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HYDROLOGIC ANALYSIS OF A SMALL AGRICULTURAL WATERSHED

by

Earl Abraham Myers

AN ABSTRACT

Submitted to the School for Advanced Graduate Studies of
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Engineering

1960

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E. H. Kidder

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Earl Abraham Myers

ABSTRACT

Five years of hydrologic data from a relatively flat, 9.34 square mile, predominately agricultural watershed in south-central Michigan were analyzed.

The Thiessen uniform depths, the unweighted gage average depths, and the depths recorded at one specific gage were compared. There was very little difference between the Thiessen and unweighted procedures, however the single gage determination was considered inadequate.

The amount and peak rate of surface runoff were determined for 15 storm periods. The amount was determined by planimetering the area between the total discharge hydrograph and the assumed straight-line base flow curve. As shown by a composite recession curve, surface runoff ceased approximately $2\frac{1}{2}$ days after the hydrograph peak for each storm.

In analyzing the rainfall-runoff process, antecedent moisture, moisture accounted for by base infiltration, and the amount of moisture required prior to surface runoff were considered. The fraction of antecedent precipitation considered effective depended upon the season and the number of days prior that the rain had occurred. Initial

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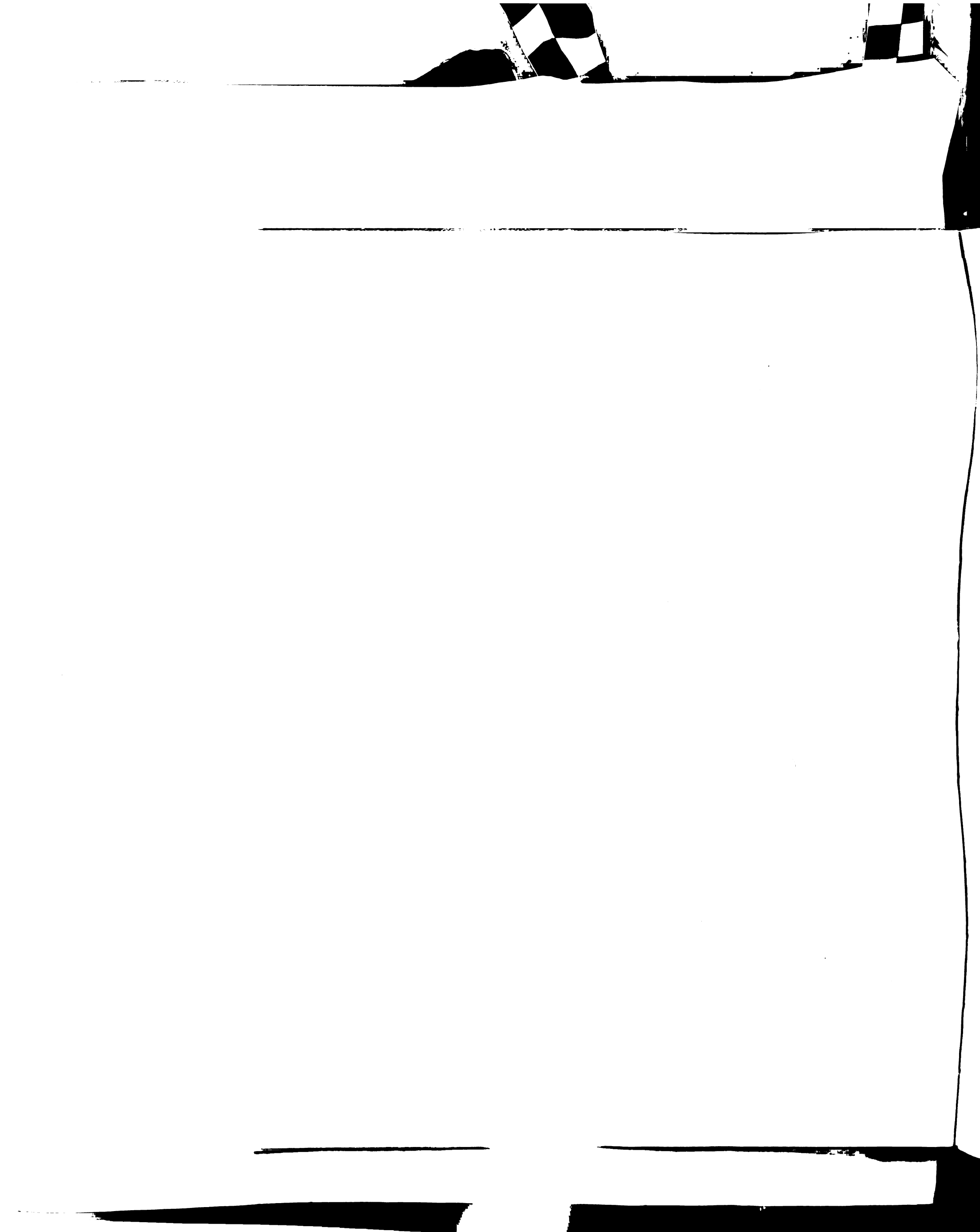
Earl Abraham Myers

that the amount required to supply initial infiltration varied with the season, probably more specifically with the moisture content of the lower soil strata.

The unit graph method of estimating flood peaks and amounts was illustrated and discussed. The procedure of combining unit graphs of various lengths was described and used for determining the 1 hour unit hydrograph for the watershed. This unit graph was used for calculating the expected hydrographs which were then compared with four natural hydrographs and very satisfactory results were obtained.

To illustrate the rational formula method, the design peak runoff rate for a once in 25 years frequency rainfall was determined. This method compared favorably with the unit graph procedure and was considered appropriate for use on small watersheds where no previous records exist.

The Soil Conservation Service's revision of Cook's formula was discussed and illustrated. This procedure was considered appropriate only for areas much smaller than Sloan Creek.



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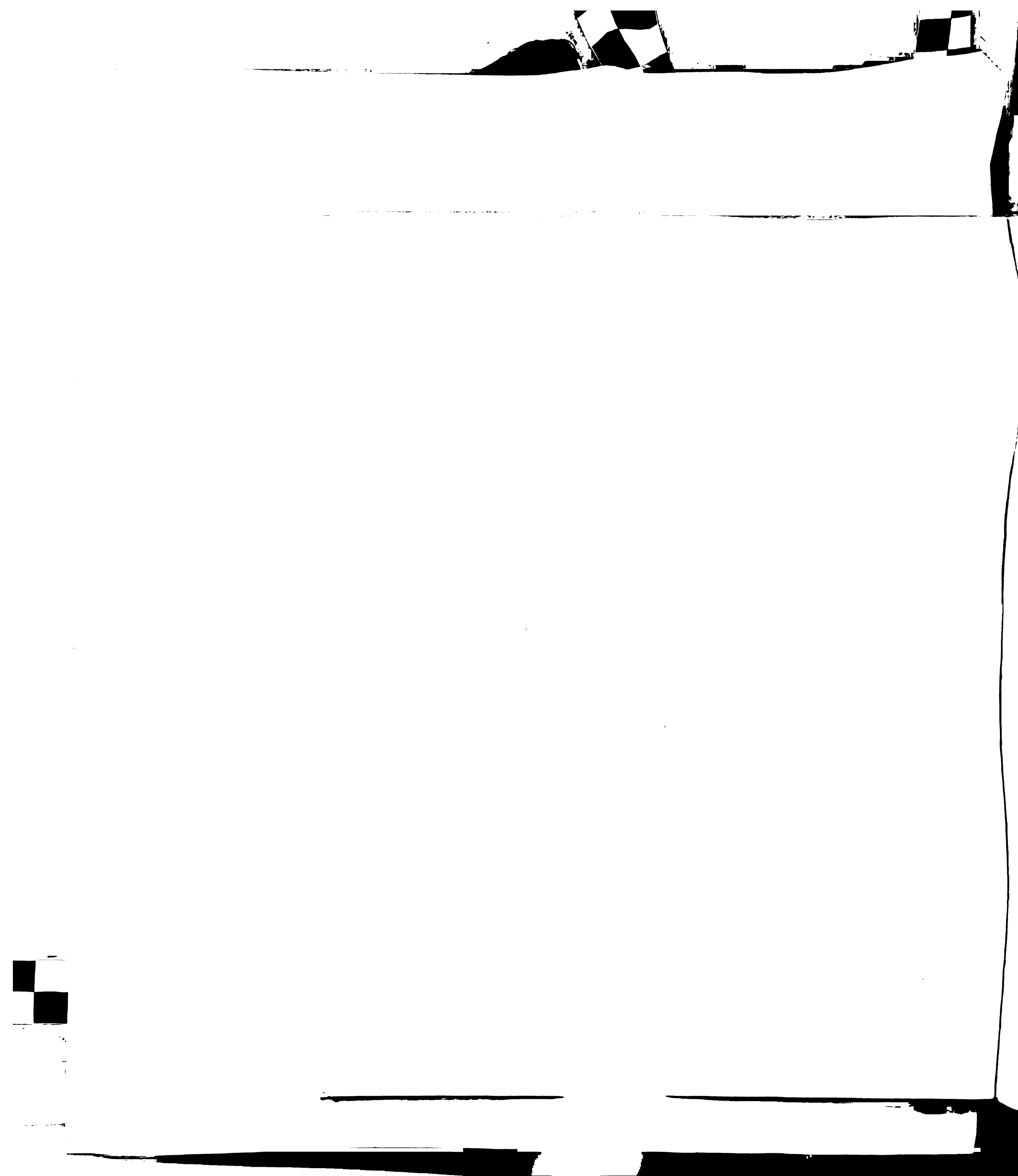
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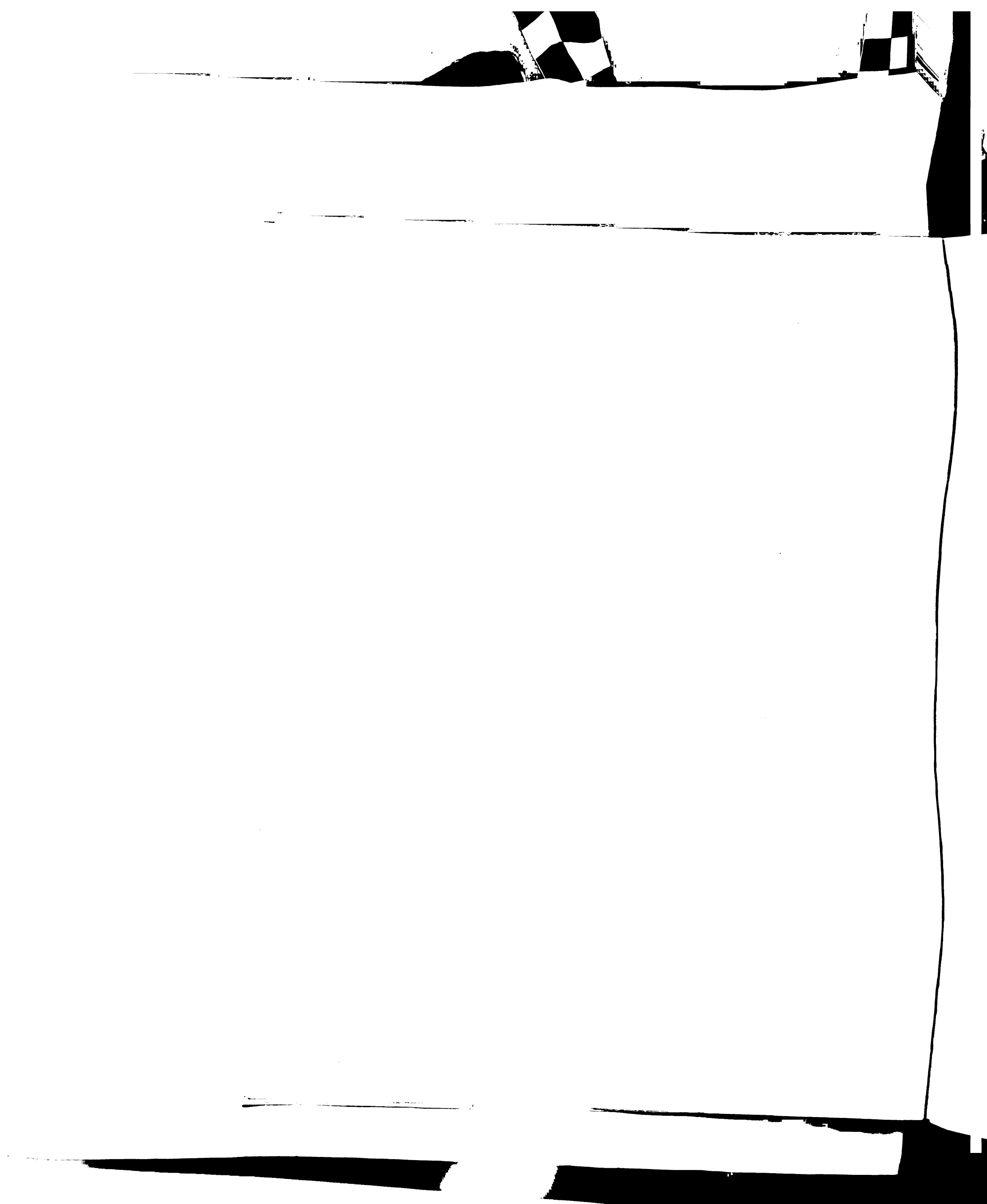
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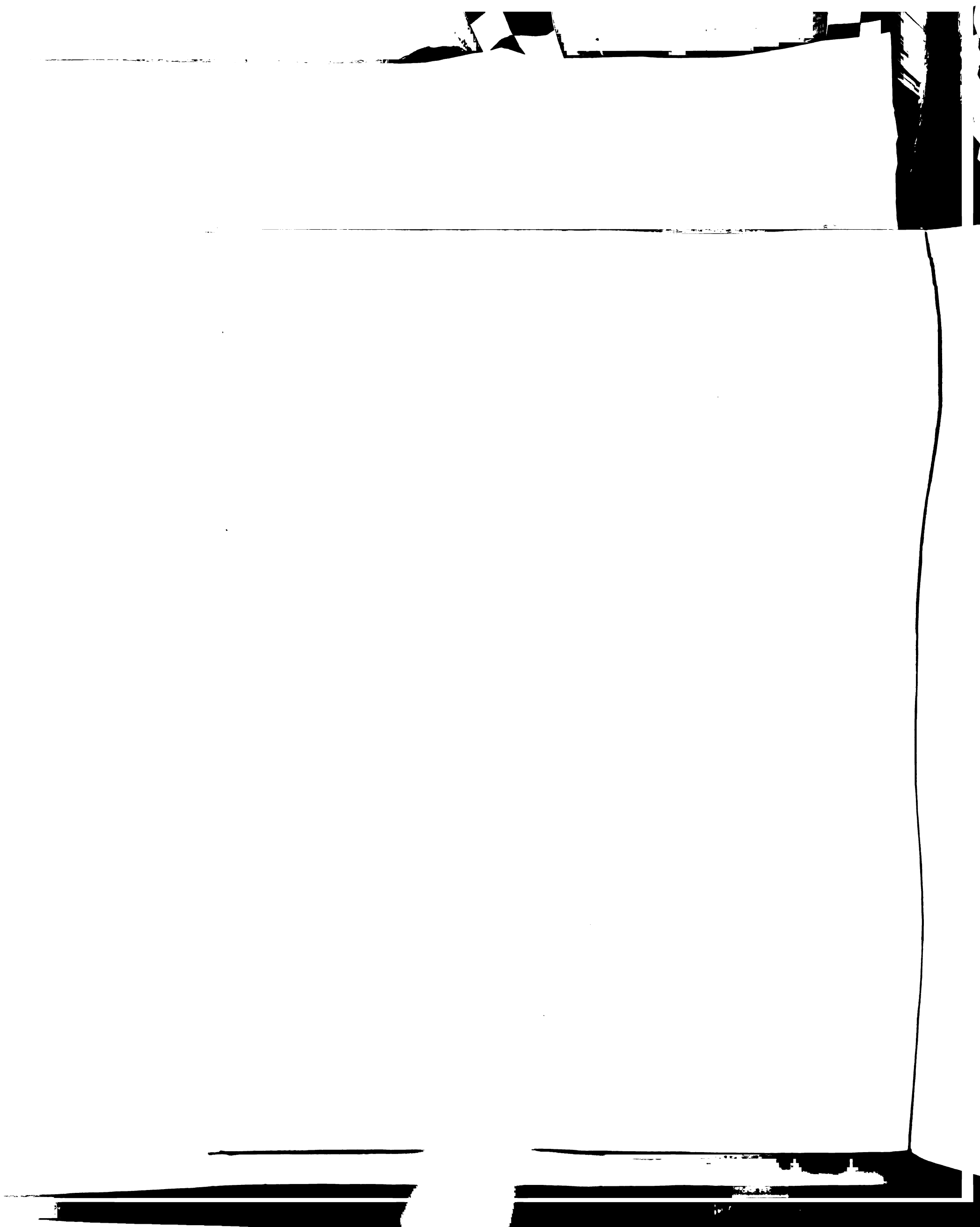
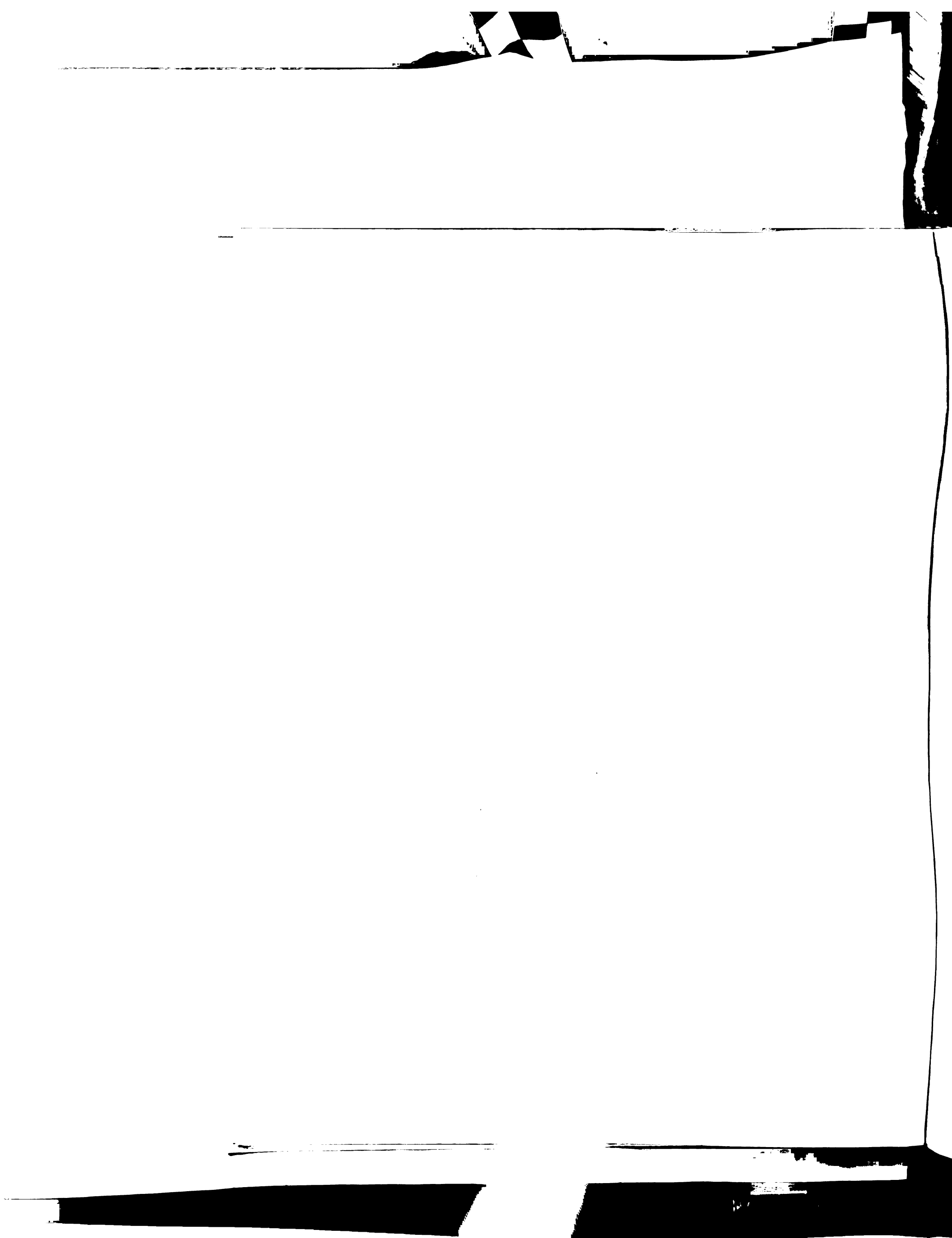


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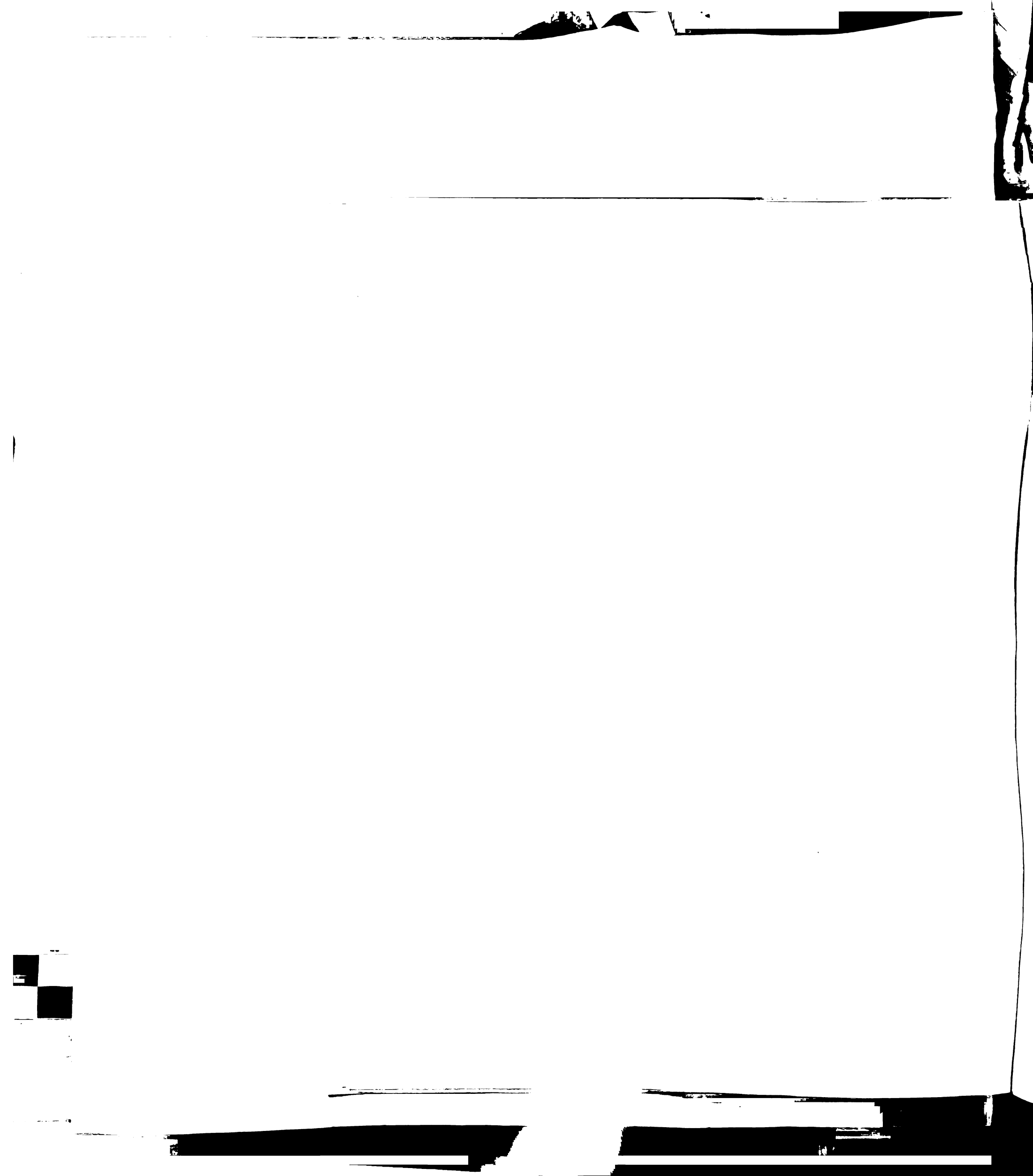
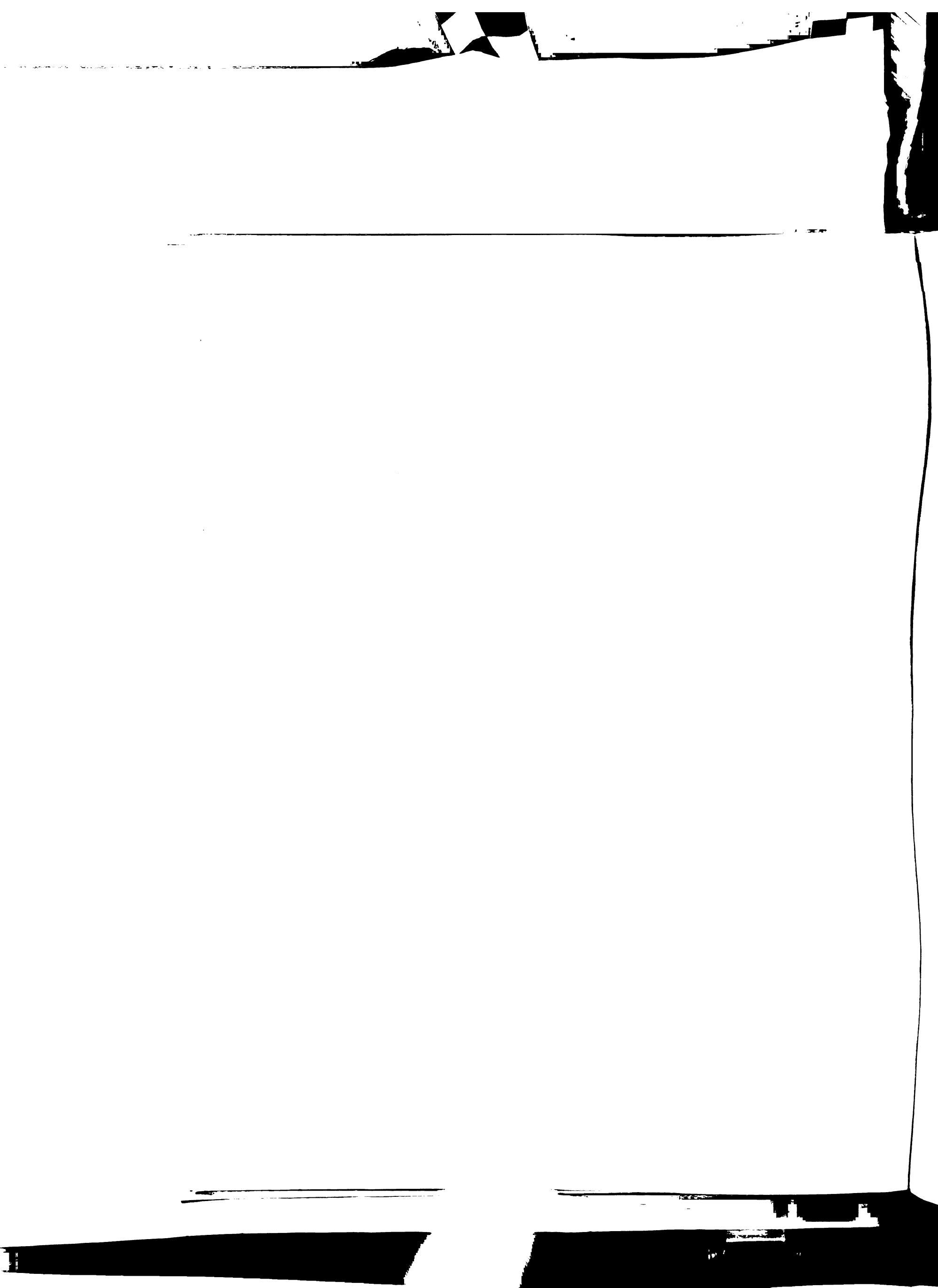


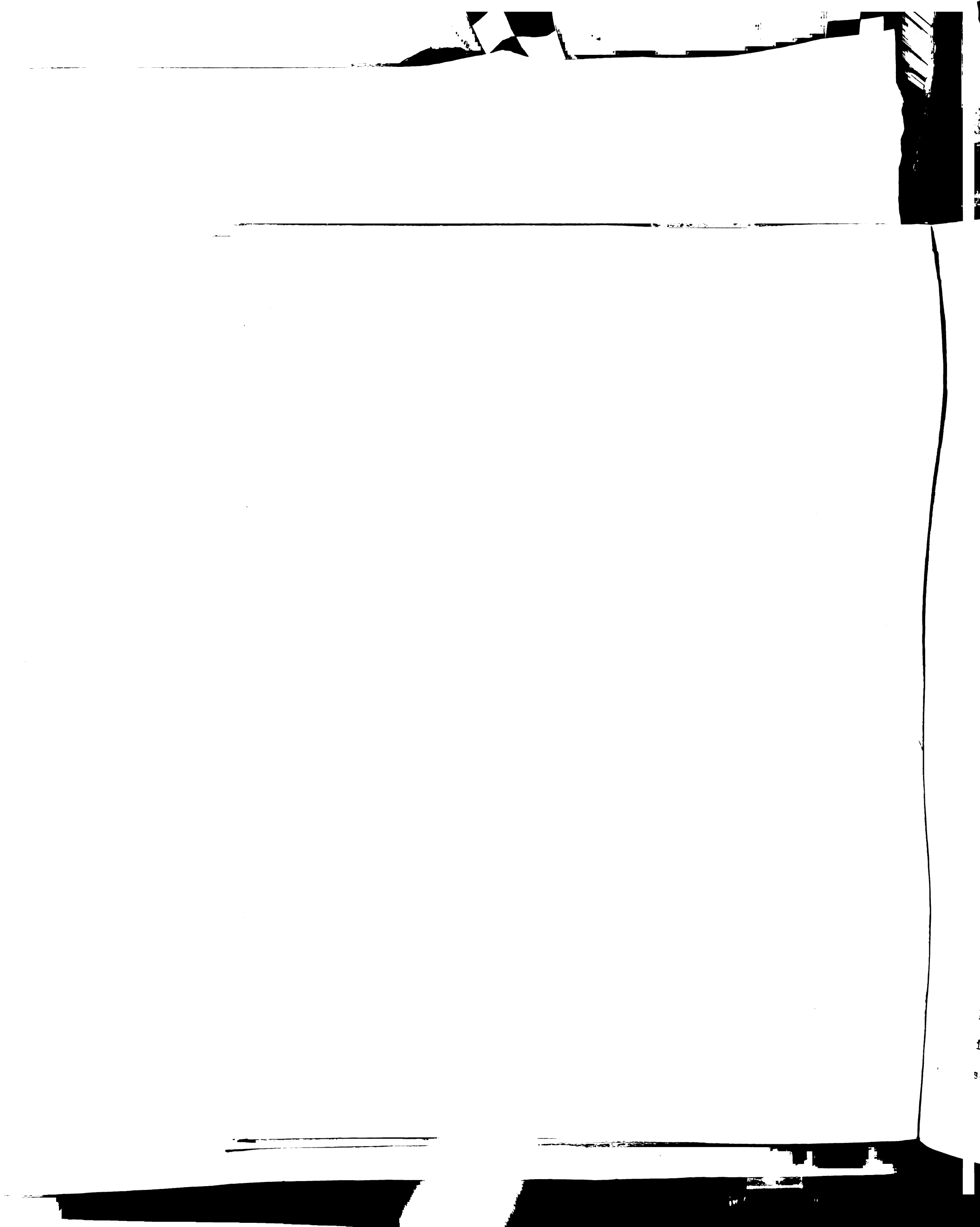
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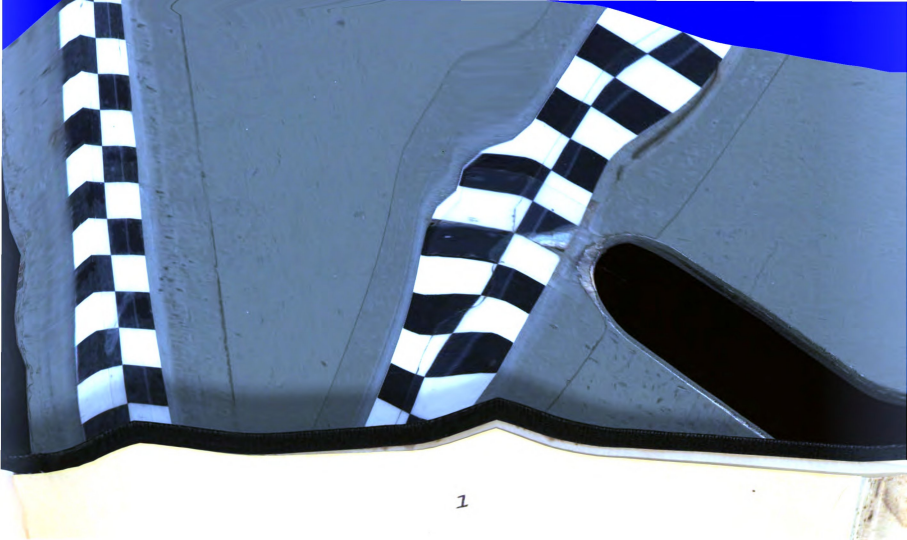




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INTRODUCTION

Peak runoff rates from small-area storms are critical in the design of spillways for dams, drainage systems, flood protection works, culverts, bridges, and storm sewers. Runoff volumes from small areas are also necessary in the design of irrigation systems, flood storage reservoirs, and other water detention and storage structures.

