SEDIMENT YIELD FROM RANGELAND WATERSHEDS IN THE EDWARDS PLATEAU OF TEXAS

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CONTENTS

Sediment Yield From Rangeland Watersheds in the Edwards Plateau of Texas[1]

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Estimating the accumulation of sediment in a proposed flood detention reservoir constitutes a major problem in planning and design. Estimates are usually based on sediment yield data that have been collected and analyzed for several physiographic areas of the United States. These data have generally been obtained from cropland and mixed land use areas, but little data are available for pasture and rangeland areas. Little or no quantitative data were available for the rangelands of the Edwards Plateau of Texas when the Soil Conservation Service planned the PL 566 project "Work Plan for Watershed Protection and Flood Prevention, Dry Devils River and Lowery Draw Watershed," at Sonora, Texas.

Five flood detention reservoirs were constructed in the Lowrey Draw Watershed in 1960-61. In 1961, the Agricultural Research Service initiated hydrologic research in the Lowrey Draw Watershed in cooperation with the U.S. Soil Conservation Service and the Texas Agricultural Experiment Station (TAES). The studies included measurement of rainfall and instrumentation of reservoirs to determine inflow and outflow, and measurement of sediment accumulation. The reservoirs were surveyed to determine stage-storage relationships. In 1969, four reservoirs were resurveyed to determine sediment accumulation during the 8-year period.

The objectives of this study were (1) to determine the factors that cause sediment to be discharged from rangeland watersheds, and (2) to develop a satisfactory procedure for predicting sediment yield from rangeland watersheds.

To accomplish these objectives, a method similar to one previously reported[3] for developing sediment prediction techniques was used. Sediment concentration was related to variables representing storm energy, land treatment, and watershed characteristics. Factor analysis was used to determine three important and relatively independent prediction factors. Principal components regression was used to develop a sediment prediction equation based on these factors.

WATERSHED DESCRIPTION

The Lowrey Draw Watershed near Sonora, Tex. is a typical rangeland watershed in the Edwards Plateau. Figure 1 shows the location of the Edwards Plateau and the Lowrey Draw Watershed. A map of the watershed is shown on figure 2. Five flood detention reservoirs,

[1] Contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Tex. Agr. Exp. Sta., Tex. A&M Univ.

[2] Research hydraulic engineers, Southern Plains Branch, USDA, Riesel, Tex.

[3] Williams, J. R., Hiler, E. A., and Baird, R. W. Prediction of sediment yields from small watersheds. A paper presented at the Ann. Amer. Soc. Agr. Engin. meeting in Minneapolis, Minn. 1970.

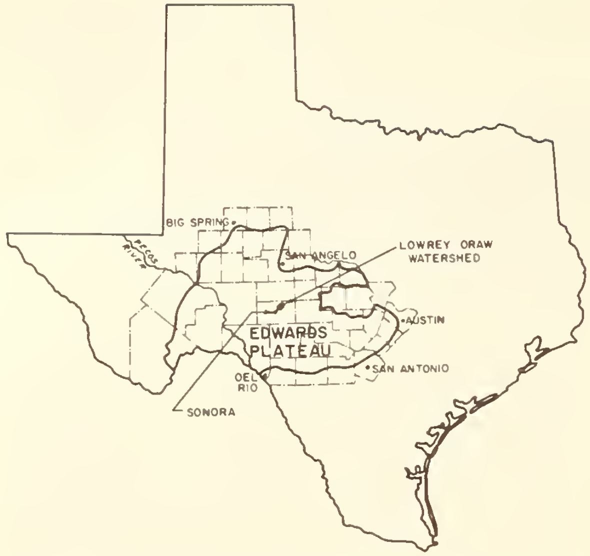

Figure 1.—Location of Edwards Plateau and Lowrey Draw Watershed in Texas.

