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SIXTH SESSION - SEDIMENT CONTROL

Lester C. Walker,* Presiding

HOW EFFECTIVE ARE SOIL CONSERVATION MEASURES IN SEDIMENTATION CONTROL?

by Carl B. Brown**

How effective are soil conservation measures in sedimentation control? To answer this question categorically would be as difficult as defining the nature of sin. Literally, the answer depends on: (1) The nature of the particular sedimentation problem; (2) the sources of the sediment which cause this particular problem; and (3) the types of soil conservation measures which may be practicable for application in the drainage basin above the site of the problem.

Let us consider first the nature of the problem. Sedimentation control in one place may require reduction of the supply and rate of movement of bed load to prevent stream-channel aggradation. In another place it may necessitate reduction of the amount of fine suspended matter to prevent the destruction of fish life. In other circumstances it may involve reduction of the total stream load to lessen the rate of silting of a storage reservoir. Any given set of conservation measures may be highly effective in controlling one type of sedimentation damage but largely ineffective in controlling another type. Thus, we are first confronted with the question: "What kind of sediment is causing the particular problem?" Generally, this question can be answered readily by appropriate field and laboratory investigations.

This brings us to our second consideration: Where does the troublesome sediment originate? Here the task is more difficult, but some field and laboratory techniques have been developed for tracing sediment from its point of damage to its points of origin in the drainage basin.

In larger drainage basins it is generally important to determine both the geographic and genetic distribution of sediment sources. Determination of sediment contribution from various watershed units is important to the development of master plans for drainage basin development. Such data are needed, for example, in estimating the useful life of proposed major reservoirs and for determining the priority of major tributary areas for watershed treatment to control soil erosion.

Several methods have been used to determine the geographic sources of the total sediment load, and of bed load and suspended load. These include: (1) Sampling the suspended load of streams; (2) analysis of reservoir survey data to determine average rates of sediment production from smaller watersheds scattered throughout the large drainage basin; (3) surveys of erosion and valley deposition to determine the net sediment output of various watershed units; (4) analysis of the heavy mineral distribution in bed material; and (5) analytical methods such as those now being developed by Dr. Einstein and others for determining the rates of bed-load move ment at various points throughout a drainage system.

In planning soil conservation measures for sedimentation control, the genetic determination of sediment sources is most important. Once the nature of the sediment problem is clearly understood, it is essential that the conservation measures, if they are to prove effective, be designed to control the production and movement of sediment that gives rise to the particular

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Figure 1. Sheet erosion on 12 percent slope cultivated in straight rows and planted to corn, near Bethany, Missouri.

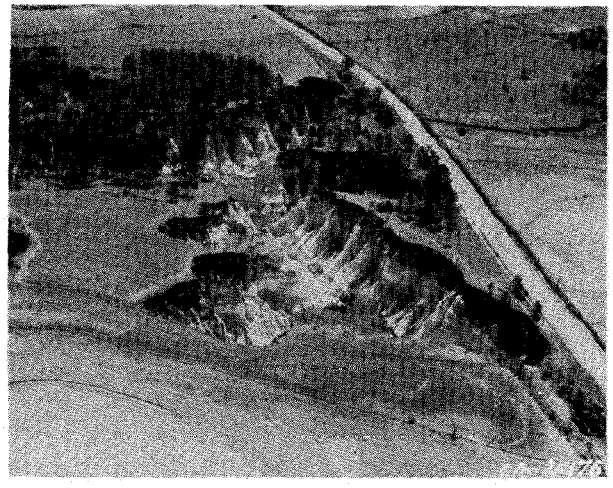

Figure 2. Enormous gullies more than 50 feet deep and less than 100 years old cut in rich agricultural land 8 miles west of Lumpkin, Stewart County, Georgia.

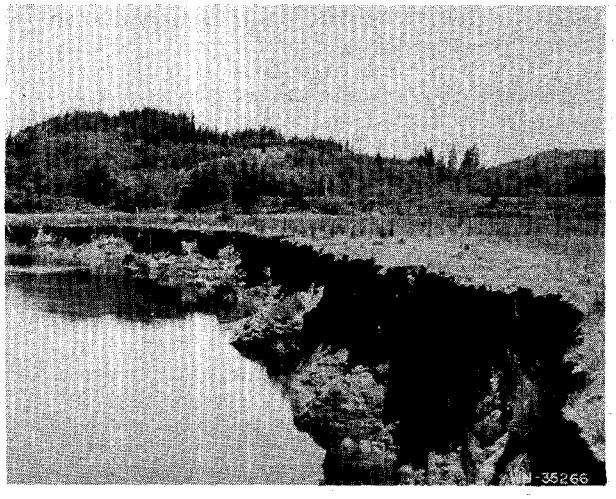

Figure 3. Stream-bank erosion along Wynooche River 5 miles northwest of Montesano, Grays Harbor County, Washington.

Figure 4. Mass movement of soil by land slip in pasture 8 miles north of Wolf, Ohio.

problem. Terracing and strip cropping, for example, would not solve the problem if the troublesome sediment was coming largely from stream-bank erosion.

Seven principal sources of sediment production are quantitatively important in some watersheds in this country. These are:

1. Sheet erosion by surface runoff on agricultural, range, forest, and waste land - sheet erosion being defined as the removal of surface soil by overland flow without the formation of channels of sufficient depth to prevent cultivation (See Figure 1).

2. Gullying, or the cutting of channels in soil or alluvium by concentrated runoff (See Figure 2).

3. Stream-channel erosion, including bank cutting and bed degradation (See Figure 3).

4. Mass movements of soil - landslides, slumps, and soil creep. (See Figure 4).

Figure 5. Flood erosion as a result of flood water scouring in cultivated field on Ohio River flood plain after flood of January 1937.

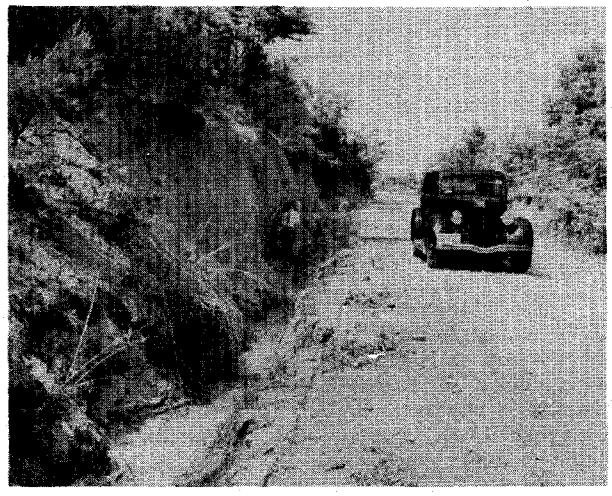

Figure 6. Road erosion in watershed of Burlington Reservoir, Alamance County, North Carolina.

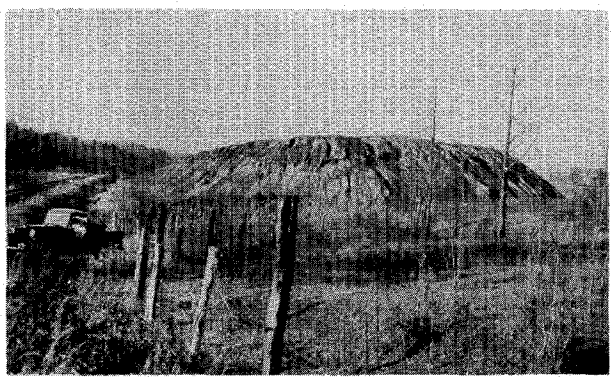

Figure 7. Mine waste dump of Docena Mine adjacent to Bayview Reservoir near Birmingham, Jefferson County, Alabama.

5. Flood erosion, or the removal of surface soil by flood flows sweeping across flood plains (See Figure 5).

6. Erosion on roads, railroads, power lines, and various construction projects (See Figure 6).

7. Mining and industrial wastes dumped into streams or left in positions favorable to erosion (See Figure 7).

Of these, the first three are by far the most important, quantitatively. Research studies and watershed surveys by the Department of Agriculture have shown that sheet erosion generally produces the greatest quantities of sediment in areas that are predominantly agricultural and have more than 20-inch rainfall. Sediment that causes particular problems such as channel aggradation, however, may come primarily from gullying or other sources. In forest and range country, and in areas having less than 20 inches of precipitation, gullying and stream-channel erosion generally furnish the greater part of the total stream load. In small watersheds any of the other sources may be the most important.

In 1941 the Soil Conservation Service made intensive studies by survey techniques of two small drainage areas above municipal reservoirs near Lexington, N. Car., and near Weatherford, Tex. In the 6.75-square-mile Leonard Creek watershed near Lexington, N. Car., which is typical of the Piedmont plateau, it was found that 38 percent of the sediment had come from sheet erosion on cultivated land where gullying was not evident; 37 percent had come from combined sheet and gully erosion on land in or suitable for cultivation; 17 percent from land completely destroyed by gullying; 6 percent from linear gullies large enough to delineate individually on a scale of 1 inch to 500 feet; 2 percent from road banks and ditches; and only a negligible amount from stream-bank erosion. Of the sediment produced in this drainage area since cultivation began, slightly more than one-third has been deposited as alluvium within the area, and slightly less than two-thirds has been transported out of the area.1/

A similar study was made of the 6.2-square-mile Town Creek watershed near Weatherford, Tex., which lies largely in the Grand Prairie belt of the West Gulf Coastal Plain. Here it was found that sheet erosion, including undifferentiated minor gullies, minor wind erosion, and some erosion termed geologic where soil profiles had not developed, accounted for nearly 90 percent of the total sediment production. Gullies large enough to delineate separately account for 5.5 percent; roadside erosion, 2.4 percent; stream-bank erosion, 1.2 percent; and erosion along the edge of stream terraces, 1.1 percent. Seventy-nine percent of the sediment was carried out of this area. 2/

A recent study of the 906-square-mile drainage area of the Sangamon River above Decatur, Ill., which lies in the gently rolling glacial drift plains, showed that sheet erosion on cultivated land having slopes of more than 2 percent, accounted for more than 90 percent of the total sediment production. Gullies, stream-bank erosion, and wave erosion around Lake Decatur together contribued less than 10 percent of the total sediment reaching Decatur. 3/

By way of exception, a study of the 437-square-mile Buffalo Creek drainage area in New York State showed that stream-bank erosion is contributing approximately 80 percent of the total sediment load reaching Buffalo Harbor, whereas sheet and gully erosion on agricultural land is contributing only about 20 percent. 4/

Investigations in the Rio Puerco drainage basin of about 6,100 square miles in New Mexico have shown that bed and bank erosion in the main channel of the Puerco in a distance of 117 miles above its mouth is contributing approximately 40 percent of the average annual sediment load. An additional 30 percent of the load is coming from enlargement and headward extension of tributary arroyos, whereas the remaining 30 percent of the load is coming from sheet and gully erosion on the land slopes. 5/

Our third consideration is to define soil conservation measures. Broadly speaking, measures used for erosion control on watershed areas may be divided into three categories: (1) Agronomic practices; (2) management of vegetation; and (3) engineering works.

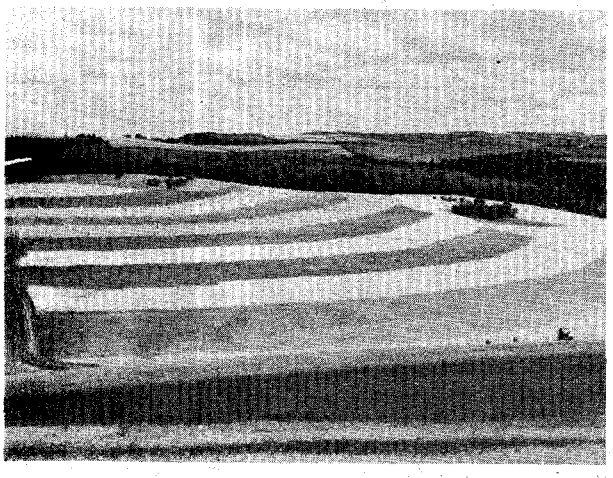

Figure 8. Strip-cropped field in four-year rotation 2½ miles west of Wallis, Steuben County, New York.

Agronomic practices include such measures as crop rotation, strip cropping (see Figure 8), cover crops, and mulching, usually carried out as a part of farm operations to protect the soil against water and wind erosion.

Management of vegetation includes control of the use and depletion of natural vegetation by regulating grazing and lumbering operations and by fire control. It includes also the re-establishment of perennial vegetation on land from which the native cover has been totally or partially destroyed. This includes reforestation, seeding of pasture and range land, and planting perennials, such as kudzu in the Southeast, on eroded and gullied areas.

Engineering measures range from terraces (see Figure 9), terrace outlets, and waterways on farm fields to ponds, gully-control

1/ 2/ 3/ 4/ 5/ See "References" at close of comments.

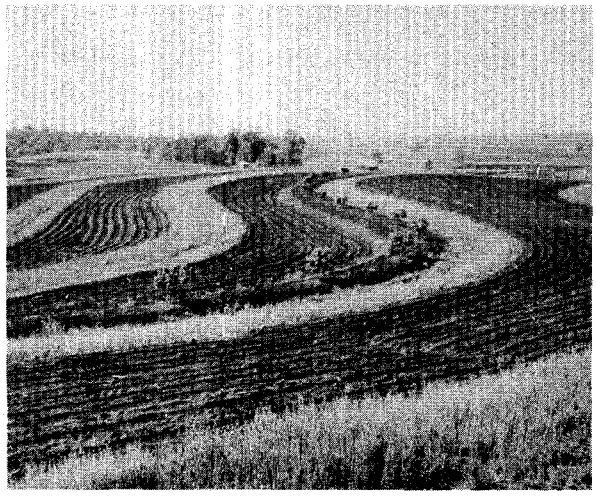

Figure 9. Terracing and contour cultivation on field having 6% slope, near Nacogdoches, Texas.

structures, desilting basins, stream-bank stabilization, and channel improvements throughout the drainage system above the sites of major engineering works, such as reservoirs, levees, and river-bank stabilization of the types installed by construction agencies, such as the Army Engineers and Bureau of Reclamation. More than 80 different soil conservation measures are now recommended by the Soil Conservation Service for use in one place or another in accordance with the needs and capabilities of the land.

What, now, are the lines of evidence on the effectiveness of soil conservation measures in reducing sediment production? In quantitative terms, what reductions can be achieved if we maintain, as we must, the level of farming and grazing operations necessary to provide a continuous and ample supply of agricultural products? 4 lines of evidence are noteworthy.

First, historical accounts of early travelers in both the East and West lead to the conclusion that the sediment load of streams must have been markedly less than they are today. For example, Col. William Byrd, one of the Virginia Commissioners who surveyed the boundary line between Virginia and North Carolina in 1728, wrote 6/ regarding the Roanoke River and its tributary, the Dan, as follows: "The river . . . . always confined within its lofty banks and rolling down its waters as clear as crystal.

"The stream, which was perfectly clear, ran down about two knots, or two miles, an hour, when the water was at the lowest. The bottom was covered with a coarse gravel, spangled very thick with a shining substance, that almost dazzled the eye, and the sand upon either shore sparkled with the same splendid particles. At first sight, the sunbeams giving a yellow cast to these spangles made us fancy them to be gold dust, and consequently that all our fortunes were made . . . . But we soon found ourselves mistaken and our gold dwindled into small flakes of isinglass." Anyone viewing the turbid Roanoke and Dan today will readily appreciate the stratling contrast.

Sir Charles Lyell, eminent English geologist of the last century, wrote 7/concerning his travels in the South in 1846: "Formerly, even during floods, the Altamaha was transparent, or only stained of a darker color by decayed vegetable matter, like some streams in Europe which flow out of peat mosses. So late as 1841, a resident here could distinguish on which of the two branches of the Altamaha, the Oconee or Ocmulgee, a freshet had occurred, for the lands in the upper country, drained by one of these (the Oconee) had already been partially cleared and cultivated, so that that tributary sent down a copious supply of red mud, while the other (the Ocmulgee) remained clear, though swollen. But no **sooner** had the Indians been driven out, and the woods of their old hunting-grounds begun to give way before the ax of the new settler, than the Ocmulgee also became turbid."

On the basis of data from erosion experiment stations and from surveys of reservoirs which have watersheds with strongly contrasted vegetal protection, it may be inferred that the sediment loads of many Eastern streams have increased 25 to 100 times since settlement of the region.

Historical accounts indicate that the existing system of continuous major arroyo channels in the Southwest has developed since about **1860 8/.** These arroyos are known to be among the chief contributors of the present sediment loads of streams. Furthermore, they act as giant flumes for transport of sediment, which was formerly deposited on valley flats as shown by geological studies. It may be inferred, therefore, that the sediment loads of some major western streams may have been doubled, quadrupled, or even more drastically increased in the past 100 years.

Secondly, geological investigations have shown a rapid increase in the rate of building of alluvial flood plains east of the 100th meridian. As Dr. Victor Jones has pointed out earlier in the conference, abundant evidence of this phenomenon has been obtained from such widely scattered areas as the Carolinas, Mississippi, Texas, tributaries of the Mississippi River in Wisconsin, Minnesota, and Illinois, and elsewhere. The geological as well as the historical

6/ 7/ 8/ See "References" at close of comments.

evidence points toward the conclusion that in most parts of the country rates of sediment production have markedly increased. Hence, any moves in the direction of restoring, even partially, the protective cover on the land or the original conditions of channels should result in decreases in rates of sediment output.

Third, valuable quantitative evidence comes from comparison of present rates of sediment production from small watersheds that have different cover conditions within the same physiographic and soil provinces. For example, three municipal reservoirs in Texas have drainage areas of 5 to 14 square miles that are from 75 to 90 percent in forest or grass. Sediment production from these watersheds ranges from 0.3 to 1.6 and averages 0.9 acre-foot per square mile annually. Three other comparable reservoirs with watersheds 40 to 75 percent in cultivation show rates of 5.8 to 7.6 and average 6.6 acre-feet per square mile annually, or 7 times as great. Comparable comparisons can be made for many sections of the country.

Fourth, the effects of specific soil conservation measures have been determined quantitatively on experiment station plots and small watersheds.

The practice of cultivation approximately along the contours of sloping land instead of in straight rows running up and down the slopes has been tested in 28 experiments in 12 States, with a large range of crops and slopes during continuous periods of 1 to 11 years. 9/ These experiments have shown that contour cultivation reduced soil loss from sheet erosion by 37.6 to 100 percent, with an arithmetic average of 73.6 percent reduction from all of the experiments.

Strip cropping has been tested in 17 experiments in 7 States, with all major crops, slopes, and rotations, during periods ranging from 1 to 7 years. 10/ The reduction in soil loss from strip cropping over that experienced from continuous cultivation of a single crop ranges from 10.7 to 94.1 percent, having an arithmetic average of 59 percent for all experiments.

Terracing has been tested in 16 experiments in 7 States on all principal crops and slopes, during periods ranging from 4 months to 9 years. 11/ Reductions in soil loss in surface runoff ranged from 37 to 98.5 percent, with an arithmetic average of 85.5 percent.

Considering both these experimental data and the results of many field observations by hundreds of soil conservation technicians working throughout the United States, erosion specialists of the Coil Conservation Service have reached certain conclusions with regard to the average effects of some important differences in land use and in farming practices. Assuming that all natural factors, such as climate, soil, and slopes, are the same and that the erosion loss from continuous row crops, such as corn, cotton, and tobacco, represents 100 percent, then erosion losses from small grain (wheat, rye, oats, and barley) will range from 15 to 40 percent. Good hay land, pasture, and woodland will have comparative losses of less than 1 percent. Well-contoured row crops will have an average erosion loss of 50 percent of straight row cultivation. A good 3- or 4-year rotation will give losses of 14 to 45 percent by comparison with continuous one-crop cultivation. Strip cropping will reduce losses to about 25 to 45 percent. Farm ponds and stock ponds are effective measures for reducing sediment production as they normally trap most of the sediment produced above them.

In the Sangamon River watershed, Illinois, where sediment is coming predominantly from land slopes, as it is throughout most of eastern United States, the writer and collaborators have estimated that if farmers would adopt the recommended rotation, use contour farming, strip cropping, terracing, and other practices where needed in accordance with the capabilities of the land, the rate of sediment production from the area would be reduced to 38 percent of its present rate without reducing the level of net farm income. 12/

In the more arid areas, having less than 20 inches of rainfall and lying generally west of the 100th meridian, where vegetation has never continuously afforded a complete cover for the soil, greater reliance must be placed on engineering measures for sediment control.

Experimental data on the effects of conservation measures in areas of less than 20-inch rainfall are extremely meager. Such data as we do have seem to indicate that the protection of major reservoirs and related developments in such basins as the Colorado, Gila, Rio Grande, and Pecos will require rather extensive engineering works such as channel barriers, gully-control structures, and stream-bank stabilization to substantially reduce rates of sediment production. Existing channels in highly erodible alluvium appear to be the principal source of sediment. Vegetation alone has been found generally ineffective in stabilizing these channels. However, adequate grazing control and watershed management with supporting practices such as water

9/ 10/ 11/ 12/ See "References" at close of comments.

spreading is needed to prevent the further rapid growth of tributary arroyos and gullies.

The effectiveness of a barrier system of sediment control was experimentally tested by the Soil Conservation Service during a 9-year period, 1935-1943, on the 65,000-acre Navajo Experiment Station located 20 miles north of Gallup, N. Mex., in the San Juan River Basin. 13/ Detailed studies of 3 out of 14 arroyo-control dams and water-spreading projects, involving a drainage area of 9,470 acres, showed practically 100 percent reduction in sediment production. Approximately 500 acre-feet of sediment, equivalent to 3.75 acre-feet per square mile annually, was kept out of the San Juan River and hence Lake Mead. An undetermined loss of surface runoff resulted, however. The possible return flow from the water spreading was not measured.

Whether appreciable net water losses will be necessary to achieve significant sediment control remains to be determined by experimental and field studies. It does seem probable from present information, however, that something like one-half to three-quarters of the sediment loads at downstream reservoir sites on major Western streams are coming from areas that contribute only 5 to 15 percent of the total water supply.

In considering sediment control in these Western basins, it is well to keep two points in mind. First, channel barriers tend to trap initially a high proportion of the sediment coming into the arroyo from the land surface, and as the arroyo trenching is thus brought under control, they will in effect shut off one of the largest sources of sediment production. Second, it does not make much difference what caused the arroyo development if engineers and conservationists are capable of devising methods for bringing them under control.

It is unfortunate that we have as yet very little quantitative evidence of what soil conservation measures have done to control sedimentation on watershed areas. This is the result of two factors: First, not many watersheds have yet been covered with sufficient completeness by conservation measures to show a measurable effect; and second, funds have not been available to evaluate the probable effects on some of the smaller areas where such data might now be obtained. A few studies, however, are indicative. By reforestation and gully control on an 890-acre area of rolling and badly eroded land above the municipal reservoir at Newman, Ga., the rate of sedimentation was reduced 62 percent during the period 1937-1945, as compared with the earlier period 1925-1937. 14/ On the 62-square-mile watershed of the municipal reservoir at High Point, N. Car., soil conservation measures applied on about 35 percent of the total acreage caused a reduction of 24 percent of the rate of sedimentation for the period 1934-1938, as compared with the earlier period 1928-1934. 15/

In summary, it is concluded that in most agricultural watersheds east of the 100th meridian the rate of sediment production can be reduced at least 50 percent, and in many cases, from 75 to 90 percent by universal application of practicable soil conservation measures without reducing the regional level of agricultural production or net farm income. This degree of reduction, however, is contingent upon practically unanimous cooperation of landowners and operators in use of the land in accordance with its capabilities and treatment of the land in accordance with its needs. To accomplish such reduction will require continuous technical services of trained conservationists in planning, installing, and maintaining conservation practices. Furthermore, the conservation measures must include any needed stream-channel stabilization, road-bank stabilization, water disposal systems, and related control measures. Some of these works will require public financing, in whole or in part.

West of the 100th meridian conditions are so varied and our existing data are so meager that it is hazardous to make any generalization. In some critical areas which have been studied, such as the Rio Puerco, it appears possible and practicable to reduce sediment production 75 percent or more by a combination of structural measures to stabilize arroyos, and by grazing control, reseeding where feasible, water spreading, and related measures on the land slopes. The effects of management and control of watershed lands largely in native cover are discussed in more detail by Mr. Reed Bailey in a later paper.

References

1/ Brown, Carl B. The Control of Reservoir Silting. U. S. Dept of Agriculture, Misc. Publ. 521, 1944, p. 115.

2/ Unpublished data in files of Soil Conservation Service.

13/ 14/ 15/ See "References" at close of comments.

3/ Brown, Carl B., Stall, J. B., and DeTurk, E. E. The Causes and Effects of Sedimentation in Lake Decatur. Illinois State Water Survey Division Bulletin 37, 1947, p. 6.

4/ Idem Ref. 1, p. 116 (See p. 4).

5/ Idem Ref. 1, p. 116 (See p. 4).

6/ Byrd, William. The Westover Manuscripts Containing the History of the Dividing Line betwixt Virginia and North Carolina, 1st ed., Petersburg, Va., Edmund and Julian C. Ruffin, 1841.

7/ Lyell, Sir Charles. A Second Visit to the United States of America, Vol. 1, New York, 1849, p. 256.

8/ Thornthwaite, C. W., Sharpe, C. F. S., and Dosch, E. F. Climate and Accelerated Erosion in the Arid and Semi-Arid Southwest, with Special Reference to the Polacca Wash Drainage Basin, Arizona, U. S. Dept. of Agriculture, Technical Bulletin No. 808, May 1942, pp. 102-104.

9/ Stallings, J. H. Review of Data on Contour Furrowing, Pasture and Range Land. U. S. Soil Conservation Service. 10 pp., processed, Washington, D. C., December 1945.

10/Stallings, J. H. Summarization of Strip Cropping Data on Crop Yield, Runoff and Soil Loss. U. S. Soil Conservation Service. 9 pp., processed, Washington, D. C., December 1945.

11/Stallings, J. H. Review of Terracing Data on Crop Yield, Runoff and Soil Loss. U. S. Soil Conservation Service. 8 pp., processed, Washington, D. C., December 1945.

12/Idem Ref. 3 (See p. 5).

13/Hubbell, D. S., and Gardner, J. L. Effects of Diverting Sediment-Laden Runoff Water to Crops and Range Lands. U. S. Soil Conservation Service, April 1945 (unpublished).

14/Brown, Carl B. Protecting Municipal Watersheds in Southeastern States. Public Works, Vol. 76, No. 5, May 1945, pp. 30-34.

15/Idem. Ref. 1, p. 150 (See p. 4).

DISCUSSION

H. V. PETERSON.* The theme of practically all papers presented thus far at the conference has been the evils of sedimentation, how to recognize them, how to measure and how to combat them. Mr. Brown's paper is particularly commendable in that he has transposed the attack to the source of the evil by showing us methods whereby erosion can be alleviated and the silt held in place where it forms a natural and productive part of the landscape as contrasted to the current condition of allowing it to enter our valleys and streams where it forms what amounts to a national menace. Most of the examples of improvement he describes are located in the humid and subhumid eastern parts of the country. This discussion will be limited on the effects of somewhat similar erosion control measures applied to the arid and semi-arid West.

