what is adequate. We have a rule of thumb that borings should be taken every 100 feet along the dam centerline and to a depth equal to the height of the dam.

Penetration tests and samples are taken in every other boring at all changes in soil strata.

Field identification tests are made on all strata represented by the samples taken. From the boring logs and field identification test, the soil strata are tentatively classified in the United Soil Classification Chart.

From these preliminary soil studies, it can usually be decided if any problem soils are present and if further testing is necessary to prove the feasibility of the dam.

HYDROLOGY AND OTHER:

A detailed field inspection is made to determine the obstructions in the lake site, such as powerlines, gas lines, buildings, roads, etc. Also a field check is made of the water-course below the dam, and the buildings, roads, and land use are noted, along with possible sites for future developments. From this information on downstream conditions, the dam is classified as to the degree of hazard to property and life. The damage that can be expected from the failure of the dam will decide what factors of safety should be used in its design.

A hydrograph for the stream at the dam site is then developed. We use methods that have been developed by the S.C.S. The infiltration rates and time of concentration can be established from soil maps, topo maps and aerial photos. The design storm is selected on the basis of the hazard condition created by the dam. For a low hazard condition, a design storm is chosen that will adequately protect the investment in the dam.

For small lake and earthfill dams in Missouri, it is uneconomical to route the entire design flood through one spillway. We route a 25, 50 or 100-year storm through the principal spillway and construct an emergency grass spillway to take the remainder of the project storm.

A cost estimate is made of the proposed construction from the preliminary designs made in the investigation.

The estimate and a critique on the concept, geology, soils, and hydrology is presented in a feasibility report to the department administration for approval.

When the project is approved and secure arrangements have been made for purchase of the land, work is started on the final design.

The final design retraces the steps taken in the investigation. Laboratory tests are made of the soil samples, if necessary, and the maximum density of borrow material is found.

The dam foundation condition is reconsidered and the design of the embankment slopes is refined. The hydrology is reviewed and checked and the final design made on the spillways.

This discussion has been brief and has only touched on some of the points to be considered in the design of a small lake. However, I see by the program that some of the more important features will be discussed in detail in other papers.

SMALL WATERSHED HYDROLOGY[1]

Introduction

Very little work had been done to develop small watershed hydrology prior to 1936 when the Flood Control Act was passed. This act authorized the Department of Agriculture to develop conservation and flood prevention plans on river basins of the United States. The Washita River in Oklahoma and the Trinity and Middle Colorado Rivers in

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[1] Paper prepared by Dean Snider, Hydraulic Engineer, Engineering and Watershed Planning Unit, Soil Conservation Service, Fort Worth, Texas, for presentation at a meeting of the Engineering Section, Game and Inland Fish Commission, Hot Springs, Arkansas, September 30, 1963.

Texas were three of the watersheds authorized under this act. The Watershed Protection Act (P. L. 566) was passed in 1954, authorizing the Department of Agriculture to do similar work on watersheds up to 250,000 acres (391 square miles) in size.

These two acts and subsequent amendments have stimulated considerable interest in Small Watershed Hydrology. The Soil Conservation Service was faced with the problem of consolidating its hydrologic procedures and criteria on a national basis, for immediate use in designing floodwater retarding structures. These structures were to store temporarily, and to release at a predetermined rate, the runoff from areas generally ranging in size from one to 50 or 60 square miles. The procedures and criteria had to be flexible enough to fit all of the conditions in the various climatic zones, including the control of runoff from snowmelt. There were very little basic data available to bridge the gap between small experimental plots and the stream gages on large streams. It would take years to install instruments (rain gages and stream gages) and gather the needed data from watersheds of this size.

As a first step the Soil Conservation Service had to have suitable procedures and criteria for immediate use, and as a second they had to select sample watersheds in various climatic zones on which to install instruments (rain gages and stream gages) that would eventually give a more direct approach to solving the hydrologic problem on small watersheds. The second step will be discussed first, although it is a long way from completion, because of its bearing on the entire problem.

In the area served by the Fort Worth E&WP Unit the following watersheds were selected for instrumentation: (1) Honey, Escondido, Cow Bayou, Mukewater, Green, and Calaveras Creeks in Texas, (2) Sandstone and Double Creeks in Oklahoma, (3) Six Mile Creek in Arkansas, (4) Bayou Dupont in Louisiana, and (5) Bernalillo and Upper Rio Hondo in New Mexico.

