain reservoirs, additional structures are used as follows:

1. Flood waters from upland areas are channelized through built-up areas into three major flood-control basins*: Hansen, Sepulveda, and Whittier Narrows basins.
2. From these flood-control basins water is released during floods at regulated discharges that can be carried by improved downstream channels.
3. Regulated releases following storms are diverted as much as possible into shallow spreading basins adjacent to the channels where the water percolates into the ground.

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*As shown in Fig. D1-5 eastern headwaters of the Los Angeles River are diverted into Whittier Narrows Basin on the San Gabriel River. All three of the large flood control basins were built by the Corps of Engineers.

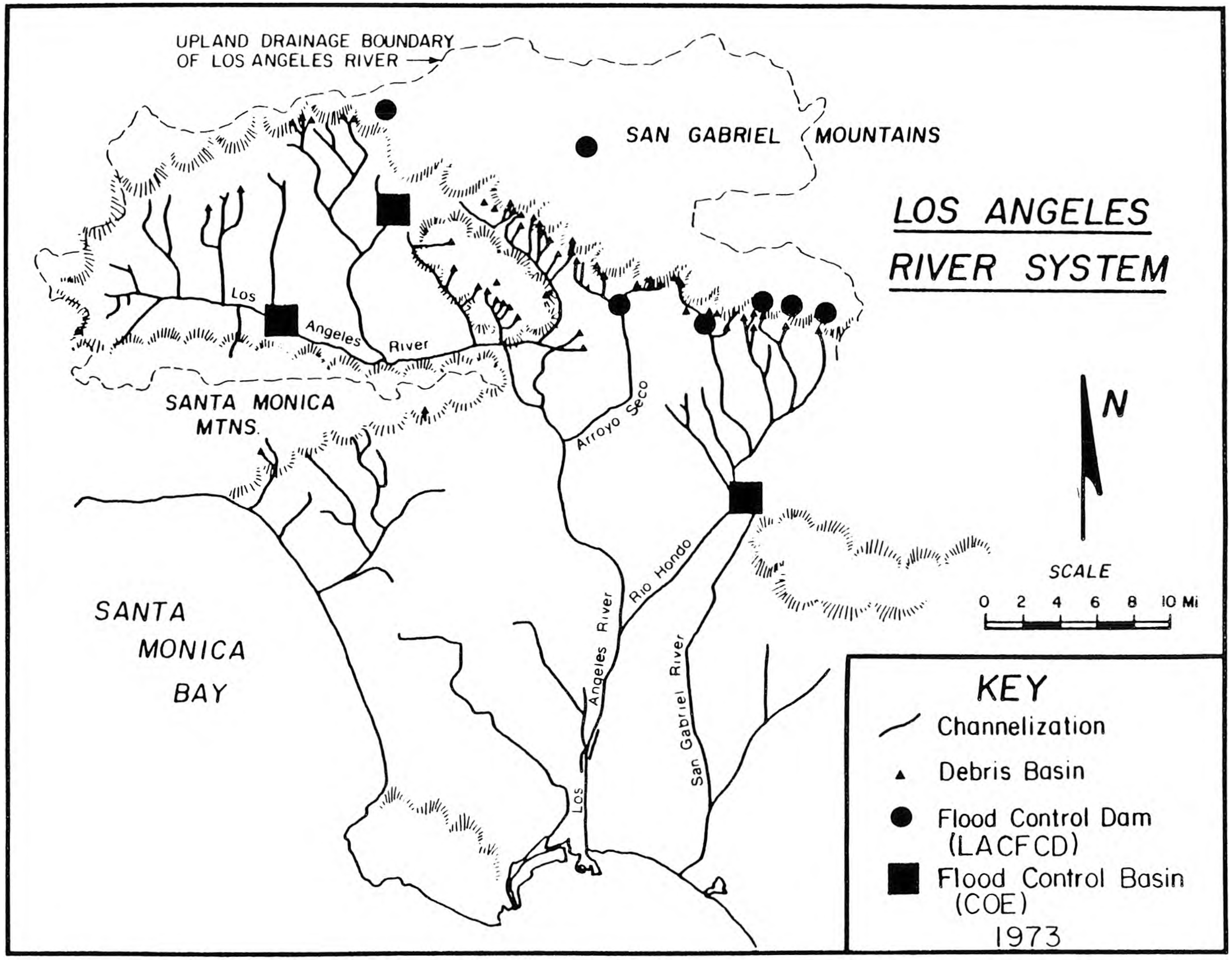

Figure D1-5. Los Angeles River System with Control Structures. (Only improved channels are shown.)

4. Within the neighboring Santa Fe-Whittier Narrows basins and channel system, it is possible to divert San Gabriel River water into the Los Angeles River and associated percolation basins via the Rio Hondo channel, thereby offering additional flexibility in flood control and water conservation.

Thus, in terms of tributary inflow from upland areas, the Los Angeles River is almost fully controlled, and with channelization this river is not permitted to spread and shift on low-lying terrain as it did under natural conditions.

Sediment flow in the Los Angeles River is also artificially regulated in several ways. First, solid materials delivered from most upland catchments are partially trapped in check dams, debris basins and storage reservoirs. Sedimentary debris is also caught in the larger flood control basins which regulate downstream discharge. Below these structures, flood discharges carrying only fine sediments (wash load) are confined in artificial channels and are not permitted to spread haphazardly, or deposit streamborne sediments, as under natural conditions. Finally, stream channelization prevents lagoons and marshes from acting as partial traps for sediments; and shoreline deliveries of water and sediment are discharged at fixed locations along the coast without any possibility for migration of the river mouth.

With the larger upland catchments flood water and debris are trapped by large flood control and water conservation dams. However there are numerous small but highly erosional catchment areas along the mountain and hill frontages, that must also be controlled due to intense urbanization on fan and floodplain areas below these catchments. This need has given rise to the use of small control structures identified earlier as 'debris basins'.

For protection of urbanized alluvial fans, there are seventy-five debris basins in the upstream portions of the Los Angeles river drainage. In some cases these basins are located on catchments where upstream check dams have also been constructed. Figure D1-2 showed an example of the conjunctive use of check dams and debris basins (and other control structures) on an upland drainage. These debris basins were constructed by the Los Angeles County Flood Control District.

This system of debris basins is somewhat unique in its breadth and operation. The seventy-five debris basins control 148.6 km^2 of upland drainage of 12% of the geologically erosional area on the river system. Figure D1-6 shows the historical development of this system of debris basins as well as the other larger control structures.

A typical time history of cumulative debris input over four decades is shown in Figure D1-7 for the West Ravine Debris Basin, based on data from the files of the Los Angeles Flood Control District. The ordinate, cumulative entrapment, is calculated from periodic surveys of the volume of debris in the basin, adjusted for the volume of debris removed; these accumulated volumes are then divided by the area (0.65 km^2) and expressed as a mean depth of erosion over the area. This value is an underestimate of the real erosion by the amount of fine material that passes through the basin during floods. The wet period during the late 1930's was amplified somewhat on the West Ravine drainage by the effects of a fire (100% burn) which occurred in October 1935. From the mid-1940's to the mid-1960's there was very little deposition in the basin. This was in part the result of lower than normal rainfall during this time. But this characteristic inflow curve is also due in part to the construction during the 1950's of several hundred check dams on upland catchments. Thus part of the debris transported in the canyon streams during this period was caught in storage behind check dams. After the middle 1960's, significant sedimentation occurred again, especially in 1969.

The time history of erosion rates for the West Ravine drainage in relation to the fire of 1935 and subsequent rainfall is shown in Table D1-2. The first few years after the fire, including the flood of early March 1938, showed erosion rates more than ten times normal. For 23 of the 75 debris basins which have periods of record of more

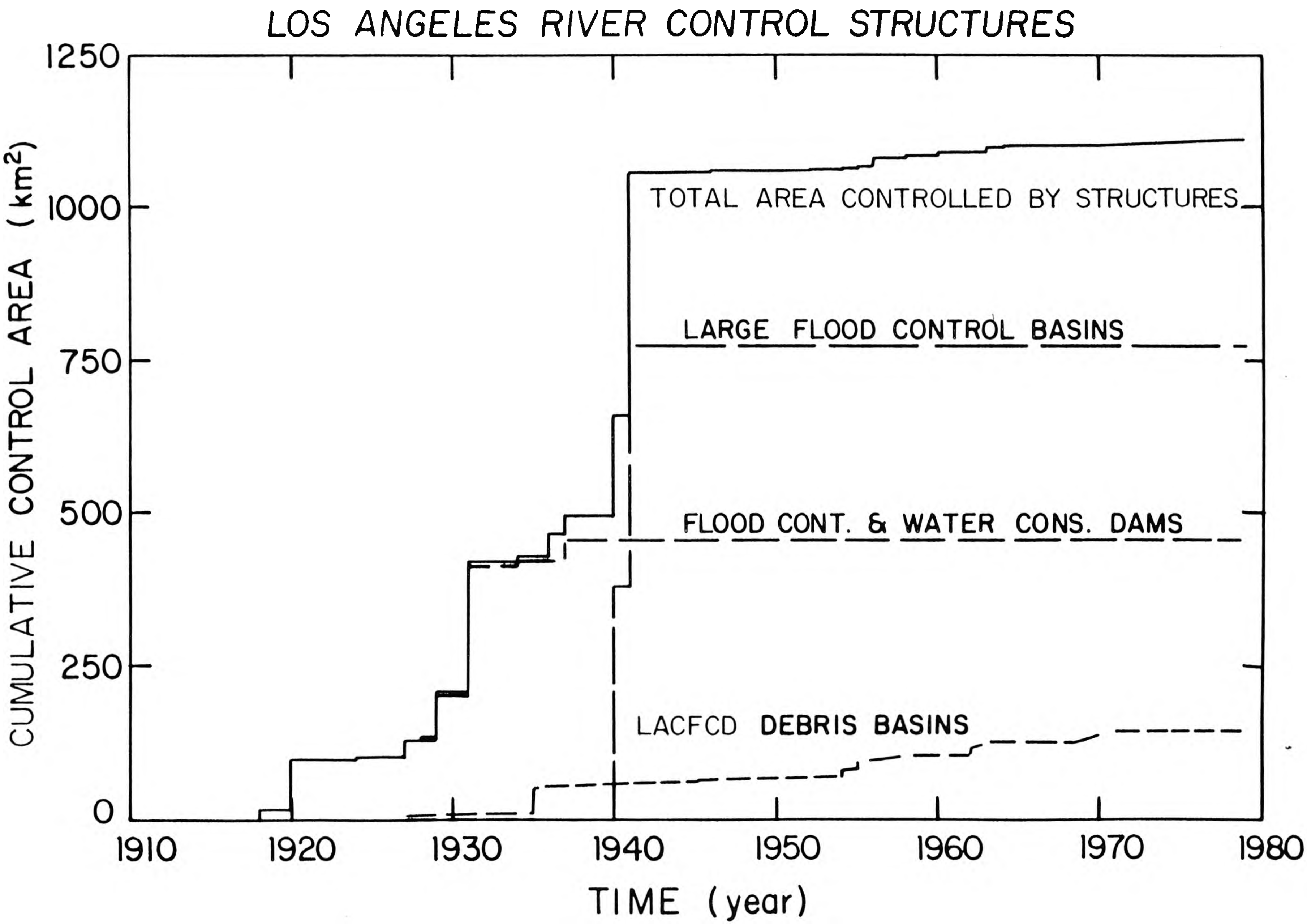

Figure D1-6. Historical Development of Control Structures on the Los Angeles River System. (Note: Areas are not additive because some catchments are upstream of more than one type of structure.)

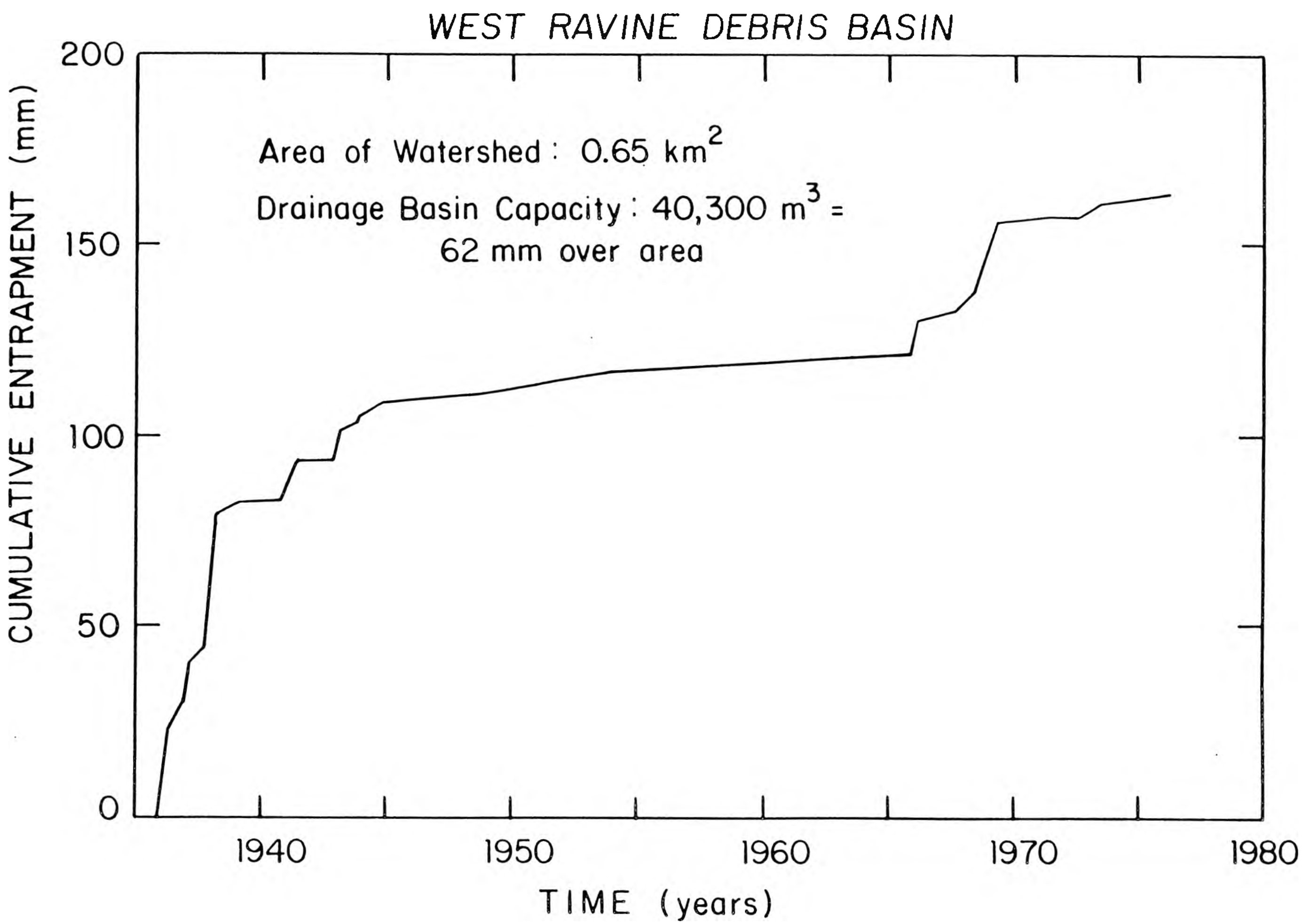

Figure D1-7. Cumulative entrapment of debris in West Ravine Debris Basin in the Los Angeles River watershed. (The units of entrapment volume are given as equivalent mean erosion on the drainage area. This erosion rate is calculated by dividing cumulative volumetric entrapment by upstream drainage area.)

TABLE D1-2:
HISTORY OF DEBRIS ENTRAPMENT
AND MEAN EROSION RATE FOR
WEST RAVINE DEBRIS BASIN
(Drainage area A = 0.65 km^2)

Survey date*	Debris volume** trapped since previous survey listed	Mean erosion rate volume (area of watershed)	Precipitation# since previous survey listed	Ratio: erosion rate to precipitation
	V	V/A	P	$\frac{V/A}{P}$
	m^3	mm	mm	
10/35		Watershed 100% burned over.		
11/7/35	0			
4/8/36	14,790	22.8	521	.0437
9/2/37	14,003	21.5	1,054	.0204
3/9/38	22,834	35.1	1,043	.0337
11/29/43	16,450	25.3	5,023	.0050
8/3/48	3,675	5.7	3,586	.0016
9/15/54	4,202	6.5	3,530	.0018
6/2/59	1,390	2.1	3,000	.0007
9/30/65	1,125	1.7	2,856	.00045
8/13/70	23,024	35.4	4,443	.0080
3/19/76	4,760	7.3	3,475	.0021

* Selected survey dates to indicate trends. Complete survey record was used to plot figure.

** Data from files of LACFCD.

Data for LACFCD rainfall station 367.

than 30 years (Table D1-3), peak year debris entrapment between 1928 and 1979 ranged from 3-35 mm* (mean value: 16 mm), with mean annual debris inflow ranging from <0.5-7 mm (mean value: 2 mm). Thus there is just less than an order of magnitude difference between mean annual values and extreme year values.

Figure D1-8 shows the ratios of debris basin capacity to peak-year entrapment versus drainage area for 23 debris basins with long records. Values of basin capacity/peak-year entrapment range from 0.5 to 5 with 20 of the 23 values larger than 1, indicating that these basins have generally been able to contain capital year inflows during the past 30-45 years. This is one of the primary design criteria.

Figure D1-9 shows the ratio of capacity to average annual entrapment for the same 23 debris basins. Values of this ratio range from 8 to 50, with a mean value of 20. Thus data obtained over the past few decades indicate a mean fill time of 20 years for the 23 basins. Due to the uncertainty of future hydrologic events i.e. floods, however, these basins have been cleaned out more frequently than this. Average annual debris entrapment for all 23 basins has been 86,500 m^3/yr. If it is assumed that these 23 drainage areas are representative in terms of erosion characteristics of all 75 debris basin drainage areas on the Los Angeles River system, the aggregate average annual debris entrapment would be 190,000 m^3/yr. This is approximately 22% of the total average annual debris production on the Los Angeles River system (Report 17-B), and 28% of the estimated coarse debris production which totals 680,000 m^3/yr. Thus while debris basins control only 12% of the erosional drainage area in the Los Angeles River system, they control approximately twice this relative amount of the total annual debris production.

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*Equivalent average annual erosion on upstream drainage area, calculated as volumetric debris entrapment per year divided by upstream area.

TABLE D1-3: DESIGN AND ENTRAPMENT DATA
FOR 23 DEBRIS BASINS
IN LOS ANGELES COUNTY*

Basin	First Year	Max. Debris Capacity(m^3)	Drainage Area(km^2)	Total Entrap.(m^3)	Peak Year Entrap.(m^3)
		(mm)**		(mm)**	
Sierra Madre	1928	122,300 (20)	6.19	252,600 (1) #	72,800 (12)
Sunset (Upper)	1929	13,500 (12)	1.14	77,200 (1)	20,600 (18)
Dunsmuir	1936	95,200 (44)	2.18	221,800 (2)	65,900 (30)
Pickens	1936	105,700 (27)	3.88	500,900 (3)	107,500 (28)
Brand	1936	159,200 (60)	2.67	158,400 (1)	40,600 (15)
Fair Oaks	1936	21,800 (40)	0.54	82,500 (4)	12,000 (22)
Halls	1936	76,200 (28)	2.75	389,300 (3)	78,100 (28)
Verdugo	1936	118,900 (5)	24.35	567,500 (1)	72,400 (3)
Fern	1936	26,000 (33)	0.78	118,400 (4)	18,300 (23)
Lincoln	1936	32,100 (25)	1.29	91,700 (2)	21,700 (17)
Las Flores	1936	48,600 (42)	1.17	128,900 (3)	27,500 (24)
Haines	1936	121,300 (31)	3.96	199,600 (1)	39,400 (10)
West Ravine	1936	40,292 (62)	0.65	110,200 (4)	22,900 (35)
Snover	1937	20,000 (33)	0.60	69,700 (3)	16,100 (27)
Eagle	1937	55,400 (17)	3.29 ##	145,600 (1)	31,900 (10)
Hay	1937	30,400 (8)	3.73##	45,900 (<.5)	13,900 (4)
Shields	1938	30,600 (2)	19.84##	97,600 (<.5)	22,600 (1)
Stough	1941	142,700 (33)	4.27	112,500 (1)	33,700 (8)
Rubio	1944	116,400 (36)	3.26	107,500 (1)	42,100 (13)
Altadena	1946	9,600 (18)	0.52	22,200 (4)	2,900 (6)
Scholl	1946	10,500 (6)	1.71	11,500 (7)	2,700 (2)
Bailey	1946	120,800 (78)	1.55	85,900 (2)	27,400 (18)
Gould	1948	41,200 (34)	1.22	81,800 (2)	13,800 (11)

* Data from files of LACFCD, records available only through January 1979.

** Equivalent mean erosion on drainage, calculated as volumetric debris entrapment divided by upstream area.

\# Average annual rate.

\## Contributing drainage area has been effectively reduced in recent years with construction of additional upstream control structures. With Eagle the reduced area is 1.24 km^2, for Hay: 0.52 km^2, and for Shields: 0.08 km^2.