An appraisal of the results of erosion control measures applied to the Eastern lands considered and analyzed by Mr. Brown certainly permits an optimistic viewpoint for further substantial improvement along these lines. The writer's experience in analyzing the results obtained on Western lands does not permit sharing that optimism to the extent indicated by the author. This does not imply that the situation is considered hopeless; it stems from an attempt to be realistic in appraising the meagre progress made thus far, in recognizing the mistakes committed in our attack to date, and in appreciating the tremendous task remaining and the innumerable problems yet to be solved before any substantial improvement can be hoped for.

The West's critical erosion problems were recognized early, and during the life of the C.C.C. camps - 1934-42 - thousands of acres were treated by various methods in an effort to prevent or alleviate further land destruction and siltation of the major streams. Although in area the

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treated plots are insignificant compared to the total area where erosion is either critical or approaching that condition, it nonetheless presents an opportunity for an appraisal of what can or might be expected from such practices. As advisors on certain matters pertaining to the soil and moisture conservation program to Department of Interior agencies administering the public domain, our office of the Geological Survey is undertaking that appraisal. Findings to date are responsible for failure to share Mr. Brown's optimism concerning progress along these lines. Later in the discussion there are presented details of findings in two selected treated plots in the Safford and Duncan Valleys, Gila River Basin, Arizona. But before describing these it will be well to point out a few relevant features related to the West's erosion problem.

First, something of the land in question. The great bulk of Western lands still remains in the public domain and in several States such lands comprise from 70-90 percent of the total area. Choice timber and wooded tracts have long since been taken into the forest reserves. More recently large areas have been incorporated into grazing districts. Other areas have been set aside as Indian reservations, or national parks or monuments but a considerable portion still remains free of any designated status and parts have not yet been surveyed. Interspersed with these public lands are private holdings which may amount to but a few 40's per township or, as in the case of railroad grants, comprise every alternate section. These lands are neither forested or capable of growing crops of any kind without irrigation, and lack of water precludes any but very minor future irrigation development. The vegetative cover is scant and in many localities, one might add, growing scantier. The chief and practically the only value is grazing, which is small on an acre-unit basis but significant when the total area is considered.

Typically arid or semi-arid in character the average annual precipitation over this vast domain varies from 6 to 12 or possibly 15 inches in some favorable localities. But averages mean little because the general pattern of precipitation distribution produces periods of drought lasting up to 5 years or more in which the rainfall may be but a small fraction of the average, followed by periods of 1 or 2 years when the precipitation may be 2-3 times normal. In brief we here have a tremendous area of low unit value land, most of it being grazed to or beyond the limit of its forage production, protected only by a scant vegetal growth, subject to periodic droughts alternating with intense flood producing storms; all of it extremely vulnerable to erosion. Here is the seat of the silt problem in the West; hold the soil on these lands and the problem disappears, fail to hold it and forecasts of the most confirmed pessimist will prove understatements.

Erosion on these lands finds its most prominent expression in the spectacular longitudinal gullies that have cut into the soft unstable alluvial-filled bottom lands of valley after valley. To those familiar with erosion in the West one need mention only a few of the more prominent gullied valleys to convey a picture of these ugly destructive scars: the San Pedro and the San Simon on tthe Gila; the Jemez, Salado and Rio Puerco on the Rio Grande; the Chaco, Chinle, and Mancos on the San Juan; the Little Colorado, the Paria, the Dirty Devil and a host of others of equal or greater magnitude on the Colorado and the Green. These and others with their innumerable tributaries and associates have fed literally millions of acre-feet of silt into our major streams and additional millions are poised and ready to follow as fast as wind and water become available to transport it.

Now, just how much have we done in the way of stopping or slowing up this action? How effective have our works to date been limited and feeble as they are in comparison with the vast extent of this eroding area? An answer to this last question should at least furnish us some clue as to whether we are on the right track to a practical and permanent solution of the silt problem.

As Mr. Brown has pointed out, there are three general methods of treating for erosion. Because these lands are non-agricultural we are limited to two of them, that is, vegetative management and engineering structures. Vegetative management means, in effect, regulation of grazing or stocking the area consistent with forage production. This subject with its political, social and economic implications is too complex to be covered in a short discussion of this type. Progress along these lines is something like the author's definition of sin, it depends on the circumstances. Some stockmen will tell you the reduction in herds is already too great, but conservationists in general, I believe, are generally agreed that further reduction and in some cases even elimination of grazing is needed in many localities.

Engineering treatment of land can take almost an infinite variety of forms ranging from large dams which trap silt and regulate flood flows to minor structures whose function is to prevent excessive movement of water and silt from the place of origin. If we consider a gullied valley with its system of tributaries there are two methods of approach for effecting a cure. The first to allow water with its silt load to reach the main stem, there by means of a dam or

other structures, trap the silt and discharge the water at some safe rate. Here we are utilizing the silt from the upland areas of the basin to fill in and replace silt which has already been removed. This requires one or at most a few major structures. The second approach seeks to hold the soil on the upland area by increasing infiltration, thus reducing the surface runoff to amounts which will pass out of the basin without damage. This type of treatment requires numerous structures of minor dimensions spread over large areas. In the main, engineering treatment utilized in the C.C.C. program was designed with this approach in mind. Only in a very few instances was an attempt made to dam any of the major gullies or their important tributaries.

The structures utilized in the program were of almost infinite variety: spreaders of many different types, check dams, contour division and training dikes, furrows and terraces, small to moderately large silt detention reservoirs and numerous modifications and adaptations of these types. Many installations obviously had some special purpose in mind, such as protection of a town or valuable farm land from floods, or preventing further gullying of rich range lands, but it may be assumed that the basic aim in each case was a restoration of a grass or other vegetal cover which would be dense enough to hold the soil in place and which would increase infiltration to the point where surface flow would be discharged at safe and non-eroding rates. In observing both casually and in detail many hundreds of these structures our examinations show a preponderant lack of the hoped for improvement and in some cases actual deterioration of the treated areas traceable to the structures. In short, failures far outnumber successes. That does not mean there have been no successes; there have been a few notable ones and one of our problems is to discriminate between the reasons for the failures and the successes.

In general the causes of failure are obvious, in some cases not so readily discernible. Chief causes may be listed as follows: (1) Physical destruction of the structures due to improper design, poor construction methods, unsuitable construction materials, and unstable foundation; (2) lack of maintenance; in general no efforts have been made to maintain the structures and many failures are directly attributable to this neglect; (3) weather; a favorable distribution of rainfall is most essential in effecting restoration of vegetation; (4) structures not adapted to the terrain or to the soils; (4) lack of grazing regulation which allows stock to crop palatable new growth before plants have the opportunity to become established; (6) failure to appreciate the hydraulic features of the problem.

It can be argued that correction of conditions leading to these failures is simple, but actually it may be very complex. As an example, consider the problem of maintenance: How long are we justified in repairing structures in areas that fail to show appreciable improvement where the reason for such failures may be entirely beyond our control such as in the case of unfavorable weather? Shall it be 5 years, 10 years, or indefinitely? It should be emphasized that with all these structures, until vegetative recovery is effective we are merely buying storage for water and silt at an absurdly high figure. Equally complex considerations are associated with the other causes of failure, each demanding further study before the proper answers can be obtained.

The present condition of two rather elaborately treated tracts in the Gila River Basin of Arizona is outlined below. These tracts perhaps are not typical of the Western area as a whole because it must be conceded that erosion is more critical and more difficult to control in the Gila River Basin than in most other localities. They are typical of conditions within the Basin, however, and numerous other tracts show results equally discouraging. Detailed appraisals of treated areas in other parts of the West have not yet been completed but preliminary observations indicate that the findings will be little if any more promising of success.

Details Showing Results of Erosion Control Measures
On Two Selected Tracts in the Safford and Duncan Valleys
Gila River Basin, Arizona

Indian Gardens

Location: Safford Valley, north of Gila River, northeast of the town of Eden, portions of secs. 24, 25, 26, 27 and 34, T. 5 S., R. 24 E. Structures installed 1934-35 with some major repairs in 1939.

Altitude, 2,850-3,200 feet; average annual precipitation, approximately 12 inches; average landslope, 1 - 2%; area of tract treated, 480 acres.

Soils: Relatively shallow - 12-16" - sandy silt underlain by a thick deposit of coarse, partially cemented gravel.

Nature of Erosion: Mainly sheet erosion. No deep gullies and only a few well defined rills.

Presumed Purpose of Treatment: To prevent further erosion of surface soil, to induce siltation on surface, and to stimulate vegetative recovery and to reduce surface runoff by increasing infiltration through water spreading.

Type of Treatment: Small earthfill dams placed across the main drainage channels connecting at one or both ends with rock spreaders extending outward on contour. Spreaders spaced at intervals varying from 250 - 500 feet. They are of 2 types: (1) loose rock which consists of a windrow of cobbles and pebbles piled loosely with little effort to key the rock in place; height of windrow approximately 8", width 18"; (2) hand placed rock - cobbles are set in previously prepared trench 8" deep and about 4' wide; rock extends about 8" above ground surface on upstream side and slopes to ground surface on downstream edge of spreader. Cobbles are keyed but no matrix was used.

Performance and Present Condition of Structures:

Earthfill Diversion Dams--Number constructed, 29; average length, 52'; total volume of earth in structure, 2,250 cu. yds.; total volume of silt caught behind dams, 461 cu. yds. One of the group is breached, all others are in fair state of repair.

Hand-placed Rock Spreaders - Number constructed, 8; average length, 210'; total volume of rock in structures, 211 cu. yds.; total volume of silt trapped behind structures, 12 cu. yds. One of the group is breached in a number of places so its effectiveness is gone, others are in fair state of repair.

Loose Rock Spreaders - Number constructed, 43; average length, 360'; total volume of rock in structures, 435 cu. yds; total volume of silt caught behind structures, 296 cu. yds., a large part of which is in position to be removed under intense rains. In the group, 17 of the structures have completely failed, 14 have partially failed, and 12 are in fair state of repair.

Vegetative Recovery: In general unnoticeable. Some new growth mainly unpalatable weeds, has started in borrow pits behind diversion dams; silt wedges behind spreaders are practically barren. Grazing has been regulated but not excluded in this area.

Black Field Wash

Location: Duncan Valley, south of Gila River and just south of town of Duncan; sections of secs. 30-31, T. 8 S., R. 32 E.; Sec. 36, T. 8 S., R. 31 E.; secs. 1 & 2, T. 9 S., R. 31 E. Structures installed 1933-35.

Altitude, 3,800-4,000 feet; average annual precipitation, 11". Slope of wash floor varies from 0.80% to 1.40%. Area of tract treated, 2 square miles.

Soil: Deep - 12-15' - sandy silt overlying impervious lake beds of clay and sandy shale.

Nature of Erosion: Deep discontinuous gullies cut in the soft silty alluvial fill of a gently sloping wash tributary to Gila River. Ungullied portions of the wash are covered with dense growth of sacaton grass. Headcutting is active in both the main gully and in numerous tributaries. Gullies vary from 2-15' in depth and from 10-50' in width.

Presumed Purpose of Treatment: Flood protection for town of Duncan and restoration of range by water spreading.

Type of treatment: Numerous diversion dikes connecting with spreaders of various types have been constructed across gullies in an effort to cause siltation in main channel and spread water across uneroded portions of the wash floor. Dikes and spreaders are spaced at intervals varying from 200 to 600 feet along the wash and tributaries.

Present Condition and Performance of Structures:

Earthfill Diversion Dams - Number constructed, 24; average length, 135'. Total volume of earth in structures, 5,100 cu. yds.; volume of silt retained behind dams, 2,550 cu. yds. with loss of silt due to failure of structures estimated at 1,400 cu. yds. Seven of the dams are breached; 3 are intact and functioning as intended; the remainder are standing but because of spreader failure, new gullies are cutting around the ends.

Hand-placed Rock Spreaders - Number of structures, 18; average length, 143'; total volume of rock in structures, 1,200 cu. yds.; volume of silt caught behind spreaders, 1,200 cu. yds. Six have completely failed; 9 have partially failed and effectiveness is gone; 3 are intact.

Loose Rock Spreaders - Number, 9; average length, 310'; total volume of rock in structures, 425 cu. yds.; volume of silt caught behind spreaders, 665 cu. yds. Two have completely failed; 6 have partially failed and effectiveness is gone; 1 is intact.

Cemented Rock Rubble Spreaders - Number, 7; average length, 125'; total volume of rubble in spreaders, 910 cu. yds.; total volume of silt caught behind spreaders, 6 cu. yds. Six have failed completely; 1 partially failed.

Brush and Rock Spreaders - Number, 20; average length, 175 feet; total volume of rock and brush in spreaders, 2,490 cu. yds.; total volume of silt trapped, 490 cu. yds. Four are intact; the remainder have either completely or partially failed so all effectiveness is gone.

Vegetative Recovery: Practically unnoticeable, a few unpalatable weeds and batamote willows are growing in some of the borrow pits behind dams, but there is no evidence of vegetative recovery above or below spreaders. Grazing has been regulated but not excluded.

In analyzing these results it is obvious that the approach to the problem of erosion control in these localities is faulty when after 10 years or more of operation of the structures all we have to show is an unfavorable trade balance between yardage in construction and yardage of silt retained. Needed revisions and corrections in this approach remain to be determined by further research and study and the point of this discussion can well be concluded by emphasizing the urgent need for such research if the erosion problem of the west is to be solved.

EVAN L. FLORY.* I came here prepared just to discuss Mr. Brown's paper, but I think I will have to discuss two. I share Mr. Brown's optimism. I think we can do something about controlling erosion in the West. In fact, we are doing something about it. When we first began an active program of erosion control very little constructive thinking had yet been done. We had an extensive CCC program dumped in our laps where thousands of men had to be put to work at once. Techniques hadn't been developed up to that time and the few technicians that we had didn't have the experience and background of research or experience to direct their activities in the field. Many of the failures referred to by Mr. Peterson happened to structures installed in the days when C.C.C. foremen and the camp superintendent were told to put those men to work; they had little or no preliminary data as to edaphic or climatic conditions on the area. As soon as it was possible for technicians to get around to inspect the work which was being done, which was sometimes a year or two later, it was recognized right then that many would fail. There has been tremendous progress made in fitting structures to conditions and making a more careful analysis of the conditions that we meet. Most of you remember that check dams were practically synonymous with erosion control in 1933 and 34. Thousands of them were put in. One can drive up numerous watersheds where check dams were constructed, heel to toe, hundreds of them, and practically every one of them a failure. But the fact that they and similar structures due to "make work"

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pressure failed doesn't mean that a program of erosion and sedimentation in the semi-arid West is a failure. Mr. Brown has covered erosion control measures on land in the Mid-West and East very effectively, and I will confine my remarks to an elaboration of the application of some practices which we have adopted in the semi-arid conditions of the West, particularly the Navajo reservation.

Exact measurements made in many regions of varying climate, soil and vegetative factors show without exception a direct and controlling relation between density of vegetation and degree of erosion and runoff. Waterspreading, revegetation and proper range use are necessary to secure a more adequate protective cover on our watersheds. We have only begun to properly utilize our ranges but we must get at the job a little more seriously if the ranges themselves are to be saved and if we are to stop sedimentation and irrepairable loss of our limited reservoir sites. Extensive grazing areas on the Colorado Basin produce silt which destroys more downstream investment and production each year than the livestock produced on the areas equal. Some areas are worth more for watershed purposes than for grazing. Furtunately, however, silt production from surface erosion can be materially decreased without penalizing a long time livestock program. Findings of State and Federal Experimental Ranges and Soil Conservation Experiment Stations confirm this fact.

In 1935 the Steamboat Demonstration Area of 25,000 acres selected because it was one of the worst depleted and eroded areas on the Navajo was fenced, water diverted and spread, grass seed planted, stock water developed and livestock reduced from 2,468 sheep units to 936, which was increased as vegetation improved to 1,315 in 1942. Since 1935 range recovery has been very satisfactory. Floods of silt laden water no longer leave the area. Water that does run off flows for many days and is relatively clear. The average lamb crop has increased from 58 to 90 percent. Average weight of lambs from 55 pounds to 61 and average wool clip from 4 to 8.6 pounds. Decreased production of total livestock products following reduction of numbers had recovered in eight years, but on a uniform price basis for the period production per sheep unit increased from $3.60 to $6.24 and total receipts increased because products of the now full fed animals have consistently graded higher than of the former partially starved ones.

Prior to the settlement of the semi-arid West flood plains, swales and valleys because of more favorable moisture and soil conditions supported relatively heavy stands of grass through which runoff water slowly flowed. Silt removed from the steeper and more sparsely covered hillsides was deposited as the rate of water flow diminished. Broad, extensive, well watered flood plain areas were built up in this manner. The same valleys provided natural avenues of travel for the white man and concentration points for livestock. Their wagon and livestock trails became a ready made system for the unrestricted escape of increasing runoff waters from overgrazed ranges. The trails rapidly became entrenched arroyos, and waters which formerly nourished heavy grass stands on the floodplains rapidly drained off. Vast barren flats now exist where overgrazed weakened grass stands were finally finished off by being deprived of flood waters and even local precipitation by the intricate and extensive gully system which quickly drains them before water can percolate into the soil.

The extreme degree to which erosion has advanced in large portions of the Colorado Basin is illustrated by the 24,132 square miles of the Navajo Indian reservation in northern Arizona and New Mexico where there is hardly a natural waterway that is not cut by one or more gullies. Fingers have advanced from the larger channels up tributaries often all the way to the top of drainages. Slopes are marked in many areas by parallel trenches extending from crests to valley bottoms.

Generally, channels extend through formerly productive alluvial valleys over which water normally spread. Concentration of runoff water in these gully systems gives rise to the typical Navajo flood: a sudden torrential discharge of water heavily laden with silt which is lost to any beneficial use. 75 to 80 percent of the silt moved by a typical Southwestern gullied stream originates from cutting and eroding banks. Water samples taken from a few of the main streams were found to contain the following volume percent of silt: Chinle 47.1 percent, Oraibi 44.1 percent, Puerco 14.9 percent, Laguna 9.2 percent, Dinnebito 7.0 percent and Polacea 6.9 percent. The Navajo reservation constituting 14 percent of the total Colorado Basin Area contributes 22 percent of the silt but only 2.5 percent of the water to Lake Mead.

Lake Mead would now be completely filled with silt if all the inflow had been of this character. It would appear therefore that whatever water might be retained near its source of origin by soil conservation measures in these high silt producing areas would be a small price to pay for prolonging the life of downstream developments.

Proper land use increases percolation of water into the soil and retards the amount and rapidity of surface runoff. To the extent that these conditions are effective, flood crests and silt removal are reduced, but in the semi-arid portions of the country and in badlands sufficient vegetative cover cannot be established or maintained to prevent high flood crests. Engineering structures designed for the particular conditions of individual small watersheds are then necessary to supplement vegetative cover.

The use of detention, retention and diversion dams and spreaders singly or in combination depending on the topography, soil and vegetative conditions on the drainage basin have proven quite effective.

On small watersheds great damages in many cases are the result of flood crests lasting only a few minutes. All measures to reduce crests, prolong runoff and retard water will reduce cutting power and carrying capacity for silt. Great numbers of small and major arroyos on the Navajo are no longer characterized by perpendicular banks and side cutting but banks are rapidly assuming an angle of repose and becoming vegetated because crests have been reduced, runoff water flow prolonged and retarded sufficiently so that caved in banks are no longer carried away and the gullies sluiced out and deepened by each runoff.

Multiple Purpose Detention - Retention Dams. Since 1883 periodic heavy expenditures have been made at Fort Defiance, Arizona, to protect the town from flood waters of Bonita Creek. In 1941 steps were taken to hold flood waters near their source and release them slowly. The steepness of the terrain, character of the soils and torrential nature of precipitation rendered proper land use measures relatively ineffective. Five multiple purpose detention-retention dams were constructed for 28,000 acres of the drainage basin.

The prolonged flow of controlled runoff, plus percolation into banks and valley floors with resulting seeps and springs has already transformed this vertical banked dry arroyo subject to infrequent torrential silt laden discharges into a clear perennial stream with sloping, grassy banks.

One typical side arroyo and the control dam illustrates how all five dams have functioned. Uncontrolled this arroyo, with a basin of 6,600 acres, has a normal yearly expectancy of 520 cubic feet per second flood crest and an estimated maximum flood crest of 2,610 cubic feet per second. Flood crests usually last less than an hour and the maximum proportion of the total flood flow is usually past in two or three hours. Water in small tributary washes is diverted and spread as much as practical but the roughness of the terrain and V-shaped valleys permits very little such work, hence the one dam provides most of the control. The reservoir will hold 175 acre-feet before flowing over the emergency spillway, 96 acre-feet of which will drain out over a period of three days with a maximum discharge of 19 cubic feet per second. Seventy-two additional acre-feet can be released at will as needed for use below or for additional flood protection. This dam affords smoothing of flood crests of 700 c.f.s. wodn to 19 c. f. s. The remaining capacity is for permanent storage for livestock water, fish and wildlife, and protection of the dam against drying, checking and shrinking.

Such developments can continue to be effective only to the extent they remain free from siltation. Located near the top of drainages on small watersheds under proper land use combined with other practices to restrain water flow and prevent formation of flood crests only finer soil particles will be carried in suspension and most of these will not settle out before running through the restricted outlet.

Diversion Dams and Spreading Areas. Wherever entrenched flood plains occur, diversion dikes that lift the water out of the arroyos plus supplemental dikes to spread it over the flood plain have proven very effective. The arroyos above the dams often silt full in one season but this does not reduce their effectiveness. The former grass cover can be re-established and portions of the area used for farming by using the diverted water for flood irrigation.

The Jeddito Wash in Arizona has such a history. It flowed about 25 miles from point of origin and then spread over a broad grassy flood plain for 15 miles, but the plain is now entrenched as much as 40 feet by an arroyo.

Three diversions were constructed on the Jeddito Wash in 1942. Heavy flows in September 1944 spread over 6,000 acres. This wash has been largely responsible for former flood damage at Leupp, Ariz. Over $40,000 was spent one year for flood protection at Leupp. The three diversions costing less than $10,000 have stopped the flood menace and are restoring grass to the denuded floodplain.

Proper land use is of primary importance in erosion and sedimentation control, but flood crests in small watersheds, gullying, entrenchment and sidecutting must also be materially checked before effective reduction can be secured.

DESIGN AND OPERATION OF DEBRIS BASINS

BY B. H. Dodge *

Introduction

Terrain.-- The metropolitan area surrounding the city of Los Angeles lies on a coastal plain between the Pacific Ocean and the base of the San Gabriel Mountains. From the ocean, the coastal plain rises more or less uniformly, interrupted only by a low range of hills near the center of the area, over a distance of 25 to 30 miles to an average elevation of about 2,000 feet at the base of the San Gabriel Mountains. The mountains rise abruptly to an average crest elevation of about 7,000 feet in a space of 1 to 3 miles. The face of the mountains is rugged and characterized by precipitous canyons. Topography of the entire area is indicated in Figure 1.

Hydrology.--Most precipitation in the area falls from December to March, inclusive. The major part of the precipitation results from general winter storms which originate in the North Pacific, move south over the ocean, and thence inland. Major storms of this type consist of one or more cyclonic disturbances and occasionally last 4 days or more. Rainfall intensity and depth are usually markedly increased as the moisture-laden air masses are deflected upward by the mountains. For example, the mean seasonal rainfall varies from 15 inches at Los Angeles on the coastal plain to more than 40 inches at the crest of the mountains. Thunderstorms sometimes occur in association with general storms or independently, and may result in intense short-period precipitation over small areas. Summer storms occur occasionally in the mountains but rarely on the coastal plain.

Sources of debris.--The mountains are composed of shattered and deeply weathered rock overlain by a thin mantle of coarse, porous, and rocky soils. Slides are common in the steep canyons during periods of prolonged heavy rain. Floodwaters rushing down the steep drainage paths in the mountains develop great erosive and debris-transporting capacity. As the debris-laden flows leave the canyon mouths, velocities are reduced and debris is deposited. Accumulations of material below canyon mouths have formed many distinct alluvial fans. In areas where canyons are adjacent, these deposits have merged to form large alluvial slopes. These slopes vary from about 2 to 10 percent. Natural flow paths on the slopes consist of numerous shallow, poorly defined, and distributive washes. During floods, the flow paths frequently change course as a result of debris deposition.

Fires are an important factor in debris production. The plant cover on the mountain slopes consists mostly of brush, which, during the dry summer months, becomes extremely susceptible to fires. When fires occur, large areas are frequently entirely denuded. The intensity of run-off and the quantity of debris eroded from burned over areas are many times greater than normal. In general, debris production diminishes only gradually over a period of years as a new plant cover becomes established.

Types of debris.--The debris brought down from the mountain areas consists of about 50 percent silt, sand, and rocks up to 3-inch diameter, and about 50 percent rocks and boulders from 3 inches to about 3 feet in diameter. Boulders considerably larger are common but constitute a small percentage of the whole. Figure 2 shows the mechanical composition of stream-bed material at the mouth of San Antonio Creek, a typical debris-producing area discussed in a subsequent section.

Development and economic features of control.--As a corollary to the growth of Los Angeles, many people were attracted to the debris slope areas. The land was relatively inexpensive, high, normally dry, and fog free; the climate is beneficial to those suffering from respiratory diseases. In the intervals between major floods, homes were built and suburban business districts established with little regard for the age-old rights-of-way of floods.

* Los Angeles District, Corps of Engineers, Department of the Army, Washington, D. C.