The U. S. Geological Survey, Economic Research Service, and various state agencies are cooperating with the Soil Conservation Service on these projects. The U. S. Geological Survey contracted to install and operate these gaging stations on a year-by-year basis.

We have been receiving data from some of these watersheds since 1951. These data are being processed and analyzed by technicians in the E&WP Unit.

Interim reports are being prepared on Sandstone Creek, Oklahoma; Six Mile Creek, Arkansas; and Honey Creek, Texas by the Soil Conservation Service. The U. S. Geological Survey has prepared reports on Sandstone Creek, Oklahoma, and Honey Creek in Texas.

It is gratifying to note that the recorded data from these watersheds have not pointed up any large deficiency in the present procedures or criteria.

Rainfall-Runoff

In order to solve the immediate problem the Engineering Division of the Soil Conservation Service developed procedures and criteria along the following line. A method of computing runoff from rainfall for different soil types and cover conditions was needed. The rainfall and runoff data that had been gathered by the Soil Conservation Service and the Agricultural Research Service from small watersheds and experimental plots were tabulated by land use, treatment or practice, hydologic condition and hydrologic soil group.

A family of curves was developed (Plate 1) based on an initial abstraction and a variable intake rate suitable for use with various soil types and three antecedent moisture conditions.

A description of the conditions follows:

Condition I—No rain has occurred for several days and the soil is dry to the extent that plants are approaching the wilting point.

Condition II—Recent rains have left the soil in the optimum condition for plowing and for plant growth.

Condition III—Recent rains have left the soil saturated and the initial abstration would be minor.

All of the rainfall events that occurred were used to develop the index or curve numbers shown in table 1.

The events that fell in the I and III antecedent moisture conditions were used to develop table 2. This table shows the curve number to use in computing runoff from rainfall events when the antecedent moisture varies from condition II.

The Engineering Division of the Soil Conservation Service also contracted with the U. S. Weather Bureau to make a study and to develop maps of the United States showing the probable maximum precipitation and the rainfall intensity-frequency for storms varying from 30 minutes to 24-hour duration. This study is now complete and is contained in U. S. Weather Bureau Publication TP 40.

Hydrographs

Considerable work had been done by L. K. Sherman and F. F. Snyder on the development and use of the unit hydrograph on large watersheds.[2] The Soil Conservation Service used these basic hydrologic procedures and by applying them to the dimensionless unit graph (G. G. Commons and Victor Mockus)[3] the present procedure for developing an Emergency Spillway Design and a freeboard hydrograph was developed. Plate 2 shows the dimensionless graph now being used. To use the dimensionless unit hydrograph, the peak discharge and time to peak were needed. In order to eliminate one of the most controversial subjects (time of concentration) plate 6 was developed from gaged data on watersheds of various sizes and shapes located in different physiographic areas in the five states served by the Fort Worth E&WP Unit.

The rainfall pattern (Plate 4) was developed by analyzing all of the large storms of record in the United States. It is the advance envelope line of the maximum six-hour segment of these storms.

The minimum criteria for floodwater retarding structures are established by the Washington Engineering Division. However, it is the practice of the Fort Worth E&WP Unit, concurred in by the various state conservation engineers, to use criteria that exceed the minimum for both storage and freeboard design.

Plate 5 shows the six-hour rainfall normally used in developing the freeboard hydrograph for a class (a) floodwater retarding structure. This rainfall is considered to cover an area of 10 square miles, and plate 3 shows the reduction applied to this rainfall for areas larger than 10 square miles.

The following example will show how these procedures and criteria are used to develop a freeboard hydrograph for a floodwater retarding structure located near Waco, Texas in the Blackland Land Resource Area.

Example: Assume a floodwater retarding structure with a drainage area of 9,280 acres, or 14.5 square miles. The watershed length-width ratio is 2.0 to 1.

The following tabulation shows the size and condition of various segments of the watershed and how they are used to compute an average curve number.

Land Use or Cover	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group	Acres	Curve Number	
Row Crop	C & T	Good	C	500	78	39,000
Small Grain	C	Good	C	800	81	64,800
Pasture	—	Fair	D	2,000	84	168,000
Pasture	—	Good	C	5,280	74	390,720
Meadow	—	Good	C	500	71	35,500
Roads (dirt)	—	—	C	200	87	17,400
		Total		9,280		715,420

$\frac{715{,}420}{9{,}280} = 77.2$ Use 77 curve.