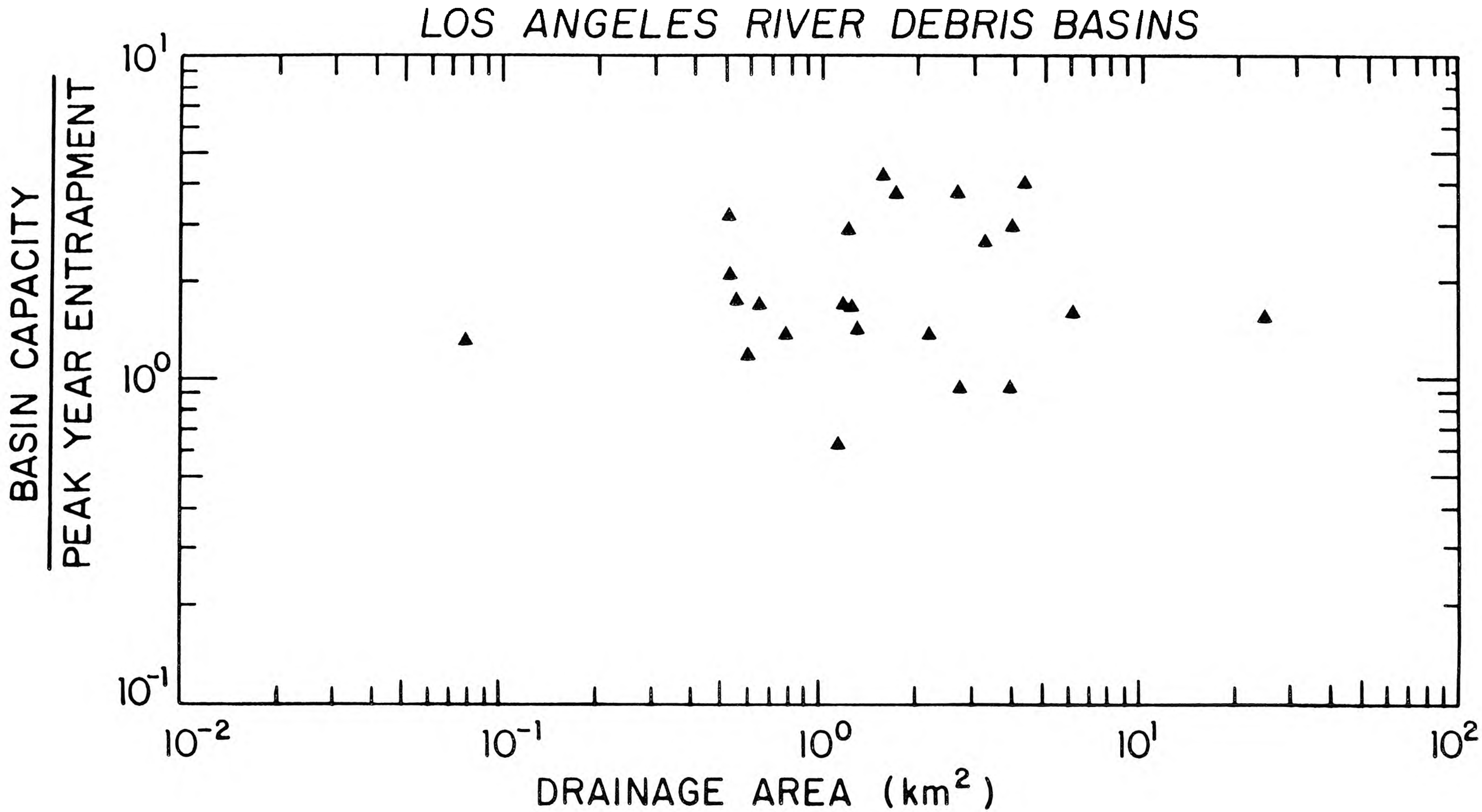

Figure D1-8. Debris basin capacity/peak year entrapment as a function of drainage area for 23 debris basins with periods of record of more than 30 years.

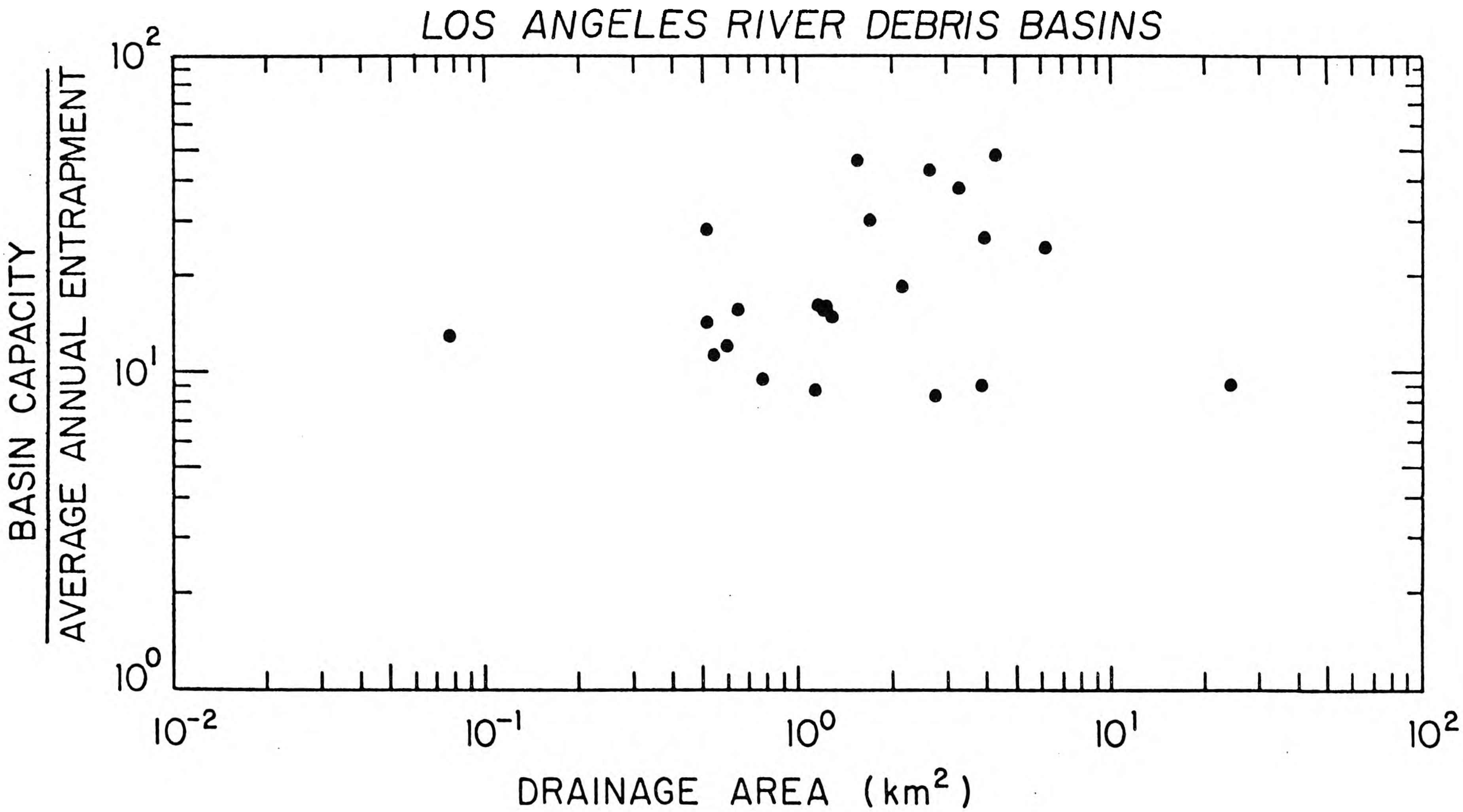

Figure D1-9. Debris basin capacity/Average annual entrapment as a function of drainage area for 23 debris basins with periods of record of more than 30 years.

D1.5 References

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SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA MOUNTAINS, COASTAL PLAINS AND SHORELINE

Section D2
(EQL Report 17-D)

Inland Artificial Sediment Movements

by

Oded C. Kolker

D2: Inland Artificial Sediment Movements

D2.1 Summary

Throughout the coastal region of southern California, since the origins of modern human development, there have been artificial relocations of natural sediments. At first, significant relocations were limited to the extraction of aggregate for use in construction. However, during the past few decades, with the advent of water conservation and flood control structures, debris cleanout operations have also become important. Available data on artificial cleanouts which, though incomplete, include all major cleanout operations, may be summarized as follows:*

County	Entrapment Structure Cleanouts (m^3)	Channel Cleanouts (m^3)
Santa Barbara	_**	-
Ventura	815,000	160,000
Los Angeles	31,878,000	-
San Bernardino	3,924,000	8,666,000
Riverside	142,000	43,000
Orange	-	1,764,000
San Diego	-	-
TOTALS:	36,759,000	10,633,000

*Artificial cleanout data and sand and gravel extraction data are reported in volume and weight units, respectively. Due to the uncertainty of conversion factors, this convention is also used in this report. Volumes are given in cubic meters (m^3) and weights in metric tonnes. Data for 1978 are not all included. In particular the data for the 1978 major storm was not available at the time this report was being prepared.

**Quantitative data not abailable.

Similarly, extraction data on sand and gravel mining in the study are indicate the following production totals:

County	Total Production (10^6 tonnes) 1934-1952	1953-1976	1934-1976
Los Angeles	114.6	472.3	586.9
San Diego	16.3	138.0	154.3
Santa Barbara	0	2.9	2.9
Ventura	0	77.0	77.0
San Bernardino	102.8 (San Bernardino, Riverside, Orange)	114.6	397.9 (San Bernardino, Riverside, Orange)
Riverside		20.5	
Orange		160.0	
TOTALS:	233.7	985.3	1219.0

Clearly, sand and gravel mining is the dominant source of inland artificial sediment movements throughout the region. From the standpoint of historical totals as well as current annual values, quantities moved for this purpose are more than an order of magnitude larger than reported artificial movements for other purposes.

D2.2 Channel, Reservoir, and Debris Basin Cleanouts

Records of sediment cleanouts from flood control structures are incomplete for much of the study area, and in many cases cover only a short, recent time span. Also, there is little consistency in the types of data collected by the different local agencies.

Santa Barbara County has a markedly incomplete record on sediment cleanouts. Cleanout operations have been conducted as routine county maintenance, and in some intances private citizens have been allowed to remove depositional materials for personal use. There have also been some removals by contract. However, quantitative data on these cleanout operations are not available in most cases.*

Within the study area in this county there is one large debris basin similar to those in the Los Angeles are, and 23 smaller basins

*James Stubchaer, Santa Barbara County Flood Control District, personal communication, November 1978.

in coastal canyons, which act as boulder traps.* Finer sedimentary materials normally wash through these structures. Material removed from the basins has the following approximate composition: 50% sand, 48% gravel and cobble, 2% silt and clay. Entrapped boulders were removed from all basins in 1965, 1969 and 1971, but there were no cleanouts during the period 1927-64. Typical boulder diameters are 1 m, but range up to 4 m.

Three silt basins in the county located just above two large coastal sloughs, prevent flooding and sediment deposition throughout the slough areas. One of the sloughs receives drainage from eight tributary streams. Approximately 240,000 m^3 of material was removed from these stream channels in 1978. The other large slough is fed by two streams for which there are no available data regarding channel cleanouts. The many other coastal streams in the county drain directly into the ocean and have sufficient gradients to flush most debris. A severe flood, though, may leave boulders in the natural channels. In 1971, following the floods of 1969, some such boulders were artificially relocated to form riprap along the natural channels and local beaches.

Ventura County has 26 debris basins, 14 of which have been cleaned out between one and seven times since 1969. Some of the debris is relocated in nearby disposal sites, but most is used as construction aggregate, in building dikes or embankments, or for agricultural improvement in low-lying areas. The relocated sediment is composed mostly of fines and makes good topsoil for farms and ranches. Entire orchards now grow on material cleaned out of debris basins. In 1978, $13 million in federal disaster funds from the Soil Conservation Service was used to clean out 13 debris basins and several channels, with all of the material being used beneficially.**

*For general structure locations in this section refer to Plate D1-1 in Section D1.

**Delores Taylor, Mike Taylor, Gail Burnham, Ventura County Flood Control District, personal communications, November and December 1978.

Table D2-1 lists cleanouts of debris basins over the last ten years and of channels in the wake of the 1978 storms. This table is based upon data supplied by the Ventura County Flood Control District. Roughly one million m^3 of material have been relocated, primarily through debris basin cleanouts. Of this 14% has been on the Ventura River drainage, 43% on the Santa Clara River drainage, and 37% on Calleguas Creek drainage.

Los Angeles County Flood Control District maintains a complete record of sediment removals from debris basins and reservoirs located in the county. There are at present 96 debris basins constructed between 1927 and 1976 that are maintained by the District. Accumulation data and cleanout records exist for each basin since its first season of operation. Total individual removal to date ranges from 737,500 m^3 for the 43-year-old Verdugo Debris basin to zero for some of the recently built basins. Table D2-2 lists cumulative totals as of the end of the 1977-78 storm season for all 96 debris basins. Nearly 9 million cubic meters have been cleaned out in the past half-century, with 81% of this total coming from tributary areas of the Los Angeles River drainage.

The Los Angeles County Flood Control District has also periodically cleaned out major reservoirs through excavation and by sluicing. Quantitative data for these operations up to 1972 are also presented in Table D2-2. The total amount removed from reservoirs, all built in the 1920's and 1930's, is 23 million m^3. Of this, about half was removed from San Gabriel Reservoir, and two-thirds from reservoirs in the San Gabriel River drainage. Debris eroded from upland catchments in the San Gabriel River drainage are trapped primarily by major reservoirs, while in the Los Angeles River drainage, debris basins play the larger role. The total quantities of sediment removed from reservoirs and debris basins in the two drainages are 16.7 and 15.0 million m^3, respectively.

Table D2-1

Ventura County Sediment Cleanouts

A. Debris Basin Cleanouts (1969-1978)

Debris Basin	Hydrographic Drainage Unit	Total Removal, m^3
Dent	Ventura River	225
Stewart Canyon	Ventura River	137,000
Arundell Barranca	Ventura Group	59,100
Jepson Wash	Santa Clara River	112,000
Real Wash	Santa Clara River	61,100
Warring Canyon	Santa Clara River	110,000
Coyote Canyon	Calleguas Creek	60,500
Fox Barranca (Somis)	Calleguas Creek	35,000
Gabbert Canyon	Calleguas Creek	146,000
Runkle Canyon	Calleguas Creek	69,000
Edgemore	Calleguas Creek	3,060
Ferro	Calleguas Creek	2,600
Honda West	Calleguas Creek	17,800
W. Camarillo Hills, East Branch	Calleguas Creek	1,240
	TOTAL:	815,000

Source: Ventura County Flood Control District, Debris Basins Inventory, Technical Data.

B. Channel Cleanouts (1978)

Channel	Hydrographic Drainage Unit	Removal, m^3
Happy Valley Drain	Ventura River	460
Real Canyon	Santa Clara River	5,500
Cavin Road Drain	Santa Clara River	2,700
Pole Creek	Santa Clara River	55,000
Orcutt Canyon	Santa Clara River	27,000
Santa Paula Creek	Santa Clara River	46,000
Keefe Ditch	Santa Clara River	550
White Oak and Hummingbird Creeks	Calleguas Creek	1,400
Las Llajas Canyon	Calleguas Creek	1,300
Topo Hills No. 2	Calleguas Creek	9,100
No. 2 Canyon	Calleguas Creek	1,000
Blanchard & Duvall Drains	Calleguas Creek	640
Santa Clara Ave. Drain	Calleguas Creek	9,100
	TOTAL:	160,000

Source: From the files of Gail Burnham, Ventura County Flood Control District.

Table D2-2

Los Angeles County Sediment Cleanouts

A. Cumulative Debris Basin Cleanouts (as of 9/78)

Hydrographic Drainage Unit	Cumulative Removal m^3
Santa Monica Mountains	118,000
Los Angeles River	7,195,000
San Gabriel River	1,590,000
TOTAL:	8,903,000

Source: Los Angeles County Flood Control District, Debris Basin Design Data and Debris Production History, January 1979.

B. Cumulated Reservoir Cleanouts (as of 8/72)

Reservoir	Hydrographic Drainage Unit (Subdrainage)	Cumulative Removal m^3
Sawpit	Los Angeles River	326,000
Big Santa Anita	Los Angeles River	640,000
Big Tujunga	Los Angeles River	3,495,000
Devil's Gate	Los Angeles River	2,136,000
Eaton Wash	Los Angeles River	1,232,000
Big Dalton	San Gabriel River	619,000
Live Oak	San Gabriel River	211,000
Puddingstone Diversion	San Gabriel River	665,000
San Dimas	San Gabriel River	1,950,000
San Gabriel	San Gabriel River	11,680,000
Thompson Creek	San Gabriel River	23,000
	TOTAL:	22,977,000

Source: From the files of John Lowry, Hydraulic Division, Los Angeles County Flood Control District.

There have been channel cleanouts in Los Angeles County, but no quantitative records of these operations have been kept.

Sediments removed from flood control structures have been used in part for road building, landfill, and other construction needs. The general coarseness of the material has precluded agricultural usage. Large volumes of cleanout materials have also been trucked to nearby disposal sites. At present, there are 26 debris disposal areas, each receiving material from between one and fourteen entrapment structures.* The total volumetric storage in those areas as of January 1978 was 6.36 million m^3, with a current average annual input rate of 500,000 m^3.

Not included in Table D2-2 are additional sediment removals by local agencies other than the Los Angeles County Flood Control District because data on these operations are not available. However quantities must be small compared to totals in Table D2-2, since the included catchments are generally in areas of lower sediment production and there are only a few basins.

The U.S. Army Corps of Engineers has built several large flood-control basins in the Los Angeles area. These basins are designed for 100-year sediment capacities. To date there have been no cleanout operations in them except for the excavation of a few thousand cubic meters from San Antonio Reservoir for earthen construction. Other minor cleanouts have been undertaken at Lopez Dam Debris Basin near Pacoima (in 1969 and 1978) and Haines Debris Basin near Sunland (1977).**

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*Los Angeles County Flood Control District, Active Debris Disposal Area Data Sheet, January 1978, prepared by K. Larrowe.

**Robert Koplin, U.S. Army Corps of Engineers, personal communication, December, 1978.

San Bernardino County Flood Control District has a complete record of debris removals for the period 1969-1973, which was obtained during a special study. Data pertaining to prior and subsequent removals are not available.

Table D2-3 lists the sediment removals in San Bernardino County during this five-year period. The portion of the county within the study area is drained by the upper Santa Ana River and its tributaries. About two-thirds of the 12.5 million m^3 cleaned out of flood control structures during the period was excavated from channels.

The volume of artificial sediment movements in San Bernardino County appears high in comparison with Los Angeles County, where, with similar topography and mountain frontage but more intensive development, 32 million m^3 were moved during a span of more than four decades. The San Bernardino five-year record, however, includes the major floods of 1969. In addition, San Bernardino County has fewer large reservoirs than Los Angeles County, so major floods deliver relatively more sediment to channels that must be cleaned out immediately following the storm. Also, part of the cleanout material may have been accumulated prior to this five-year period. Some of the cleanout material in San Bernardino County has been used by aggregate companies, and the remainder for embankments, subdivision developments, and other beneficial purposes.*

Riverside County has a less intensive sediment control system than Los Angeles and San Bernardino counties, primarily because this area does not have extensive steep mountain frontages abutting heavily developed areas. Information on cleanouts in this county is available only for the areas drained by the Santa Ana River. In the wake of the 1978 storms, federal funds were used to excavate four flood control reservoirs located southeast of Riverside, for the first time since prior surveys in 1962 (Sycamore and Box Springs) and 1970 (Prenda and Alessandro). The volumes removed listed in Table D2-4,

*Chris Bahnsen, San Bernardino County Flood Control District, personal communication November, 1978 and January, 1979.

Table D2-3

San Bernardino County Cleanouts, 1969-1973

Hydrographic Drainage Unit (Subdrainage)	Removals, m^3 Basins	Channels	Total
Santa Ana River (Total)	3,924,000	8,666,000	12,590,000
(San Antonio-Cucamonga Creeks	558,000	1,200,000	1,758,000)
(Day-San Sevaine Creeks	1,826,000	354,000	2,180,000)
(Lytle-Cajon Creeks	4,600	500,000	505,000)
(San Timoteo Wash	4,600	340,000	345,000)

Source: San Bernardino County Flood Control District, Debris Removal, 1969 through 1973; and tabulated listing of flood control basins.

Table D2-4

Riverside County Sediment Cleanouts

Basin	Type	Accumulation Period	Removal m^3
Prenda	Flood Control	1970-1978	6,600
Sycamore	Flood Control	1962-1978	13,700
Alessandro	Flood Control	1970-1978	6,850
Box Springs	Flood Control	1962-1978	11,900
Woodcrest	Flood Control	1962-1978	53,000
Mabey	Debris	1973-1978	50,300
		TOTAL:	142,350

Channel	Removal m^3
San Sevaine Creek	19,200
Temescal Wash	23,800
TOTAL:	43,000

represent only the amount believed to have been deposited by the 1978 storms. It is estimated that as much as 10% of the pre-1978 accumulations may have been removed previously without record. A fifth flood control basin, Woodcrest, was entirely cleaned of debris accumulated since 1962. Mabey Debris Basin in Corona was cleaned out for the first time since its construction five years before, and the San Sevaine Channel north of Norco and the Temescal Wash at Corona were also cleaned out in 1978. The total sediment removals of 185,000 m^3 from the Santa Ana River drainage system in Riverside County are insignificant in comparison with removals upstream in San Bernardino County and downstream in Orange County. The excavated material, mostly sand, was used primarily for construction aggregate and fill in this rapidly developing area. Some, however, was used for agricultural purposes.

No sediment removal information is available for the internally-drained basin of Lake Elsinore and the San Jacinto River. To the south, in the upper Santa Margarita River drainage, sand has been removed periodically since 1970 from the Murrieta Creek channel and relocated in disposal sites, but volumes were not recorded.*

Orange County does not have debris basins, but it has several reservoirs that have never been cleaned out. Percolation basins and stream channels are cleaned out by the Orange County Environmental Management Agency, but no records have been kept of these routine maintenance operations. However, removals by private contractors have been recorded since 1972. These volumes are listed in Table D2-5. More than 900,000 m^3 were sold in the $5\frac{1}{2}$ year period (1972-77). This sediment was primarily sand, with some coarser material.

Other agencies have also removed sediment from channels in Orange County. The Orange County Water District removed material from the Santa Ana River prior to 1969, and the Corps of Engineers conducted

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*Robert Nelson and Grant Becklund, Riverside County Flood Control and Water Conservation District, personal communication, January 1979.

Table D2-5

Orange County
Stream Channel and Percolation Basin Cleanouts
July 1972 through 1977

Hydrographic Drainage Unit (Subdrainage)		Removals for Sale, m^3
San Gabriel River (1)		137,480
Huntington Beach Group (2)		65,400
Santa Ana River (3)		444,800
Laguna Hills Group (Total)		276,500
(San Diego Creek	195,200)	
(San Juan Creek	81,300)	
TOTAL:		924,180

Notes:

(1) Coyote Creek, Carbon Creek, and Los Alamitos Channel.

(2) Bolsa Chica Channel and East Garden Grove-Wintersburg Channel.

(3) Includes Greenville-Banning Channel.

Source: From the files of Orange County Environmental Management Agency, Operations Office.

emergency cleanouts after the 1969 storms. In 1969, 700,000 m^3 was removed from the Santa Ana River channel, and 140,000 m^3 from San Juan Creek.