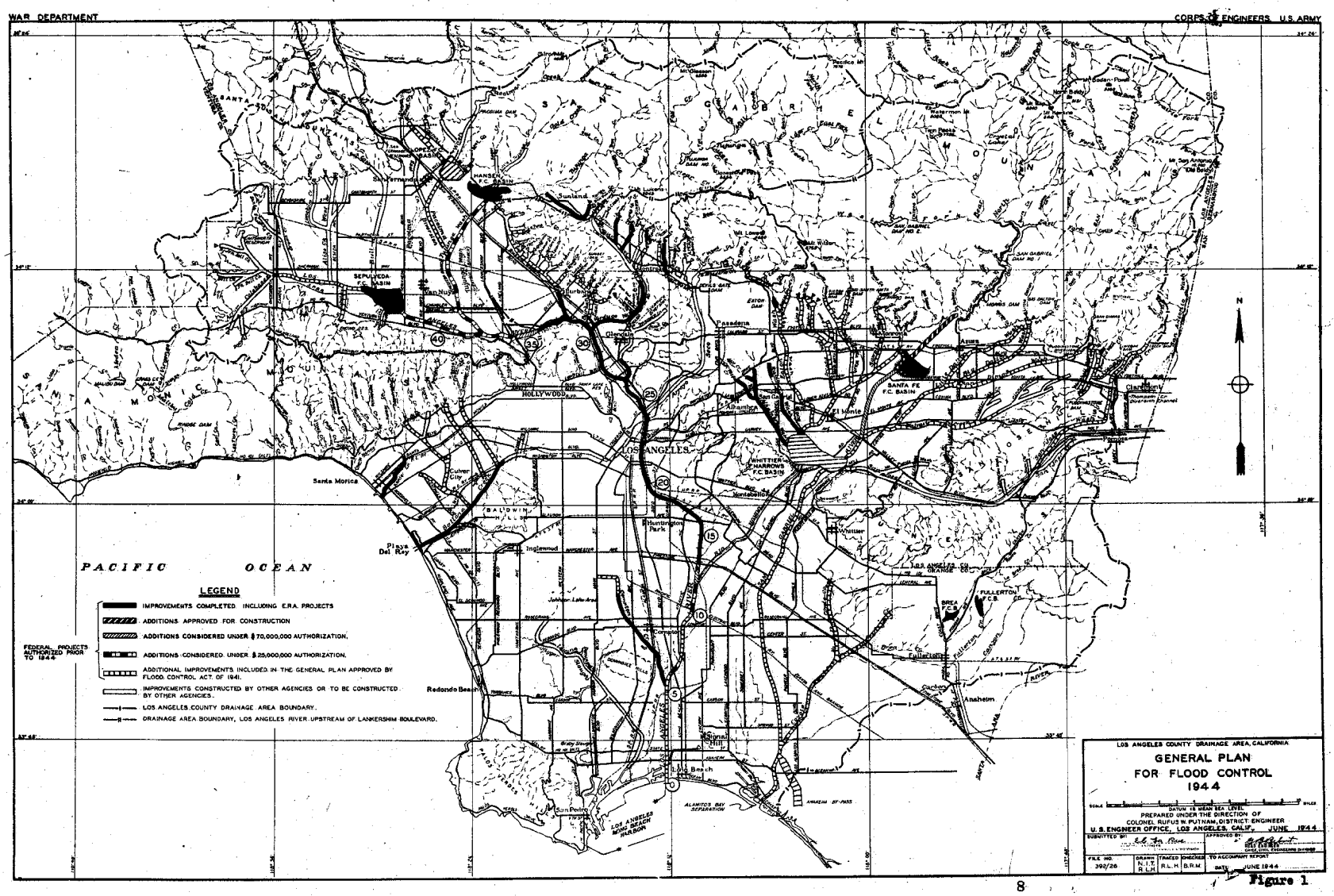
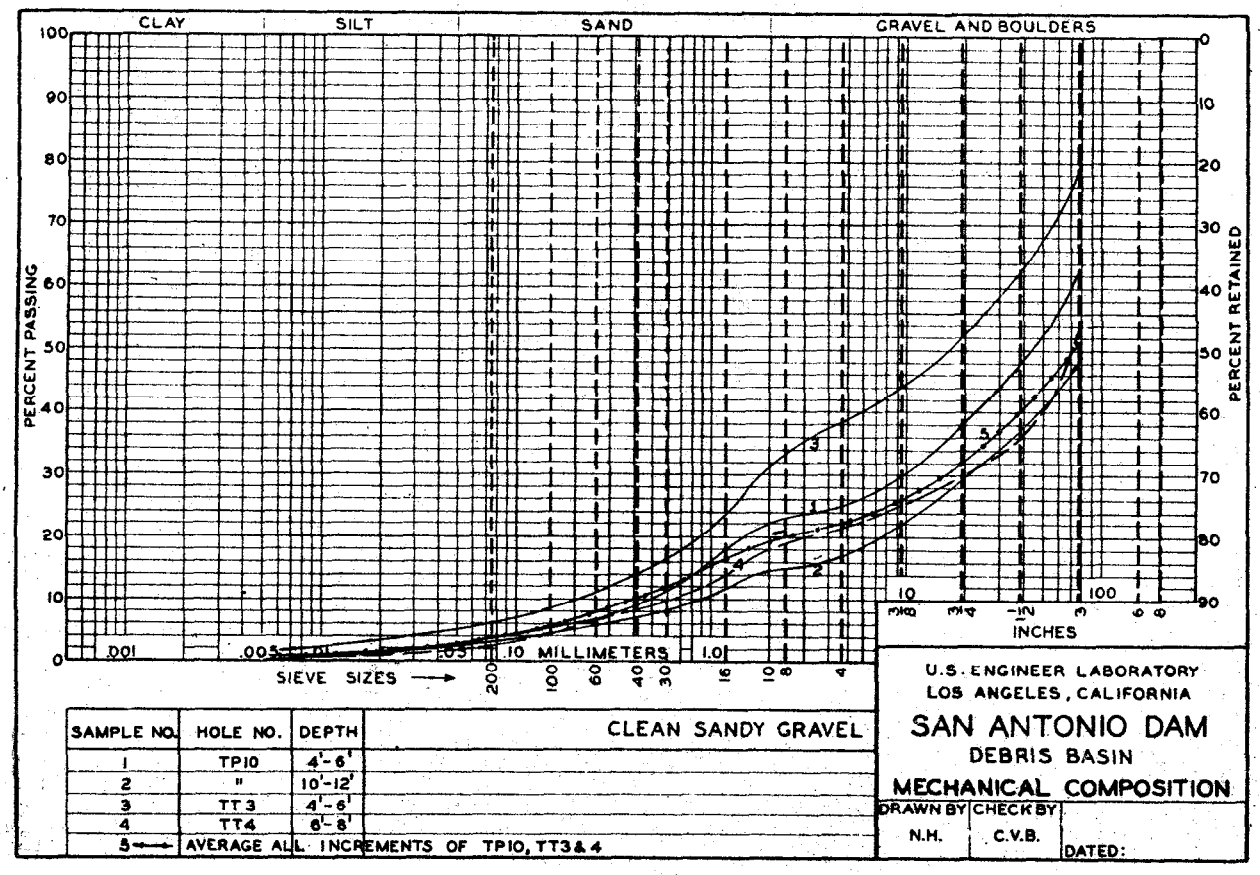

WAR DEPARTMENT
CORPS OF ENGINEERS U.S. ARMY
PACIFIC OCEAN
LEGEND
IMPROVEMENTS COMPLETED INCLUDING E.R.A. PROJECTS
ADDITIONS APPROVED FOR CONSTRUCTION
ADDITIONS CONSIDERED UNDER $70,000,000 AUTHORIZATION.
FEDERAL PROJECTS AUTHORIZED PRIOR TO 1944
ADDITIONS CONSIDERED UNDER $25,000,000 AUTHORIZATION.
ADDITIONAL IMPROVEMENTS INCLUDED IN THE GENERAL PLAN APPROVED BY FLOOD CONTROL ACT OF 1941.
IMPROVEMENTS CONSTRUCTED BY OTHER AGENCIES OR TO BE CONSTRUCTED BY OTHER AGENCIES.
LOS ANGELES COUNTY DRAINAGE AREA BOUNDARY.
DRAINAGE AREA BOUNDARY, LOS ANGELES RIVER UPSTREAM OF LANKERSHIM BOULEVARD.
LOS ANGELES COUNTY DRAINAGE AREA, CALIFORNIA
GENERAL PLAN
FOR FLOOD CONTROL
1944
PREPARED UNDER THE DIRECTION OF
COLONEL RUFUS W. PUTNAM, DISTRICT ENGINEER
U.S. ENGINEER OFFICE, LOS ANGELES, CALIF. JUNE 1944
SEPULVEDA F.C. BASIN
HANSEN F.C. BASIN
SANTA FE F.C. BASIN
WHITTIER NARROWS F.C. BASIN
LOS ANGELES
HOLLYWOOD
Santa Monica
Pico Del Rey
Redondo Beach
Long Beach
Anaheim
Pasadena
Glendale
Burbank
Sunland
Pomona
Claremont
Whittier
Fullerton
Inglewood
Huntington Park
Compton
Signal Hill
San Pedro
BALDWIN HILLS
SANTA MONICA MOUNTAINS
SAN GABRIEL MOUNTAIN
ALAMITOS BAY SEPARATION
LOS ANGELES RIVER BEACH HARBOR
ANAHEIM BY-PASS
FILE NO. 392/26
DRAWN R.L.H.
TRACED R.L.H.
CHECKED B.R.M.
TO ACCOMPANY REPORT
DATE JUNE 1944

Figure 1



The suburban communities of La Crescenta and Montrose, located about 10 miles directly north of the center of Los Angeles typify such development. By 1933, the development had reached a high state (see photograph 1). Small floods and incidental debris had at various times caused minor damage. Corrective measures such as rock-and-wire check dams in some canyons (see photographs 2, and 3), and some minor channel improvements on the cones had been constructed at some places. In the fall of 1933, 4,830 acres on the mountain face directly above the community were practically denuded by fire. Beginning on 30 December 1933, a general storm of moderate intensity reached the area and produced continuous rain over a period of about 48 hours. At Flintridge gage, just east of La Crescenta, rainfall was recorded as follows: total storm, 14.63 inches; maximum 24 hour, 13.19 inches; maximum 1 hour, 1.33 inches; and maximum 10 minute, 0.34 inches. Approximately at midnight on 31 December an intense local burst of rainfall apparently occurred over the La Crescenta area. Floodwater, described as 8- to 10-foot walls of water, rushed from the canyons, passed through the community, and subsided in less than 15 minutes. Estimates of peak run-off rates vary considerably, the highest being from 2,500 to 3,000 cubic feet per second per square mile of drainage area. It was estimated that 660,000 cubic yards of debris were brought down from an area of about 7.5 square miles during the storm. Forty-two lives were lost and 500 homes were destroyed or damaged. Total property damage was estimated at $5,000,000. This flood clearly indicated that only major engineering construction would provide adequate and immediate protection under such conditions. Photographs 4 to 7, inclusive, show general views of the area, damaged houses, and debris deposits.

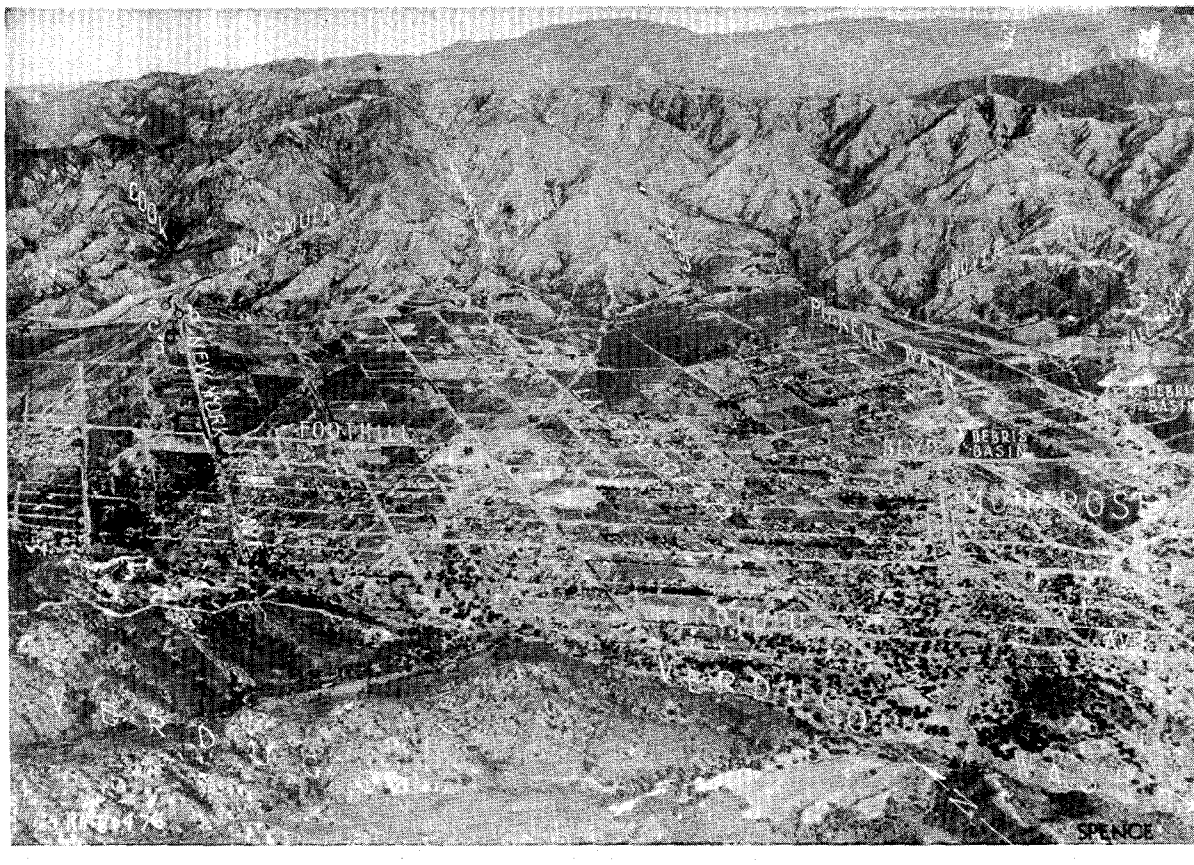
The situation in the La Crescenta area is illustrative of that which exists in various degrees all along the face of the San Gabriel Mountains and related lesser ranges. Development in these areas has progressed at a pace comparable to the rapid development of the adjacent parts of the metropolitan area. The formulation and publicizing of a comprehensive plan for flood control by the Los Angeles County Flood Control District and the Los Angeles District, Corps of Engineers, and control of subdivisions by planning commissions are effective means of diverting development to less vulnerable areas. However, the pressure of development is great and vulnerable locations continue to be developed. This, coupled with prior development, presents a situation where great loss of life and property damage is possible and economically justifies the construction of costly flood-control works. The Los Angeles County Flood Control District has constructed 22 debris basins and plans to construct at least that many more. The

Corps of Engineers, first under E.R.A. funds and later under various flood control acts passed by Congress from 1936 on, has constructed 6 debris basins at a cost, including downstream channels, of $3,330,000. The comprehensive plan for Los Angeles County drainage area approved by Congress in 1941 includes 27 additional basins.

Design

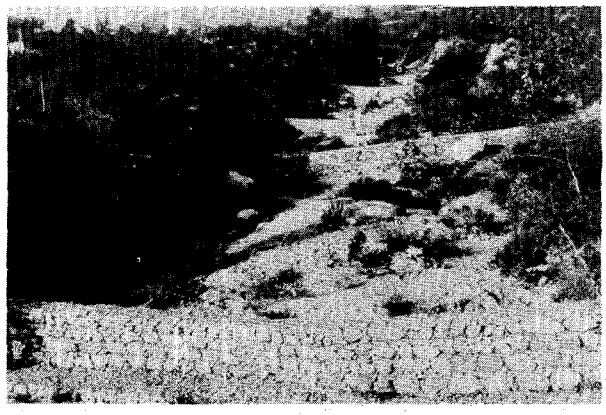
Location of protective works and channelization of Debris Flows.--In areas where the development to be protected is located near the bottom of the debris cone, or where the available floodway on the cone is wide, it is usually more economical to take advantage of the natural deposition of debris which takes place on the cone and locate the flood-control structures as far downstream as feasible, providing such confining levees as may be required to prevent the escape of floods between the canyon mouth and the downstream flood-control structures.

However, in debris-cone areas in which a high degree of development extends to the canyon mouth, as in the La Crescenta area, the available floodway is usually narrow. Protection of the area by channelization alone is impracticable because of the possibility that the channel will be blocked by deposition of debris. Under certain favorable conditions of gradients in the canyon and on the cone, and assuming that all necessary factors were known, it might be theoretically possible to design a channel so that flood-flow velocity and debris-transporting capacity at the canyon mouth could be maintained in a channel throughout the area to be protected. At



Photograph taken December 16, 1934, showing the La Crescenta delta cone area with the burned over mountain area in the background. On January 1, 1934, the debris flows from these burned over mountain areas, destroyed or damaged some 500 homes, and caused a loss of 42 lives and a property damage estimated at $5,000,000.

Photograph No. 1



Typical check dam construction. Pickens Canyon, before the flood of January 1, 1934. Taken about 1925.

Photograph No. 2

Same view as 2 after the flood of January 1, 1934. 7-19-34. Photograph No. 3

some point downstream, however, provision would have to be made for deposition of the debris and this would complicate design of flood-control works in the downstream area where development is usually greater. Such a channel, if protected only at the banks would be adequate only for flood flows containing a capacity debris load for the velocity obtainable in the channel. Sediment loads greater than this would deposit and block the channel; lesser sediment loads would result in erosion of the channel bottom and undermining of the bank protection. Little factual information is available on the proportion of debris to water because floods in the area occur suddenly and without warning and because no practicable method of gaging these flows has yet been devised. From testimony of observers, it is known that the proportion of debris to total flow may vary from a negligible quantity to enough to result in mud flow. However, the records of the Los Angeles County Flood Control District show one instance of factual information in which the entire flow, both debris and water, was trapped in a debris basin (Pickens Canyon debris basin, 18 October 1936). From records of maximum pool elevation and before-and-after surveys of the basin, it was possible to compute the total run-off and the percentage of debris. In this instance, the "wet solids" represented 88.2 percent of the total flow. Assuming that the debris volume included 30 percent voids filled with water, the dry solid matter was 62 percent of the total flow. The difficulty of providing for variable debris loads in a channel might be overcome by use of a concrete-lined channel designed for the worst probable concentration of debris. However, no concrete channel of reasonable dimensions would long withstand the destructiva action of boulders traveling at the high velocities which exist in concrete channels constructed on slopes of 2 to 10 percent.

Functions of debris basins.-- The problems outlined in the preceding paragraph can be overcome by providing a debris basin at the upstream end of the channel. The **functions** of a debris basin are:

a. To provide a settling pool for the separation of debris from water.

b. To provide storage space for retention of the debris.

c. To discharge cleared water into a downstream channel.

Estimates of debris quantity.--As mentioned previously, the debris deposit in the La Crescenta area as a result of the 1934 flood was estimated at 660,000 cubic yards and came from a mountain drainage area of about 7.5 square miles. This represents an average rate of erosion of the mountain drainage area of about 85,000 cubic yards per square mile. Probably the rates in some portions of the area were considerably higher.

By the beginning of 1938, nine debris basins had been constructed in the La Crescenta area and eight at various other points in the Los Angeles area. A storm which occurred 27 February-3 March 1938 produced one of the greatest floods of record in the area and much additional information on rates of debris production was secured from before-and-after surveys of the existing debris basins. During the period 1-25 February preceding the storm, total precipitation was about one and one-half times the normal for that period. Consequently, ground conditions were conducive to high rates of run-off. At Flintridge gage, just east of La Crescenta, rainfall was recorded as follows: total storm, 14.80 inches; maximum 24 hour, 7.84 inches; maximum 1 hour, 0.89

Photograph taken January 2, 1934, the day after the debris flow that destroyed or damaged some 500 homes in the La Crescenta area. This view shows Montrose after the debris flow from Hall-Beckley Canyon.

Photograph No. 4

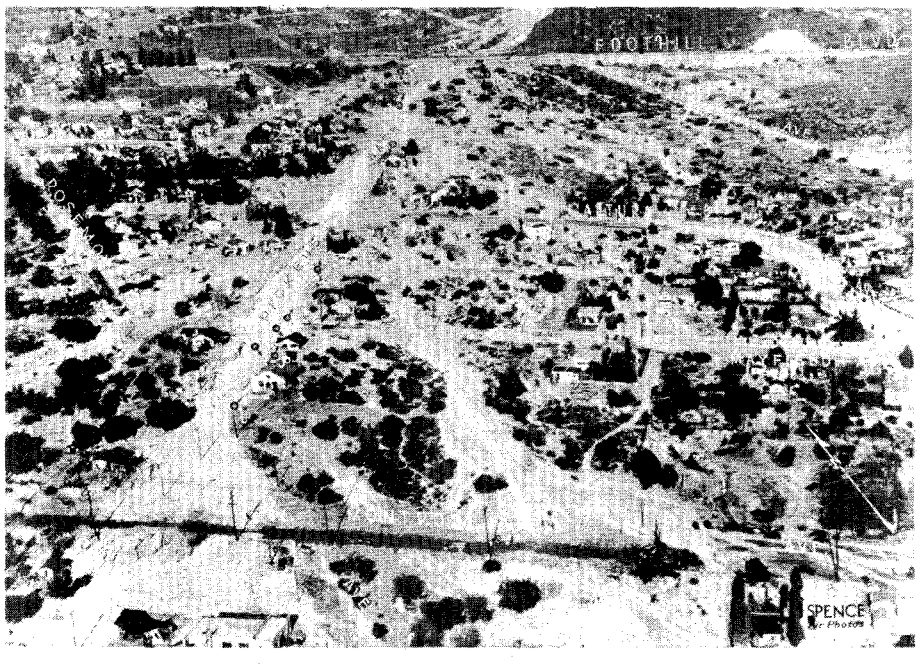
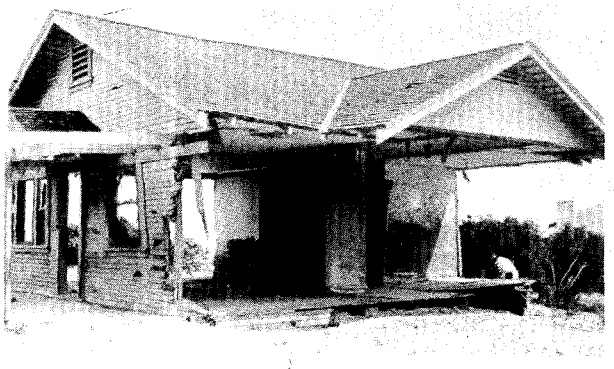


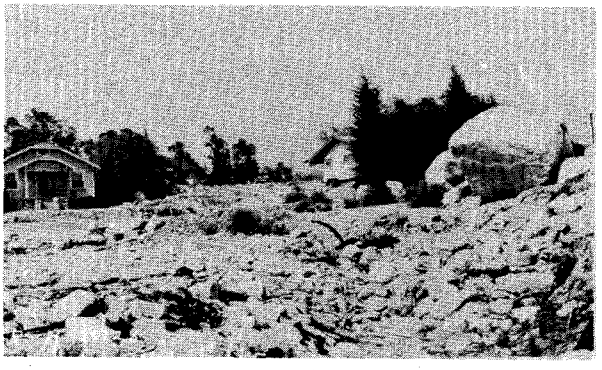
Photo taken January 8, 1934, 8 days after the debris flow that caused the loss of 42 lives, and destroyed or damaged some 500 homes in the La Crescenta area. This picture shows the debris flow from Pickens Canyon. Note depth of debris where Montrose Avenue is being uncovered.

Photograph No. 5



House on east side of Pickens Canyon flood channel just south of Mayfield Avenue. 1/6/34

Photograph No. 6



Upstream view of Pickens Canyon flood channel from Mayfield Avenue. 6/1/34

Photograph No. 7

inches; and maximum 10 minute, 0.35 inches. Table 1, from the records of the Corps of Engineers, Los Angeles District, and Los Angeles County Flood Control District, shows the estimated quantities of debris deposited in the debris basins completed at that time. In the basins that were filled to spillway crest an undetermined amount of debris passed over the spillway during the flood.

With the exception of Shields, which was designed to provide 170,000 cubic yards of debris storage per square mile of drainage area, the basins constructed by the Corps of Engineers were

TABLE 1
ACTION OF DEBRIS BASINS IN LOS ANGELES COUNTY, CALIFORNIA
FLOOD OF MARCH 1938

Debris basin	Drainage area Sq.mi.	Mean slope Ft./ft.	Total capacity* Cu.yds.	Burned area			Total debris deposited flood of Feb.-Mar. 1938	
				Year burned	Total area burned	Percent of area burned	Cu.Yds.	Cu.Yds. per sq. mi.
La Cresenta area								
Dunsmuir**	0.84	.235	128,200	1933	0.78	94	58,800	70,000
Eagle-Goss**	.61	.155	71,900	1933	.46	73	40,900	67,000
Haines	1.53	.186	158,200	1933	1.01	67	52,000	34,000
Hall-Beckley	.83	.160	91,800	1933	.63	76	86,300	104,000
Hay**	.20	.244	37,800	1933	.06	35	12,600	63,000
Pickens	1.84	.158	112,700	1933	1.75	93	122,200	66,400
Shields**	.27	.292	45,500	1933	.24	89	33,500	124,100
Snover**	.23	.243	34,800	1933	.11	46	16,800	73,000
Verdugo***	15.24	.029	105,700	1933	4.55	30	85,300	5,600
Pasadena area:								
Fair Oaks	.21	.226	20,200	1935	.26	100	12,000	57,000
Fern	.30	.229	21,100	1935	.30	100	20,700	69,000
Las Flores	.45	.306	36,400	1935	.31	69	36,000	80,000
				1922	.14	31		
Lincoln	.50	.147	23,500	1935	.50	99	8,000	16,000
West Ravine	.25	.195	44,900	1935	.24	100	29,800	119,000
Burbank area:								
Brand	1.03	.224	69,500	1927	.77	72	No record	No record
Sunset	.44	.304		1927	.42	100	6,600	15,000
Beverly Hills area								
Nichols	.94	.082	32,200	-	-	-	17,900	19,000

* The total capacities of debris basins shown are based on a debris slope taken as a straight line between the spillway sill and the floor of the top of the inlet structure.
** Constructed by Corps of Engineers. All others by Los Angeles County Flood Control District.
*** Dunsmuir, Eagle-Goss, Hall-Beckley, Pickens, Shields, and Snover are located in the drainage area of this basin.

designed to provide approximately 100,000 cubic yards of debris storage per square mile of drainage area. The design capacity was presumed to be adequate for a single major flood and it was planned to maintain that capacity by repeated excavation as necessary. The original debris capacities provided at basins designed on the above basis were adequate for the flood. However, considering the general absence of excessively high short-time rainfall intensities over the area during the 1938 storm, such as are associated with cloudbursts, and considering that 5 years had elapsed since the area had been burned over, it is apparent that under less favorable circumstances the debris catch during a single flood could be considerably greater. These facts and the increasing development in the area make it appear advisable and economically justifiable to design future basins in areas similar to the La Crescenta area for a debris capacity equivalent to a greater rate of debris production, perhaps even as much as 200,000 cubic yards per square mile of drainage area. Elsewhere in the Los Angeles area, particularly along the southern face of the Verdugo Mountains above Burbank and along the Santa Monica Mountains above Beverly Hills, the geologic characteristics are less critical and the rates of debris production are appreciably lower. In such areas, designs providing an equal degree of protection are based on debris production rates of 50,000 to 75,000 cubic yards per square mile of drainage area.