Unit Hydrograph

The peak discharge of the unit hydrograph (5,900 c.f.s.) is read from plate 6. The correction factor for a length-width ratio of two to one is read from small insert on plate 6 to be 0.7; therefore 5,900 x 0.7 = 4,130 c.f.s. peak of unit hydrograph. Using the formula, $q = \frac{484\ A,}{T_p}$ and rearranging to the form of $T_p = \frac{484\ A}{q} = \frac{484 \times 14.5}{4{,}180} =$ 1.7 hours.

Using a $T_p = 1.7$ and a $q_p = 4{,}130$ along with the dimensionless hydrograph, plate 2, a unit hydrograph is developed. The data are plotted and shown as plate 7.

Freeboard Storm

From plate 5 near the center of McLennan County, Texas read 14.7 inches of rain. This amount of rainfall is reduced to 14.5 square miles of areal coverage. Enter plate 3 at 14.5 square miles and read .975

TABLE 1

RUNOFF CURVE NUMBERS FOR HYDROLOGIC SOIL-COVER COMPLEXES FOR WATERSHED CONDITION II, AND $I_a = 0.2(S)$

Land Use or Cover	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group			
			A	B	C	D
Fallow	Straight row	——	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close-seeded legumes[4] or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		——	59	74	82	86
Roads (dirt)[5]		——	72	82	87	89
(hard surface)[5]		——	74	84	90	92

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[4] Close-drilled or broadcast.

[5] Including right-of-way.

(14.7 x .975) = 14.3. This is the amount of six-hour duration rainfall used to develop the freeboard hydrograph for this structure.

Enter plate 1 with 14.3 inches of rainfall and a curve number 77 and read 11.2 inches of runoff.

Freeboard Hydrograph

Using the A_2 pattern (plate 4) the 14.3 inches of rain is tabulated at 0.4-hour intervals and the accumulated runoff is read from the number 77 curve by use of the accumulated rainfall. The accumulated runoff is divided into increments for the 0.4-hour intervals and these incremental segments are then applied to the unit hydrograph to develop the freeboard hydrograph for the six-hour storm, plate 8.

This hydrograph is then routed through the structure considering no inflow for 10 days prior to this storm. The top of the settled dam is set at the elevation reached by this routing.

Small watershed hydrology has advanced considerably in the past decade and we in the Soil Conservation Service are proud of our contribution to this advancement. We feel that our present criteria are entirely adequate for the safe design of structures that will be built under present authorization. However, we feel that it is our duty to pursue the second step and gather data that will lead to better work in the future.

References

2. L. K. Sherman, 1932. Streamflow from Rainfall by Unit Hydrograph, Engineering News-Record, April 7, p. 501-505. F. F. Snyder. Synethic Unit Graphs, Trans. Am. Geophys. Union 19, 447-455, 1938.
3. G. G. Commons. Flood Hydrographs, Civil Eng., N. Y. 12, 571-572, 1942. Victor Mockus—National Engineering Handbook, Hydrology Guide.

TABLE 2
CONVERSIONS AND CONSTANTS
FOR THE CASE $I_a = 0.2$ S

1	2	3	4	5
Curve Number for Condition II	Corresponding Curve Numbers for:		S Values*	Curve* Originates where P=
	Condition I	Condition III		
100	100	100	0	0
95	87	99	.526	.10
90	78	98	1.11	.22
85	70	97	1.76	.35
80	63	94	2.50	.50
75	57	91	3.33	.67
70	51	87	4.29	.86
65	45	83	5.38	1.08
60	40	79	6.67	1.33
55	35	75	8.18	1.64
50	31	70	10.00	2.00
45	27	65	12.2	2.44
40	23	60	15.0	3.0
35	19	55	18.6	3.72
30	15	50	23.3	4.66
25	12	45	30.0	6.00
20	9	39	40.0	8.00
15	7	33	56.7	11.34
10	4	26	90.0	18.00
5	2	17	190.0	38.00
0	0	0	infinity	infinity

*For curve number in column 1.