The Soil Conservation Service recently has funded cleanouts of debris deposited during 1978 storms. The removed material may be stockpiled temporarily, but most of it will eventually find beneficial use. In the past, part of the relocated materials have been used to nourish local beaches.

Stream channel cleanouts in Orange County are sometimes hampered by ecological considerations. An endangered tern species, which is disturbed by noise, feeds on the Santa Ana River bottom. Consequently, the State Fish and Game Department forbids excavation in the stream bed between April and September, leaving only a brief dry period for operations. Also, in the San Diego Creek channel, which has not been cleaned in five years, a new willow community has sprung up. As a result, the Fish and Game Department has blocked cleaning of this channel except in a checkerboard fashion, with mandatory replanting.[*]

San Diego County has only a few small debris basins, and there are no flood-control reservoirs *per se*. All of its major rivers have water-conservation reservoirs. However, these reservoirs have never been cleaned out. After the 1978 storms, the Soil Conservation Service removed material from stream channels, but records of these activities were not kept because it was done on a very small scale.[**]

Data on other historical channel cleanout activities are also not available.

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[*] Jim Williams, Joe Natsuhara, Bill Reider, and Lon Hanson, Orange County Environmental Management Agency, personal communications, November 1978 and February 1979.

[**] Joe Hill, San Diego County Department of Sanitation and Flood Control, personal communication, November 1978.

These data for the seven counties, while incomplete, give a good quantitative indication of the scale of cleanout activities as well as the general character of the debris removed and the adopted modes of disposal. In all, more than 36 million m^{3*} have been removed from entrapment structures and more than 10 million m^{3*} through channel cleanouts. Disposal material in all counties except Los Angeles, has been applied primarily to beneficial uses. Most of this material relocation has taken place during the last 25 years.

D2.3 Sand and Gravel Mining

Sand, gravel, and crushed rock are mined throughout the study area for use as construction aggregate. A suitable deposit must contain hard, relatively unweathered and unreactive minerals. The desired grain sizes and angularity vary according to use -- concrete, asphaltic concrete, road base, fill, or plaster. Construction aggregate is a basic material for buildings, roads, dams, and flood-control structures. Southern California Rock Products Association data indicate that 68% of the aggregate mined in the greater Los Angeles area during the period 1930-1969 went into freeways, dams, and other public structures.** The greater Los Angeles area has, for its size, one of the highest rates of aggregate consumption in the world.

Because aggregate is a high-bulk, low-value commodity, transportation distance is critical. The price of aggregate in downtown Los Angeles is more than double its cost in Irwindale or Sun Valley, the nearest large deposits. Consequently, local production generally reflects local demand.

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*Based on recorded values, actual totals may be significantly larger.

**From the files of Don Reining, SCRPA.

The aggregate industry classifies sediments by particle size as follows:

Fines:	< 0.074 mm
Sand:	0.074 - 6.4 mm
Gravel:	6.4 - 38 mm
Crushed Rock:	> 38 mm

Fines (silt and clay) are generally not sold, but separated out and retained within the mining property.

In obtaining satisfactory materials, four types of geologic deposits are mined in the study area: (a) stream beds, (b) floodplains and terraces, (c) alluvial fans, and (d) bedrock.

Stream beds are a favorite type of deposit because they frequently contain the desired size mix and roundness, are not threatened by competing land uses, and are often subject to natural replenishment. Aggregate has been mined in the study area from the following stream channels: The Ventura River near Ventura; the Santa Clara River below Fillmore and in Soledad Canyon; Sespe Creek near its mouth; Castaic Creek; the Arroyo Seco above Devil's Gate; San Antonio Creek in Upland; Lytle Creek above Fontana; the Santa Ana River near Redlands, Riverside, and Anaheim; Temescal Wash above Santiago Creek; Santa Ysabel Creek near Escondido; the San Dieguito River near its mouth; the San Diego River below El Capitan Reservoir; the Sweetwater River above Sweetwater Reservoir; and the Otay and Tijuana rivers near their mouths (Goldman, 1968).

Floodplain mining is less common in the study area. Principal locations of this type of excavation are the Santa Clara River basin near Saticoy, the Santa Ana River basin in Orange County, and Temescal Wash in Riverside County.

Alluvial fans have not been worked as long as stream beds have, but now constitute the largest source of sand and gravel in southern California. The four large fan deposits mined in the study area include Tujunga fan near Hansen Dam, San Gabriel fan in Irwindale, San Antonio Creek-Cucamonga Creek fan in Ontario-Upland, and the Lytle Creek fan above Rialto. All of these fans lie along the south and west frontages of the San Gabriel Mountains.

Bedrock is mined from hillslopes throughout the study area. Poorly consolidated sandstones and conglomerates, where not excessively weathered, afford usable sources of sand and gravel. Such formations, usually of Miocene age (6-25 million years) or younger are mined in the Simi Hills, in Soledad Canyon along the upper Santa Clara River, tne Montebello Hills near Los Angeles, in the Santa Ana Mountains and the hills of south Orange County, and the hills near Miramar. Unindurated Pleistocene (less than 2 million years old) beach sands are mined on the north flank of the Palos Verdes Hills. Even igneous rocks are mined for aggregate -- preCambrian gabbro in Soledad Canyon, quartz diorite at Pedley near Riverside, and older volcanics in Mission Gorge, San Deigo. The Kaiser Steel slag dump in Fontana also provides a small-scale man-made source of aggregate.

Most of the sand and gravel mining in coastal southern California during the past few decades has taken place in the greater Los Angeles area. In a special report (Evans et al., 1977) the California Division of Mines and Geology identifies nine sand and gravel mining districts in the study area falling within a 97 km (60 mile) radius of the Los Angeles Civic Center. Table D2-6 tabulates recent annual production totals for these districts. Tujunga fan, the oldest producing district with records dating back to 1908, has been declining in production with only modest reserves. San Gabriel fan has experienced large production levels but still has very large reserves. Production in the upper Santa Clara River district dates from about 1950, and has large reserves. The Santa Ana Mountains and coastal district production dates from the 1920's. This district, which covers all of Orange County and the Prado operation in Riverside County, has experienced rapid growth in output but is nearing depletion. Production for the Temescal Wash district was very small prior to the 1960's but has expanded greatly

Table D2-6

Sand & Gravel Mining Districts
In And Around Los Angeles County

District	County	Deposit Type	1960-1975 Average Annual (10^6 tonnes)	1960-1975 Total Production (10^6 tonnes)
San Gabriel Fan	Los Angeles	Alluvial Fan	13.5	216.3
Tujunga Fan	Los Angeles	Alluvial Fan	4.8	76.7
Upper Santa Clara River	Los Angeles	Stream Channel, Bedrock	0.5	7.7
Santa Ana Mountains - Coastal	Orange-Riverside	Stream Channel Floodplain, Bedrock	8.5	136.3
Temescal Wash	Riverside	Stream Channel, Floodplain, Alluvial Fan	0.5	8.1
Lytle Creek Fan-upper Santa Ana River	San Bernardino	Stream Channel, Alluvial Fan	2.9	46.0
San Antonio Creek - Cucamonga Creek Fan	San Bernardino	Alluvial Fan	2.6	41.9
Lower Santa Clara River-Ventura	Ventura	Stream Channel	2.8	44.7
Simi Valley	Ventura	Bedrock	0.9	15.1
		TOTALS:	37.0	592.8

Source: Evans et al., 1977

since 1972 in response to local development. The Lytle Creek fan-upper Santa Ana River district, perhaps the oldest in the area, has been expanding rapidly, and still has large reserves. The San Antonio Creek-Cucamonga Creek fan district is also very old, but production has been declining and reserves are not large. The lower Santa Clara River-Ventura district dates from the 1920's and its production has been stable since 1960. The Simi Valley district, which is entirely bedrock based, was insignificant in 1960 but has been responsible for all the recent growth in Ventura County production.

Other mining operations in the study area not included in the above districts include operations in the Palos Verdes Hills and the Arroyo Seco channel (both old operations of small scale), and at Pedley and the San Jacinto Valley in Riverside County. In addition, San Diego County has several scattered operations.

Sand and Gravel Production by County

Since 1953, sand and gravel productions have been reported by county in the U.S. Bureau of Mines Mineral Yearbook. Data from this publication are tabulated in Table D2-7, with adjustments for mining operations outside the study area. For Ventura, Orange, and San Diego counties all aggregate production is within the coastal drainage. On the other hand, in Los Angeles County, Little Rock Creek district on the northern flank of the San Gabriel Mountains is outside the study area. To adjust for this during the years 1960-1975, this district's production as given by Evans et al., (1977) is subtracted from the Bureau data. For the years 1976 and 1953-1959, average annual production values for this district during 1971-1975 and 1964-1969, respectively, have been subtracted from the county total.

In San Bernardino County, the Mojave River and Twentynine Palms mining operations are outside the study area. Since their production is not known, the figures given in Table D2-7 for 1960-1975 are the totals of annual production in the San Antonio-Cucamonga Creeks and Lytle Creek-upper Santa Ana River districts as reported by Evans

Table D2-7

Reported Production of Sand and Gravel by County: 1953-1976
10^6 Tonnes

Year	Santa Barbara	Ventura	Los Angeles	San Bernardino	Riverside	Orange	San Diego
1953	*	0.8	17.4	1.6	0.2	2.7	2.8
1954	0.1	1.4	22.6	3.1	0.2	3.3	3.7
1955	*	3.6	16.6	1.9	0.2	4.2	2.5
1956	0.1	2.6	25.8	3.2	0.3	3.7	2.9
1957	0.1	2.8	17.3	3.2	0.6	4.5	3.1
1958	0.1	2.0	17.9	4.9	0.4	5.1	4.4
1959	0.2	2.2	15.3	4.5	0.5	5.3	6.6
1960	0.1	2.0	17.0	4.6	0.6	5.9	5.2
1961	0.2	2.8	22.7	4.8	0.4	5.9	4.0
1962	0.2	4.1	23.0	5.7	0.4	7.7	3.8
1963	0.1	2.9	23.7	3.6	0.6	8.3	4.6
1964	0.1	3.5	23.2	5.9	0.8	7.2	4.6
1965	0.1	3.4	22.0	5.5	0.8	7.2	5.3
1966	0.2	3.6	22.7	5.6	0.9	8.5	5.7
1967	0.1	3.4	18.9	4.5	0.7	7.8	6.0
1968	0.2	4.4	20.2	6.3	0.7	9.3	8.0
1969	0.1	4.3	18.9	6.1	0.7	7.0	8.3
1970	0.1	5.5	22.2	6.9	0.8	8.3	9.5
1971	0.1	4.4	18.4	6.5	0.7	7.8	10.5
1972	0.1	4.0	18.3	5.4	1.2	8.5	8.9
1973	0.1	4.6	19.3	6.2	1.8	12.1	8.5
1974	0.1	3.4	17.8	5.2	2.0	7.5	6.6
1975	0.2	3.6	15.0	4.9	2.2	5.6	5.6
1976	0.2	3.6	16.1	4.5	2.8	6.6	7.9
TOTALS:	2.9	78.9	472.3	114.6	20.5	160.0	139.0
AVERAGE ANNUAL:	0.1	3.3	19.7	4.8	0.9	6.7	5.8

*County total too low to be reported.

Sources: See text.

et al., (1977). For the remaining years, the figures given are 0.78 of the county totals, this being the average production ratio of the latter two districts to the county total from 1960 to 1975.

In Riverside County, sand and gravel are mined outside the study area in the San Gorgonio River, at three sites in the Coachella Valley, and at one site in the Palos Verdes area. For the period 1960-1975, the figures in Table D2-7 are for the Temescal Wash district, plus 0.5 million tonnes per year for the Prado and Pedley operations -- an estimate based upon their annual production category (Evans et al., 1977, p. 3). 1953-1959 figures are 0.27 of the county's total, this being the production ratio within the study area to total county production during 1960-1965. The 1976 figure listed is 59% of the county's total, which is the average production ratio for the period 1973-1975. This change in proportion is primarily the result of an expansion of the Temescal Wash district production during the early 1970's.

In Santa Barbara County, the major sand and gravel deposits are in the Santa Ynez and Sisquoc rivers, both outside the study area. Of nine operations in the county, only the small one at Ellwood Ranch is in the study area. Estimated figures given in Table D2-7 are 0.10 of the reported county totals.

It should be noted that district productions given by the California Division of Mines and Geology (Table D2-6) do not always match the county productions as given by the U.S. Bureau of Mines (Table D2-7). The reason for the discrepancy is that crushed rock has been included with sand and gravel production in the state study, whereas the federal figures do not include this product for plants that report it separately. In addition, the state report omits government-operated mining, which is minor.*

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*Tom Anderson, California Division of Mines and Geology, Los Angeles, personal communication, February 1979.

Only limited aggregate production data for Los Angeles and San Diego counties prior to 1953 are available. These data, compiled in Table D2-8, were obtained for San Diego County from San Diego Integrated Planning Office.* In Los Angeles County figures for the period 1945-1952 are based upon estimates by the Southern California Rock Products Association of production in the San Fernando Valley (Tujunga fan) district, the San Gabriel Valley district, and the Harbor district (Palos Verdes operation).** To these, 0.3 million tonnes per year were added for the Arroyo Seco and Montebello operations, based upon their production categories (Evans et al., 1977). Similarly, for the upper Santa Clara River district, which began production in 1948, .01 million tonnes were added for 1948 and 1949, and 0.1 tonnes per year subsequently.

Los Angeles County production can be estimated for the period prior to 1945 from its relationship to total California production. According to the Forty-First Report of the State Mineralogist, California Division of Mines (1945), Los Angeles County accounted for nearly 50% of the state's sand and gravel output in the year 1915. 1945 production in the county was estimated at 30% of the state total, a proportion that held through 1952, declining to 28% in 1955, 23% in 1964, and 19% in 1970. The decline of Los Angeles County production compared to the California total has followed a somewhat smooth trend. Therefore, by interpolation, estimates of county production may be obtained as far back as 1934, the earliest date statewide totals were reported by the U.S. Bureau of Mines. The values given for Los Angeles County in Table D2-8 are 35% of total California production for the period 1934-1939, and 31% for the period 1940-1944.

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*From the files of Charles Lough, San Diego County Office of Environmental Management.

**From the files of Don Reining, SCRPA.

Table D2-8

Early Sand and Gravel Production
Los Angeles and San Diego Counties

Year(s)	Los Angeles County (10^6 tonnes/yr)	San Diego County (10^6 tonnes/yr)
1934-1939	3.4	0.3
1940-1944	7.1	0.7
1945	5.9	1.1
1946	9.3	0.6
1947	10.3	1.0
1948	10.5	1.4
1949	10.0	1.4
1950	12.4	1.7
1951	12.8	1.6
1952	14.4	2.4
Average annual	7.5	0.9
Total 1934-1952	142×10^6 tonnes	16.5×10^6 tonnes

Source: See text.

The relative aggregate production in counties suburban to Los Angeles -- Orange, Riverside, San Bernardino, and Ventura rose from 30% in 1953 to 49% in 1955; from around 70% in the late 1950's and early 1960's to 96% in 1960 and 109% in 1975-1976. By extrapolation of these data, it is estimated that the adjoining counties produced 10% as much as Los Angeles in 1950, and their combined output during the period 1950-1952 was probably around 20% of that in Los Angeles County, or 7.9 million tonnes. It might be assumed that the adjoining-county aggregate production was more or less stable at a very low level prior to this, perhaps 1 million tonnes per year in the 1940's and late 1930's. If we assign 15 million tonnes to these suburban counties for the period 1934-1949, and neglect Santa Barbara production as insignificant, estimated total sand and coarse aggregate production for the study area during the period 1934-1976 is nearly 1,200 million tonnes.* Of this, more than 84% was extracted during the last 24 years, when average annual production totalled 41 million tonnes per year.

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*This does not include the volume of material made available through channel and entrapment structure cleanouts, which is small by comparison.

D2.4 References

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SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA
MOUNTAINS, COASTAL PLAINS AND SHORELINE

Section D3
(EQL Report 17-D)

Role of Vegetation in Sedimentation Processes of Coastal Southern California

by

Wade G. Wells II and Nancy R. Palmer

D3: Role of Vegetation in Sedimentation Processes of Coastal Southern California

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Wade G. Wells II* and Nancy R. Palmer**

D3.1 Introduction

Vegetation is a major factor influencing the movement of sediment. Because it is variable in both space and time and because different vegetation types influence the various erosion processes differently, some way of characterizing vegetation in terms of its effect on these processes is necessary. The first step is to organize the vegetation into more or less homogenous types and then map the distribution of these types within the study area. This has been done as a part of the initial assessment study, and two vegetation maps of the study area are included as a part of this report.

The first map (Plate D3-1) shows the vegetation as it appears today and includes areas of significant urbanization and agricultural activity. The second map (Plate D3-2) is our estimate of how vegetation was distributed before the arrival of European man. Neither map is intended to be a definitive floristic map of the area. Rather, they represent a first critical attempt to classify and map the vegetation of the study area in terms of its effect on sedimentation. They are intended to reflect our current state of knowledge on the role of vegetation in sediment movements.

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*Wade G. Wells II is a hydrologist with the Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service.

**Nancy R. Palmer is formerly a landscape architect with the Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service.

D3.2 Vegetation and Sedimentation Processes

In order to understand the role of vegetation in sediment movements, we must also understand the processes responsible for these movements. Sedimentation, which is a collective term, encompasses all the processes involved in the erosion, entrainment, transport, deposition and compaction of sediment (Vanoni, 1975). Vegetation has little influence on the processes of entrainment, transport and compaction, so our study considers only erosion and deposition. Of these two processes, the interaction of vegetation with the erosion process is the more important and will be discussed first.

Each type of vegetation must be evaluated in terms of both the processes with which it interacts and the way this interaction takes place. On erosional surfaces vegetation reduces the impact of eroding forces by acting as a kinetic energy sink and as a soil stabilizer. The major eroding forces are wind, falling raindrops, the various types of surface flow and the direct effects of gravity on the soil mantle. Gravity's direct effects are manifested in two important processes, mass-wasting and dry ravel. Mass-wasting is a collective term for such things as landslides and soil slips, while dry ravel refers to the intermittent flow of individual particles, often in considerable volume, over the surface of steep slopes during dry weather.

Each of these processes has a characteristic zone of action and interacts only with certain corresponding parts of a plant. For example, mass-wasting, which is a sub-surface phenomenon, involves only the root zone. Surface flow, as the term implies, operates at or very near the ground surface and only interacts with the plant material found in this rather narrow zone. The same can be said for dry ravel. Wind and falling rain, however, are affected by the entire plant canopy from the ground surface to the tops of the tallest trees. The most logical way to look at how vegetation affects sediment movements is to divide a plant community structurally, according to the processes with which it interacts. To do this, we have recognized three zones in the plant community: the root zone and two zones of plant material above the ground, which we have termed near-surface and above-surface vegetation.

The difference between near-surface and above-surface vegetation is not easily defined because it is not a precise concept. We defined them according to the concentration of a plant's leaf and stem surface relative to the ground. Near-surface vegetation has most of its leaf and stem surface concentrated at or very near the ground, with this concentration tending to decrease with distance above the ground. Above-surface vegetation is just the reverse. Its leaf and stem surface is concentrated well above the ground. Implied in this definition is the fact that vegetation having a distinct stem or trunk is above-surface vegetation. Representatives of the two types of vegetation are shown in Fig. D3-1.

Graminoids (grasses and grass-like plants), many forbs (broad-leaved herbaceous plants) and a few shrubs constitute near-surface vegetation, while trees, most shrubs and certain forbs are above-surface. No distinct line of demarcation between near-surface and above-surface vegetation is drawn. Rather, the growth form of each individual plant will determine to which type it belongs.

This two-level approach to studying surface vegetation is not intended as a formal classification scheme; it is simply a convenient way to relate vegetation to the eroding forces that are a part of its environment. Formal classification schemes have been proposed, however, that do use this structural approach, notably those of Raunkier (1934) and Dansereau (1957).

Now we are ready to look more closely at individual erosion processes and the vegetation affecting them. The agents most directly influenced by above-surface vegetation are falling raindrops and wind. Any layer of vegetation will tend to reduce wind velocities near the surface, resulting in diminished erosive power. While both near-surface and above-surface vegetation perform this function, the above-surface layer is more effective because it produces a deeper layer of

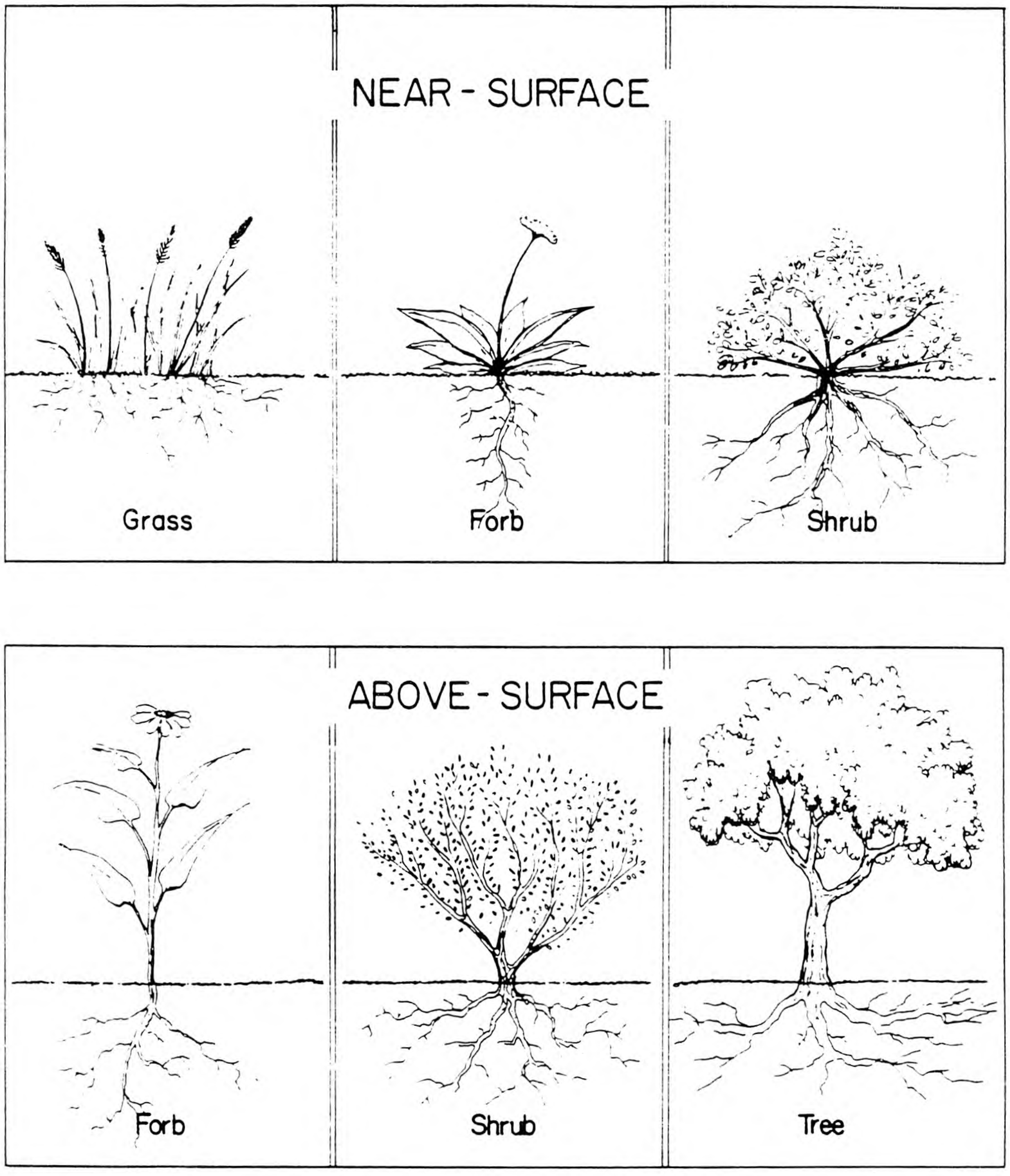

FIGURE D3-1. Examples of near-surface and above-surface vegetation. Groups are determined by structure rather than height.

slow-moving air. This deeper zone will tend to produce lower wind velocities at the erosion surface and will provide greater protection from turbulent bursts.