Most previous rainfall and runoff data have been secured from either large areas, above 25 square miles, or extremely small areas of several acres or fractional acreages. And for most of these areas only one or at best relatively few recording rain gages have been used. Thus little detailed rainfall data exist on areas of 5 to 25 square miles in size. This is especially true for predominately agricultural watersheds.

It was for the above reasons that in 1954, the Michigan Water Resources Commission; Surface Water Branch, Michigan District Office, United States Geological Survey; United States Weather Bureau office at East Lansing; and the Agricultural Engineering Department,



Williamston in south-central Michigan, from which all the data for this thesis have been secured.

The dominant land use of the Sloan Creek watershed was agricultural, with no urban infringement on the area. Nearly 60 percent of the area was cropland, with corn being the major crop. About 12 percent of the area was in pasture and 20 percent either idle or in wood land. The overall cultural picture of this watershed was one of a typical agricultural area.

From a U.S. Geological Survey topographic map and detailed field checks on the basin boundaries, the drainage area above the stream gage was determined to be 9.34 square miles. The watershed was approximately four and one-half miles wide by six miles long, see Figure 1. The topography was flat to gently undulating and the channel slopes averaged 10 feet per mile. The main channel, a constructed drainage ditch excavated about 1917, had several small meanderings; however the ditch bottom was generally straight and reasonably clear of debris and woody vegetative growth.

The watershed had mainly imperfectly-drained Conover and poorly-drained Brookston loam to clay loam soils with less than five percent of the area occupied by undulating to rolling well-drained, sandy loam Hillsdale and Bellefontaine soils. Also small areas of Brady and Griffin stratified, sorted, poorly-drained sands and

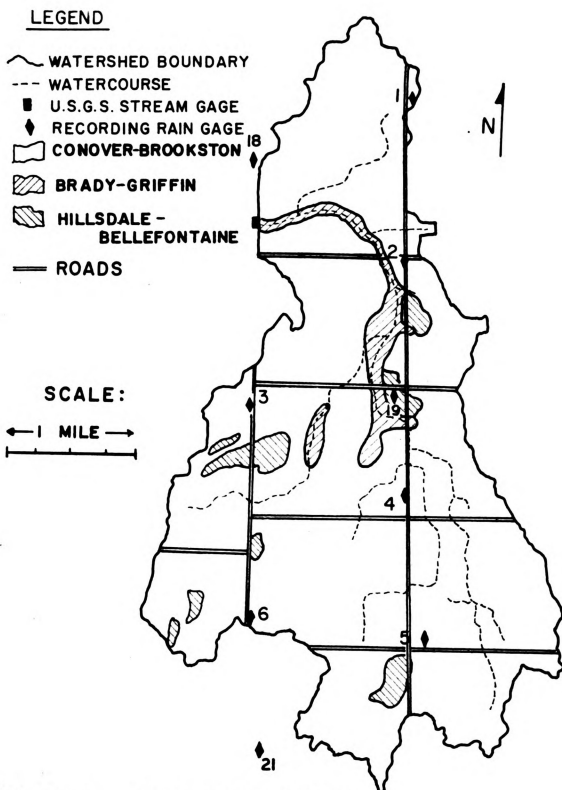
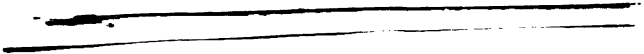
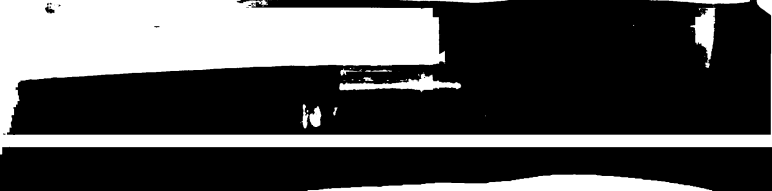


FIGURE 1. SLOAN CREEK BASIN



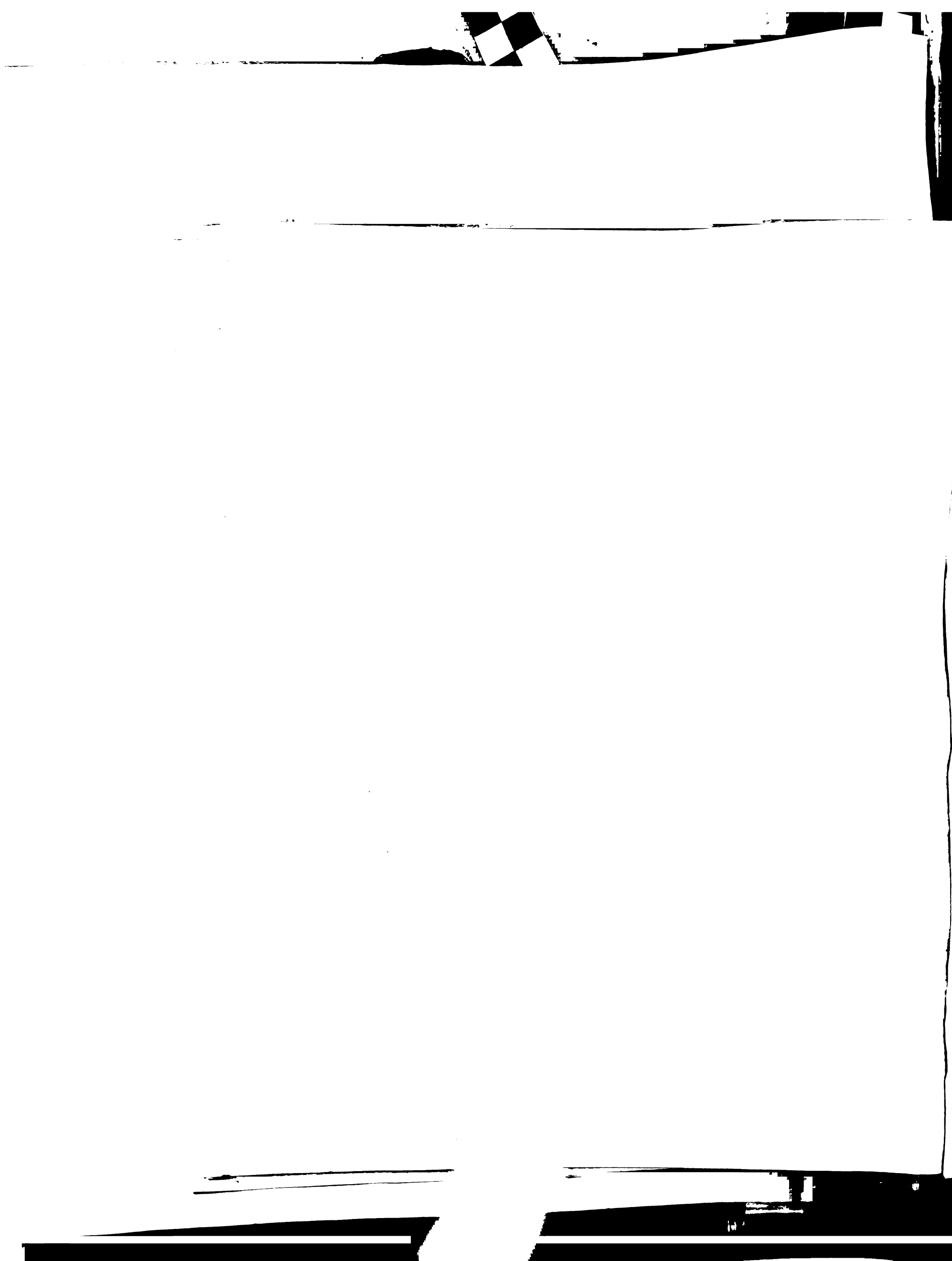
gravels occurred along the creek.

In June 1954 the United States Geological Survey established the stream gaging station. The equipment consisted of a Stevens A-35 waterstage recorder in a wooden shelter over a welded-steel pipe well and concrete control with 90 degree steel V-notch sharp-crested weir. The operation and maintenance of this station were completely under the jurisdiction of the U.S.G.S.

Six recording rain gage stations were established in April 1956 under the supervision of the United States Weather Bureau, East Lansing office. Three additional stations were installed in April 1958 to give an even better coverage of the area. These gages were installed and calibrated by the Weather Bureau and were serviced by Agricultural Engineering personnel.

The Water Resources Commission of Michigan aided in publication of data and supplied matching funds to the U.S. Geological Survey for stream gaging. The Soil Science Department advised on watershed soils problems.

The Agricultural Engineering Department was responsible for changing the rain gage charts and helped maintain all field equipment in efficient operation. Another of its functions was to aid in the analysis of the data, under which this thesis was prepared.



OBJECTIVES

The basic objectives of this study were to collect, process, and analyze the five years of available Sloan Creek watershed rainfall and runoff records. More specifically these objectives were as follows:

1. To determine the adequacy of a single raingage for the watershed.
2. To compare the various methods of evaluating the average depth of rainfall of a small watershed.
3. To choose an applicable procedure for separating surface and base flow so the volume of runoff can be determined.
4. To study the specific watershed characteristics which have the greatest effect on the runoff process and if possible to determine their specific values for the Sloan Creek watershed.
5. To determine the applicability of various methods of estimating flood peak rates and/or volumes of discharge for watersheds of this size with or without prior hydrologic records concerning them.

REVIEW OF LITERATURE

A "small watershed" may refer to any area from a fractional acre to several hundred square miles in size. As implied in the Introduction, small watersheds in this thesis refer specifically to areas of 5 to 25 square miles. Very small watersheds pertain to areas from this size down to a fraction of an acre, while large watersheds refer to areas larger than 25 square miles.

Rainfall and runoff records concerning large watersheds have been secured for a long period of time, mainly by the U.S. Weather Bureau and the U.S. Geological Survey. The early, published records contained only daily average stream discharge and raingage data, thus only areas over 500 square miles could be adequately analyzed. (10) As recording rain gage and stream gage records became available, areas much smaller than these were given more consideration.

In 1917 the Miami Conservancy District gathered data on many large-area storms in connection with the design of flood-protection works for the Miami River above Dayton, Ohio. In 1931 this study was expanded to include depth-area-duration curves for 250 of the greatest storms in eastern United States. The Corps of Engineers in cooperation with the Hydrometeorological

Section of the Weather Bureau, in 1937, undertook a study of about 1000 major storms which occurred in all parts of the United States. The data from this study were more detailed and supersede the Miami Conservancy work. (24)

Since 1930, much experimental work has been in progress on watersheds ranging from a few acres to several square miles in size. These experiments were designed primarily to determine the effects of land use and of conservation practices on runoff. The procedures on and the results of many of these studies are summarized by Krimgold (12,14) and Cardwell (4).

The previous references verify that the size of the watershed affects greatly the approach required for its analysis, as it affects both the rate of runoff and the manner of its occurrence. On larger watersheds, floods reach their crest slowly, remain at flood stage for days, and subside slowly; while on smaller watersheds they crest more quickly, remain at flood stage only a short time, and subside quickly. When large streams overflow, the resulting damage is more extensive because of the larger flood plains and greater length of flood period; but the suddenness of small watershed floods frequently causes a heavy loss of life and property. (23) (29)

Floods on small watersheds are generally caused by very intense precipitation, which occurs over small areas only. It is usually rains of low intensities covering



the entire watershed and lasting for several days which cause floods on large watersheds.

Small and very small watersheds may consist entirely of steep slopes and impervious soil, causing a high percentage of runoff and a rapid concentration of flow; while the varied topography and soil of a large watershed usual result in a smaller percentage of the rain running off and in a slower rate of concentration. For example, the June 1903 flood of Willow Creek, Oregon produced 1800 cfs per square mile from a 20 square mile watershed; while the 1904 flood on the Illinois River with a drainage area of 27,900 square mile had a flood runoff rate of only 4.48 second-feet per square mile. (23)

On very small watersheds the rates and amounts of runoff are influenced primarily by the physical conditions of soil and cover over which man had some control, and thus most attention in hydrologic studies is given to these factors. The channel storage effect for large watersheds becomes more pronounced and is given the most attention when considering runoff from large areas. (5)

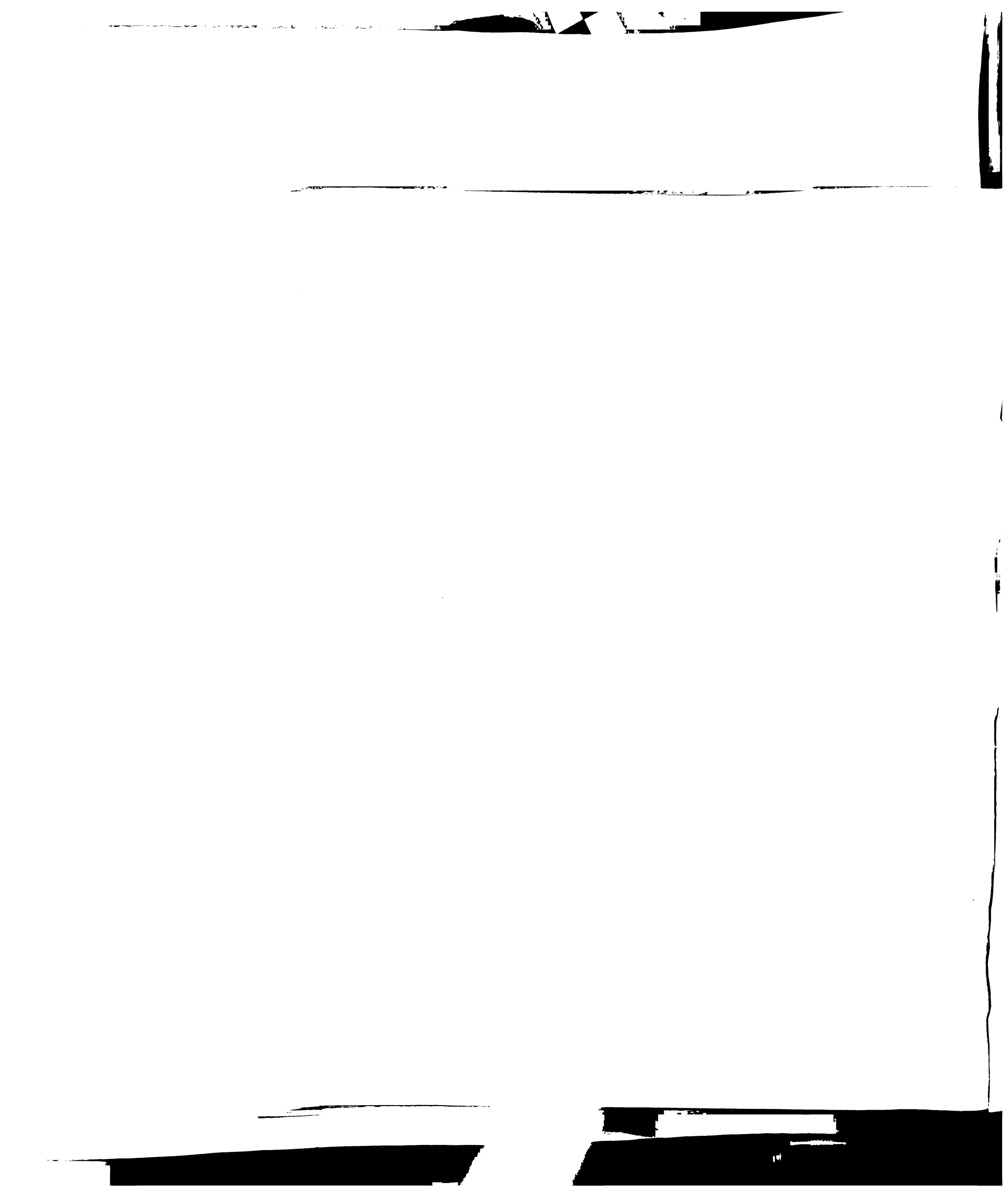
During the past ten years much information has been made available concerning large watersheds and also very small areas; however, information concerning the 5 to 25 square mile areas is still very inadequate. Decisions concerning runoff from these small areas, which include

smaller watersheds, must nevertheless continue to be made. Each year these determinations of runoff must permit more economical design of structures and at the same time assure a high degree of safety. Thus more accurate rainfall-runoff data must be secured.

Pickles (23) lists and discusses a number of empirical formulas that have been used for estimating future flood flows. He also states, "The paper by Gregory and Arnold and the extensive discussion on it contain the most complete coverage of the subject of runoff formulas of which the author is aware."

Most of the previously used empirical formulas have been grouped into two categories by Linsley, et al. (17) The first category is of the type used by Fuller, Myers, Fanning, and Talbot which has the general form of $q_p = b A^m$. That is the peak flow is considered a power of the basin area. The exponents used differ to such an extent that this reference concluded that theses formulas "should never be used for engineering design."

The second group is typified by the Burkli-Ziegler formula $q_p = A c i \sqrt{\frac{s}{A}}$. In this expression i is the expected average rainfall in inches per hour, s is the average slope of the watershed in feet per 1000 feet, A is the area in acres, and q_p is in cfs. This type of



modern engineering design".

After considering all available references and the data available from the Sloan Creek watershed, three methods of estimating runoff were chosen. Before discussing these methods however, certain rainfall and watershed factors need to be considered.

The major rainfall characteristics required for hydrologic analyses are intensity, duration, amount, and distribution. (2) Direction of storm movement also affects runoff. To analyze this factor, however, requires greater synchronization of raingage timing and longer periods of record than were available for this study. Recording gages supply adequate intensity, duration, and amount of rainfall data. The number and distribution of gages in the raingage network should be such that the rainfall data are congruent with the permissible variation in basin discharge. (16)

The equivalent uniform depth of precipitation over a given area may be computed by one of four methods. The simplest is by taking the unweighted mean of the precipitation recorded by the various gages in the area. If the gages are regularly spaced this procedure is frequently as satisfactory as any of the others.

The Thiessen procedure makes allowance for irregularities in gage spacing by weighting the amount received by each gage in proportion to the area which the gage represents.

The gage is assumed to represent all areas closer to it than to any other gage. The isohyetal map makes even greater use of the gage data by taking into account the evidence of other nearby gages and making corrections accordingly. (10) (24)

In the isohyetal method, the human element enters into the drawing of isohyetal lines which account for influences of areal distribution and topography on intensities. The Myers (20) method is a mathematical procedure which assumes uniform areal variations due to storm patterns and uniform changes in precipitation due to differences in elevation, but is always consistent when used to analyze a number of storms over the same watershed.

Besides the storm characteristics previously discussed, the quantity of runoff produced by a storm depends upon the moisture deficiency of the basin at the onset of the rain. Direct determination of the moisture conditions throughout the basin is not feasible, as depression and interception storage, as well as three-dimensional soil moisture measurements are required. (17)

Nevertheless, various procedures have been considered for approximating these initial moisture conditions. Thames and Ursic (30) indicated that surface runoff is strongly correlated with storage opportunity in the upper 6 inches of soil. In this case soil moisture

throughout the watershed was determined by a network of fiberglass resistance units. Variations in groundwater discharge at the beginning of storm periods and pan-evaporation data have been used with varying success. At the present time, the most common index is based on antecedent precipitation. (17)

If moisture deficiency is broadly interpreted it also includes infiltration. Actually, storm loss is mainly due to infiltration and the infiltration rate at any time depends upon the water available for infiltration and on the infiltration capacity of the soil. If the rainfall intensity is greater than the infiltration capacity the excess water fills depressions and then runs off. (3)

The infiltration capacity is extremely variable and has been the cause of much study. Kidder (11) analyzed the effects of crops and tillage on the amount of infiltration that took place during individual natural storms. His review of literature summarized many factors which affect the infiltration process.

Kringold (13) quoted from a paper of H. K. Rouse to show "why the records from (very) small agricultural drainage areas with constantly changing vegetal cover, soil moisture, and structure of surface soil show such a great variation in peak rates of runoff which overshadow the relation to intensity of rainfall." Zingg (31) stated, "The infiltration rate decreased throughout the

storm, from a value of 0.12 inch per hour at the initial time of rainfall excess, to less than 0.01 inch per hour about 15 hours later."

The previous data point out some of the variables which must be considered in the rainfall-runoff process. These variables, individually and through interactions, affect the shape of the runoff hydrographs of a watershed, hydrograph being defined as a graph of discharge rate versus time.

Each runoff hydrograph consists of three segments, a rising limb, a crest segment, and a falling limb or recession. The shape of the rising limb for any specific watershed is influenced mainly by the rainfall characteristics of the storm producing the runoff, whereas the recession is largely independent of these characteristics. (17)

A flood-period hydrograph is usually a hydrograph of surface runoff superimposed on a hydrograph of groundwater discharge. A base flow line, between the point where the rising limb begins and the position on the recession where surface runoff ends, is used to separate these two flows. This line is assumed to be straight if groundwater data for a particular watershed is nonexistent. However, it may be concave downward or upward depending on the particular watershed characteristics. (10)

Various methods have been considered for determining the position on the recession curve where surface runoff

essentially ends. (9) The methods discussed in the Processing of Data section were suggested by references (3), (17), and (24). Pickles (23) recommended using the recession record from a similar, previous period to estimate the groundwater component.

A mathematical procedure using unit graph theory to determine the expected values of surface runoff is suggested by Johnstone and Cross (10). These computed values are then compared with the natural hydrograph values and adjustments of time made until reasonable agreement between the calculated and actual rates is reached. This procedure is frequently used when previous recession curve data are not available.

The first procedure of estimating watershed runoff to be considered in this thesis is the unit graph method. A unit graph is defined as a hydrograph resulting from 1 inch of runoff from the entire watershed as the result of a uniform rainfall lasting one unit of time. This method was introduced in 1932 by L.K. Sherman and is based on the principle that identical amounts of runoff should be produced from identical rains falling on identical watersheds. Recognizing that identical situations never occur in nature and that reasonable variations are acceptable for practical applications, certain tolerances are permitted. (15) (23)

The unit graph principle was used in the approaches of Bernard, McCarthy, and Snyder. Each of their procedures



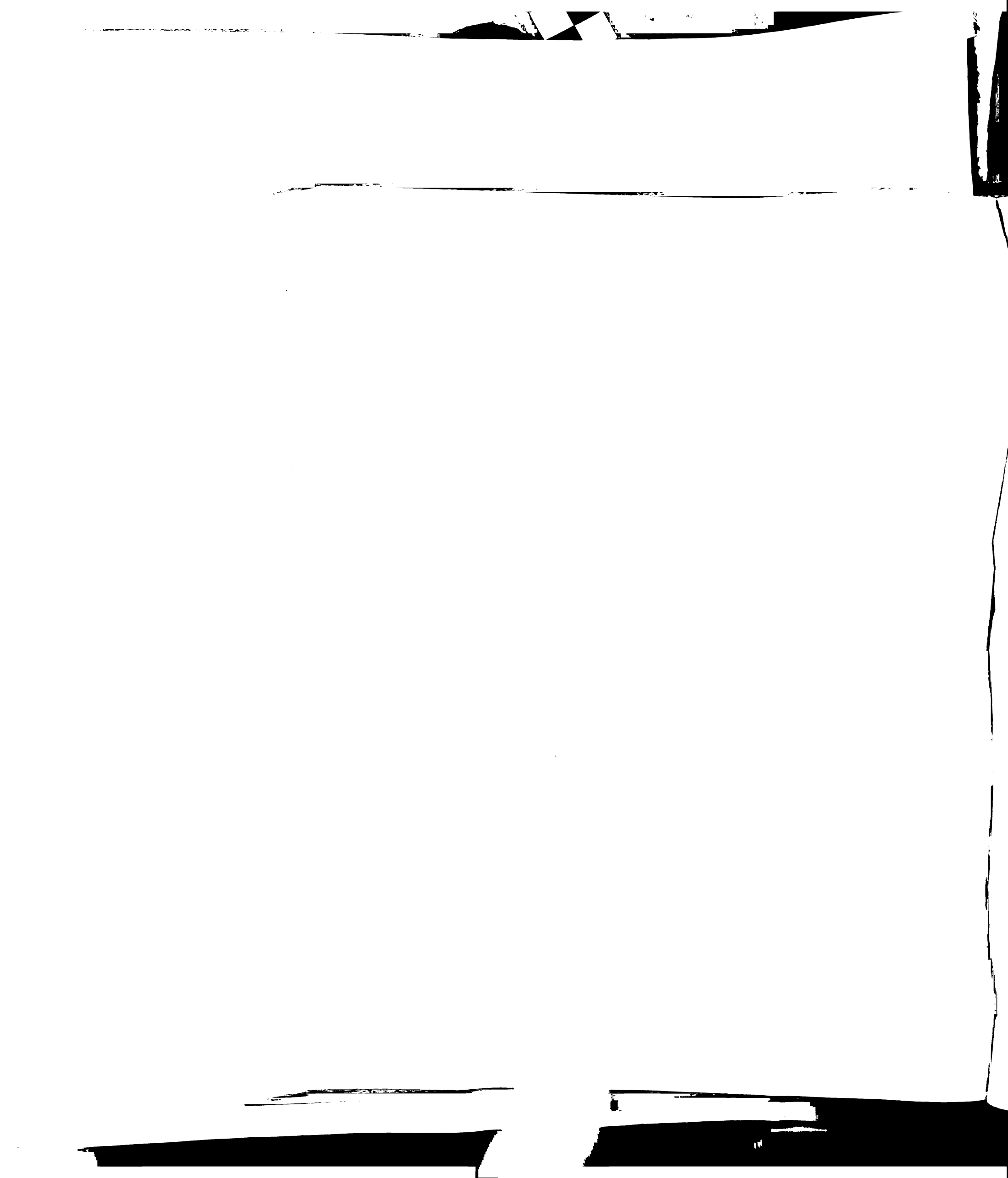
is outlined in detail in reference (10). Their work was all on large areas. Linsley (15) has found unit hydrographs to be applicable to drainage basins in the 5-10 square mile area range. Minshall (19) is presently investigating the use of this method on areas less than 1 square mile in size.

The unit graph method is most applicable where a number of years of rainfall and discharge records from recording gages are available. Besides this possible limitation some of the assumptions and other considerations required are discussed in the following paragraphs.

For most watersheds variations of ± 25 percent for lengths of rainfalls used to develop a unit graph are permissible. (17) The unit length chosen should be short enough to adequately define the hydrograph peak (24), or be about one-fourth of the basin lag (15).

Besides being relatively uniform in length of rainfall, the rainstorm should be evenly distributed over the entire area and of such magnitude that all parts of the watershed contribute to the runoff. The directions and rate of storm movement its intensity, and the season of its occurrence should be similar. (10)

It is assumed that the time distribution of surface runoff from a given storm period is independent of concurrent runoff from antecedent storm periods, and that for storms of equal lengths the rates of runoff at corresponding times are in the same proportion to each



other as the total volumes of surface runoff. (10)

The composite unit graph from a number of similar storms is considered more applicable than from any specific one. This is because of inaccuracies in the basic data, nonuniform distribution of storms, and departures of drainage basin performance from unit graph theory. (10)

All the authorities agree that none of these assumptions are rigorously correct, but they believe that a maximum variation and peak discharge of ± 20 percent about the mean can be obtained.

The rational formula $Q = C i A$ is a very simple formula. It is a very satisfactory formula however, if all the rainfall and watershed characteristics can be properly determined. Sharp (25) has done an excellent job of outlining its two main weaknesses.

"The first of these is the determination of the proper rainfall intensity to use. This will vary with the season of the year, the size of the watershed, the type of storm, direction of travel of rain wave, and many other factors Watersheds, other than those measured by square feet in area, rarely have uniform rainfall intensity even instantaneously over the entire watershed much less for periods of minutes or hours which are the most normal duration of concentration time."

"The second is the determination of the coefficient C. This coefficient must be adjusted to accommodate surface storage, detention storage, initial abstracts, rainfall interception, and a varying rate of infiltration. Detention storage varies with land slopes and channel gradients, stream meander, pondage, and other factors. Infiltration may be affected by land use, land treatment, vegetative conditions, antecedent soil moisture, temperature, and other factors."

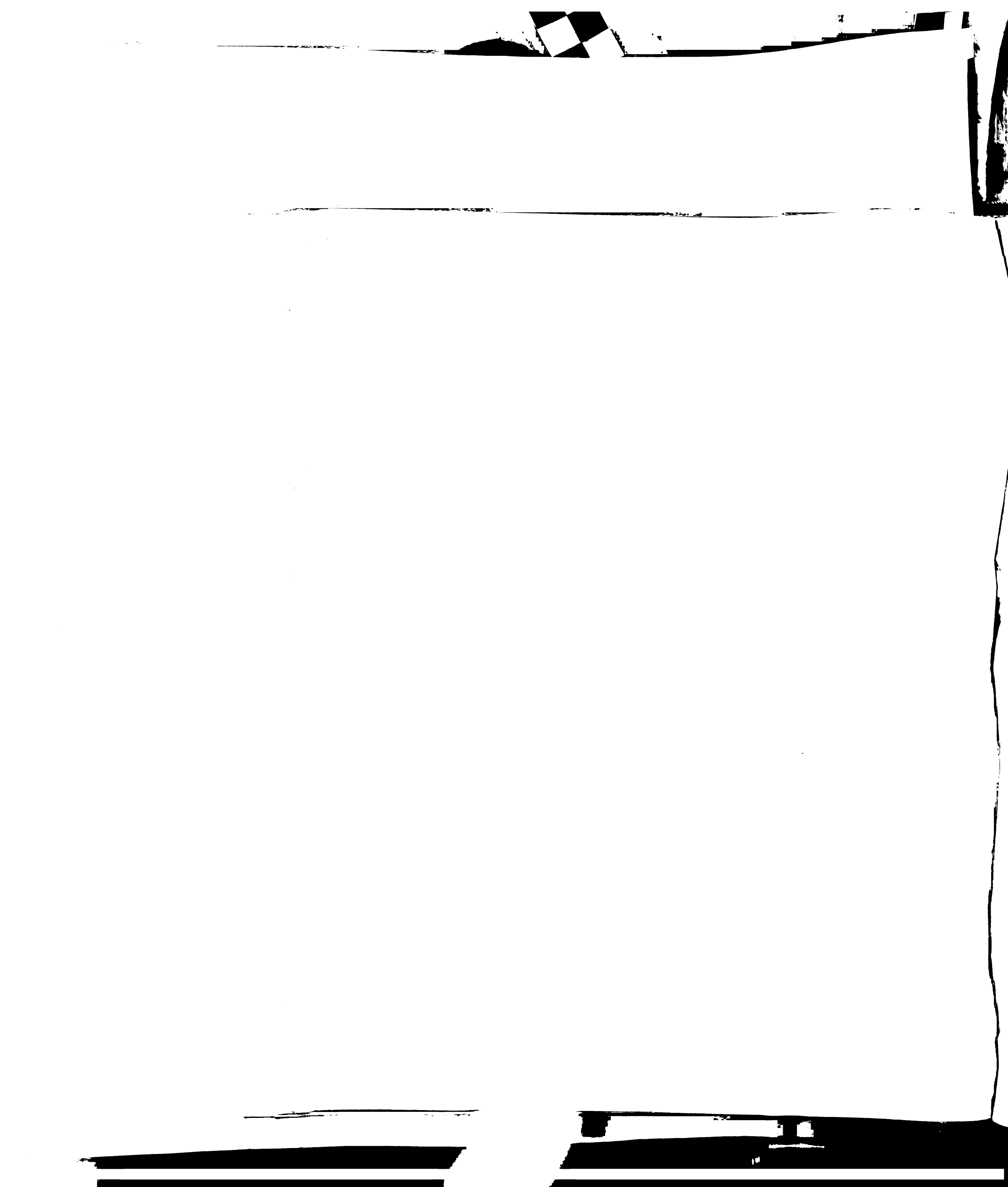
This certainly is true, but without previous rainfall

or runoff information for a watershed any other formula must consider these same factors. An example of rational formula use is given in the Analysis and Discussion of Runoff Data section.