HYDROLOGY: SOLUTION OF RUNOFF EQUATION $Q = \frac{(P-0.2S)^2}{P+0.8S}$

P = 0 to 12 inches
Q = 0 to 8 inches

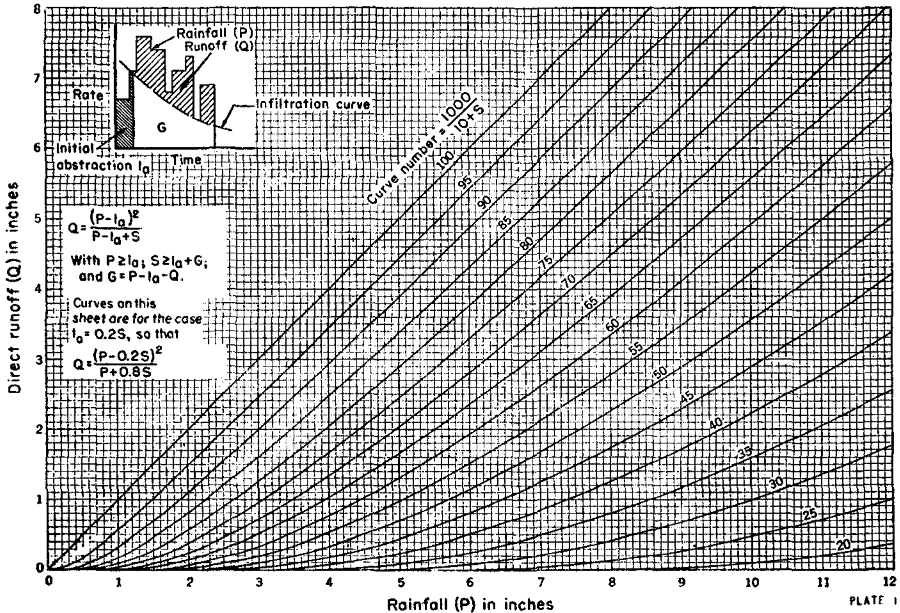

PLATE I

REFERENCE
Mockus, Victor; Estimating direct runoff amounts from storm rainfall: Central Technical Unit, October 1955.

U. S. DEPARTMENT OF AGRICULTURE
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STANDARD DWG. NO.
ES-1001
SHEET 1 OF 2
DATE 6-29-56

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE 4-L-18280

HYDROLOGY: SOLUTION OF RUNOFF EQUATION $Q = \frac{(P-0.2S)^2}{P+0.8S}$

P = 8 to 40 inches
Q = 0. to 40 inches

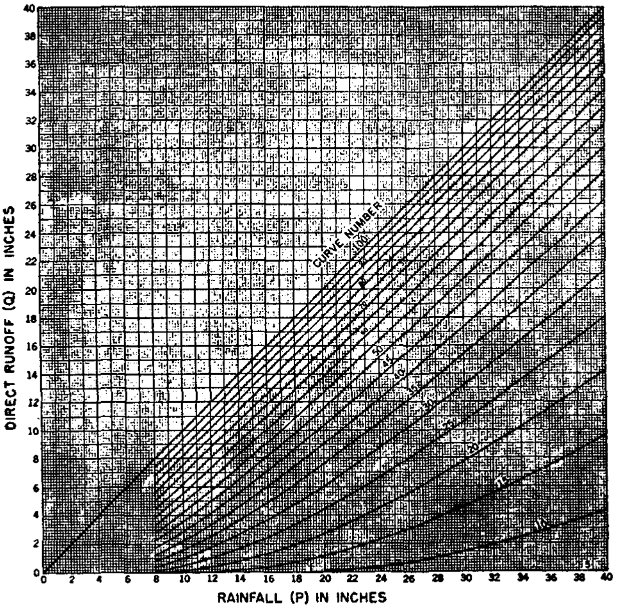

PLATE I

REFERENCE
Mockus, Victor; Estimating direct runoff amounts from storm rainfall: Central Technical Unit, October 1955.

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SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - CENTRAL TECHNICAL UNIT

STANDARD DWG. NO.
ES-1001
SHEET 2 OF 2
DATE 6-27-56

HYDROLOGY— Dimensionless hydrograph and mass curve.