It is usually more economical to provide debris storage adequate only for a single large flood and to re-excavate the basin as often as necessary to maintain design capacity. Occasionally, however, it might be found more economical to provide storage adequate for the 50-year assumed life of the structure. Factors which might lead to that conclusion would be the existence of a site where permanent debris storage could be provided at less than the cost of periodic excavation, or the necessity of utilizing a site where no feasible spoil area could be provided, such as a site within a canyon. Estimates of 50-year debris accumulation for such designs would

TABLE 2
DEBRIS BASINS IN LOS ANGELES COUNTY DRAINAGE AREA
DEBRIS PRODUCTION RECORDS, INCLUDING SEASON OF 1945-46

Debris basin	Drainage area Sq.mi.	Number of seasons	Total capacity	Average annual rate of debris production		Maximum annual debris production	
				Cu.yds.	Cu.yds./sq.mi.	Rate Cu.yds./sq.mi.	Year
La Crescenta area							
Dunsmuir	0.84	10	122,200	13,600	16,200	70,000 Est.	1937-38
Eagle-Goss	.61	10	71,900	8,900	14,600	67,000 Est.	1937-38
Haines	1.53	11	158,600	11,300 Est.	7,400 Est.	34,000 Est.	1937-38
Hall-Beckley*	1.06	11	104,000	23,300	22,000	96,300	1937-38
Hay	.20	10	39,800	2,500	12,300	63,000 Est.	1937-38
Paradise	.96	2	13,200	1,600	1,700	1,900	1944-45
Pickens	1.84	11	116,500	27,000	14,700	66,400	1937-38
Shields	.27	9	46,600	6,000	22,300	124,100 Est.	1937-38
Snover	.23	10	37,700	Unknown	Unknown	73,000 Est.	1937-38
Verdugo**	15.50	11	151,700	Unknown	Unknown	5,600 Est.	1937-38
Ward	.64	2	6,700	Unknown	Unknown	Unknown	-
Pasadena area							
Bailey	.57	1	10,200	800	1,400	800	1945-46
Fair Oaks	.21	11	28,500	5,200	24,600	57,000 Est.	1937-38
Fern	.30	11	32,900	6,900	23,100	69,000 Est.	1937-38
Las Flores	.45	11	61,600	7,600	17,000	80,000 Est.	1937-38
Lincoln	.50	11	40,800	5,700	11,400	16,000 Est.	1937-38
Rubio	1.26	3	143,900	1,400	1,100	3,400 Est.	1943-44
Sierra Madre	2.39	19	81,200	6,500 Est.	2,700 Est.	26,300 Est.	1937-38
West Ravine	.25	11	49,600	8,300	33,300	119,000	1937-38
Burbank area:							
Brand	1.03	11	72,500	800	800	3,000	1942-43
Scholl	.66	1	30,900	Unknown	Unknown	Unknown	-
Stough	1.65	6	103,700	8,600 Est.	5,200 Est.	20,400	1942-43
Sunset	.44	17	17,500	800	1,800	15,000 Est.	1937-38
Chatsworth area							
Aliso-Wilbur	8.63	4	54,500	26,100	3,000	5,100	1942-43
Vanalden	1.08	1	5,400	560	500	500	1945-46
Beverly Hills area							
Nichols	.94	9	32,200	3,200	3,400	19,000 Est.	1937-38

* Includes uncontrolled drainage area of Weber Canyon.
** Includes drainage areas of the following basins; Dunsmuir, Eagle-Goss (which includes Shields), Hall-Beckley, Pickens, Snover, and Ward.

Note.--Data based on records of Los Angeles County Flood Control District.

be based on an average annual rate considerably less than that which would be assumed for a single storm. Table 2, derived from the records of the Los Angeles County Flood Control District, shows average annual debris production rates for debris basins in the Los Angeles County drainage area. Total capacities shown in Table 2 represent current capacities. In the process of re-excavation, the capacities of some of the basins have been increased over those capacities originally provided. Other differences between some identical items in Tables 1 and 2 are primarily due to differences in basic data, surveys, and methods of computation.

Records of existing debris basins are a valuable index for design. However, the final selection of design debris capacity must also be based on careful consideration of (1) topography and geologic structure of the drainage area; (2) character of alluvial fan; (3) type of vegetal cover; (4) fire history; and (5) degree of development in the area to be protected.

Disposal of clear water.--On the steep slopes of the debris cones, clear water released into an unlined channel generally results in rapid and severe erosion just below the basin and deposition of eroded material on the flatter slopes in lower areas. Under such conditions, the best solution for complete protection of downstream areas is provision of a concrete channel. Concrete channels have been constructed below all debris basins constructed by the Los Angeles District, Corps of Engineers, and below many of those constructed by the Los Angeles County Flood Control District. In some cases, a paved street with high curbs serves as the channel.

Where the required disposal channel is long or where channel rights-of-way are costly or restricted, the over-all project cost might be materially reduced by providing flood-control storage at the basin in order to reduce the size of the downstream channel. However, for such a plan some means of regulating the basin outflow would be required. Manual operation of regulating works would require 24-hour attendance during all storm periods because critical floods in small areas may occur without warning. Furthermore, since such floods are of brief duration, little time would be available during a flood for manual adjustment of control works. Thus, completely automatic operation of outflow regulating works has been considered requisite to such a plan. Many plans have been conceived and considered for automatic outflow regulating facilities designed to operate reliably despite debris inflows and the large quantities of floating trash which accompany floods in such areas. However,none of the plans considered have been thought sufficiently reliable to be adopted. In the highly developed areas of Los Angeles County drainage area, the results of misoperation could be disastrous and damage might greatly exceed any initial saving in project cost.

Disposal of debris and selection of site.--In the design of debris basins having debris storage adequate only for a single major flood, the operation of the basin involves repeated excavation to maintain the design storage capacity. One factor to be considered in the selection of the site for such a basin is the availability of an adjacent spoil area. Such an area should be as close to the basin as possible and be free from attack by local or tributary run-off. Basin sites within canyons are sometimes favorable for economic dam construction. However, the steep canyon sides restrict access of excavating equipment and trucks to the basin and excavated debris cannot safely be disposed of in the narrow canyon bottoms downstream of the dams, but must be hauled out of the canyon. The best location for a debris basin is, therefore, usually at the canyon mouth, in such a position that the basin is outside the canyon for ease of access and the inlet structure is tied to the canyon walls to prevent flanking of the basin by flood flows.

Design details - debris basin only.--A debris basin consists essentially of four basic parts:

a. A bowl-shaped pit excavated in the surface of the debris cone.

b. An embankment, usually U-shaped in plan, constructed from the pit material, and located along the two sides and downstream end of the pit.

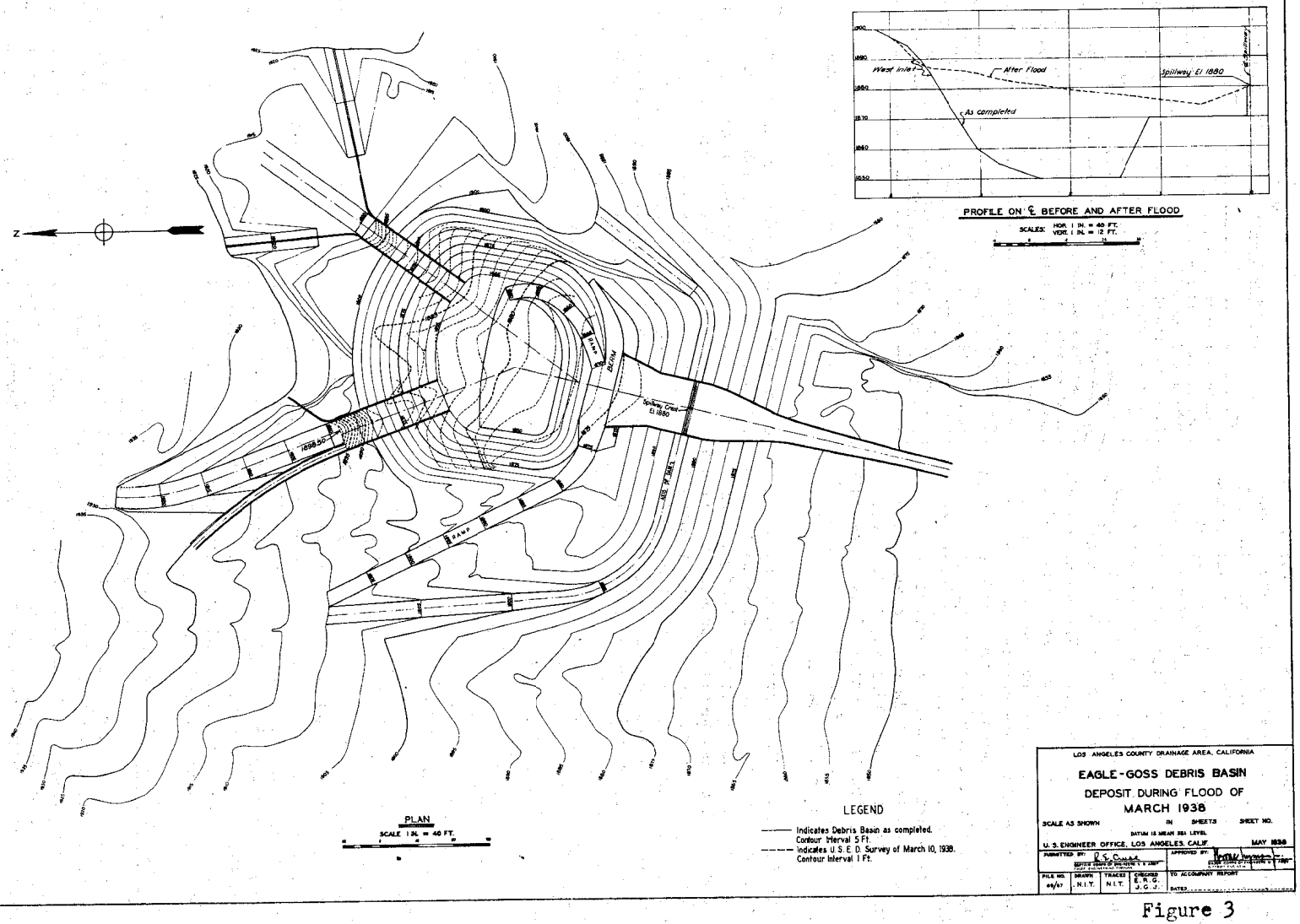
c. An inlet chute at the upstream end of the pit.

d. An outlet and spillway at the downstream end.

Basin layout.--Figure 3 shows the plan and site topography of Eagle-Goss debris basin, one of the basins constructed in the La Crescenta area by the Los Angeles District, Corps of Engineers. This basin is constructed just below the mouths of two adjacent canyons, Goss on the east and Eagle on the west. In addition, a concrete discharge channel from another debris basin, Shields, enters the basin at the Eagle canyon inlet (see photograph 1). Pertinent data for the basin and downstream channel are given in Table 3.

WAR DEPARTMENT

CORPS OF ENGINEERS. U. S. ARMY.



LOS ANGELES COUNTY DRAINAGE AREA, CALIFORNIA

EAGLE-GOSS DEBRIS BASIN

DEPOSIT DURING FLOOD OF MARCH 1938

SCALE AS SHOWN | IN SHEETS | SHEET NO.

DATUM IS MEAN SEA LEVEL

U. S. ENGINEER OFFICE, LOS ANGELES, CALIF. | MAY 1938

SUBMITTED BY: R. S. Cuttle, Senior Civil Engineer | APPROVED BY: Chief Engineer

FILE NO.	DRAWN	TRACED	CHECKED
49/67	N.I.T.	N.I.T.	E.R.G. J.G.J.

TO ACCOMPANY REPORT

DATED:

Figure 3

In laying out a debris basin, particular attention must be given to the shape of the basin and the relative location of inlet and outlet structures. As the flow of debris and water enters the basin, the debris deposits first at the base of the inlet chute. Succeeding deposits progressively raise the upper surface on more or less parallel slopes and extend the front face of the deposit outward into the basin. The shape of the deposit is similar in all such basins. The upper surface which is relatively flat and fan shaped with its apex at the inlet structure, has the appearance of a miniature debris cone. At the front face of the deposit, the surface usually breaks sharply downward and extends to the bottom of the pit. In order to prevent discharge of debris through the outlet prior to the time that the full debris-storage capacity of the basin has been utilized, it is important to shape the basin and to locate the outlet so that the front face of the deposit will not reach the outlet prior to the time it has spread over the entire basin.

TABLE 3
DATA ON EAGLE-GOSS DEBRIS BASIN AND CHANNEL

Length of project	8,800 ft.
Debris basin drainage area	0.62 sq. mi.
Debris basin capacity	71,500 cu. yds.
Elevation, top of dam	1,895 ft. m.s.l.
Elevation, spillway crest	1,880 ft. m.s.l.
Width of spillway	60 ft.
Area drained above mouth of channel	2.24 sq. mi.
Average width of channel	13 ft.
Average depth of channel	7.5 ft.
Earth excavation	183,000 cu. yds.
Earth fill and backfill	146,000 cu. yds.
Concrete	12,150 cu. yds.
Reinforcing steel	2,295,000 lbs.
Bridges or street crossings	18
Date of completion	October 1936
Approximate cost	$624,000
Rate of discharge (Q)	3,300-6,700 c.f.s.
Average gradient of flow (channel)	7.5 ft. per 100 ft.
Velocity of flow (V) (channel)	36-58 ft. per sec.

To determine the proper basin shape and to estimate the total debris capacity of the basin, it is necessary to assume the probable slope of the upper surface of the debris deposit. Studies made by the Los Angeles County Flood Control District of the slope of debris deposits in basins indicated that a reasonably accurate determination of this slope could be made by assuming it to be equal to six-tenths the slope of the natural debris cone at the basin site. A check of the debris slopes resulting from the flood of 1938 in those basins constructed by the Corps of Engineers showed that that assumption gave reasonably consistent results. It should be noted, however, that profiles taken between the inlet and outlet of debris deposits in basins in the La Crescenta area which were filled during the 1938 flood were generally concave upward. Beginning with a level surface at the outlet sill, the slope increased to a maximum at the inlet. Assumption of a slope of .4 to .5 would therefore be advisable to allow for concavity of deposits in conservative design capacity estimation.

Inlet design.--The basin inlet structure consists of a concrete chute near the upper end of the basin and extends from natural stream-bed elevation to the bottom of the excavated debris pit. At the upstream end the inlet is tied by wing walls to the canyon sides to prevent flood flows from flanking the basin. Purposes of the inlet structure are to direct flood flows into the basin and to prevent back scour upstream of the excavated pit. The inlet structure is subjected to severe wear and battering from the debris which passes over it. Inlet structures of wood, asphalt, and concrete have been constructed. In the design of concrete inlets, consideration should be given to the relative cost of frequent repair and provision of an extra thickness of concrete facing. The inlet structures constructed by the Los Angeles District, Corps of Engineers, are concrete. After 10 to 11 seasons of service, these structures have worn sufficiently to require repair in the near future. If debris deposited on a slope upstream of the outlet sill should approach or exceed the elevation of the top of the inlet walls, subsequent debris flows might bypass the basin. The top of inlet walls should, therefore, be placed above an assumed maximum debris slope projected upstream from the outlet sill. For design, such a slope can be assumed equal to the slope of the natural cone at the site.

Outlet Design.--During general storms, which may last 4 days or more, major run-off may occur more than once. A major storm may also be followed within a week or 10 days by a second major storm. Thus, there exists the possibility that insufficient time will elapse between floods to permit excavation of filled debris basins. Failure of the basin embankment by overtopping under these conditions would result in the sudden release of stored debris and greatly increase downstream damage. The basin outlet should, therefore, be capable of passing the estimated maximum possible flood at a time when the basin has been filled by a previous flood. Because major floods in these areas are sudden and brief, the basin outlet should be completely and reliably automatic in operation.

The outlet shown on Figure 3 is typical of those constructed by the Corps of Engineers. It consists of a concrete-lined approach channel, an unobstructed ogee-crest spillway, and a transition leading to the downstream channel. The spillway capacity is computed as a broad crest

weir under the assumption that the basin is level-full to spillway crest with debris. The entire spillway capacity was maintained in the downstream channel to a point where overtopping of the channel walls would not induce failure of the debris basin structure. At the spillway, the top of the basin embankment was set 5 feet above the spillway-design surcharge level. Under other spillway-design assumptions, the basin would be full of debris on a slope rising upstream from the spillway crest. The surface of the flow of debris and water through the basin above this slope would, accordingly, be on a similar slope. The top of the basin embankment was, therefore, set on progressively higher elevations upstream from the spillway in order to maintain approximately 5 feet of freeboard above spillway-design flow.

Drainage of pool.--Following a flood which results only in partial filling of the debris storage, drainage of water stored in the basin below spillway crest is accomplished in two stages. A series of holes about 12 inches in diameter provided through the base of the spillway ogee serve to drain the pool to the base of the ogee without permitting an appreciable amount of debris to pass into the downstream channel. Drainage of the pool below the elevation of the base of the ogee can be accomplished by pumping, or by installing a pipe leading from the bottom of the pit through one of the holes in the base of the ogee, to a point 200 to 300 feet downstream in the channel. Because of the steep slopes of these areas such a pipe can be made to operate as a siphon. An alternative and automatic method of draining the pool below the base of the ogee is to incorporate in the basin construction a pipe 2-4 feet in diameter extending on a flat grade between the bottom of the pit and a suitable point in the downstream channel. The inlet of such a drain is covered with a mound of boulders to prevent the entrance of debris.

Downstream Channel.--In the location and orientation of the outlet structure, consideration should be given to the available locations and alignment of the downstream channel. Because of the high design-flow velocities (30-60 feet per second) in such channels, channel design can be simplified and cost reduced if the outlet structure is oriented so as to lead to the downstream channel with minimum curvature.

Construction Costs.--In Figure 4, relative costs per acre-foot of storage of debris basins and comparably situated flood-control basins constructed by the Los Angeles District, Corps of

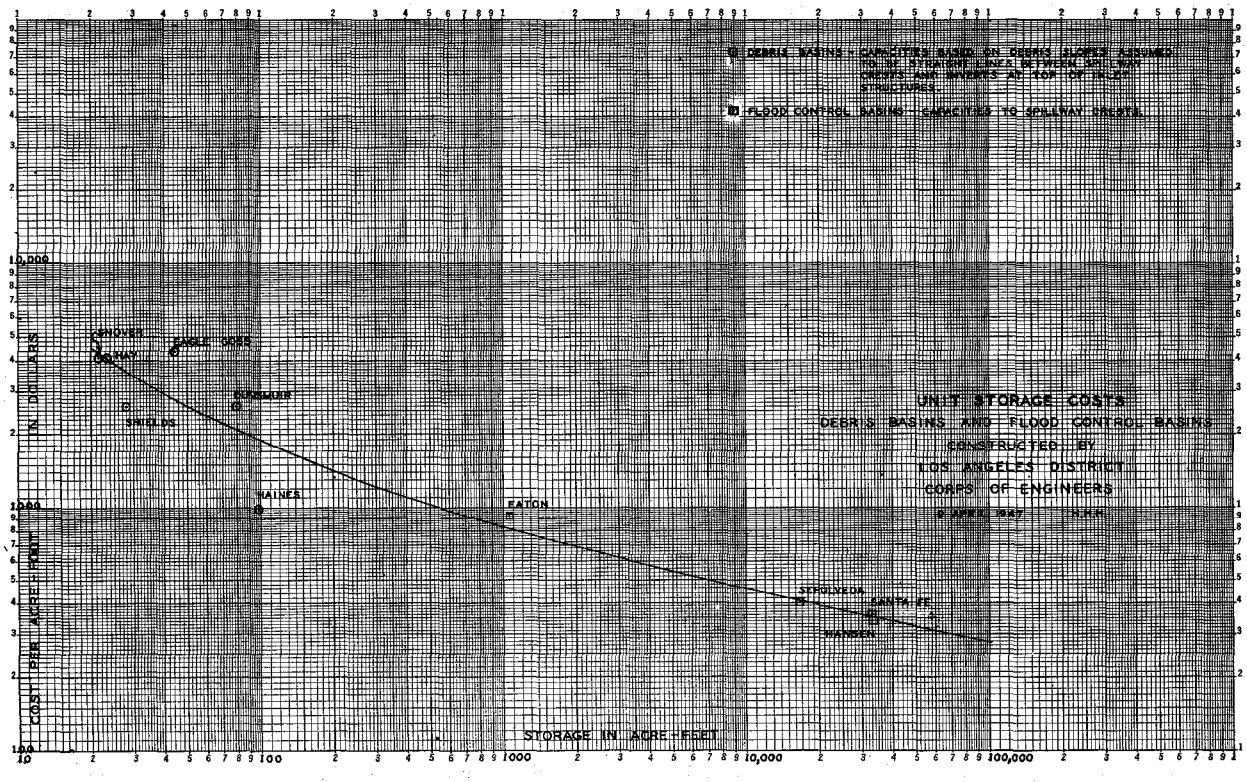


Figure 4

Engineers, are shown plotted against total storage capacities. In general, the flood-control basins represented in Figure 4, although located on flatter slopes and providing much greater storage space, are similar in type to the debris basins. From comparison of storage capacities with corresponding costs, it is apparent that costs per unit of storage are high as compared to storage costs usually considered in reservoir construction, and that unit storage costs decrease rapidly with increased total storage.

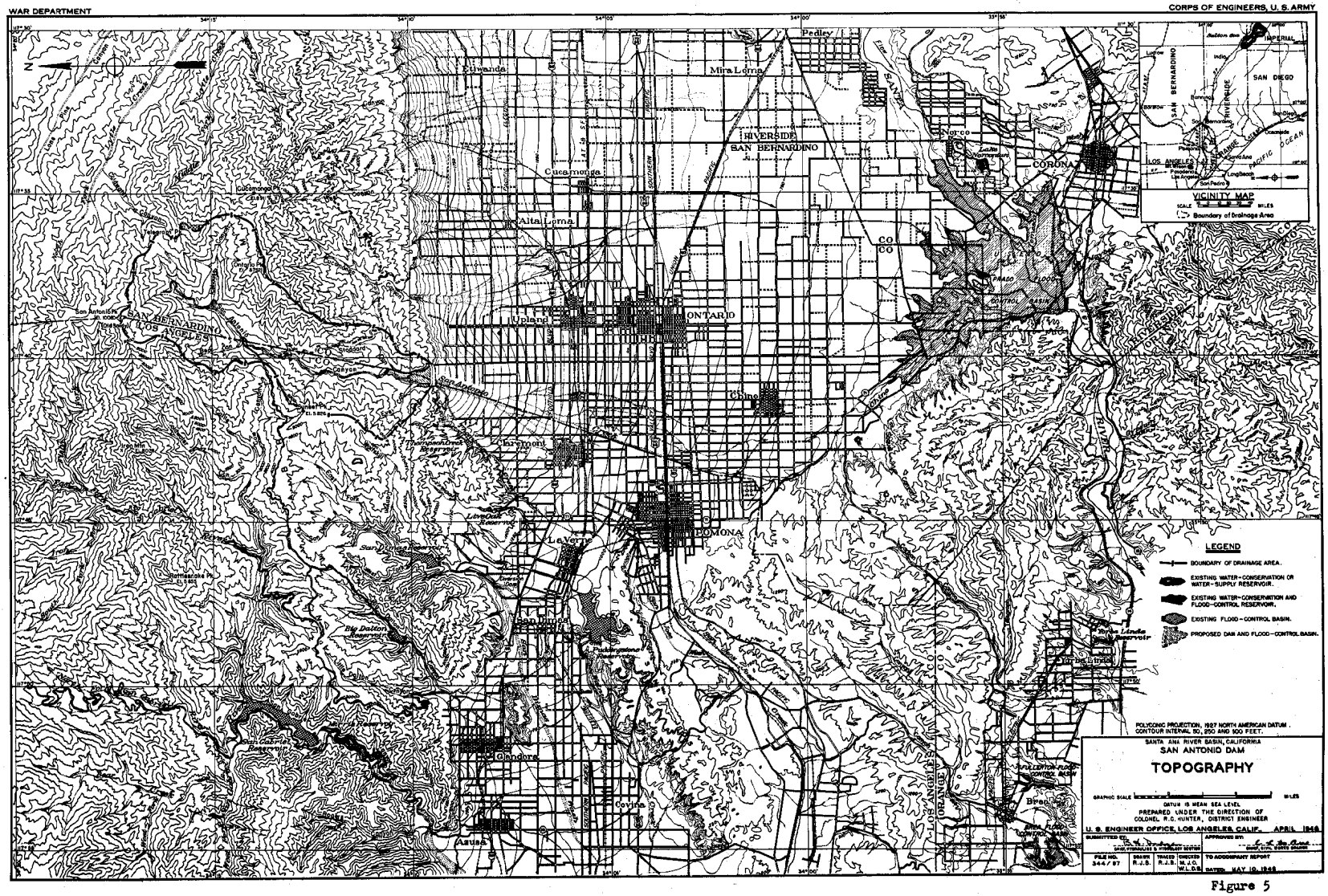
Design details - combined debris and flood control.--San Antonio Canyon is located on the southern face of the San Gabriel Mountains, approximately 30 miles northeast of Los Angeles and 30 miles east of the La Crescenta area. Except for the size of the drainage area, 26.7 square miles, and the greater range in elevation, 2,250 feet to 10,000 feet (see Figures 5 and 6 and photographs 8 and 9), the topography and geologic structure of the drainage area are similar to those of the canyons above the La Crescenta area. One plan for control of flood and debris flow from San Antonio Canyon is shown in Figure 7 and described below. In addition to provision for debris storage, the plan provides for flood-control storage to reduce flood peaks and conserve water. This plan is one of many considered for the project. It is not the final plan and is referred to here only as an illustration for the following brief outline of problems which requires consideration in designs involving both debris and flood-control storage.

Estimate of debris storage.--The plan for control of debris and floods from San Antonio Canyon discussed herein provides for storage of the estimated 50-year debris production from the drainage area. Because quantitative data on debris carried by floods in San Antonio Canyon are not available, the volumes of debris that might be deposited in the basin during floods of various magnitudes were estimated from a study of available records of volumes of run-off and debris deposition during the floods of March 1938 and January 1943 at 14 nearby debris and flood-control basins with generally comparable drainage-area characteristics. Flood and debris data for the 14 basins are shown in Table 4. In Figure 8, volumes of debris in acre-feet per square mile of drainage are shown plotted against total flood volume in acre-feet per square mile of drainage area. A line drawn through the average position of the plotted points indicates an approximate relationship of debris to flood volume. It is apparent from the positions of the plotted points that a line could equally well be drawn which curved upward, or as an enveloping line, curved downward. Figure 8 shows one practical application of debris and sediment data and illustrates the need for many more such records. At San Antonio Canyon total flood-volume estimates were available for the 13 largest floods in the 60-year period of record. Applying the debris to total flood-volume relationship, indicated by the curve in Figure 8 to these 13 floods, and assuming debris production of smaller floods to be negligible, the total debris deposition for the 60-year period of record was estimated. This total, reduced proportionally to a 50-year period (the basic period for design economics), was 3,350 acre-feet, and it was assumed that this volume of debris would be deposited in the basin during the 50-year period following construction of the project. From the curve in Figure 8, it was also estimated that the reservoir-design flood having a total volume of 23,400 acre-feet would include 1,350 acre-feet of debris (equivalent to a rate of about 80,500 cubic yards per square mile of drainage area). Deducting 1,350 acre-feet from the total of 3,350 left a remainder of 2,000 acre-feet. The net capacity curve used to determine the storage necessary for control of the reservoir-design flood was then based on the gross capacity curve reduced to reflect deposition of 2,000 acre-feet of debris distributed uniformly with elevation up to the top of spillway gates in closed position.