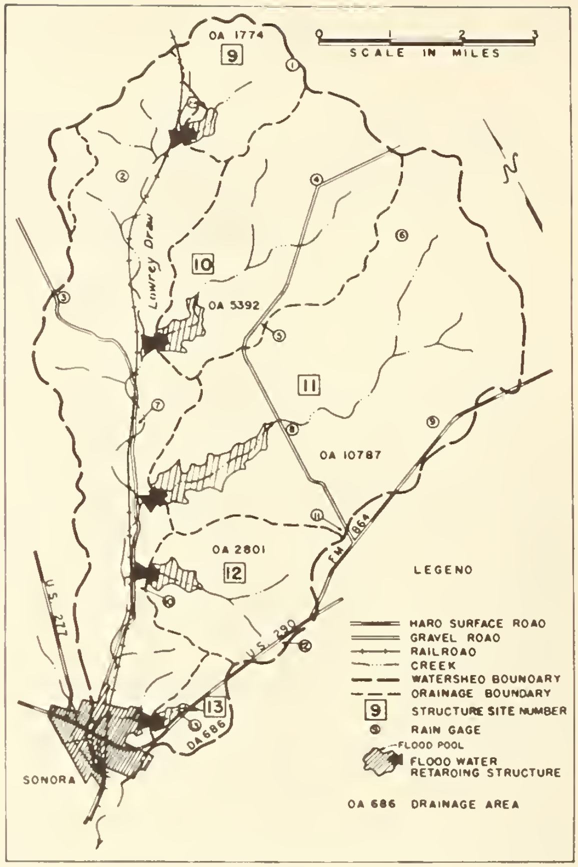

Figure 2.—Lowrey Draw Watershed.

constructed by the Soil Conservation Service under the provisions of PL 566, control the runoff from 70 percent of the 48-square-mile watershed. Four of the reservoirs—sites 9, 10, 12, and 13—were used in this study. Site 11 was not resurveyed in 1969.

The geology of the Lowrey Draw Watershed was described[4] as Edwards and associated limestones of Lower Cretaceous age. Thirty percent of the watershed area (the plateau) is covered with thin beds of hard limestone and thicker beds of marly limestone from 0 to 20 feet thick. Marly limestone, from 0 to 25 feet thick, outcrops on 18 percent of the area where the plateau slopes steepen. Alternating beds of hard limestone and marly limestone, from 0 to 20 feet thick, outcrop on the middle slopes, which include about 15 percent of the area. Twenty to 70 feet of hard limestone, jointed and cavernous, covers the steeper slopes of the lower 32 percent of the watershed. Alluvium and colluvium along stream channels cover 5 percent of the area.

The soils of the watershed[5] are dark-colored, calcareous clays that range in depths from 0 on the steep slopes and rock outcrop to 24 inches on the flat plateau. Watershed slopes range from 0 to 20 percent. Table 1 describes physical characteristics of watersheds draining into the four detention reservoirs used in this study.

More than 98 percent of the land use for each of the four watersheds is rangeland. The remainder is hard surface roads.

[4] Blank, H. R., Knisel, W. G., and Baird, R. W. Geology and groundwater studies in part of the Edwards Plateau of Texas, including Sutton and adjacent counties. U.S. Dept. Agr., Agr. Res. Serv., ARS 41-103, 41 pp. 1966.

[5] Wiedenfeld, C. C., and McAndrew, J. D. Soil survey, Sutton County, Texas. U.S. Soil Conserv. Serv., 103 pp. 1968.

Table 1.—Physical characteristics of Lowrey Draw subwatersheds

Characteristics	Unit	Reservoir No.			
		9	10	12	13
Drainage area	Square miles	2.77	8.43	4.38	1.07
Drainage density	Miles per square mile	.66	1.43	2.30	2.18
Main stem slope	Feet per mile	34.1	32.6	53.7	94.3
Watershed slope					
0-3	Percent	96.0	67.0	30.0	10.0
3-8	do.	4.0	33.0	70.0	87.0
8-20	do.	---	---	---	3.0
Average	do.	1.66	2.82	4.30	5.36
Soil type					
Tarrant stony clay	Percent	4.0	34.0	79.0	90.0
Valera clay	do.	76.0	48.0	---	---
Kavett clay	do.	---	---	14.0	---
Tobosa clay	do.	20.0	18.0	1.0	---
Knippa clay	do.	---	---	6.0	10.0

Source: Wiedenfeld, C. C., and McAndrew, J. D. Soil survey Sutton County, Texas. U.S. Soil Conserv. Serv., 103 pp. 1968.

DATA COLLECTION

The reservoirs were equipped with water level recorders for continuous water stage measurements. Detailed topographic surveys were made in the flood pools of the reservoirs, and stage-storage relationships were developed. The observed rate of change of water level was applied to the stage-storage relation to calculate reservoir inflow.

Rainfall was measured by a network of 14 recording rain gages. The rain gage locations are shown on figure 2. Table 2 shows annual amounts of rainfall and runoff measured for each reservoir and average annual rainfall and runoff during 1961-68. This 8-year period represents near normal climatic conditions for the area. Average annual rainfall during a 45-year period at the TAES near Sonora was 21.48 inches.