Cook's method of evaluating runoff for a particular watershed by examining the relief, soil infiltration, vegetal cover, and surface storage characteristics has been modified by Soil Conservation Service personnel. Its latest modification has been recently outlined by Ogrosky (22), who states, "The approach takes into consideration the soil, land use or cover, treatment or practice, hydrologic condition of the cover, soil moisture condition and rainfall."

The field hydrologists are then provided with the range of data which is to be used in a prescribed procedure. This information includes 2000 major soils which have been placed in four hydrologic groups; curve numbers for various combinations of soils, cover, and treatment; a series of curves relating rainfall and runoff; and description of the various soil moisture conditions.

The procedure is very exacting; all field men arrive at the same runoff from a given set of data. These values of runoff are probably fairly accurate if the rainfall and watershed conditions were of the "average" type for which the procedure was designed.



COLLECTION OF DATA

In determining the specific rainfall-runoff periods to study, it was necessary to use raingage and streamgage records simultaneously. It is merely for convenience that they are here discussed separately.

The hourly precipitation from each of the raingage charts was read and tabulated by Weather Bureau personnel. Copies of the tabulated sheets were maintained by the Agricultural Engineering Department. These tabulations were rechecked for arithmetical accuracy and where comparisons between gages indicated possible errors original charts were referred to.

These records were satisfactory for the determination of average depth of rainfall over the watershed and for indicating the hourly amounts of precipitation for the runoff hydrographs. The original tracings, however, had to be used for preparing unit hydrographs, as specific lengths, intensities, and uniformity of rainfall are critical in their construction.

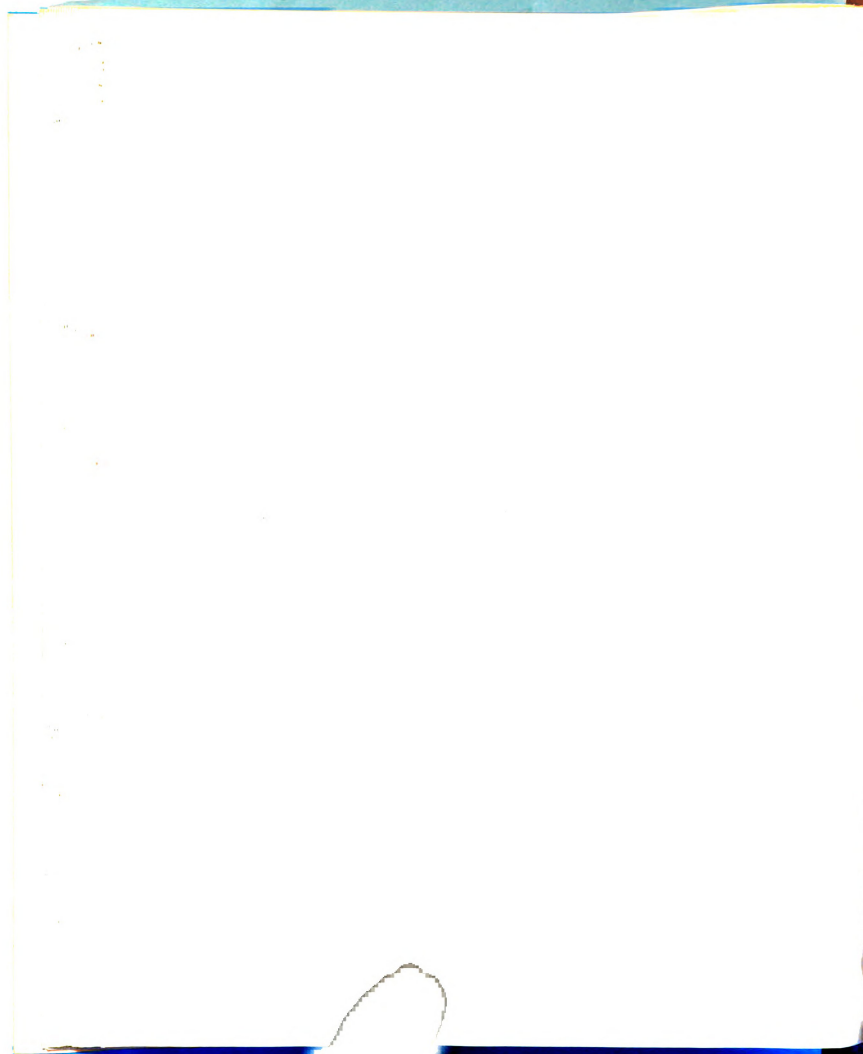
In securing runoff data it was necessary to refer to the original tracings of the waterstage recorder, as U.S. Geological Survey personnel tabulate only daily average discharges. Their notes for the calculation of

these discharges, however, served as an excellent check on the author's work.

Forty five possible discharge peaks were checked. Many were discarded due to frozen ground or to water from melting snow being in the discharge; others were eliminated because the peaks could not be readily separated or there was insufficient data. Assistance of U.S.G.S. personnel in determining the appropriate runoff peaks to use was invaluable.

Eventually data were secured for 19 hydrographs, with peak flows ranging from 685 cfs to 3 cfs. Fifteen of them were used for determining the rainfall-runoff process for spring, summer, and fall conditions; two were representative of winter conditions with no snow; one was for exemplifying snow melt runoff; and one was for showing the effect of very light precipitation during extremely high antecedent moisture.

Only sufficient points necessary to obtain a true reproduction of the original hydrograph were secured. These data and an explanation of their derivative are presented in Appendix 1.



PROCESSING OF DATA

Rainfall distribution

According to Linsley, Kohler, and Paulhus (17), the Thiessen method of determining equivalent uniform depth of precipitation will give "essentially the same" results as linear interpolation used with the isohyetal procedure. Since there are no topographic influences which warrant modification from linear interpolation and since the Thiessen method is easier to apply it was used for this watershed.

Table 1. Percentage of watershed ascribed to each gage using Thiessen procedure.

Gage number	Six gages percent	Nine gages percent
1	9.8	7.2
2	19.1	11.0
3	14.2	12.4
4	19.6	14.8
5	22.9	20.8
6	14.4	14.1
18		6.0
19		11.1
21		2.6
Total	100.0	100.0

Figures 2 and 3 show the areas ascribed to the various rainfall gages for the six and nine gage arrangements, respectively. The specific percentages of the watershed assigned to each gage are listed in Table 1.

Using the percentages given in Table 1, the Thiessen procedure rainfall analysis data were calculated. These data and additional information concerning them are presented in Appendix 2.

Hydrograph construction

The data of Appendix 1 were used to construct hydrographs for the 19 runoff periods. Figures 4 through 22 show chronologically these hydrographs with their respective base flow separations. These figures also include the Thiessen hourly precipitation values, each plotted in the center of the hour of its collection.

A uniform scale of time for the abscissas was used, but the scales for the ordinates were varied to secure maximum area under the curves. The greater area permitted increased accuracy in the determination of runoff by planimetering.

As discussed in the next section, $2\frac{1}{2}$ day surface runoff recession curves were used for nearly all hydrographs. Occurrence of another storm before the ending of this period required the lengthening of three hydrographs by using data from similar storms. Typical recessions for the



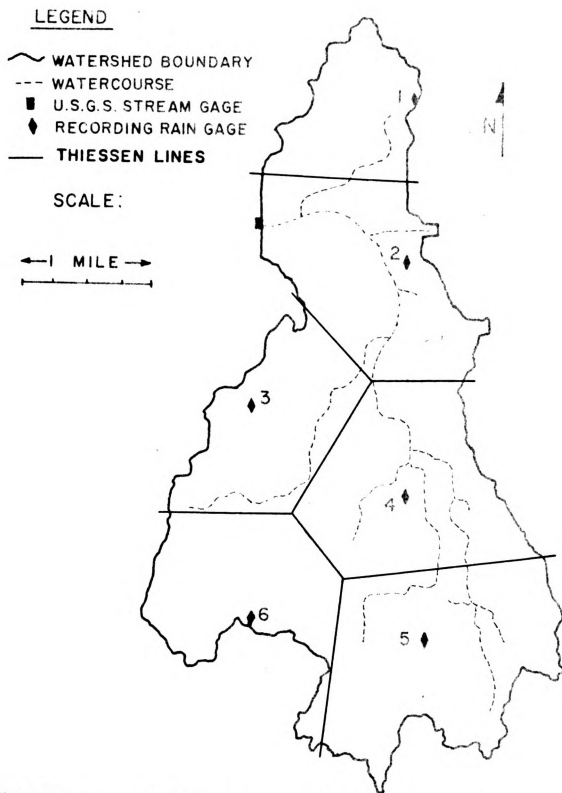
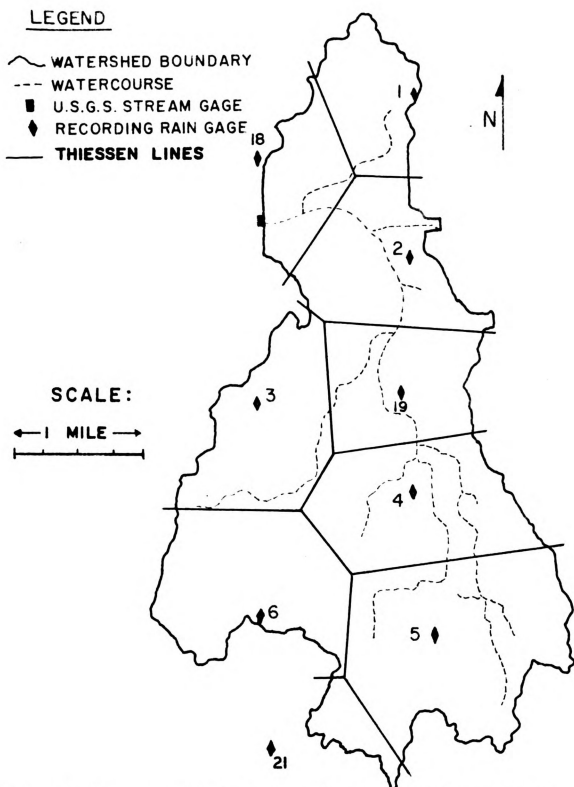
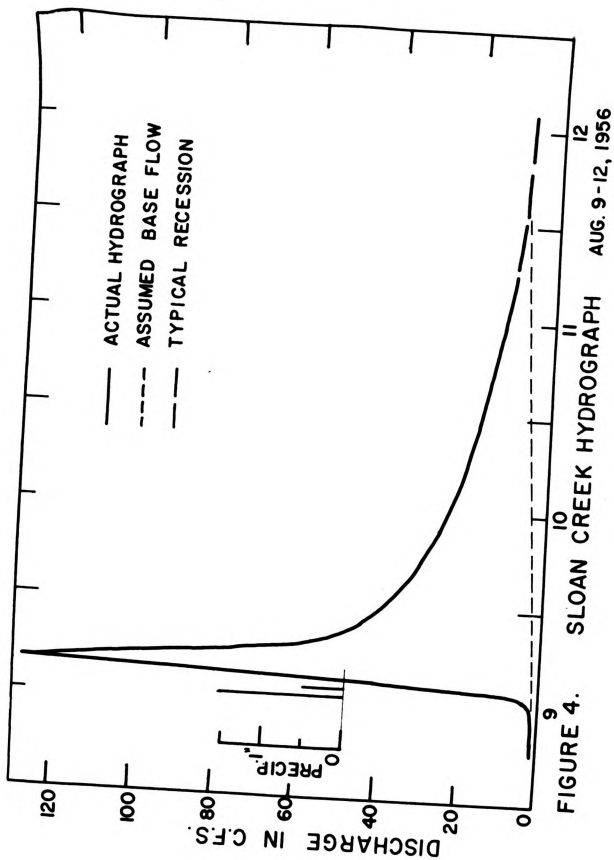


FIGURE 2. SLOAN CREEK BASIN SIX GAGE
THIESSEN PROCEDURE



**FIGURE 3. SLOAN CREEK BASIN NINE GAGE
 THIESSEN PROCEDURE**



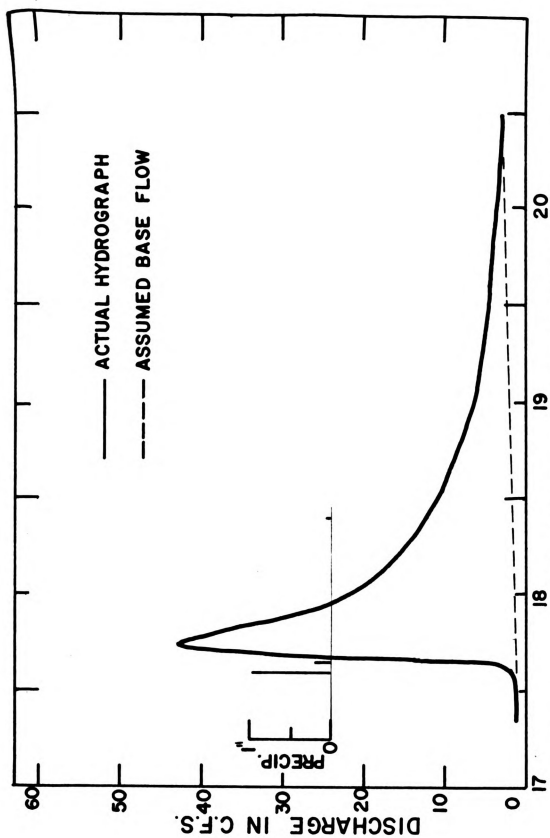
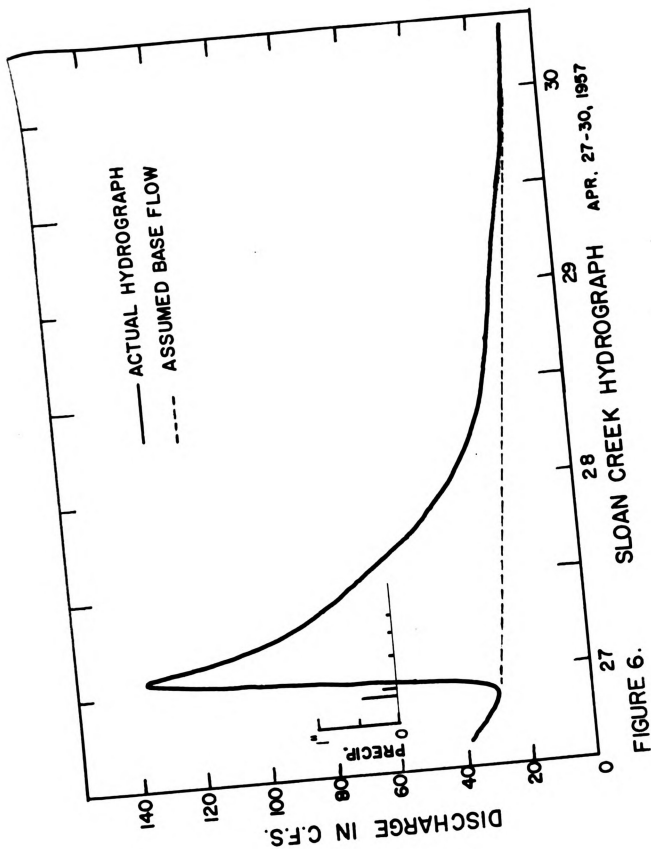


FIGURE 5. SLOAN CREEK HYDROGRAPH AUG. 17-20, 1956



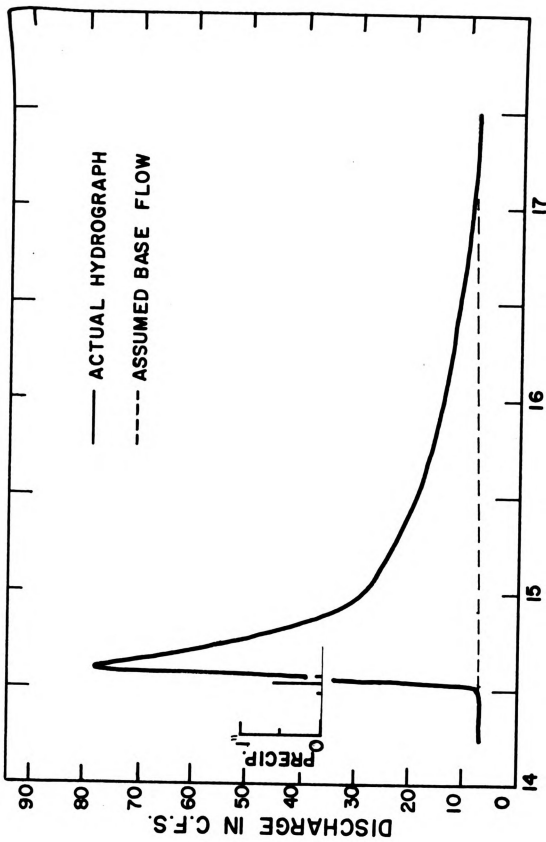


FIGURE 7. SLOAN CREEK HYDROGRAPH MAY 14-17, 1957

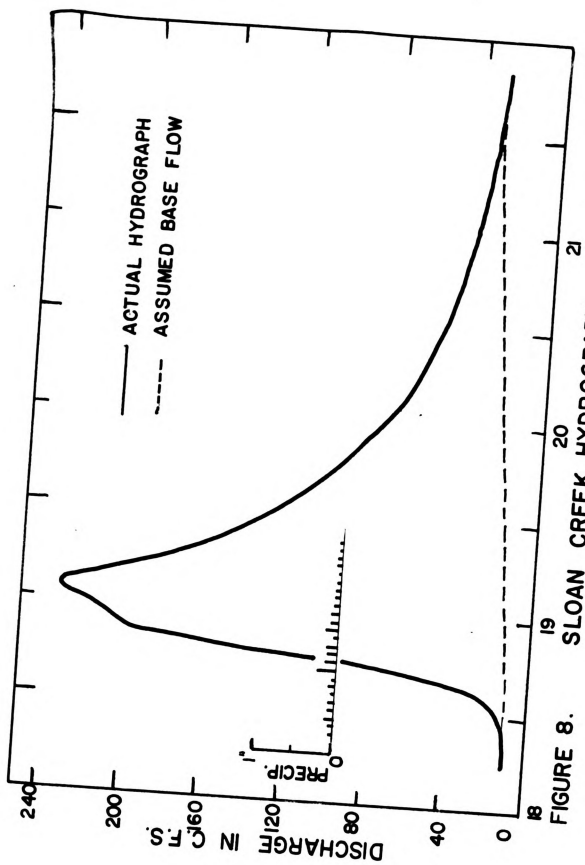


FIGURE 8. SLOAN CREEK HYDROGRAPH MAY 18-21, 1957

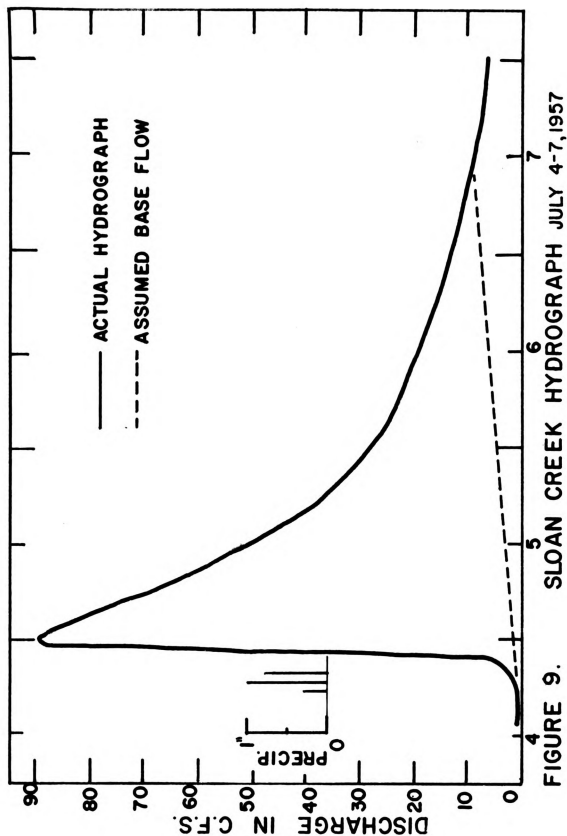


FIGURE 9. SLOAN CREEK HYDROGRAPH JULY 4-7, 1957

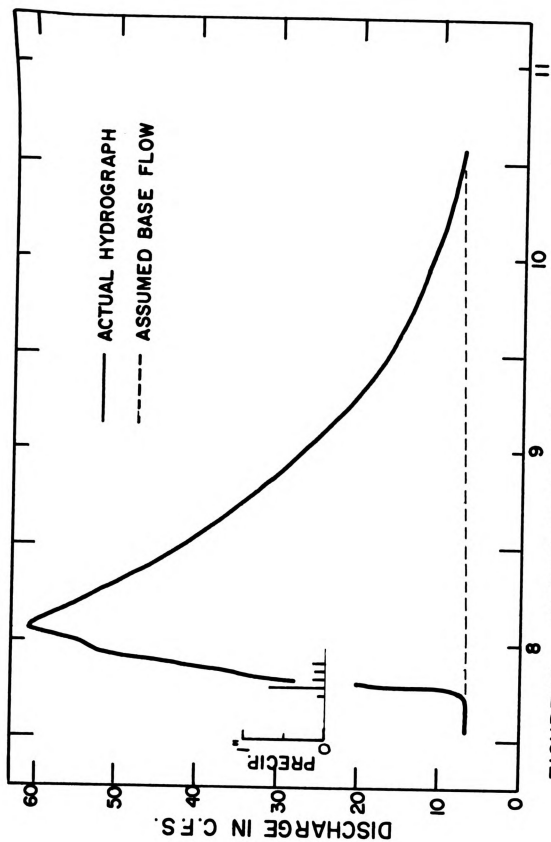


FIGURE 10. SLOAN CREEK HYDROGRAPH JULY 8-11, 1957

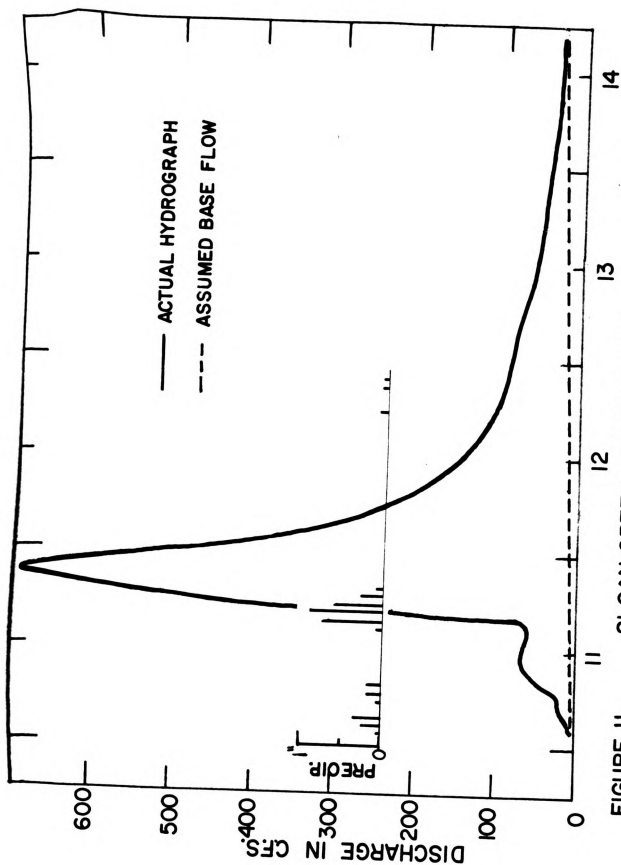


FIGURE 11. SLOAN CREEK HYDROGRAPH JULY 11-14, 1957

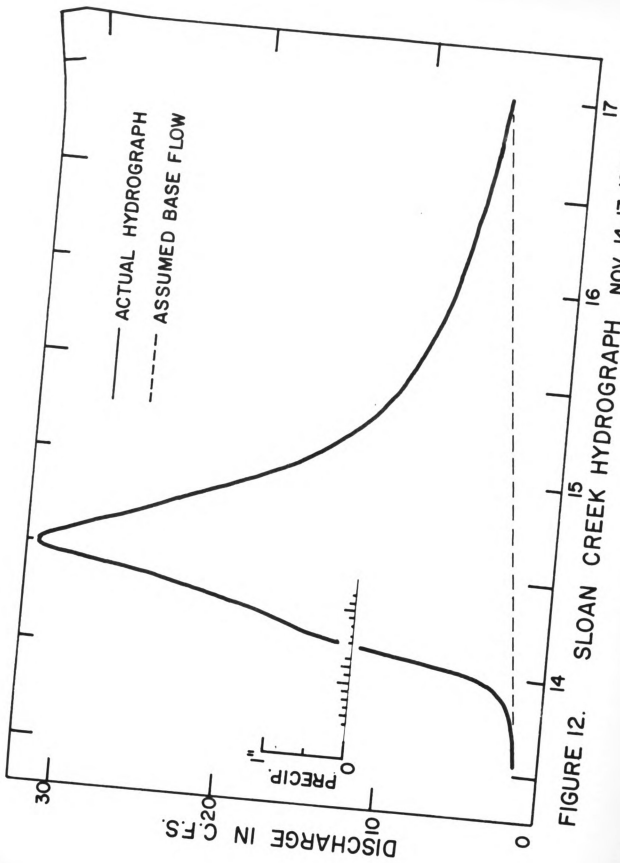


FIGURE 12. SLOAN CREEK HYDROGRAPH NOV. 14-17, 1957

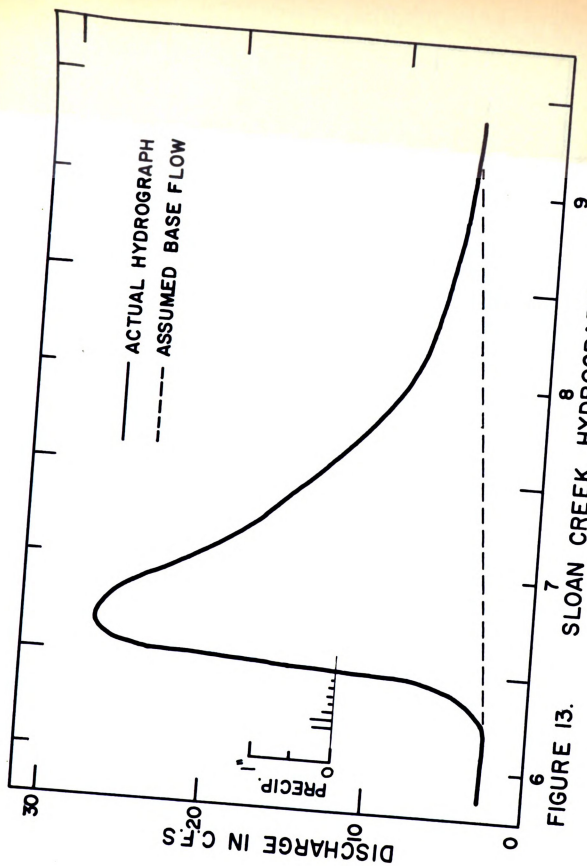


FIGURE 13. SLOAN CREEK HYDROGRAPH APR. 6-9, 1958



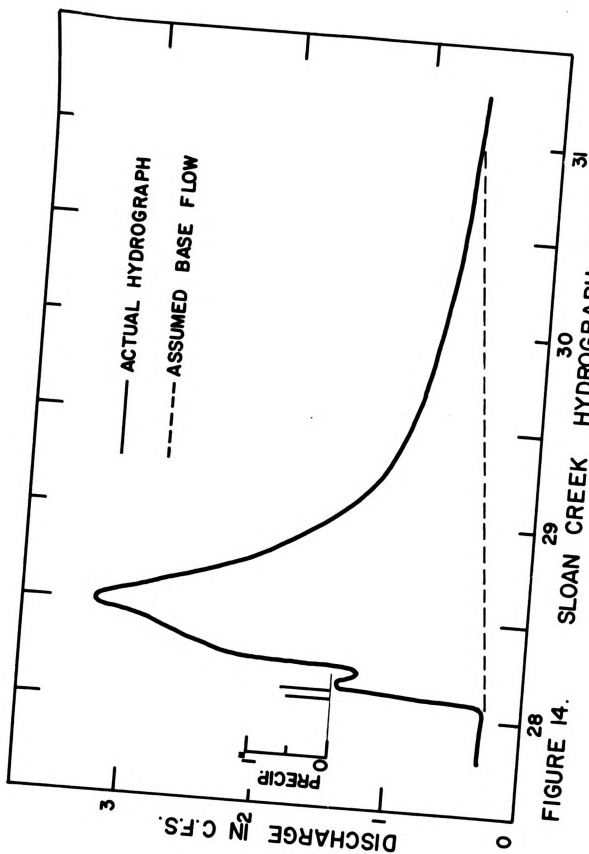
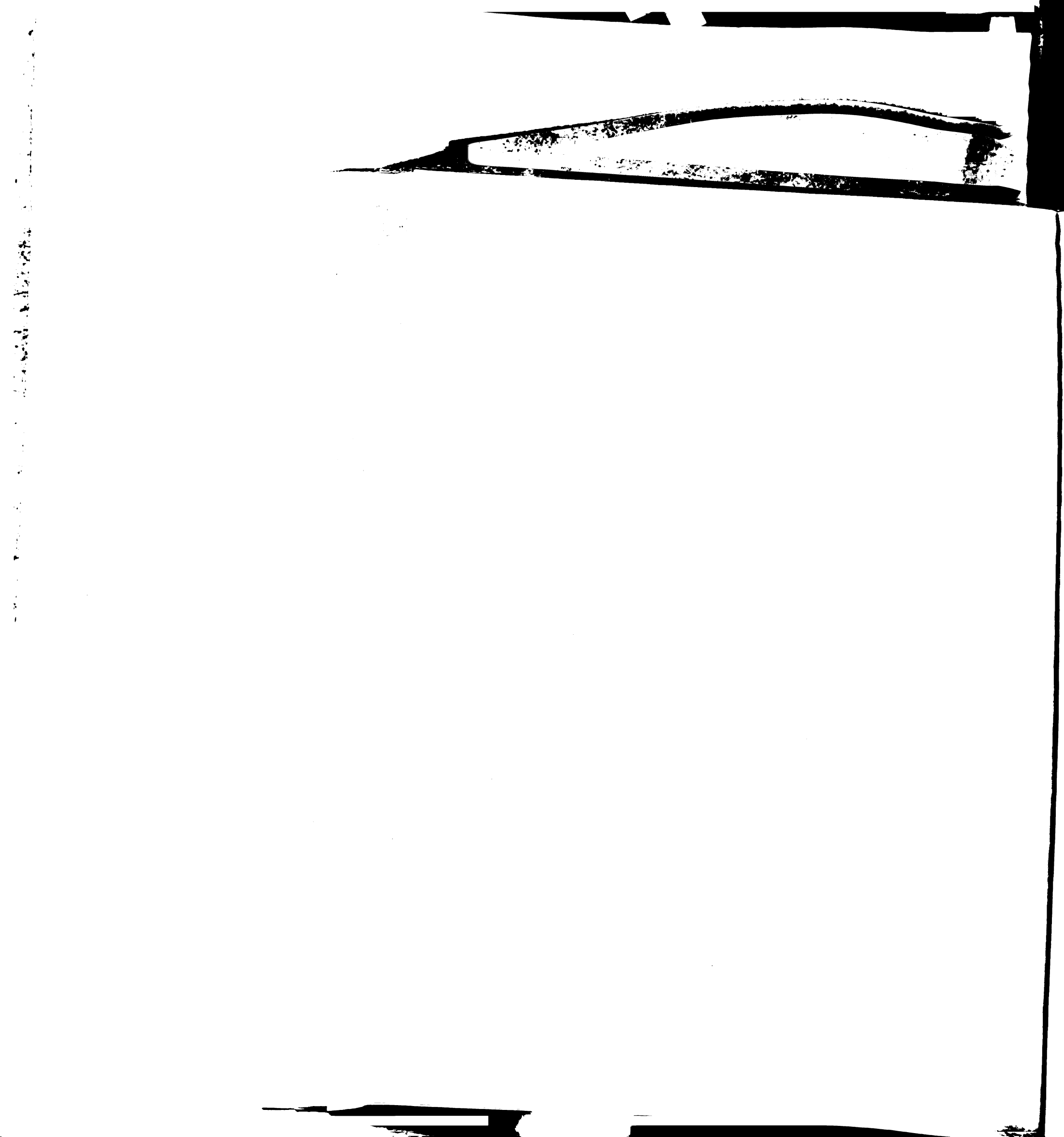