Above-surface vegetation also intercepts falling raindrops, which reduces not only the amount and intensity of rainfall, but also the total energy reaching the ground. It reduces energy by momentarily interrupting the fall of raindrops, which reduces their velocity and breaks them up into smaller sizes. Also, because plants present a large amount of surface area to falling rain, vegetation reduces both the intensity and amount of rainfall reaching the ground by catching and holding the drops. Of the rainfall retained on plant surfaces, up to 12 percent evaporates and never reaches the ground (Hamilton and Rowe, 1949). The remainder is delivered to the ground as either stemflow or drip. Hamilton and Rowe (1949) found stemflow to be extremely variable, accounting for 8 to 32 percent of the total precipitation delivered to the ground. Stemflow is generally low velocity laminar flow with little, if any, erosive power. Drip, on the other hand, can be highly erosive. Water that falls from plant surfaces has usually coalesced into extremely large drops (4 to 6 mm in diameter) before it breaks free and, if it falls for an appriciable distance, develops considerable momentum causing splash erosion on impact. This process requires the concentration of large numbers of drops on an area to be effective. These concentrations only occur at certain places, such as the tips of large tree branches and the edges of roofs. As a result the effects of drip are extremely localized, and it does not play a major role in overall sediment production.

Overland flow, which is defined here as comprising all classes of surface flow from low-velocity sheet flow to concentrated prechannel flow, is most directly affected by near-surface vegetation. This vegetative component slows flow velocities and increases the sinuosity of individual flow paths. The stems of above-surface plants also do this, but at their junction with the ground the stems make up such a small part of the total ground area that their contribution is minor.

Near-surface vegetation is also an effective interceptor of rainfall, and because it is close to the surface, it does not produce any appreciable drip. Therefore, its role in diminishing total rainfall energy may be even more important than that of above-ground vegetation. The large amount of leaf surface in this type of vegetation also provides a holding area for water that eventually infiltrates the soil.

It appears that near-surface vegetation also exerts a strong restraining influence on dry ravel. On steeper topography dry ravel is a major hillslope process (Rice, 1973). Although it is obviously driven by gravity, its modes of initiation are not well known. Animals moving across steep slopes can start it, and so, probably, can wind. However, it is so common in the Transverse Ranges that other mechanisms should be investigated, such as desiccation and detachment by thermal expansion and contraction. Dry ravel has been observed to increase immediately after fires, and tends to be associated with coarse-grained materials that are more stable when wet than when dry. Our understanding of this process is still quite limited.

The root zone of a plant community is important in the control of mass-wasting. Plant roots tend to bind the soil into large coherent masses, which are less susceptible to the small-scale slippage that can occur in an average storm. Root strength and rooting depth are thought to be important factors in maintaining slope stability. A high incidence of small, shallow soil slips in the San Gabriel Mountains has been linked to shallow-rooted grass vegetation as compared with the much deeper-rooted chaparral (Rice et al., 1969; Rice and Foggin, 1971). When the entire root zone becomes saturated in large storms, however, large failures can occur in spite of the most extensive root systems.

In many parts of the study area the soil mantle on steeper slopes is a coarse-textured, poorly consolidated layer less than one meter thick, which lies on highly fractured, hydrologically active parent material. Plants with strong roots and a deep rooting habit are expected to be most effective in controlling mass-wasting on these areas. Fortunately, the most common vegetation on these areas, chaparral, has very deep roots which actually penetrate the parent material and anchor the soil mantle to it, much like a series of rivets (Hellmers et al., 1955). Grass, with its shallow, finely divided roots, cannot do this.

Another important factor associated with roots and mass-wasting involves the rate at which root strength diminishes after a plant dies. For most woody species, when many members of a plant community die (as in an unusually hot fire) the roots will probably retain their strength for three to five years, depending on site conditions. After this, the roots decay and their soil holding capability diminishes, which results in increased soil slippage. This increased slippage continues until about the tenth year, when the site again tends to stabilize. The exact reasons for this stabilization have not been studied, but it is probably due to gradual readjustments of the hillslope, establishment of new root systems, or a combination of the two.

A layer of plant material which has an important effect on erosion processes but cannot truly be called vegetation is the litter layer. Except for a few areas where vegetation is sparse or absent, it forms an almost continuous cover over the mineral soil. Litter is important because, besides impeding the mechanical processes of erosion, it is susceptible to decay and to combustion. These chemical processes influence the erodibility of soil because they are instrumental in the formation of soil aggregates and water repellent layers.

In its interactions with erosion processes, litter functions very much like near-surface vegetation. The light, uncompacted surface absorbs raindrop energy, and its many voids hold water that can eventually infiltrate the soil. It usually increases the roughness of the ground surface so that overland flow velocities are reduced and flow path sinuosity is increased. However, because it is not attached to the soil like vegetation, it can be moved by the impact of intense rainfall, entrained in high runoff flows or blown about by wind.

The effectiveness of the litter layer in retarding erosion is largely determined by its thickness, which varies with plant community and site conditions. In 20-to 30-year-old chaparral, for example, a litter layer thickness of about 2.5 cm is maintained by the balance between leaf fall and microbial activity. As the stand gets older, microbial activity decreases and the litter layer deepens until a fire occurs and removes it. In the first years after a fire microbial activity remains low, allowing the litter layer to build up again. Microbial activity then increases and balance is re-established.*

One special effect of vegetation on sediment movement involves its interaction with fire. Vegetation carries fire, and the character of a plant community often determines the intensity of burning. Aside from the removal of protective plant cover, fire and vegetation can also interact to alter the erodibility of a site. The formation of water repellent soil layers, discussed in Section D4, is an example. Different plant communities exhibit different levels of flammability over time, and this affects long-term fire frequencies. Certain plant communities seem to be maintained by periodic fires, even to the point that fire becomes an essential part of their development cycle. Chaparral, which is highly flammable and dominates the study area, is such a type.

The effect of vegetation on depositional areas and processes is less pronounced than it is on erosional areas because vegetation tends to augment rather than work against depositional processes.

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*Dunn, Paul H., Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, personal communication, 1979.

Depositional areas are those which have relatively gentle gradients and would induce deposition even if vegetation were not present. Near-surface vegetation, because it interacts directly with surface flow, is by far the most influential part of a plant community in depositional areas. The large number of stems divert flow and increase effective surface roughness. This leads to decreased flow velocities, which induce deposition. In some areas, like marshes and deltas, vegetation is probably the dominant agent for inducing deposition.

D3.3 The Riparian Zone

An area of special importance to sedimentation studies is the reparian zone. This is normally a narrow depositional belt next to an active stream channel which supports a distinctive plant community. This zone is usually so narrow that it cannot be mapped accurately, except at very large scales, and therefore it does not appear on the vegetation maps that accompany this report. However, its location can generally be inferred from the drainage networks appearing on the other maps.

It is difficult to find an acceptable definition for the riparian zone, since there are differing opinions about its limits. For our purposes, however, it can be defined as the area on either bank of a continuous or intermittent stream which is primarily depositional and supports a plant community that is distinctly different from that of the adjacent upland areas. This vegetation is present because of a high local water table. It is usually more hydric (adapted to wetter habitats) than the upland vegetation and often includes phreatophytes. Phreatophytes are deep-rooted plants that draw their water directly from the water table or from the soil layers immediately above it. From a sedimentation standpoint, the term "riparian" can be extended to include the depositional areas adjacent to ephymeral upland streams (dry washes). These areas are not normally considered riparian because they are not influenced by the water table, and usually support no distinctive vegetation. However, the sedimentation processes operating in these areas are so similar to those operating in true riparian zones that the two areas can be treated alike.

The effectiveness of vegetation in controlling erosion by running water has long been recognized. In agricultural practice it is used to help stabilize active gullies and to line erosion-prone drainageways. The literature dealing with naturally occurring riparian vegetation is not extensive, and the exact role it plays in sedimentation processes is not yet well defined. Parsons (1963) has suggested that vegetation on a streambank may perform at least three significant functions. Reduction of water velocities and tractive forces at the erosional surface is perhaps the most important of these. Vegetation may also act as a buffer against logs, ice, and other transported materials, and can enhance bank stability by inducing deposition. Rice et al. (1969) have indicated that riparian vegetation also plays an important part in maintaining the stability of adjacent upland slopes. The effect of riparian vegetation on sedimentation was demonstrated during an experiment conducted by the U.S. Forest Service in Monroe Canyon on the San Dimas Experimental Forest. The object of the experiment was to study the effects of vegetation on water yield, and its study plan called for the removal of 17 ha of riparian vegetation from the canyon bottom followed by the removal of 57 ha of chaparral from its lower side slopes. An adjacent canyon, Volfe Canyon, served as a control for the experiment and was left in its natural state. Both canyons are about the same size (approximately 325 ha) and under normal conditions have comparable flows and sediment yields.

The riparian vegetation was removed in 1958, but before the side-slope vegetation could be removed, the Johnstone Fire of 1960 burned the entire Experimental Forest. Both basins were completely burned over, but the riparian vegetation in Volfe Canyon, although scorched, remained essentially intact. It was, therefore, decided that the fire would not significantly affect the validity of the experiment. The side-slope vegetation was removed in 1961. For the next five years, significantly higher flows were reported from Monroe Canyon, but no problems with excessive sedimentation were noted. However, 1966 and 1967 were wetter than normal, and in both of these years significant damage from flows and debris production was reported for Monroe Canyon but not for Volfe. In both years, the Monroe gaging station was so severely damaged by debris that several weeks of record were lost. The Volfe gaging station recorded very high flows but suffered no damage (Rice and De Bano, 1966). Channel scour was at least an order of magnitude greater in Monroe than in Volfe Canyon. At the end of the 1967 season, channel widths were 36.6 m for Monroe and 3.7 m for Volfe (Rice, 1967).

During the record hydrologic year of 1969, all gaging stations on the San Dimas Experimental Forest were damaged to some extent, but the Monroe station was totally destroyed. Aerial photos of Monroe and Volfe canyons showed a marked difference in the extent of damage to the two stream channels and its banks more heavily debris-laden. Orme and Bailey (1970) reported that 2,192 m^3 of debris were discharged from Monroe Canyon between 1963 and 1969, while Volfe Canyon delivered only 267 m^3. Channel scour and widening were also significantly greater in Monroe Canyon than in Volfe Canyon.

Although it is not possible to separate the effects of the riparian vegetation from those of the side-slope vegetation, it is reasonable to assume that the removal of the riparian vegetation made a significant contribution to the increased sediment yield. This assumption is supported by the greater channel scour noted in Monroe Canyon. Since both canyons were burned to a similar extent, it can also be assumed that the Johnstone Fire did not affect the conclusions drawn from the experiment. Furthermore, both watersheds had five years to recover before the major storms began. It is clear from this experiment that riparian vegetation plays an important role in basin sedimentation processes but the exact nature of this role is not fully understood. This is a subject that needs more detailed study.

D3.4 Vegetation Maps of the Study Area

The vegetation maps included with this report (Plates D3-1 and D3-2) were produced to contribute to the sedimentation assessment study by organizing and cataloguing the major vegetation complexes that influence sedimentation. They are not floristic maps, although they use floristic designations for the mapping units. Except for that portion of the study area located in Baja California, they are based on early classification work done by the U.S. Forest Service (Wieslander et al., 1945, soil surveys done by the Soil Conservation Service, reports of early explorers, recent field information,* and the vegetation map of Kuchler (1977). For Baja California, the map of Brown and Lowe (1977) was the principal source of information. Both maps represent only a first approximation, and changes are anticipated as more information becomes available.

The two maps have been drawn at a rather small scale (1:1,000,000), because our present understanding of the relationship between vegetation and sedimentation does not warrant greater precision. In organizing and describing the mapping units, the classification system of Paysen et al. (1980), has been used as a guide, although some of their names have been changed to accommodate the needs of this study. Most of the mapping units correspond to the "formation" level of their hierarchy, although some (coastal salt marsh and California grassland) correspond to the "series" level.

In determining mapping units, the major emphasis was placed on growth form and susceptibility to fire, surficial geology and topography. Floristics and other vegetative characteristics were also considered but to a lesser degree. Surficial geology and topography are important because, as the relative dominance of different erosion

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*Paysen, Timothy E., PSW Station, U.S. Forest Service, personal communication, 1978. Derby, Jeanine A., San Bernardino National Forest, U.S. Forest Service, personal communication, 1978.

processes changes, the relative importance of vegetation types changes also. For example, in oak savannas, which are oak woodlands with California grassland understories and which tend to occupy gentler and depositional areas, the grassland understory is probably more important than the oaks themselves. In coniferous forest, however, steeper slopes predominate, so the extensive root systems of the forest trees probably make them a more important component than the understory.

The book Terrestrial Vegetation of California (Major and Barbour, 1977) has served as a major source of information, and citations from this book are referenced directly to individual contributors. For each mapping unit, only the most important plant species are listed, and whenever possible, common names of plants are used (although scientific names for each species are given at least once). A Flora of Southern California by Munz (1974) is used as the authority for both common and scientific names.

D3.5 Vegetation Classes

Ten vegetation classes have been recognized for this study and seven of them have been mapped. The mapped vegetation units are:

A. Chaparral

B. Oak woodland

C. Coastal sage scrub

D. Coniferous forest

E. Coastal salt marsh

F. California grassland

G. Pinyon-juniper woodland

The unmapped vegetation classes are:

a. Riparian woodland

b. Beach and dune communities

c. Alpine communities

The unmapped units are so small or narrow that they cannot be mapped accurately at the scale used. Also, the present-day vegetation map shows three additional mapping units: urban land, cultivated land and a mixture of these two land uses.

A. Chaparral

Chaparral is by far the most important vegetation type in the study area. Its importance stems from its high efficiency as a watershed protector and slope stabilizer, its extreme susceptibility to fire, and the fact that it covers fifty percent of the study area. Chaparral occurs on the slopes of all major mountain ranges as well as the slopes of most hilly areas. Generally, it occurs above and inland from coastal sage scrub and below the coniferous forests, but it can occur within these two types as well. In parts of Ventura and Santa Barbara counties it extends nearly to the Pacific Ocean. It is less common on depositional areas but can occur there too.

The most distinctive feature of chaparral is its growth habit. Chaparral plants are evergreen sclerophyll ("hard-leaved") shrubs which tend to form dense thickets, usually with no understory of forbs or grasses. In addition to its dense, above-ground biomass, it also forms deep, extensive root systems. These roots are extremely strong, often exceeding the roots of commercial forest trees in a shear and tensile strength.* This strong root system combined with the dense overstory makes chaparral the most valued watershed protector in California (Hanes, 1977).

Chaparral, as a type exhibits great species diversity. A few species, however, can serve to characterize the entire type for our purposes. The most important of these are: Chamise (Adenostoma fasciculatum), red shank (A. sparsifolium), California-lilac (Ceanothus

*Rice, Raymond M., Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, personal communication, 1978.

spp.), manzanita (Arctostaphylos spp.), scrub oak (Quercus dumosa), toyon or Christmas berry (Heteromeles arbutifolia), sumac (Rhus spp.) and, at higher elevations, bush chinkapin (Chrysolepis sempervirens). One additional species, which often mingles with chaparral as well as some other types, is the sub-shrub, California buckweat (Eriogonum fasciculatum).

Despite its great floristic variability on a broad scale, chaparral does exhibit some local consistency. Because of this consistency, Hanes (1977) has recognized nine distinct chaparral types, seven of which occur in the study area. These are:

a. Chamise chaparral
b. Red shank chaparral
c. Ceanothus chaparral
d. Manzanita chaparral
e. Scrub oak chaparral
f. Woodland chaparral
g. Montane chaparral

Of these, the first five are dominated by the species for which they are named. The other two can be thought of as a mixture of chaparral with another vegetation class. Woodland chaparral, as the name implies, is a woodland with a chaparral understory. Within the study area the trees are usually oaks. Woodland chaparral generally occurs on shady slopes above 900 m elevation. Montane chaparral occurs at still higher elevations and is a combination of chaparral and coniferous forest. Following fires in this type, chaparral may dominate until the forest trees take over; then it often remains as an understory. Both of these types are classed as chaparral for botanical reasons, but because the brush affects sedimentation processes more directly than do the trees, this classification also suits our needs.

The interaction and interdependence of chaparral and fire is another important part of chaparral's influence on sedimentation processes. Chaparral is one of the most flammable vegetation complexes in the world (Lewis, 1961). Fires occur with a frequency of once every 10 to 40 years (Muller, et al., 1968), and dramatic increases in sedimentation rates after fires are a well-established fact in southern California (Rowe, et al., 1954). Despite the fact that fire is a major de-stabilizing influence on chaparral watersheds, there is a growing body of evidence that suggests that chaparral evolved under, and is maintained by, some sort of fire cycle. For example, Hanes (1974) has noted that the post-fire successional patterns in chaparral are remarkably similar throughout its range, indicating a well-established mode of adaptation. If this is true, it is necessary to change our traditional thinking about minimizing sediment yields from chaparral watersheds. Rather, periodic fire, with its subsequent high sediment yields, must be accepted as a natural phenomenon in southern California and dealt with accordingly.

B. Oak Woodland

The oak woodland is difficult to describe, not only because of the large variety of plants included in it, but also because it occupies both erosional and depositional sites. Griffin (1977) describes it as a group of variable communities geographically placed between grassland or scrub and montane forests. Communities with an oak overstory occur in valleys, foothills and canyon bottoms, as well as in a wide belt between the lower chaparral and the lower coniferous forest zones. At the higher elevations oaks may form a broken overstory above a chaparral community. Where this occurs we have called the type woodland chaparral and mapped it under the chaparral designation. Imbedded in this woodland chaparral are small islands of oaks over grass and forbs, frequently associated with bigcone Douglas fir (*Pseudotsuga macrocarpa*). It typically occurs on the cooler side-slopes of small canyons. This community, although it is usually in stands too small to map, typifies what is probably our best definition of an oak woodland: a woodland dominated by oaks with an understory of grass, forbs and scrub. This description implies the inclusion of savannas, which are grasslands with more or less scattered trees. To distinguish oak woodland from California grassland, we have used Paysen's cutoff to twenty-five established trees per hectare (Paysen et al., 1980). The sparser savannas with localized areas of greater tree density thus appear as California grassland on the maps. Some examples are the valleys inland from San Diego and the Santa Monica Mountains, and the foothills of the San Gabriel Mountains.

The oak woodland is best recognized by its dominant tree species, which include coast live oak (*Quercus agrifolia*), valley oak (*Q. lobata*), Englemann oak (*Q. engelmannii*), and the California walnut (*Juglans californica*). A frequent associate, especially in the San Gabriel and San Bernardino mountains, is the bigcone Douglas fir. Understory plants are quite variable but usually include representatives from the California grassland and coastal sage scrub type.

The typical distribution of trees on valley foothills is a relatively sparse woodland or savanna that becomes more dense on steeper slopes. Reasons for this are unclear, but the pattern is such that tree roots, which are effective against mass-wasting processes, increase in density on sites where gravity is a more important erosive agent. On gentler topography, where trees become less dense, rainfall and surface flow are the more important eroding agents. Because of this, the near-surface vegetation in the understory becomes the more important vegetation factor. In the mountains, where gravity and mass-wasting are always important, the trees with their deep, strong root systems are probably the most important part of the vegetation complex.

In earlier times the oak woodland, like the California grassland and coastal sage scrub, occupied some of the best sites for settlement in southern California. Much of its former range has been reduced by cultivation and urbanization. For this reason its role in the sedimentation processes of coastal southern California is less important than it was formerly.

C. Coastal Sage Scrub

This type occurs mainly along the coast and inland below the chaparral zone. In appearance, it is similar to chaparral but the plants are smaller and less woody than are the chaparral plants. Principal species include black sage (Salvia mellifera), white sage (S. apiana), California sagebrush (Artemisia californica), California buckwheat (Eriogonum fasciculatum), California encelia (Encelia californica), lemonadeberry (Rhus integrifolia) and purple sage, (Salvia leucophylla).

Coastal sage scrub associates closely with chaparral throughout the study area. Because of their similar appearance, the term "soft chaparral" as a synonym for coastal sage scrub is gaining popularity. Compared to chaparral, however, coastal sage scrub probably is quite different in its effects on sedimentation. First, coastal sage scrub tends to be of the near-surface type, whereas chaparral plants are distinctly of the above-surface type. Second, the root systems of coastal sage scrub are probably less effective against mass wasting than are those of chaparral. Hellmers, et al., (1955) report that rooting depths for coastal sage scrub are only about half that of chaparral. No information on root strength appears in the literature.