To determine accumulated sediment, the sediment pools of the reservoirs were surveyed in 1961 and again in 1969. The normally dry reservoirs permitted standard differential leveling surveys on the bed. An example of survey range lines is shown on figure 3. The range lines were located on the ground by transit survey and marked at regular intervals so that they could be easily relocated. Elevations were determined at all points where the slope changed along the ranges. In 1969, the ranges were relocated and breakpoint elevations were determined for each range. The 1961 and 1969 cross sections of a typical range are shown on figure 4.

The area of sediment accumulated at each range is the difference between the 1961 and 1969 cross section end areas. The volume of sediment between two ranges is the product of average sediment area of the ranges and distance between ranges. The sum of between-range volumes is the total sediment accumulated during 1961-68. Photographs of the sediment accumulated in sites 9 and 13 are shown in figures 5 and 6, respectively. The dark areas in the photographs are sediment

Table 2.—Annual rainfall and runoff for Lowrey Draw subwatersheds[1]
(P, rainfall; Q, runoff)

Year	Site 9		Site 10		Site 12		Site 13	
	P	Q	P	Q	P	Q	P	Q
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1961	24.73	0.45	23.80	0.15	21.45	0.21	21.22	0.06
1962	17.02	.03	17.70	0	17.17	.01	18.98	.12
1963	16.21	.03	17.47	.01	15.64	.01	15.06	.06
1964	27.94	2.70	26.57	1.94	26.49	1.74	25.36	.92
1965	17.92	.05	19.25	.19	20.22	1.39	18.52	.48
1966	16.84	.03	16.90	0	20.60	.22	19.44	.35
1967	22.09	.13	21.39	.12	22.31	.01	20.98	.03
1968	22.83	.01	21.36	.03	22.78	.73	22.60	.40
Average . .	20.70	.43	20.56	.31	20.83	.54	20.27	.30

[1] Rainfall was weighted by the Thiessen method.