FIGURE 14. SLOAN CREEK HYDROGRAPH JULY 28-31, 1958



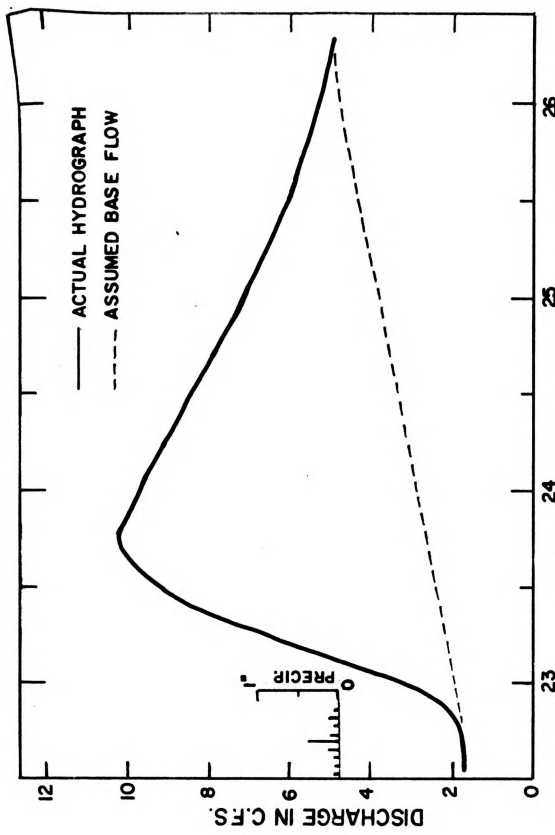


FIGURE 15. SLOAN CREEK HYDROGRAPH MAY 23-26, 1959



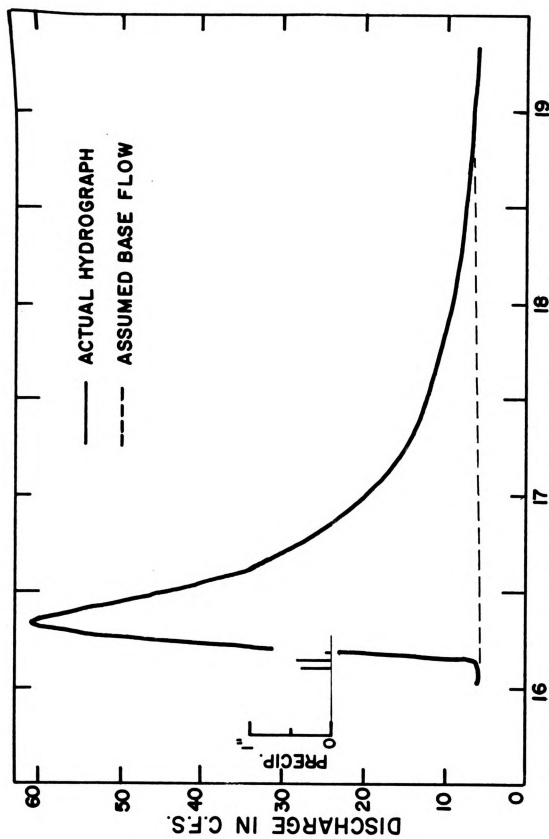
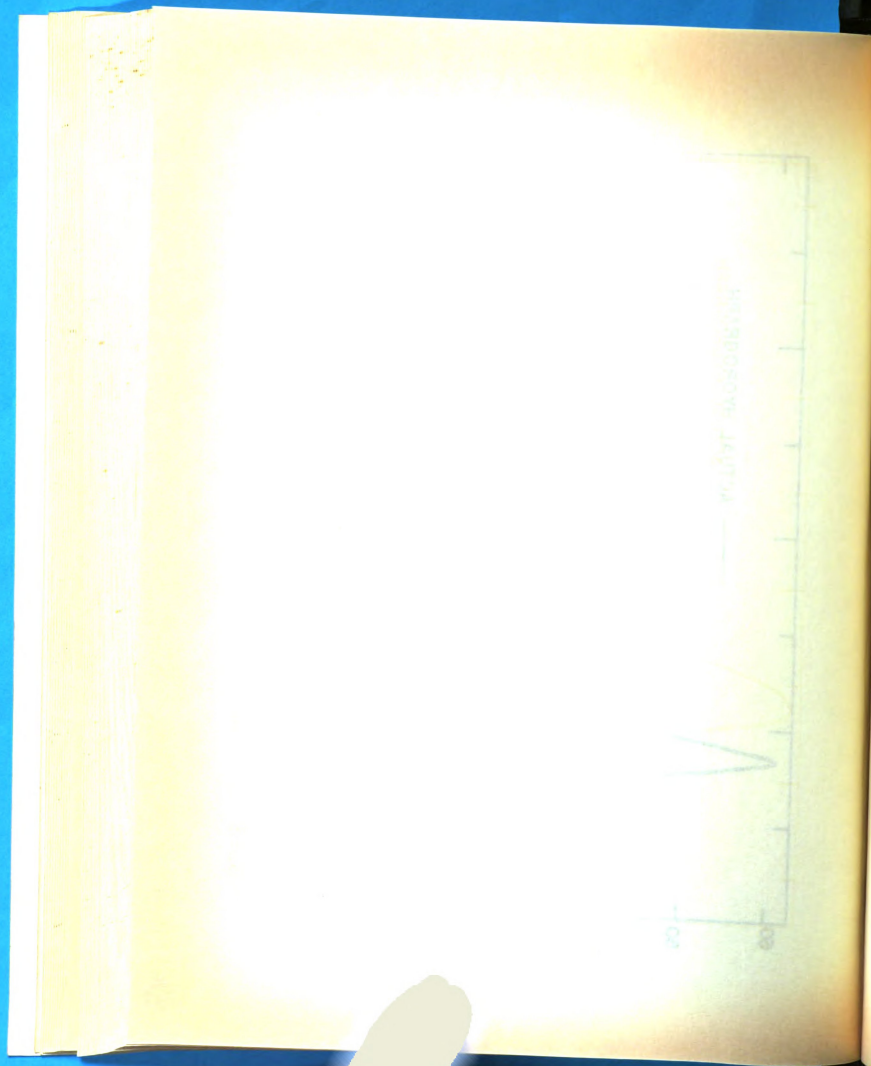


FIGURE 16. SLOAN CREEK HYDROGRAPH AUG. 16-19, 1959



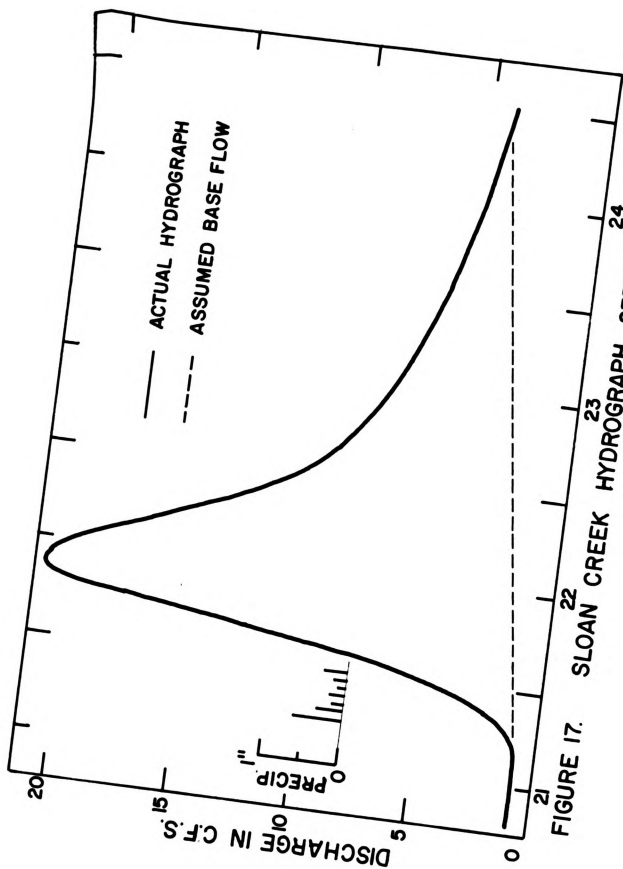


FIGURE 17. SLOAN CREEK HYDROGRAPH SEPT. 21-24, 1959



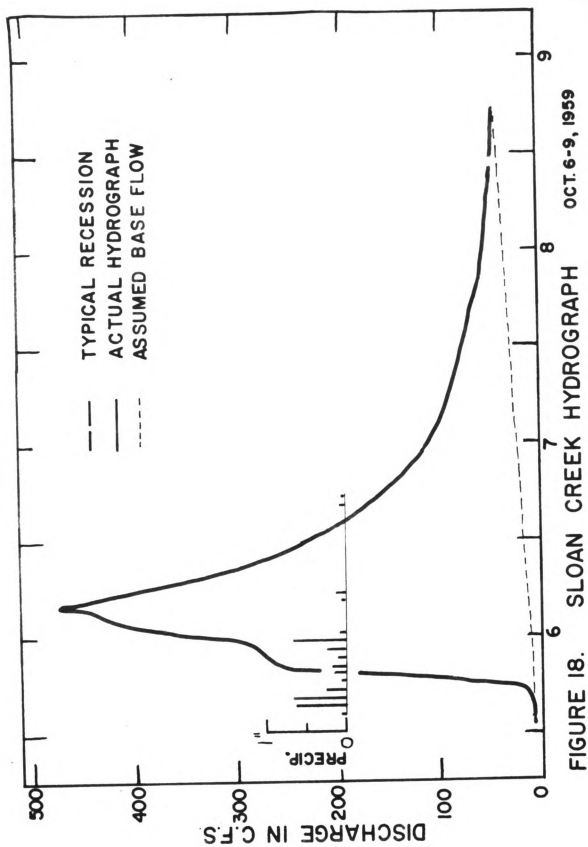


FIGURE 18. SLOAN CREEK HYDROGRAPH OCT. 6-9, 1959

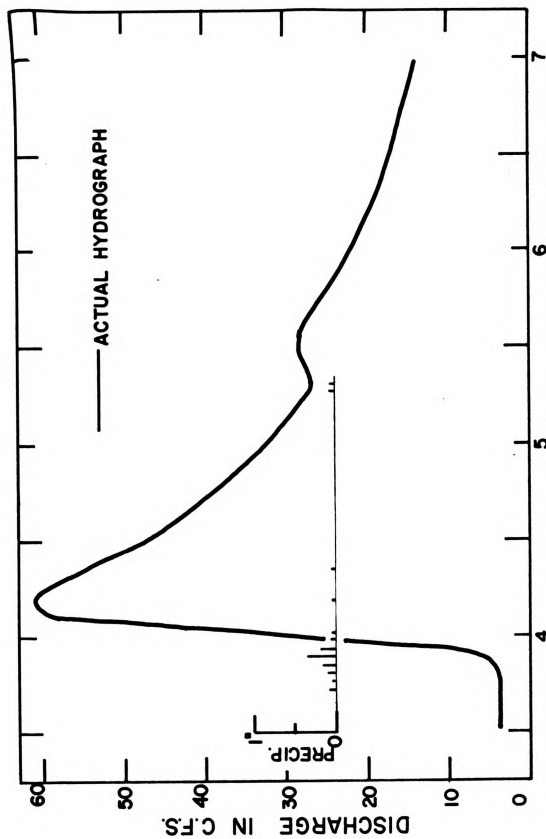
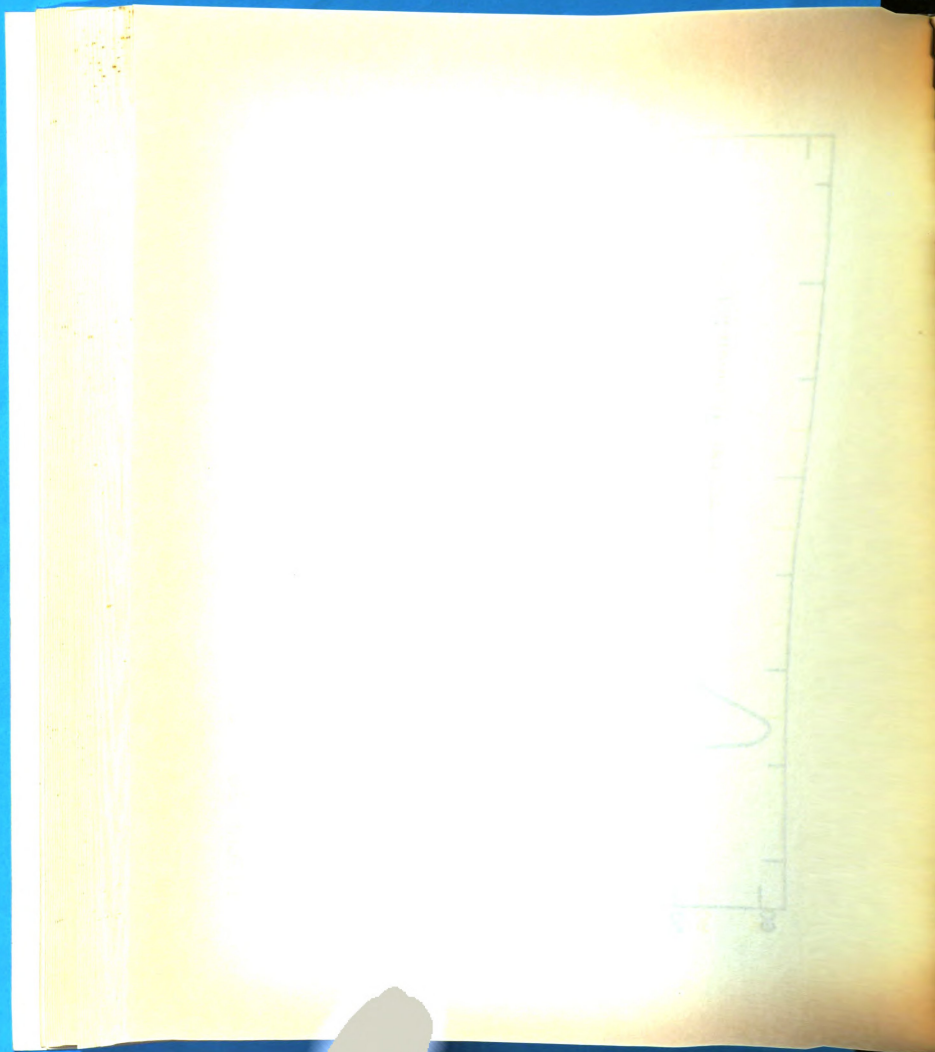


FIGURE 19. SLOAN CREEK HYDROGRAPH NOV. 4-7, 1959



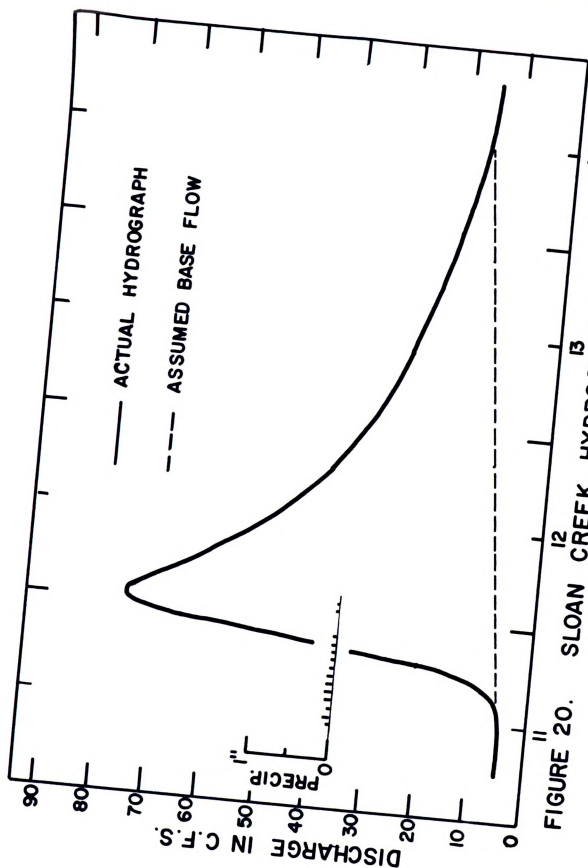


FIGURE 20. SLOAN CREEK HYDROGRAPH DEC. 11-14, 1959



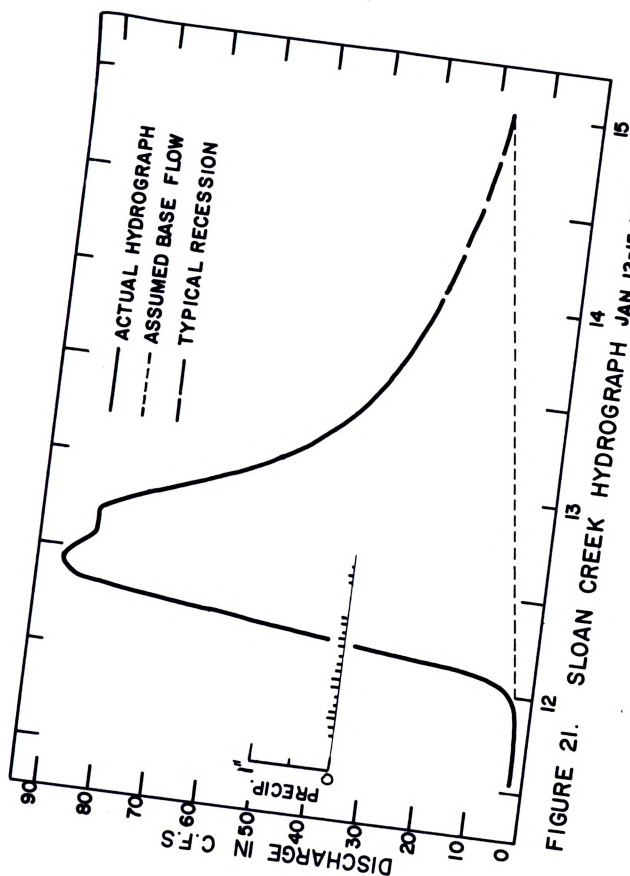
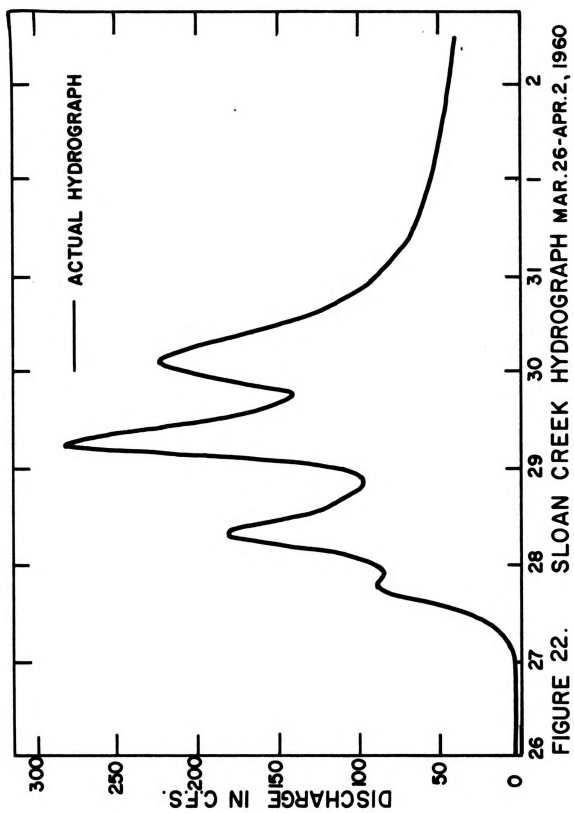
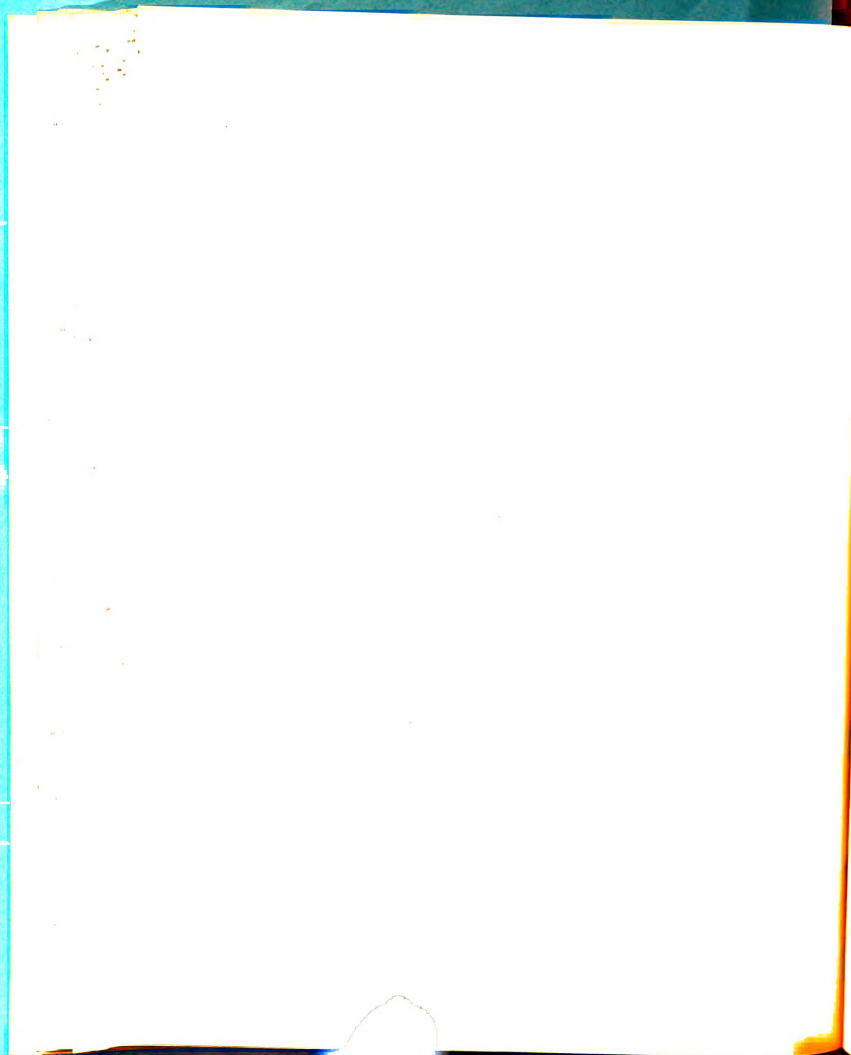


FIGURE 21. SLOAN CREEK HYDROGRAPH JAN. 12-15, 1960







August 9-12, 1956; October 6-9, 1959; and January 12-15, 1960 hydrographs were obtained from the July 4-7, 1957; July 11-14, 1957; and January 4-7, 1955 storms, respectively.

Recession curve and base flow

A specific point on the recession curve which defines the ending of surface flow is more theoretical than realistic. However, the position where this essentially occurs can be determined by methods described in the Review of Literature. With the data available for this analysis the use of a typical base flow recession curve was the most appropriate method of estimating this point.

Since a sufficiently long, rainless period following a major storm did not occur, a typical recession curve was constructed synthetically by combining short recessions. Figure 23 shows the construction of the composite recession curve from seven individual storm recessions. The data for the individual storms are tabulated in Appendix 3.

Curves from the base flow section of the composite recession curve plotted to the appropriate scales were used to determine where surface flow became insignificant. This occurred essentially two and a half days after the peak for all hydrographs except April 27-30, 1957 and July 11-14, 1957. For these the storm recessions deviated

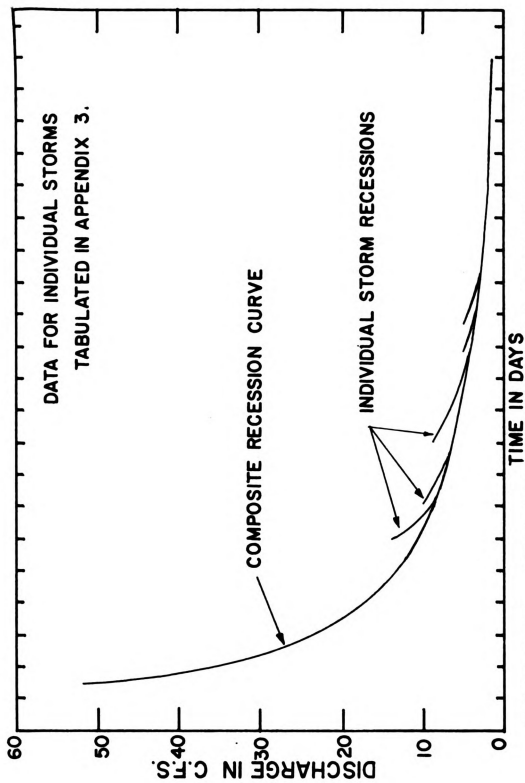


FIGURE 23. COMPOSITE RECESSION CURVE FOR SLOAN CREEK



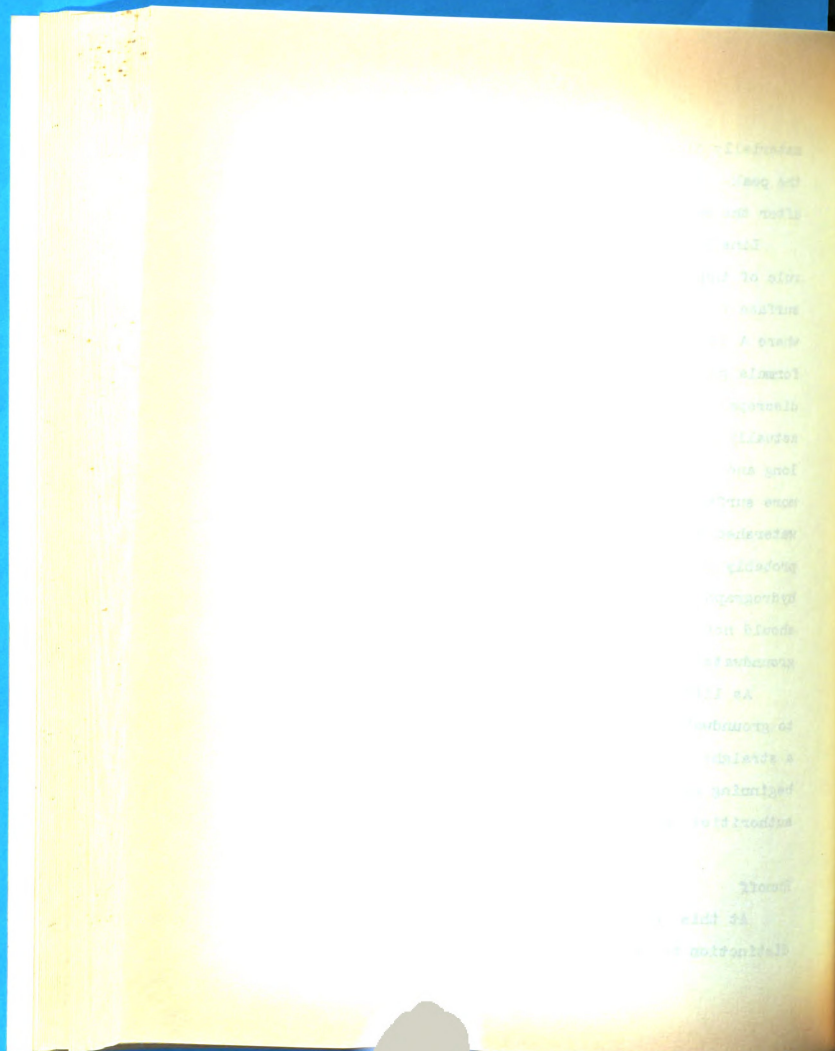
materially from the base recessions about three days after the peak. This was due to light showers occurring shortly after the main storm in each case.

Linsley, Kohler, and Paulhus (17) suggests, as a rule of thumb, that the time in days N from the peak to surface flow secession may be approximated by $N = A^{0.2}$ where A is the drainage area in square miles. This formula gave an N of 1.56 days for the watershed. The discrepancy between this value and the two and a half days actually found was probably due to the watershed being long and narrow, being flatter, and having proportionally more surface storage than the "typical" watershed. Our watershed exemplifies their statement, "However, N is probably better determined by inspection of a number of hydrographs, keeping in mind that the total time base should not be excessively long and the rise of the groundwater should not be too great".

As little is known of the rate at which accretion to groundwater discharge takes place from infiltration, a straight line joining the positions of surface runoff beginning and ending was assumed. This concurs with the authorities referred to in the Review of Literature.

Runoff

At this point it would be well to make a precise distinction between "total surficial outflow" and "surface



runoff". According to Johnstone and Cross (10), "Total surficial outflow is to be taken as meaning all water moving out of the drainage area in surface streams, regardless of whether it has reached the stream directly from overland flow or indirectly via underground movement". Whereas, surface runoff has a narrower connotation; strictly defined, it is that portion of total surficial outflow (total runoff) from a given drainage area that has come from precipitation which has at no time infiltrated into the soil.

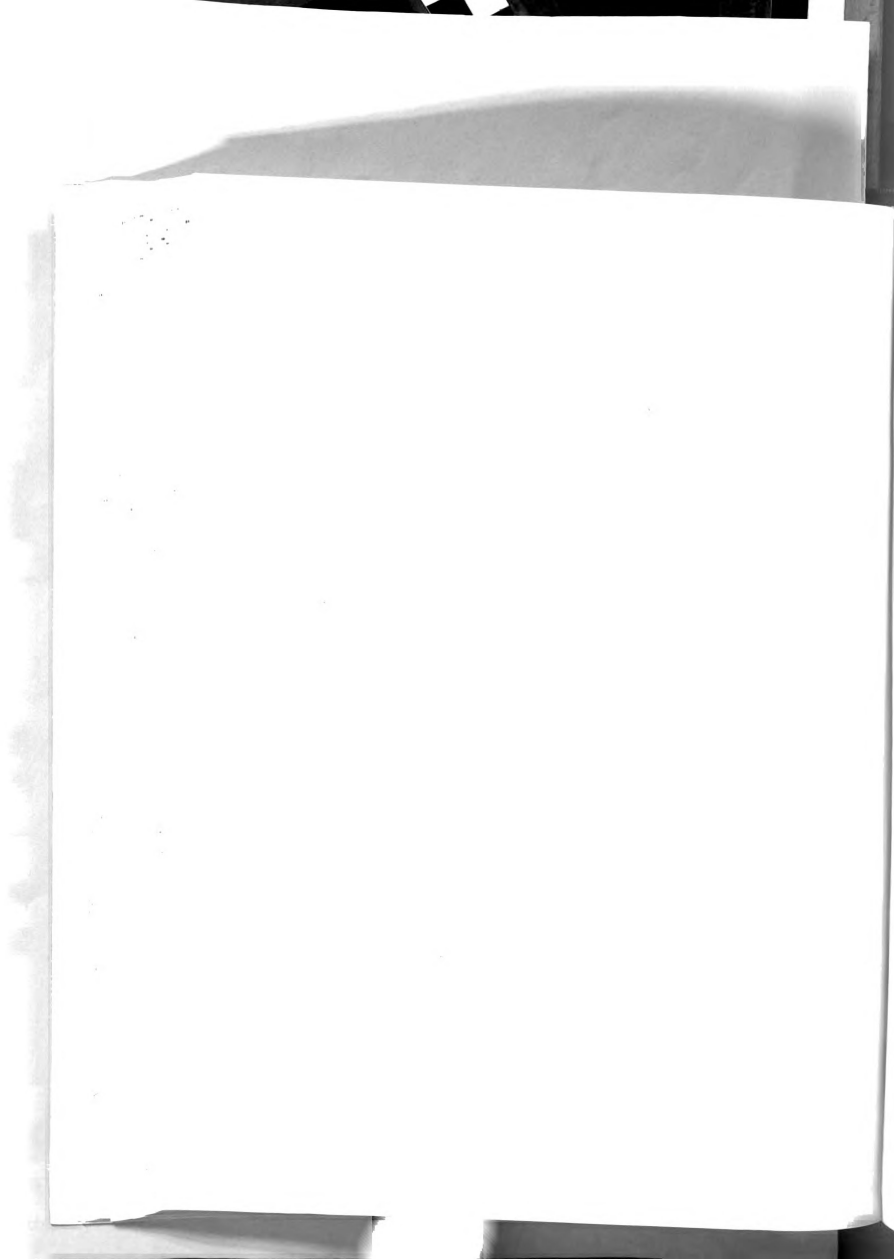
The data of Appendix 1 are measures of total surficial outflow. They include certain amounts of base flow which were derived from groundwater. The straight, dashed, base flow line essentially separates that portion due to surface runoff from that due to groundwater. Actually, the portion referred to as surface runoff contains a small amount of water which has infiltrated into the soil surface but has come out again very quickly from seeps or from tile lines. This water is frequently called interflow but is usually so small in comparison that it was not considered in this analysis.