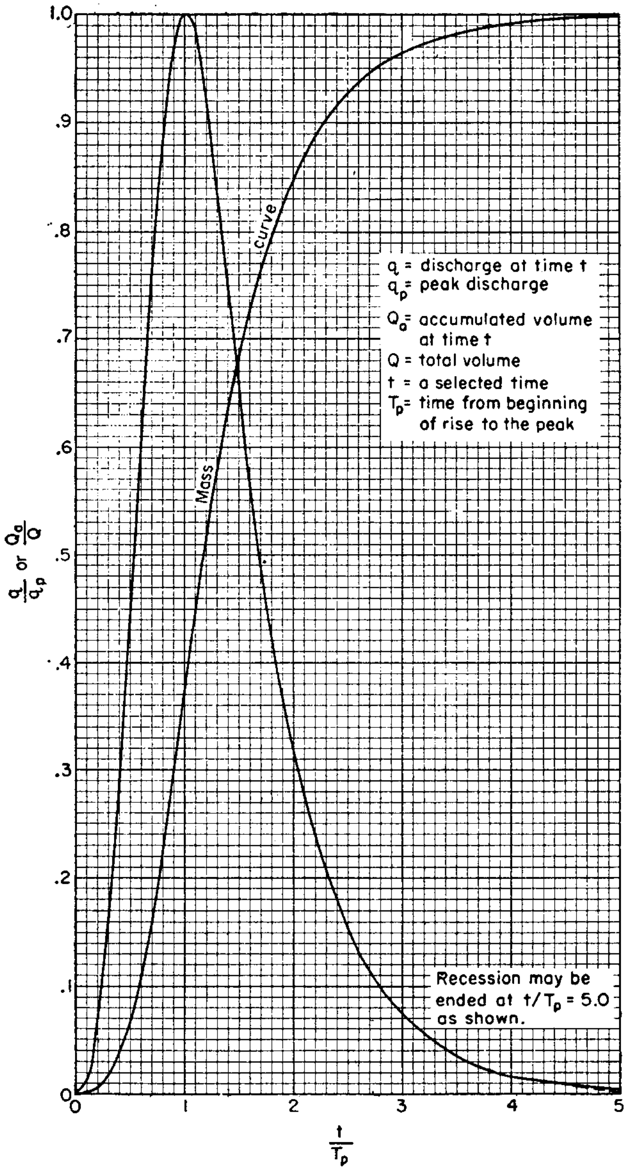

PLATE 2

REFERENCE Developed by Victor Mockus.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - CENTRAL TECHNICAL UNIT	STANDARD DWG. NO. ES-1004 SHEET 1 OF 1 DATE 2-19-67