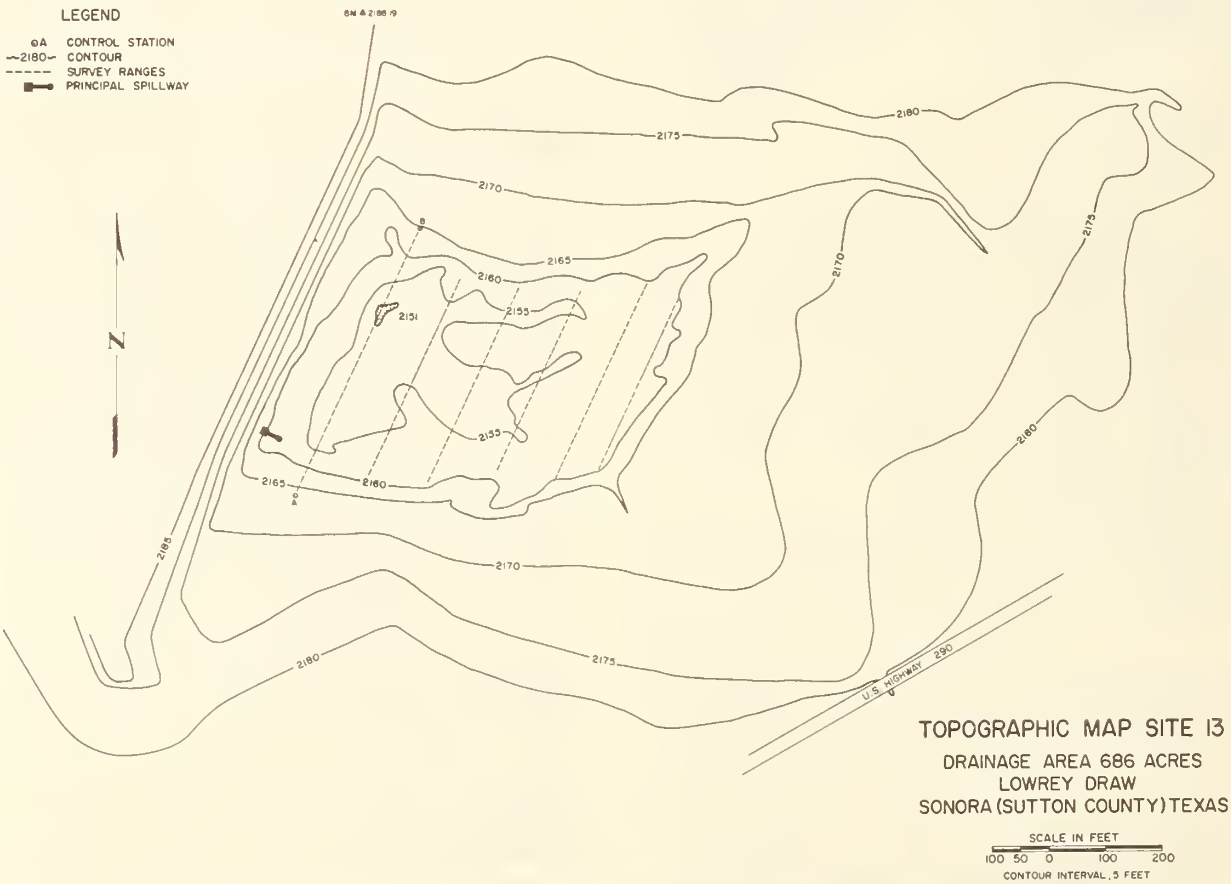

Figure 3.—Survey ranges and sediment pool of site 13, Lowrey Draw Watershed.

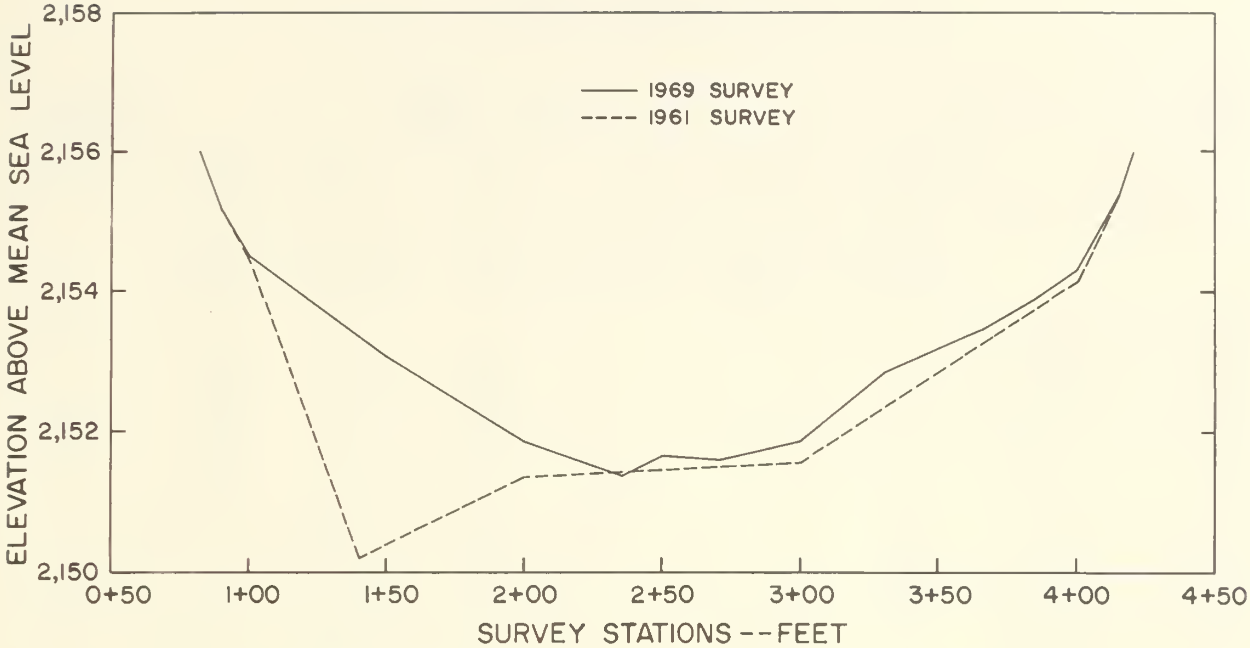

Figure 4.—Cross sections surveyed in sediment pool of site 13, Lowrey Draw Watershed.

Figure 5.—Lowrey Draw Watershed, Sonora, Tex., reservoir site 9, 1969. Dark area in bottom of reservoir is sediment accumulation.

deposits, and the light areas are rock and caliche not covered by sediment. The figures show that very little sediment has accumulated in the reservoirs since construction. Samples taken from the reservoirs indicate that the sediment weighs about 64 pounds per cubic foot.

