TB 639 (1939) USDA TECHNICAL BULLETINS UPDATA
EFFECTING OF ACCELERATED EROSION ON SILTING IN MORENA RESERVOIR
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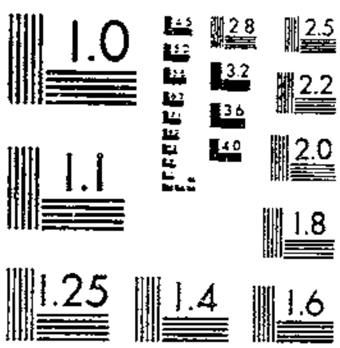

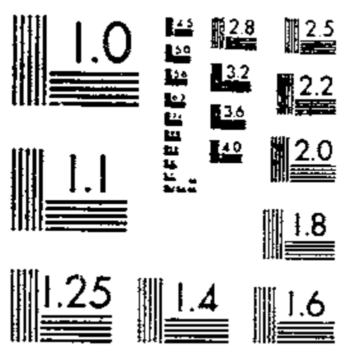

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NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 639 December 1939

UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

EFFECT OF ACCELERATED EROSION ON SILTING IN MORENA RESERVOIR, SAN DIEGO COUNTY, CALIF.[1]

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CONTENTS

	Page
Introduction	1
Sedimentation survey of Morena Reservoir	3
Description of dam and reservoir	3
Sediment deposits	4
Summary and analysis of data	9
Probable future trends of silting and remaining life of Morena Reservoir	10
Causes of erosion	11
Natural factors influencing erosion	11
Human factors influencing erosion	15
Sources of eroded material	17
Extent and history of the valley trenches	18
Remedial measures	19
Summary	20

INTRODUCTION

This report is the product of a study of erosion and reservoir sedimentation in the Morena drainage basin of southern California (fig. 1), which was made in 1935 cooperatively by the Soil Conservation Service and the Forest Service. A sedimentation survey of Morena Reservoir was made by the Soil Conservation Service to measure the amount and study the distribution of sediment in the reservoir, to compute the rate of accumulation, and to ascertain the probable future trends of silting and the remaining life of the reservoir. The studies by the Forest Service had as their objective (1) the determination of the nature and causes of accelerated erosion in the Morena drainage basin and the principal sources of reservoir sediment, and (2) the interpretation of reservoir silting in relation to the production of erosional debris in the drainage area.

The part of this bulletin that deals with the sedimentation survey of Morena Reservoir was prepared by F. F. Barnes of the Sedimentation Division, Office of Research, Soil Conservation Service, and is based on a survey of the reservoir made by the Division during the period October 25 to December 31, 1935. The survey party consisted of F. F. Barnes, in charge, L. H. Barnes, L. J. Butler, A. T.

[1] Submitted for publication, April 14, 1939.

Talley, and G. L. Anderson. T. L. Kesler was in charge of the early part of the survey.

Field work for the sedimentation survey consisted primarily of mapping the original and the 1935 contours at the present spillway crest level (elevation 3,044.90 feet) and measuring sediment and water depths at close intervals on 29 cross-section ranges (fig. 2). The work was begun by establishing a triangulation net of 23 stations, expanded from a 2,000-foot chained base line on the delta of the Morena Creek arm. The shore lines were mapped by plane table and telescopic alidade on a scale of 1 inch to 500 feet. Soundings and direct sediment-depth measurements were made on each range by the range method of survey developed by Eakin.[2] Sediment depths were determined over most of the basin with the 10-foot silt-sampling spud, but in the deeper and coarser-textured deposits in the delta areas it was necessary to resort to auger borings. In the lower mile of the reservoir the sediment depth over the original channel was too great for complete penetration with the spud, and the water depth was likewise too great to permit the use of the auger. It was therefore necessary to interpolate the channel-bottom elevations on the four lowest ranges across the main lake by using the known elevation of the channel at the dam, the channel elevation on the first range above the dam on which complete penetration was possible (R19–R20), and the length of channel between ranges and the dam as determined from an original somewhat generalized contour map of the reservoir basin.

The part of this bulletin that deals with erosion in the drainage basin was prepared by C. J. Kraebel and R. S. LaMotte of the California Forest and Range Experiment Station, Forest Service. This section is based on a reconnaissance survey of conditions in the drainage area above Morena Reservoir and a study of their effect on the rate of silting made in December 1936. This study constitutes a part of an erosion reconnaissance of the mountainous areas in the national forests of California begun in the summer of 1934 for the purpose of making an inventory of the most active foci of abnormal erosion as a necessary basis for a comprehensive plan of control. As one approach to this problem a reconnaissance examination of silting in various strategically located reservoirs throughout the State was carried out by a two-man party consisting of an engineer and a geologist, working under the immediate supervision of S. M. Munson and the general direction of C. J. Kraebel. Under this program some 40 reservoirs were examined, and a report on 21 in the San Diego area was completed in January 1935 by N. F. Meadowcroft and E. C. Marliave. This work was the basis for the selection of Morena Reservoir and its drainage area for detailed cooperative studies by the Soil Conservation Service and Forest Service.

Morena Reservoir is on Cottonwood Creek, in T. 17 S., Rs. 4 and 5 E., San Diego County, Calif., 35 miles east of San Diego (fig. 1). Water is impounded not only in the valley of Cottonwood Creek, on which the dam is located, but also on Morena Creek, one of the larger tributaries. The reservoir, owned by the city of San Diego, serves as a reserve storage unit of the municipal water-supply system. The dam was completed in March 1910.

[2] EAKIN, HENRY M. SILTING OF RESERVOIRS. U. S. Dept. Agr. Tech. Bull. 524, 142 pp., illus. 1936. See pp. 25–28, 129–135.

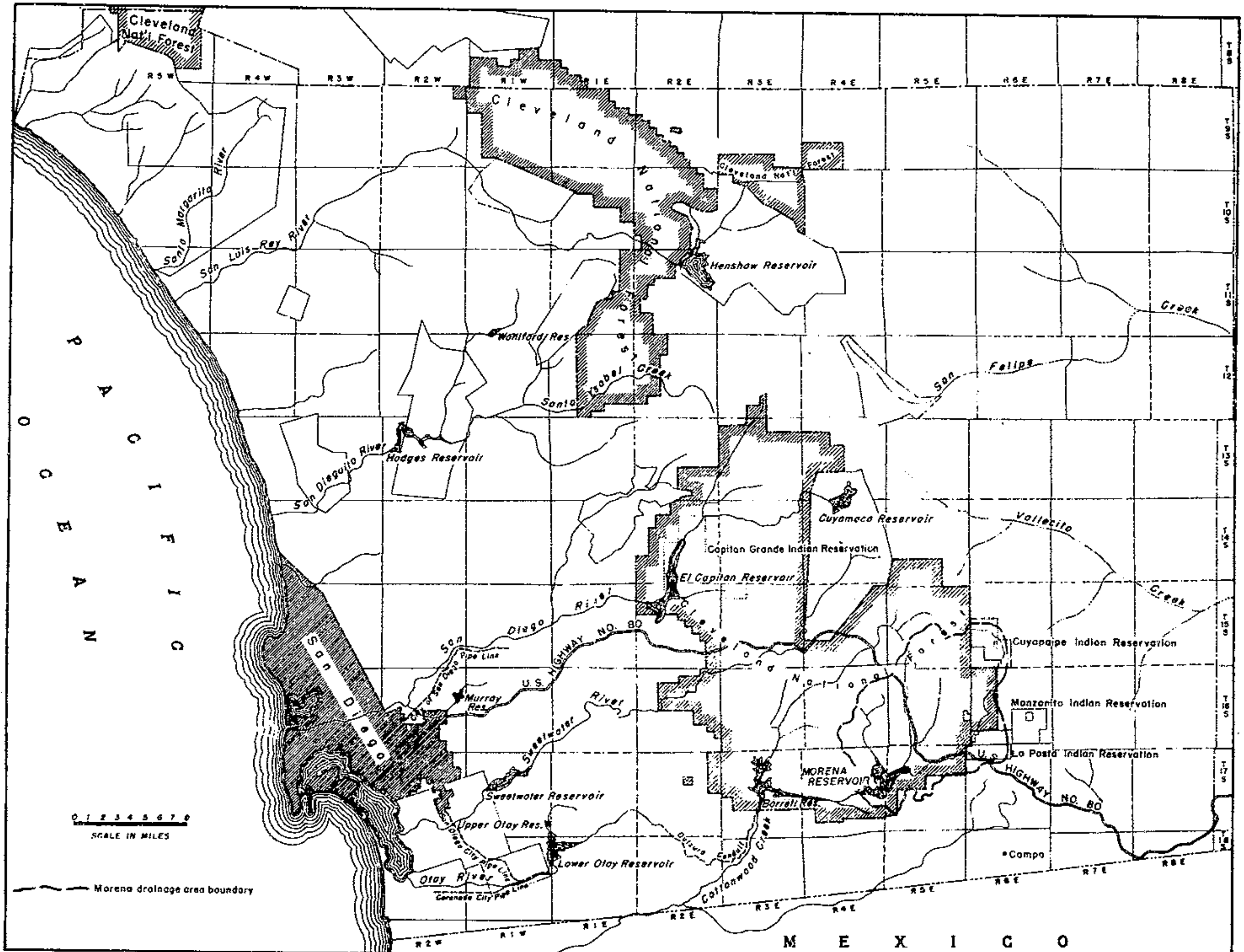

FIGURE 1.—Map of San Diego County, Calif., showing the location of Morena Reservoir and its drainage basin.