Surface runoff, hereafter referred to merely as runoff, is thus that portion between the hydrograph and the base flow line. The volume of runoff can be obtained by multiplying the average hourly ordinate in cubic feet per second by 3600 seconds in an hour and summing over the



Table 2. Rainfall and runoff data for 17 Sloan Creek hydrographs.

Date	Peak dis- charge C.F.S.	Total rain- fall In.	Runoff area Sq. In.	CFS- Hours per Sq. In.	Run- off CFS- Hours	Run- off In.
Aug. 9-12, 1956	128	2.15	4.62	288	1330	0.22
Aug. 17-20, 1956	43	1.19	3.85	144	555	0.09
Apr. 27-30, 1957	137	0.67	4.03	360	1450	0.24
May 14-17, 1957	79	0.60	4.00	216	864	0.14
May 18-21, 1957	234	1.80	8.87	576	5110	0.85
July 4- 7, 1957	90	2.09	8.00	216	1728	0.29
July 8-11, 1957	61	1.19	9.13	144	1316	0.22
July 11-14, 1957	685	3.69	7.13	1440	10280	1.70
Nov. 14-17, 1957	32	1.13	9.59	72	690	0.11
Apr. 6- 9, 1958	27	0.82	8.15	72	587	0.10
July 28-31, 1958	3	1.20	6.83	9	58	0.01
May 23-26, 1959	10	1.07	10.84	29	312	0.05
Aug. 16-19, 1959	61	0.84	6.00	144	864	0.14
Sep. 21-24, 1959	21	1.74	10.20	48	490	0.08
Oct. 6- 9, 1959	476	3.28	7.40	1152	8530	1.41
Dec. 11-14, 1959	76	0.73	7.89	216	1703	0.28
Jan. 12-15, 1960	90	1.18	10.40	216	2250	0.37



duration of runoff. Or it can be determined by planimetering the area between the curves, as each unit of area represents a specific volume in cfs-hours. Since in this study each hydrograph was reproduced to a reasonably large scale it was concluded that planimetering was a satisfactory procedure.

Table 2 shows the area of the hydrograph representing surface runoff, the cfs-hours per square inch for the scales used, the runoff, and other associated information for each of the 17 storm periods thus analyzed. The conversion between cfs-hours and inches over the 9.34 square mile watershed area was 6040.

ANALYSIS AND DISCUSSION OF RAINFALL DATA

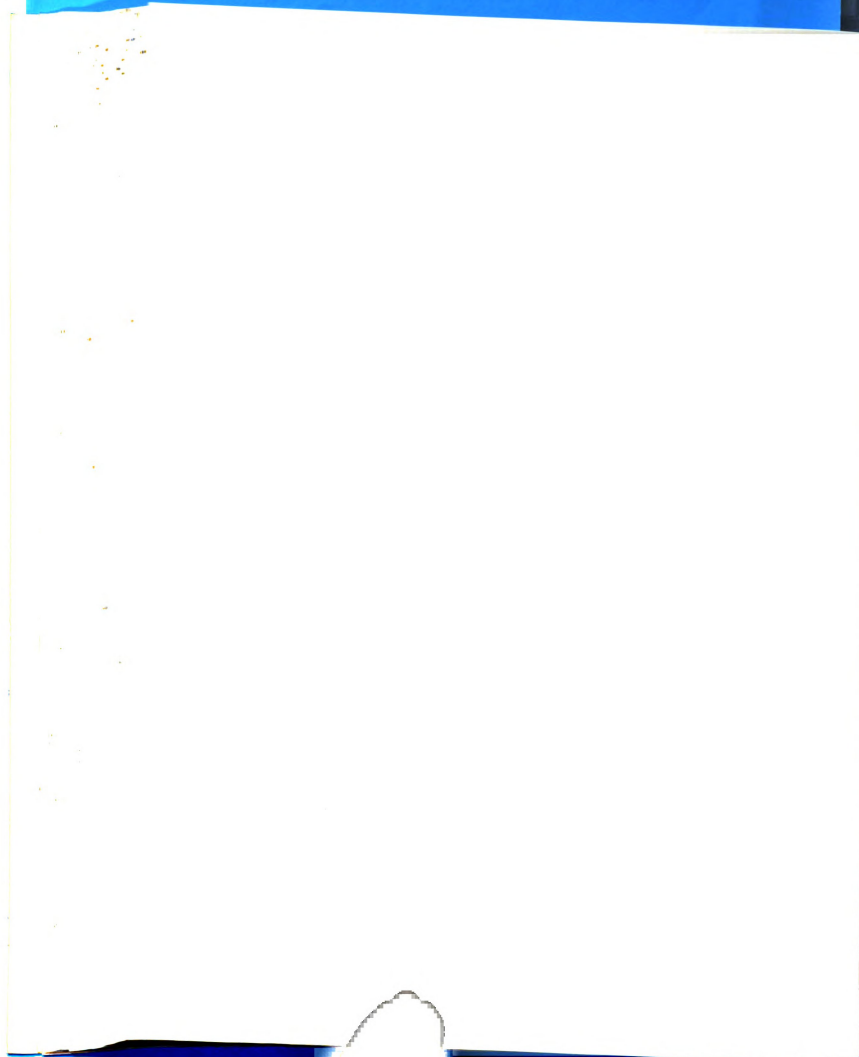
The storms considered in this analysis are essentially of two types; 1. the steady, rather uniform, and widespread rains occurring during the approach of warm fronts with stable air masses; and, 2. the thunder-shower type, which develops in connection with convectively unstable air masses or the passage of cold fronts and squall lines. (2) The former type occurs mainly in the early and late parts of the growing season and frequently lasts several days. Most of the summer storms are of the thundershower type, which frequently result in high intensities for short durations, and may produce large runoffs to overload drainage systems. (7)

Existing Weather Bureau raingage stations spaced 20 to 30 miles apart serve well for describing storms of the first category. The irregularly distributed and small area summertime storms, however, may pass between these stations. As these storms are important in the design of many water management facilities, especially for small agricultural areas, the dense network of gages in this project were necessary.

Rainfall data pertaining to 18 of the storm periods included in this analysis are presented in Table 3. Comparisons of the Thiessen averages and unweighted

Table 3. Sloan Creek rainfall data for 18 storm periods,

Date	Thiessen average Inches	Unweighted average Inches	Gage 4 Inches
Aug. 9-12, 1956	2.15	2.10	2.70
Aug. 17-20, 1956	1.19	1.14	1.70
Apr. 27-30, 1957	0.67	0.67	0.75
May 14-17, 1957	0.60	0.67	0.45
May 18-21, 1957	1.80	1.81	1.80
July 4- 7, 1957	2.09	2.10	2.50
July 8-11, 1957	1.19	1.20	1.19
July 11-14, 1957	3.69	3.68	4.00
Nov. 14-17, 1957	1.13	1.10	1.40
Apr. 6- 9, 1958	0.82	0.81	0.81
July 28-31, 1958	1.20	1.17	1.56
May 23-26, 1959	1.07	1.06	1.13
Aug. 16-19, 1959	0.84	0.90	0.60
Sep. 21-24, 1959	1.74	1.70	2.05
Oct. 6- 9, 1959	3.28	3.20	3.92
Nov. 4- 7, 1959	0.95	0.97	1.04
Dec. 11-14, 1959	0.73	0.73	0.85
Jan. 12-15, 1960	1.18	1.19	1.33



averages show that 50 percent of these differ by less than one percent. This agrees with the Weather Bureau's concept that for much work, averaging methods more detailed than unweighted averages are unnecessary.

The location of gage 4 was considered an appropriate single gage position for the entire watershed. Table 3 shows this gage recorded more rainfall than the Thiessen average 13 of the 18 times; several times by over 0.5 inch and one of these being 43 percent larger. As the location and calibration of this gage met all standard specifications, why it recorded consistently high has been of great concern.

Even greater variation was noted when single gages at different ends of the watershed were compared. The May 15, 1957, storm produced rainfall amounts ranging from 1.36 inches at gage 1 to 0.26 inch at gage 6. The range for the August 16, 1959 storm was 1.64 inches at gage 2 to 0.23 inch at gage 5. The distances between gages 1 and 6 and 2 and 5 were respectively, 4.3 and 3 miles. These data were confirmed by those of reference (6) and indicated that for accurate rainfall information it is imperative that irrigation farmers have their own raingages.

The long axis of the watershed was North-South which is perpendicular to the general West to East direction of storm travel. The effect of direction of

storm travel on the peak discharge rate was therefore minimized. This, coupled with only small differences in the beginning time of the rain between gages, made it impossible to measure an effect due specifically to direction of storm movement.

It was possible to determine storm centers from the intensity and amount of precipitation recorded by the various gages. However, an insufficient number of storms of uniform size but with different storm centers, prevented adequate determination of their effect on peak runoff rates.



ANALYSIS AND DISCUSSION OF RUNOFF DATA

The actual average amount of rain which fell on the watershed and the amount of runoff which it produced are shown in Figures 4 through 21. This information and other pertinent data used in analyzing the rainfall-runoff process of the watershed are presented in Table 4.

Only 15 of the 19 hydrographs were considered in this analysis. The December 11-14, 1959 and January 12-15, 1960 storms occurred after the ground had been frozen and are thus not considered. It was impractical to use the November 4-7, 1959 storm period because of the additional rise on the recession due to showers on the afternoon of the fifth.

The March 26-April 2, 1960 period was included only to show a late-spring, snow-runoff hydrograph. The 285 cfs peak, due only to melting snow, was the third largest peak-discharge recorded in the five years of data and emphasizes the extreme antecedent conditions which must be considered when estimating design peak runoffs.

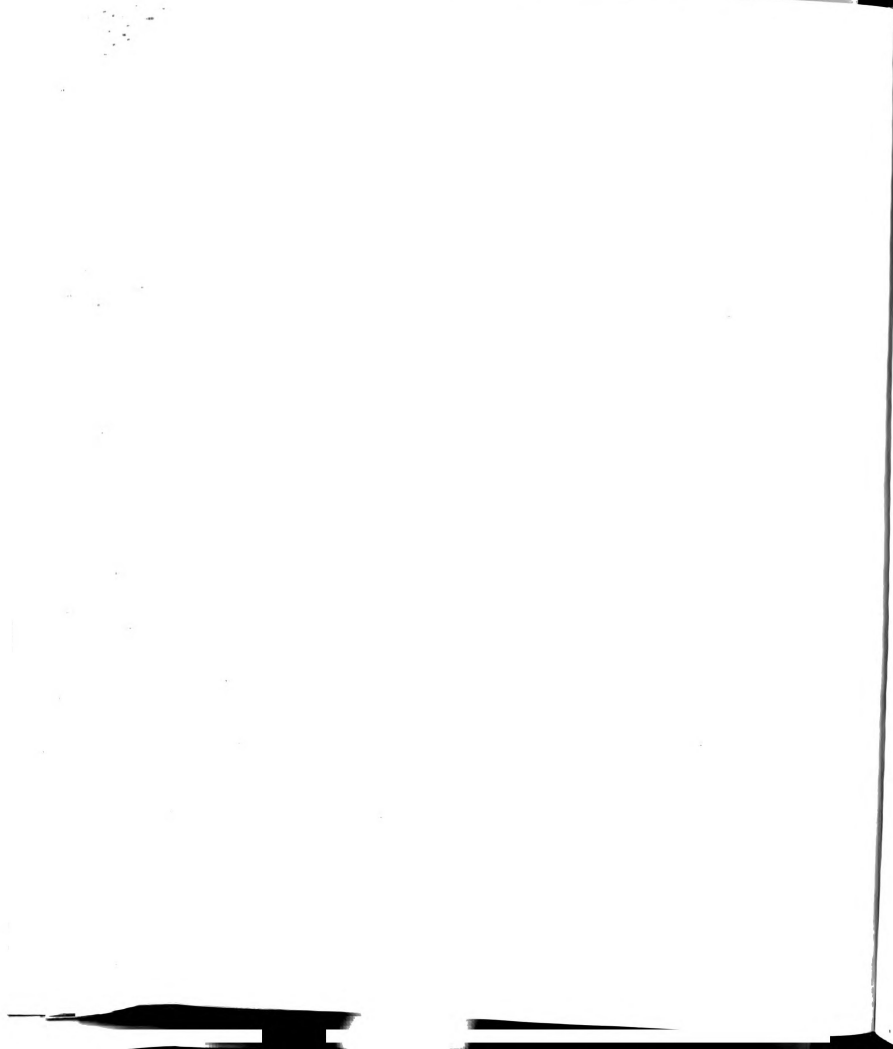
The total inches of rainfall and runoff for each of the storm periods are listed in columns (2) and (3), respectively. Column (4) is merely the difference between the previous two. This amount of water from the storm having just occurred did not leave the watershed as surface flow and had to be accounted for in some other way.

Various methods considered for determining the soil

Table 4. Data used in the analysis of the rainfall-runoff process for the watershed.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Date	Rain- fall In.	Run- off In.	2-3 In.	Ante- cedent Moist. In.	Total moist. In.	Inf1. In.	Prior runoff In.
Aug. 9-12, 1956	2.15	0.22	0.93	0.47	2.40	0.19	2.21
Aug. 17-20, 1956	1.19	0.09	1.10	0.00	1.10	0.19	0.91
Apr. 27-30, 1957	0.67	0.24	0.43	0.88	1.31	0.25	1.06
May 14-17, 1957	0.60	0.14	0.46	0.59	1.05	0.09	0.96
May 18-21, 1957	1.80	0.85	0.95	0.65	1.60	0.65	0.95
July 4- 7, 1957	2.09	0.29	1.80	0.00	1.80	0.25	1.55
July 8-11, 1957	1.19	0.22	0.97	0.55	1.52	0.44	1.08
July 11-14, 1957	3.69	1.70	1.99	0.50	2.49	1.13	1.36
Nov. 14-17, 1957	1.13	0.11	1.02	0.40	1.42	0.59	0.83
Apr. 6- 9, 1958	0.82	0.10	0.72	0.35	1.07	0.28	0.79
July 28-31, 1958	1.20	0.01	1.19	0.00	1.19	0.19	1.00
May 23-26, 1959	1.07	0.05	1.02	0.38	1.40	0.34	1.06
Aug. 16-19, 1959	0.84	0.14	0.70	0.88	1.58	0.19	1.39
Sep. 21-24, 1959	1.74	0.08	1.66	0.00	1.66	0.56	1.10
Oct. 6- 9, 1959	3.28	1.41	1.87	0.54	2.41	1.20	1.21

moisture conditions of a watershed prior to a storm have been mentioned in the Review of Literature. Most authorities recognize the importance of antecedent moisture and feel that antecedent precipitation gives a satisfactory index of its effects on runoff. They also agree that soil



moisture usually decreases logarithmically with time during periods of no precipitation. The exact rate of decrease depends mainly on the amount and type of watershed vegetation, the type of soil, and the climatic conditions. Since these are extremely variable any system which gives a reasonable indication of the amount present is all that can be justified.

The season of the year effects both the number of antecedent days for which precipitation will effect runoff and the fraction of the antecedent precipitation which will be effective. Ten days of antecedent precipitation were considered to effect runoff for April, May, and November and only five days for July, August, September, and early October. The specific fraction of the rain which was considered effective for each of these preceding days were 0.9, 0.7, 0.5, 0.4, 0.3, 0.2, 0.2, 0.1, 0.1, and 0.1 for the ten day period and 0.9, 0.7, 0.5, 0.3, and 0.1 for the five day period. These depletion rates compare favorably with irrigation concepts, as well as with prior hydraulic analyses.

The specific values of effective antecedent moisture computed for the surface eight to twelve inches of the watershed prior to each storm period are listed in column (5). These values added to the moisture of column (4) gave the total inches of moisture in the basin which had to be accounted for at the end of each storm period.

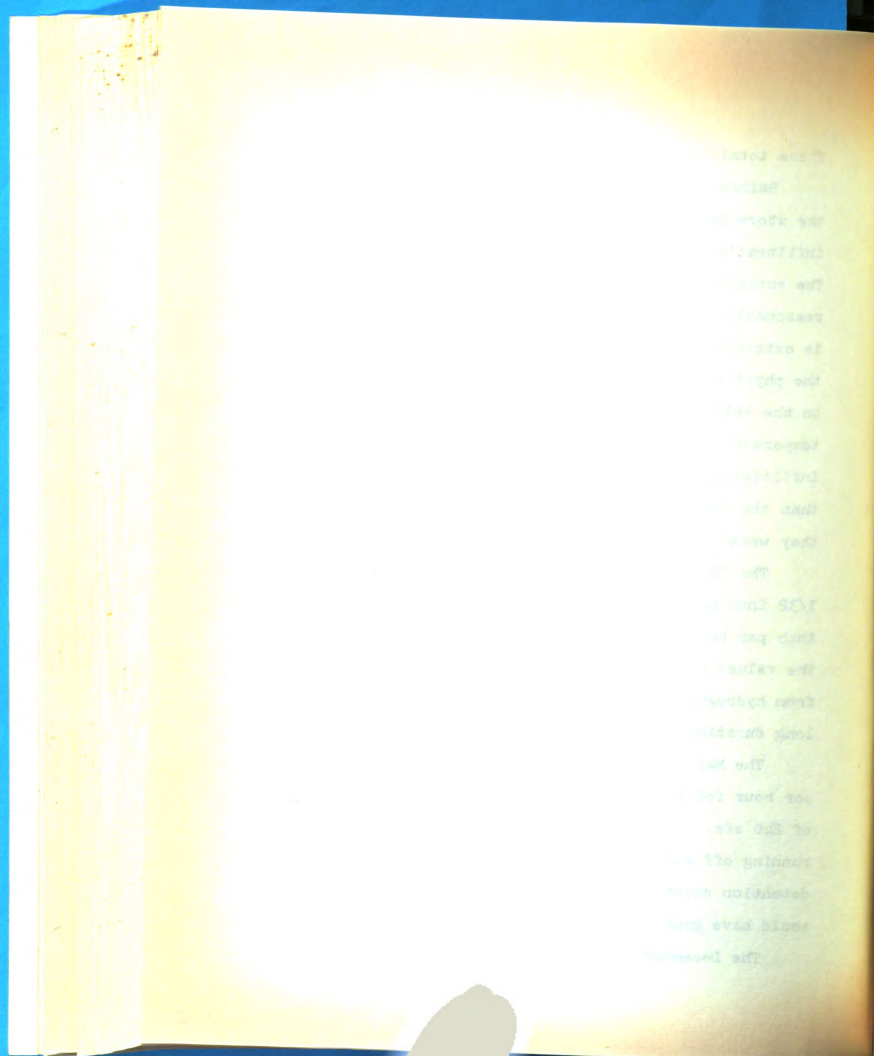
These totals are listed in column (6), Table 4.

Rainfall which did not run off as surface flow during the storm period was considered a combination of infiltration, surface storage, and detention storage. The surface and detention storage of a watershed is reasonably uniform from storm to storm, but infiltration is extremely variable. Infiltration depends not only upon the physical characteristics of the soil and the cover on the soil, but also on such factors as soil moisture, temperature, and rainfall intensity. Since the initial infiltration rate is much more rapid and more variable than the "normally approached constant infiltration rate" they were considered separately.

The "constant" infiltration rate was estimated at 1/32 inch per hour for April, May, and November and 1/16 inch per hour for July, August, September and October. The values for each of the two periods were determined from hydrographs which occurred due to low intensity but long duration storms.

The May 19, 1957 rain fell at an average of 0.1 inch per hour for the first 17 hours and produced a peak runoff of 240 cfs. With approximately 50 percent of the rainfall running off and a small amount going into surface and detention storage no more than about 0.03 inch per hour could have gone into the soil.

The December 11-14, 1959 and January 12-15, 1960



storms, by the same procedure of analysis, gave infiltration rates of less than $1/32$ inch per hour. These, however, can be justified due to previously frozen soil. The rise produced in the hydrograph recession by the 0.12 inch of precipitation of November 5, 1959 attests also to the low infiltration rate of the watershed when extremely high antecedent conditions exist.

Each infiltration amount of column (7) was obtained by multiplying the appropriate infiltration rate by the number of hours two greater than the length of rainfall. The addition of two hours accounted for infiltration during the time required for overland flow. This moisture was assumed to have gone into the deeper soil strata of the watershed and to be no longer effective watershed moisture.

The total effective moisture required prior to surface runoff for each storm is listed in column (8) and was determined by subtracting column (7) from column (6). Total effective moisture included surface and detention storage, initial infiltration, and effective antecedent moisture.

The column (8) values of Table 4 listed timewise, irrespective of the year of occurrence, are presented in column (B) of Table 5. In this manner they more clearly indicate the total effective moisture required to produce runoff from month to month throughout the season. Omitting those with asterisks, the values increased from spring through the middle of August and then decreased from there



to winter. As these values depend upon the amount of moisture in the lower soil strata, the specific time they begin to decrease depends upon the amount of fall rain received.

Those storm periods marked with asterisks are not appropriate for comparison. The storm of July 28-31, 1958 produced virtually no runoff, as shown in column (C), and thus the watershed had not reached its maximum water holding capacity when the rain stopped. The other three followed previous storms which had increased the substrata moisture; thus required less initial infiltration before runoff began.

It was considered advisable to test the previously developed procedure on storms with which the author had no previous knowledge. The storms for testing, therefore, had to come from the spring of 1960 records. The multiple storm periods of April 14-17, May 19-23, and June 13-16 were chosen, as the records included no individual storm of major consequence.

In following the procedure previously outlined the author's estimated peak discharges versus those which actually occurred were as follows: April 14-17, 10-20 cfs versus 39 cfs; May 19-22, 20-40 cfs versus 18 cfs; and June 13-16, 90-125 cfs versus 31 cfs. The differences for April 14-17 were caused by the extremely late spring, whereas, those for June 13-16 were due to no prior June records, both of these indicating a lack of knowledge of the moisture content of the subsurface soil layers.

Table 5. Data showing the month by month variation in amount of moisture required prior to runoff and the percent of runoff for each storm period.

(A)	(B)	(C)
Date	Prior to Runoff Inches	Runoff Percent
Apr. 6- 9, 1958	0.79	11.8
Apr. 27-30, 1957	1.06	35.8
May 14-17, 1957	0.96	23.8
May 18-21, 1957	0.95	47.0
May 23-26, 1959	1.06	4.8
July 4- 7, 1957	1.55	13.7
July 8-11, 1957	1.08*	18.3
July 11-14, 1957	1.36*	54.0
July 28-31, 1958	1.00*	0.8
Aug. 9-12, 1956	2.21	10.3
Aug. 16-19, 1959	1.39	17.0
Aug. 17-20, 1956	0.91*	7.7
Sep. 21-24, 1959	1.10	4.7
Oct. 6- 9, 1959	1.21	43.0
Nov. 14-17, 1957	0.83	10.1

*These values are not appropriate for comparison.
For specific reasons see text.

TABLE 1.

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Unit graph method

As stated previously a unit graph is a hydrograph which results from a one inch runoff from the entire watershed. It also implies the fulfillment of the other specifications stated in the Review of Literature. This rarely or never occurs in nature. However, since a perfect procedure is not available, this and other methods will be discussed as reasonable approximations.

A study of the rainfall and runoff records revealed five periods of reasonable conformation to unit graph specifications. Original raingage charts were used in the preparation of all unit graphs. Two of the rainfall periods were each $\frac{1}{2}$ hour in length, two were 1 hour, and the other was 2 hours. This proved very convenient in the selection of the unit time.

The procedure of obtaining a unit graph is explained by using the August 17-20, 1956 data as listed in Table 6. Columns (2) and (3) show the total surficial outflow and base flow, respectively. Values for both of these columns were obtained from the curves of Figure 5. The surface runoff presented in column (4) is the total flow minus the base flow.

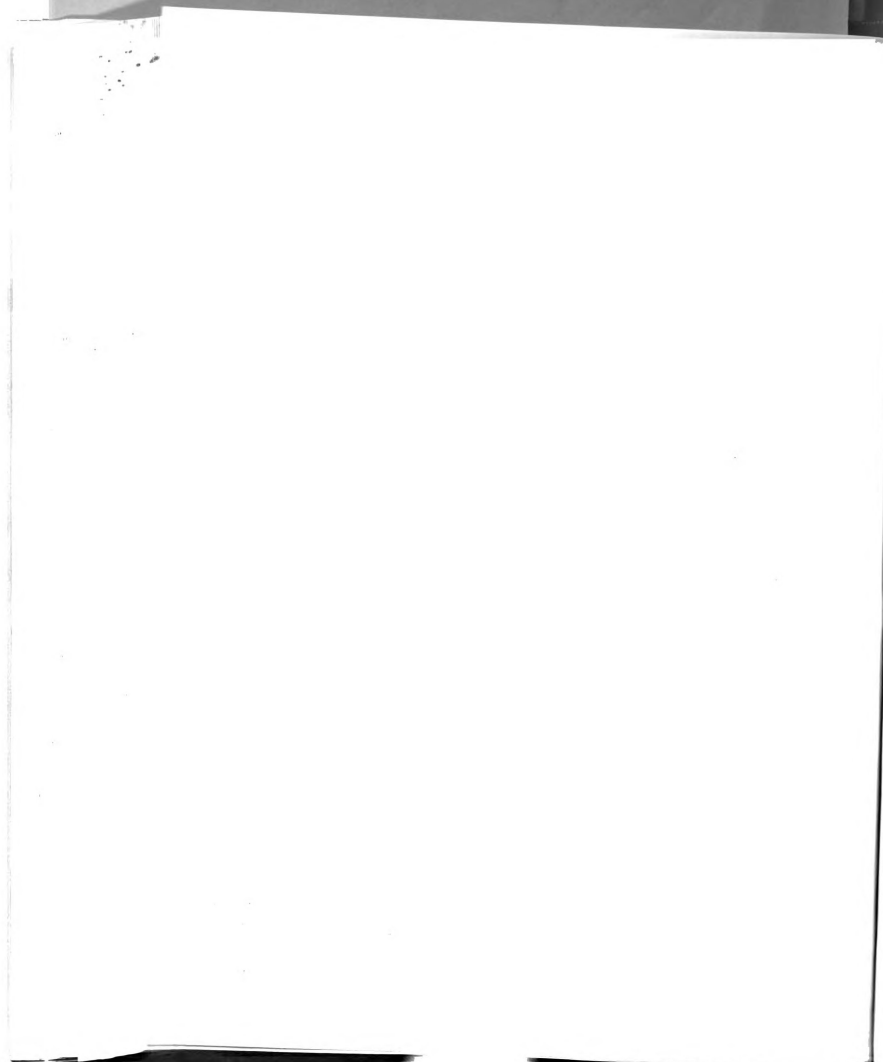
The actual depth of runoff over the entire watershed from this storm was 0.0919 inch. If 1 inch had run off, each value of column (4) would have been 10.9 times as large and the values would have been as recorded in

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Table 6. Data for unit graph from August 17-20, 1956 hydrograph.

(1) Time	(2) Total* flow C.F.S.	(3) Base flow C.F.S.	(4) Run- off C.F.S.	(5) Unit graph C.F.S.
18- 2	1.2	1.2	0.0	0
3	2.0	1.2	0.8	9
4	6.1	1.2	4.9	53
5	34	1.3	32.7	356
6	43	1.3	41.7	454
7	39	1.4	37.6	409
8	35	1.4	33.6	366
10	27	1.5	25.5	278
12	22	1.5	20.5	223
15	18	1.6	16.4	179
18	15.4	1.7	13.7	149
21	13.1	1.8	11.3	123
24	11.4	1.9	9.5	103
19- 8	7.8	2.0	5.8	63
12	6.8	2.1	4.7	51
24	4.9	2.6	2.3	25
20-12	3.6	2.9	0.7	8
18	3.1	3.1	0.0	0

* This column is essentially data secured from standard U.S.G.S. rating tables where values above 10 cfs are considered only to the nearest whole number.



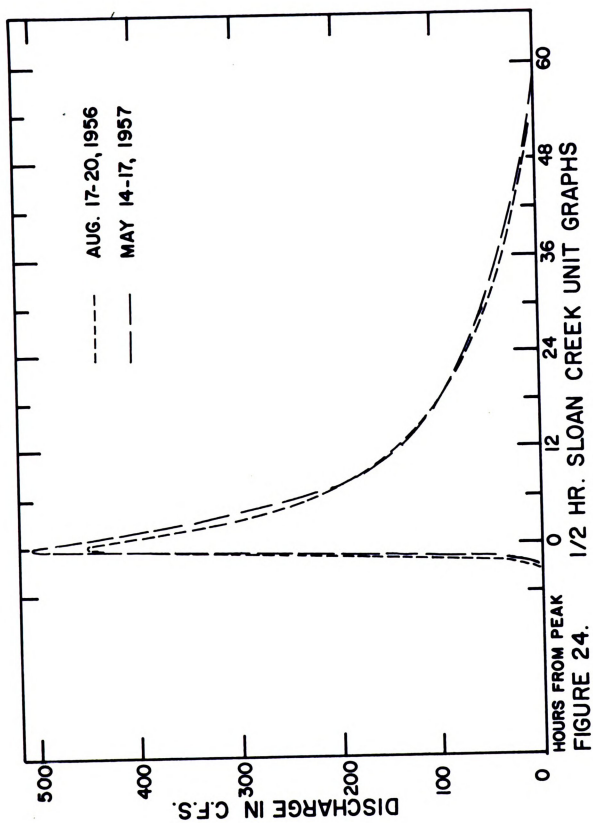
columns (5). The graph of discharges from column (5) plotted against time give a unit graph.

Data for the unit graphs from the periods of August 9-12, 1956; May 14-17, 1957; July 4-7, 1957; and August 16-19, 1959 are tabulated in Appendix 4.

Due to nonuniform distribution of storms and departures of drainage basin performance from unit graph theory, it is common practice to derive the unit graph for a watershed from a number of storms. The two $\frac{1}{2}$ hour unit hydrographs are shown in Figure 24. The peaks were made to coincide in time as recommended by Johnstone and Cross (10). The magnitudes of the peaks differed by less than 10 percent which is considered excellent for unit graph work.

If a unit graph of $\frac{1}{2}$ hour duration is added to itself lagged by $\frac{1}{2}$ hour the resulting hydrograph represents the hydrograph for 2 inches of runoff in 1 hour. If the ordinates of this hydrograph are divided by 2 a unit graph of 1 hour results. This is the procedure which was used to convert the composite of the $\frac{1}{2}$ hour unit hydrographs to a 1 hour unit graph. The data for this procedure are tabulated in Table 7. The composite unit graph is shown with the 1 hour unit graph from the August 9-12, 1956 storm in Figure 25. The peaks of these two hydrographs differ only by approximately 20 percent which is still satisfactory.