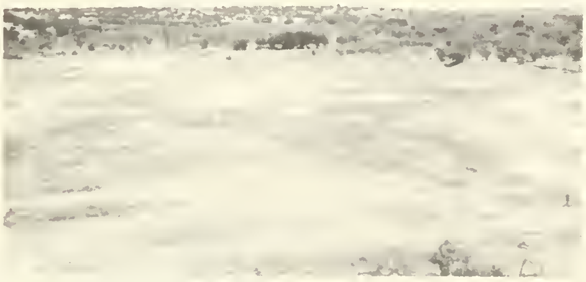

Figure 6.—Lowrey Draw Watershed, Sonora, Tex., reservoir site 13, 1969. Dark spots are sediment, light spots are caliche and rock without sediment.

Range conditions were determined by reconnaissance surveys of each watershed during 1963-65 (table 3). Since a large portion of the 8-year runoff occurred during 1963-65 (table 2), it is likely that most of the sediment was accumulated during those 3 years.

Figure 7 shows range conditions typical of "low poor" and "fair," which resulted from overgrazing and moderate grazing management, respectively. Although there is little residue on the "low poor" site, the short stubble and stones may afford considerable protection against splash erosion and resistance to flow.

Table 3.—Range conditions of Lowrey Draw subwatersheds

Watershed above site	Year	Percentages of climax vegetation for the following range conditions—						Weighted range condition
		Low poor (0-8)	Poor (9-17)	High poor (18-25)	Low fair (26-34)	Fair (35-42)	High fair (43-50)	
		Percent of watershed	*Percent of watershed*	*Percent of watershed*	*Percent of watershed*	*Percent of watershed*	*Percent of watershed*	
9	1963	---	---	---	---	47.0	53.0	1.62
9	1964	---	---	---	4.0	96.0	---	
9	1965	---	---	---	17.0	---	83.0	
10	1963	---	14.1	---	1.8	48.5	35.6	2.02
10	1964	---	---	---	25.6	74.4	---	
10	1965	---	---	16.4	.3	22.1	61.2	
12	1963	9.1	---	---	78.0	12.9	---	3.42
12	1964	27.2	---	---	---	72.8	---	
12	1965	39.5	---	---	43.8	16.7	---	
13	1963	79.8	---	---	---	20.2	---	4.18
13	1964	---	36.8	---	---	63.2	---	
13	1965	55.8	---	---	---	44.2	---	

Figure 7.—Across-the-fence comparison of "low poor" and "fair" range conditions in the Edwards Plateau of Texas.

The amount of sediment accumulated in each reservoir and the average sediment concentration of the inflow during the 8-year period are shown on table 4. Also shown on table 4 are the sediment pool capacities and the number of years before these pools will be filled (based on the 1961-68 deposition rate). These sediment pools were designed for a 50-year life. However, as stated earlier, very little was known about sediment yields from rangeland watersheds in the Edwards Plateau when the reservoirs were designed.

A sediment prediction technique, based on data collected in this study, would be useful for future design of reservoirs in the Edwards Plateau. Sediment prediction techniques can be developed by using multivariate analysis to relate average sediment concentrations of individual storms to causal factors (see footnote 3). This method of developing a sediment prediction technique produces a rational prediction equation based on watershed characteristics, land use and treatment, and climatic variables.

The first step in the procedure is to select the dependent variable and the prediction variables. Because sediment data are not available for individual storms for the Lowrey Draw reservoirs, the dependent variable is the average sediment concentration of the inflow to each reservoir for the entire 8-year period. Five prediction variables representing land treatment, climatic conditions, and watershed characteristics were selected. The five variables and their definitions are:

1. WRC = Weighted range condition. (Based on arbitrary range condition numbers from 1 to 6. High fair = 1, fair = 2, low fair = 3, high poor = 4, poor = 5, low poor = 6.)

$$WRC = \frac{\sum_{j=1}^{N} \sum_{i=1}^{6} RC_i \times PA_j}{N}$$

in which,

RC_i = Range condition number.

PA_j = Portion of watershed area in range condition i, during j^{th} year.

N = Number years of record.

2. S = Average watershed slope.
3. DD = Drainage density in miles per square mile.
4. E/P = Kinetic energy of rainfall[6] in

[6] Wischmeier, W. H., and Smith, D. D. Rainfall energy and its relationship to soil loss. Amer. Geophys. Union Trans. 39(2): 285-291. 1958.