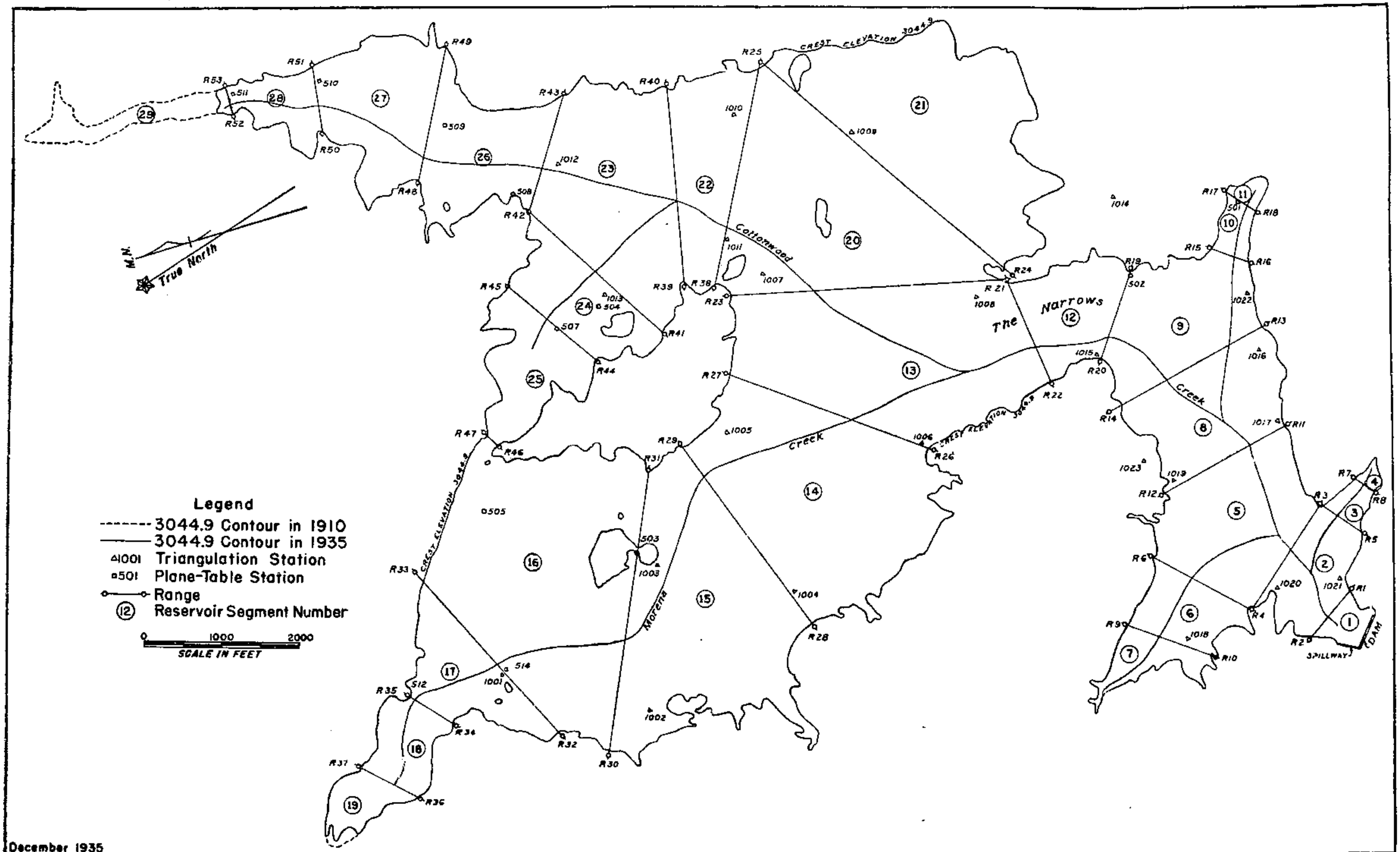

Figure 2.—Map of Morena Reservoir, San Diego County, Calif., surveyed December 1935.

The drainage basin tributary to Morena Reservoir covers an area of 112 square miles of mountainous country lying west of the main crest of the Peninsular Range, which separates the coastal drainage from that of the interior and the Gulf of California.

SEDIMENTATION SURVEY OF MORENA RESERVOIR

DESCRIPTION OF DAM AND RESERVOIR

Morena Dam is a loose rock-fill structure with masonry water face, 506 feet long and 167 feet in maximum height above the stream bed. A concrete spillway, the crest of which is 155 feet above stream bed, extends 310 feet upstream from the north end of the main dam and discharges through a channel, 60 feet wide, 5 feet deep, and on a 2-percent grade, cut from solid rock on the north canyon wall. The concrete lip of the spillway is surmounted by 7½-foot automatic steel flash gates, which raise the controlling crest level to 162.5 feet above the stream bed and 3,044.90 feet above mean sea level.

Water is released from the reservoir through a tunnel 387 feet long, 8 feet wide, and 7½ feet high drifted in solid rock 30 feet above the stream bed. The concrete outlet tower has five gates opening to 24-inch pipes connected with a 30-inch vertical down pipe that discharges into the tunnel. The four upper outlets are 28 feet apart vertically, the highest one being at the 127.5-foot level, 32 feet below the crest. The lowest gate is 31 feet above the stream bed and was designed to be used for washing out sediment that might accumulate near the base of the tower.

At the time of construction in 1910, the spillway was only 146 feet above the stream bed, but in 1923 it was raised to its present height of 155 feet. In this bulletin all calculations are based on a crest level at the top of the flash gates, 162.5 feet above the stream bed at the dam. This seems justified by the history of the reservoir, which shows that in ordinary years the run-off is too small to fill the reservoir and that severe floods, which occur in cycles of about 11 years, are so violent that the lower position of the spillway probably has had little effect on the quantity of silt carried past the dam.

The length of the lake (the distance from the dam to the crossing of the spillway crest-level contour on Cottonwood Creek) was originally 3.9 miles, but by 1935 advance of the delta had shortened this to 3.5 miles. The principal tributary arm, on Morena Creek, was originally about 2 miles long and had not been appreciably shortened by silting at the time of the survey. If the dam had been built to its present height in 1910 the original reservoir area at spillway-crest level would have been 1,687 acres and the storage capacity 68,388 acre-feet, but in 1935 silting had reduced the area at this level to 1,669 acres and the capacity to 61,204 acre-feet.

The reservoir basin (fig. 2 and pl. 1, *A* and *B*) is about 500 feet wide at the dam, which was constructed at the upper end of a narrow, steep-walled gorge. A few hundred feet above the dam it widens abruptly to about 2,000 feet and maintains this width with little variation for 1 mile to the Narrows, formed by the convergence of two rocky spurs, where the width is only about 1,200 feet. Above the Narrows the reservoir widens again in a broad, relatively flat-bottomed basin, formed by the junction of the alluvium-floored valleys, or potreros, of

Morena and Cottonwood Creeks, nearly a mile in maximum width. Above this basin both arms range between 2,000 and 4,000 feet in width for a mile or less and then narrow abruptly between confining canyon walls to a few hundred feet for the remaining distance to their upper ends.

The gradient of the original channel of Cottonwood Creek averages 40 feet per mile between the head of backwater and the dam; it increases from 30 feet per mile in the upper half of this distance to 50 feet per mile in the lower half. In the first mile below the dam the stream drops 800 feet through a narrow rocky canyon. The original Morena Creek channel has a fairly uniform gradient below crest level of about 30 feet per mile.

Morena Reservoir serves the city of San Diego as a reserve water supply from which water is released as needed into Barrett Reservoir, about 8 miles downstream on Cottonwood Creek. No records of average daily or monthly draft are available. The reservoir level stood at 34 feet below the crest during the entire period of the survey and is said to stay near this level, except during unusually wet or dry seasons.

The cost of the dam and reservoir, completed to the present height, was approximately $1,250,000.

SEDIMENT DEPOSITS

CHARACTER OF SEDIMENT

The sediment in Morena Reservoir is of two distinct types: The fine-textured bottom-set beds of the main lake basin and the coarser sandy delta deposits in the heads of the Morena and Cottonwood arms. The bottom-set beds, which extend over the greater part of the lake area, consist of very uniform fine dark brownish-gray to black silt and clay, varied in color and texture only by occasional patches of organic matter. This sediment is characterized by an unusually high percentage of mica flakes, derived from the granitic rocks that underlie a large part of the drainage basin. The upper layers of these deposits are extremely soft and yielding, except on the extensive flats around the margins of the main basin above the Narrows, where thin deposits above the level of low-water stages have been compacted by drying during exposure. At depths of several feet below the normally submerged sediment surface, however, the deposits are perceptibly more compact and become increasingly so with greater depth of burial, but at no point is the compaction as thorough, even under depths of 10 or more feet of sediment, as that produced by drying.

Delta deposits, consisting of imperfectly stratified fine sand, silty sand, sandy silt, and minor amounts of coarse sand and gravel, occur in the upper parts of the Cottonwood and Morena arms. The Cottonwood delta has a very even surface, broken only by the creek channel incised 4 to 6 feet below the general level, and extends with barely perceptible slope from the head of the reservoir basin to range R39–R40 (fig. 2). Just below this range the delta drops off rather abruptly and gives way to the finer-textured bottom-set beds. The Morena delta has a somewhat more irregular surface, which terminates in a sloping delta front near range R30–R31.

A, View of Morena Reservoir, looking west toward the dam (left) and north up Morena and Cottonwood Valleys toward the Corte Madera (center) and Laguna (right) Plateaus; *B*, view of Morena Reservoir, looking upstream over the lower basin toward the Narrows, from a point about opposite the dam; *C*, aggraded channel of Cottonwood Creek about one-half mile above the present (1938) head of backwater of Morena Reservoir.

DISTRIBUTION OF SEDIMENT

The volumetric distribution of sediment in Morena Reservoir is summarized in table 1. In the preparation of the table the reservoir was treated as four more or less distinct units, consisting of a lower basin, including all the reservoir below range R21–R22 at the head of the Narrows; an upper basin, extending from the Narrows to ranges R30–R31 and R39–R40 on the Morena and Cottonwood arms, respectively; and the two deltas above these last-mentioned ranges.

TABLE 1.—*Distribution of sediment in Morena Reservoir, 1935*

Section	Storage capacity			Sediment deposits		
	Original	At time of survey	Loss	Volume	Relation to original capacity of reservoir	Relation to total sediment in reservoir
	Acre-feet	*Acre-feet*	*Per-cent*	*Acre-feet*	*Per-cent*	*Per-cent*
Lower basin (below range R21–R22)	21,686	20,674	4.67	1,012	1.48	14.09
Upper basin (above range R21–R22 and below ranges R30–R31 and R39–R40)	32,623	31,295	4.07	1,328	1.94	18.49
Cottonwood delta (above range R39–R40)	9,896	5,390	45.53	4,506	6.59	62.72
Morena delta (above range R30–R31)	4,183	3,845	8.08	338	.49	4.70
Total reservoir	68,388	61,204	10.50	7,184	10.50	100.00

The outstanding feature brought out by table 1 is the heavy concentration of sediment in the Cottonwood delta. Excessive deposition, in fact, is not confined to the actual limits of the reservoir but extends for some distance above the head of backwater, as shown by the aggraded condition of the creek channel above the head of the Cottonwood arm (pl. 1, *C*). A second feature, much less pronounced but perhaps equally significant with respect to sediment distribution, is the somewhat greater proportionate reduction in the capacity of the lower basin as compared with that of the upper basin. This suggestion of a secondary concentration of sediment toward the dam is borne out by computations of maximum and average sediment depths on the several ranges. Figures 3 and 4, respectively, show the original (1910) and existing (1935) maximum and average water-depth profiles along the main axes of the reservoir. The average sediment depth (the difference between the original and existing average water depths) increases gradually from less than 2 feet just below the limits of the deltas to 10 feet just above the dam, and the maximum sediment depth shows an even greater increase from about 4 feet in the upper basin to more than 40 feet near the dam. Transverse profiles across the main channel below the Narrows reveal a sediment surface that is nearly flat in cross section and has a downstream slope of less than 0.2 percent, in contrast with the V-shaped cross section and 1-percent gradient of the original channel.