On the other hand, as a watershed protector, coastal sage scrub may make more efficient use of its available biomass than chaparral. Mooney (1977) reports that it has only about one-sixth as much above-ground area (on a per plant basis). However, leaf area indexes, which are indicative of available plant surface, are about half that of chaparral while leaf to stem ratios are about the same. It seems possible, therefore, that this type could be more effective against rainfall and surface flow than chaparral.

In former times coastal sage scrub extended inland to occupy the basins around San Diego and San Bernardino, and for a considerable distance up the Santa Clara Valley. Along the coast it occupies the dry, lower slopes while chaparral is found on the more mesic upper slopes. Mooney (1977) describes a common pattern where coastal sage occurs with chaparral but occupies the drier habitats. This dryness can result from surficial geology and soil type as well as from actual rainfall patterns. Inland from the coast this type tends to occur more frequently on depositional sites, especially those with coarse-textured soils. This change in site seems to be accompanied by a change in character. The inland coastal sage is less woody than the coastal version, which indicates a reduction in total biomass. Although its influence has been reduced by cultivation and urbanization, coastal sage scrub is still one of the most important watershed protectors in the study area. It is also susceptible to fire.

D. Coniferous Forest

This mapping unit encompasses several recognized vegetative types. However, since the gross community structure of these types is quite similar, they are mapped together as a single unit. This unit is characterized by moderately tall to tall coniferous trees along with some hardwoods and an understory consisting of varying proportions of brush, grass, forbs, litter, and bare ground. The trees generally grow close together in a closed canopy forest but can form an open canopy woodland, especially on drier sites and at higher elevations.

Coniferous forests grow predominantly in mountainous areas above 1,600 m and form a belt extending from the chaparral and oak woodland to the islands of alpine communities on the highest summits. They occur in most of the major mountain ranges of the area but are probably best developed in the San Bernardino, San Gabriel and San Jacinto mountains. There are at least four distinguishable types in this mapping unit. They are listed below with their dominant species.

a. Coulter Pine Forest

Principal species: Coulter pine (*Pinus coulteri*), bigcone Douglas fir (*Pseudotsuga macrocarpa*), California black oak (*Quercus kelloggii*), and canyon live oak (*Q. chrysolepis*).

b. Yellow Pine Forest

Principal species: Jeffrey pine (*Pinus jeffreyi*), ponderosa pine (*P. ponderosa*).

c. Upper Montane Coniferous Forest

Principal species: White fir (*Abies concolor* ssp. *concolor*), sugar pine (*Pinus lambertiana*), lodgepole pine (*P. contorta* ssp. *murrayana*), incense-cedar (*Calocedrus decurrens*), mountain juniper (*Juniperus occidentalis* ssp. *australis*), and mountain mahagony (*Cercocarpus ledifolius*).

d. Subalpine Coniferous Forest

Principal species: Lodgepole pine (*Pinus contorta* ssp. *murrayana*), limber pine (*P. flexilis*).

With a few local exceptions, the entire coniferous forest zone must be considered erosional, and gravity is its most influential eroding agent. Because of this and because of its variable understory, the coniferous trees exert the greatest influence on erosion processes. Typically, these trees have shallow, but extensive, root systems with great lateral development. Soils are usually shallow, coarse textured and poorly developed, and bare ground frequently appears under the trees, especially in the harsh environments of higher elevations. Precipitation usually occurs as snow in winter or as short-duration thunderstorms in summer, so major erosion events from rainfall and runoff are not common. Strong winds are common but the coarse-textured soils and tall trees combine to make their effects minimal.

E. Coastal Salt Marsh

Although it covers a limited part of the study area, this vegetation type is mapped because it occupies the zone where fluvial and tidal processes meet. Coastal salt marshes are found in the upper intertidal zone of coastal lagoons, estuaries and protected shallow bays. Because of the tidal influence, halophytes (salt-loving or salt-tolerant plants) make up a significant part of the vegetation on these sites. Within the study area there are two distinct types of coastal salt marsh. They are distinguished by whether or not they have sufficiently deep ocean inlets to permit continuous tidal action (MacDonald, 1977).

The type which is subject to this continuous tidal action has a varied and stratified composition. It can be divided into low, middle and high marsh habitats. In this type the dominant species are cordgrass (Spartina foliosa) in the low marsh, and glasswort or pickleweed (Salicornia virginica) in the high marsh. These two species also occur as stunted specimens in the middle marsh, where saltwort (Batis maritima) and an annual species of glasswort (Salicornia bigelovii) are dominant. Although glasswort dominates the high marsh, there are several associated species, including seablite (Suadea californica), saltgrass (Distichlis spicata), and sea lavender (limoneum californicum). This floristic variety does not extend into the middle or low marshes, however.

The second type of marsh occurs in the shallower tidal prisms and contains only high marsh vegetation. Because these sites experience alternating tidal and freshwater influences, their salinity regime fluctuates widely and permits the encroachment of nonhalophytic vegetation. As a result, the flora of these marshes often include some of the more aggressive representatives of adjacent upland floras.

The development of coastal salt marsh vegetation is dependent to a great extent on the sediment balance of its habitat. Flood tides carry offshore sediments onto the tidal flats, where they are joined by upland sediments being carried out of the marsh by ebbing tides (Pestrong, 1972). As the intertidal halophytes become established on these depositional locations they act as baffles to wave and current action. This induces further deposition, extends the marsh seaward, and provides space for more vegetation to become established.

Increases in marsh area and elevation expand the marsh's drainage system and the rate of ebb-tide deposition. Because of this, large marshes expand more rapidly than smaller ones. Equilibrium is reached when marsh expansion makes the tidal prism shallower to the point that flood tide deposition is replaced by scour. This scour is then balanced by the deposition at ebb tide from incoming fresh water (MacDonald, 1977).

F. California Grassland

At the time of European man's arrival in southern California, the California grassland occupied the choicest sites for settlement. As a result it has suffered the greatest reduction in area from cultivation and urbanization. Today, the area around Lake Henshaw in San Diego County is the only large representative of this type left in our study area.

Heady (1977) has applied the term "California Annual Type" to the present-day California grassland. This term reflects the change in its character from perennial bunch grasses to annuals since the coming of European man. Although the two types of grasses exhibit different growth regimes and somewhat different growth habits, the effects of these differences have not been studied because there is not enough bunchgrass left for the comparison. We can assume, however, that the effects are rather small. Principal species in the present-day annual grassland include wild oat (*Avena fatua*), soft chess (*Bromus mollis*), foxtail chess (*B. rubens*), which is also called red brome, and filaree (*Erodium cicutarium*). In the earlier perennial grassland, two species of needlegrass, *Stipa pulchra* and *S. cernua*, were dominant.

In southern California, California grassland associates closely with coastal sage scrub and certain types of oak woodland, particularly oak savannas. It usually is found on depositional sites and on gentle slopes where erosional pressures are not great. It is also associated with finer textured soils. Because of its near-surface growth form it is particularly good at retarding erosion by surface flow and at inducing deposition. It does not necessarily create the depositional areas on which it grows; rather, it occupies and enhances them after they have been formed.

Several workers from the U.S. Forest Service have shown that grass, when it is found or planted on steep slopes, is not particularly effective against the gravity-induced, mass wasting processes that normally prevail there (Rice, et al., 1969; Rice and Foggin, 1971). When such an area burns, however, the grasses' shallow, finely-divided root systems may temporarily help retard post-fire erosion caused by flowing water. This effect has been observed in the San Gabriel Mountains, but it usually does not last through even the first rainy season.

G. Pinyon-Juniper Woodland

Within the study area pinyon-juniper woodland occurs near Baldwin Lake in the San Bernardino Mountains, in the Sierra Pelona Valley of Los Angeles County, and in the Lockwood Valley area on the south side of Mt. Pinos in Ventura County. This very distinct floristic type is characterized by California juniper (*Juniperus californica*) at lower elevations and single leaf pinyon (*Pinus monophylla*) higher up. The understory is an open stand of typical Great Basin shrubs, particularly big sagebrush (*Artemisia tridentata*) and rabbitbrush (*Chrysothamnus nauseosus*).

Because of the dryness typical of pinyon-juniper sites, this area probably contributes little to the total sediment discharge of the basin in which it occurs. Therefore, the influence of the vegetation on sedimentation processes is probably not too important. The root systems of these plants are quite extensive, and their most important influence is probably the maintenance of slope stability.

H. Unmapped Vegetation Types

Three distinctive types of vegetation are not shown on the accompanying maps. Two of these, the alpine and the beach and dune communities, do not cover enough of the study area to be mapped at the scale used. The third, riparian woodland, is the typical vegetation of the riparian zone, which, though extensive and influential, is usually too narrow to permit accurate mapping.

a. Riparian Woodland

The riparian zone as an area of special concern in sedimentation studies has already been discussed. The plant community that it supports it quite variable but is generally dominated by a few species of moderately tall trees and includes an understory of grasses, forbs, and tall shrubs. It has been labeled riparian woodland but riparian forest would be an equally acceptable name.

The principal species of the riparian woodland include California sycamore (*Platanus racemosa*), Fremont cottonwood (*Populus fremontii*), black cottonwood (*P. trichocarpa*), white alder (*Alnus rhombifolia*), mule fat (*Baccharis glutinosa*), several species of willow (*Salix* spp.) and, at higher elevations, bigleaf maple (*Acer macrophyllum*) and California bay (*Umbellularia californica*). From a sedimentation standpoint, the root systems of these plants are their most important feature. Although root depths are variable depending on the water table, they are extensive and show great lateral development.

b. Beach and Dune Community

Structurally this community is quite similar to coastal sage scrub, but it exhibits a distinctly different species composition. It has never been extensive because of its unique habitat but as well represented around San Diego Bay and Redondo Beach before the onset of heavy urbanization. It is still well-represented around Point Conception. Today, it forms a narrow, much interrupted belt of vegetation between the mean tide line and the adjacent upland communities.

Floristically, it can be divided into two zones that run parallel to the mean tide line. The foredune, or furthest inland reach of storm waves, marks the division between the beach community on the seaward side and the dune community on the landward side (Barbour and Johnson, 1977).

The typical vegetation is herbaceous (but with a total lack of grasses in the study area) on the beach but takes on a more shrubby character on the dunes. Beach vegetation is dominated by sand verbena (Abronia maritima), sea-rocket (Cakile maritima), sea-fig (Carpobrotus [formerly Mesembryanthemum] aequilaterus) and Ambrosia chamissonis, for which no common name is given. The dune community includes goldenweed (Haplopappus ericoides) with California sagebrush (Artemisia californica) in the north and Mormon tea (Ephedra californica) in the south.

c. Alpine Communities

This vegetative type is found on only three very restricted sites: Mt. San Antonio (3,067 m) in the San Gabriel Mountains, Mt. San Jacinto (3,292 m) in the San Jacinto Mountains, and the highest summits of the San Bernardino Mountains between Mt. San Gorgonio (3,505 m) and Anderson Peak (3,311 m). The alpine belt occurs above timberline and below the nival belt (zone of perpetual snow), which is not present in southern California.

Alpine floras are quite diverse and vary greatly from one location to another. Few characteristic species occur at all three alpine locations except for a few species of buckwheat (Eriogonum spp.). Two timberline trees, limber pine (Pinus flexilis) and lodgepole pine (P. contorta ssp. murrayana) are present in all three alpine sites and exhibit the prostrate shrubby habit (krummholz) that is typical of them at these elevations.

D3.6 Discussion

From this assessment two important conclusions can be drawn. First, it is evident that certain plant communities have a significant impact on sedimentation processes, while others exhibit only minor influences. Second, the influence of man has resulted in changes to these communities, some of which are minor and some, considerable. Direct evidence that these changes have also changed the sediment balance of the area is lacking, but, considering the interaction of vegetation with erosion processes, such changes can be inferred.

Of the ten vegetation types identified, four appear to have a major influence on sedimentation processes. These are chaparral, coastal sage scrub, the riparian woodland and the coastal salt marsh communities. Chaparral and coastal sage scrub occupy most of the erosional surfaces in the study area and both seem to control the sediment regime of the sites they occupy. Both have deep roots and form dense canopies, which minimize erosion, but both are extremely susceptible to periodic fires, which multiply erosion rates many times. Therefore, it seems reasonable that areas covered by, or downslope from, these types would exhibit a sediment discharge cycle which reflects the fire cycle. Riparian woodland is important because it is indispensable for maintaining the stability of natural stream channels. When this vegetation is removed, excessive sedimentation results. Coastal salt marsh vegetation buffers the erosive action of waves and currents and is the primary agency for inducing deposition. Thus, it is important in both maintaining and building the estuarine shoreline. Man influences sedimentation through his manipulation of native plant communities. Urbanization and cultivation have changed species composition and in many areas entirely removed the native vegetation. Fire control efforts have caused changes in age class distribution. The total effect of these activities on overall sediment yields is only partially understood.

The effect of fire can never be totally separated from vegetation because the two are interdependent. The historical significance of cyclic burning in chaparral and coastal sage scrub is beginning to be recognized and high sediment yields following fires have been an accepted fact for years. It follows then, that there must have been a sediment delivery cycle that followed the fire cycle, which man's fire control activities have possibly altered. A common opinion is that fires, today, are more frequent than formerly but are smaller in size. This still needs to be verified. A complete discussion of fire and its effect on sedimentation is presented in the following section.

A final question to be asked is, where should we direct our future research efforts? First, a more precise measurement of the effects of plant communities on sedimentation would be useful, particularly for the four communities mentioned earlier in this discussion. These studies should focus on the interaction of plants and erosion processes. Second, the changes man causes in native vegetation, and the resultant effects on sediment yield, should be carefully examined. If the relationships can be thoroughly understood, better decisions can be made to optimize sediment balance through the management of both native and introduced plant communities.

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SEDIMENT MANAGEMENT FOR SOUTHERN CALIFORNIA
MOUNTAINS, COASTAL PLAINS AND SHORELINE

Section D4
(EQL Report 17-D)

Effects of Fire on Sedimentation Processes

by

Wade G. Wells II and William M. Brown III

D4: Effects of Fire on Sedimentation Processes

by

Wade G. Wells II* and William M. Brown III

D4.1 Introduction

Wildfires are a major cause of sediment movements in southern California. An important characteristic of the area's Mediterranean climate is that the peak fire season immediately precedes the onset of winter rains. Heavy, debris-laden floods emanating from freshly burned slopes during the early rains are such a common occurrence that the term "fire-flood sequence" has been coined to describe it. Chaparral and coastal sage scrub, two vegetation types which make up over half the plant cover in the area, have a long history of recurring fires. These fires create conditions which render watersheds extremely susceptible to eroding forces for about three years, and it is during this time that the major sediment movements take place.

D4.2 Sedimentation Following Fires

Fire-related sedimentation has not been researched extensively but of the studies made, one of the more interesting comes from Australia. Brown (1972) studied the effects of a fire in a eucalypt forest in southeastern New South Wales. His study catchments included one which was completely burned, Wallaces Creek, and one, the Yarrangobilly River, which was burned only in its lower reaches. Suspended sediment samples collected in the two streams indicated sediment loads that were as much as an order of magnitude greater following the fire than before. During the first eighteen months following the fire, streamflow records were available only from the Yarrangobilly River, because the fire destroyed the gaging station on Wallaces

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*Wade G. Wells II is a hydrologist with the Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service.

Creek and it was not immediately re-established. Staff gage readings were taken on Wallaces Creek, however, and they showed record high storm flows for the period immediately following the fire.

Of particular interest are the storm hydrographs for the first two years following the fire on the Yarrangobilly River. Normally, storm hydrographs will show a smooth, somewhat rounded peak with a long recession limb. Over half the storm hydrographs for the two years immediately following the fire showed, not only this normal peak, but also a sharp secondary peak with an exceedingly steep recession limb <u>preceding</u> the normal one (Fig. D4-1). Also, this secondary peak was often considerably higher than the normal one. Brown identified this peak as a fire effect, and his conclusion tends to agree with our experiences in southern California. Because the lower part of the basin was burned and the upper part was not, it may also be inferred that the two parts of the basin were functioning as separate hydrologic units, each with its own characteristic hydrograph. This could lead to a further inference that, because the two hydrographs were so different from each other, the processes responsible for them were also quite different. Brown's final conclusion was that the basins had recovered, hydrologically, after four to five years and were behaving as they had before the fire. This recovery time is about half the accepted figure for southern California, but current studies here indicate that Brown's figures are probably more accurate.

The most definitive study for southern California was that done by Rowe et al., in 1954. They concluded that sediment yields increased by two to eight times normal (i.e. the long-term average) during the ten years following a fire. Over half of this increase occurs in the first year when sediment yields can be as much as 35 times normal. Total increase was highest in the Transverse Ranges of Los Angeles and San Bernardino Counties and lowest in the Peninsular Ranges of San Diego County. These increases are illustrated in Figure D4-2. It is apparent that a return to normal occurs quite

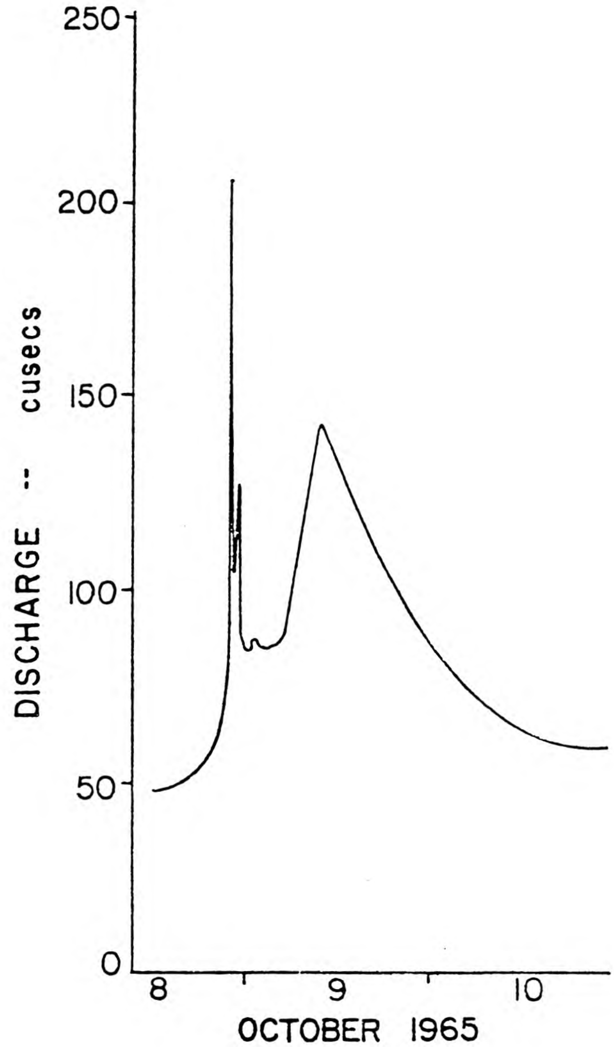

Figure D4-1 Hydrograph of the Yarrangobilly River showing sharp initial peak caused by burned portion of the watershed. (After Brown, 1972) (cusec = cfs = ft^3/sec = 0.028 m^3/sec.)

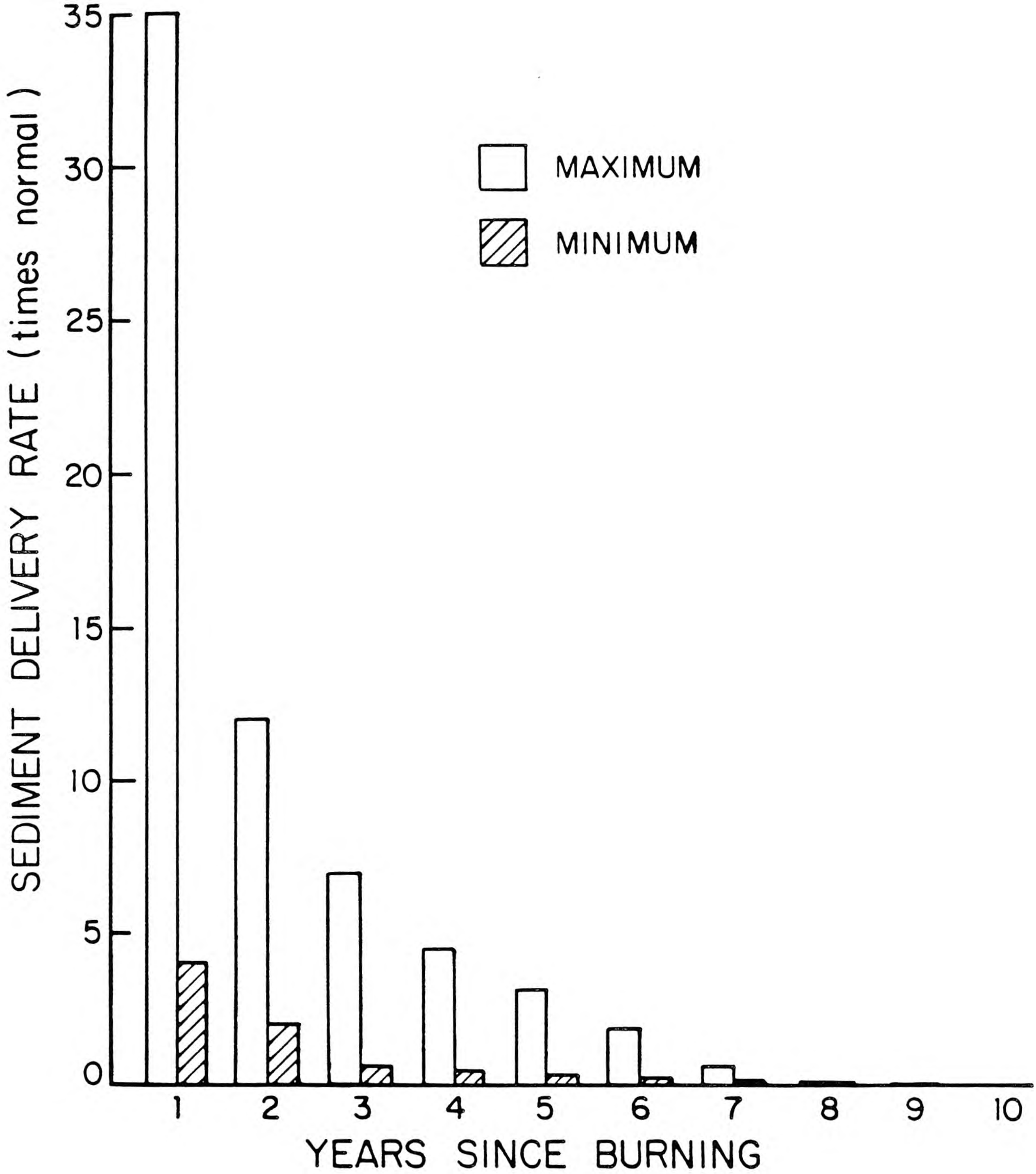

Figure D4-2. Expected increases in sediment delivery rates following fire (see text).

rapidly, being essentially complete by the end of the fifth year. This is shown in more detail by Table D4-1. In the table, column 2 gives the same data as is illustrated in Figure D4-2. Column 3 shows that fraction of the total increase occurring in each year after a fire. Column 4 shows the cumulative fraction of the total increase that has occurred at the end of each year after a fire. It is clear from column 4 that over 95 percent of the total increase in sediment production has occurred by the end of the fifth year. Although the actual amounts of increase vary from basin to basin, the percent of the total increase for a given year seems to be constant for all basins. Complete return to normal occurs in eight to ten years. Brown (1972) reported a return to normal in four to five years.