Basin layout.--The plan of the basin is shown in Figure 7. The basin, while larger and more complex, would be basically similar to the debris basins discussed previously. The plan provides for construction of an earth dam across the canyon mouth with material excavated from within the basin. Excavation within the basin would be performed according to a predetermined plan so as to leave a pit for debris deposition. Back scour into the canyon upstream from the pit would be prevented by an inlet sill consisting of a derrick-stone blanket across the upstream and of the pit. Because of the inclusion of flood-control storage and regulated outflow in the design, the spillway and flood-control outlets would be separate facilities as compared to a single combined outlet and spillway used for basins designed only for debris storage.

Debris deposition.--With the exception of the finer particles, which could be held in suspension by the currents in the reservoir and which constitute but a minor part of the total debris load (see Figure 2), all of the debris would deposit near the upstream edge of the relatively quiet reservoir pool. The debris pit as planned would be long and narrow and extend lengthwise upstream from the dam. Thus, the higher the reservoir stage (and hence the larger the flood), the farther from the dam and flood-control outlets would be the deposition of debris.

Outlets.--In this type of dam construction, considerations of economy, structural limitations of the site, and necessary protection of the outlets from blocking by floating trash, make


WAR DEPARTMENT
CORPS OF ENGINEERS, U. S. ARMY
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Pedley
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Cucamonga
Alta Loma
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Upland
ONTARIO
Chino
Claremont
POMONA
Ganesha
Covina
Azusa
Brea
SAN BERNARDINO
LOS ANGELES
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
PACIFIC OCEAN
VICINITY MAP
SCALE
MILES
Boundary of Drainage Area
LEGEND
BOUNDARY OF DRAINAGE AREA.
EXISTING WATER-CONSERVATION OR WATER-SUPPLY RESERVOIR.
EXISTING WATER-CONSERVATION AND FLOOD-CONTROL RESERVOIR.
EXISTING FLOOD-CONTROL BASIN.
PROPOSED DAM AND FLOOD-CONTROL BASIN.
POLYCONIC PROJECTION, 1927 NORTH AMERICAN DATUM.
CONTOUR INTERVAL 50, 250 AND 500 FEET.
SANTA ANA RIVER BASIN, CALIFORNIA
SAN ANTONIO DAM
TOPOGRAPHY
GRAPHIC SCALE
MILES
DATUM IS MEAN SEA LEVEL
PREPARED UNDER THE DIRECTION OF
COLONEL R.G. HUNTER, DISTRICT ENGINEER
U. S. ENGINEER OFFICE, LOS ANGELES CALIF. APRIL 1948
SUBMITTED BY
APPROVED BY
FILE NO. 344/87
DRAWN R.J.B.
TRACED R.J.B.
CHECKED M.J.O. W.L.D.B.
TO ACCOMPANY REPORT
DATED MAY 10, 1948

Figure 5

it desirable to locate the flood-control outlets at the bottom of the reservoir, provided adequate provision can be made against blocking of the outlets by debris deposits. As planned, the flood-control outlets would be located in the southwest corner of the basin with inlet sills at elevation 2,125 (bottom of debris pit) and would consist of three short slide-gated conduits, 7 feet wide and 12 feet high. These conduits would transition into a single arched conduit with an 8-foot radius which would extend downstream through the base of the dam and discharge into a stilling basin. As provision against partial blocking by debris or floating trash, the outlet system would have approximately three times the clear-water discharge capacity required to pass the design controlled outflow.

Reservoir operation.--In addition to the debris-pit design and excess outlet capacity, further safeguard against blocking of the outlets would be in the reservoir-operation plan. During floods of reservoir design and lesser magnitude, a debris pool would be developed by limiting releases through the outlet gates to conservation flows of about 200 cubic feet per second until

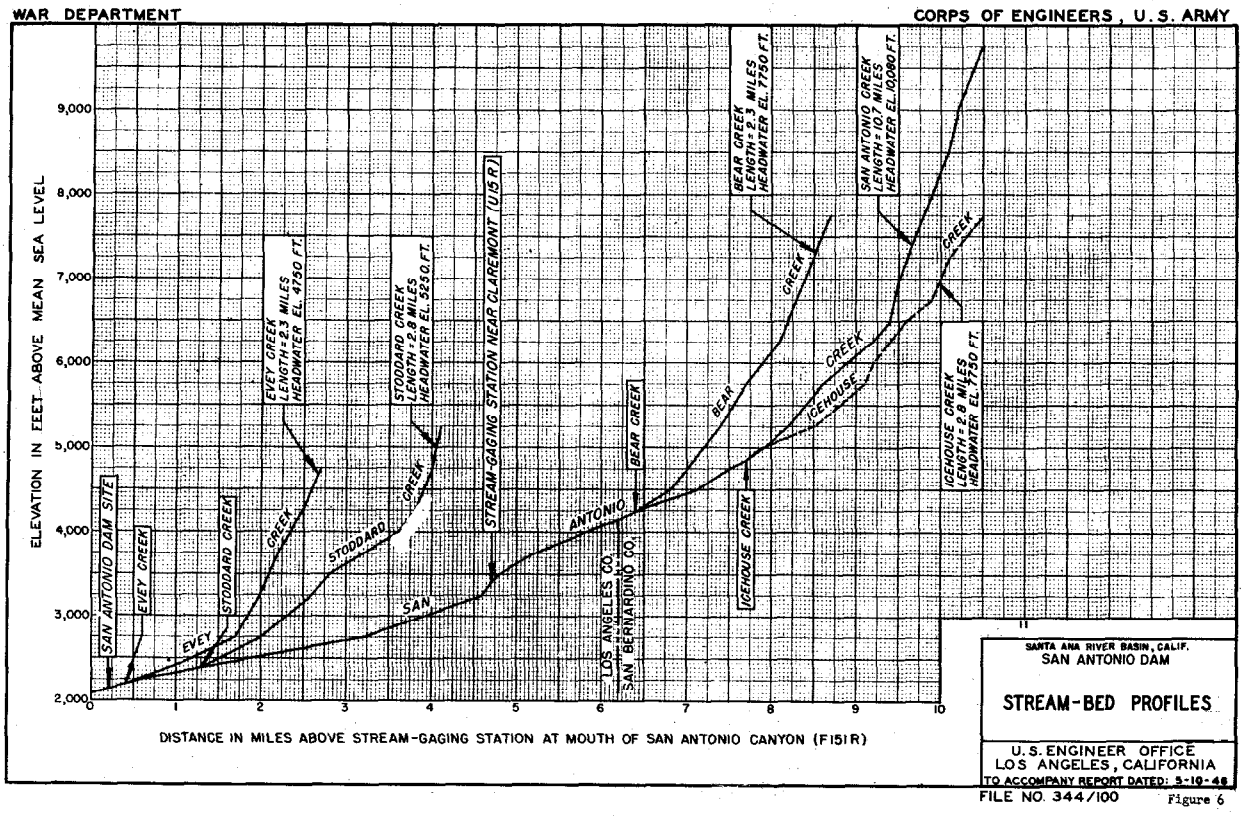
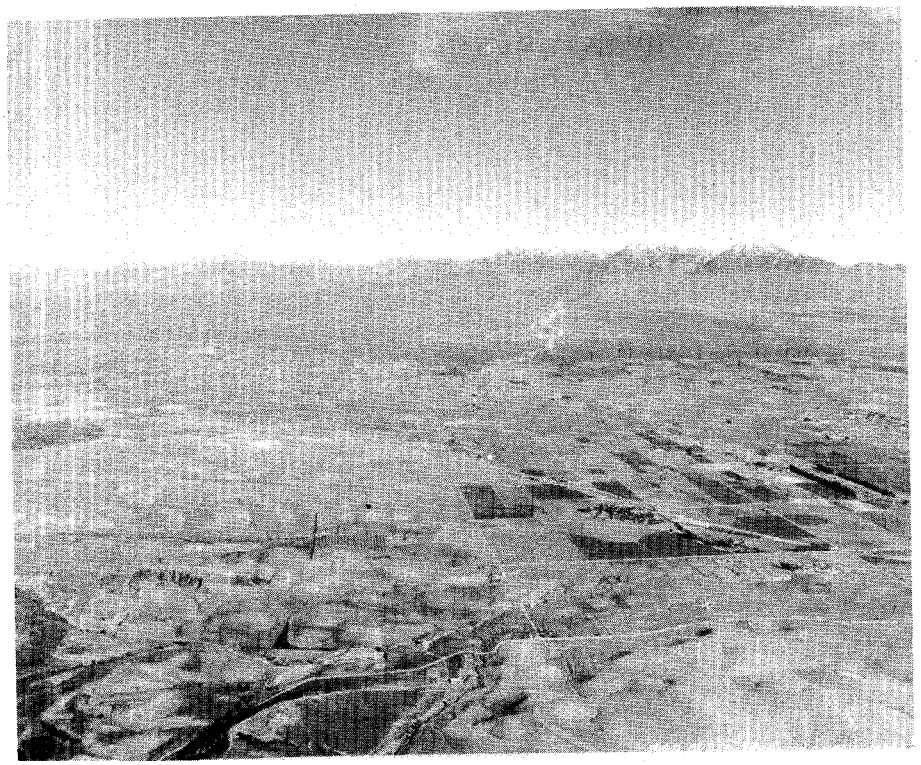


Figure 6

the water surface in the reservoir rose to elevation 2,160. With the water surface at that elevation, the pool depth in the approach channel to the outlet works would be 35 feet and the gross storage would be 1,430 acre-feet. This pool would prevent blocking of the outlet works by causing debris to deposit at the upstream edge of the pool and trash to float on the water surface. With the water surface in the reservoir at elevation 2,160, the gates would be operated so that outflow would be equal to inflow until the outflow increased to 3,200 cubic feet per second. Thereafter, during rising stages, the discharge would be controlled to 3,200 cubic feet per second until the water surface rose to the top of spillway gates (elevation 2,165, closed position). The operation described above would be reversed during falling stages of the reservoir.

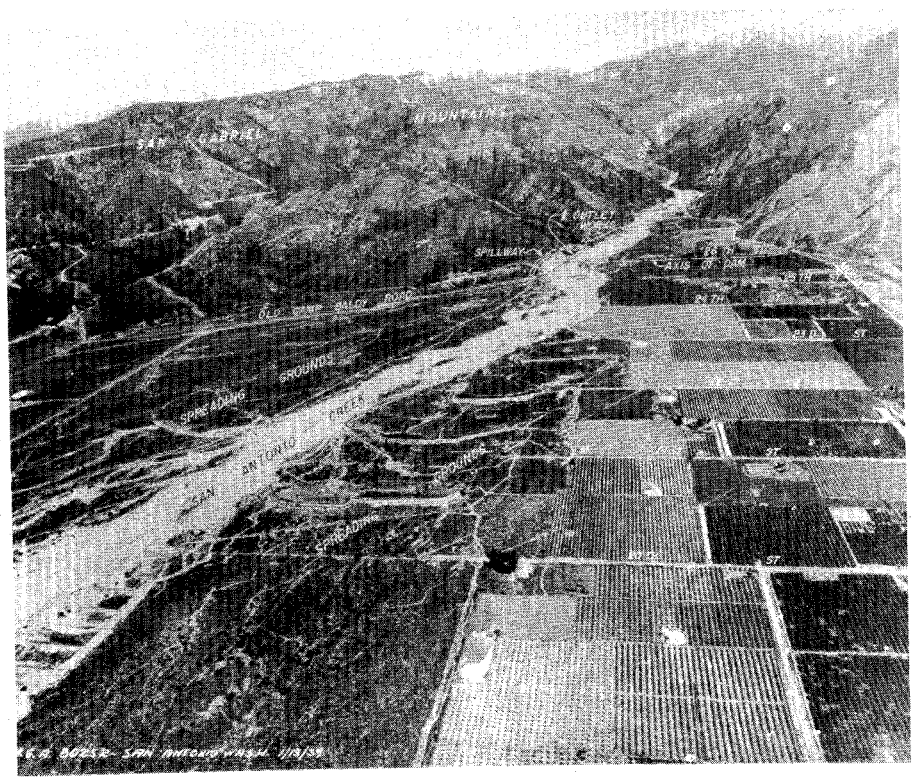
Spillway.--A spillway containing three 30-feet wide by 20-feet high radial gates would be provided at the right abutment. Top of the gates in closed position would be at elevation 2,265 (elevation of the maximum water surface for the reservoir-design flood). A concrete chute would carry spillway discharge to the level of the debris cone and terminate in a bucket adjacent to the flood-control-outlet stilling basin.

Provision for debris disposal.--Although the plan provides for 50-year debris accumulation, consideration would be given to reserving a nearby area (preferably along the toe of the dam) for disposal of debris. Excavation of debris deposits would become necessary to maintain flood-



Distant view of San Antonio Wash.

Photograph No. 8



Aerial view of San Antonio Canyon and upper part of debris cone. Dam site shown is site discussed in text.

Photograph No. 9

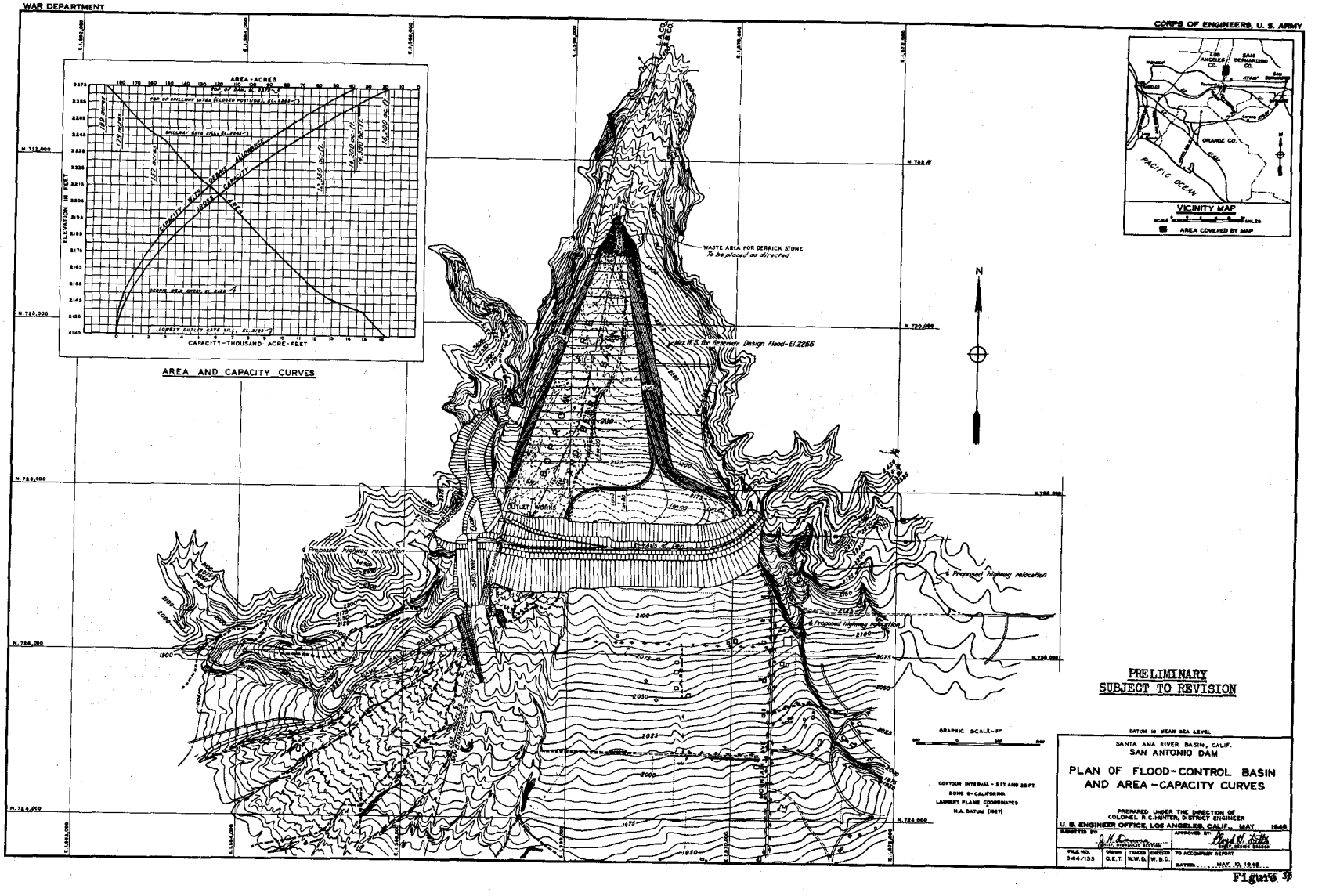

WAR DEPARTMENT
CORPS OF ENGINEERS, U. S. ARMY
AREA-ACRES
ELEVATION IN FEET
CAPACITY-THOUSAND ACRE-FEET
AREA AND CAPACITY CURVES
VICINITY MAP
AREA COVERED BY MAP
PACIFIC OCEAN
ORANGE CO.
WASTE AREA FOR DERRICK STONE
To be placed as directed
Max. W.S. for Maximum Design Flood-El. 2265
OUTLET WORKS
Proposed highway relocation
N
PRELIMINARY
SUBJECT TO REVISION
GRAPHIC SCALE-FT
CONTOUR INTERVAL - 5 FT. AND 25 FT.
ZONE 6 - CALIFORNIA
LAMBERT PLANE COORDINATES
N.A. DATUM 1927
DATUM IS MEAN SEA LEVEL
SANTA ANA RIVER BASIN, CALIF.
SAN ANTONIO DAM
PLAN OF FLOOD-CONTROL BASIN
AND AREA-CAPACITY CURVES
PREPARED UNDER THE DIRECTION OF
COLONEL R.C. HUNTER, DISTRICT ENGINEER
U. S. ENGINEER OFFICE, LOS ANGELES, CALIF., MAY 1948
SUBMITTED BY:
APPROVED BY:
FILE NO. 344/155
DRAWN C.E.T.
TRACED M.W.D.
DIRECTED W.B.D.
TO ACCOMPANY REPORT
DATED MAY 10, 1948

Figure 3

TABLE 4
FLOOD-CONTROL BASINS IN LOS ANGELES COUNTY DRAINAGE AREA
DEBRIS PRODUCTION RECORDS FOR FLOODS OF MARCH 1938 AND JANUARY 1943

Reservoir	Drainage area Sq. mi.	March 1938 flood				January 1943 flood			
		Flood volume		Debris volume		Flood volume		Debris volume	
		Ac.-ft.	Ac.-ft. per sq. mi.	Ac.-ft.	Ac.-ft. per sq. mi.	Ac.-ft.	Ac.-ft. per sq. mi.	Ac.-ft.	Ac.-ft. per sq. mi.
Big Dalton.....	4.5	1,420	316	66	14.7	511	114	16	3.6
Devils Gate.....	30.6	11,788	385	848	27.7	9,564	313	224	7.3
Eaton.....	9.5	2,970	313	242	25.5	2,024	213	90	9.5
Hansen.....	147.4					23,250	158	1,100	7.5
Live Oak.....	2.3	457	199	13	5.7	258	112		
Pacoima.....	27.8	8,820	317	588	21.2	2,694	97		
San Dimas.....	15.9	5,010	315	211	13.3	2,063	130	74	4.7
San Gabriel No. 1.....	202.0	114,716	568	6,143	30.4	65,364	324	1,727	8.5
San Gabriel No. 2.....	40.4	25,860	640	1,511	37.4	16,694	413	414	10.2
Santa Anita.....	10.8	6,380	590	327	30.3	4,654	431	160	14.8
Sierra Madre.....	2.4	888	370	39	16.3			13	
Sawpit.....	3.3	1,250	379	69	20.9	666	202	20	6.1
Thompson.....	3.9	845	217	26	6.7	393	101		
Tujunga.....	81.4	31,290	384	1,506	18.5	18,409	226	397	4.9

control storage required for control of the reservoir-design flood (1) if at any time during the initial 50-year period the accumulated debris deposits exceeded the 2,000 acre-feet allowance, or (2) to extend the period of full usefulness of the structure when the sediment space becomes full.

Costs.--The plan would provide 14,350 acre-feet of storage at elevation 2,265 (top, spillway gates, closed) at an estimated cost of $6,300,000. This is equivalent to a cost of $438 per acre-foot (see Figure 4).

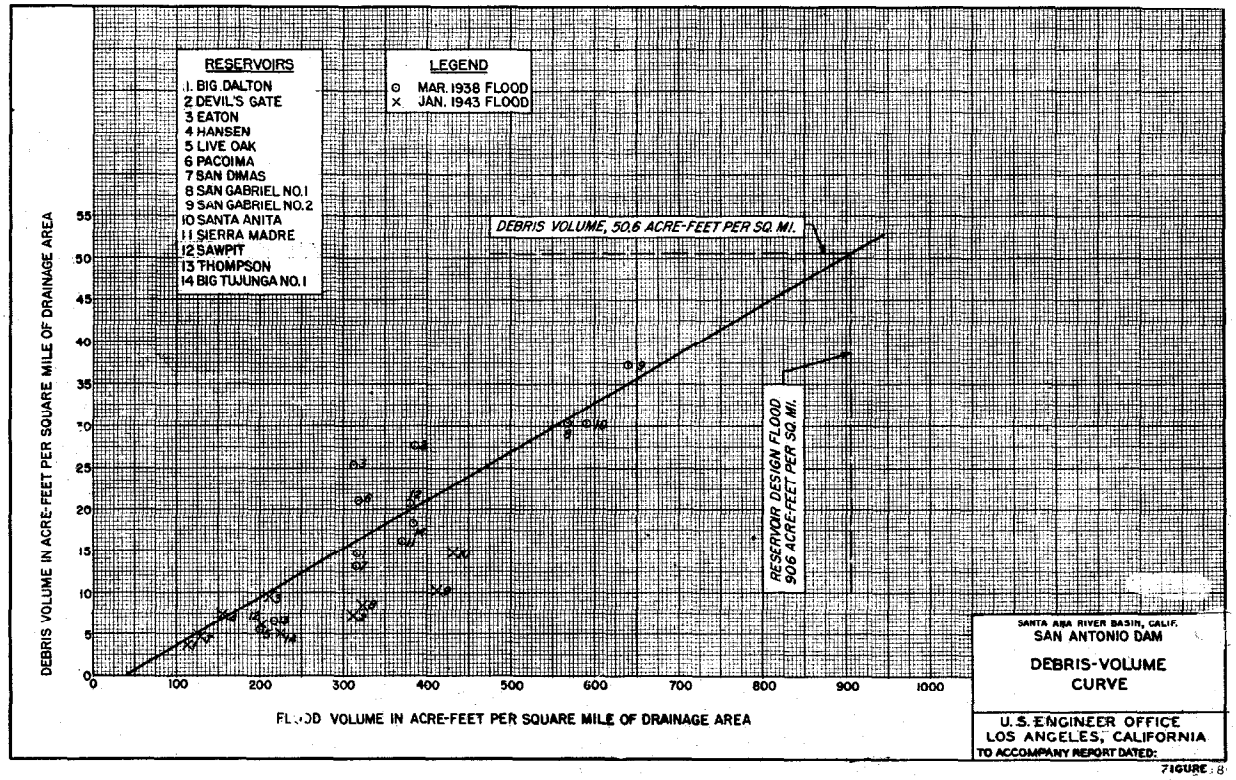
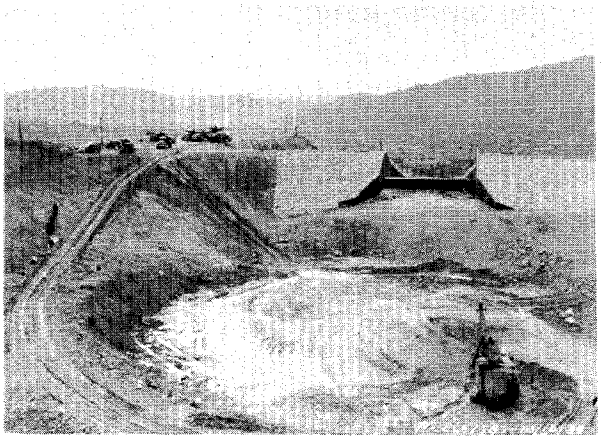


FIGURE 8

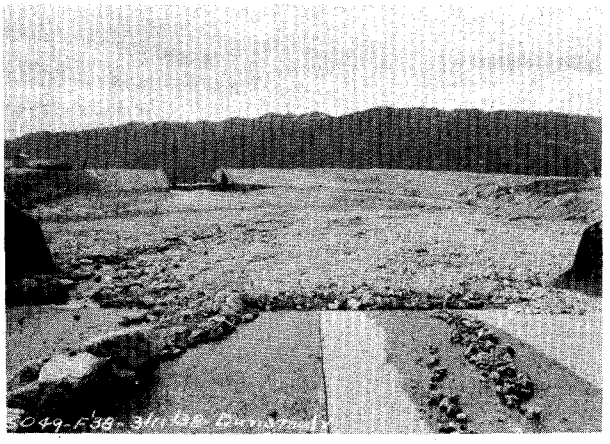
Operation

Maintenance of debris capacity.--Under normal conditions, when the mountains are covered with well-established growth and no major run-off occurs, the deposits in debris basins will accumulate so slowly that removal may be necessary only once in several years. It is the present practice under these conditions to permit accumulation of debris ranging up to 25 percent of design capacity before re-excavation of the basin. Under abnormal conditions caused by burned drainage areas or major floods, the deposits might have to be removed several times in a single year. Basins located below drainage areas recently denuded by fire would be maintained at or near design capacity at all times between floods. Photographs 10 and 11 showing before-and-after 1938 flood views of Dunsmir debris basin illustrate the effect of a single major flood.



Dunsmuir debris basin viewed from inlet structure across the basin to spillway at time of construction. 10/16/36

Photograph No. 10



Dunsmuir debris basin viewed from inlet structure across the basin to spillway after flood of March 1938, showing debris deposited during that flood.

Photograph No. 11

Debris accumulation estimates - small basins.--Several methods of estimating debris accumulations are used for small debris basins such as have been discussed herein. When the deposit is of considerable size it is advisable to make an accurate survey of the basin. Cross sections or plane-table topography will, by comparison with previous surveys, provide adequate data for computation of debris deposits. From the viewpoint of the designing engineer, plane-table topography is preferable to cross sections because it facilitates study of the configurations of the deposits. When the deposit is small a satisfactory estimate of quantity can be made with a hand level. The simplest method consists of counting truck loads of material removed. Following excavation, the basin should be resurveyed in order to determine the restored capacity and to serve as a comparison with future surveys.