This distribution is just the reverse of what might be expected from the progressive settling of sediment from suspension as the inflowing waters passed down the reservoir. It appears, rather, to be the result of one or all of several other factors, which are discussed in the following paragraphs.

One factor that may at least partly account for this distribution is the tendency for sediment depths to be proportional to the depth of water at the point of deposition. This tendency should be most pronounced in a quiet body of uniformly turbid water, which condition is probably closely approximated immediately after one of the flash floods characteristic of the reservoir, when rapid influx of a large volume of sediment-charged water is followed by an abrupt cessation of inflow. Even though water passes the dam only at comparatively rare intervals, and hence currents through the reservoir should be at a minimum, an analysis of ratios of sediment depth to original water depth [3] showed that this factor alone is not sufficient to account

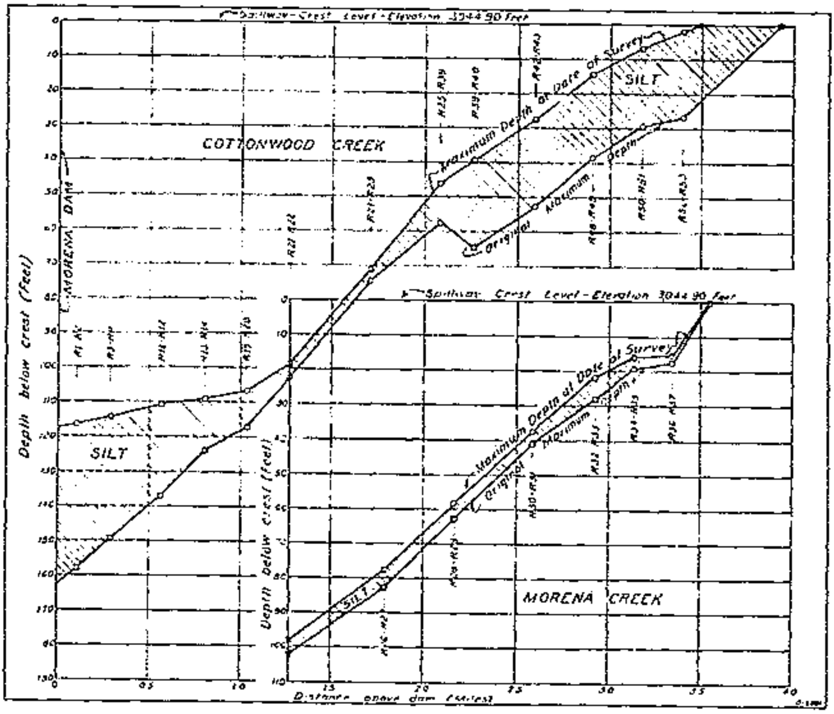

FIGURE 3.—Maximum-depth profiles of Morena Reservoir.

entirely for the greater sediment depths near the dam. In other words, the ratios, instead of being equal in all parts of the reservoir, showed a marked increase toward the dam. The average ratio on range R13-R14, 4,200 feet above the dam, is 4 percent and the maximum 16, whereas the average ratio on range R1–R2, 600 feet above the dam, is 9 percent and the maximum 33.

A second factor to be considered is the effect of the slope of the bottom on distribution of sediment. An analysis of sediment depths and original water depths in the lower basin revealed that in any given cross section the sediment depths tend not only to increase with

[3] In computing these ratios, allowance for the effect of the lower water level on sediment distribution was made by measuring the original water depths not from crest level but from the prevailing water level, 34 feet below the crest.

increases in water depth but to increase at a much greater rate, so that the sediment-water depth ratio in the deepest part of the cross section may be 15 to 20 times that at shallower points. It is obvious therefore that the thicker deposits in the deeper parts of the basin are due to something more than increased water depth. In the lower half mile of the reservoir the valley sides have slopes as high as 35 to 40 percent extending to the bottom of the basin, and it seems probable that considerable shifting to lower levels of sediment in a flocculent state could take place on such slopes. On the other hand, there is no apparent relation between the steepness of the slope and the degree of concentration of sediment in the channel, similar conditions

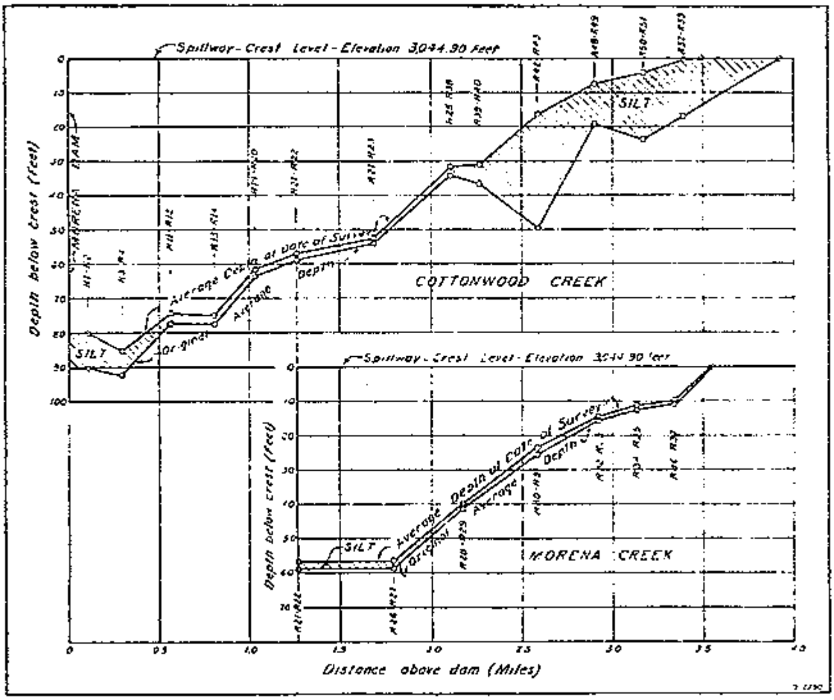

FIGURE 4.—Average-depth profiles of Morena Reservoir.

existing whether the slopes are 4 or 40 percent. Furthermore, the slope of the original channel through the lower basin is less than 1 percent, and, in view of evidence found in other reservoirs, the migration down such a slope of considerable volumes of precipitated sediment impelled only by gravity is highly improbable. It appears, therefore, that although concentration of sediment probably has occurred by lateral movement down the steeper sides of the lower basin, some other cause must determine the longitudinal distribution characterized by increase in depth of sediment toward the dam.

Underflow, or the passage of relatively dense, sediment-laden inflowing water as a current along a reservoir bottom toward the dam, has been observed in a number of reservoirs in the Southwest, notably

Lake Mead, above Boulder Dam,[4] Elephant Butte Reservoir, N. Mex.,[5] and San Carlos Reservoir, Ariz. In each of these reservoirs the distribution of sediment is similar to that in Morena Reservoir in the occurrence of thicker deposits and a nearly level sediment surface near the dam. Two conditions that seem to favor the development of underflows are present in this reservoir, namely, run-off occurring chiefly as flash floods that carry heavily sediment-laden water into the reservoir and a well-defined channel through the entire length of the basin. It therefore seems probable that the concentration of sediment near the dam is due largely to underflow. At all reservoirs where underflow has been reported it was observed that muddy water was discharged through the dam while the surface water remained clear. At Morena Dam the opportunity to check the phenomenon in this manner rarely exists, and, so far as is known, no such observation has ever been reported. Under the existing conditions of infrequent discharge of water through the outlet tunnel, it is assumed that the usual process is for the denser water of the underflow, coming from a flash flood, to flow along the bottom of the channel to the dam and there pile up and gradually lose its identity by precipitation of its sediment load and diffusion into the reservoir water.

One other fact that has a bearing on the longitudinal distribution, as well as the total volume, of sediment accumulated since 1910 is the existence of a 30-foot dam, the beginning of the present one, during the 12-year period (1898–1910) preceding the completion of the dam to the 146-foot height. This earlier dam would have formed a lake at crest stage with an estimated length of less than three-fourths of a mile and an average width of only 200 feet. In order to determine how much storage may have been lost through silting in this lake all available sources of information, chiefly engineering reports on the construction of the dam,[6] were consulted and the following facts obtained.

The dam was built over a narrow boulder-filled fissure in the country rock extending 112 feet below the stream bed. A concrete toe wall extending from the bottom of the fissure to 30 feet above the stream bed was completed in 1898. This toe wall had a leakage of 57,800 gallons per day in 1898, with water at the 30-foot level. In 1911, after construction of the present dam, the leakage had decreased to 33,604 gallons per day, with water at the 65-foot level. This diminution in leakage with increased head has been attributed to the compression of mud and silt in front of the old toe wall.

No specific reference to sediment accumulation above stream-bed level in the earlier pond could be found in the rather comprehensive engineering reports. It might therefore be inferred that if such deposits existed they were too small to be noticed or to be considered important. It seems probable, from the facts set forth in the preceding paragraph, that at least a large part of the sediment carried down the stream between 1898 and 1910 settled into the interstices of the boulder-filled fissure, and hence did not displace capacity above

[4] GROVER, N. C., and HOWARD, C. S. THE PASSAGE OF TURBID WATER THROUGH LAKE MEAD. Amer. Soc. Civ. Engin. Proc. 63: 643–655. 1937.

[5] FIOCK, L. R. RECORDS OF SILT CARRIED BY THE RIO GRANDE AND ITS ACCUMULATION IN ELEPHANT BUTTE RESERVOIR. Amer. Geophys. Union Trans. 15 (pt. 2): 468–473. 1934.