Hillslope studies show even more striking results. Wells (1981) reports an increased sediment delivery of over two orders of magnitude from hillslopes during the first year after fire (see Table D4-2). Recovery is rapid and hillslopes return to normal in about 3 years. This suggests that increased sediment production after the third year following fire is the result of channel scour.

The Rowe et al. study gives a good overall picture of fire-induced flood events and sedimentation in the study area. The methods employed in the study were sound, but the data base was necessarily small. Begun in 1945, the study seldom had access to runoff records more than 20 years old and sediment discharge records were even more meager. Much of the information was extrapolated from rainfall records which were the most plentiful form of data. It seems that an update of this work using the greatly expanded data base available today would fill a real operational need in sediment management. Davis (1977) working with 30 years additional data in Los Angeles County, has found that the post-fire sediment yield estimates of Rowe et al., agree, essentially, with his. Therefore, until such updating can be done, it appears that their present estimates can continue to be used with confidence.

TABLE D4-1

INCREASES IN EXPECTED SEDIMENT DELIVERY FROM A TOTALLY BURNED WATERSHED IN THE YEARS FOLLOWING A FIRE
(After Rowe et al., 1954)

Year Following Fire	Increase Over Normal (Normal = x)	Fraction of Total Increase (Total = 1.0)	Cumulative Fraction of Total Increase (Total = 1.0)
1	4 - 35x	.55	.55
2	2 - 12x	.18	.73
3	0.7 - 7.0x	.11	.84
4	0.4 - 4.5x	.07	.91
5	0.3 - 3.2x	.048	.958
6	0.2 - 1.9x	.028	.986
7	0.1 - 0.6x	.013	.999
8	0.01 - 0.06x	<.001	.999+
9	Trace	<.001	1.000
10	0	0	1.000

TABLE D4-2

Annual rainfall, runoff, and sediment delivery from 0.008 hectare plots on the San Dimas Experimental Forest. Note post-fire sedimentation on Fern Canyon plots. This accounted for almost 99 percent of all sediment delivery. Recovery took 3 years (after Wells, 1981).

Year[1]	Fern Canyon Plots				Tanbark Plots			
	Rainfall	Runoff		Sediment delivery	Rain-fall	Runoff		Sediment delivery
	mm	mm	% rainfall	m^3/km^2	mm	mm	% rainfall	m^3/km^2
1935-36	635	8	1.3	7	559	5	0.9	10
1936-37	1120	10	0.9	4	1041	3	0.3	8
1937-38	1331	8	0.6	9	1146	13	1.2	10
Fern Canyon plots burned on November 18, 1938								
1938-39	559	36	6.4	1907	513	1	0.2	5
1939-40	820	15	1.8	231	840	1	0.1	3
1940-41	1468	15	1.0	69	1184	3	0.3	3
1941-42	495	1	0.2	1	417	1	0.2	3
1942-43	1359	5	0.4	1	1148	3	0.3	2
1943-44	1029	25	2.4	1	831	1	0.1	1
1944-45	902	5	0.5	1	754	1	0.1	1
1945-46	762	10	1.3	1	663	1	0.2	1

[1] Water year. Begins October 1 and runs through September 30.

D4.3 Fire History

Because fire has such a significant effect on sediment production, a compilation of the area's fire history was made as a part of this study. This fire history is summarized in Plate D4-1, a fire map showing the areas which have burned since 1910 and the number of times they have burned during this period. Originally, seven maps of burned areas were compiled. Each map depicted the location and areal extent of fires 40 hectares and larger. Six of the maps depicted burns during 10-year intervals from 1910 through 1969, and the seventh represented the six-year interval, 1970-1975. These seven "decade" maps were photographically composited to provide a base for the final product.

Compilation of the Map Data

The basic data for the maps were collated primarily from maps of many different scales supplied by the U.S. Forest Service and the Flood Control Districts of the seven counties in the study area. Additional data were derived from other regional and local agencies and from individuals who, for various reasons, are interested in fires. The burned area depictions were then transferred to base maps of a common 1:250,000 scale. Although the original data were of many different degrees of precision and accuracy, most of the burned areas were plotted on maps of significantly larger scale than the one accompanying this report. Therefore, errors on the original maps will be masked somewhat by reduction to the 1:250,000 scale. Also, the original data showed only the extreme perimeters of burned areas, and it was unclear from them whether or not the entire area within these perimeters was burned. Commonly, fires burning over large areas leave extensive stands of unburned vegetation within the fire perimeter. In view of these qualifications, the final map should be viewed as a general representation of burn area and frequency but one which is not adequate for site-specific uses.

When the area of a burn was not given with the original data, the area was planimetered after being transferred to the 1:250,000 base map. The date of each fire and the area burned were then entered directly onto the maps with each burned area outline. Each of the seven "decade" maps was drawn in ink on a transparent, scale-stable mylar that was registered to a scale-stable topographic base map.* Thus, the maps could be overlain in sequence beginning with the 1910-19 map, to aid the interpreter in determining how many times a given area had burned.

Nearly all upland regions in the study area have burned at least once, and some areas have burned as many as five times, between 1910 and 1975. Part of the unburned upland areas are sparsely vegetated so that widespread burning is unlikely. Vegetated areas that did not burn during the study period, however, may represent tinder boxes of accumulated fuel ready to burn at any time. Repeated burning of many areas suggests that fuel buildup is rapid enough to make some areas susceptible to reburning every 5-10 years.

Burns in areas readily accessible to ground-based fire-fighting equipment tend to be smaller in area than burns in remote or rugged terrain. In either case, most burned areas are bounded by roads, valley margins, streams, ridgetops, or firebreaks -- the places of access for people and fire-fighting equipment. This suggests that the configuration and area of the burns are artificially controlled and do not represent what might occur under natural conditions. In the absence of controls, one might expect fewer burns, but a larger area per individual burn during a given period. Thus, Plate D4-1 represents a complex combination of fire ignitions by people and natural phenomena and more than a half-century of fire suppression and control.

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*Prints of these basic maps are available at cost from the Environmental Quality Laboratory, Caltech, Pasadena, California 91125.

D4.4 Factors Promoting Frequent Fires

The history of frequent fires in southern California reflects a natural condition that is strongly influenced by two factors, the dominant vegetation and Mediterranean climate. The characteristics of each of these important factors, as they relate to fire, will be discussed briefly.

Vegetation Characteristics

The majority of the erosional areas in the study area are covered by chaparral, a vegetation type which is noted for its flammability (see Section D3). Philpot (1977) has stated that chaparral possesses physical, chemical and physiological characteristics which all enhance its flammability. Typically, these plants have many stems emanating from a single root-crown and form dense, extensive thickets. This creates a high surface-to-biomass ratio which ensures excellent access to the plant material by fire, and a continuous source of fresh fuel which enhances rapid fire spread over large areas.

It has been found that chaparral is low in silica-free minerals and high (relative to other plants) in solvent extractives. Plants with low silica-free mineral content exhibit high burning rates, low char production and high available energy content. Solvent extractives have extremely high caloric heat content and low ignition temperatures. In one species of chaparral (chamise) as much as 24 percent of its available caloric heat can come from these extractives (Philpot, 1977).

During the dry California summers most chaparral plants become dormant and exhibit a marked drop in live fuel moisture. This combines with an increase in solvent extractive content to increase the flammability of chaparral plants dramatically. Another physiological characteristic of chaparral is the marked buildup in standing dead material after it reaches 30 years of age. At this time, up to 50 percent of the plant biomass may be dead (Philpot, 1973). These characteristics combine to make chaparral one of the most flammable vegetation complexes there is. Although its fire characteristics are less well-known, the same is generally true for coastal sage scrub.

Climate

The study area has a typical Mediterranean climate characterized by hot, dry summers and mild, wet winters, with a moderate marine influence throughout the year. There is a long dry season in the summer and fall and an equally long wet season in winter and early spring.

Associated with this weather pattern are periodic foehn-type winds called Santa Anas. These hot, dry winds originate from a large high-pressure center over the Great Basin and blow seaward in a south or southwesterly direction. Air, as it descends from this high pressure zone, becomes hot and dry and can create disastrous fire conditions in a matter of hours. The annual frequency distribution of these winds follows a bimodal pattern with its major peak in November and a smaller peak in March. The months of lowest Santa Ana activity are July and August. Although late summer and fall are southern California's worst fire season, major fires have also occurred in early spring (McCutcheon, 1977).

This weather pattern has particular significance to sedimentation because it creates a typical sequence of first a fire season, then a rainy season, and finally a growing season. This sequence sabotages many attempts to stabilize burned watersheds by the artificial seeding of grass or other vegetation after fires. Storms often occur within a few days of the autumn fires, and, since these are the ones that have the greatest potential for sediment movement, they simply move sediment into channels before the newly planted seeds have a chance to germinate. Typically, germination begins in mid-February and, by this time, most of the vulnerable hillslope sediments have already been washed into the channels. Once established, vegetation does appear to stabilize burned slopes, but by the time this happens, slopes are already approaching a new equilibrium on their own.

D4.5 Effect of Fire on Erosion Processes

Qualitatively, catchment sedimentation can be divided into three stages: delivery to the channel from adjacent slopes, storage in the channel, and transport down the channel when flow occurs. In the semi-arid climate of southern California, where ephemeral streams are common, the delivery and transport stages usually occur at different times so that the amount of sediment in channel storage when flow occurs is a major factor in determining downstream sedimentation rates. Equally important is the delivery rate, and regimen, from the adjacent slopes. Anderson et al. (1959) report that, for seven of nine study sites in the San Gabriel Mountains about 60 percent of the sediment delivery occurred during the dry season when there was no flow in the channels.

Available data suggest that the primary effects of fire are to increase the sediment delivery rates from the hillslopes and the amount of runoff from a given storm. This latter effect means increased channel flows with a consequent increase in sediment transport capacity.

Field observations have suggested that fire increases delivery rates in two general ways. First, the area contributing sediment to the stream channel is increased many-fold following a fire. Plot studies suggest that on unburned (or fully recovered) catchments, most of the hillslopes contribute little or no sediment to the stream channel. Most of the sediment production can be traced to specific areas such as slips and slides, rock outcrops, areas of excessive steepness, roads, etc. These areas often account for less than 20 percent of the total catchment surface (Kelsey et al., 1981). In contrast, after a fire virtually all parts of the hillslopes are contributing sediment, and delivery rates to the channel increase correspondingly.

The second fire effect is a change in the relative dominance of the different erosion processes. On an undisturbed watershed, the dominant processes seem to be dry ravel, which is the unconsolidated flow of loose, dry particles downslope, and the various forms of mass-wasting (Rice, 1973). Both processes require rather steep slopes to be effective. Consequently, the gentler slopes produce very little sediment in an unburned condition. After a fire, the dominant erosion processes are hydraulic -- driven by moving water. These processes are effective even on relatively gentle slopes so that slopes which are quite stable in an unburned condition can become major sediment producers after a fire. Dry ravel also increases after a fire (Krammes, 1960), but the hydraulic processes increase to a much greater degree. This is particularly true in the second and third years after a fire (Krammes, 1965).

As indicated earlier, fire increases the runoff from a catchment, and this increases channel flow which increases channel transport capacity. This combined with vastly increased sediment deliveries from the hillslopes provides a plausible explanation for the fact that many runoff events from freshly burned watersheds have the appearance of sediment flows. During a storm, fresh sediment arriving from the hillslopes can be entrained immediately in the channel flow. The result is the highly viscous sediment flows which have been observed in the field. Because of the expanded contributing area and increased delivery rates, the amount of newly arriving sediment will usually exceed the transport capacity of the flow. Therefore, even after such events, channels are often filled with debris and show little evidence of scour. The hillslope delivery rates drop off rapidly in the succeeding storms, but channel flows remain high for most of the season. As a result, the runoff from later storms scours these channels until they are often deeper than they were before the fire occurred.

Direct Effects of Fire on Erosion Surfaces

Fire directly affects the erosion surface by:

1. Removing the vegetative cover and, usually, the litter layer below it.
2. Changing the infiltration capacity at the surface and the permeability of the subsurface material.
3. Rendering the surface material more susceptible to eroding forces.

The first effect is obvious even to a casual observer in the field, but the other two require some explanation. Increases in the hydraulic conductivity of certain soils from California's Central Valley were reported by Scott and Burgy (1965) after subjecting them to simulated wildfire temperatures in the laboratory. This suggests that after a fire, the soil at the surface may be more permeable than that lying a few millimeters beneath it. Water entering the soil will be moving from an area of higher permeability to one of lower permeability, and it will not percolate downward as fast as it enters the soil. More important, however, is the fire-induced formation of water-repellent soil layers below the soil surface. This phenomenon has been extensively reported by De Bano and by others and appears to occur throughout the world (De Bano, 1981, De Bano et al., 1979).

In a recent study Duriscoe and Wells (1982) found that fire temperatures can change the particle-size distribution of certain soils. It appears that temperatures above 400°C cause a marked reduction in the clay fraction of certain soils with a proportional increase in the sand and silt-sized fractions. This shift in particle-size distribution suggests that soils will become more erodible after a fire because the cohesive influence of the clays is removed. This may also help to explain the increase in dry ravel after fire.

Post Fire Erosion Processes

Field observations indicate that the two most important erosion processes on burned catchments are dry ravel and rill formation. Immediately after a fire and before the first rains, evidence of dry ravel can be found everywhere. The movement of soil particles can be heard almost constantly and channels fill with cones of loose debris. With the first rains comes the formation of numerous rills throughout the burned area, and they remain the dominant erosional feature for the remainder of the rainy season.

Miniature soil slips also are common during early storms on burned catchments. During storms, small masses ($< 1000\ cm^3$) of soil have been observed to break away from the surface and slide, more or less intact, down the slopes. This has been observed by Rice and by several other workers in the field.* These small-scale soil slips seem to be linked to the extensive rill formation mentioned earlier and to the presence of water repellent soil layers.

The increased effectiveness of raindrop impact as an important erosion process on burned catchments can be inferred from the removal of vegetation and litter. The actual amount of raindrop erosion in southern California wildlands has not been quantitatively studied. After the removal of vegetation by fire, there is little protection to the erosion surface against raindrop energy, and this can amount to several hundred joules per hectare in a typical storm (Wischmeier and Smith, 1958). According to Mutchler and Young (1975) raindrop impact is the primary sediment transporting agent on interrill areas.

The effect of raindrop impact is difficult to observe and measure, and for this reason its role in the erosion of burned catchments may be underestimated. Rills can be measured and counted, and the amount of material lost in their formation can then be estimated. It is

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*Rice, Raymond, M., USFS, PSW Station, personal communication, 1978.

more difficult, however, to estimate the amount of sediment which passes through these rills but which originated in the adjacent interrill areas. This would represent the contribution of raindrop impact.

Water Repellent Soils

The phenomenon of water repellent soils in southern California has been particularly well-studied, but its effects on sedimentation, while recognized, are still not well understood. De Bano (1981) reports that water repellent soils occur world-wide but are not necessarily produced by fire. However, fires do intensify their effects, and marked increases in soil water repellency following fires have been reported from many parts of the world.

In southern California water repellent soils have been linked directly to chaparral and strongly implied for most other vegetation types. Although the role of water repellent soils in sedimentation processes is still being investigated, the factors contributing to their formation have been well-studied. Organic substances seem to be their major constituent. These substances vary both regionally and with vegetation type, and often more than one substance seems to be responsible for soil water repellency at a given location. In chaparral, these substances appear to be wax-like complexes of long-chain hydrocarbons (Savage et al., 1972). Their exact chemical structure has not yet been determined. They seem to occur during the normal breakdown of plant litter and are leached from the litter into the mineral soil, where they are fixed as a result of normal microbial activity. Even unburned sites, therefore, can show a slight degree of water repellency.

The intensification and translocation of water repellent substances by fire has been rigorously demonstrated. De Bano (1969) found dramatic increases in the time required for water drops to penetrate a sample of chaparral soil that had been heated to typical wildfire temperatures (see Fig. D4-3). He has further shown that surface heating of a mildly water repellent soil lying on top of a clean, thoroughly wettable sand produces an intense water repellent layer in the sand (De Bano, 1966). This suggests that these substances move downward to the lower soil layers and condense there.

Also evident from Fig. D4-3 is the fact that water repellency disappears with higher temperatures and longer heating times, so that the surface soil of burned catchments typically is extremely wettable. This wettable layer, however, is usually underlain by a layer of soil that is virtually waterproof.

For southern California the typical formation process for water repellent soils is shown in Fig. D4-4. First, litter falls from the plants to the soil surface and begins to decompose. Products of this decomposition form a mildly water repellent layer immediately below the litter layer in the mineral soil. This layer is so weak that it usually does not significantly impede water penetration. When the site burns, the litter burns with it, and the water repellent substances, which are vaporized at the surface, move downward into the soil along temperature gradients. At the same time they are chemically altered and become intensely water repellent. Because of the low thermal conductivity of mineral soil, the high surface temperature resulting from the fire and burning litter decreases rapidly with depth. A fire which produces surface temperatures of $800^{o}C$ often produces temperatures of no more than $250^{o}C$ at a depth of 2 cm. As the water repellent substances move downward and encounter cooler temperatures, they condense and coat the soil particles to produce a sub-surface water repellent layer. Typically, this layer forms at depths of 2 to 6 cm (De Bano, 1969; Savage, 1974). The surface soil is usually extremely wettable because the water-repellent substances were either destroyed or moved downward during the fire. This produces the layered arrangement shown in Figure D4-4c.

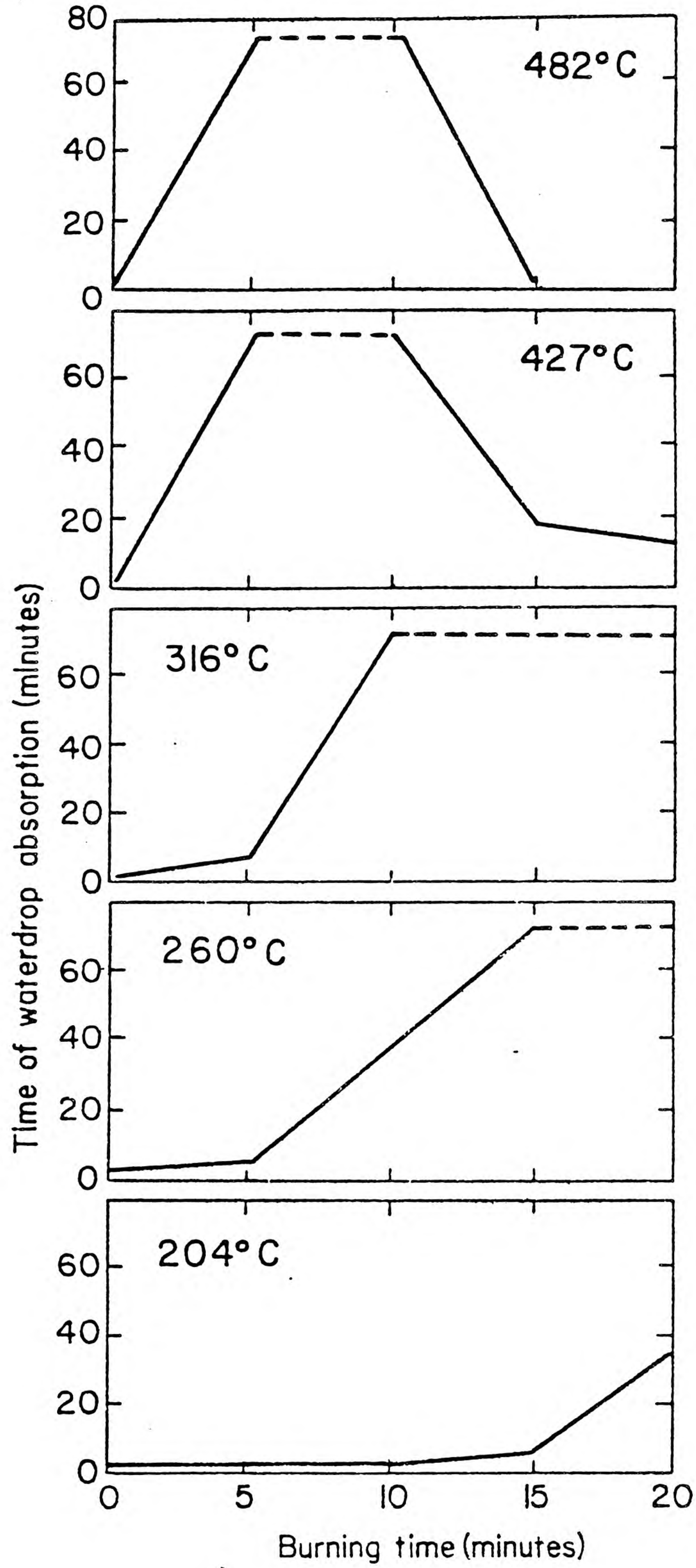

Figure D4-3 Development of soil water-repellency as a function of burning time and temperature. Dashed lines indicate that water drops evaporated before any penetration took place. (After DeBano, 1969)

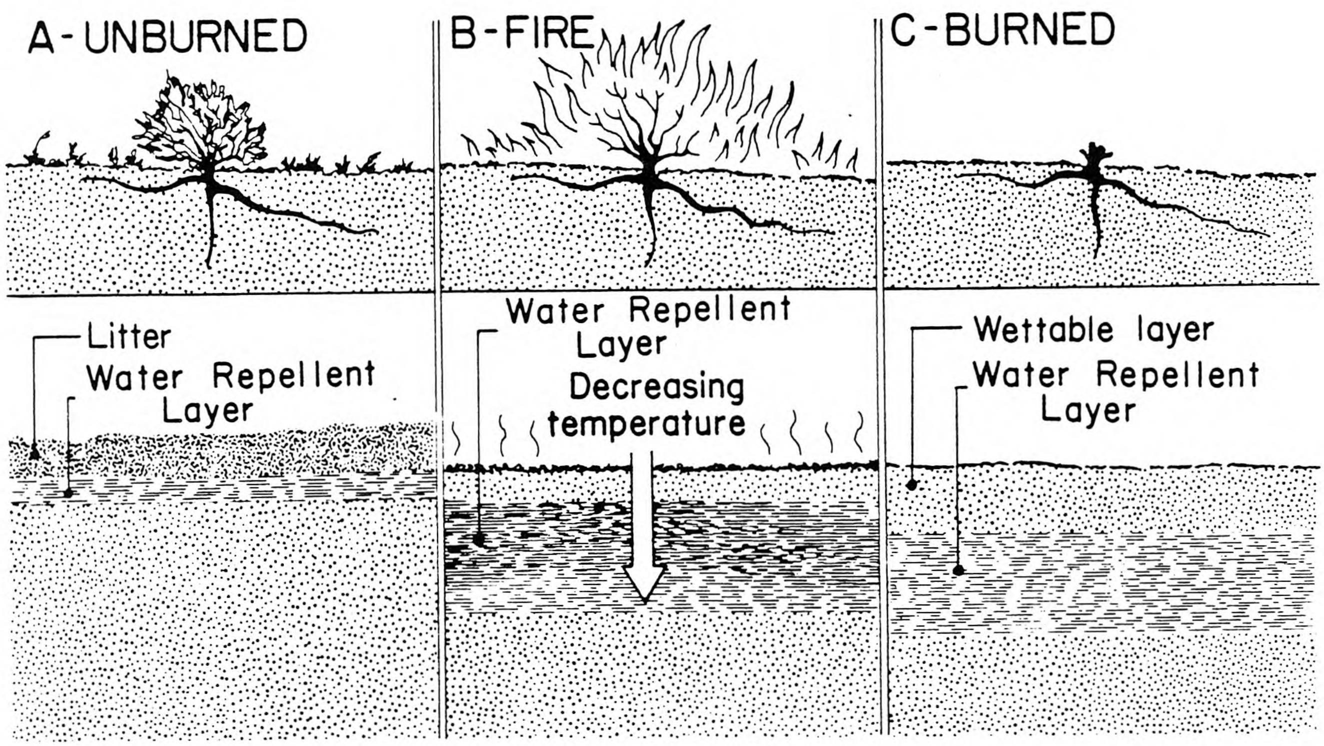

Figure D4-4 Development of a water repellent layer in the field. (A) Before fire, mildly hydrophobic substances accumulate in the litter layer and mineral soil immediately beneath it; (B) fire burns the vegetation and litter layer, altering the hydrophobic substances and causing them to move downward following temperature gradients; (C) after fire, a very strong water repellent layer is located below and parallel to a wettable layer on the soil surface (After De Bano, 1969).