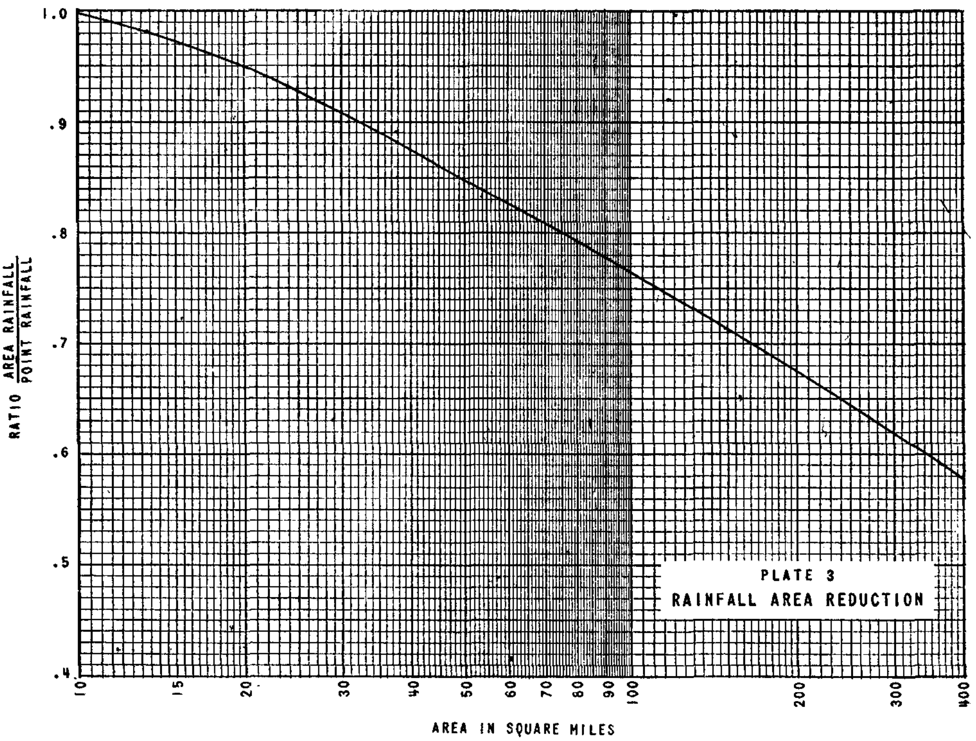

PLATE 3
RAINFALL AREA REDUCTION

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE 9-63 4-L-18275

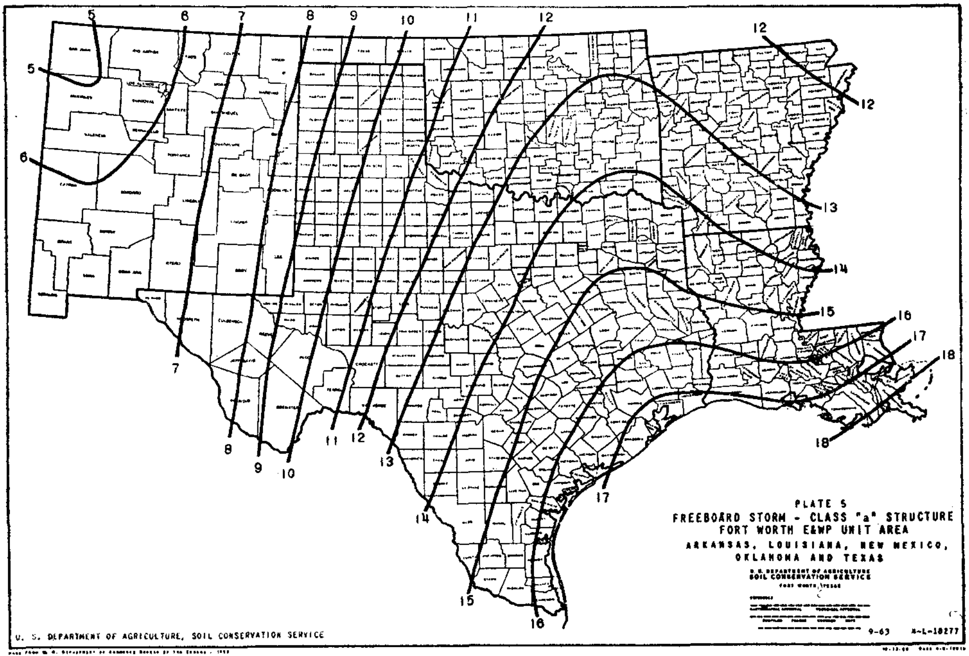

PLATE 5
FREEBOARD STORM - CLASS "a" STRUCTURE
FORT WORTH E&WP UNIT AREA
ARKANSAS, LOUISIANA, NEW MEXICO,
OKLAHOMA AND TEXAS
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
FORT WORTH, TEXAS