[6] The most complete report is the one by the designer and builder of the present dam. O'SHAUGHNESSY, M. M. CONSTRUCTION OF THE MORENA ROCK FILL DAM, SAN DIEGO COUNTY, CALIFORNIA. Amer. Soc. Civ. Engin. Trans. 75: 27–51 illus. 1912. Discussion pp. 52–67.

stream-bed level. The history of the drainage area suggests further that the volume of sediment carried to this point before 1910 may not have been large. As noted on page 12, the most rapid growth of valley trenches, considered to be the major source of reservoir sediment, followed extraordinarily wet seasons in 1916 and 1927.

It is therefore concluded that neither the determined volume nor the longitudinal distribution of sediment was appreciably affected by deposits accumulated behind the 30-foot dam before 1910. Moreover, even under the impossible assumption that the 30-foot dam was silted to the crest, a considerable excess of sediment above that level in the lower basin still remains to be accounted for in some other manner. In the present problem underflow appears to be the most reasonable explanation.

SUMMARY AND ANALYSIS OF DATA

The quantitative results of the detailed sedimentation survey of Morena Reservoir are summarized in the following tabulation:

Summary of data on Morena Reservoir, San Diego County, Calif.

Age [1]	years	25.7
Drainage area [2]	square miles	112
Reservoir:		
Area at crest stage:		
Original (1910)	acres	1,687
At date of survey (1935)	do	1,669
Storage capacity to crest level:		
Original	acre-feet	68,388
At date of survey	do	61,204
Capacity per square mile of drainage area: [2]		
Original	do	610.61
At date of survey	do	546.46
Sedimentation:		
Delta deposits	do	4,538
Bottom-set beds	do	2,646
Total sediment	do	7,184
Average annual accumulation:		
From entire drainage area	do	280
Per 100 square miles of drainage area [3]	do	256
Per acre of drainage area [2]	cubic feet	174
	tons [4]	5.2
Depletion of storage:		
Loss of original capacity:		
Per year	percent	.41
To date of survey	do	10.50

[1] Storage began in March 1910; average date of survey, December 1935.
[2] Including area of reservoir.
[3] Excluding area of reservoir.
[4] Based on an estimated average dry weight of 60 pounds per cubic foot of sediment.

Some indication of the average rate of erosion or degradation of the drainage basin can be obtained from these data. The rate so obtained, however, is applicable only to the drainage basin as a unit. The actual rate of degradation of most of the area is much less than the average because the greater part of the reservoir sediment is known to have come from the relatively small areas occupied by valley trenches. Considering only the volume of sediment deposited below the spillway level, and taking 1½ cubic feet of sediment in the reservoir as equivalent to 1 cubic foot of soil in the drainage area,[7] the calculated time required to remove an average depth of 1 inch of soil from the entire drainage basin is 31 years.

This is necessarily a minimum rate, since no allowance was made for sediment deposited above the reservoir or bypassed entirely through it. A large but undetermined volume of erosional debris is known to have come to rest on the valley floors above the reservoir. On the other hand, in view of the infrequent overflow and low draft on the reservoir, comparatively little sediment is believed to have been bypassed. The actual rate of erosion in the drainage area is therefore probably considerably greater than 1 inch in 31 years, but even this minimum rate is exceptionally high in comparison with other basins covered by similar studies. Of 95 reservoir drainage basins for which minimum erosion rates were computed in the same manner, only 9 were found to be eroding more rapidly than the Morena drainage basin.

PROBABLE FUTURE TRENDS OF SILTING AND REMAINING LIFE OF MORENA RESERVOIR

If the conditions of accelerated erosion in the drainage basin continue uncontrolled, the future trends of silting in the reservoir, as indicated by the amount and distribution of sediment accumulated to 1935, will probably be somewhat as follows:

The Morena and Cottonwood deltas will continue to advance their gently sloping surfaces downstream, building up vertically, meanwhile, until they meet in the vicinity of the Narrows. At the same time the level surface of the bottom-set beds near the dam will continue to rise and extend upstream to merge into the advancing delta front. The lower basin will probably be the last to fill, and silting will continue, unless steps are taken to prevent it, until the entire basin is filled practically to crest level, although the useful life of the reservoir will long since have ended.

If sedimentation in Morena Reservoir should continue at the same average rate as was determined for the period 1910–35, the basin would be completely silted to crest level by the year 2154, or 219 years from the date of the survey in 1935. However, several factors may act to terminate the useful life of the reservoir at a much earlier date.

(1) The reservoir will cease to fulfill its purpose long before it is completely silted, or, more specifically, as soon as its decreasing capacity falls below the ever-increasing water requirements of the growing city of San Diego.

(2) A factor that may aid in reducing the life of the reservoir is the tendency for the erosional output of a gullied or trenched area to increase rather than to remain constant, since the sphere of action of the gully or trench system is constantly extended by headward growth and the development of new members. In this way the rate of erosion, and consequently the rate of sedimentation, in the Morena area may be increased far above the 1910–35 rate, unless steps are soon taken to check the growth of the already extensive system of trenches in the potrero valleys.

[7] This ratio has not been checked by laboratory tests, but, on the basis of data on comparative dry weights of soils and reservoir sediment in many sections of the country, it is believed to be correct within reasonable limits.

(3) Another factor that may have considerable importance in this particular locality is the effect of sedimentation on water losses through evaporation. It has been shown that the most rapid sedimentation (outside the narrow delta areas) is occurring in the deepest part of the basin. This means that the ratio of surface area to storage capacity is increasing at a maximum rate, and hence the porportionate water loss through evaporation is continuously becoming higher. In this part of California, where it is necessary to store enough water in wet seasons to provide a reserve for several dry years, evaporation may play an important part in reducing the period of usefulness of the reservoir.

Although no reliable estimate of the remaining period of usefulness of the reservoir can be made, it seems clear that its assured life is short enough to make immediate steps to control erosion and sedimentation highly desirable.

CAUSES OF EROSION

For the interpretation of erosion in any area a distinction must be made between the natural erosion rates that are normal for the area in its primitive state, undisturbed by the uses and works of man, and the accelerated rates that may be started by man's interference. Erosion in the Morena drainage basin has proceeded in the recent past, and is still proceeding today, in a manner and at a rate determined by the combined effect of several closely interrelated natural and human factors. Evidence within the watershed indicates that excessively rapid erosion has resulted largely from the occupancy and use of the area by the white man. The characteristics of the local climate and physiography, however, are such that the effects of the human disturbances seem to have proceeded more swiftly and spectacularly here than is usual elsewhere in the country. To give a fair picture of the erosional history of the area, the natural factors of climate, topography, geology, soils, and vegetation must be considered.

NATURAL FACTORS INFLUENCING EROSION

CLIMATE

Although this area is marginal to a hot steppe climatic zone, it lies essentially within a belt of warm temperate climate characterized by arid summers and wet winters. Precipitation is seasonal, occurring normally during the period November to April. The average annual precipitation is 22 inches at Morena Dam and 30 inches in the Laguna Mountains; 26 inches is probably a fair average for the drainage area as a whole. Precipitation usually occurs in the form of rain at lower altitudes and snow at higher altitudes. Cyclonic storms from the northwest provide most of the rainfall, and torrential downpours are not uncommon. When these cyclonic storms encounter air masses from the tropical Pacific region, storms of long duration and high precipitation intensities are produced. Such storms bring from 4 to 12 inches of rain within 2 or 3 days, often attain intensities of more than 1 inch per hour, and produce high run-off rates. Where the vegetation of mountain slopes has been destroyed by fire or seriously depleted by grazing, the run-off of such storms reaches abnormally high rates, causing excessive erosion on the slopes and deep trenching of the valley soils. Storms of this character in 1916 and 1927 produced conditions of peak run-off, under which valley trenching in the Morena drainage basin was greatly accelerated.

TOPOGRAPHY

The Morena drainage basin, 112 square miles in extent, is a distinctly mountainous area lying immediately west of the main crest of the Peninsular Range. Elevations range from 3,000 to 6,000 feet, and the general direction of drainage is south and southwest.

The drainage basin encloses parts of three major plateaus (fig. 5), which stand at unequal elevations and are separated by more or less distinct fault scarps. Two high plateaus occupy the northern half of the area. The Laguna Plateau, in the northeast, averages 5,400 feet in elevation and is surmounted by Laguna Peak, elevation 6,329 feet. The Corte Madera Plateau, in the northwest, stands about 4,200 feet above sea level and is separated from the Laguna Plateau on the east by the Cottonwood Scarp. The southern half of the area is designated as the La Posta Plateau, which ranges from a mean elevation of about 3,200 feet in the southwest to 3,600 feet in the northeast. It is separated from the higher plateaus to the north by an irregular and sinuous scarp 1,200 to 1,800 feet in height.

The most important topographic features in terms of present production of erosional debris are the valley meadows, locally called potreros, which lie on gentle gradients along the principal stream courses. Formed in comparatively recent geologic time by accumulation of erosional waste from the surrounding hills, the potreros are composed of deep and easily eroded alluvium. They occupy approximately 14 percent of the total drainage area, whereas mountains and minor stream courses take up 84 percent and the reservoir, 2 percent. The potreros are significant in being the site of extensive valley trenching, the most severe erosion that is taking place in the drainage basin (fig. 6).

GEOLOGY

The general character and distribution of the principal rock formations of the area are presented in table 2 and figure 5. The La Posta Plateau is underlain by decomposed quartz diorite that is weathered to great depths. The weathered surface mantle of this formation erodes readily by sheet wash and has been a prolific source of sediment deposited in the valleys and reservoir. The northern plateaus are underlain by a complex of schist, quartzite, gneiss, and granitic rocks that are comparatively fresh and not easily eroded. This contrast in erodibility of rock types may account for some of the difference in elevation between the three plateaus, although faulting is believed to be the main cause.[8]

[8] MILLER, WILLIAM J. GEOMORPHOLOGY OF THE SOUTHERN PENINSULAR RANGE OF CALIFORNIA. Geol. Soc. Amer. Bull. 46: 1535-1561, illus. 1935. See pp. 1546-1554.