The depth, intensity and extent of the water repellent layer appears to increase with fire intensity. This means that the fires occurring during the fall in old (> 40 years of age) chaparral can be expected to produce the most pronounced and extensive water repellent layers. Water repellency also depends on soil texture, soil moisture and available organic matter (De Bano et al., 1970; De Bano et al., 1976). Since the substances are of organic origin, it can be expected that greater amounts of litter at the time of burning will produce more severe water repellency. Because moisture in a soil increases its heat capacity, lower soil temperatures and less pronounced temperature gradients should result from fires burning over wet soils as opposed to dry ones. It can be expected, therefore, that wetter soil conditions during a fire will inhibit the development of water repellent layers, and evidence of this has been observed in the laboratory. Soil water-repellency has also been associated with coarse-textured soils. This is probably because the reduced surface area of these soils permits a more thorough coating by water-repellent material. Fine-textured materials have so much specific surface that there may not be enough water-repellent material available to coat them completely. Also, the smaller pore spaces found in fine-textured soils may inhibit the downward movement of water repellent substances. The longevity of the water repellent layer is not well documented, but it appears to last for many years.

The typical layered arrangements of these soils can have a significant effect on erosion processes. Because the water repellent layer is often totally impervious to water penetration, it produces a confining layer which limits the water storage zone of a burned area to about the upper 5 cm of soil (see Fig. D4-5). The soil depth (A and B horizons) for an average chaparral site is usually less than 1 m, but because the parent material is often highly fractured, the hydrologically active zone can be several meters deep. When a water repellent layer forms 5 cm below the surface, the effective

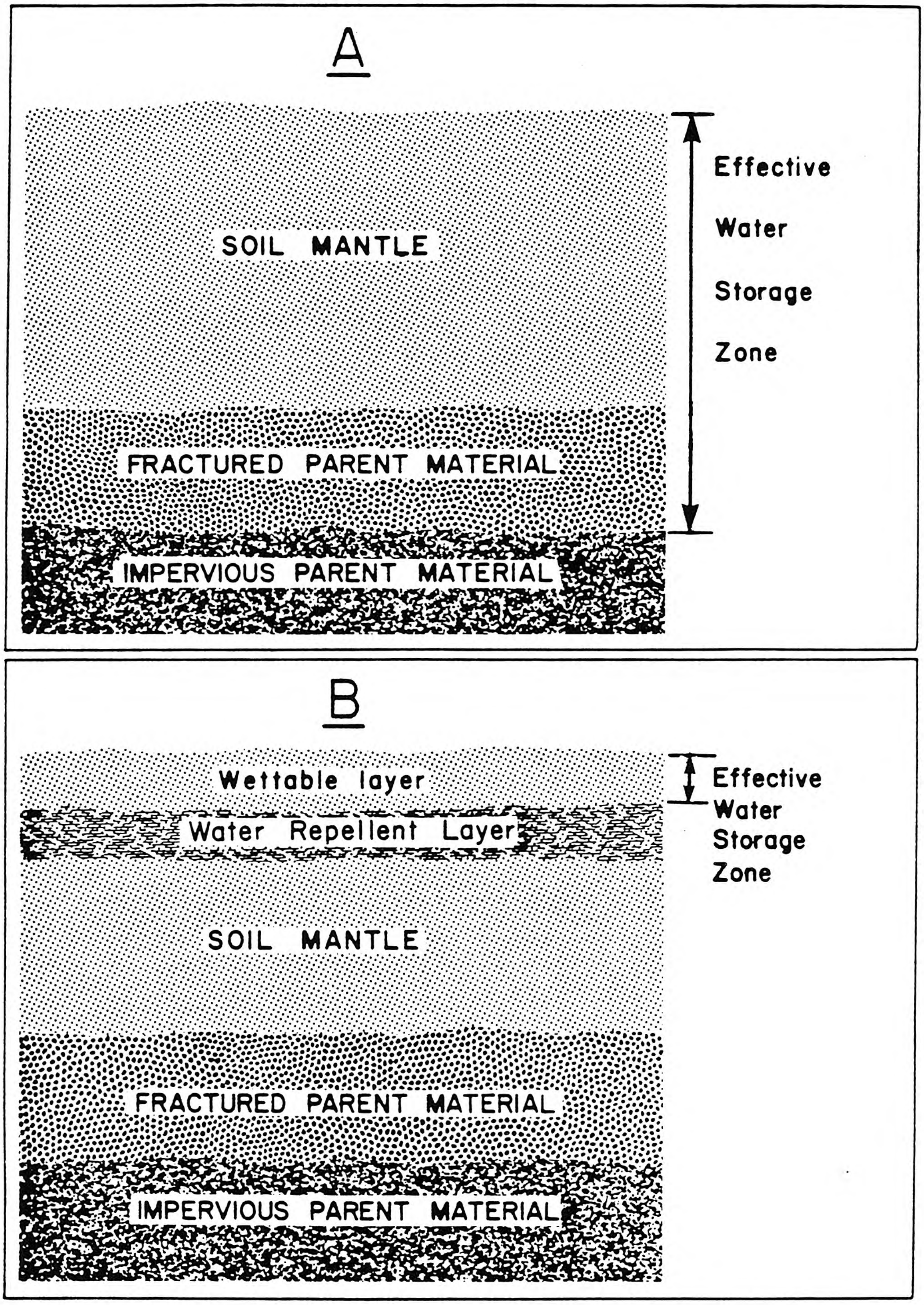

Figure D4-5 Reduction in water storage capacity caused by the formation of a water repellent layer.

storage capacity of the soil mantle is reduced by 20 times or more. During a storm, the remaining storage space fills up rapidly, and runoff begins much sooner than it would before the fire. The result is higher runoff rates and a longer period of time during which runoff occurs. Therefore, one inch of rainfall can have the same effect on a burned catchment that five or six inches would have on an unburned one.

Rill Formation

The most striking erosional features on freshly burned catchments are the extensive rills that form after the early storms. Figure D4-6 shows a typical example. It has long been suspected that these rills are somehow related to water repellent soils, and recent field observations have tended to strengthen this hypothesis.

Figures D4-7 and D4-8 show two common features of rills formed on burned catchments. Figure D4-7 shows levees on either side of a small rill that formed after the Vetter Fire of 1977 burned the upper reaches of Big Tujunga Canyon in Los Angeles County. These levees are a common feature of the post-fire rills that form in the coarse-textured soils of the San Gabriel and San Bernardino mountains. They have also been observed, though less pronounced, in the finer-textured soils of the Sierra Madre Mountains of Santa Barbara County. These levee-bordered rills are miniature replicas of the debris flow paths seen in many arid regions. This suggests that many rills form, not from local concentrations of surface flow, but as the result of miniature debris flows. Rills of both types have been observed in the field, but on burned surfaces, those exhibiting the debris flow features predominate.

Figure D4-8 illustrates the second feature of rills that form in burned catchments, a bed composed of wettable soil lying immediately below walls composed of water repellent soil. In the figure, the pencil is lying on the bed of the rill and the light-colored area

Figure D4-6 Burned watershed in the upper reaches of Mill Creek, a tributary to Big Tujunga Creek. Note extensive rill formation.

Figure D4-7 Levee-bordered rill on a burned slope. This rill formed in a small study basin located in Big Tujunga Canyon during the storm of 26 - 29 December, 1977. The area was burned by the Vetter fire in June 1977.

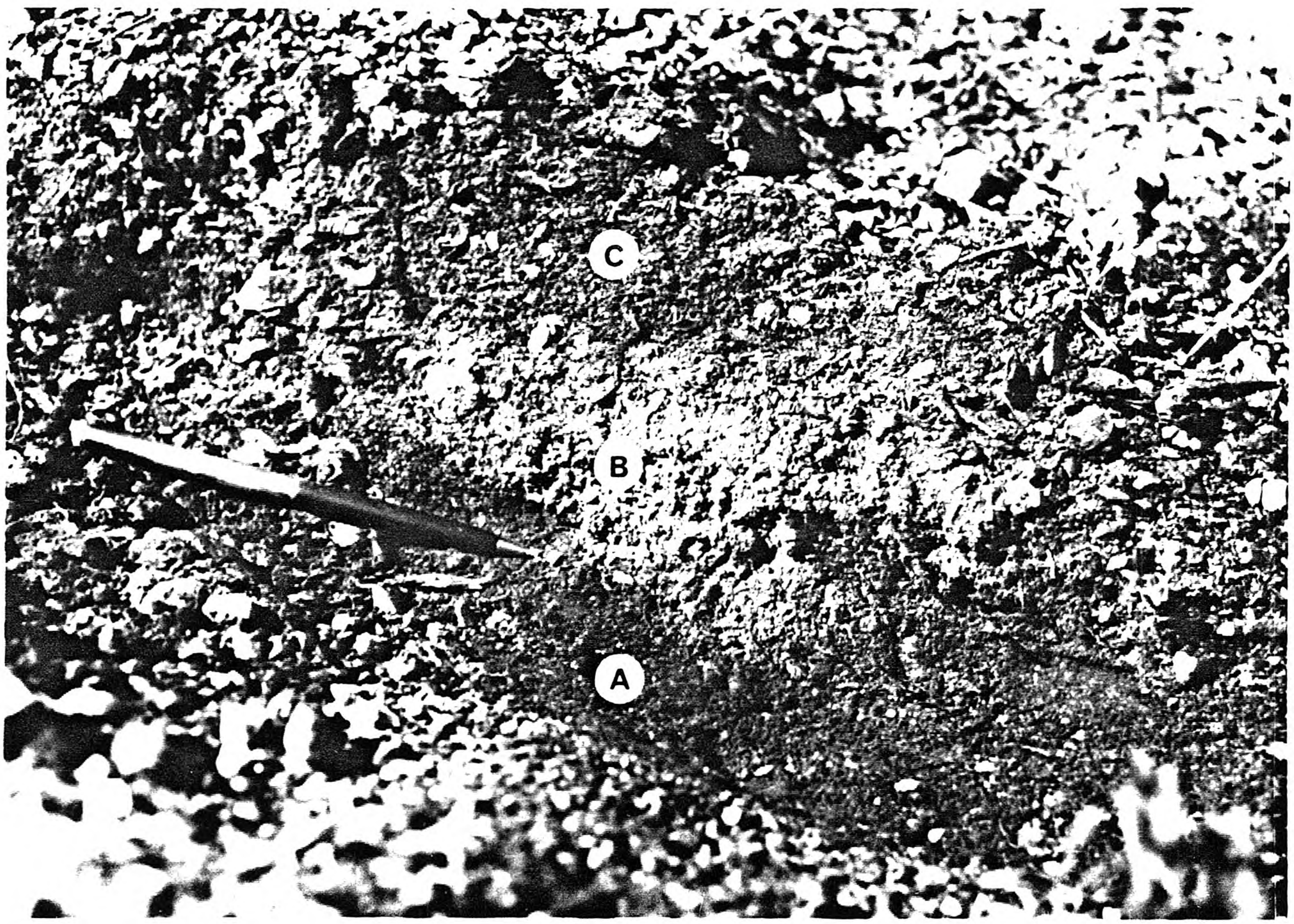

Figure D4-8 Rill formed on burned hillslope. Pencil is lying on wettable bed (A). Note water repellent walls (B), and wettable surface soil (C) above the water repellent layer.

above it is the water repellent wall. It has been observed that, unless the rill lies in a depression where flow would naturally concentrate, downcutting seems to end at the bottom of the water repellent layer.

Figure D4-9 is a diagram of a typical rill with the levees on either side, the wettable bed and the water repellent walls immediately above it. The structural consistency observed in these rills suggest a rather definite mode of formation. The most plausible hypothesis seems to be the following. During a storm, water enters the wettable surface soil and percolates downward until it encounters the water repellent layer. This occurs at a rather uniform rate over an entire slope so that when the water reaches the water repellent layer it can drain neither downward nor laterally. As the rain continues water fills all the available pore spaces until the wettable soil layer becomes saturated. Since the soil cannot drain, pore pressures build up, especially in the zone immediately above the water repellent layer. This increased pore pressure results in reduced intergranular stress among the soil particles. The reduced intergranular stress results in reduced internal friction which causes a reduction in the shear strength of the soil mass. As a result, potential zones of failure develop closer to the boundary between the wettable and water repellent layers (Fig. D4-10A) where pore pressures are greatest. Pore pressures continue to increase, and shear strength is further reduced until it is exceeded by the shear stress of gravity acting on the soil mass. When this happens, a failure occurs and a portion of the wet soil begins to slide down the slope (Fig. D4-10B). If the soil is coarse-textured, this initial failure causes a reorientation of soil particles in the failure zone which causes them to momentarily lose contact with each other. This loss of intergranular contact further reduces shear strength and extends the failure zone downslope. When most of the soil grains lose contact a quick condition develops in which the shearing soil becomes almost entirely fluid (Scott, 1963).

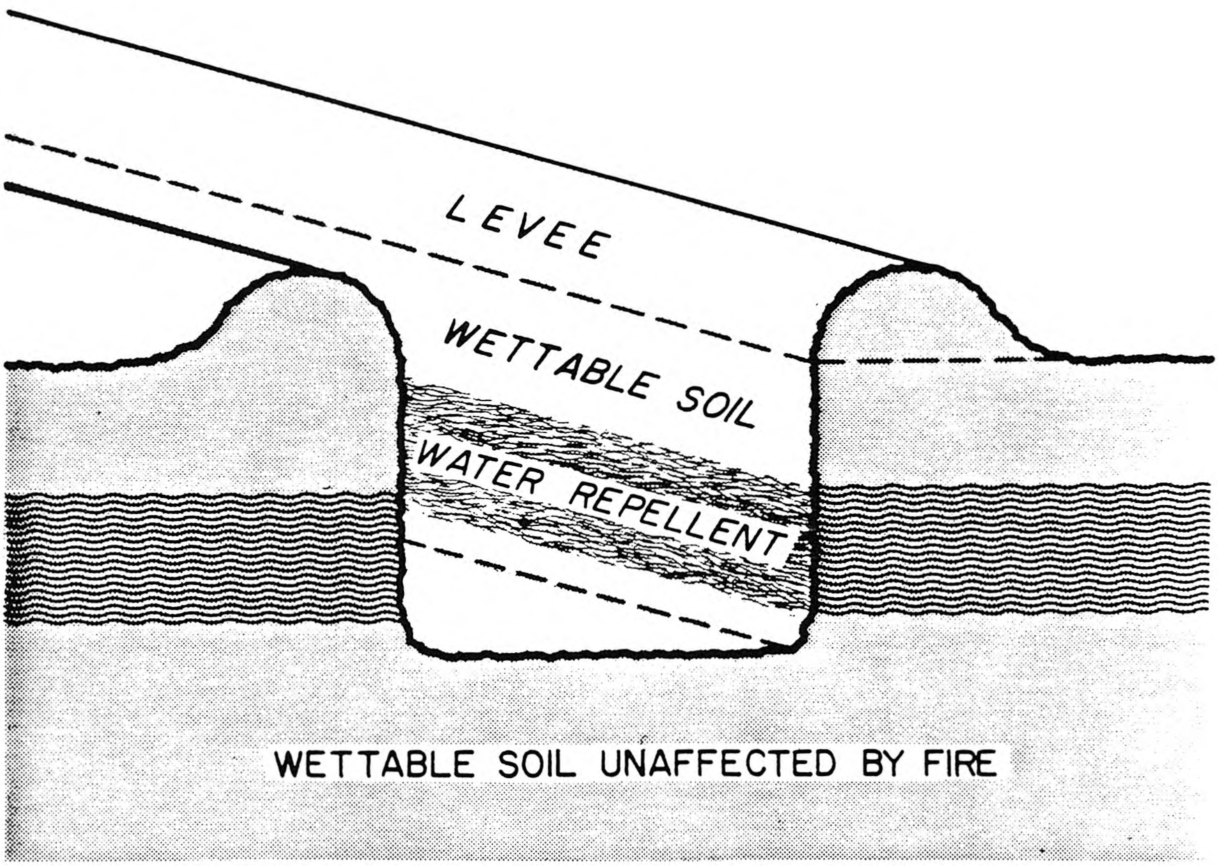

Figure D4-9 Diagram of a rill formed on a burned slope with a water repellent layer. Note levee at either side of the rill and water repellent layer forming lower wall.