Table 4.—Sediment concentrations and comparison of sediment yields to capacity of sediment pools

Site No.	1961-68 Accumulated sediment	1961-68 Average sediment concentration		Sediment pool capacity	Time[1]	Sediment yield
	Acre-feet	*P.p.m.*	*Tons per acre-feet*	*Acre-feet*	*Years*	*Tons per acre-year*
9	0.26	531	0.72	21	947	0.026
10	.62	582	.79	95	1,226	.020
12	1.43	1,451	1.97	83	1,395	.089
13	.16	1,176	1.60	56	2,835	.040

[1] Length of time it would take to fill each sediment pool.

foot-tons per acre divided by rainfall in inches.

5. SMS = Difference in elevation in feet divided by distance in miles along the main stream flood plain from the outlet to the watershed divide.

The next step in the procedure is factor analysis. The basic objective of factor analysis is to reduce a number of correlated variables to a lesser number of relatively independent vectors or factors. Factor analysis reduced the five variables in this study to three relatively independent vectors. Table 5 shows the loadings of each of the three vectors on the dependent variable, sediment concentration, and the loadings of the highest loading variable on each vector.

Table 5.—Factor loadings from rotated vectors obtained by factor analysis

Variable	Vectors		
	1	2	3
WRC	---	---	0.46
MSS	---	-0.89	---
DD	0.86	---	---
SC	.50	-.44	.75

Based on the results of factor analysis, the three highest loading variables—weighted range condition, main stem slope, and drainage density—were chosen to represent the three vectors. Principal components regression with the three relatively independent variables related to sediment concentration produced the equation,

(1)

$$SC = 0.35 \times WRC^{0.38} \times DD^{0.40} \times MSS^{0.17}$$

The multiple correlation coefficient squared is 0.78. To obtain sediment yield in tons per acre, equation 1 is multiplied by runoff volume and becomes

(2)

$$SW = 0.0292 \times Q \times WRC^{0.38} \times DD^{0.40} \times MSS^{0.17}$$

in which

SW = sediment yield in tons per acre per year, and

Q = volume of runoff in inches per year.

Sediment yield in acre-feet can be computed by the equation,

(3)

$$SV = 0.0134 \times Q \times A \times WRC^{0.38} \times DD^{0.40} \times MSS^{0.17}$$

in which

SV = sediment yield in acre-feet per year, and

A = drainage area in square miles.

RESULTS AND DISCUSSION

Factor analysis shows that watershed characteristics and land treatment are closely related to sediment concentration. The analysis showed no independent vector for storm energy, because there was little variation in the kinetic energy of rainfall (E/P) between watersheds for the 8-year period. However, if individual storms could be considered, the rainfall energy factor would probably show a much stronger influence on sediment concentration.

Although storm energy is not included in the prediction equation, accuracy of sediment predictions should be adequate for reservoir design on rangeland watersheds of the Edwards Plateau. As mentioned earlier, climatic conditions were near normal for the Lowrey Draw Watershed during 1961-68. One storm produced a 1-hour rainfall amount equal to the 100-year frequency shown in TP-40.[7] There was also a 7-day period of rainfall almost equal to the 100-year frequency shown in TP-40.

Generally there were no extremely high

[7] U.S. Weather Bureau Mean Annual Precipitation Map. Tech. Paper 40. Sept. 1963.

rates of runoff during 1961-68. An extreme runoff event might have increased sediment yields, but the increase probably would be small since the watersheds are almost entirely rangeland. Records from small blackland watersheds near Temple, Tex.[8] show that sediment yield from grassed watersheds is negligible when compared to that from increases in sediment yield caused by extreme cultivated areas. A factor of safety could be included in the estimate to offset possible events. If the estimate is increased by 100 percent (safety factor of two), sediment pool requirements would still be small. As an example, the drainage area above site 13 has the worst range conditions and the highest slopes of the four watersheds, but even with a safety factor of two, the reservoir would require less than 3 acre-feet of sediment capacity for 50 years.

[8] Smith, R. M., Henderson, R. C., and Tippit, O. J. Summary of soil and water conservation research from the Blackland Experiment Station, Temple, Tex., 1942-53. Tex. Agr. Expt. Sta. Bul. 781, pp. 42-52. 1954.

CONCLUSIONS

Sediment yields from rangeland watersheds in the Edwards Plateau are low. Three factors representing watershed characteristics and land treatment explained about 78 percent of the variation in sediment concentration from four rangeland watersheds. The prediction equation can be used to compute sediment yields from similar rangeland watersheds if the runoff can be measured or computed.

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