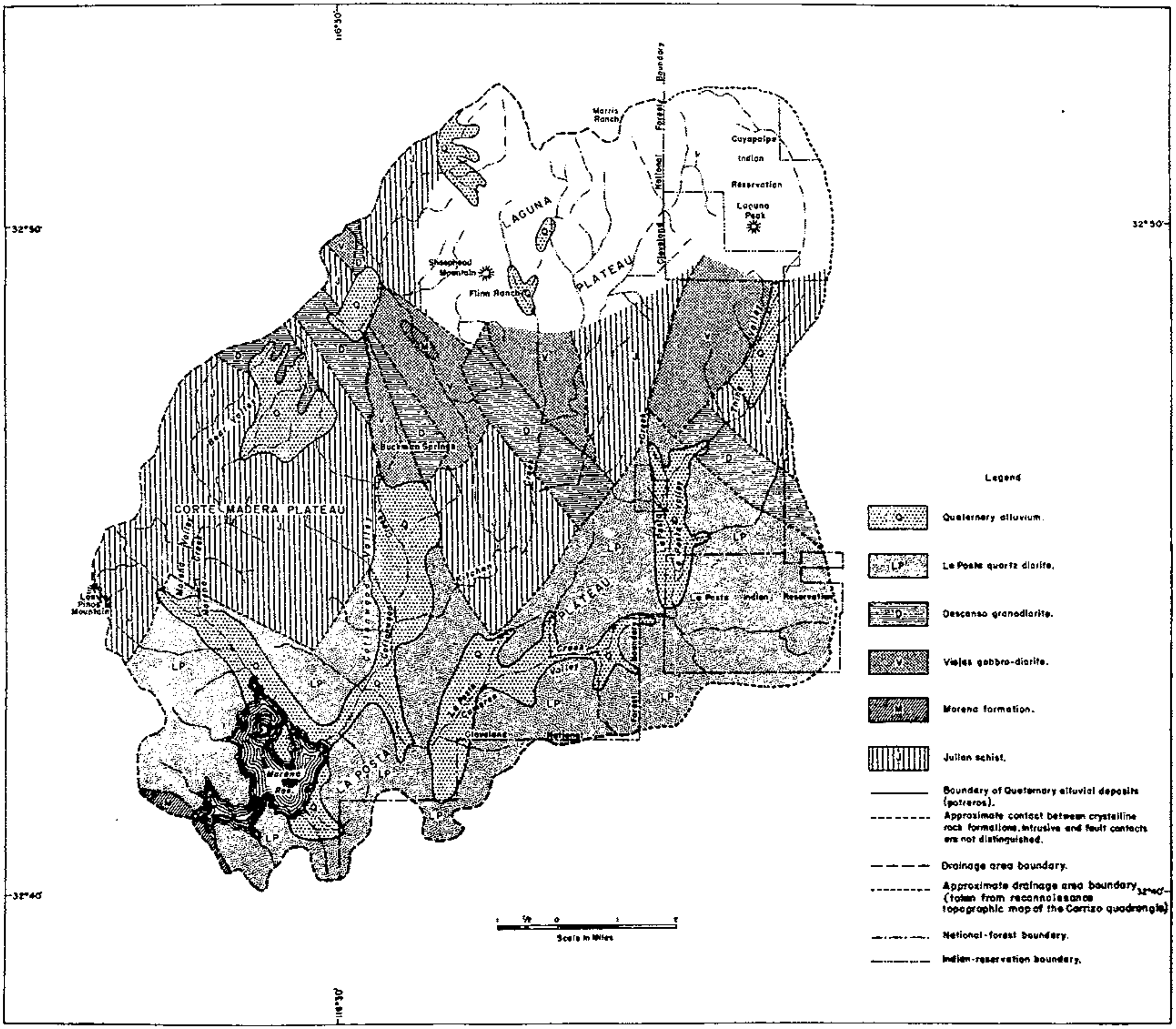

FIGURE 5.—Geognostic map of the Morena drainage basin, showing areal distribution of rock formations.

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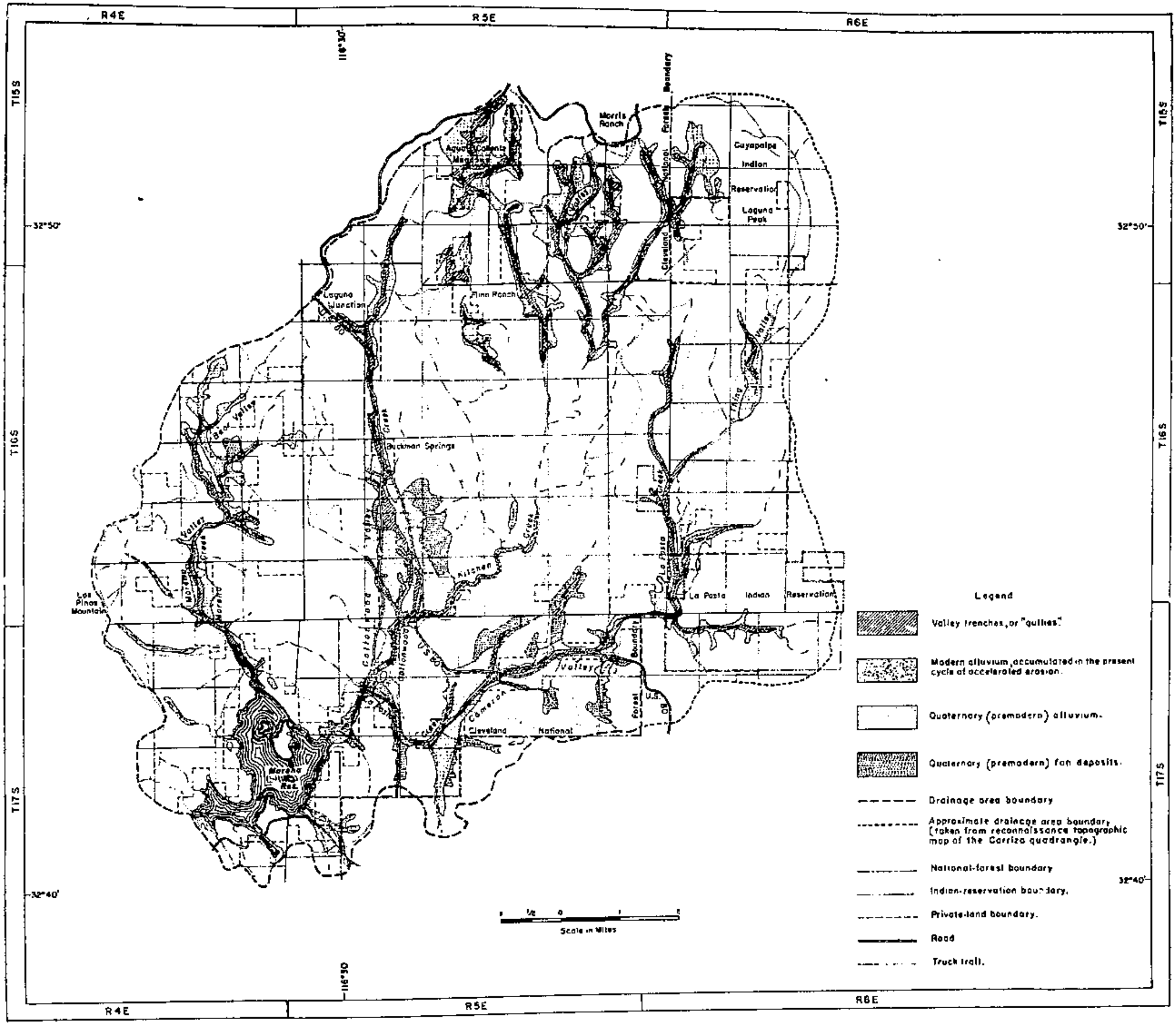

FIGURE 6.—Map of the Morena drainage basin, showing distribution of valley trenches and surficial deposits.

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A, Hundreds of acres of potrero grasslands in Cameron Valley have been shaved away in this valley trench. The meandering stream continues to cut the bank, and sparse sagebrush invades the sandy bottom. B, Unconsolidated alluvial deposits in Pine Valley, immediately west of the Morena watershed. Exposure of these strata within the last 30 years, by a valley trench originating in a wagon road on an overgrazed potrero, illustrates strikingly the swift acceleration of erosion caused by careless use of the land.

A, Actively growing valley trench in the upper Kitchen Valley. The thin grass cover is insufficient to prevent advance of the trench into the deep unconsolidated potrero deposits. *B*, Large transverse valley trench in Agua Caliente Meadow. A few weeks after this picture was taken the gully head reached the rocky slope, destroying the road and completing the bisection of the valley.

TABLE 2.—*Rock formations of the Morena drainage basin, San Diego County, Calif.*

Age	Formation	Erosion characteristics	Occurrence
Late Jurassic or Early Cretaceous	La Posta quartz diorite	Weathered to depths of 50 feet or more. Disintegrates readily to highly erodible mantle rock.	Entire La Posta Plateau.
	Descanso granodiorite	Very resistant. Hard, dense, not highly fractured.	Southern edge of Laguna Plateau; northern edge of Corte Madera Plateau.
	Viejas gabbro-diorite	Moderately resistant	Laguna Plateau
	Morena formation (a crystalline rock of syntectic origin.	Very resistant	Southwest end of La Posta Plateau; also small area near west edge of Laguna Plateau.
Triassic (?)	Julian schist (mica schist, quartzite, amphibolite, marble, and chert).	Disintegrates readily but forms a tight, erosion-resistant mantle rock.	Two-thirds of the Laguna Plateau along the south and west margins; all but the northern corner of the Corte Madera Plateau.

The valleys have been filled to considerable depths in recent geologic time with loose, unconsolidated sediments that are highly susceptible to trenching.

SOILS

The soils of this drainage area have not yet been officially classified. They are immature, usually thin, and diverse in character. A classification by position, into potrero and slope soils, is of use to the erosion specialist.

The potrero soils are sedimentary, derived from the erosion of igneous and metamorphic rocks, and contain much sand, some clay, and a little gravel (pls. 2 and 3). They range in depth from a few inches to 30 feet, are very fertile, and are highly susceptible to trenching notwithstanding their relatively level position.

The slope soils have developed in situ on the brush-covered mountainsides. They range in texture from fairly erosion-resistant sandy clay, derived from the Viejas gabbro-diorite, to very erodible coarse sandy soil derived from the La Posta quartz diorite. Colluvial deposits at slope bases are insignificant in volume. The erosion of slope soils under their usual protective cover of vegetation is slight, averaging probably less than 100 cubic yards per square mile per year. Maximum erosion of slope soils occurs when they are suddenly denuded of their protective brush cover by fire and then exposed to heavy rains. Under such conditions erosion rates of more than 100,000 cubic yards per square mile per year have occurred in southern California.

VEGETATION

The distribution of cover types in the drainage area is shown graphically in fig. 7, and their areas are given in table 3. The relation of these cover types to erosion is important in the analysis of sedimentation in Morena Reservoir.