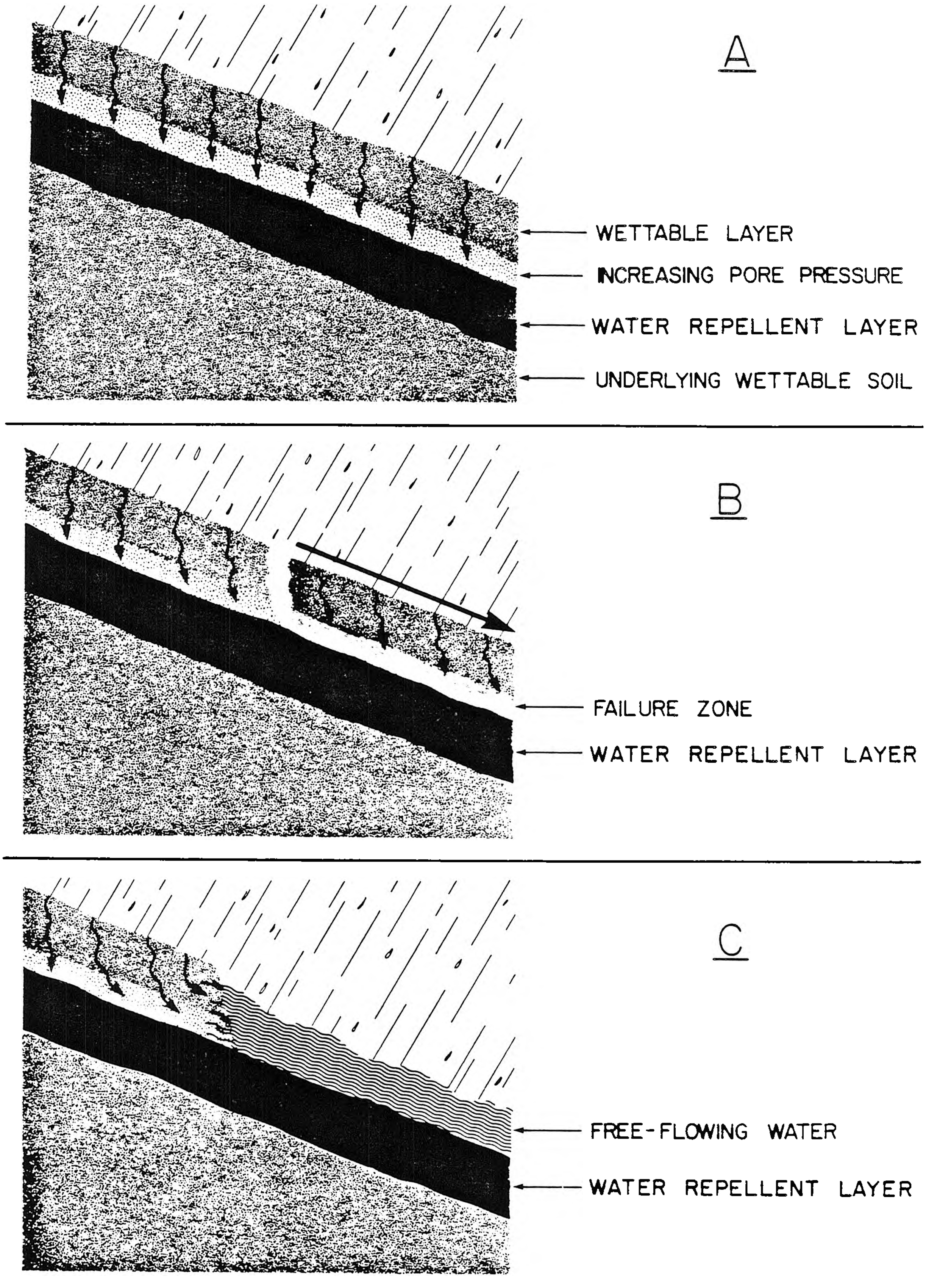

Figure D4- 10 Inferred sequence of events in the process of rill formation on a burned slope with a water repellent layer. (See Text)

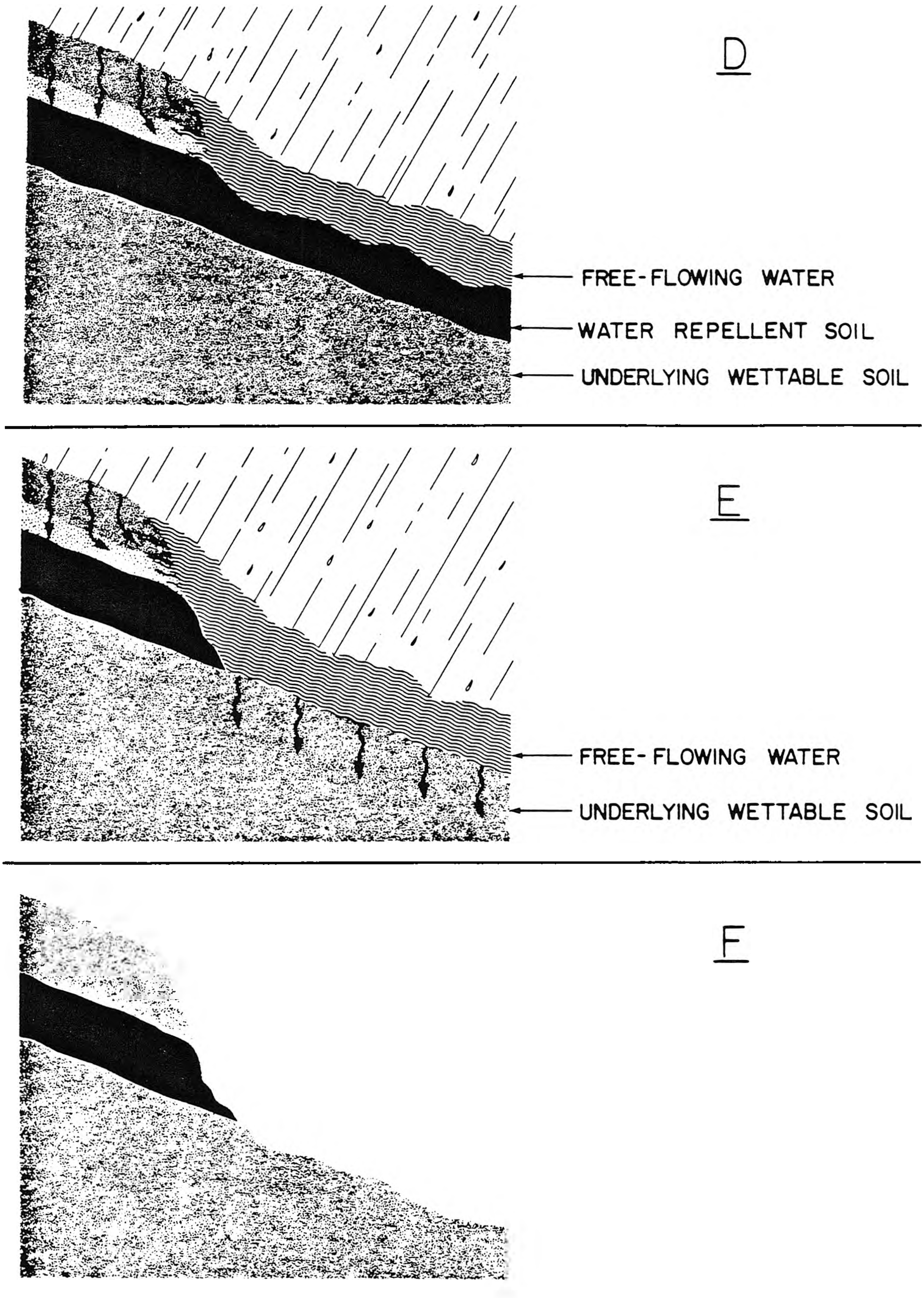

Figure D4-10 (Continued) (See Text)

This results in a miniature debris flow in the upper layer of wettable soil, which propagates downslope all the way, usually, to the bottom.

Water in the wettable soil adjacent to the debris flow track is now no longer confined and can flow out into the track (Fig. D4-10C). Here, because it still cannot infiltrate the water repellent soil, it flows down the debris flow track as free water in an open channel. As it flows down the track, it can achieve sufficient depth and velocity for turbulence to develop. Even though the water still cannot wet the water repellent soil particles, the turbulence of the flow is able to erode and entrain them, and downcutting in the water repellent layer is achieved by this action (Fig. D4-10D). Because water still cannot infiltrate the water repellent layer, flow in the track is not appreciably diminished, so erosive power remains high. Eventually, the flow cuts completely through the water repellent layer to the wettable soil below. When this happens the water begins to infiltrate and flow diminishes (Fig. D4-10E). As flow diminishes, depth and turbulence are reduced and downcutting ceases. As a result, the rill stabilizes immediately below the lower edge of the water repellent layer (Fig. D4-10F).

This hypothesis also seems compatible with observations made during a flood event on a burned watershed. During the storm of 10-11 November 1978, a channel debris flow occurred and was observed in Carter Canyon above the town of Sierra Madre in Los Angeles County. This catchment was severely burned in the Mountain Trail Fire of 23-25 October 1978. During the storm, 38 mm of rainfall were recorded in a gage at nearby Sierra Madre Dam (17 mm on 10 November and 21 mm on 11 November). The actual flood event was preceded by 5 to 10 minutes of intense rainfall, perhaps 12 to 25 mm per hour, which included some hail. In addition to the debris flow, several events were observed on the hillslopes above the channel. First, two or three small soil slips of about 500 cm^3, each, occurred, and the soil surface exposed by these slips had what appeared to be dry patches on it. These occurred very low on the slope so that no rill was formed by them. However, on a more distant slope (about 100 m away), a rill was seen to form, and its manner of formation seems to fit the hypothesis stated above.

The rill began in mid-slope, about 2/3 of the way upslope from the stream channel, apparently in a small depression. Once begun, it progressed quickly downslope in a single continuous movement. The entire event took less than 10 seconds. The rill first appeared as a dark line on the slope but as the storm progressed the dark area faded out, and the rill seemed to disappear. A short time later, it reappeared because of light reflecting off clear water which was then flowing in it. Inspection of the rill after the storm revealed that it followed a small depression in the hillslope. It was about 20 cm wide after the storm and had water repellent walls. Its bottom, however, was mostly parent rock with little soil remaining.

Further qualitative evidence was obtained near Red Box Gap on the Angeles National Forest after the Sage fire of 1979. A storm on 19-20 October 1979 dropped about 60 mm of rain on the area which resulted in the features shown in figures D4-11 through D4-14.

It appears that water repellent soil layers can cause major increases in sedimentation through rill formation, but this observation has not been tested. If the rill formation process described earlier does occur, it would not be necessary for the water repellent layer to be continuous. A debris flow, once begun, can propagate itself for some distance by its own momentum.

D4.6 Summary and Research Needs

From the information currently available, it appears that, while we have a good understanding of the cause-effect relationship of fire and sedimentation, we know very little about the processes responsible for this relationship. An understanding of these processes is

Figure D4-11 Tension cracks in wet surface soil overlying a water repellent layer on a burned slope.

Figure D4-12 Scar left by soil slip in wet soil overlying a water repellent layer on a burned slope. Maximum width of the scar is about 30 cm. Note that the scar narrows down to a rill at the bottom of the photo.

Figure D4-13 Rill formed by soil slip shown in Figure D4-10. Photo is taken about 3 m below the soil slip scar. Note levee on left side of rill and debris lobe on the right.

Figure D4-14 Debris flow track left in an unburned surface (abandoned truck trail). Picture is taken about 30 m below Figure D4-11 after several rills have merged into one.

essential if we expect to obtain maximum return from our erosion control and sediment management efforts. It is possible at this time to formulate a qualitative model for fire-induced sedimentation and watershed recovery. Such a model can provide a useful framework for both definitive quantitative studies and management strategies.

Davis (1977) has concluded that any method for modeling sediment production in southern California must incorporate fire effects and the probability of fire occurrence. The most promising modeling approach is to start with a freshly burned catchment, identify and quantitatively describe the sedimentation processes operating on it, then model their changes over time until a relatively stable condition is achieved. One of the first problems in building such a model will be to estimate the amount of sediment production that is actually fire related. Several estimates have been made, but they vary widely. Fall*, studying several catchments of varying size in the San Gabriel Mountains, noted wide variations in the net effect of fire on denudation rates. He estimated that, for the catchments he studied, fire increased the mean denudation rate by only 10 to 20 percent. On the other hand, Rice (1974) estimates that up to 70 percent of all long-term sedimentation from chaparral-covered areas occurs during the first year after a fire. Data reported by Wells (1981) from 0.08 hectare plots in the San Gabriel Mountains suggest that fire-related sediment production may approach 90 percent of the total (see table D4-2).

Recovery of catchments after burning is another area needing study. The accepted recovery time for southern California is eight to ten years, but recent studies indicate that, at least for practical purposes, it could be less than half that long. Data presented in Table D4-2 suggest that hillslopes have recovered from fire by the

*Fall, Edward F., personal communication, 1978.

end of the third year and that 60 to 90 percent of their sediment production occurs in the first year. It then seems plausible that most downstream sediment production in the second and third years after a fire, and all of it after the third year, results from scouring of sediment already in the channel. A study of sediment budgets in small catchments would help resolve this question, and considering the amount of money spent rehabilitating burned watersheds, such a study would be very timely.

In order to develop a realistic model, some basic work on post-fire processes is needed. Specific problems, such as dry ravel, water repellent soil layers and raindrop impact, have already been identified but there are certainly others. Mass-wasting, particularly shallow soil slips on steep slopes is a major source of sediment and is at least partially fire-related. There is some evidence to suggest that it is a delayed fire effect. Its occurrence may diminish immediately after a fire, being pre-empted by the more superficial processes. Later on, however, it may again increase as the root systems of fire-killed plants decay.

Fire is an important factor in southern California's overall sedimentation picture, and we still do not fully understand the part it plays. Its intense local effects are known, but we do not know how man's fire control efforts have changed sediment deliveries on a large scale. A complete understanding will only come when we successfully join the results of process studies to our knowledge of fire frequency, intensity and times of occurrence.

D4.7 References

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LEGEND
SYMBOL TYPE; PRIMARY FUNCTION NUMBER
NATURAL LAKE BASIN 2
DAM; WATER SUPPLY 259
DAM; FLOOD CONTROL 26
DAM; DEBRIS BASIN 192
DAM; SEDIMENT CHECK 399
PIT; SAND & GRAVEL MINING 96
BASIN; PERCOLATION, SPREADING 65
RESERVOIR; FED BY AQUEDUCT 23
SCALE
0 10 20 30 Miles
0 10 20 30 40 Kilometers
PRINCIPAL DRAINAGES
Ⓐ Santa Barbara - Ventura Co. Coastal Streams
Ⓑ Ventura River Basin
Ⓒ Santa Clara River Basin
Ⓓ Calleguas Creek Basin
Ⓔ Ventura - Los Angeles Co. Coastal Streams
Ⓕ Los Angeles River Basin
Ⓖ San Gabriel River Basin
Ⓗ Santa Ana River Basin
Ⓘ Orange - San Diego Co. Coastal Streams
Ⓙ Santa Margarita River Basin
Ⓚ San Luis Rey River Basin
Ⓛ San Diego Co. Coastal Streams
Ⓜ San Dieguito River Basin
Ⓝ San Diego Co. Coastal Streams
Ⓞ San Diego River Basin
Ⓟ Sweetwater River Basin
Ⓠ Otay River Basin
Ⓡ Tijuana River Basin
N
PACIFIC OCEAN
OCEAN
MOJAVE
DESERT
LOS ANGELES
PLATE D1-1
INLAND STRUCTURES
WHICH AFFECT SEDIMENT MOVEMENTS
in Southern California
COMPILED BY JESSIE MANIATIS & WILLIAM BROWN III
1979
CALIFORNIA
INDEX MAP
STUDY AREA
Report 17-D
1981
ENVIRONMENTAL QUALITY LABORATORY
California Institute of Technology

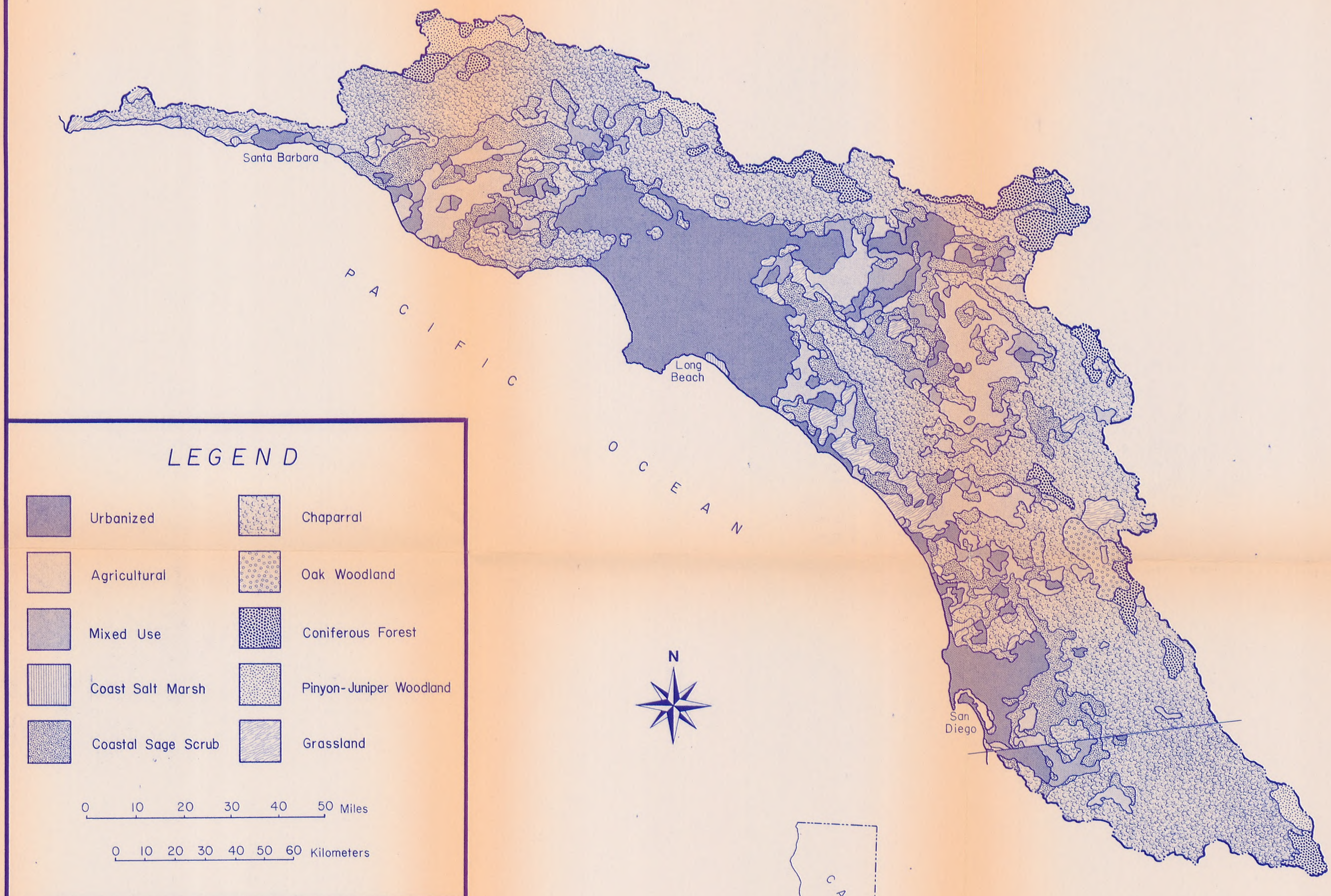
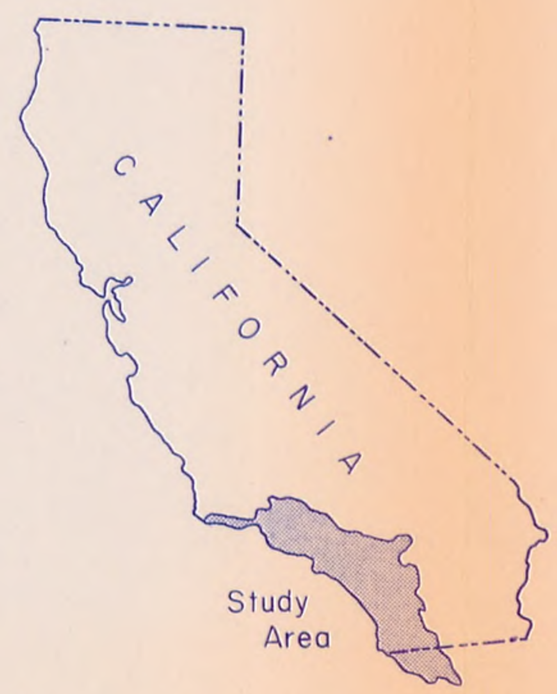


PLATE D3-1

CURRENT VEGETATION

COMPILED BY NANCY PALMER

1979



INDEX MAP

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1981
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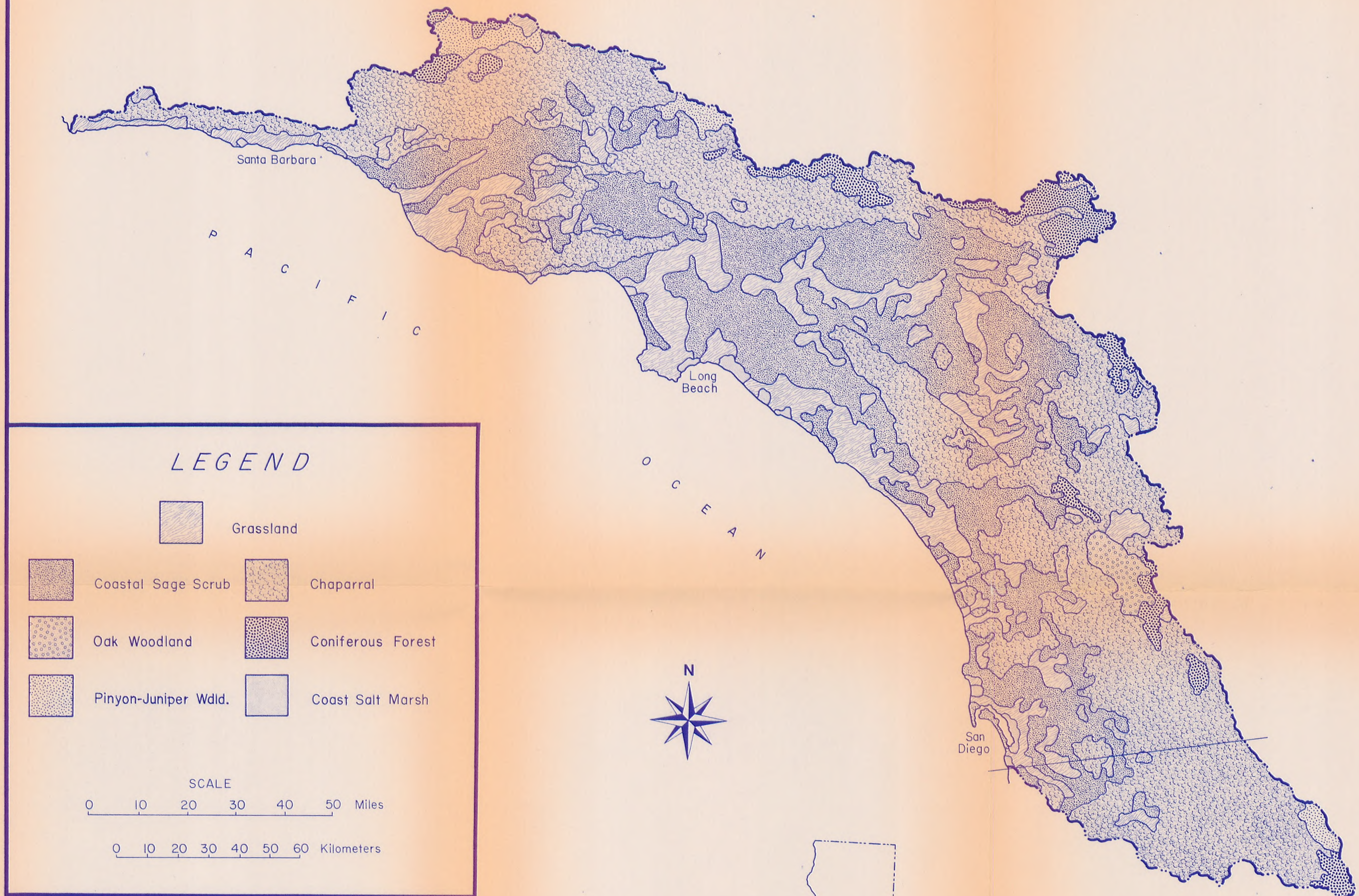

PLATE D3-2

ORIGINAL VEGETATION

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PLATE D4-1

THE EXTENT AND FREQUENCY OF FOREST, BRUSH, AND GRASS FIRES

in coastal stream basins of Southern California,* 1910 - 1975

COMPILED BY S. SAYER, R. BROWN, & W. BROWN III

1979

* DATA FROM BAJA CALIFORNIA OMITTED: FIRE HISTORY UNAVAILABLE

#25781