9-63 4-L-18277

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE

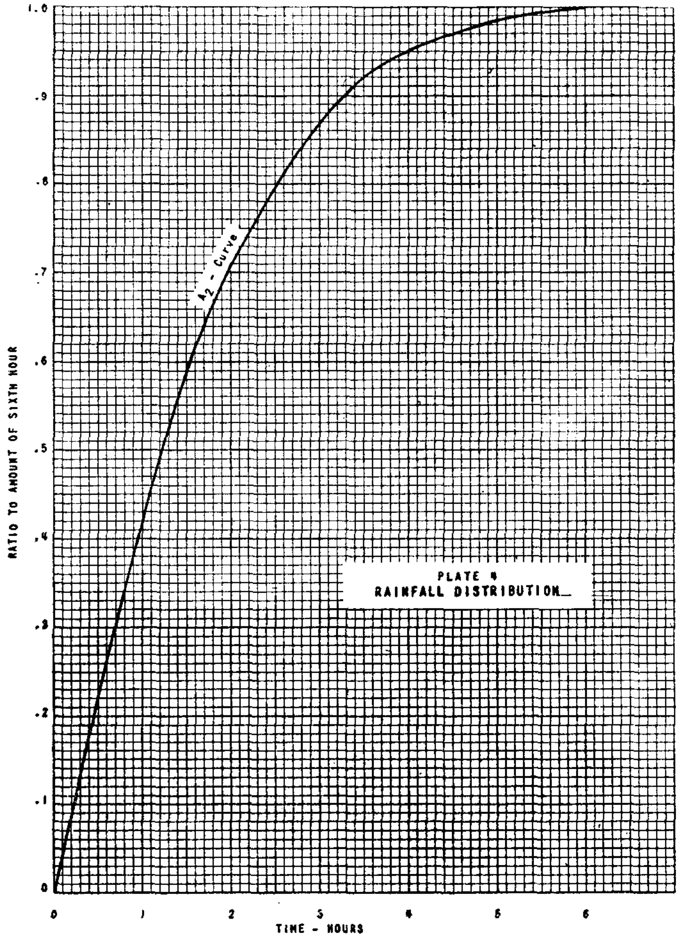

PLATE 4
RAINFALL DISTRIBUTION

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE 9-53 4-L-18276

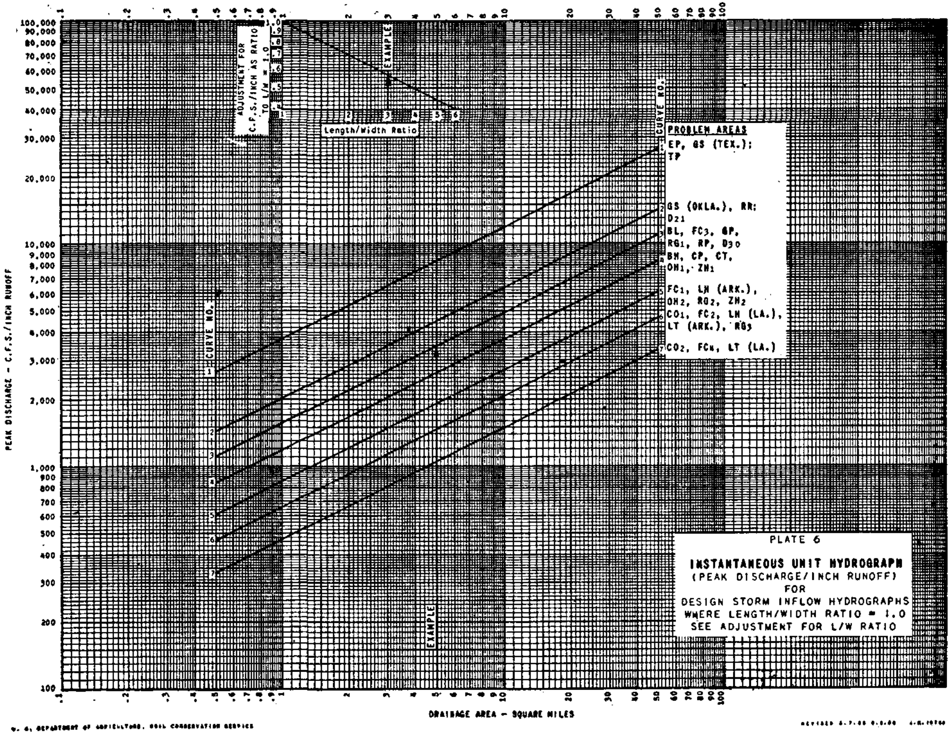

PLATE 6

INSTANTANEOUS UNIT HYDROGRAPH
(PEAK DISCHARGE/INCH RUNOFF)
FOR
DESIGN STORM INFLOW HYDROGRAPHS
WHERE LENGTH/WIDTH RATIO = 1.0
SEE ADJUSTMENT FOR L/W RATIO