TABLE 3.—*Types and extent of vegetation in the Morena drainage basin*

Type of vegetation	Area		Type of vegetation	Area	
	Acres	*Percent*		*Acres*	*Percent*
Brush	61,811	86.26	Cultivated land	1,200	1.67
Trees	5,131	7.16	Reservoir	1,687	2.35
Grassland	1,831	2.56			
			Total drainage area	71,660	100.00

The dominant brush type, commonly called chaparral, which blankets the slope soils of nearly nine-tenths of the drainage area, is widely characteristic of southern California mountains. The type is usually a complex of many species growing very densely and reaching a height of 6 to 10 feet. When undisturbed by fire for a decade or more, it offers efficient protection to the slope soils, reduces erosion to negligible rates, and reduces peak run-off by increasing percolation of rain water into the soil. Through the peculiar ability of its constituent species to strike roots deep into rock crevices, and indeed into the weathered rocks themselves, the chaparral possesses remarkable ability to survive drought and to recover after fire. Many of the shrub species in burned areas sprout profusely from their charred stumps, while many nonsprouters, by a compensation of nature, reproduce abundantly from seed.

The principal tree types occur above the 5,000-foot level, forming open forests of conifers and oaks, in which Jeffrey pine (*Pinus jeffreyi*), Coulter pine (*P. coulteri*), and California black oak (*Quercus kelloggii*) are dominant. As precipitation at these altitudes occurs largely in the form of snow and as forest fires are infrequent, both run-off and erosion rates are well controlled in areas of this type, and hence the total volume of eroded material derived therefrom is negligible in the present problem. Small areas of other tree types include scattered groves of valley oak in the potreros, and narrow ranks of sycamore, willow, and cottonwood along the stream courses. These are effective aids to the herb-grass cover in holding valley soils, but once the sod is broken by trenching, the trees are easily undermined and their effectiveness is rapidly lost. Bank erosion of streams is normally retarded by the tree roots, but, when deep channel cutting by flood flows occurs, even large trees are undermined and toppled into the channels (pls. 2, *A*; 3, *B*; and 4, *A*).

The grassland has an importance in the present problem entirely out of proportion to its limited extent. Although occupying less than 3 percent of the total drainage area, mainly in the lower potreros, the grass type forms a protective thatch over highly erodible alluvial deposits hundreds of thousands of acre-feet in volume. The type is composed not of grass alone but of a mixture of grasses, sedges, and herbs with a densely matted but shallow root system. When intact, the type affords excellent protection to the loose alluvial soils, but once the sod is broken, as by a trail or rill, it offers only a feeble defense against trench development. In effect, this surface protection might be compared to the "case-hardening" of a soft metal, which, when the surface is broken, is rapidly worn away by abrasion.

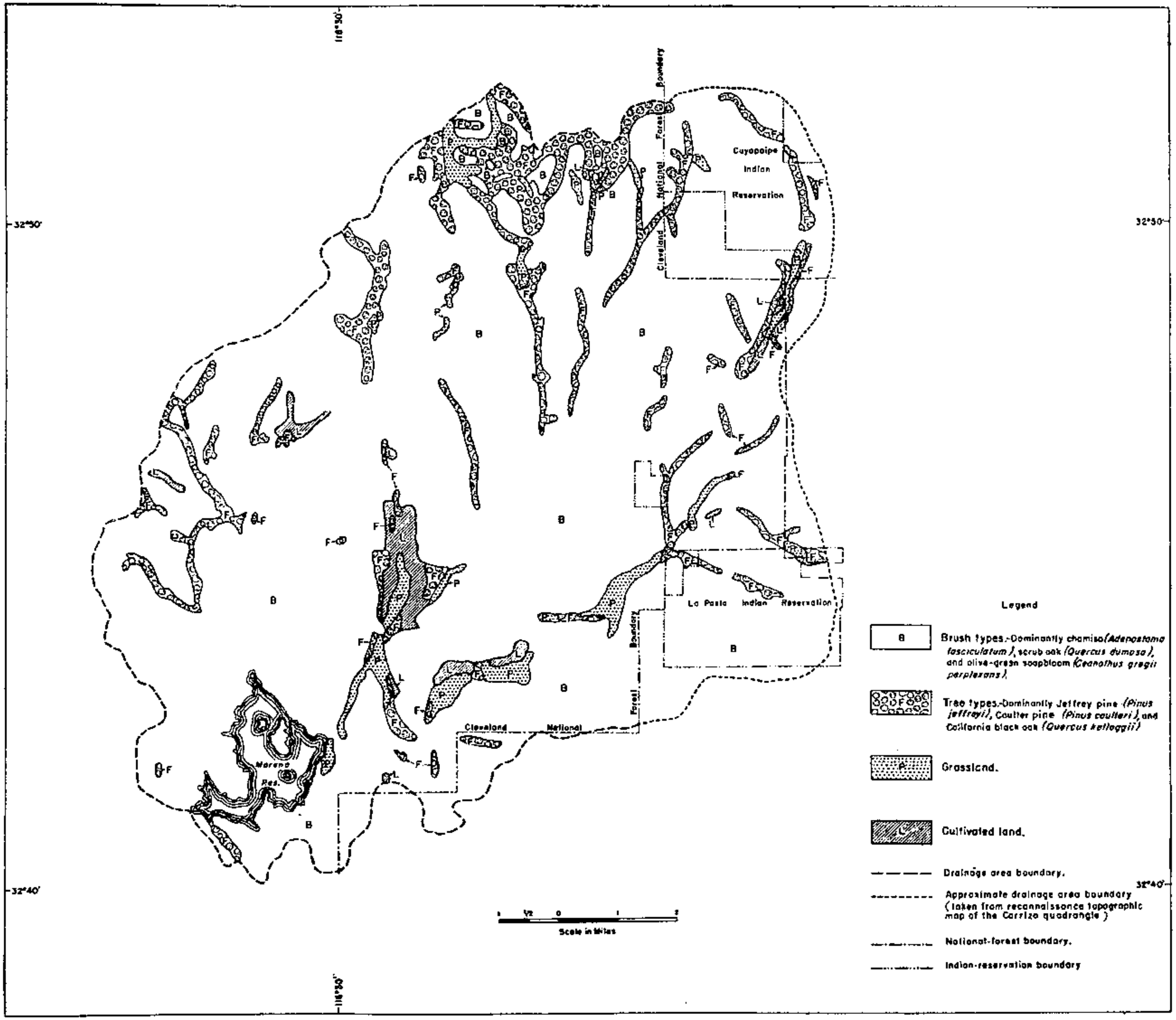

FIGURE 7.—Map indicating types of vegetation in the Morena drainage basin.

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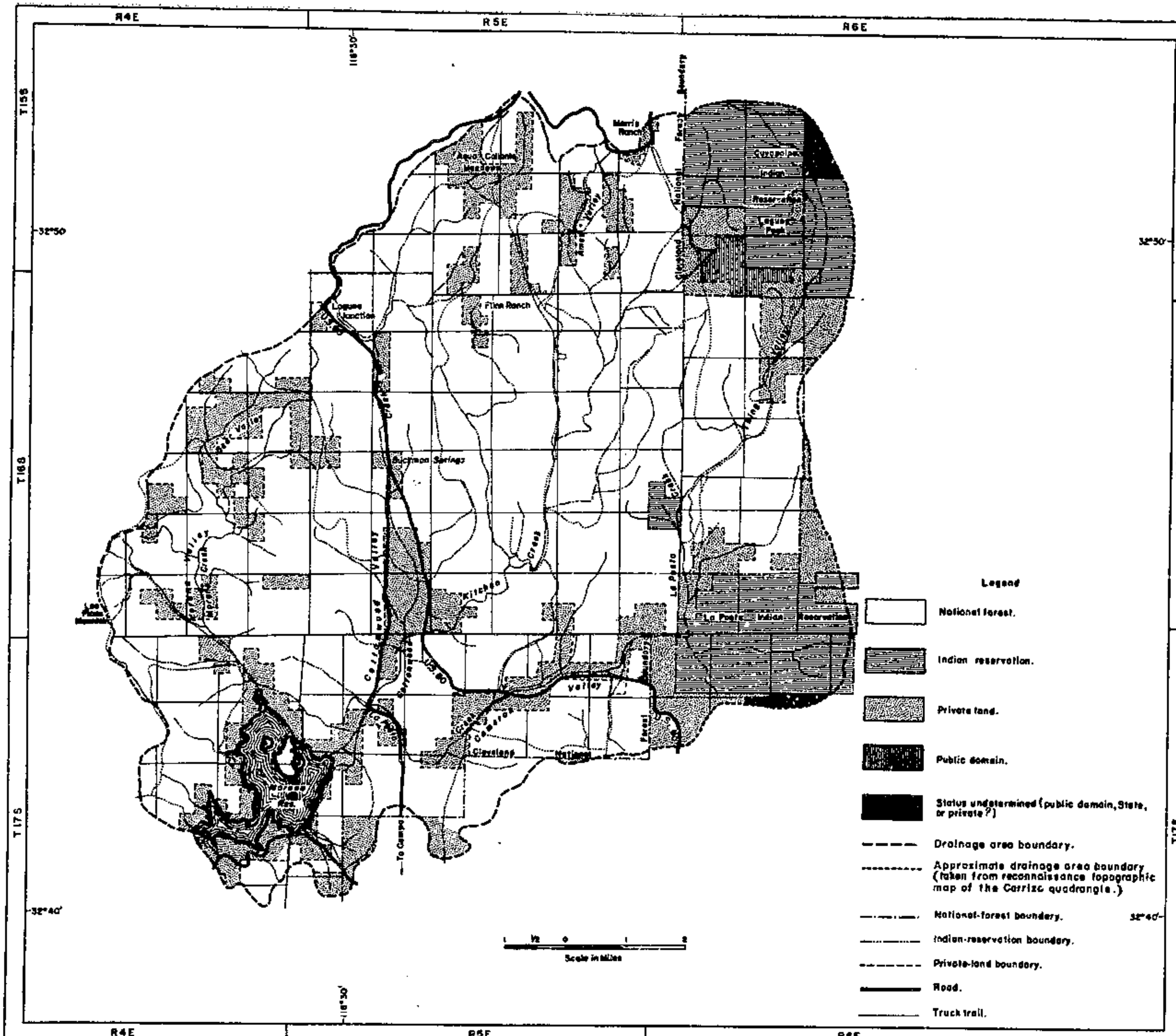

FIGURE 8.—Map of Morena drainage basin, showing the status of land ownership.