Debris-accumulation estimates - large basins.--In the Los Angeles District, Corps of Engineers, estimates of debris quantities in larger basins constructed by the Corps have concerned basins designed primarily for flood control. In these basins, allocation of debris storage adequate for estimated 50-year accumulations were included in the designs. However, periodic determination of debris accumulations in such basins is desirable:

a. To furnish data for future design.

b. To maintain current capacity tables for flood operation uses.

c. In connection with water conservation or recreational use of debris storage prior to its depletion.

Debris-accumulation determinations made by the Los Angeles District, Corps of Engineers, have been based on plane-table topography, on profiles across the basins taken along monumented ranges, and on combinations of the two. While the choice of method depends largely upon features of individual basins, each method offers certain basic advantages. In basins of fairly regular

shape, such that the number of monumented ranges required is not excessive, the use of ranges will usually result in greater speed and economy (except perhaps for the initial cost of monumentation). Furthermore, such surveys are subject to a minimum of personal judgment on the part of the surveyor and subsequent surveys will yield relatively exact comparison at each range. In basins containing many irregularities, the number of ranges required for accurate delineation may become excessive. Plane-table topography provides better delineation of basin irregularities such as side canyons and islands. For basins of any shape, a topographic survey results in a more detailed map of the basin and capacity computations are simplified. The accuracy of topographic surveys depends largely upon the experience and ability of the topographer, however, and since subsequent surveys are often performed by different personnel, comparison of such surveys is not always satisfactory. Thus, it is usually desirable to supplement a topographic survey with monumented ranges established at key points in the basin. In Hansen flood-control basin (area at spillway crest, 790 acres), borrow-pit areas below the elevation of the outlets serve as debris deposition areas and are normally submerged. (Other flood-control basins maintained by the Los Angeles District, Corps of Engineers, are dry between flood seasons.) Surveys of the Hansen basin have been made by use of established ranges, approximately 200 feet apart, for the portions of the basin below the outlets; by survey of shore lines as the water surface receded after a flood; and by topography of the remaining parts of the reservoir. In addition, eight ranges approximately 1,000 feet apart have been established across the entire basin. These ranges serve as a check upon topographic surveys, provide direct comparison of debris deposits, and are useful in determining when sufficient debris has accumulated to warrant a new topographic survey.

Stereoscopic analysis of aerial photographs for determining topography may offer considerable economy in surveys of some types of basins. While the applicability of that process to a specific basin depends upon individual features of the basin such as the topographic relief, cover growth, lake levels in the basin, and the aerial extent of the basin, it can be stated in general that basins which are dry or nearly empty, have at least moderate relief, and have an area in excess of about 6,000 acres can usually be economically and satisfactorily surveyed by that process. For smaller basins, the cost of airplane mobilization becomes disproportionate unless surveys for a number of nearby basins are programmed for the same flight. The process requires a partial ground survey for control purposes. Aerial photographs are taken with special cameras and topography is derived in the office from stereoscopic analysis of the photographs using special projection equipment. By having operators check each other, the element of personal interpretation is largely eliminated. The method is particularly applicable to basins having rolling topography. However, on areas where slopes are nearly flat, such as reservoir-sediment deposits, the method does not yield satisfactory results within the limits of practical flight altitudes. At the present time, the Los Angeles District, Corps of Engineers, is completing a multiplex survey, supplemented by soundings and plane-table topography in the reservoir bottom, of the San Carlos Reservoir. This survey is jointly financed by the Soil Conservation Service, Bureau of Reclamation, Gila Water Commissioner, and the Corps of Engineers. It is estimated that the cost of the survey will be less than one-half that of a survey performed by other methods.

One other method of survey would be applicable only in special cases. It would apply principally to flood-control basins which may become filled with water during floods and are drained as rapidly as feasible thereafter. Such a survey would involve taking a series of vertical aerial photographs showing the shore line. Knowing the reservoir water-surface elevation at the time each photograph was taken and using established landmarks to determine scale and orientation of the photographs, contours could be derived.

Methods of debris removal.--Excavation of small debris basins in the Los Angeles County drainage area has been accomplished almost entirely by use of power shovels and dump trucks. In some of the Los Angeles County Flood Control District flood-control dams, located in canyon areas where access of equipment to the basin is difficult and where haul distances are great, sluicing programs have been undertaken. Principal costs of such excavation are those connected with personnel and equipment used to direct low flows against the banks of deposits in the reservoirs. Records of the Los Angeles County Flood Control District indicate that sediment concentrations up to 12 percent in sluicing discharges have been indicated by sampling measurements, and concentrations of about 4 and 8.5 percent have been determined from before-and-after surveys. It should be noted, however, that removal by sluicing may result in transferring the problem of disposal further downstream. The Los Angeles County Flood Control District has also cut experimental V-shaped notches in the ogee spillways of Verdugo, Scholl, Ward, Bailey, and Snover debris basins. The theory of this procedure is that flood run-off will carry and sluice the fine materials such as silt and sand through the notch and that the residual deposit in the basin which must eventually be excavated will thus be reduced. Since Verdugo, Bailey, and Snover debris

basins discharge into concrete channels, the economy of this procedure in those cases will finally depend upon the relative cost of repairing the concrete channel inverts as a result of increased wear caused by the material released and the cost of excavation of this material if retained in the basin. Precise cross sections in the downstream channels have been obtained and will serve as a basis of determining invert wear caused by the material released.

Costs.--From records of the Los Angeles County Flood Control District, the cost of debris removal using power shovel and dump trucks, based on the most recent excavation at individual basins and during the years 1939-44, has varied from about $0.30 to $0.76 per cubic yard, with an average of about $0.45 per cubic yard. It is estimated that at the present time these costs would be doubled. The cost of debris removal by sluicing at dams is affected by the amount of water available, slope in the basin, and the amount of equipment and labor used to direct flows against deposits. Unofficial estimates of the same agency indicate that the cost of material removed by sluicing has varied from less than $0.01 to about $0.22 per cubic yard, with an average cost of about $0.02.

Operating Personnel.--During flood periods, the operation of basins designed solely for debris storage is entirely automatic. However, when available, personnel are assigned to debris basins during flood periods to observe the action of the basins, record staff-gage readings, and report on the general condition of the basins. Both the Los Angeles County Flood Control District and the Los Angeles District, Corps of Engineers, maintain crews and equipment for emergency repairs. Because of the extremely brief duration of peak flows into the basins and the lack of prior warning, little opportunity exists for making emergency repairs or reinforcing the structures during a flood. Emergency maintenance, therefore, consists primarily of preparing the basins for succeeding floods.

DISCUSSION

H. C. STOREY.* Mr. Dodge's statements as to the importance of considering fire history in designing debris basins illustrate the thoroughness with which he has covered the entire problem. The tremendous influence of fire in increasing erosion rates has been repeatedly demonstrated in southern California, but some workers still do not recognize the magnitude of the influence or the number of years it might last. Mr. Dodge says, "In general, debris production diminishes only gradually over a period of years as a new plant cover becomes established." Recent studies completed by the California Forest and Range Experiment Station corroborate this statement. Evidences of accelerated erosion rates from watersheds in southern California are apparent for eight to twelve years after burning of the chaparral cover. These studies further indicate that in the first year after denudation by fire, the volume of eroded material yielded by a watershed may be increased up to thirty-five times the normal pre-burn rate.

In the author's Table 2, the columns 5 and 6 present average annual rates of debris production as measured in a number of debris basins. It should be borne in mind that these figures may not be at all indicative of a long-time normal rate. Most of the basins in the La Crescenta and Pasadena areas were constructed immediately after the watershed had been swept by fire. Consequently, erosion rates during the next four years were considerably accelerated. Further, although the period of record cited by the author is comparatively short, it includes one flood which might be expected to occur only once in 75 to 100 years, and another flood of about a 35 year occurrence. These factors all cause the recorded rate of debris production to be considerably above that which might be expected if the vegetation were undisturbed and if a full 100-year record were available. The Experiment Station indicates that the normal erosion rates from these watersheds, if vegetation is undisturbed, would range from 800 to 2,400 cubic yards per square mile per year.

In discussing the design of debris basins, Mr. Dodge mentions the necessity of assuming the probable slope of the debris deposit. He recommends the assumption of a slope of .4 to .5 of the natural debris cone at the basin site. These figures correspond very closely to results of surveys made by A. C. Kaetz and L. R. Rich for the Soil Conservation Service, Albuquerque, N. Mex., December 1939. The surveys showed the average grade of deposition above barriers in alluvial washes was 37 percent of the original grade, and in heavy gravel washes the average grade was 49 percent of the original grade.

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* Geologist, Division of Forest Influences, California Range and Experiment Station, Forest Service, Berkeley, Calif.

W. J. PARSONS, JR.* Mr. Dodge has made a very able presentation of the manner in which the Los Angeles District, in cooperation with the Los Angeles County Flood Control District, has met the problem of debris control under the peculiar conditions which exist in the Los Angeles area. The Sacramento District, in its solution of a similar problem of debris control on the streams draining the gold mining country in the Sierra Nevada, has developed designs and methods of operation of debris basins which differ radically from those used in the Los Angeles District. The difference between these two solutions of the debris control problem demonstrates the paramount influence of local conditions on the design and operation of debris basins.

A brief comparison of hydrologic and sedimentation conditions in these two areas illustrates how radically such conditions can vary. The Los Angeles debris basins are located on the debris cones of small ephemeral streams draining the precipitous exposed seaward face of the San Gabriel Mountains near the ocean. The watersheds above these debris basins are deeply weathered, and have been known to produce an average annual debris load from small watersheds of as much as 15 acre-feet per square mile with production of as much as 75 acre-feet per square mile during a single major storm. Even the larger streams of this group, with drainage areas in excess of 20 square miles, produce average annual rates in excess of 2 acre-feet per square mile. Debris ranges in size from mud to gigantic boulders, and as much as one-half of the deposited debris may consist of boulders larger than one-man size. Debris basins must be located in intensely developed urban areas, and therefore must be severely restricted in size. The major part of the debris is produced during sudden torrential rains, and the majority of the debris produced by a storm may enter the debris basin within one or two hours or less. Consequently, automatic operation is essential since operating staffs would have little or no warning of the debris inflow. As much as 60 percent of the inflowing water may consist of debris. The source of the debris is generally uncontrollable except by long-range planting, fire protection, and check dam programs.

In contrast, the debris basins of the Sacramento District are located in the canyon sections of large permanent streams draining the gently sloping seaward face of the Sierra Nevada. These mountains are located about 100 miles inland from the ocean and are separated from it by the shielding ridges of the coast ranges. Soil cover on these mountain slopes is relatively stable, and the large basins to be controlled are estimated to have an average annual rate of debris production of only .2 to .3 of an acre-foot per square mile under normal present conditions of development. Although large volumes of debris can be produced by hydraulic mining operations above the debris basins, this mining is rigidly controlled by permits issued by the California Debris Commission, and can be stopped at any time when inflow of debris to the basins becomes dangerous to their safety or operation. This debris is quite uniformly graded from sand to cobblestones and contains only minor amounts of fine clay and large boulders. The basins are located in unimproved canyon reaches, remote from large centers of population, and can easily be made large enough to control all debris movement, both natural and from mining operations, for periods of 20 to 100 years. The primary production of debris occurs principally during the summer snowmelt period when sufficient water is available for hydraulic mining operations, and the transport of this debris from the mining pits down the main channel into the debris basin is largely accomplished by the sustained flows which last a considerable portion of the year. The region is relatively free from the torrential rains which occur near the seacoast, and the majority of the run-off originates from prolonged gentle rainstorm or from the slow melting of accumulated winter snows. Because the general time of occurrence and relative amount of debris inflow during each year can be quite closely predicted, operation can be planned for long periods in advance and emergency measures are rarely necessary. Failure of the basins to fully control debris will result in only minor monetary damage and no threat to life is involved.

The natural rate of production of debris from the Sierra basins is usually well within the capacity of the channels to transport to deep water in Suisun Bay. Normal cultural improvement of these basins has not materially increased the debris problem or produced dangerous conditions along downstream channels. Intensive mining activities during the period from 1849 to 1884 tore loose tremendous quantities of debris, a large part of which was carried downstream and deposited throughout the valley floor reaches of the principal streams with resultant severe damage to developments along these channels. Following the cessation of this form of mining the streams have succeeded in clearing their channels of most of the mining debris, and these channels have attained a reasonably stable condition. The Debris Act of 1893 prepared the way for the resumption of hydraulic mining, provided that proper debris basins were constructed to prevent any repetition of the damaging debris problem of the 1800s. Under the authority of this Act, two

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debris basins have been constructed by the Sacramento District and two more basins are being planned. These basins are intended to balance the erosive action of mining and to maintain the status quo rather than to improve a naturally hazardous condition. Any incidental improvement of natural conditions resulting from the inevitable storage of natural debris along with the mining debris has not been evaluated.

As a result of these peculiar conditions, the design and operation of Sacramento District debris basins differ radically from those of the Los Angeles District. A brief summary of the basic criteria used in the location and design of the debris basins in the Sacramento District is as follows:

Location. - Basins should be located so as to control, at a single point, as large a portion of the area adapted to mining operations as possible; should be located below all important mining sites in this portion of the area; and should be located above the intake of all important irrigation or water supply diversions from the stream. This criteria places the debris basins in the canyon reaches of large permanent streams well behind the foothill line.

Type. - Basins should be of permanent type which will have a long life and require a minimum amount of maintenance; of relatively large size so as to function over long periods of time without requiring removal of the trapped material; and capable of providing a highly efficient settling action. These criteria, when considered in conjunction with the indicated location in narrow rocky canyon sections, indicate the use of relatively high dams to hold back a deep quiet pool of water several miles in length which would settle out all except the finest suspended load.

Volume required. - The volume should be sufficient to store the entire yield from the controlled area for a long period of time. The yardage of gold-bearing gravel in the controlled area which could be profitably mined during the economic life of the project was estimated by questionnaires and by field reconnaissance, and the conservative assumption made that each cubic yard of gravel mined would eventually cause the deposition of a cubic yard of debris in the downstream reservoir. To this yardage was added the estimated yardage of natural debris which would enter the basin during the life of project. This method was extremely conservative since it is known that a considerable portion of the mined material will not pass down the stream in the foreseeable future but will be permanently lodged at some point between the mine workings and the debris basin. It should therefore be possible to control considerably more mining from areas not now recognized as mining prospects or to control debris for a longer period of time.

Volume provided. - The volume of debris storage provided by each reservoir was computed as the volume below a sloping line rising above the crest of the spillway at a rate of from 3 to 5 feet per mile (about 25 percent of the natural slope of the streams). This estimation of the probable slope storage is also extremely conservative in view of recent observations in the vicinity of the debris dams which indicate debris slopes of as much as 20 feet per mile or more in locations similar to the debris basins.

Outlets. - There should be no large functional outlets below the crest of the dam so that the entire flow of the river must pass over the top of the dam. This design will create and maintain a deep, permanent pool behind the dam which will insure the settlement of all heavy debris at a considerable distance upstream from the dam and will cause settlement of all except the very finest portions of the debris. Outlets should be entirely automatic so that operational responsibility will be light.

Other uses. - Debris storage may be combined with other uses such as power production or flood control, provided that water is taken out at a relatively high level in the reservoir so as to prevent transport of appreciable quantities of debris through the reservoir and the minimum pool is sufficiently deep and long to cause deposition of the majority of the debris well upstream from the outlets.

A typical example of a debris dam designed according to the above criteria is the North Fork Debris Dam located on the North Fork of American River, east of Sacramento. This dam is a concrete dam of thin arch type, about 140 feet high, and capable of impounding about 28,000,000 cubic yards (17,000 acre-feet) of debris (the estimated debris load in the next 20 years). It is located some 20 miles back of the foothill line in a deep rocky canyon. The sole function of this reservoir is to store debris, and there are now no functional conduits through the dam (except for a small sluice gate for emergency draining operations or other special purposes), and all outflow must pass over an uncontrolled spillway at the top of the dam. Operation is therefore entirely automatic. The reservoir has no appreciable reducing effect on floods and

the flood control value is inappreciable. The pool above the dam extends about 5 miles upstream. Only a very small percentage of the storage space in the dam has been filled during the 7 years of operation. This is largely due to war conditions, which have minimized mining operations above the dam. Only about 400,000 cubic yards of material have been excavated during the last 7 years instead of the estimated 9,000,000 cubic yards. With the resumption of normal mining operations, the annual rate of excavation is expected to increase rapidly, with resultant increased deposits in the basin. No heavy debris has passed the reservoir since its construction, and the only outflow of debris has been some extremely fine suspended material. Although it was generally hoped that the dam would almost completely clarify the water, this was found not to be the case. There has been sufficient turbidity in the outflow to induce some minor nuisance claims by operators of downstream diversions. The Upper Narrows Debris Dam (Fig. 1) on the main channel of Yuba River, about 10 miles behind the foothill line, has been adapted for power production by a private power company under a leasing agreement.

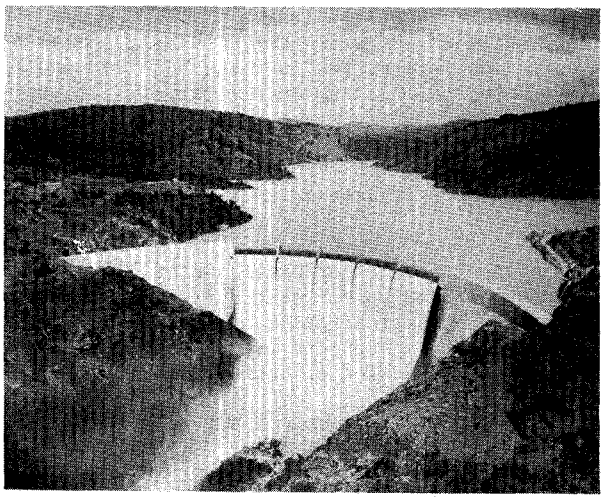


Figure 1. UPPER NARROWS DAM.

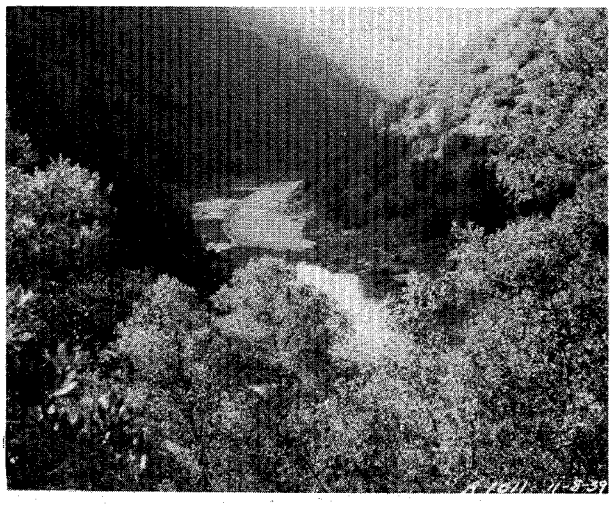


Figure 2. RUCK-A-CHUCKY SITE.

A long and useful life is anticipated for these two dams. Two other similar dams, one near Rollins on Bear River, and the other at the Otter Creek site on the Middle Fork of American River, are under consideration. The entire cost of the debris control features of these dams will be repaid by an assessment against those mining interests which will use these debris basins, the assessment being based on the excavated yardage.

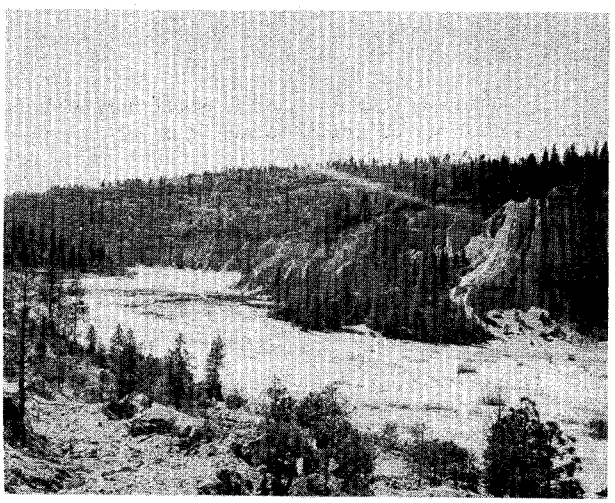


Figure 3. MINING PIT

Passing mention will be given to another type of debris control works which is intended to control mining debris which has already been transported out of the mining areas and deposited in the valley floor channels near the foothill line. These deposits still contain considerable gold values and are being redredged by mining companies. The dredging permits issued to these companies require the excavation of a single channel through the center of the debris-covered area, and the placing of the spoil in the form of continuous dikes on either side of this channel so as to prevent erosion of the deposited materials in overbank areas by swiftly moving water during large floods. By this means, most of the temporarily deposited materials are permanently fixed in place and will not move downstream into the navigable reaches of the river. Our office has also encouraged the use of gold dredging methods which will insure redeposit of dredged materials in the immediate

vicinity of the dredging areas and prevent such materials reaching permanent stream channels and the navigable reaches of Sacramento River.

All the foregoing discussion demonstrates how radically local conditions will modify the design criteria for debris basins, and how necessary it is to fit these criteria to local conditions.

J. H. DOUMA.* The author has assembled and presented much of the available data on the design and operation of debris basins in southern California. Many engineers in private practice, in local agencies such as the Los Angeles County Flood Control District, and in the Department of Agriculture and Corps of Engineers of the Federal Government have been concerned with the problem of debris control in the Los Angeles area. The basic principles of design and optimum methods of operation have been based on the accumulated experience of those engineers.

While one may find many publications on the design of flood control dams, channels, and related structures, the author's paper is the only source of information on the subject of debris basins known to the writer. Check dams for the control of gullying in upland areas and for the stabilization of stream beds and banks are designed, in general, by the principles and methods cited by the author. Design criteria for and the application of drop structures to gully and channel control have been presented in paper No. 2198, "Hydraulic Design of Drop Structures for Gully Control," by B. T. Morris and D. C. Johnson, Transactions of American Society of Civil Engineers, Vol. 69, 1943, page 887.

Early debris control structures in southern California consisted of small and inexpensive timber, rock and concrete check dams and drop structures which served as temporary expedients but proved wholly ineffective during large floods. As suburban areas continued to develop, it became necessary to construct larger control structures (debris basins) to prevent the costly loss of life and destruction of homes and other property by the action of debris flow during flood discharges.

The terms "debris dam," "check dam," and "drop structure," have frequently been misused and, generally, the functions of each are not clearly understood. A drop structure is sometimes called a check dam, and a check dam is often called a debris dam. The following definitions are suggested for general use in flood control work.

A debris dam consists of an earth embankment constructed of material excavated from an upstream debris pit and a spillway structure, usually located at the mouth of a canyon, to form a settling basin for the separation of bed-load debris from flood flows. The debris dam and pit together with one or more inlet structures for stream-bed control upstream of the pit are called a debris basin.

A check dam consists of a small dam with spillway crest a few feet higher than stream bed level, constructed across a gully or small stream channel, to eliminate upstream bank and bed erosion by reducing velocities. Check dams control the stream grade not only at the overflow crest, but also through the ponded reaches upstream from the structures.

A drop structure consists of a small overflow structure with crest at stream-bed level, located across a gully or small stream channel, to establish permanent control elevations below which an eroding stream cannot lower its stream bed. Thus, drop structures, placed at intervals, stabilize a gully or small flood channel by changing the stream-bed profile from a continuous steep gradient to a series of more gently sloping reaches separated by the drop structures.

It is apparent from the meager amount of debris production data presented that there is need for many more records before reliable relationships can be determined between debris production and such factors as drainage area, topography, geologic structure, character of alluvial fan, type of vegetal cover, and fire history. Figures 1 and 2 of this discussion illustrate how available records may be analyzed to determine design criteria for debris capacity. Data given in the author's Table 1 on design debris capacity and total debris deposited during the flood of February-March 1938, in the La Crescenta area have been plotted in Figure 1 for drainages up to two square miles in area. Separate plots should be made for drainage areas having different debris-producing characteristics.

* Office, Chief of Engineers, Department of the Army, Washington, D. C.

The plotted points in Figure 1 indicate a straight line relationship between drainage area and debris deposited during the 1938 flood. Also, design debris capacities, which have been selected for those basins in the La Crescenta area, are related approximately by a straight line to the drainage area. The plotted locations of points 1 and 2, which correspond to the design debris capacities of Dunsmuir and Pickens debris basins, respectively, are of particular interest. Based on the average straight line relationship for design debris capacity, it appears that Dunsmuir debris basin is somewhat over designed and Pickens debris basin is considerably under designed. The latter is evidenced by the fact that the amount of debris deposited in Pickens debris basin during the 1938 flood exceeded its design capacity.

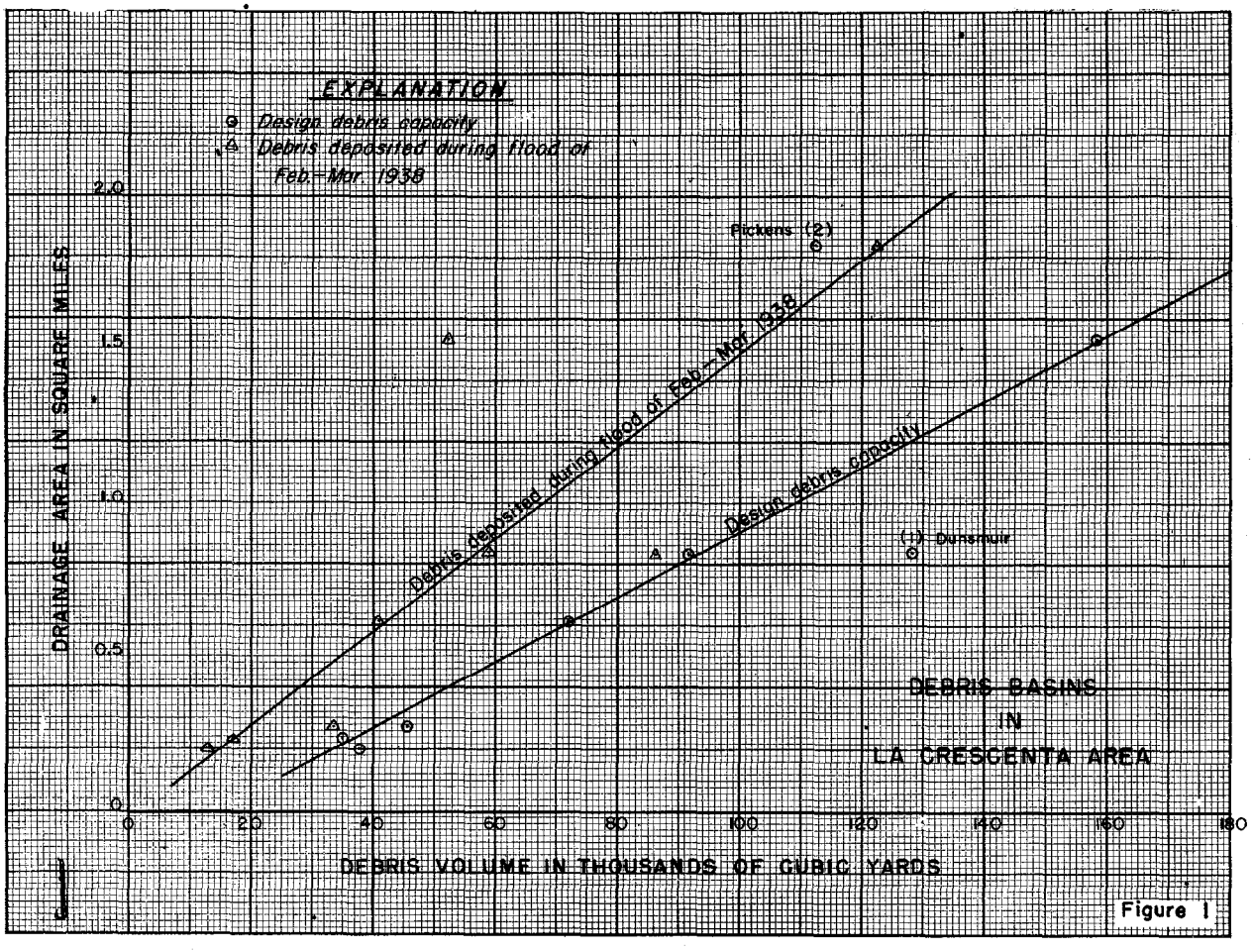


Figure 1

It can be determined from Figure 1 that design debris capacities of basins constructed in the La Crescenta area exceed deposits during the 1938 flood, varying from approximately 50 percent for a drainage of two square miles to 100 percent for 1/4 of a square mile. Larger allowances should be made for smaller drainage areas, as has been the practice, because estimates of debris production are probably less reliable for small drainage areas.