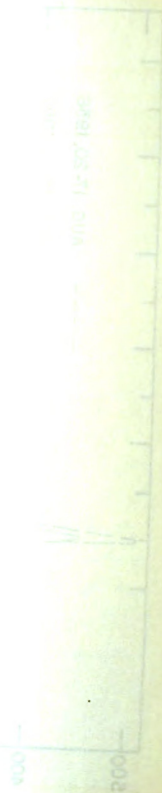
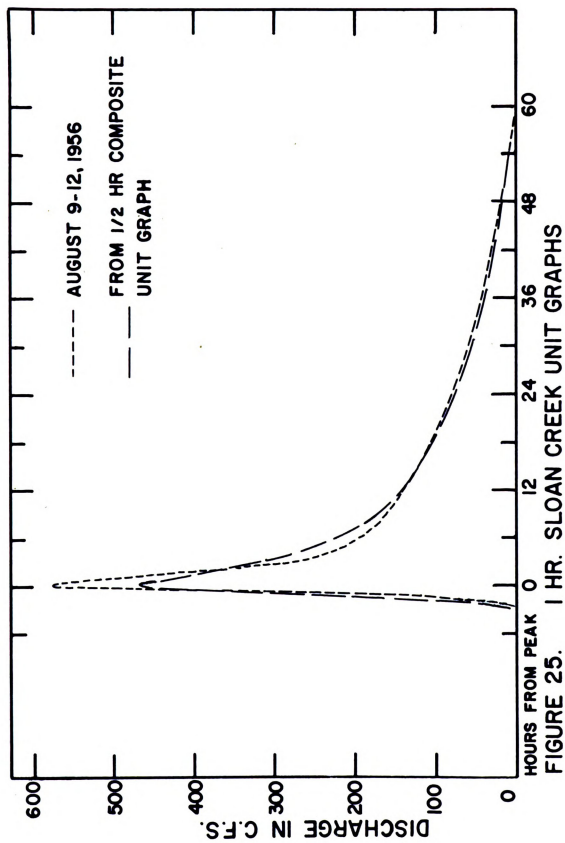
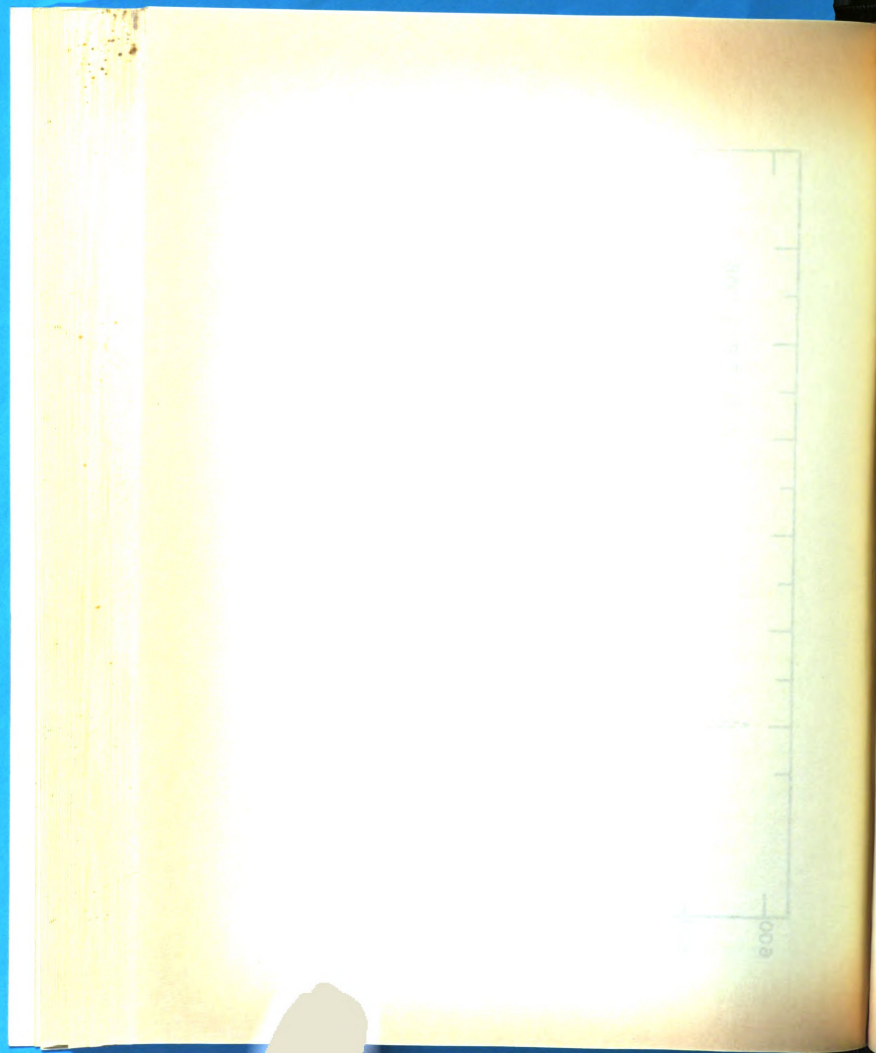


Table 7. Data for comparison of a 1 hour unit graph calculated from a $\frac{1}{2}$ hour composite unit graph and the actual 1 hour August 9-12, 1956 unit graph.

Hours from peak	Composite $\frac{1}{2}$ hour unit graph C.F.S.	Unit graph shifted $\frac{1}{2}$ hour C.F.S.	Double 1 hour unit graph C.F.S.	Calculated 1 hour unit graph C.F.S.	Actual 1 hour unit graph C.F.S.
- $3\frac{1}{2}$	0		0	0	0
- 3	4	0	4	2	
- $2\frac{1}{2}$	23	4	27	13	7
- 2	42	23	65	32	
- $1\frac{1}{2}$	182	42	224	112	67
- 1	322	182	504	252	
- $\frac{1}{2}$	401	322	723	361	253
0	481	401	882	441	
+ $\frac{1}{2}$	455	481	936	468	574
+ 1	429	455	884	442	
+ $1\frac{1}{2}$	404	429	833	416	478
+ 2	379	404	783	391	
+ $2\frac{1}{2}$	351	379	730	365	365
+ 3	324	351	675	337	
+ $3\frac{1}{2}$	306	324	630	315	264
+ 4	288	306	594	297	
+ $4\frac{1}{2}$	272	288	560	280	232
+ 5	256	272	528	264	
+ 8	186				
+ $8\frac{1}{2}$	179	186	365	182	167
+18	102				
+ $18\frac{1}{2}$	99	102	201	100	103
+32	47				
+ $32\frac{1}{2}$	45	47	92	46	55
+44	23				
+ $44\frac{1}{2}$	21	23	44	22	26
+50	14				
+ $50\frac{1}{2}$	12	14	26	13	14
+55	8				
+ $55\frac{1}{2}$	6	8	14	7	6
+60	0	0	0	0	0





The data for the conversion of the composite of the two 1 hour unit graphs to a 2 hour unit graph are listed in Appendix 5. This 2 hour unit graph was compared with the 2 hour unit graph of the July 4-7, 1957 storm in Figure 26. The peaks of the two 2 hour unit graphs differed by 57 percent which was considered too great for use in this study.

The discrepancy between the magnitudes of the peaks was due to the nonuniformity of the rain. Each of the six gages showed that the storm of July 4-7, 1957 was composed of three bursts of rain rather than a continuous one. The storm period of August 16-19, 1959 was also discounted due to nonuniformity of rain. In this case there was much variation in the intensity at each gage, as well as amounts from gage to gage.

From the previous unit graph data it was considered reasonable to use the 1 hour composite unit hydrograph to check several actual storms periods. This unit time compared favorably with Linsley (15) who states, "In general, the unit duration should probably be in the order of 25 percent of the basin lag", basin lag being the time from the centroid of rainfall to the hydrograph peak. An hour interval was also very convenient for making computations and using regularly tabulated rainfall data.

Comparison of the calculated hydrograph and actual

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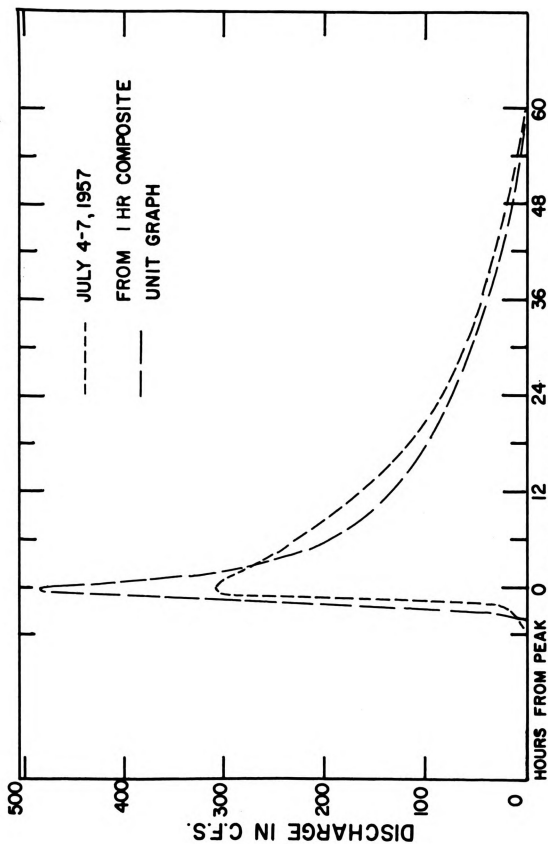
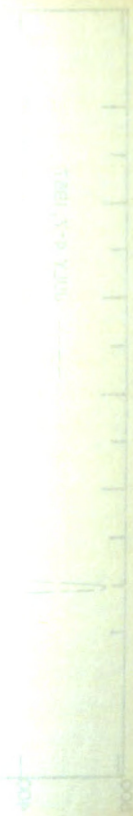


FIGURE 26. 2 HR. SLOAN CREEK UNIT GRAPHS



hydrograph for the July 11-14, 1957 storm period is shown in Table 8. The hydrograph values for the specific hours of the storm were determined by multiplying the amount of runoff for that hour by the corresponding unit graph value. Uniform runoff of 46.6 percent was considered for the four hours because of high antecedent moisture. Actual average rainfall amounts for each of the four hours were 0.88, 0.83, 0.58, and 0.43 inches.

It should be noted that only the four hours of rainfall causing the main peak were considered in this analysis. The actual runoff rates were secured by subtracting the values of the July 4-7, 1957 recession curve from the total runoff rates of Figure 11.

The comparisons between calculated and actual hydrographs for July 4-7, 1957; July 8-11, 1957; and Oct. 6-9, 1959 are shown in Appendix 6. Listed in Table 9. are the calculated and actual peaks and this percent difference based on the actual peak for each of the four storm periods.

The data of Table 9 indicate that the unit graph method is applicable to watersheds of this size. This agrees with the findings of Linsley (15) and of Minshall (18), who believes unit graph theory applicable to areas even less than one square mile in size. The unit graph method is especially appropriate for estimating runoff rates and volumes for watersheds having at least

Table 8. Comparison of calculated and actual hydrographs for July 11-14, 1957.

Hours from peak	Comp. unit graph CFS	1st. hour CFS	2nd. hour CFS	3rd. hour CFS	4th. hour CFS	Calc. run-off CFS	Act. run-off CFS	Hours from peak
- 4	0	0				0	0	- 6
- 3	10	4	0			4	37	- 5
- 2	90	37	4	0		41	283	- 4
- 1	307	126	35	3	0	164	397	- 3
0	521	215	118	24	2	359	496	- 2
+ 1	447	183	200	82	18	483	570	- 1
+ 2	365	150	172	140	61	523	644	0
+ 3	290	119	141	120	104	484	617	+ 1
+ 4	256	105	112	98	89	404	548	+ 2
+ 5	228	93	99	78	73	343	459	+ 3
+ 6	208	86	89	69	58	303	386	+ 4
+ 7	190	78	80	62	51	271	345	+ 5
+ 8	174	72	76	56	46	250	308	+ 6
+ 9	164	67	67	51	42	227	275	+ 7
+10	155	64	63	47	38	212	241	+ 8
+11	148	61	60	44	35	200	216	+ 9
+12	139	57	57	42	33	189	196	+10
+13	133	55	54	40	31	180	176	+11

several years of rainfall and runoff records.

Table 9. Calculated and actual peak differences for the selected storm periods.

Date	Calculated peak C.F.S.	Actual peak C.F.S.	Difference Percent
July 4- 7, 1957	136	88	55
July 8-11, 1957	84	54	56
July 11-14, 1957	523	644	19
Oct. 6- 9, 1959	388	464	16

Rational formula method

This formula was originally devised nearly 100 years ago and the Review of Literature attests its "battle-scarred" background. Theorist continue to attack it because of nonconformity to perfect theory, but practicing engineers use it more than any other method for small basins. When a greatly superior procedure is developed this method will disappear, but until then it should be given its due consideration.

An estimate of peak flow from a drainage basin where no useful streamflow data are available can generally best be made by an application of the rational method according to Low Dams (26). Linsley, et al, (17) comments, "Of all the flood formulas, the rational formula has the advantage that its physical meaning is

reasonably clear".

The rational formula is for predicting design peak runoff rates. It is thus specifically for the watershed conditions and rainfall intensity and duration of particular frequency for which a structure can be economically designed. It is not necessarily applicable for predicting runoff rates under any and all conditons. The following analysis considers the rational method for estimating the design peak runoff rate for a once in 25 years period for the Sloan Creek watershed.

The first step was to determine the time of concentration t_c , which is defined as the time of travel of a water particle from the most remote point hydrologically to the outlet of the drainage basin. This was accomplished by estimating the average velocity for the principle reaches. Assuming an n of 0.06 and a hydraulic radius of 1 with the 10 feet per mile channel gradient gave an average velocity of 1.1 feet per second.

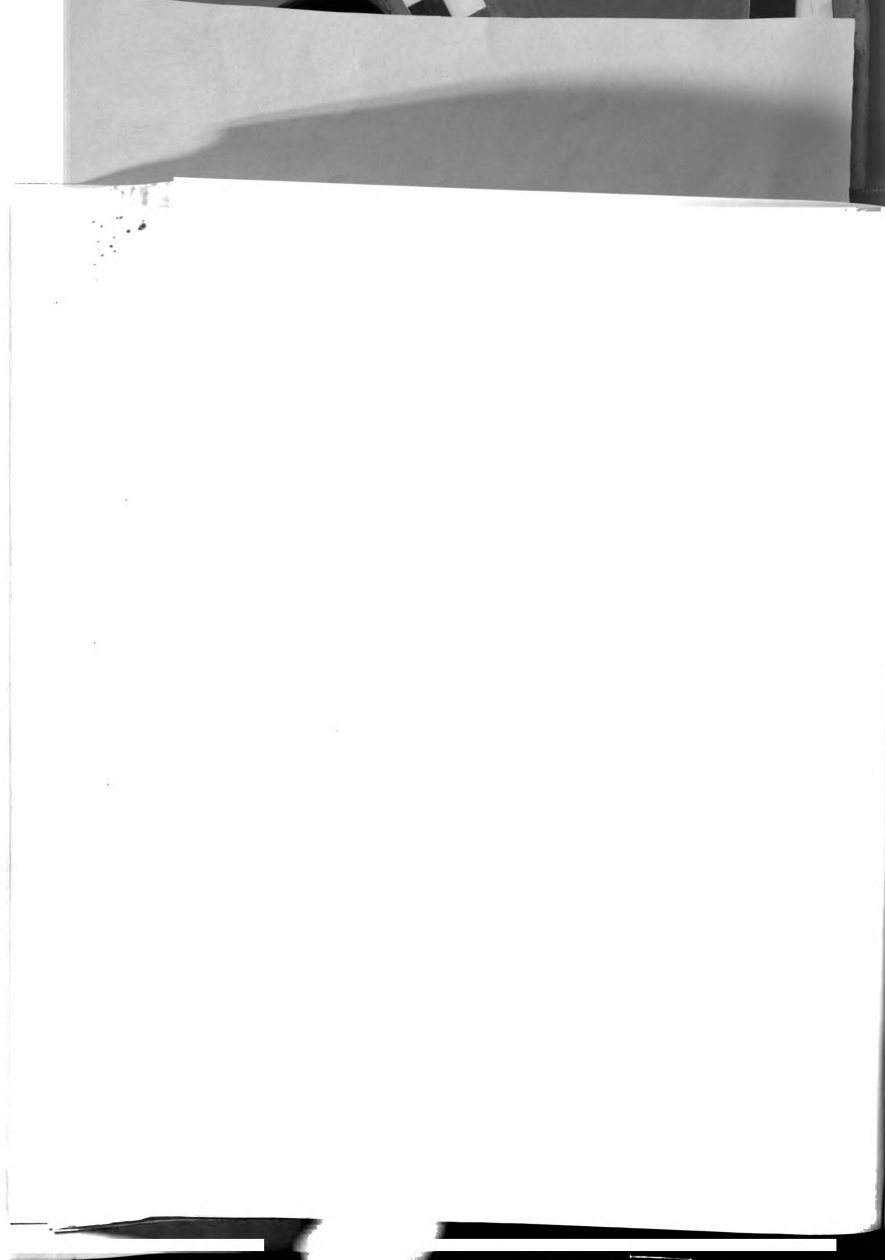
Lateral inflow into a stream usually creates a flood wave which is superimposed on the normal stream flow. Assuming this wave to increase the apparent velocity by 30 percent (26) increased the velocity from 1.1 to 1.4 feet per second. At this velocity it required 5.3 hours to traverse the approximately 5 miles of well-defined channel. Overland flow time for nearly $\frac{1}{2}$ mile gave a total of about 6 hours as t_c for the watershed.

The t_c as previously calculated is for the channel at flood stage and does not account for the retarding effects due to surface detention and channel storage. These effects are aggravated when the basin is relatively flat and has appreciable storage. but if antecedent moisture conditions are very high as would be the case when designing for peak flows these aspects are not too important. For the above period the storms of July 4 and July 8 had the watershed antecedent moisture sufficiently high for the 6 hours value to be satisfactory.

In many studies, especially on small watersheds, the t_c is considered to be the same as the time for the hydrograph to peak t_p . This is true when the rain lasts for the time of concentration but naturally cannot be true for rains of much shorter periods. Considering this, the 3-5 hours basin lag for the more intense but shorter duration storms was satisfactory even with a 6 hour t_c .

The i of the rational formula is the average rainfall intensity for the storm sufficiently long to cause runoff from the entire watershed. That is for the storm of length equal to t_c , in this instance 6 hours. Rainfall intensity-frequency curves are shown (27) for only 4 and 8 hours for the longer storms. Interpolating for the once in 25 years frequency gave approximately 0.5 inch per hour for a 6 hour period.

As defined for use in the rational method C is the



ratio of the maximum peak flow per acre expressed in cubic feet per second to the average rate of rainfall in inches per hour throughout the period of concentration. This follows by solving for C in the formula $Q = C i A$. Frequently the ratio of total runoff to total rainfall is used as the value of C . This is satisfactory for uniform rainfall lasting for t_c and when the antecedent moisture conditions are very high, but not necessarily true for other conditions.

The coefficient C depends not only on the principle losses related to soils, cover, and topography, but must also account for geographical location and seasonal considerations. Under the conditions prevailing in the late winter and spring months in eastern United States a runoff coefficient reaching or exceeding unity can be produced. (26) This watershed in southern Michigan, being predominately cropped land, having relatively pervious soils, and being reasonably flat should have a maximum value of C around 0.5.

Using the previously determined values of i and C , the formula $Q = C i A$ gave an expected once in 25 years runoff rate peak of 1495 cfs for this 5980 acre watershed. The highest peak thus far recorded was 644 cfs for the July 11-14, 1957 period. If the once in 25 years rain of July 11, had occurred at a continuous and uniform rate the peak could have been much higher. The long,

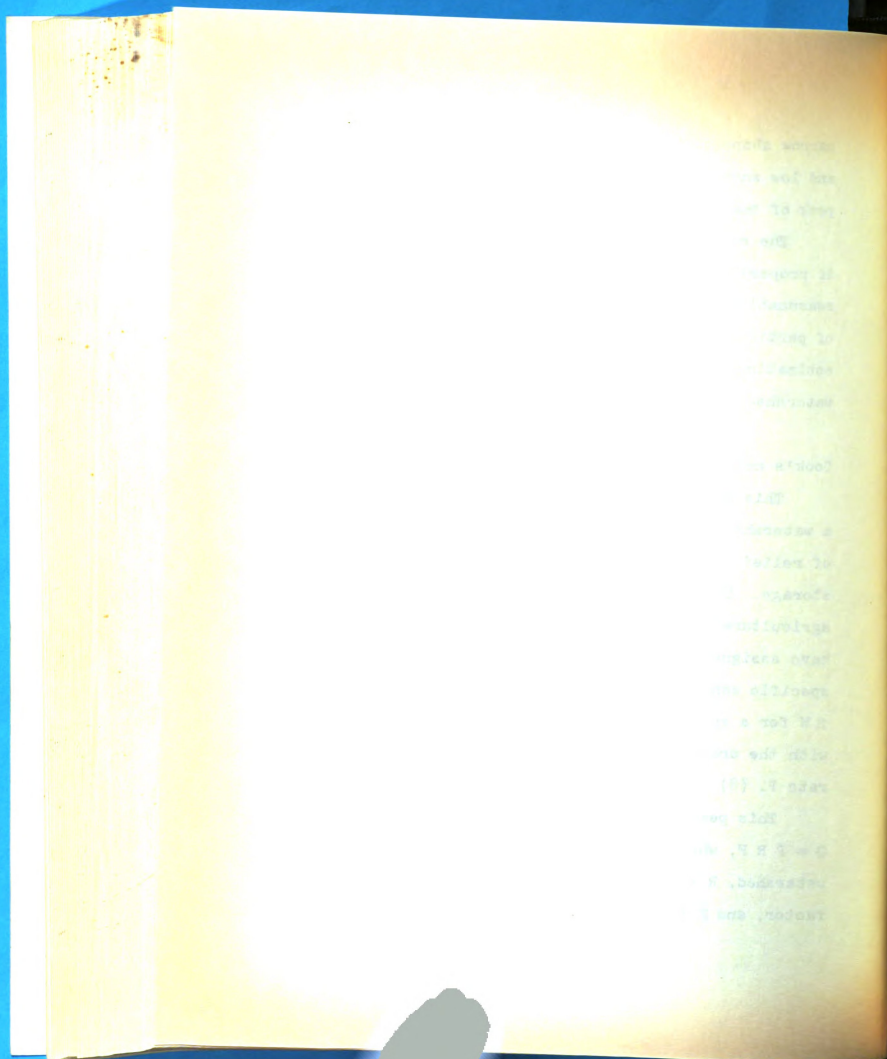
narrow shape of the watershed, nonuniformity of the rain, and low antecedent moisture caused the relatively low peak of the October 6-9, 1959 storm.

The results obtained in this storm indicate that if properly used, the rational formula can predict with reasonable accuracy design peak runoff rates for storms of particular frequencies. Its greatest value is for estimating these peak runoff rates for the smaller watersheds where no rainfall or runoff records exist.

Cook's method

This method examines the runoff characteristics of a watershed of specific size under the four categories of relief, soil infiltration, vegetal cover, and surface storage. Through observation of peak floods from agricultural areas, Soil Conservation Service personnel have assigned numerical values to these categories for specific conditions. The sum of the numerical values ΣW for a specific watershed is used in conjunction with the drainage area to determine the peak runoff rate P . (8)

This peak runoff value is modified by the formula $Q = P R F$, where Q is the peak runoff rate for the watershed, R is the geographical rainfall characteristics factor, and F is the frequency of storm recurrence factor.



On occasions S is also added to the formula as a shape factor which decreases in magnitude as the length to width ratio of the watershed increases. (21)

The Engineers Handbook for Michigan (27) presents a graph of P versus drainage area for watersheds up to 2000 acres. But adds the note, "On drainage areas larger than 600 acres, additional methods of runoff determination should be used to aid your judgement in arriving at proper peak runoff rates". Even though the Sloan Creek watershed is three times this size, certain information can still be obtained by its use.

As listed in the Soil Conservation Service, Hydrology Supplement A (28), the soils of the Sloan Creek area are predominately in hydraulic soils group B. Using the cover complex as listed in the Introduction and considering the land to be receiving the best soil treatment and to be in the "good" hydrologic group gave a L/W of 50. For this value of L/W and a 2000 acre watershed, a P of 2400 cfs was obtained. Correcting for once in 25 years frequency and geographic location still gave a probable maximum discharge peak rate of 1500 cfs.

As implied by the above note, this graph was developed primarily for small areas. If it had considered the very mild slopes, the fair degree of surface storage, and the somewhat elongated shape of the watershed a value more in line with those of the previous two methods should

have been secured.

A further extension of Cook's original method is explained in the article, "Hydrologic Techniques in Watershed Planning", by H. O. Ogrosky (22). This procedure presents a graph of inches of runoff as inches of rainfall for specific values of watershed conditions. Thus one can determine only the expected amount of runoff and not the probable peak rate of discharge with this approach.

For the determination of the probable maximum peak rate of discharge for an area of 2000 acres or over the most likely S. C. S. procedure would be the hydrograph method. This technique is similar to the unit graph method previously explained and needs no further discussion here.



SUMMARY

Five years of hydrologic data from a relatively flat, 9.34 square mile, predominately agricultural watershed in south-central Michigan were analyzed. The rainfall data were secured from a network of raingages which were installed and calibrated by U.S. Weather Bureau personnel. The operation and maintenance of the stream gaging station for the watershed were under the jurisdiction of the U.S. Geological Survey.

The Weather Bureau's hourly raingage data were rechecked for accuracy and then used to determine equivalent uniform rainfall depths per hour and per storm by using the Thiessen procedure. These depths were nearly identical with those obtained from unweighted gage averages, but differed appreciably with depths recorded for gage 4 which was considered an appropriate single gage position.

After the runoff data were secured from the original Geological Survey records, total discharge hydrographs were plotted for each of 19 storm periods. The surface runoff portion of the total discharge ceased approximately $2\frac{1}{2}$ days after the hydrograph peaked, as determined by a composite curve constructed from seven appropriate recessions. The area between the total discharge curve and the assumed straight-line base flow curve was planimetered to determine



the amount of surface runoff for each storm analyzed.

An analysis was made of the factors involved in the rainfall-runoff process for 15 of the storm periods. The moisture supply which affected runoff was due to the storm rainfall and antecedent precipitation. The fraction of antecedent precipitation considered effective depended upon the season of the year and the number of days prior that the rain had fallen.

Initial infiltration, surface storage, and detention storage had to be satisfied before runoff could occur. When the surface runoff and the base infiltration were subtracted from the total moisture supply the amount of moisture required prior to runoff was obtained. As surface and detention storage were relatively constant the amount of moisture required prior to runoff was determined. This amount varied with the season of the year, probably more specifically, with the moisture content of the lower soil strata.

The unit graph method of estimating peaks and amounts of flood discharge was discussed. Two $\frac{1}{2}$ hour unit graphs were combined and the composite was then converted into a 1 hour unit graph. This 1 hour composite unit graph was combined with the August 9-12, 1956 1 hour unit graph to give the most appropriate unit graph for the watershed. The composite 1 hour unit graph was used to determine expected hydrographs for four actual storms. The calculated



and actual peaks differed only between 16 and 56 percent. Thus this method of analysis was considered very satisfactory for estimating peak flows and volumes of discharge for watersheds where at least several years of records exist.

To illustrate the rational formula approach, the design peak runoff rate was determined for a once in 25 years frequency storm. The results of this method compared favorably with the unit graph procedure and with the actual hydrograph values. This method may be used to estimate design peak runoffs from small watersheds where no records presently exist.

The soil Conservation Service's revision of Cook's formula was discussed and illustrated. This procedure was not considered appropriate for areas as large as the Sloan Creek watershed.

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CONCLUSIONS

1. For much work, rainfall averaging methods more detailed than unweighted averages are unnecessary.
2. Accurate rainfall information, as required by irrigation farmers, etc., necessitates a minimum of one raingage per square mile.
3. Recession curves are largely independent of the rainfall characteristics of the storm producing the rise and are relatively uniform in length for a particular watershed. The length of time from the peak to the end of surface runoff was approximately $2\frac{1}{2}$ days for the Sloan Creek watershed.
4. Initial infiltration varies extensively throughout the season, generally increasing from spring through late summer and then slowly decreasing towards winter.
5. The unit graph method is appropriate for estimating the volume and rate of runoff from small area watersheds when at least a few years of rainfall and runoff records are available.
6. For watersheds up to 10 square miles, the rational formula may be advantageously used for estimating peak design rates of runoff if no prior records exist.
7. Cook's method as modified by the Soil Conservation Service is not appropriate for determining peak discharges for areas as large as Sloan Creek.

SUGGESTIONS FOR FUTURE STUDIES

1. Information is needed on more large storms to evaluate in greater detail the unit graph and rational method's applicability to small watersheds.
2. A determination of the relationship between the moisture content of the subsurface layers and the initial infiltration amount required prior to surface runoff is needed.
3. Electrical synchronization of raingage timing is needed for the study of effect of storm direction and rate of movement on peak rates of runoff.

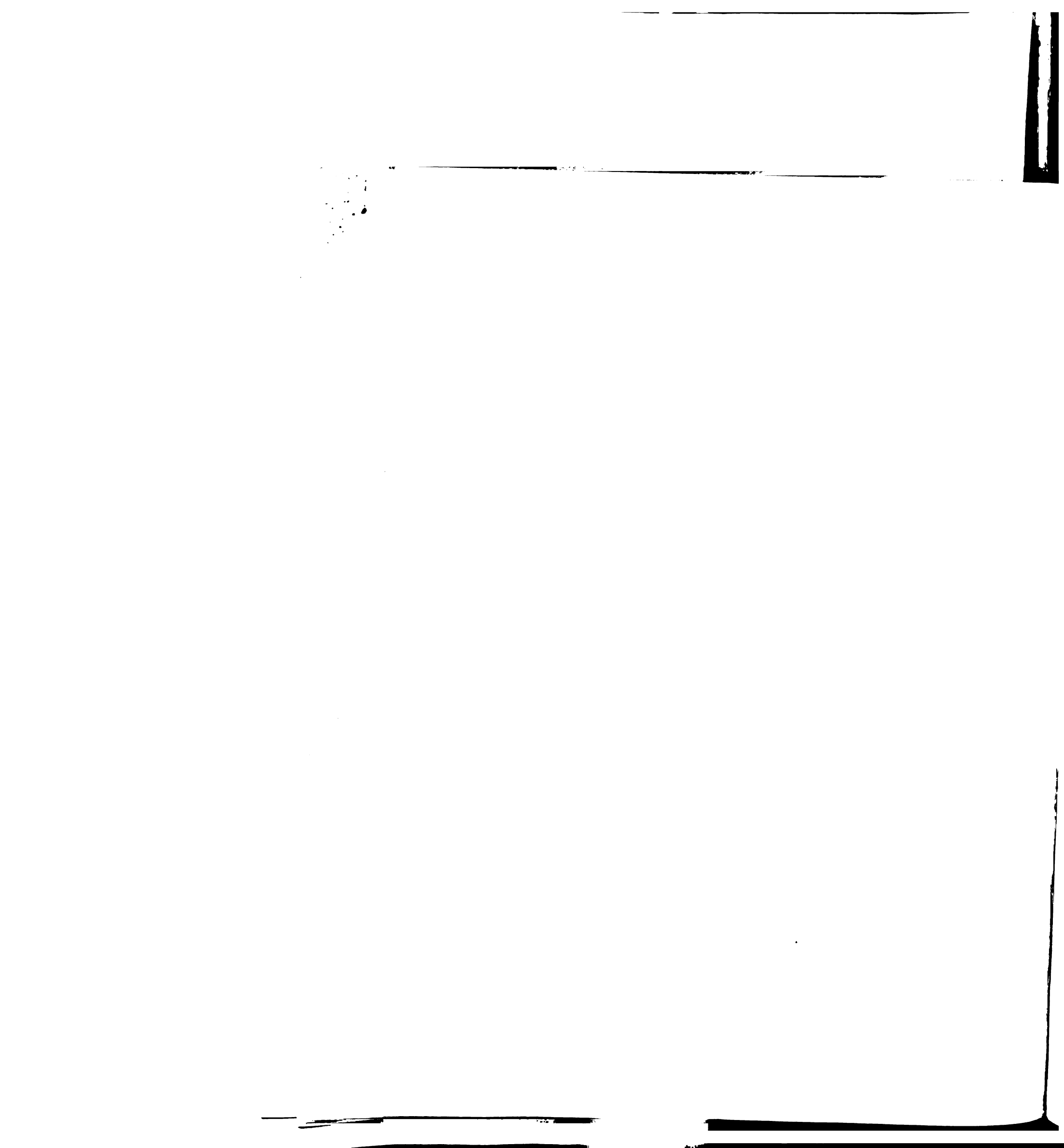
REFERENCES

1. Ash, A. D., A. H. Eichmeier, E. H. Kidder, D. W. Granger and others (1958). Hydrologic studies of small watersheds in agricultural areas of southern Michigan, Report no. 1. Water Resources Commission. Lansing, Michigan. 77pp.
2. Blair, T. A. and R. C. Fite (1957). Weather Elements. 4th ed. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 444pp.
3. Butler, Stanley S. (1957). Engineering Hydrology. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 356pp.
4. Cardwell, David W. (1940). Runoff from small agricultural watersheds. Jour. Agr. Engr. 21:479-482.
5. Chow, Ven Te (1958). Frequency analysis in small watershed hydrology. Jour. Agr. Engr. 39:222-225, 231.
6. Eichmeier, A. H., R. Z. Wheaton and E. H. Kidder (1959). Variation in summertime rainfall in south-central Michigan. Mich. Agr. Expt. Sta. Quarterly Bulletin, Vol. 41, No. 4, 886-888.
7. Eichmeier, A. H., R. Z. Wheaton and E. H. Kidder (1959). Preliminary report of excessive precipitation over Sloan Creek Basin, a small watershed. Mich. Agr. Expt. Sta., Quarterly Bulletin, Vol. 41, No. 4, 889-893.
8. Frevert, R. K., G. O. Schwab, T. W. Edminster and K.K. Barnes (1955). Soil and Water Conservation Engineering. John Wiley & Sons, Inc., New York.
9. Hoyt and others. Rainfall and run-off in the United States. Dept. of Interior, USGS. Water Supply Paper 772.
10. Johnstone, Don and W. P. Cross (1949). Elements of Applied Hydrology. The Ronald Press Co., New York.
11. Kidder, Ernest H. (1947). The analysis of hydrologic data from small agricultural plots. Thesis for degree of M.S. Univ. of Ill., Urbana, Ill. (Unpublished)

12. Krimgold, D. B. (1938). Runoff from small drainage basins. Jour. Agr. Engr. 19:439-446.
13. Krimgold, D. B. (1947). Rates of runoff from small drainage basins. Jour. Agr. Engr. 28:25-28.
14. Krimgold, D. B. (1947). Runoff as a phase of agricultural hydrology. Jour. Agr. Engr. 28:29-30.
15. Linsley, Ray K. (1960). Executive Head, Department of Civil Engineering, Stanford University. Stanford, Calif. Personal Correspondence. July.
16. Linsley, Ray K. and Max A. Kohler (1951). Variations in storm rainfall over small areas. National Research Council, Transactions, American Geophysical Union. Vol. 32, No. 2. 245-250.
17. Linsley, Ray K., Max A. Kohler and J. H. Paulhus (1958). Hydrology For Engineers. McGraw-Hill Book Co., Inc., New York. 340pp.
18. Minshall, Neal E. (1960). Predicting storm runoff on small experimental watersheds. Proceedings of the ASCE., Journal of the Hydraulics Division. Vol. 86, No. HY8, Part 1. 17-38.
19. Minshall, Neal E. (1960). Supervisory Hydraulic Engineer. Madison, Wisconsin. Personal Correspondence. August.
20. Myers, Victor I., A method of determining average watershed precipitation. Idaho Agr. Expt. Sta. Res. Paper No. 386. 10pp.
21. Neff, Earl L. and Paul C. Sheffer (1959). Determination of peak discharge-frequency relationships for streams within a selected area in California. U.S.D.A., Agricultural Research Service Bul. 41-32. 20pp.
22. Ogrosky, H. O. (1960). Hydrologic techniques in watershed planning. Transactions of ASAE, 3:84-86.
23. Pickels, George W. (1941). Drainage and Flood-Control Engineering. 2d. ed. McGraw-Hill Book Co., Inc., New York. 476pp.
24. Rouse, Hunter, ed. (1950). Engineering Hydraulics. John Wiley & Sons, Inc., New York. 1039pp.