HUMAN FACTORS INFLUENCING EROSION

HISTORY OF SETTLEMENT

There is no record that the Morena basin was subjected to the white man's utilization during the Spanish regime. The nearest Spanish center of influence was the Mission San Diego, founded in 1769, and the limits of that colony extended only to Descanso, about 6 miles northwest of the Morena watershed. The intervening country was extremely rugged, and the Morena drainage area itself seems to have been left to the Indians during the Spanish period.

After the Civil War, particularly in the decade 1870–79, permanent white settlers began to take up land in the basin. Since the potreros furnished the necessary home pasture and plow land, as well as agreeable sites for dwelling places, all potreros of any size were soon taken up. By 1890, when the area now known as the Cleveland National Forest was withdrawn from the public domain, practically all the valley meadows had passed into private ownership (figs. 6 and 8).

Although no attempt was made to check in detail the history of the ranching units, the number of old building sites indicates that a larger number of families formerly lived in the area than at the present time. During and following the pioneer period, each valley probably supported one or more family stock-ranching units centering around the 160-acre homestead, which was staked out to include the choice meadowland of the locality. Conditions have changed to the extent that at present a single permittee grazes more than two-thirds of the total number of livestock authorized for the nine range allotments on the portion of the drainage area within the Cleveland National Forest. This permittee owns or leases all or most of the private land within the four forest allotments on which his livestock are grazed. The other one-third of the total permitted livestock belongs to six permittees, and is grazed on five allotments. Only two of these six permits cover sufficient livestock to support a family unit entirely dependent on the income from cattle. A similar situation exists with respect to range use on the private and Indian lands outside the national forest but inside the drainage basin (fig. 8).

The present situation, therefore, contains elements of the absentee-ownership evil. which has resulted in serious soil depletion elsewhere in the United States.

GRAZING

Cattle were introduced into the basin by the white settlers about 1875, and cattle grazing has continued as the dominant land use to the present time. The excellent natural feed resulted in heavy stocking of the range, a practice that increased as the ranges closer to the coast became impoverished. This heavy use of the mountain areas, especially in years of drought, resulted in serious depletion of the range and reduction in the protective value of the plant cover. There was, of course, no regulation of the use of private lands or, in the early days, of the private use of public lands. Under these conditions overgrazing and other forms of range misuse, especially periodic burning of the brushy uplands, were commonly practiced. Although it is impossible, in the absence of recorded observations, to state definitely how and when the present accelerated trenching of the valleys began, evidences still active on the ground today indicate that the chief cause of gully and trench formation was the breaking of the protective sod by livestock trails at critical points and the concentration therein of run-off water from the surrounding areas of depleted cover. Indubitably, overgrazing on the potreros of the Laguna and Corte Madera Plateaus and on the lower potreros of the La Posta Plateau set the stage for the rapid valley trenching that followed heavy precipitation in the 1916 and 1927 seasons (pls. 4, *B* and 5, *A* and *B*).

FIRE

It has been pointed out (p. 13) that the chaparral-covered slopes, when denuded by fire, may suffer spectacular erosion, the degree depending chiefly on the intensity and duration of subsequent rainfall. Since run-off from the denuded slopes is also greatly increased, both in volume and rate, established drainage channels are subjected to flood flows with their usual accompaniment of channel scouring and transportation of enormous loads of soil and rock.

In the Morena drainage area, as elsewhere throughout southern California, fire has played its part. In the 25-year period following completion of the dam in 1910, nearly 20 percent of the total area has been burned over. All the major fires, 19 in number, were man-caused, and 17 of these were incendiary or were so regarded. Noteworthy is the fact that this burning has occurred largely on the La Posta Plateau, the section most susceptible to erosion. The distribution and dates of fires and the areas burned are shown in figure 9 and table 4. Although no record of fires before 1911 is available, the practice of burning antedated the period of record by many decades.

TABLE 4.—*Areas burned in the Morena drainage basin, 1911–36*

Date	Area		Date	Area	
	Acres	*Percent*		*Acres*	*Percent*
1911–15 only	3,328.7	4.64	1930 only	609.6	0.85
1917 only	291.4	.41	1930 on 1911–15	7.7	.01
1919 only	793.6	1.11	1930 on 1924	57.6	.08
1921 only	3,136.0	4.38	1931 on 1911–15	6.1	.01
1921 on 1911–15	102.4	.14	1931 on 1921	32.0	.04
1924 only	2,259.2	3.15			
1924 on 1911	217.6	.30	Total area burned	13,600.7	18.98
1925 only	172.8	.24			
1926 only	441.6	.62	Area unburned	58,089.3	81.02
1928 only	1,939.2	2.71			
1929 only	147.2	.21	Total drainage area	71,690.0	100.00
1929 on 1921	57.6	.08			

In the early days fire was commonly used by the ranchers as a means of obtaining fresh, tender forage for their livestock. The shrubby species of the chaparral that covers the slopes surrounding the grassy potreros are, for the most part, rough and unpalatable when the plants are 6 to 10 years old. At that age, also, the chaparral is usually very dense, the shrubs are very stiff, and the whole is practically impenetrable to livestock. Burning clears the ground and is followed by fresh growth from the stumps of species that have the ability to sprout and often by a dense growth of herbs and grasses that flourish in the intershrub spaces for a few years before the shrub canopy again closes over them and shades them out.

Periodic burning of the chaparral as a means of obtaining additional forage, therefore, became a common practice during the period before

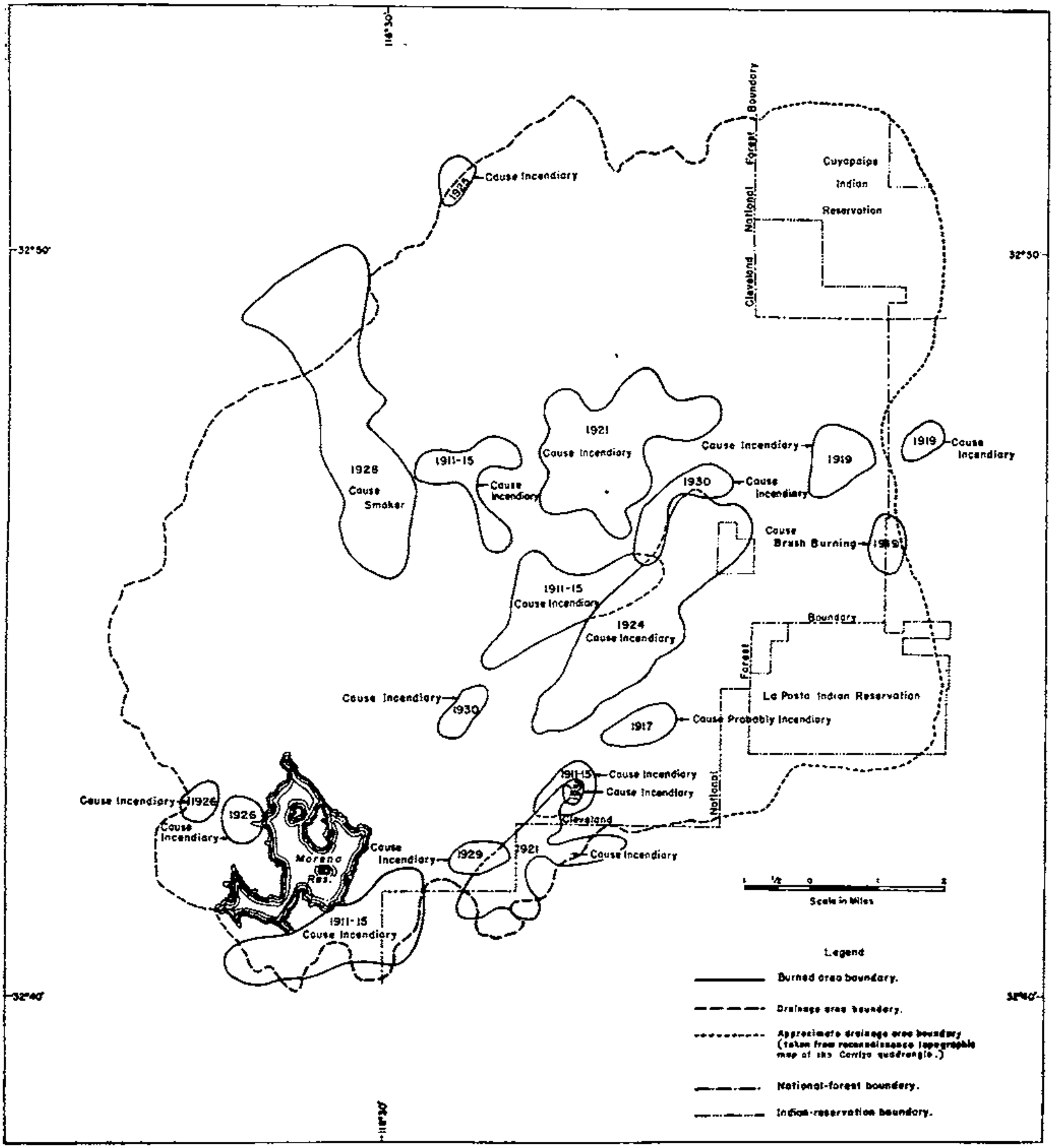

FIGURE 9.—Map showing burned areas in the Morena drainage basin.

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the area was placed under Federal administration as part of the Cleveland National Forest. The cause-and-effect relation between fire and erosion was either unobserved or disregarded. The immediate benefits to the stockman were sufficient, in any case, to assure continuation of the practice despite its long-range consequences.

Fire, therefore, was added to overgrazing as a cause of the extensive erosion and valley trenching of the Morena drainage basin.

ROADS

Human influence on erosion within the Morena drainage basin is also apparent in the road system. A primary road, United States Highway 80, enters the area from the west at Laguna Junction and crosses it southeastward via Buckman Springs, Cottonwood Valley, Cameron Valley, and La Posta Creek. This is a high-speed, modern automobile route with heavy excavation and fills to maintain standard curves and grades. Consequently, erosion of cuts and fills by sheet wash and gullying has contributed sediment to the creeks leading to Morena Reservoir, especially in the La Posta Valley section and the steeper part of Cottonwood Canyon. A second primary road, running southward from Buckman Springs through the gently sloping Cottonwood Valley, has not caused serious erosion.