The author has suggested that plans for future debris basins in areas similar to the La Crescenta area provide for debris capacities up to 200,000 cubic yards per square mile. For drainage areas of two square miles that allowance would represent an increase of 100 percent in design debris capacities and would provide capacities equivalent to approximately three times the amount of debris deposited during the 1938 flood. In view of the fact that the 1938 flood was the largest occurrence in approximately a 60-year period of record, it is questionable whether design debris capacities, based on an allowance of 200,000 cubic yards per square mile of drainage area, are economically justifiable.

The data given in the author's Table 2 for maximum and average annual debris production in the La Crescenta area are plotted in Figure 2. While more data are needed to establish

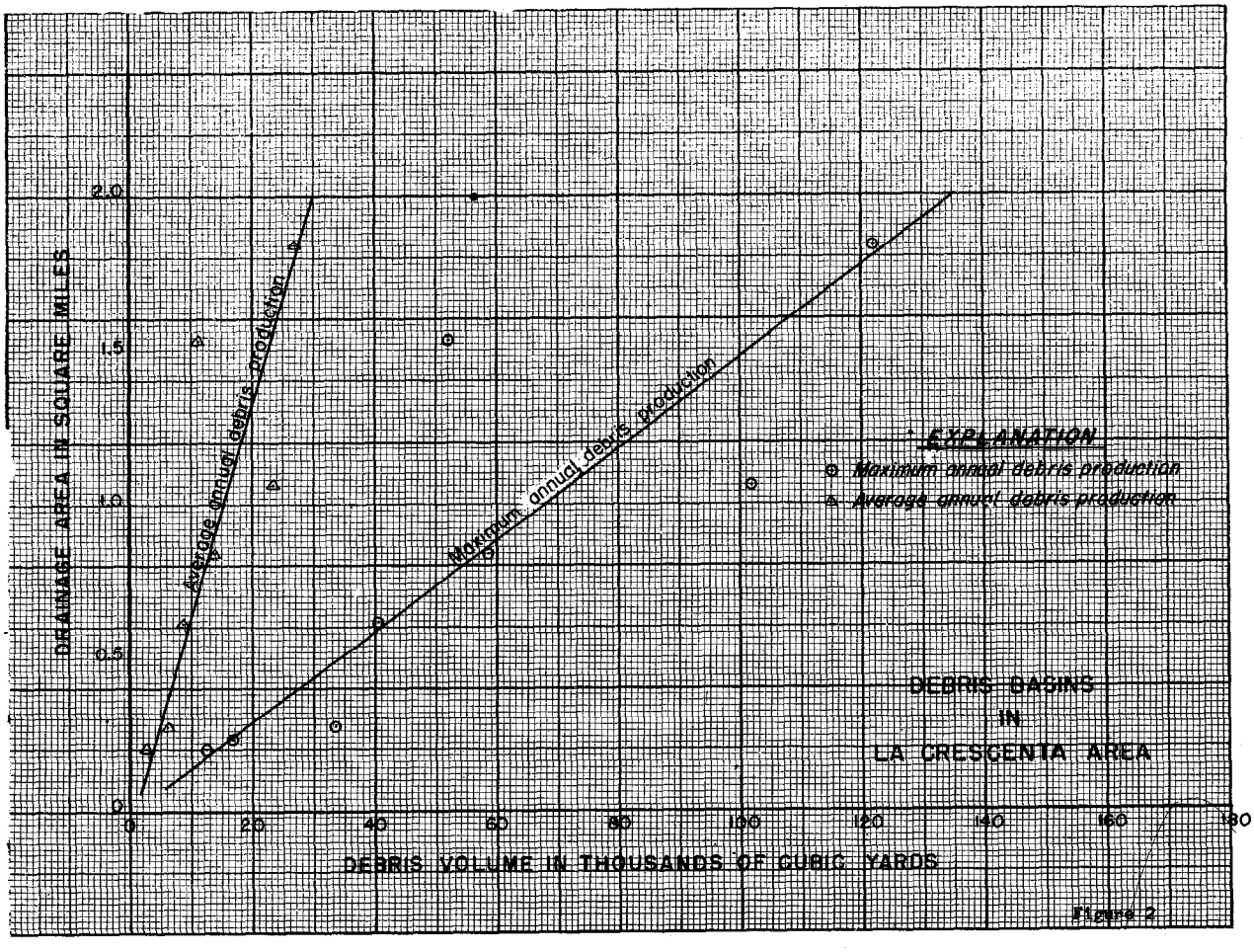


Figure 2

completely reliable relationships, the two straight lines may be used as guides to determine maximum and average annual costs of removing future debris deposits from debris basins which control drainage areas up to two square **miles** that have debris producing characteristics similar to those of the La Crescenta area.

Mention has been made of the probable stable slope of material deposited in a debris basin. The grade which the debris deposits finally will take after a basin is eventually filled is of importance in determining its effective capacity. Average values of 40 percent to 60 percent of the natural stream bed slope, based on data obtained from the operation of existing debris basins during the 1938 flood, have been used for design purposes. Additional studies are required to determine whether definite relationships can be derived for debris slope and drainage area characteristics. It would appear that when other factors are equal the final debris slope in any basin would be inversely proportional to the size of the drainage area. The size and gradation of material transported by the stream have very definite effects on the debris slope, coarser material taking a steeper slope.

The practice of sloping the top of the debris basin embankments upward from the spillway structure is required to maintain the design freeboard only when the embankment extends upstream from the spillway to form a crescent shaped basin. The top of the embankment should not be sloped upward when short embankment sections are located normal to the stream flow at or near the mouth of a narrow canyon because, in this case, debris would discharge over the spillway before it would deposit to spillway-crest elevation along the upstream side of the embankment and there would be no encroachment on the freeboard.

The author's Figure 8 was prepared originally by the writer for estimating debris production in San Antonio Canyon. The straight line was drawn to envelope all plotted points, except points 2, 3 and 6 for the 1938 flood. The enveloping line was not drawn to include those points because they included undetermined amounts of debris which were deposited during several smaller floods which occurred during the 1938 flood season. The enveloping line is believed to provide a

conservative basis for determining debris storage allocations for combined debris and flood control basins in southern California.

The problem of floating debris has been an important one in the Los Angeles area. Trash racks have been constructed to prevent blocking of the outlet conduits of combined debris and flood control basins. However, as experienced in the January 1943 flood, large percentages of trash rack areas were plugged by small floating debris unless a pool of considerable depth was formed before making large reservoir releases. The most serious case of plugging occurred at Sepulveda Dam during the January 1943 flood, where the maximum trash rack loss was approximately 24 feet and the outlets with all gates open were able to discharge only 35 percent of the required reservoir release because of the plugged trash racks. The trash problem at Sepulveda and other dams in the Los Angeles area was solved by removing the trash racks thus permitting the trash to pass through relatively large conduits.

The experience with floating debris in the Los Angeles area indicates that in many cases trash racks should not be used with relatively large conduit openings when small floating debris would pass through the outlets, but would plug trash racks. In cases like San Antonio basin, where enormous quantities of both small and large sizes of floating debris would probably block the outlets if attempts were made to pass such debris through the outlets, the reservoir should be operated to cause the trash to float on the reservoir water surface. The operation would require that the reservoir be filled to provide a pool depth above the bottom of the outlet openings equivalent to approximately three times the conduit height before making large reservoir releases.

The author has discussed the need for inlet structures or a derrick stone stabilizer across the canyon at the upstream end of a debris pit to prevent degradation of the stream bed. While these structures are used in narrow canyons, they are usually too costly for a wide debris pit excavated on a broad debris cone, as in the case of Santa Fe flood-control basin, which is located about one mile downstream of the mouth of San Gabriel River Canyon. Periodic measurements of debris accumulations in Hansen flood-control basin reveal that when an inlet structure or stabilizer is not provided, stream-bed degradation upstream of an excavated pit and debris accumulation in the basin will be at an accelerated rate, until the stream-bed grade upstream of the pit is reduced to approximately the original stable grade. Stream-bed degradation together with normal debris movement at Hansen has depleted approximately 50 percent of the 50-year design debris capacity in only seven years of operation.

Sluicing operations at a combined debris and flood control basin will effectively reduce bank caving and stream-bed degradation in an unlined downstream channel. Although the stream-bed degrades during operations for flood control, it agrades during sluicing operations. With regard to sluicing material into concrete channels, experience of the Los Angeles County Flood Control District indicates that if the sluiced material is limited to sand and gravel up to pea size, the wear of concrete inverts will be negligible.

The job which these small debris basins are being designed to do is an enormous one. As the crumbling San Gabriel Mountains continue to creep toward and threaten burial of developments in the adjoining valleys, the debris basins will be the only line of defense. The total amount of excavation that will be required to maintain debris basin capacities over the centuries may well be equivalent to a large percentage of the total volume of the mountains. The problem of obtaining disposal areas will become critical with time.

WATERSHED MANAGEMENT FOR SEDIMENT CONTROL

by Reed W. Bailey and George W. Craddock.*

Introduction

Management of forest and range lands must be a part of any comprehensive approach to the control of sedimentation. These lands embrace about 80 percent of the land surface of the United States. They are covered for the most part by a mantle of soil and rock materials to depths of from a few inches to many feet. Because of shortcomings in management a portion of this mantle has been loosened and eroded. Much of this material has been added to the normal load of sediment carried by streams and has accentuated the seriousness of sedimentation problems in all parts of the country. There is a tremendous volume of soil and mantle material remaining on these lands. This material must be kept in place for productive purposes as well as for the prevention of an enormous increase beyond present sedimentation rates.

Management of forest and range lands for sediment control is for the most part a system of protecting, improving, and utilizing the timber, forage, and other resources in such a manner as to perpetuate them and, above all, to perpetuate the soil. The basis for this system is well founded: It rests on demonstrable evidence 1/ that plant cover--by reason of its binding effect and its influence in promoting the infiltration and storage of precipitation and in minimizing surface run-off--is essential to soil development, productivity, and stability.

There has been general public acceptance of the need for adequate watershed management and of the principles on which it is based. Recognition of the need for more effective watershed management was a major reason for creating the system of National forests, for passing the basic Soil Conservation Act and the Taylor Grazing Act, for undertaking the C.C.C. program, and for broadening the Omnibus Flood Control Act of 1936 to include surveys and action programs on watershed lands.

There is a rather wide appreciation of the role of dense forests in maintaining soil stability. However, uncertainty continues to prevail regarding the effectiveness of watershed management for coping with sedimentation problems in the West. One reason for this, no doubt, is because the vegetation on extensive areas is less impressive than forests, consisting of low shrubs, grasses, and other herbs. Another reason is that because high rates of normal erosion and sedimentation have been observed in places where these phenomena are the natural result of bare rock and sparse vegetation, it has been easy to conclude that all manifestations of erosion and sedimentation are geologically normal.

These, however, are mistaken concepts. There is ample evidence that much erosion in the West has been induced by man's activities and that even the lesser vegetation in this area is effective in restraining run-off and in keeping soils stable.

Proponents of watershed management do not claim that vegetation will prevent normal erosion or that it will reduce the normal sediment load of streams. They claim only, first, that plants and litter can prevent an enormous increase in erosion and sediment production, and second, that restoration of adequate cover conditions can reduce sedimentation rates materially where misuse of the land has caused a speeding up of gradational processes above the normal.

Geologically Normal Sedimentation

Before man entered the picture, streams in this country had developed definite characteristics of flow. In some instances they were generally clear and flowed with a relatively constant volume. The regimen of other streams was marked by great variations in volume and time of flow,

* Director and Conservationist, respectively, Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah.

1/ See "References" at close of comments.

and vast differences in silt content. Each stream was the reflection or resultant of such normal factors and forces as the climate, the topography, the geology, and the soil and plant mantle. All of these factors and forces had been operating through the ages to give rise to definite land forms, specific soils, and to characteristic stream channels, steam flow, and sediment loads.

Normal erosional processes of varying rapidity and consequence are continuing to operate. We know, for example, that erosion is proceeding so slowly on some areas that soil is being formed or accumulated more rapidly than it is being removed. Streams from such areas carry only negligible loads of sediment. We know, too, that in other areas such as Bryce Canyon, Utah (Fig. 1), in certain Mancos shale areas in Colorado and Utah, in the breaks of the Missouri River and in the badlands of the Dakotas, climatic and geologic conditions have prevented soil formation and plant growth and the fixing of the land surface. In these drainages, run-off always has been rapid and normal erosion pronounced, giving rise to muddy and highly fluctuating streams. Moreover, we know that between these extremes are all gradations of normal watershed condition and sedimentation rates.

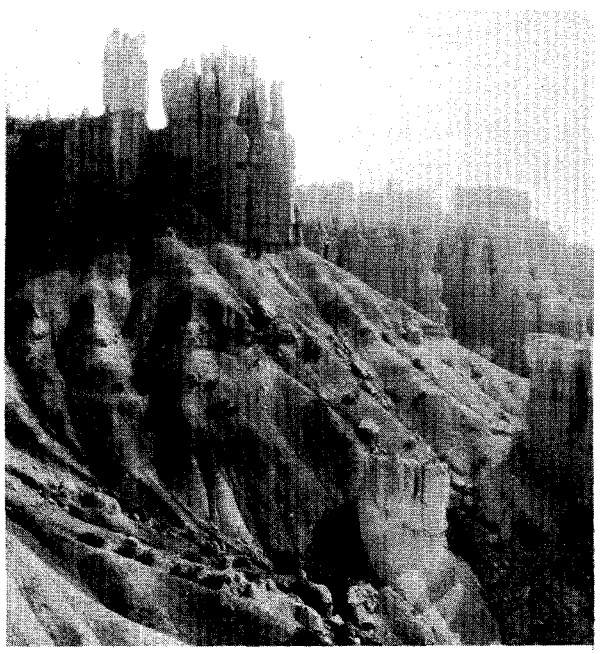


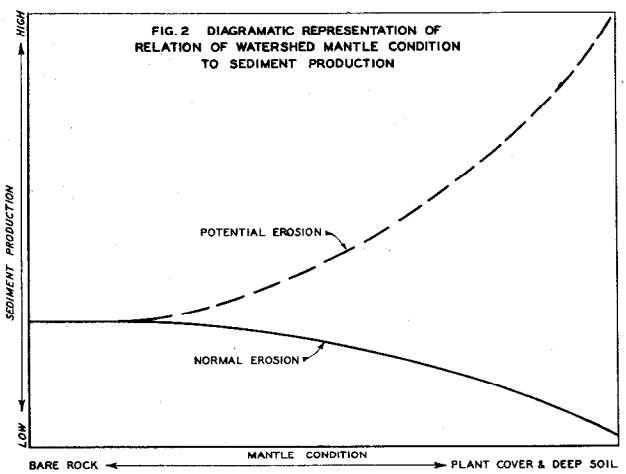
Figure 1. Normal geologic erosion high and storm run-off from such areas is heavily charged with sediment.

Watershed managers recognize that mountains have been carved by erosion and that valleys have been filled with this waste material as a result of normal geologic processes operating over the ages. Watershed management must recognize what the normal is and adjust use of the land to it. Management must be able to recognize these normal rates as a basis for judging the extent to which normal rates have been speeded up. Management is also concerned with the fact that erosion and sediment production can be greatly increased on forest and range lands as a result of unwise use above the geologic norm.

Stable Soil on Steep Slopes

Knowledge of how soils are formed and attain stability on steep slopes is helpful in understanding sediment potentials and how these potentials are released through destruction of vegetation. Most of the soils on mountain slopes are a residual product of rock weathering and plant development. This residual mantle developed and arrived at the present relatively stable condition under the influence of all of the weather--the lightest and heaviest storms, drought and frost, and the effects of fire, rodents, game, and all other natural influences--to which the slopes have been subjected over a period of time much greater than is measured by man's experience. This is obvious or the soil would not be there today.

Soil and rock waste that has accumulated on mountain slopes under the formative and protective influence of vegetation constitutes a high sedimentation hazard. On a given slope the more water from precipitation that infiltrates into the soil mantle the deeper the soil becomes due to an increase in rock weathering, the denser the vegetative cover, and the finer and richer the soil. With this development there arises a high erosion potential and consequently a greater and greater source of **potential**



sedimentation. The sediment potential on these soil-covered slopes is much higher than on slopes where soil has not developed (Fig. 2).

Sediment potentials also increase with steepness of slope. As has been previously reported 2/ numerous measurements have been made on slopes in the semiarid region, including Utah and Idaho, to determine the maximum angles at which they stand at rest with and without vegetative cover. These revealed that nonvegetated talus material stood at gradients between 68 and 80 percent, or an angle of about 36 degrees. Vegetated slopes, on the other hand, underlain by fine-textured soils, but derived from the same parent material as the barren talus, stood at angles up to about 60 degrees, or 173 percent. Without the protection of vegetation, slopes of such fine material would not stand even at gradients as high as the coarse talus. It would fall from the slopes by the force of gravity.

The only way the soil mantle could have been formed and maintained on these overly steep slopes during the steepening period, or held in place today against the forces of gravity, impact of rain, freezing, thawing, and surface run-off was through interdependent development of the plant cover and soil profile in which the plant cover serves the dual purposes of binding the soil and maintaining a high rate of infiltration (Fig. 3). Such slopes, by reason of the binding effect and adequate infiltration rates afforded by the vegetation, have existed during their development in spite of the cyclic changes of the climate as well as extreme variations within these cycles. All vegetated slopes, in other words, are a manifestation of an adjustment between aggradational and degradational forces in which the plant cover is the key to stability. Without it, the mantle will be released.

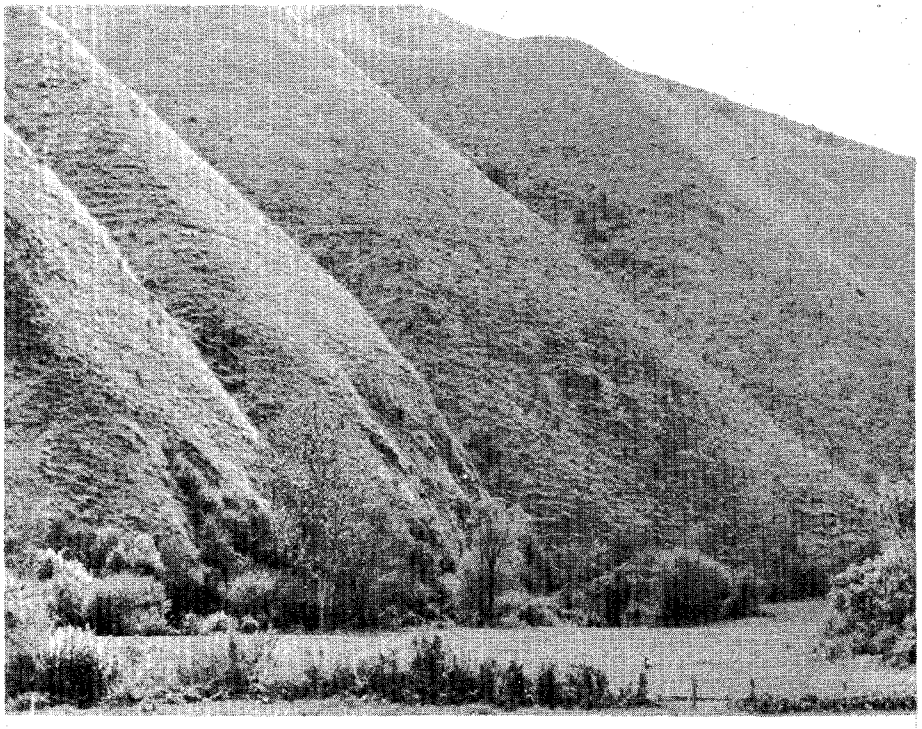


Figure 3. Vegetated slopes underlain by fine textured soils with well developed profiles are stabilized at angles far steeper than the angle of repose for earth materials not protected by plant cover. Here on the Little Salmon River drainage, Idaho, grass soil mantle rests at angles up to 60 degrees (173 percent). Erosion is slight and streams from watersheds with this type of cover and soil carry little sediment. The erosion and sediment production potential, however, is extremely high.

2/ See "References" at close of comments.

Accelerated Erosion

The reduction of the plant cover below critical density for protection sets in action violent erosional processes. Surface run-off is increased. Erosion is accelerated and more sediments are added to the normal stream load.

Reduction of plant cover not only sets in motion the erosion of soil from slopes, but the increased volume of run-off and the newly acquired load of debris cuts into the canyon and valley fill. The valley fill, when once disturbed by being gullied or channeled, yields to erosive action of running water more readily so that less rainfall causes more run-off and more erosion with increased sedimentation in the lower gradient sections of the drainage. This change goes on at an accelerated rate until a new base level is reached--until gullies cut to bedrock or the stream becomes stabilized again by developing a graded condition.

Because of a disturbance of this equilibrium, due primarily to the destruction or depletion of the plant cover, we are now witnessing on certain areas in all regions of the United States an abrupt change in the normal erosional processes. Through the action of wind and water, the alluvium of graded valleys is being deeply trenched, the soil is being stripped from formerly stable slopes and accompanying this is excessive deposition on the aggrading areas. In short, we are witnessing a new epicycle of erosion on land surfaces that had been graded and relatively stable for thousands of years (Fig. 4). It is with the perplexing problems caused by quickened run-off from these areas and the destructive accelerated erosion accompanying it that we are most vitally concerned, and not the so-called normal erosion that has throughout millennia sculptured and molded the face of the earth.

Induced Sedimentation in the Colorado River Basin

The Colorado River drainage has long been recognized as one of the most rapidly eroding areas in the United States. Evidence has been uncovered, however, revealing widespread induced or accelerated erosion in this already rapidly eroding area. A reversal of gradational processes has been recognized by geologists whose observations show that the present degrading habits of many of the streams are of comparatively recent origin. Examinations conducted by the Intermountain Forest and Range Experiment Station revealed that 111 of the 115 major tributaries of the Colorado and Green Rivers above Lees Ferry in Utah, together with the Virgin River, Kanab Creek, and Johnson Wash, are cutting deep channels, scouring bedrock, and rapidly removing the valley alluvium.

Figure 4. Soil mantle developed on steep slopes under the influence of vegetation constitutes a potential source of large quantities of sediment. Thinning out of the vegetation or removing it from the slope by fire or overgrazing releases destructive run-off.

Concurrent with these extensive observations, detailed physiographic and historical studies are highly significant since they not only substantiate the occurrence of new and widespread channeling but also throw light on the cause 3/. In this study it was observed that the recent channeling not only has cut more deeply than ever before into the valley fill, but the channeling is more extensive and in many places is cutting into previously undisturbed valley fill.

In the narrow valley along Kanab Creek, near the town of Kanab, Utah, for illustration, several old erosion channels are exposed in the banks of the recently formed wash which is 90 feet deep and from 200 to 300 feet wide. In this gorge, all of the exposed old erosion channels are definitely higher than the present channel bottom. Moreover, in the upper reaches of this same drainage, a broad valley is being deeply channeled by several washes working back by headward erosion.

3/ See "References" at close of comments.

Here there are no terraces to mark higher stages of valley filling or erosional unconformities in the exposed alluvium of the channel walls. This evidence indicates that upper Kanab Valley is now being channeled for the first time since the valley began to fill with sediment.

Johnson Valley, 12 miles to the east of Kanab Creek and Kitchen Valley, a tributary of the Paria, are being trenched in a similar manner. Here again no evidence of previous disturbance was observed in the newly exposed alluvium.

The cause of this speeding up of erosion and sedimentation in the Colorado drainage area has been the subject of much speculation. Climatic change and the depletion of plant cover have been advanced as possible causes. No doubt climatic change of the right magnitude and nature could bring about such changes. But in considering climatic change as a probable cause of increased erosion and sedimentation in this area, it would be well to ponder the fact that other areas throughout the United States as well as in other countries, located in regions with radically different climatic conditions, are also being subjected to extremely accelerated erosion. Such a widespread occurrence of a speeding up of soil erosion would require that a proponent of climatic change have extraordinary proof before advocating it as a primary cause of recently accelerated erosion in the Colorado River Basin.

Climatic records for this area show no distinct change in precipitation or temperatures. Climatological measurements are not, however, the only reliable indicators of climatic change. Among the best of other indicators are changes in rates of erosion and sedimentation in drainage basins where soil and plant cover have never developed. In these areas, erosion and sedimentation respond readily to a change in climate.

Bryce Canyon in Utah and the badlands near Chinle, Ariz., are typical of such drainages. Observations in these areas revealed no evidence of storm run-off having cut deeper channels or deposited a larger volume of sediments than has been occurring normally for a period beginning long before settlement. This indicates a change of climate sufficient to disturb the gradational equilibrium of this region has not occurred.

A major change which has occurred and which is known to be capable of accelerating erosion 4/and increasing sediment loads is the depletion of the plant cover that has taken place on extensive areas since settlement, mostly because of unregulated grazing. That depletion of the vegetation is the primary cause of the accelerated erosion is further borne out by historical records. These show that floods and channeling have followed settlement in place after place irrespective of the dates of settlement.

For example, herds were first moved into the headwaters of Santa Clara Creek in southern Utah in 1863. Seven years later (1870) the famous "mountain meadows" began to erode vigorously. Kanab and Long Valleys were settled in 1868, while channeling began in 1883, or 15 years later. Paria, a settlement on the middle section of Paria River drainage, was settled in 1871, and has since been abandoned because of the destruction of the arable land by floods which began in 1883 and 1884. Escalante, farther east on the Escalante River, was settled in 1875, and 15 years later channeling of the valley flats was in progress. Kitchen Valley, a tributary of the Paria, was among the latest areas to be converted into cattle ranches, but since 1915 a new channel in the valley fill, in places 40 feet deep, has cut through half the length of the valley, destroying shallow lakes and draining much meadow land.