25. Sharp, A. L. (1960). Supervisory Hydrologist. Lincoln, Nebraska. Personal Correspondence. July.
26. Small Water Storage Projects subcommittee of National Resources Committee (1938). Low Dams. U. S. Govt. Printing Office, Washington, D. C. 431pp.
27. Soil Conservation Service. Engineers Handbook for Michigan. USDA. Washington, D. C.
28. Soil Conservation Service Hydrology Supplement A. USDA. Washington, D. C.
29. Sutton, John G. (1939). Hydraulics of open ditches. Jour. Agr. Engr. 20:175-178.
30. Thames, J. L. and S. J. Ursic (1960). Runoff as a function of moisture-storage capacity. Jour. of Geophysical Research. 65:651-654.
31. Zingg, A. W. (1943). The determination of infiltration-rates on small agricultural watersheds. National Research Council, Transactions of 1943, American Geophysical Union, Part II. 475-480.



Appendix 1 Data for plotting Sloan Creek hydrographs.

The values listed under "Stage" are those indicated on the original, waterstage recorder charts before any corrections were applied. The "Corrections" listed are those applied by the U.S. Geological Survey according to their standard procedure for any discrepancy between indicated and true stage. Standard U.S.G.S. rating tables for this stream were used to convert these corrected stage values to total discharges in cubic feet per second. It is regular U.S.G.S. procedure to consider discharge less than 10 cfs to the nearest 0.1 cfs and discharge over 10 cfs to the nearest whole cfs.

Appendix 1 Data for plotting Sloan Creek hydrographs.

Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.	Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.
August 9-12, 1956					8	3.09	-.06	3.03	35
9- 6	1.70	-.06	1.64	0.9	10	2.96	"	2.90	27
12	1.68	"	1.62	0.8	12	2.87	"	2.81	22
13	2.00	"	1.94	2.6	15	2.76	"	2.70	18
14	2.68	"	2.62	16	24	2.54	"	2.48	11.4
15	3.35	-.06	3.29	57	19- 8	2.40	"	2.34	7.8
16	3.68	-.07	3.61	128	12	2.35	"	2.29	6.8
17	3.61	"	3.54	107	24	2.22	"	2.16	4.9
19	3.38	"	3.31	60	20-12	2.12	"	2.06	3.6
20	3.32	"	3.25	53	24	2.05	-.06	1.99	2.9
24	3.15	"	3.08	39	April 27-30, 1957				
10-10	2.95	"	2.88	26	27- 3	2.96	+.08	3.04	38
24	2.74	"	2.67	17	6	2.89	"	2.97	32
11-12	2.56	"	2.49	12	9	2.83	"	2.91	28
18	2.50	-.07	2.43	9.9	11	3.00	"	3.08	41
August 17-20, 1956					12	3.35	"	3.43	81
17-20	1.77	-.06	1.71	1.2	13	3.67	"	3.75	120
18- 2	1.77	"	1.71	1.2	14	3.80	"	3.88	137
4	2.30	"	2.24	6.1	15	3.68	"	3.76	122
5	3.08	"	3.02	34	16	3.57	"	3.65	108
6	3.20	"	3.14	43	18	3.45	"	3.53	93
7	3.15	-.06	3.09	39	20	3.38	+.08	3.46	84

Appendix 1 Continued

Time	Stage Feet	Corr. Feet	Dis-Stage charge Feet	C.F.S.	Time	Stage Feet	Corr. Feet	Dis-Stage charge Feet	C.F.S.
22	3.31	+.08	3.39	76	24	2.38	+.08	2.46	11
24	3.25	"	3.33	69	17-12	2.32	"	2.40	9
28- 6	3.07	"	3.15	48	24	2.28	+.08	2.36	8.2
12	2.96	"	3.04	38	May 18-21, 1957				
18	2.87	"	2.95	30	18-18	2.36	+.08	2.44	10
24	2.78	"	2.86	25	23	2.37	"	2.45	10
29-12	2.67	"	2.75	20	19- 1	2.48	"	2.56	14
24	2.52	"	2.60	15	3	2.86	"	2.94	30
30-12	2.38	"	2.46	11	5	3.20	"	3.28	63
20	2.31	+.08	2.39	8.8	6	3.42	"	3.50	89
May 14-17, 1957					8	4.05	"	4.13	171
14-18	2.20	+.08	2.28	6.7	9	4.25	"	4.33	200
24	2.18	"	2.26	6.4	12	4.36	"	4.44	216
15- 1	2.65	"	2.73	19	13	4.45	"	4.53	229
2	3.25	"	3.33	69	14	4.48	"	4.56	234
2 $\frac{1}{2}$	3.34	"	3.42	79	15	4.42	"	4.50	225
3	3.30	"	3.38	75	16	4.32	"	4.40	210
6	3.10	"	3.18	52	19	4.04	"	4.12	170
11	2.83	"	2.96	31	23	3.82	"	3.90	140
17	2.75	"	2.83	24	20- 6	3.49	"	3.57	97
24	2.64	"	2.72	19	11	3.36	"	3.44	82
16-12	2.49	+.08	2.57	14	18	3.21	+.08	3.29	64

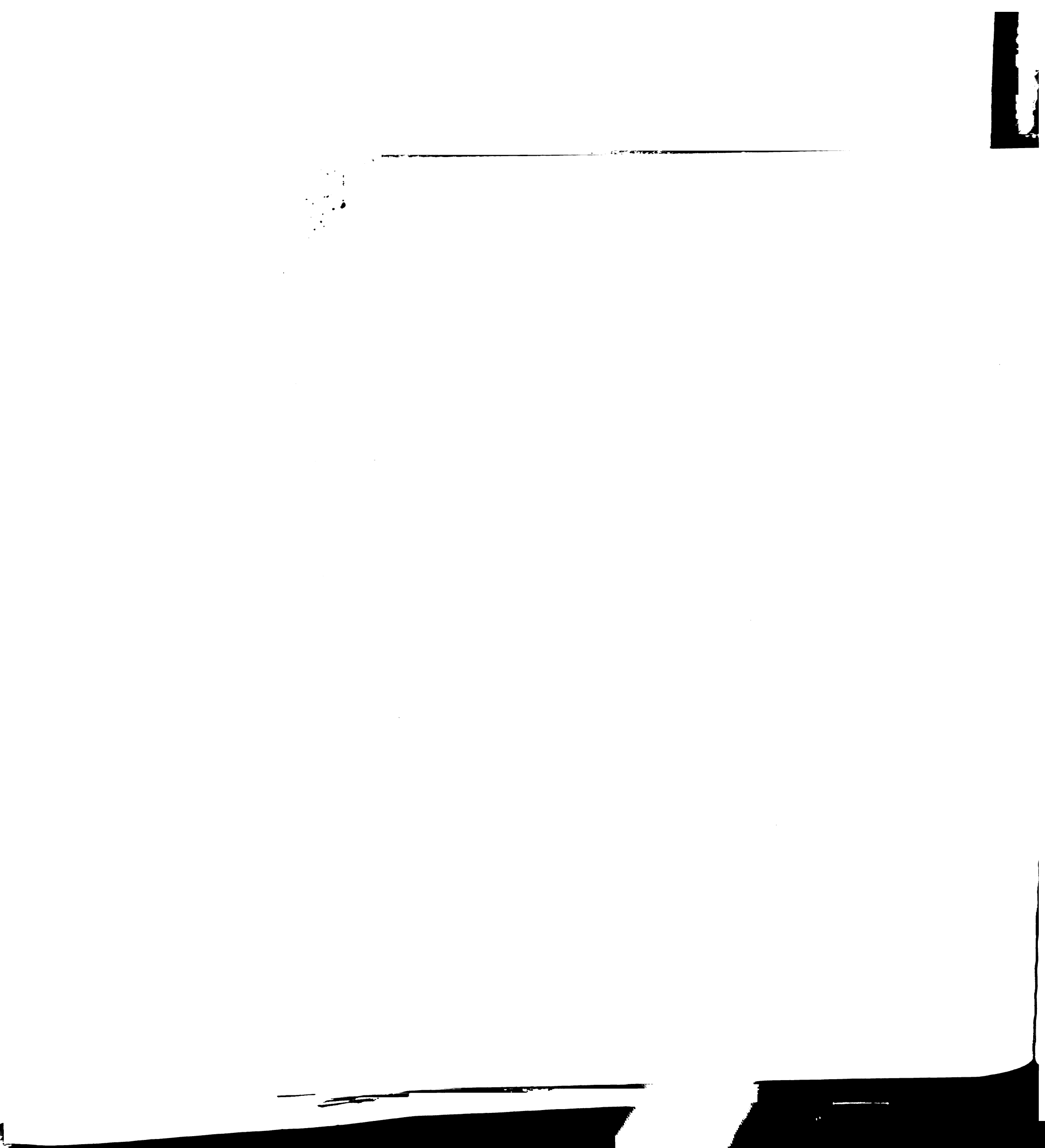


Appendix 1 Continued

Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.	Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.
24	3.11	+.08	3.19	53	24	2.30	+.02	2.32	7.4
21-12	2.98	"	3.06	39	July 8-11, 1957				
24	2.89	"	2.97	32	8- 1	2.29	+.02	2.31	7.2
22- 8	2.84	+.08	2.92	28	5	2.27	"	2.29	6.8
July 4-7, 1957					7	2.45	"	2.47	11
4-13	1.69	+.01	1.70	1.1	8	2.96	"	2.98	33
18	1.68	"	1.69	1.1	9	3.00	"	3.02	36
19	1.91	"	1.92	2.4	10	3.07	"	3.09	42
21	2.19	"	2.20	5.5	11	3.16	"	3.18	52
22	2.70	"	2.71	18	12	3.18	"	3.20	54
23	3.43	"	3.44	82	13	3.22	"	3.24	58
24	3.50	"	3.51	90	14	3.24	"	3.26	61
5- 1	3.48	"	3.49	88	16	3.20	"	3.22	56
3	3.41	"	3.42	79	24	3.07	"	3.09	42
13	3.14	"	3.15	48	9-11	2.90	"	2.92	28
21	2.98	"	2.99	33	24	2.66	"	2.68	17
24	2.92	"	2.93	29	10-12	2.48	"	2.50	12
6-10	2.77	"	2.78	21	18	2.39	"	2.41	9.3
16	2.68	"	2.69	18	24	2.35	"	2.37	8.4
24	2.55	+.01	2.56	14	11- 2	2.34	+.02	2.36	8.2
7-12	2.40	+.02	2.42	9.6	July 11-14, 1957				
18	2.33	+.02	2.35	8.0	11-2	2.34	+.02	2.36	8.2

Appendix 1 Continued

Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.	Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.
4	2.52	+.02	2.54	13	18	3.68	-.02	3.66	109
5	2.80	"	2.82	23	21	3.57	"	3.55	95
6	2.78	"	2.80	22	24	3.53	"	3.51	90
8	3.13	"	3.15	48	13- 2	3.50	"	3.48	87
10	3.28	"	3.30	65	12	3.29	"	3.27	62
11	3.31	"	3.33	69	24	3.14	"	3.12	45
13	3.26	"	3.28	63	14-12	3.04	"	3.02	36
14	3.23	"	3.25	60	24	3.02	-.02	3.00	34
15	3.23	"	3.25	60	November 14-17, 1957				
16	3.50	"	3.52	91	14- 1	1.77	none	1.77	1.5
17	5.20	"	5.22	333	4	1.79	"	1.79	1.6
18	5.95	"	5.97	445	9	1.93	"	1.93	2.4
19	6.50	"	6.52	542	12	2.19	"	2.19	5.4
21	7.33	"	7.35	685	15	2.55	"	2.55	14
22	7.17	"	7.19	656	18	2.72	"	2.72	19
24	6.22	"	6.24	495	21	2.86	"	2.86	25
12- 1	5.76	"	5.78	420	23	2.96	"	2.96	31
3	5.25	"	5.27	340	24	2.97	"	2.97	32
5	4.78	"	4.80	270	15- 2	2.95	"	2.95	30
6	4.60	"	4.62	243	4	2.90	"	2.90	27
8	4.32	"	4.34	201	7	2.82	"	2.82	23
10	4.14	+.02	4.16	175	12	2.67	none	2.67	17

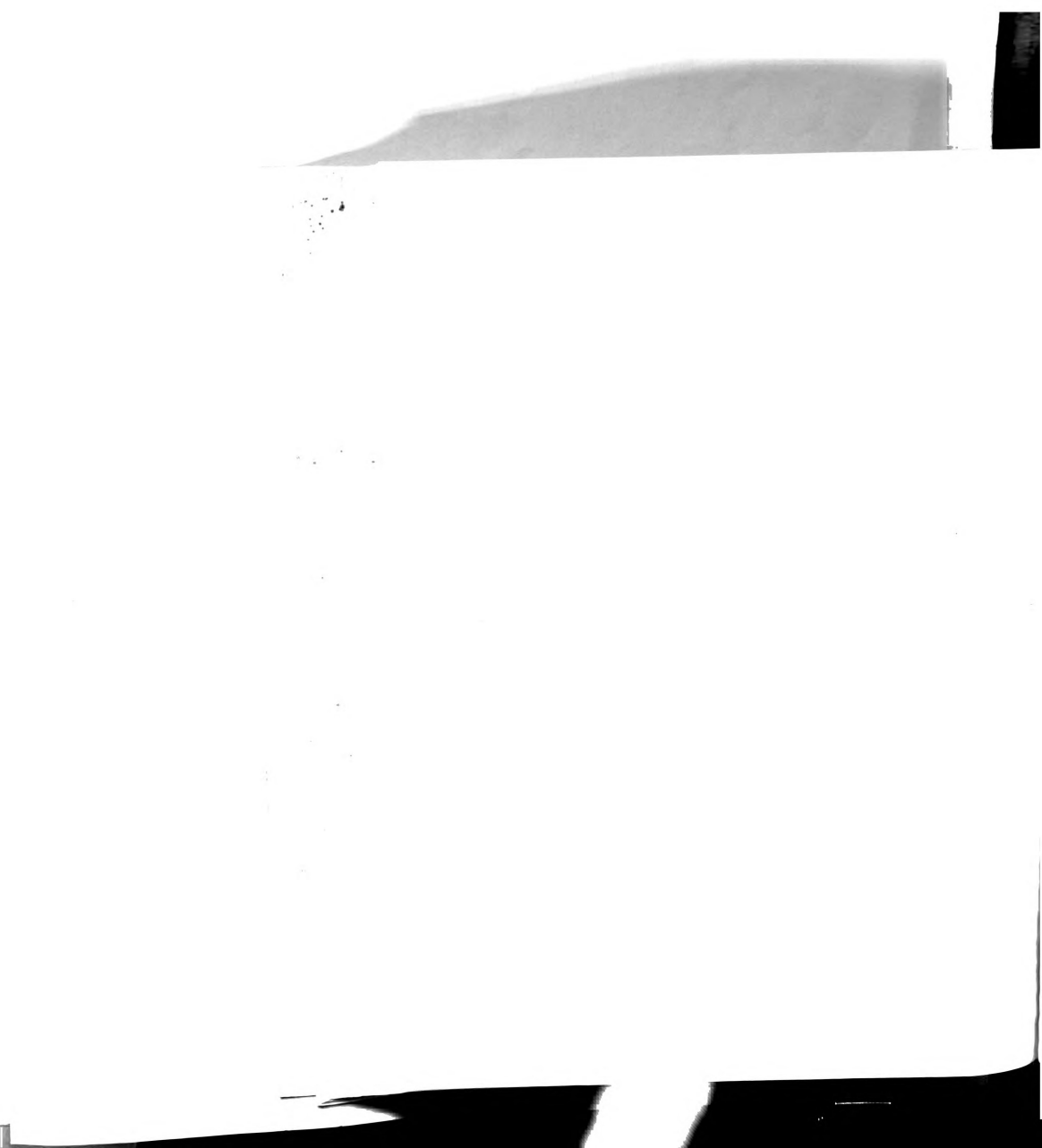


Appendix 1 Continued

Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.	Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.
24	2.45	none	2.45	10	9-12	2.20	none	2.20	5.5
16-12	2.33	"	2.33	7.6	21	2.17	none	2.17	5.1
24	2.24	"	2.24	6.1	July 28-31, 1958				
17-12	2.17	none	2.17	5.1	28- 7	1.42	none	1.42	0.3
April 6-9, 1958					13	1.41	"	1.41	0.3
6- 8	1.98	none	1.98	2.8	14	1.56	"	1.56	0.6
17	1.97	"	1.97	2.7	15	1.75	"	1.75	1.4
19	2.05	"	2.05	3.5	16	1.75	"	1.75	1.4
21	2.15	"	2.15	4.8	17	1.72	"	1.72	1.2
23	2.36	"	2.36	8.2	18	1.90	"	1.90	2.2
24	2.71	"	2.71	18	20	1.96	"	1.96	2.6
7- 1	2.85	"	2.85	24	22	1.99	"	1.99	2.8
2	2.88	"	2.88	26	24	2.03	"	2.03	3.3
4	2.90	"	2.90	27	29- 2	2.00	"	2.00	2.9
8	2.87	"	2.87	26	4	1.95	"	1.95	2.5
10	2.84	"	2.84	24	6	1.90	"	1.90	2.2
12	2.80	"	2.80	22	9	1.84	"	1.84	1.8
18	2.68	"	2.68	17	12	1.78	"	1.78	1.5
24	2.56	"	2.56	14	15	1.73	"	1.73	1.3
8- 6	2.46	"	2.46	11	18	1.70	"	1.70	1.2
12	2.37	"	2.37	8.4	24	1.66	"	1.66	1.0
24	2.28	none	2.28	6.7	30- 6	1.63	none	1.63	0.9

Appendix 1 Continued

Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.	Time	Stage Feet	Corr. Feet	Corr. Stage Feet	Dis-charge C.F.S.
12	1.61	none	1.61	0.8	August 16-19, 1959				
24	1.58	"	1.58	0.7	16-12	2.23	none	2.23	6.0
31-12	1.56	"	1.56	0.6	14	2.21	"	2.21	5.6
18	1.54	none	1.54	0.6	17	3.07	"	3.07	4.0
May 23-26, 1959					18	3.17	"	3.17	5.1
23-1	1.81	none	1.81	1.7	20	3.26	"	3.26	6.1
4	1.81	"	1.81	1.7	22	3.18	"	3.18	5.2
8	1.87	"	1.87	2.0	24	3.11	"	3.11	4.4
12	2.03	"	2.03	3.3	17-3	3.00	"	3.00	3.4
18	2.28	"	2.28	6.7	8	2.87	"	2.87	2.6
21	2.36	"	2.36	8.2	12	2.77	"	2.77	2.1
24	2.41	"	2.41	9.3	18	2.65	"	2.65	1.6
24-3	2.43	"	2.43	9.9	24	2.55	"	2.55	1.3
5	2.44	"	2.44	10.2	18-12	2.41	"	2.41	9.3
10	2.43	"	2.43	9.9	24	2.34	"	2.34	7.8
13	2.42	"	2.42	9.6	19-12	2.28	"	2.28	6.7
18	2.40	"	2.40	9.0	20	2.23	none	2.23	6.0
24	2.37	"	2.37	8.4	September 21-24, 1959				
25-12	2.31	"	2.31	7.2	21-7	1.61	none	1.61	0.8
24	2.24	"	2.24	6.1	17	1.60	"	1.60	0.7
26-12	2.19	"	2.19	5.4	19	1.76	"	1.76	1.4
20	2.16	none	2.16	4.9	22	2.03	none	2.03	3.3



Appendix 1 Continued

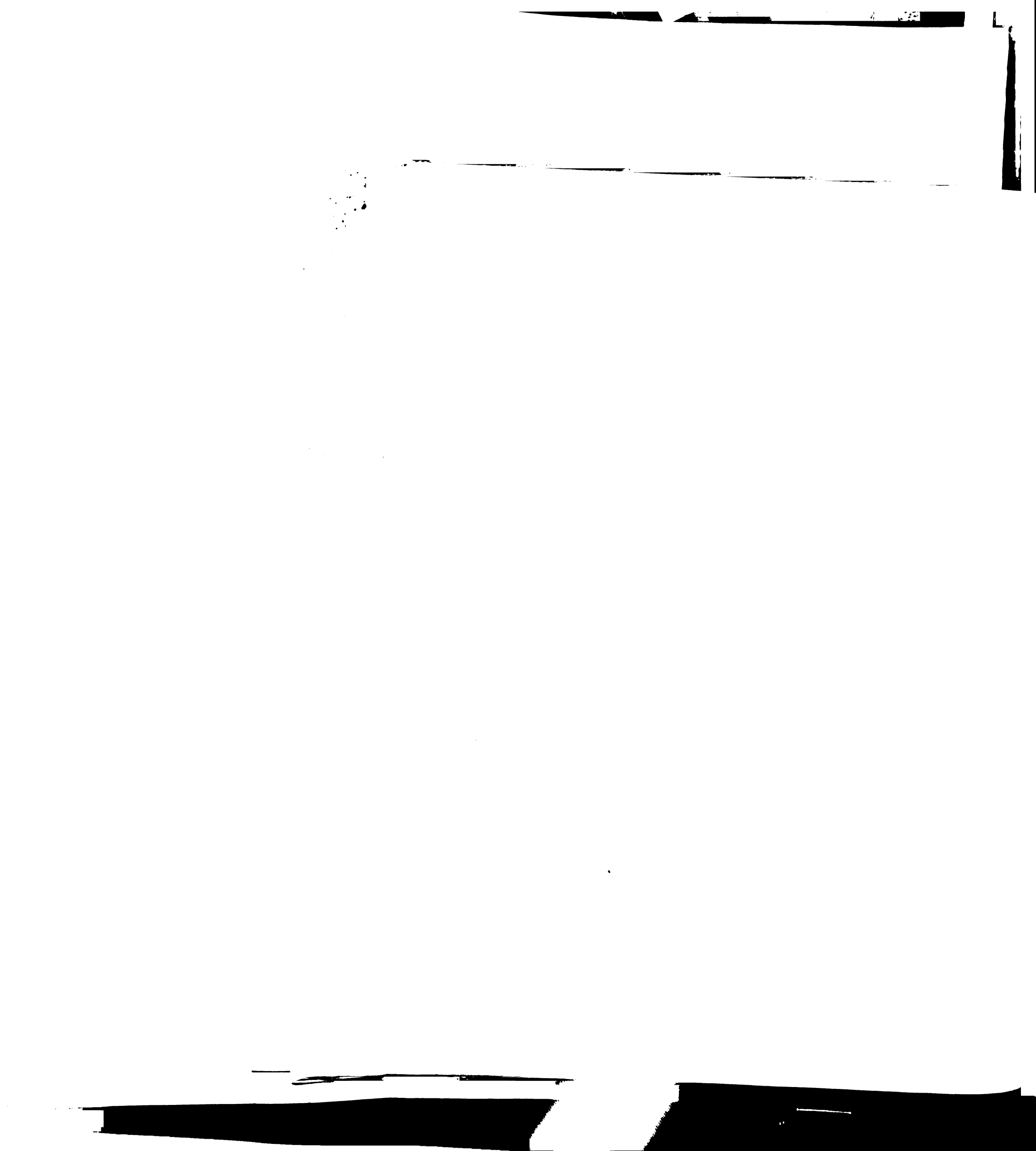
	Time	Stage Feet	Corr. Feet	Stage Feet	Dis-charge C.F.S.	Time	Stage Feet	Corr. Feet	Stage Feet	Dis-charge C.F.S.
	24	2.21	none	2.21	5.6	10	4.81	none	4.81	272
22-	2	2.40	"	2.40	9.0	11	4.83	"	4.83	275
	6	2.70	"	2.70	18.0	12	5.15	"	5.15	322
	7	2.75	"	2.75	20.0	13	5.55	"	5.55	383
	9	2.77	"	2.77	20.8	14	5.77	"	5.77	418
	11	2.76	"	2.76	20.6	15	5.85	"	5.85	431
	12	2.74	"	2.74	19.6	16	6.13	"	6.13	476
	14	2.69	"	2.69	17.9	17	5.85	"	5.85	431
	17	2.62	"	2.62	15.6	20	5.08	"	5.08	312
	20	2.54	"	2.54	12.7	24	4.50	"	4.50	225
23-	2	2.43	"	2.43	9.9	7- 6	4.00	"	4.00	153
	12	2.33	"	2.33	7.6	12	3.68	"	3.68	111
	24	2.20	"	2.20	5.8	18	3.49	"	3.49	88
24-12	2.15	"	2.15	4.8		24	3.38	"	3.38	75
	24	2.09	none	2.09	4.0	8-12	3.20	"	3.20	54
October 6-9, 1959						22	3.12	none	3.12	45
6- 1	2.26	none	2.26	6.4	November 4-7, 1959					
	4	2.30	"	2.30	7.0	4- 1	2.06	none	2.06	3.6
	5	2.44	"	2.44	10	6	2.05	"	2.05	3.5
	6	2.74	"	2.74	20	9	2.11	"	2.11	4.2
	7	3.75	"	3.75	120	11	2.44	"	2.44	10
	8	4.64	none	4.64	246	12	2.87	none	2.87	26

Appendix 1 Continued

Time	Stage		Corr.		Dis-charge C.F.S.	Time	Stage		Corr.		Dis-charge C.F.S.
	Feet	Feet	Feet	Feet			Feet	Feet	Feet	Feet	
13	3.01	none	3.01	35	18	2.60	none	2.60	15		
14	3.17	"	3.17	51	19	2.81	"	2.81	22		
15	3.25	"	3.25	60	21	3.13	"	3.13	46		
16	3.26	"	3.26	61	23	3.34	"	3.34	70		
17	3.26	"	3.26	61	24	3.38	"	3.38	75		
18	3.25	"	3.25	60	12- 1	3.39	"	3.39	76		
21	3.20	"	3.20	54	2	3.38	"	3.38	75		
24	3.14	"	3.14	47	6	3.28	"	3.28	63		
5-12	2.98	"	2.98	33	11	3.18	"	3.18	52		
18	2.91	"	2.91	28	24	3.00	"	3.00	34		
20	2.90	"	2.90	27	13-12	2.85	"	2.85	25		
24	2.92	"	2.92	28	24	2.74	"	2.74	20		
6- 3	2.91	"	2.91	28	14-12	2.62	"	2.62	16		
12	2.80	"	2.80	22	20	2.57	none	2.57	14		
24	2.68	"	2.68	17	January 12-15, 1960						
7-12	2.57	none	2.57	14	12- 1	1.97	none	1.97	2.7		
December 11-14, 1959					4	1.97	"	1.97	2.7		
11- 6	2.18	none	2.18	5.2	7	2.00	"	2.00	2.9		
11	2.18	"	2.18	5.2	12	2.17	"	2.17	5.1		
13	2.20	"	2.20	5.5	15	2.85	"	2.85	24		
15	2.25	"	2.25	6.2	18	3.27	"	3.27	62		
17	2.43	none	2.43	9.9	20	3.45	none	3.45	83		

Appendix 1 Continued

Time	Stage				Time	Stage			
	Feet	Feet	Feet	C.F.S.		Feet	Feet	Feet	C.F.S.
21	3.50	none	3.50	89	24	3.85	none	3.85	134
22	3.51	"	3.51	90	29- 4	3.70	"	3.70	114
24	3.49	"	3.49	88	9	3.57	"	3.57	97
13- 2	3.46	"	3.46	84	12	3.65	"	3.65	108
5	3.46	"	3.46	84	15	4.12	"	4.12	170
9	3.33	"	3.33	69	17	4.75	"	4.75	262
12	3.23	"	3.23	57	18	4.90	"	4.90	285
24	3.01	"	3.01	35	20	4.78	"	4.78	267
14-11	2.87	"	2.87	26	24	4.28	"	4.28	192
24	2.81	none	2.81	22	30- 4	4.00	"	4.00	153
March 26 - April 2, 1960					7	3.90	"	3.90	140
26-12	1.90	none	1.90	2.2	9	4.08	"	4.08	164
27-12	1.93	"	1.93	2.4	12	4.35	"	4.35	202
18	2.32	"	2.32	7.4	15	4.50	"	4.50	225
24	3.00	"	3.00	34	18	4.36	"	4.36	204
28- 3	3.31	"	3.31	66	24	3.98	"	3.98	150
7	3.50	"	3.50	89	31- 6	3.69	"	3.69	113
10	3.45	"	3.45	83	12	3.51	"	3.51	90
12	3.51	"	3.51	90	24	3.31	"	3.31	66
15	3.70	"	3.70	114	1-24	3.16	"	3.16	50
18	4.11	"	4.11	168	2-24	3.07	none	3.07	40
20	4.21	none	4.21	182					



Appendix 2 Thiessen procedure rainfall analysis data.

The hourly precipitation for each gage was read and tabulated by Weather Bureau personnel following standard Weather Bureau procedure. These values were multiplied by the percentage of the watershed area each gage represented, according to Thiessen procedure, and listed on the following pages. The right hand column thus shows the average weighted depth of rain for each hour and at the end of each storm period indicates the equivalent uniform depth of rain over the watershed.

As the March 26-April 2, 1960 runoff period was included only to show the effect of snow runoff, the small amount of rain which fell during the end of this period was not included. It should also be noted that the average hourly precipitation values of less than 0.01 inch were not shown on Figures 4 through 21.

Appendix 2 Thiessen procedure rainfall analysis data.