A considerable system of farm roads and truck trails reaches into every corner of the drainage area. These roads are all unsurfaced, but since they do not have deep cuts or fills they are roughly equivalent to barren areas where native vegetation has been removed and the surface exposed to erosive processes. Assuming the average width of the roads to be 15 feet, the 108 miles of truck trails within the Morena basin represent about 200 acres of barren land, which gullies, washes, and otherwise contributes to the general sum of erosion. In part, erosion from this source may be justified by the fact that the minor roads facilitate fire suppression and thus prevent much larger volumes of erosion from burned areas. Moreover, methods of revegetation recently developed to prevent the greater part of such road erosion are being introduced on these roads.

CULTIVATION

Cultivation is confined to the potrero lands, and most of the 1,200 acres under cultivation in 1935, chiefly hayfields and ranch gardens, lies in the Cottonwood and Cameron Valleys within 5 miles of Morena Reservoir. These lands have contributed to the Morena Reservoir deposits through sheet erosion, but in comparison with the great volume derived from valley trenching the amount from sheet erosion is practically negligible.

SOURCES OF ERODED MATERIAL

The valley lands are dissected by an extensive system of recently cut gullies, or valley trenches, having a total cavity volume estimated to be in excess of 14,000 acre-feet (fig. 6). The survey of sediment in the reservoir showed deposits to the volume of 7,184 acre-feet, representing 10.5 percent of the original storage capacity of the reservoir. Of the 7,000-acre-foot difference between these two quantities, a small part was no doubt transported beyond the reservoir site before the construction of Morena Dam in 1910, but by far the greater part has been deposited in the lower stream courses above the crest level of the reservoir. These deposits in the lower stream courses are being moved down into the reservoir basin during periods of heavy run-off.

Abundant evidence of sheet erosion was observed in the drainage area, particularly in the granitic lowlands in the southern part. For lack of reference points this type of erosion was not susceptible to measurement, but, owing to the large area of slope land in proportion to potrero land, it is possible that the total volume of sheet erosion has been at least equal to that of valley trenching.

EXTENT AND HISTORY OF THE VALLEY TRENCHES [9]

The widespread geological development of potreros in the Peninsular Range has been ascribed by writers on this subject to different causes. Miller [10] believes they are, for the most part, relatively sunken fault blocks between raised ones. Sauer [11] believes that "the narrow linear depressions are due to long continued erosion in fault zones," and that "the broad intermontane basins are features of denudation primarily, of erosion secondarily." Whatever their tectonic cause, they are obviously recent fills resulting from the deposition of eroded materials in relatively depressed parts of the area. The depressions probably owe their origin to more than one cause, but they have in common a downstream control of resistant rock that has maintained the filled back country at a temporary base level. The significance of the potreros is that their unconsolidated soils offer very little resistance to the rapid growth of valley trenches once these are started. The widespread occurrence of valley trenches is shown on the map of the Morena basin (fig. 6), which was compiled from field examinations supplemented by study of an aerial survey and photographs made in 1928 for the San Diego County tax assessor.

The total length of trenches observable in the aerial photographs of 1928 was 86 miles; and, as determined in the field in 1936, their average width was 141 feet; and their average depth, 10 feet, with depths ranging from 3 to 30 feet. Practically every valley in the drainage area has been dissected by still-active trenching to the extent that nearly 20 percent of the land suited to agriculture has been destroyed (table 5).

TABLE 5.—*Classification of potrero land in the Morena drainage basin*

Class	Area	
	Acres	*Percent*
Nontillable potrero land:		
Land destroyed by modern valley trenching (formerly tillable)	1,983.5	19.3
Fan and channel deposits (originally nontillable)	1,449.0	14.0
Total	3,432.5	33.3
Tillable potrero land	6,884.6	66.7
Total potrero land	10,317.1	100.0

[9] Valley trenches are known locally as gullies, but they are to be distinguished from the gullies developed on uplands and slopes in more humid regions in that they have developed entirely on the alluvium-floored valley bottoms.

[10] MILLER, W. J. See pp. 1538–1539 of reference cited in footnote 8.

[11] SAUER, CARL. LAND FORMS IN THE PENINSULAR RANGE OF CALIFORNIA AS DEVELOPED ABOUT WARNER'S HOT SPRINGS AND MESA GRANDE. Calif. Univ. Pubs., Geog. 3: [199]–290, illus. 1929. See p. 247.

It is within the memory of living men that the present system of great trenches has developed. The first trenches very probably appeared as long ago as 1890, or even earlier, but their early stages were given so little heed that they have passed out of memory and cannot be precisely dated. The forest ranger of the Descanso district, J. B. Stevenson, remembers when most of the potreros were not noticeably trenched. He assigns the period of most rapid trenching to two precipitation seasons, 1916–17 and 1927–28. It was in these seasons that trenching was sharply accelerated along existing drainage channels and new systems of trenches were started. These seasons correspond to years of unusually high rainfall, when extensive floods and debris flows occurred throughout San Diego County.

Today, valley trenches, more numerous than ever, are advancing their heads in every valley, with scant hindrance by the thin grass and weed cover. Midvalley trenches in many places have virtually become minor canyons and have established new base-level gradients 10 to 30 feet below the beds of previous drainage channels. In some of the broader valleys formerly narrow entrenched channels have widened by lateral erosion until their present banks stand hundreds of feet apart, and run-off waters follow a meandering course over wide sandy bottoms (pl. 2, *A*).

Although the years of maximum valley trenching in the Morena basin coincided with recent flood years, there can be no doubt that similar flood years must have occurred periodically through many centuries in San Diego County. Yet the potreros show no evidence of prehistoric trenching. Geologically, the potreros of La Posta Creek, though formed since the Pleistocene period, which closed some 20,000 years ago, are nevertheless many thousands of years old; the Laguna and Corte Madera potreros, formed much earlier, probably within the Pleistocene, may be as much as 100,000 years old. Why, then, were these ancient potreros not trenched during many previous centuries, and through what circumstances have they lain practically intact until 1890, 1916, and 1927?

It is palpably unreasonable to assume that the floods of 1916 and 1927 were the only ones in tens of thousands of years with sufficient intensity or other peculiar ability to cause serious dissection and trenching of the potreros. Nor can a secular change in climate be advanced as the basic cause; for the development of the existing types of vegetation has required a long period of climate very similar to that of today. Rather, the significantly short interval between the occupancy of the land by the white man and the first development of the trenches shows conclusively that intensive and unwise land use was the true cause of the greatly accelerated erosion in the Morena drainage basin.

REMEDIAL MEASURES

The need for control of excessive soil movement in this area has long since passed the point where such measures as regulation of grazing, or even complete cessation of grazing for a few years, can stop the process of soil removal, much less restore the land to productive use. In a comprehensive program of control and restoration, engineering works would be needed to prevent further degradation of drainage channels and restore them to their original condition by the establishment of new base levels. This could be accomplished by permanent dams at strategic points on La Posta and Cottonwood Creeks, together with a large number of gully-control structures throughout the drainage basin. Simultaneously, rigid regulation of grazing would have to be instituted, requiring at first complete exclusion of livestock from some areas and greatly curtailed use in others. Future grazing would have to be strictly adjusted to carrying capacity, ample margins of ungrazed vegetation being left annually to protect the soil. The need for and extent of planting to hasten restoration of the cover would have to be determined by detailed examination. The prevention of forest fires, particularly cessation of all deliberate burning and some additional capital investment to improve fire detection and suppression facilities in the area, would be essential parts of the program.

This program of control, if ever undertaken, will be a long and a costly one. Though the necessary structures can be built quickly, many years will pass before gradual aggradation can refill the extensive valley trenches, and long years also before any substantial amount of grazing can again be safely permitted. Indeed, it is pertinent to challenge the wisdom of continuing grazing in the basin at all if it is to serve as a water-catchment area for the city of San Diego. Further study would be required to strike a balance between the value of the livestock industry in the basin and the water resource it threatens. Under present conditions the two uses are definitely incompatible. As to which should survive, there is no choice. Water for the great and growing city, already at a high premium, must be provided at any cost; beef can be imported from other ranges.

It should be remembered, however, that the major sediment-source areas, the potreros, are privately owned. For the ranch owners alone to undertake an adequate program of erosion control would be economically impossible. In these circumstances one possible solution might lie in a cooperative plan under which the ranchers, the city, and the Federal Government would each assume certain responsibilities. Under this arrangement the necessary engineering structures could be started at once, and grazing and other uses of the area would be controlled in such a manner as to safeguard the water resource. The alternative solution would be the acquisition of the private lands by the city of San Diego, the elimination of grazing, and a subsequent program of erosion control on a cooperative basis by the city and the Federal Government.

SUMMARY

The Morena drainage basin, in the Laguna Mountains of southern California, is an important water-gathering area for the city of San Diego. In 1910 the city completed a dam and reservoir to impound the waters of the basin. By 1935, 10.5 percent of the reservoir storage capacity had been displaced by sediment deposits and large volumes of similar material had been deposited in the lower stream courses above the spillway level of the reservoir. A study of the drainage area revealed that most of the sediment had come from deep trenching of alluviated valleys, locally called potreros, and from mountain slopes denuded of their protective cover by fire.

Rapid trenching of the potreros began between 1890 and 1895, within 20 years after first occupancy of the basin by white settlers (1875). The pioneers, under the homestead laws, took up the grassy potreros and introduced cattle. Cattle grazing has been maintained

A, Valley trenches cutting headward and exposing the roots of valley oaks despite grass cover. *B*, Typical potrero, or valley meadow, in the Morena drainage basin. A large trench has grown headward across the valley from the canyon on the left to the rock ledge on the extreme right. The smaller channel in the foreground follows a cattle trail.

A, "Cow-trail" gullies in an early stage of development, Agua Caliente Meadow. The trees in the background are pines and deciduous oaks. *B*, Valley trench in heavily grazed grassland. Oak grove on the right, brush-covered slope on the left. A small earth dam (center) provides water for livestock and stops further deepening of the trench.

as the principal land use in the area to the present time. Overgrazing of the valleys and repeated burning of the brushy slopes for the production of sprout and weed forage have been the chief causes of accelerated erosion.

Notwithstanding the depleted condition of the valley lands and the constant growth of the trenches, largely the result of overgrazing, no attempts to regulate grazing have been made. Erosion is still accelerating, and, unless control measures are undertaken, the reservoir can be expected to receive sediment at a more rapid rate in the future than it has in the past.

Control of erosion in the drainage area will require a coordinated program of engineering works, regulation or elimination of grazing, improved fire control, and possibly some planting. The most practical solution appears to lie in a cooperative plan of action by the ranch owners, the city of San Diego, and the Federal Government.

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U. S. GOVERNMENT PRINTING OFFICE: 1939

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