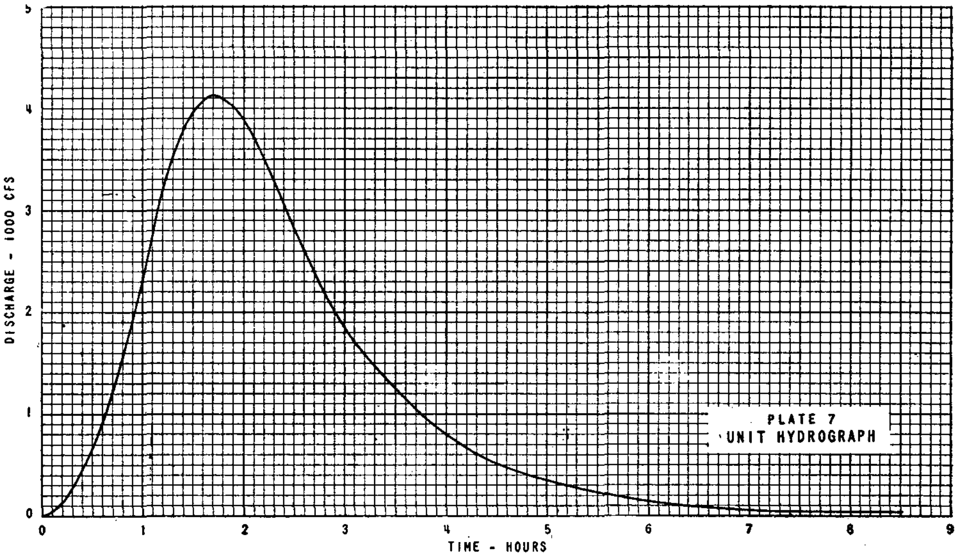

PLATE 7
UNIT HYDROGRAPH

U. S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE

9-63 4-L-18278

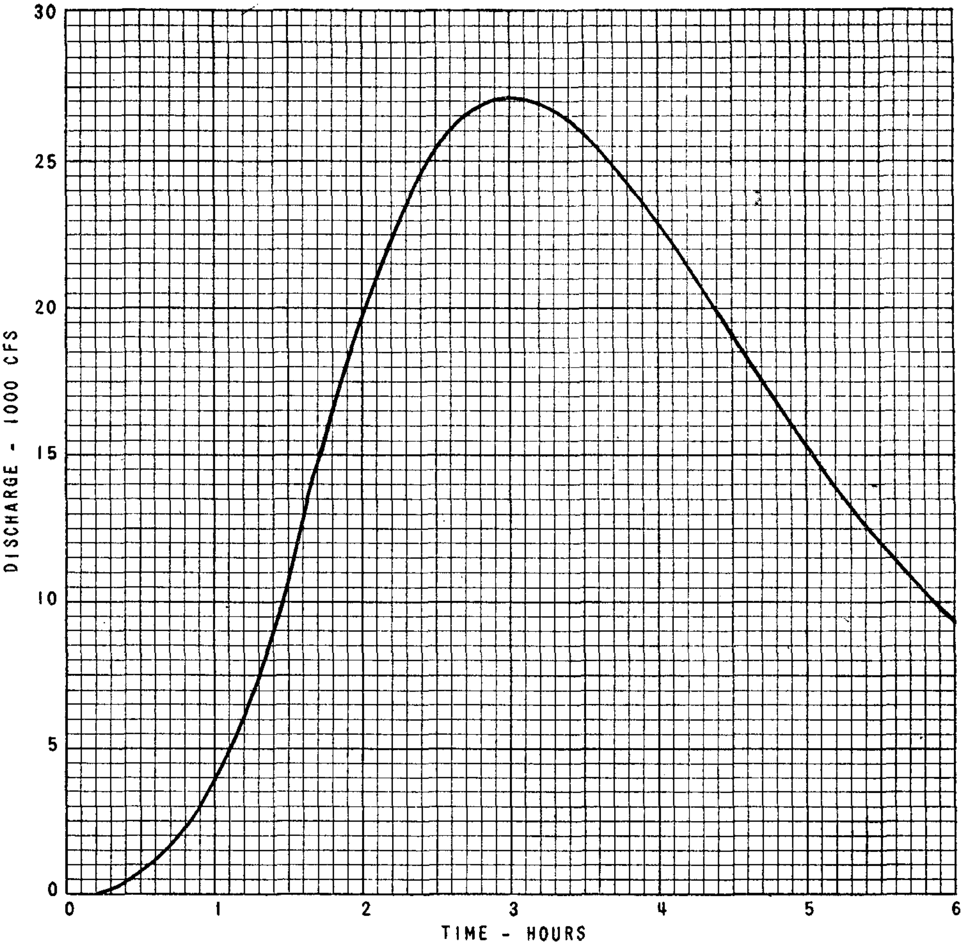

PLATE 8
FREEBOARD HYDROGRAPH

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