Induced Mud-Rock Floods in Northern Utah

There has been a similar sequence of events--settlement and watershed use followed by accelerated erosion and debris floods--in practically all parts of the West. Some of the most spectacular manifestations of this sequence are certain mud-rock flows which have occurred in recent years along the west front of the Wasatch Mountains in northern Utah. Six of seven watersheds ranging in size from about 1,200 to 6,000 acres in the Farmington-Centerville portion of Davis County, Utah, have produced such floods. Here in 1923, and again in 1930, mud-rock flows issued from the short, steep canyons and deposited boulders weighing as much as 200 tons and other debris on valuable community property at the base of the mountain.

This area offered unusual opportunities for the study of the history of flooding and for measuring the effects of watershed management and the lack of management on run-off, erosion, and sedimentation. The fact that the ancient Lake Bonneville left deltas, terraces, and other deposits at the mouths of the canyons made it possible to differentiate between pre-Bonneville, and post-Bonneville deposition.

4/ See "references" at close of comments.

Geological observations revealed that the recent floods in several canyons of this area cut to extraordinary new depths into previously undisturbed sands and gravels of the deltas and terraces of ancient Lake Bonneville. They also deposited quantities of debris and sediment on the former bottom of the old lake far in excess of the previous normal rate of deposition, thus indicating these new floods to be unprecedented in modern times 5/.

By following the freshly scoured channels, the sources of these floods were found to be areas of from a few acres to less than one acre in extent in the headwaters at elevations of from 7,500 to 9,000 feet on which the plant and litter mantle had been drastically reduced by very heavy overgrazing and to some extent by fire. That these areas were the source of the flood run-off was evidenced by an efficient system of gullies freshly cut in the soil mantle. In the aggregate these deteriorated and gullied flood-source areas covered less than 10 percent of the mountainous catchment areas.

Surrounding and intermingled with these flood sources were well-vegetated areas on which there was no evidence of surface run-off or of soil loss. Here the litter was undisturbed and there were no rill marks and freshly incised gullies. That these areas received as much rainfall as the gullied, flood-producing areas but were able to absorb and hold it is supported by examinations of the soil mantle immediately following flood-producing storms. These showed penetration of moisture to depths of 6 to 10 inches on the nonflood sources, whereas on the deteriorated areas, penetration of moisture was generally less than 2 inches.

This same relationship between vegetation and erosive run-off has been demonstrated many times by measurements on plots representative of the flood- and non-flood-source areas on these watersheds since 1934. During several of the heaviest rains experienced in this area, for example, the denuded areas yielded from 24 to 43 percent of the rainfall as surface run-off, whereas run-off on the nonflood-source areas has been less than 1 percent. The flood-source areas have lost the equivalent of from 83 to 181 cubic feet of soil per acre during individual storms, whereas on the nonflood-source areas there has been no measurable amount of soil lost (Table 1).

Table 1. SUMMER STORM RAINFALL AND RESULTANT RUN-OFF AND SOIL LOSSES FROM PARRISH PLOTS, WASATCH EXPERIMENTAL WATERSHED, DAVIS COUNTY, UTAH

Storm dates	Total rainfall	Nonflood-source area*		Flood-source area**	
		Rainfall run-off	Soil eroded	Rainfall run-off	Soil eroded
	inches	percent	cu.ft.per acre	percent	cu.ft.per acre
7/10/36	1.14	0.7	0.00	42.8	181.5
7/16/36	0.89	0.4	0.00	43.4	153.6
7/28/36	1.21	0.2	0.00	33.0	83.2
8/18-20/45	3.09	0.5	0.00	24.3	92.8

* Average of four 1/10-acre plots with dense plant cover.

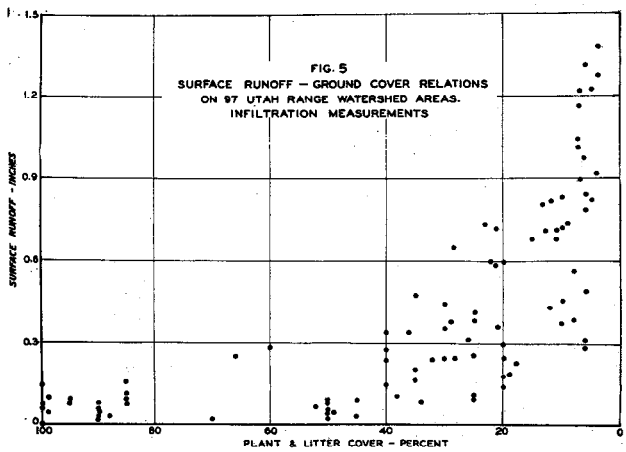
** average of twelve 1/40-acre plots with sparse plant cover.

The measured run-off and erosion behavior described above is not peculiar to the watershed lands in Davis County. Comparable behavior has been measured by means of plots and small watersheds over wide areas and conditions. For example, 97 different sites representing a cross section of grass, sagebrush, and mountain brush ranges from central to southern Utah were measured. These show that on areas where the plant and litter cover sheltered more than 50 percent of the ground surface, generally less than 5 percent of the first 1.5 inches of rainfall ran off. On the other hand, runoff increased with successively decreased amounts of plant cover density, areas of virtually denuded soil yielding from 20 to 80 percent or more of the applied rainfall as runoff (Fig. 5).

One of the most serious aspects of the erosion and sedimentation problem on the Western

5/ See "References" at close of comments.

range lands is that once plant cover depletion progresses to the stage where the soil mantle becomes broken, less and less rainfall is required to produce destructive runoff. The situation in Ford Canyon illustrates the point.



This canyon had produced violent floods as a result of headwater denudation. Subsequently, on July 4, 1934, this basin was subjected to a summer storm which produced 0.47 inch of rainfall. There was runoff only from about 100 acres on which the soil mantle had previously been broken. This small storm on this small area produced enough storm flow to carry boulders measuring 9 feet across out of the canyon.

The often advanced assumption that debris floods in this region are always the product of exceptionally heavy rainfall and a saturated mantle has no support in fact. On the contrary, destruction of plant cover and the concomitant reduction of infiltration capacity and of detention-retention storage can change a watershed slope from one capable of absorbing and retaining virtually all high intensity summer rainfall to one that may yield up to 75 percent of the same rainfall as storm flow.

Restoration By Watershed Management

Recognizing these relationships, a watershed program was designed to reestablish the plant cover and to stabilize the soil on deteriorated portions of the flood producing watersheds between Centerville and Farmington in the Davis County, Utah, area. Other drainages were treated, but only those meeting certain standards of construction and completeness were included in the experimental area. The two main features of this program were: (1) closure of the area to grazing and intensification of fire control to prevent further depletion of the plant cover; and (2) construction of contour trenches and artificial reseeding on about 1,300 acres of the flood source areas. Contour trenches were installed to break up the gully system, to store and force infiltration of precipitation where it fell and thus prevent surface run-off and erosion, and create favorable conditions for revegetation. Artificial reseeding was done to hasten the recovery of the vegetative cover.

The watersheds have responded remarkably to the improvement measures. The depleted and eroded slopes are now being reclothed with vegetation and gullies are rapidly disappearing.

This program of rehabilitation in the experimental watershed has been tested by numerous summer storms since work was initiated in 1933 and in no case have floods developed from the adequately treated areas. The nonflooding behavior of these watersheds is particularly significant when it is considered that during two storms greater rainfall rates were attained than have ever been recorded in the State of Utah (Fig. 6). During a rainfall of 1.14 inches on July 10, 1936, a rate of 5.04 inches per hour for a 5-minute period was registered. The previous maximum 5-minute rate of 4.80 inches per hour was recorded at Salt Lake City in 1931. On the evening of August 19, 1945, when 1.09 inches of rainfall occurred, rates at several of the recording gages exceeded 6.00 inches per hour for a 5-minute period and at one a rate of 6.86 inches per hour was registered.

Whereas the July 10, 1936, storm produced no floods from the treated watersheds, the same rainfall caused mud-rock floods in four drainages within the area which had not been treated (Fig. 7). The treated watersheds again on August 19, 1945, when subjected to the unusually high rainfall rate of 6.00 inches per hour, were able to dispose of the precipitation without erosion or runoff of flood proportions.

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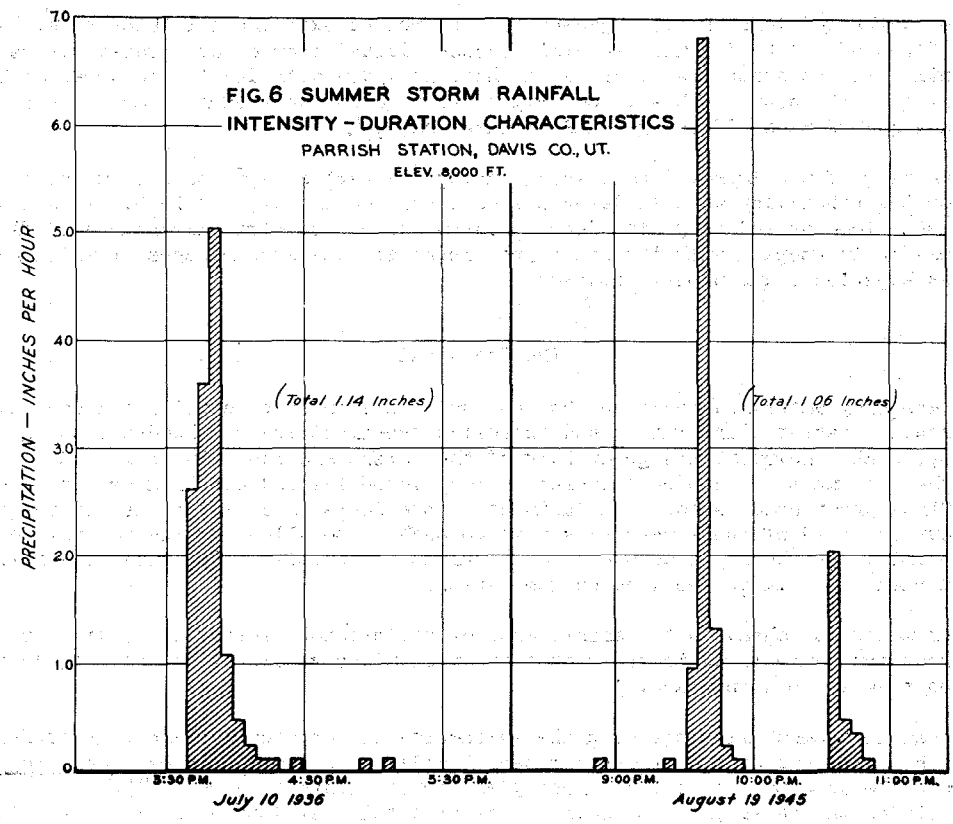

Centerville Canyon, one of the experimental watersheds which has not been deteriorated and which has never produced a mud flow in recent times, received the same amount and intensity of rainfall as the adjacent fully treated Parrish Canyon. There was no evidence of surface run-off reaching the stream channels in either of these basins during the record-breaking rains on July 10, 1936, and August 19, 1945. The only storm flow from these basins was that which came from precipitation that fell in the stream channels.

In contrast, on the same evening of August 19, 1945, a mud-rock flood issued from a

Fig. 7. Watershed lands damages by use (left) can be rehabilitated by management (right). Change in vegetation shown occured during a 10-year period.

deteriorated watershed immediately adjacent to the treated experimental watersheds. Another flood--the first of its kind since the Pleistocene-- issued from an overgrazed watershed at Ogden, 15 miles to the north. Another flood, heavily laden with debris, occurred at Salt Lake City, 15 miles to the south. This flood originated in a 600-acre burn on a 1,000-acre foothill watershed and caused $346,000 damage in Salt Lake City 6/.

The behavior of the improved watersheds during the period 1936, to date marks a radical departure from their behavior when in deteriorated condition in 1923 and 1930. This change from one of violent flooding and very high debris content to one of virtually regulated flow and low sediment load is in keeping with the basic principles of watershed management which have developed from wide experience and experimentation.

The Job Ahead

There are many watershed areas in the West which are in such deteriorated condition that they will require essentially similar and intensive treatment as the flood-producing areas in Davis County, Utah. However, the great bulk of the forest and range lands in need of rehabilitation in the West must and can be restored by less intensive and costly measures. On these areas the first great need is for an adjustment in the degree and kind of use of the forage and timber resources. Use of these resources must be such as to allow for the natural reestablishment of a plant cover that will more adequately protect the soil. Supplemental artificial reseeding and planting will be required on some areas.

Another major job ahead is the maintenance of satisfactory watershed conditions on the vast area of forest and range lands in order that the tremendous volume of potentially destructive sediments on them is kept in place.

Watershed management will not stop the weathering and erosion of bare rock surfaces. There will always be large quantities of waste material added to certain streams from such areas. Moreover, considerable erosion and sediment yields must always be expected from areas on which aridity precludes the development or maintenance of a fully effective plant cover. There may also continue to be much sediment produced from areas on which accelerated erosion has advanced to such a stage that stabilization is practically impossible. However, on the great bulk of the forest and range lands, watershed management can make a big contribution to the solution of the sediment problem.

References

1. Influences of Vegetation and Watershed Treatments on Run-off, Silting, Stream Flow. USDA Misc. Pub. 397, July 1940.

2. Land Erosion--Normal and Accelerated--in the Semiarid West. Reed W. Bailey. Trans. American Geophysical Union, 1941.

3. Epicycles of Erosion in the Valleys of the Colorado Plateau Province. Reed W. Bailey. Journal of Geology 43(4): 337-355, May-June 1935.

4. Is Utah Sahara Bound? Walter P. Cottam. Bulletin of the University of Utah, vol. 37, No. 11, February 19, 1947.

5. Floods and Accelerated Erosion in Northern Utah. USDA Misc. Pub. 196, August 1934.

6. Salt Lake City Flood, 1945. George W. Craddock. Proc. Utah Academy Sci., Arts, and Letters, vol. 23, 1945-46, pp. 51-61.

DISCUSSION

RALF R. WOOLLEY.* Mr. Bailey in his discussion of watershed management for sediment control very ably sets forth his opinions and conclusions as they have been developed by research work in the Forest Service.

In the eight minutes allotted to me I can do little more than call attention to the

6/ See "References" at close of comments.
* Senior Hydraulic Engineer, Geological Survey, Salt Lake City, Utah.

magnitude of the problem as it extends from forest to forest and into the vast areas outside the forests.

All watersheds are subject to periods of aggradation and degradation--a tearing down in one place and a building up in another. In some watersheds, agriculture, grazing, lumbering, and other pursuits of man have little apparent effect. In other watersheds periods of man's occupancy coincide with aggradation and degradation cycles, making it difficult if not impossible to ascribe definite reasons for the changes noted.

Agreement is general among those studying watersheds that human activities in many places disturb the soil so as to hasten the natural process of leveling. However, these activities are necessary to human existence and the problem is resolved into one of weighting benefits against detriments. In vast areas throughout the country there is little evidence to show that the extensive activities of man have materially aggravated natural changes, and there is a prevailing belief among certain groups of scientists that the benefits received from man's activities in general far outweigh any damage which artificial changes may have induced. In such places there is apparently a minimum necessity for watershed management except perhaps for local communities that wish to maintain natural conditions on watersheds used for recreation or public water supply, or communities such as those along the Wasatch front that are flooded periodically as a result of cloudburst storms on the small watersheds discussed by Mr. Bailey.

In contrast to these vast areas where watershed management is not a serious problem, there are other vast areas such as those non-arable areas in parts of Arizona, New Mexico, and Utah where the natural changes in ground surface of the watersheds are occasionally rapid and extensive. Storms are torrential and often violent; vegetation is sparse or practically absent; soil is loose and easily eroded; and as a result the stream channels intermittently carry huge loads of sediment. In these sections highways and railroads adjacent to water courses are in constant jeopardy--often seriously damaged, and when reservoirs are constructed their effective life expectancy is a factor in their economic feasibility.

In these areas sedimentation is a serious problem, and the magnitude of the watershed management problem is one that transcends the research activities of any one agency.

This is emphasized by the fact that studies in New Mexico indicate that sediment comes chiefly from the lower elevations. For example, unit sediment production in the low-lying part of the Pecos River Basin is 60 times greater than in the mountainous and forested part of the basin. Obviously, watershed management in this instance would be quite different and much more complex than that on the small watersheds of less than 10 square miles on the steep west front of the Wasatch Mountains in Utah.

Although the speaker considers watershed management as not being concerned with the geologically normal processes of erosion which have leveled mountains and filled valleys, these processes may be very significant with respect to the proper interpretation of recent arroyo cutting and other spectacular erosion features that are so often cited as results of man's abuse of watershed lands. For example, Doctor Bryan, who is often quoted as showing post-settlement origin for the new cutting in certain valleys, also says that our previous known drought period came in the second half of the 13th century; arroyos were cut all over the Southwest and refilled by about 1400 A. D.

Chas. B. Hunt, regional geologist of the Geological Survey, advises me that the recent history of the Fremont and Dirty Devil Rivers in Utah provides a significant record of arroyo cutting. He says--

"The arroyo cutting now in progress started about 15 years after the area was first settled, but at least two earlier periods of arroyo cutting occurred prior to 1,000 A. D. Both these earlier periods of cutting involved the removal of vastly more material than has been removed since the present cutting started. Prior to each of the three periods of arroyo cutting there was alluviation. The two younger alluvial deposits are alike and evidently were formed under like conditions; the earlier one is different and evidently was the product of a different condition. We do not know why there is a difference, and until we do know we cannot appraise the causal factors. Clearly, though, we cannot attribute the three periods of alluviation to wise land management. Nor can we attribute the two early periods of arroyo cutting to land abuse except by nature itself. Man's abuse of the lands no doubt hastened the start of the present period of arroyo cutting, but the record of what went on before his arrival indicates that natural processes, over which he has no control and very little understanding, are also operating."

Mr. Hunt's present studies in Utah Valley indicate that the recent geological history can be divided into three periods. Immediately prior to Lake Bonneville was a period of aridity during which erosion of the mountains produced huge and extensive alluvial fans and playa deposits. This was followed by the Lake Bonneville (and glacial) period. Since Lake Bonneville time the conditions of erosion are similar to those that preceded the lake period, or at least the conditions are giving rise to the same kind of deposits in the valley. The volumes of the deposits dumped into the valley during these three periods are in the ratio of roughly 300: 100: 1. The sediment brought into Utah Valley since Bonneville time is entirely like that brought in prior to Bonneville time, but the volume of the post-Bonneville deposits is only 1/300 the volume of the pre-Bonneville deposits. It should be further pointed out that the volume of material deposited in the valley since 1847 is only a trifling fraction of the total post-Bonneville sediment in the valley. It may be true that land abuse is aggravating a bad situation, but the record indicates that we would be confronted with a bad situation even under the finest sort of land management.

In conclusion may I direct your attention to Mr. E. N. Munns'* statement a year ago, May 8, 1946, at the Annual Conference of the American Water Works Association at St. Louis, Mo. In his remarks under the heading "Research in Watershed Management" he says--

"In presenting these suggestions for watershed management, the author knows well that some of them are not too well substantiated by incontrovertible facts. This is unfortunate, but the studies of the Forest Service have been directed toward other problems. In developing its research in forest and water relations, the Forest Service has spent perhaps more time in development of basic principles than in the development of specific practices.

"In the development of past research the Service has not worked particularly closely with the water-supply engineers and watershed managers. . . . But in view of new developments, what the Service has to offer concerning the management of forested water-source areas makes clearly evident that the time has now arrived when the Forest Service and the Association should get together."

May I extend Mr. Munns' suggestion to include all Federal agencies that may contribute in any way to the solution of this problem, specifically those now doing research work on different phases of the problem, namely U. S. Engineer Corps, Soil Conservation Service, Office of Land Utilization, Bureau of Land Management, and Geological Survey.

W. J. ENDERSBEE.** There are many of us who are very much concerned with the land problem throughout the United States, realizing that good land management is very essential to the maintenance of soil fertility throughout the country. Mr. Bailey has, in my opinion, very ably discussed that particular problem. During the past three days many other excellent technical papers have been presented from a great diversity of angles, covering a wide range of problems and activities, and all pertain to the sedimentation problem. During the brief time allotted me I should like to divert from the technical side and discuss watershed management from a different angle, namely, the correlation and integration of watershed programs.

A watershed, as used herein, is a tract of land comprising the drainage area of any stream. It is made up of many ownerships devoted to many types of uses--part rural, composed of forest and grazing lands, farms and ranches, and part urban and industrial.

Products from these lands satisfy two types of hunger--one for food, the other for industry. Surpluses, of whatever kind, produced in the area and not needed therein are available for export. Water, the fluid resource, is essential to satisfy both rural and urban requirements. Irrigation, power, navigation, industry and domestic needs, both within and without the catchment basin, insist upon their share of this product. A management program in the watershed must recognize and reconcile the interests of all these elements. Land and its resources are the basic elements supplying these needs and requiring first attention.

Man's hunger for food and industry's hunger for raw materials are the compelling forces leading to the abuse of land. Too often we take too much from the land and put back too little. In this country one of the compelling factors leading to Western migration was the desire for virgin land. As land wore out in the East farmers moved West in search of more. To the pioneers

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**Office of Land Utilization, Department of the Interior, Washington, D. C.

our land resources appeared so vast that the possibility of soil exhaustion and soil losses was of little if any concern. It was only when we reached and passed the last frontier and became aware of our declining resources--nationwide--that we came to realize the necessity of efficient land and water husbandry.

Meanwhile industry has grown by leaps and bounds. It demands more and more from the land to feed huge and hungry machines. Rural and urban forces vie with each other for more and better land, more and better water. Food to satisfy the hunger of the people and raw materials to satisfy the hunger of industry are taxing the land to the utmost. A land and resources management program to bring these forces into proper balance is most timely. In some cases it may be too late. In any event the reconciliation of all these conflicting interests as they exist today is in order.

Sedimentation is one of the normal operations of nature going on everywhere. It results from soil erosion usually in a very mild form, or occasionally a violent form of denudation. This process has been taking place since the beginning of time. Tiny soil particles which result from the decay of rocks find their way in time to the ocean. Many linger on their way, often for centuries, in the form of fertile fields. All of them at some period of their migration muddy the waters of the streams. Attempts by man to control this normal erosion is of little avail and may even be harmful. When the tempo of denudation is vastly accelerated by human agencies a natural process becomes transformed into a menace to civilization. It is this stepped-up soil erosion which aggravates our problem and plagues us now. We have abused our land in many places, and in protest silt is being formed too fast and laid down in unwanted places. We have also in many instances attempted to inhabit and cultivate areas where it was evident that natural forces of large magnitude were in operation.

One important function of any watershed is the sustained delivery of high quality water. The success of watershed management is related directly to the quality, quantity and regulated use of the water produced. This may depend on the degree to which water is managed in the fields, the pastures, the range lands and the forests. When surface run-off can be reduced in volume and the run-off period prolonged, the danger from flood crests is correspondingly reduced. The farmer prefers water held in place where it falls because this helps to curb soil depletion, maintain soil fertility and increase crop yields. The water user in general wants water delivered in quantity to the reservoirs, free from silt and clear as crystal.

Unnatural silt loads in the streams and reservoirs are indicators of serious conditions upstream. It requires no study to determine its presence. We do need to know whence it comes and why. Our attention must be directed toward the underlying causes for all increased unnatural movement of soil and the correction of those causes. Sedimentation arising from human agencies is a symptom of a major disease--improper management of the land and its resources.

Every Federal bureau, every State agency, and every individual who causes or permits silt to develop or accumulate in excessive amounts in unnatural situations has a responsibility in the proper management of the watershed. This includes forces both within and without the catchment basin. Proper management means the application of approved practices to each and every part of the watershed. It requires performance on a unified and orderly basis without undue emphasis being placed upon any specific use or resource.

Fortunately as a nation we are aroused to the general seriousness of the problem and an organized program is under way to maintain the soil on the farms and restore the fertility. Long ago the farmer learned that if he wished to keep livestock he must have food and drink to sustain them, buildings to shelter them and fences to restrain them. When these things were accomplished he found he had to combat diseases and pests which attacked both his animals and his crops. Every move he made affected something and led to new problems. Farming is not a single problem but a combination of problems involving drainage, irrigation, fertility, soil structure, and many other elements.

Today on many farms water is being managed as never before, soil losses are being stopped, fertility is being restored, and crop yields are being increased. Within appropriate limits more water is being held and utilized where it falls. It is lingering on the farm, percolating through the soil as nature intended and loitering on its way to the sea. On many areas where proper land use practices are employed the tempo of denudation is moderating and the sedimentation menace is declining. These things are being accomplished on the farm through the teamwork of the agriculturist and the engineer working with the farmer. I see no reason to believe that the same teamwork when extended to the watershed would not obtain comparable results.

History tells us of certain nations that developed, blossomed and declined as the land and its resources were wasted. Their cities are covered by the windblown sands of the deserts. There are other areas that have been used by man for thousands of years where care has been exercised in the management of the soil and its resources. In the former there was destruction; in the latter there was conservation. In the former there was mismanagement or lack of management; in the latter there was proper management.

As representatives of the Federal Government, charged with the administration of nationally owned lands and resources, as officials representing agencies charged with investigations and studies looking to the welfare of the citizens of this country, and finally as citizens ourselves we should be interested in giving full measure of ourselves and our knowledge to furthering programs that will leave the land and its resources the better for our kindly care. We should not have to be forced into a constructive, far-seeing program. We should be leading the way. The program that is slowly developing between the principal agencies interested in soil and water resources of the country gives promise for the future but the speed with which it is developing is pitifully slow. This three-day conference now ending is the latest move in this direction and marks another milestone in the movement toward more complete integration.

There is no argument here as to the best way to mitigate the silt menace. There is no argument here as to the superiority of dams over contour furrowing. There is, however, a plea that both of them may have their proper place in the watershed. There is the reminder that elements and interests in the watershed and its resources are varied, compelling and far reaching. This leads to the final plea that some way, somehow, all of us who are concerned must unite in a common program.

Proceedings of the
Federal Inter-Agency
Sedimentation Conference

Held at Bureau of Reclamation Laboratories, Denver, May 6-8, 1947, by the following agencies represented on the Subcommittee on Sedimentation, Federal Inter-Agency River Basin Committee

Page 314 is the last page in these proceedings of the First Federal Interagency Sedimentation Conference.

U. S. Department of Agriculture
SOIL CONSERVATION SERVICE
FOREST SERVICE

U. S. Department of the Army
CORPS OF ENGINEERS

U. S. Department of Commerce
COAST AND GEODETIC SURVEY

U. S. Department of the Interior
BUREAU OF RECLAMATION
GEOLOGICAL SURVEY
OFFICE OF LAND UTILIZATION
BUREAU OF INDIAN AFFAIRS

Federal Power Commission

Tennessee Valley Authority

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