Time	Gage number and weighted inches of rain						Rain Inches
	1	2	3	4	5	6	
August 9-12, 1956							
9-13	0.076	0.334	0.173	0.333	0.389	0.274	1.579
14	0.078	0.029	0.149	0.186	0.092	0.014	0.548
15	<u>---</u>	<u>---</u>	<u>0.004</u>	<u>0.010</u>	<u>0.005</u>	<u>0.003</u>	<u>0.022</u>
	0.154	0.363	0.326	0.529	0.486	0.291	2.149
August 17-20, 1956							
18- 2	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	0.007	0.007
3	0.029	0.229	0.171	0.245	0.149	0.148	0.971
4	0.002	0.008	0.048	0.088	0.030	0.003	0.179
22	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	<u>0.014</u>	<u>0.014</u>	<u>0.028</u>
	0.031	0.237	0.219	0.333	0.193	0.172	1.185
April 27-30, 1957							
27- 9	0.001	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	0.001
10	0.033	0.075	0.064	0.090	0.105	0.065	0.432
11	0.012	0.023	0.016	0.039	0.037	0.019	0.146
12	<u>---</u>	0.002	<u>---</u>	0.002	<u>---</u>	0.003	0.007
14	0.001	0.002	0.003	<u>---</u>	<u>---</u>	<u>---</u>	0.006
15	0.004	0.006	0.004	0.002	0.009	<u>---</u>	0.025
16	0.002	<u>---</u>	0.001	0.004	<u>---</u>	<u>---</u>	0.007
17	<u>---</u>	0.002	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	0.002
18	0.001	0.004	0.004	<u>---</u>	0.007	0.004	0.020
19	<u>---</u>	0.002	<u>---</u>	0.004	0.002	0.001	0.009

Appendix 2 Continued

Time	Gage number and weighted inches of rain						Rain Inches
	1	2	3	4	5	6	
20	<u>0.003</u>	<u>0.004</u>	<u>0.006</u>	<u>0.004</u>	<u>---</u>	<u>0.001</u>	<u>0.018</u>
	0.057	0.120	0.098	0.145	0.160	0.093	0.673
May 14-17, 1957							
14-24	0.001	---	---	0.004	---	0.006	0.011
15- 1	0.133	0.177	0.092	0.084	0.048	0.036	0.570
2	---	---	---	---	0.016	---	0.016
3	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	<u>0.002</u>	<u>0.001</u>	<u>0.003</u>
	0.134	0.177	0.092	0.088	0.066	0.043	0.600
May 18-21, 1957							
18-20	0.001	---	---	---	---	---	0.001
21	0.004	0.006	0.003	0.004	0.002	0.004	0.023
22	0.006	0.011	0.006	0.014	0.011	0.006	0.054
23	0.004	0.017	0.018	0.022	0.023	0.025	0.109
24	0.010	0.019	0.013	0.018	0.025	0.016	0.101
19- 1	0.011	0.017	0.013	0.020	0.021	0.013	0.095
2	0.002	0.006	0.007	0.008	0.011	0.007	0.041
3	0.012	0.019	0.011	0.014	0.011	0.007	0.074
4	0.003	0.010	0.006	0.005	0.002	0.007	0.034
5	0.022	0.044	0.036	0.053	0.066	0.043	0.264
6	0.014	0.029	0.020	0.024	0.021	0.014	0.122
7	0.014	0.029	0.020	0.024	0.018	0.019	0.124
8	0.017	0.027	0.020	0.024	0.021	0.016	0.125

Appendix 2 Continued

Time	Gage number and weighted inches of rain						Rain Inches
	1	2	3	4	5	6	
9	0.005	0.011	0.009	0.012	0.009	0.007	0.053
10	0.014	0.021	0.014	0.027	0.032	0.023	0.131
11	0.008	0.019	0.014	0.020	0.018	0.012	0.091
12	0.012	0.019	0.014	0.022	0.023	0.013	0.103
13	0.006	0.015	0.009	0.014	0.018	0.013	0.075
14	0.003	0.004	0.004	0.004	0.005	0.035	0.055
15	0.002	0.004	0.001	0.006	0.005	---	0.018
16	0.002	0.004	0.001	0.002	0.002	0.003	0.014
17	0.002	0.002	0.001	0.004	0.002	0.003	0.014
18	0.001	0.004	0.003	0.004	0.005	0.001	0.018
19	0.004	0.004	0.001	0.004	0.002	0.004	0.019
20	0.001	0.002	0.001	0.004	0.005	0.003	0.016
21	0.001	0.002	0.003	0.002	0.002	0.007	0.017
22	0.001	---	---	---	0.002	---	0.003
23	0.001	---	---	---	---	---	0.001
24	---	---	---	0.002	---	---	0.002
	0.183	0.345	0.248	0.358	0.362	0.301	1.797

July 4-7, 1957

24-18	0.034	0.076	0.063	0.029	0.043	0.043	0.288
19	0.075	0.097	0.092	0.296	0.263	0.193	1.016
20	<u>0.047</u>	<u>0.097</u>	<u>0.081</u>	<u>0.165</u>	<u>0.232</u>	<u>0.160</u>	<u>0.782</u>
	0.156	0.270	0.236	0.490	0.538	0.396	2.086



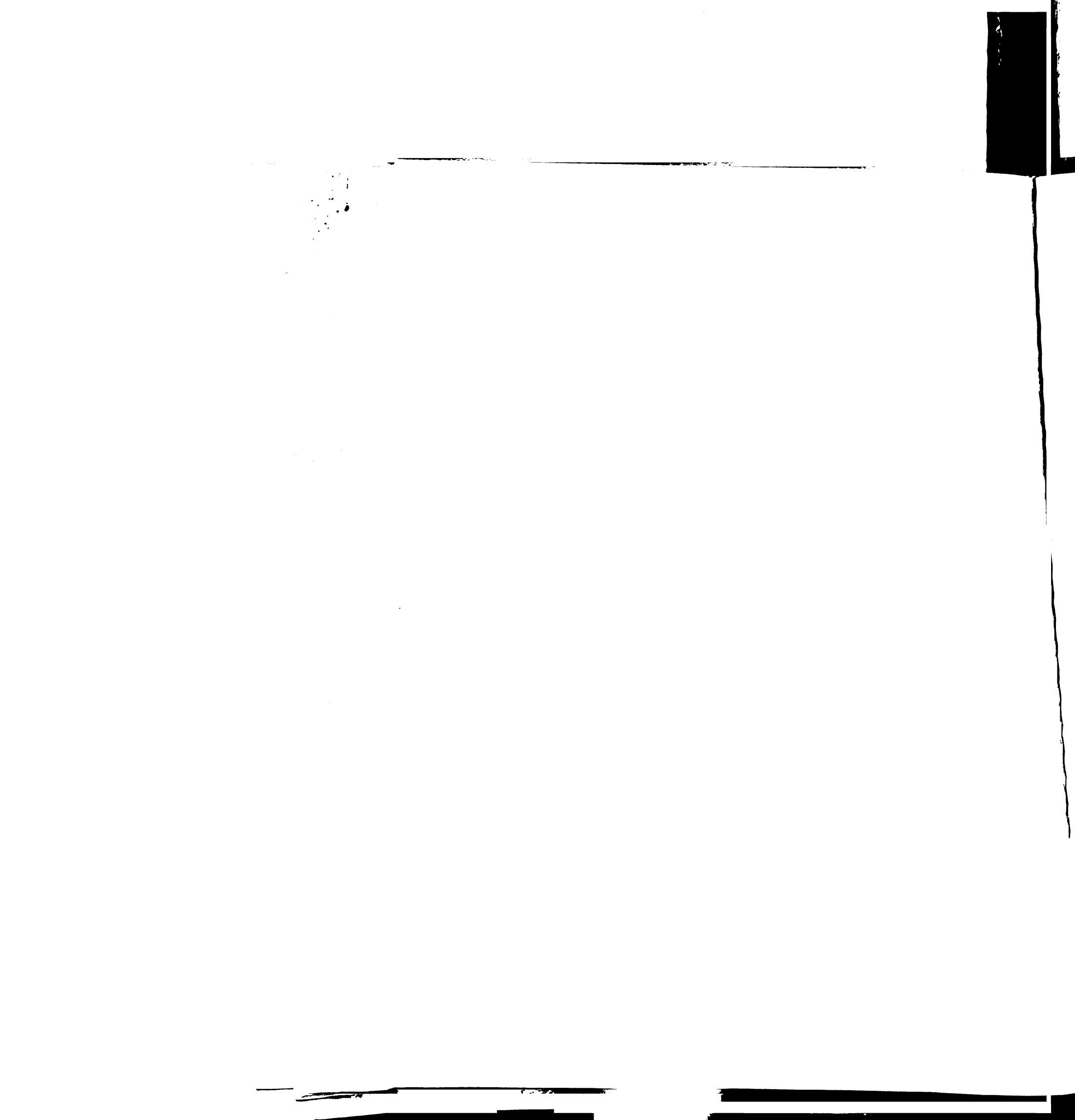
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Appendix 2 Continued

Time	Gage number and weighted inches of rain						Rain
	1	2	3	4	5	6	Inches
July 8-11, 1957							
8- 5	0.001	---	---	---	---	---	0.001
6	0.029	0.025	0.009	0.016	0.009	0.001	0.089
7	0.073	0.149	0.094	0.135	0.142	0.094	0.687
8	0.011	0.027	0.017	0.024	0.037	0.022	0.138
9	0.011	0.019	0.014	0.026	0.030	0.019	0.119
10	0.015	0.029	0.020	0.033	0.034	0.025	0.156
11	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	<u>---</u>	<u>0.003</u>	<u>0.003</u>
	0.140	0.249	0.154	0.234	0.252	0.164	1.193
July 11-14, 1957							
11- 2	0.001	---	0.004	---	---	0.010	0.015
3	0.033	0.101	0.031	0.041	0.034	0.022	0.262
4	0.009	0.035	0.068	0.096	0.092	0.048	0.348
6	0.003	0.008	---	---	---	---	0.011
7	0.007	0.029	0.026	0.029	0.032	0.043	0.166
8	0.010	0.019	0.018	0.035	0.057	0.029	0.168
15	0.004	0.010	---	---	---	---	0.014
16	0.119	0.193	0.099	0.141	0.130	0.073	0.755
17	0.087	0.208	0.121	0.196	0.206	0.092	0.910
18	0.066	0.115	0.078	0.133	0.137	0.066	0.595
19	0.017	0.025	0.043	0.075	0.076	0.049	0.285
20	0.004	0.002	0.001	0.004	0.005	---	0.016



Appendix 2 Continued

Time	Gage number and weighted inches of rain						Rain Inches
	1	2	3	4	5	6	
12-18	0.009	0.008	0.011	0.006	0.005	0.003	0.042
19	---	---	0.001	0.004	0.002	0.001	0.008
21	0.002	0.010	0.007	0.008	0.009	0.003	0.039
22	0.004	0.011	0.007	0.012	0.011	0.007	0.052
23	---	---	---	0.004	---	---	0.004
	0.375	0.774	0.515	0.784	0.796	0.446	3.690
November 14-17, 1957							
14- 5	0.004	0.006	0.006	0.008	0.005	0.004	0.033
6	0.008	0.019	0.009	0.020	0.027	0.010	0.093
7	0.004	0.015	0.006	0.010	0.011	0.007	0.053
8	0.006	0.006	0.009	0.014	0.014	0.012	0.061
9	0.008	0.015	0.009	0.022	0.023	0.012	0.089
10	0.015	0.031	0.018	0.031	0.037	0.021	0.153
11	0.006	0.015	0.007	0.012	0.018	0.010	0.068
12	0.009	0.021	0.009	0.024	0.025	0.016	0.104
13	0.005	0.010	0.007	0.014	0.011	0.007	0.054
14	0.001	0.002	0.001	0.002	---	0.001	0.007
15	0.004	0.011	0.006	0.010	0.014	0.007	0.052
16	0.003	0.006	0.004	0.002	0.005	0.001	0.021
17	0.002	0.006	0.003	0.008	0.005	0.006	0.030
18	0.004	0.008	0.007	0.018	0.014	0.004	0.055
19	0.007	0.015	0.011	0.037	0.034	0.017	0.121

Appendix 2 Continued

Time	Gage number and weighted inches of rain						Rain Inches
	1	2	3	4	5	6	
20	0.004	0.013	0.014	0.027	0.021	0.013	0.092
21	0.003	0.004	0.003	0.010	0.009	0.001	0.030
22	<u>0.001</u>	<u>0.002</u>	---	<u>0.006</u>	---	---	<u>0.009</u>
	0.094	0.205	0.129	0.275	0.273	0.149	1.125
April 6-9, 1958							
6-17	0.012	0.027	0.023	0.037	0.092	0.065	0.256
18	0.029	0.044	0.041	0.051	0.069	0.035	0.269
19	0.012	0.029	0.020	0.027	0.023	0.019	0.130
20	0.003	0.002	0.006	0.012	0.009	0.006	0.038
21	0.006	0.010	0.007	0.018	0.009	0.007	0.057
22	0.002	0.008	0.006	0.010	0.007	0.007	0.040
23	0.002	0.006	0.004	0.002	0.002	0.004	0.020
24	<u>0.001</u>	<u>0.002</u>	---	<u>0.002</u>	<u>0.002</u>	<u>0.001</u>	<u>0.008</u>
	0.067	0.128	0.107	0.159	0.213	0.144	0.818

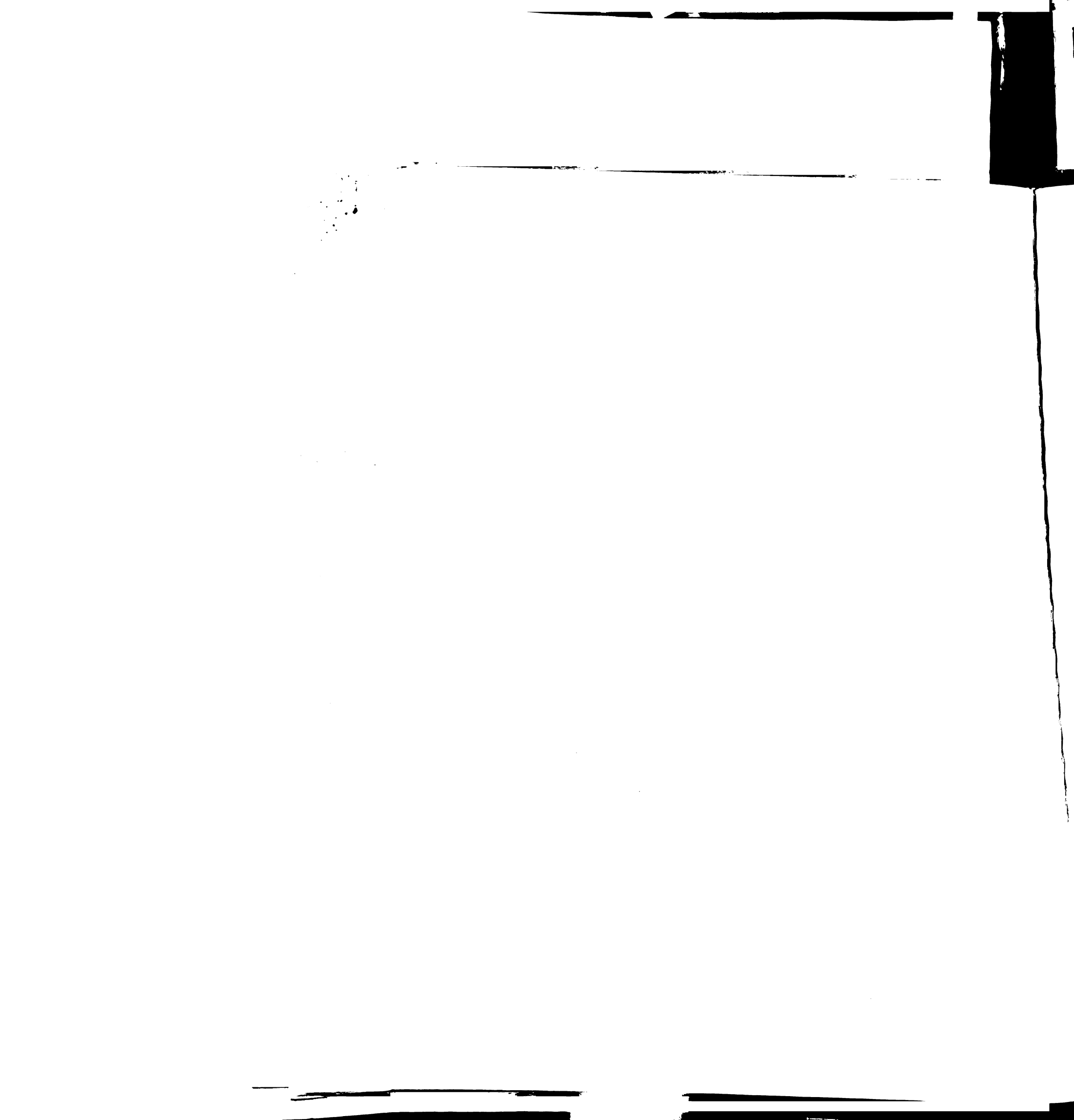
Appendix 2 Continued

Time	Gage number with listing of weighted inches of rainfall										Main Inches
	1	2	3	4	5	6	18	19	21		
July 28-31, 1958											
28-14	0.042	0.054	0.099	0.092	0.102	0.077	0.020	0.078	0.007	0.571	
15	0.016	0.077	0.092	0.136	0.106	0.082	0.037	0.062	0.021	0.629	
16	---	---	---	<u>0.003</u>	---	---	---	---	---	<u>0.003</u>	
	0.058	0.131	0.191	0.231	0.208	0.159	0.057	0.140	0.028	1.203	
May 23-26, 1959											
23- 1	0.002	0.003	0.005	0.003	0.008	0.003	0.001	---	---	0.025	
2	0.003	0.002	0.001	0.003	0.002	0.006	0.002	0.003	---	0.022	
3	0.005	0.008	0.007	0.007	0.010	0.007	0.004	0.003	0.002	0.053	
4	0.011	0.017	0.022	0.025	0.044	0.026	0.010	0.009	0.003	0.167	
5	0.028	0.042	0.061	0.056	0.090	0.055	0.022	0.043	0.012	0.409	
6	0.007	0.010	0.009	0.022	0.031	0.011	0.007	0.019	0.004	0.120	
7	0.006	0.011	0.011	0.015	0.012	0.010	0.005	0.009	0.002	0.081	
8	0.012	0.019	0.020	0.019	0.029	0.021	0.007	0.006	---	0.133	
9	<u>0.001</u>	<u>0.002</u>	<u>0.005</u>	<u>0.016</u>	<u>0.010</u>	<u>0.003</u>	<u>0.003</u>	<u>0.018</u>	<u>0.004</u>	<u>0.062</u>	
	0.075	0.114	0.141	0.166	0.236	0.142	0.061	0.110	0.027	1.072	



Appendix 2 Continued

Time	1	2	3	4	5	6	18	19	21	Rain Inches
August 16-19, 1959										
16-15	0.053	0.107	0.108	0.034	---	0.011	0.033	0.014	---	0.360
16	0.050	0.070	0.075	0.047	0.037	0.038	0.044	0.058	0.003	0.422
17	<u>0.002</u>	<u>0.003</u>	<u>0.004</u>	<u>0.007</u>	<u>0.010</u>	<u>0.006</u>	<u>0.001</u>	<u>0.022</u>	---	<u>0.055</u>
	0.105	0.180	0.187	0.088	0.047	0.055	0.078	0.094	0.003	0.837
September 21-24, 1959										
21-18	0.073	0.078	0.060	0.077	0.069	0.062	0.050	0.051	0.003	0.523
19	0.010	0.021	0.041	0.065	0.083	0.044	0.009	0.038	0.011	0.322
20	0.003	0.018	0.017	0.031	0.040	0.028	0.003	0.013	0.005	0.158
21	0.009	0.018	0.024	0.044	0.031	0.030	0.008	0.033	0.005	0.202
22	0.006	0.009	0.010	0.012	0.015	0.011	0.005	0.009	0.002	0.079
23	0.004	0.013	0.026	0.010	0.040	0.051	0.004	0.002	0.002	0.152
24	<u>0.022</u>	<u>0.041</u>	<u>0.034</u>	<u>0.064</u>	<u>0.044</u>	<u>0.023</u>	<u>0.020</u>	<u>0.050</u>	<u>0.005</u>	<u>0.303</u>
	0.127	0.198	0.212	0.303	0.322	0.249	0.099	0.196	0.033	1.739
October 6-9, 1959										
6-2	---	0.001	---	0.001	0.002	0.001	0.001	---	0.001	0.007



Appendix 2 Continued

Time	Gage number with listing of weighted inches of rainfall										Rain Inches
	1	2	3	4	5	6	18	19	21		
3	0.002	---	0.002	0.003	0.002	0.004	0.002	0.001	0.001	0.017	0.017
4	0.044	0.080	0.096	0.124	0.125	0.124	0.037	0.026	0.011	0.667	0.667
5	0.036	0.067	0.085	0.124	0.121	0.087	0.031	0.100	0.017	0.668	0.668
6	0.014	0.020	0.019	0.037	0.046	0.041	0.010	0.058	0.006	0.251	0.251
7	0.001	0.002	0.004	0.015	0.021	0.011	0.001	0.010	0.002	0.067	0.067
8	0.004	0.007	0.012	0.028	0.042	0.040	0.003	0.011	0.006	0.153	0.153
9	0.009	0.017	0.019	0.038	0.052	0.017	0.008	0.019	0.006	0.185	0.185
10	0.014	0.011	0.011	0.015	0.017	0.011	0.010	0.008	0.003	0.100	0.100
11	0.017	0.029	0.048	0.022	0.037	0.065	0.014	0.008	0.003	0.243	0.243
12	0.034	0.064	0.069	0.139	0.160	0.087	0.025	0.071	0.020	0.669	0.669
13	0.004	0.004	0.002	0.013	0.015	0.004	0.002	0.031	0.005	0.080	0.080
17	---	---	0.010	---	---	0.014	---	0.001	---	0.025	0.025
18	0.011	0.014	0.011	0.019	0.025	0.004	0.008	0.008	0.003	0.103	0.103
7-5	---	0.002	0.002	0.003	0.002	---	0.001	---	---	0.010	0.010
6	---	---	---	0.004	0.004	0.001	---	0.002	---	0.011	0.011
9	---	0.001	---	---	---	0.003	0.001	---	---	0.005	0.005

Appendix 2 Continued

Time	Gage number with listing of weighted inches of rainfall										Main Inches
	1	2	3	4	5	6	18	19	21		
10	---	0.002	---	0.001	---	---	0.001	0.001	---	0.005	
11	0.002	0.001	0.004	---	---	---	---	---	---	0.007	
12	---	---	<u>0.001</u>	---	---	---	<u>0.001</u>	<u>0.002</u>	---	<u>0.004</u>	
	0.192	0.322	0.395	0.586	0.671	0.514	0.156	0.357	0.084	3.277	
November 4-7, 1959											
4- 6	0.004	0.006	0.005	0.007	0.010	0.006	0.004	0.001	0.001	0.044	
7	0.003	0.004	0.005	0.007	0.002	0.004	0.002	0.002	0.001	0.030	
8	0.007	0.011	0.012	0.015	0.021	0.013	0.007	0.007	0.002	0.095	
9	0.011	0.017	0.016	0.024	0.027	0.021	0.008	0.016	0.004	0.144	
10	0.023	0.035	0.041	0.052	0.071	0.051	0.017	0.018	0.006	0.314	
11	0.013	0.021	0.030	0.021	0.025	0.020	0.013	0.040	0.007	0.190	
12	0.006	0.009	0.007	0.013	0.010	0.008	0.005	0.009	0.002	0.069	
13	0.001	0.001	0.001	0.003	0.002	0.001	0.005	0.004	0.002	0.020	
17	0.001	0.001	0.005	0.003	---	0.001	---	---	---	0.011	
18	0.001	0.001	---	0.001	---	0.001	0.001	0.001	---	0.006	
21	<u>0.001</u>	<u>0.001</u>	<u>0.002</u>	<u>0.006</u>	<u>0.010</u>	<u>0.003</u>	<u>0.001</u>	<u>0.003</u>	<u>0.001</u>	<u>0.028</u>	
	0.071	0.107	0.124	0.152	0.178	0.129	0.063	0.101	0.026	0.951	

Appendix 2 Continued

Time	Gage number with listing of weighted inches of rainfall										Rain	
	1	2	3	4	5	6	18	19	21	21	Inches	Inches
December 11-14, 1959												
11-11	0.004	0.007	0.006	0.007	0.006	0.006	0.002	0.001	0.001	0.001	0.040	0.040
12	0.006	0.010	0.011	0.012	0.015	0.008	0.004	0.010	0.002	0.002	0.078	0.078
13	0.004	0.005	0.007	0.009	0.010	0.007	0.004	0.008	0.002	0.002	0.056	0.056
14	0.006	0.010	0.009	0.009	0.015	0.011	0.005	0.007	0.001	0.001	0.073	0.073
15	0.004	0.007	0.010	0.015	0.021	0.016	0.004	0.010	0.003	0.003	0.090	0.090
16	0.007	0.010	0.010	0.015	0.019	0.014	0.005	0.011	0.002	0.002	0.093	0.093
17	0.004	0.007	0.007	0.012	0.012	0.008	0.004	0.010	0.002	0.002	0.066	0.066
18	0.004	0.005	0.006	0.009	0.010	0.010	0.003	0.007	0.002	0.002	0.056	0.056
19	0.006	0.007	0.006	0.007	0.010	0.007	0.004	0.007	0.001	0.001	0.055	0.055
20	0.003	0.003	0.004	0.006	0.008	0.003	0.002	0.004	0.001	0.001	0.034	0.034
21	0.001	0.003	0.001	0.004	0.002	0.004	0.001	0.004	---	---	0.020	0.020
22	0.001	0.002	0.001	0.004	0.002	---	0.001	0.001	---	---	0.012	0.012
23	0.001	0.001	0.001	---	0.002	0.001	0.001	---	---	---	0.007	0.007
24	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	---	---	0.009	0.009
12- 1	0.001	0.001	0.001	0.001	0.002	0.003	0.001	0.001	---	---	0.011	0.011

Appendix 2 Continued

Time	Gage number with listing of weighted inches of rainfall										Rain Inches
	1	2	3	4	5	6	18	19	21		
2	0.001	0.001	0.002	0.004	0.002	0.001	0.001	0.001	---	0.013	
11	---	---	0.001	0.001	0.002	---	---	0.001	---	0.005	
12	---	---	---	0.003	---	0.001	---	---	---	0.004	
13	0.001	---	---	0.001	0.002	---	---	---	---	0.004	
14	---	---	---	0.003	0.002	0.001	---	---	---	0.006	
	0.055	0.080	0.084	0.123	0.144	0.102	0.043	0.084	0.017	0.732	
January 12-15, 1960											
12- 5	0.001	0.003	0.004	0.003	0.002	0.001	0.003	0.001	---	0.018	
6	0.004	0.009	0.009	0.010	0.012	0.007	0.006	0.008	0.001	0.066	
7	0.007	0.012	0.011	0.016	0.021	0.015	0.007	0.016	0.003	0.108	
8	0.006	0.008	0.007	0.010	0.015	0.011	0.005	0.011	0.002	0.075	
9	0.004	0.006	0.005	0.007	0.008	0.006	0.004	0.006	0.001	0.047	
10	0.004	0.005	0.006	0.007	0.008	0.007	0.002	0.004	0.001	0.044	
11	0.006	0.009	0.012	0.015	0.021	0.014	0.002	0.006	0.002	0.087	
12	0.006	0.011	0.011	0.016	0.021	0.015	0.005	0.011	0.003	0.099	
13	0.007	0.008	0.010	0.012	0.017	0.010	0.005	0.011	0.002	0.082	

Appendix 2 Continued

Time	Gage number with listing of weighted inches of rainfall										Rain	
	1	2	3	4	5	6	18	19	21		Inches	
14	0.005	0.009	0.007	0.012	0.010	0.010	0.006	0.010	0.002		0.071	
15	0.005	0.007	0.009	0.009	0.017	0.010	0.003	0.003	0.002		0.065	
16	0.004	0.009	0.007	0.010	0.012	0.008	0.005	0.011	0.002		0.068	
17	0.004	0.008	0.011	0.013	0.019	0.014	0.004	0.008	0.002		0.083	
18	0.005	0.007	0.006	0.009	0.010	0.007	0.003	0.006	0.001		0.054	
19	0.002	0.003	0.002	0.007	0.008	0.006	0.002	0.004	0.001		0.035	
20	0.003	0.004	0.005	0.007	0.006	0.004	0.003	0.006	0.001		0.039	
21	---	0.001	---	0.001	0.002	---	---	---	---		0.004	
22	---	---	---	0.001	---	0.001	0.001	0.001	---		0.004	
23	0.001	---	0.001	---	0.002	0.001	0.001	---	---		0.006	
24	0.002	0.004	0.007	0.013	0.006	0.004	0.002	0.006	0.001		0.045	
13- 1	0.001	0.003	0.006	0.007	0.015	0.008	0.001	0.001	0.001		0.043	
2	<u>0.002</u>	<u>0.003</u>	<u>0.004</u>	<u>0.007</u>	<u>0.006</u>	<u>0.008</u>	<u>0.001</u>	<u>0.007</u>	<u>0.001</u>		<u>0.039</u>	
	0.079	0.129	0.140	0.192	0.238	0.167	0.071	0.137	0.029		1.182	

Appendix 3 Data for Sloan Creek composite recession curve.

Dis-charge C.F.S.	Date	Dis-charge C.F.S.	Date	Dis-charge C.F.S.	Date	Dis-charge C.F.S.	Date
<u>June 57</u>							
1	4.4						
2	3.4						
3	2.8						
4	2.6						
5	2.3						
6	2.2						
7	2.0						
8	1.8						
9	1.6						
10	1.5						
<u>Nov. 59</u>							
7	14.0						
8	9.0						
9	7.4						
10	6.6						
11	5.8						
12	5.2						
26	3.3						
27	2.9						
28	2.6						
29	2.3						
30	2.0						
1	1.8						
2	1.7						
3	1.6						
4	1.5						
<u>May 57</u>							
20	83						
21	36						
22	24						
23	17						
<u>May 59</u>							
1	9.0						
2	6.6						
3	5.2						
4	4.2						
5	3.5						
6	2.9						
<u>Apr. 59</u>							
11	10.0						
12	7.8						
13	6.7						
14	5.8						
15	5.1						
16	4.4						
17	3.9						
<u>Oct. 59</u>							
11	24						
12	17						
13	13						
14	10						
15	8.6						
16	7.4						
17	6.4						
18	5.8						
19	4.9						
20	4.4						
21	3.9						

Appendix 4 Data for obtaining unit graphs.

The specific procedure for calculating unit graph values is presented in the Analysis and Discussion of Rainfall Data section. The May 14-17, 1957 data are for a $\frac{1}{2}$ hour unit graph, the August 9-12, 1956 and August 16-19, 1959 data are for 1 hour unit graphs, and the July 4-7, 1957 data are for a 2 hour unit graph.

The total flow values as listed under each of these storm periods were essentially all from Appendix 1 data and thus list values above 10 cfs only to the nearest whole cfs. The base flow data were all from the respective hydrograph figures, therefore were read to the nearest 0.1 cfs. The tenths were maintained under the surface runoff column because this column had to be proportionally increased to 1 inch of runoff which required a large magnification in most cases.

Appendix 4 Data for obtaining unit graphs.

Time	Total flow CFS	Base flow CFS	Run- flow off CFS	Unit graph CFS	Time	Total flow CFS	Base flow CFS	Run- flow off CFS	Unit graph CFS
August 9-12, 1956					May 14-17, 1957				
9-12	0.8	0.8	0.0	0	14-24	6.4	6.4	0.0	0
13	2.6	1.0	1.6	7	15- 1	19	6.4	12.6	88
14	16	1.1	14.9	67	2	69	6.4	62.6	438
15	57	1.2	55.8	253	24	79	6.4	72.6	508
16	128	1.3	126.7	574	3	75	6.5	68.5	479
17	107	1.4	105.6	478	6	52	6.6	45.4	318
18	82	1.5	80.5	365	11	31	6.8	24.2	169
19	60	1.6	58.4	264	17	24	7.0	17.0	119
20	53	1.7	51.3	232	24	19	7.2	11.8	83
24	39	2.2	36.8	167	16-12	14	7.6	6.4	45
10-10	26	3.3	22.7	103	24	11	8.0	3.0	21
24	17	4.9	12.1	55	17-12	9	8.3	0.7	5
11-12	12	6.2	5.8	26	15	8.5	8.5	0.0	0
18	9.9	6.9	3.0	14					
23	8.8	7.4	1.4	6					
12- 4	8.0	8.0	0.0	0					



Appendix 4 Continued

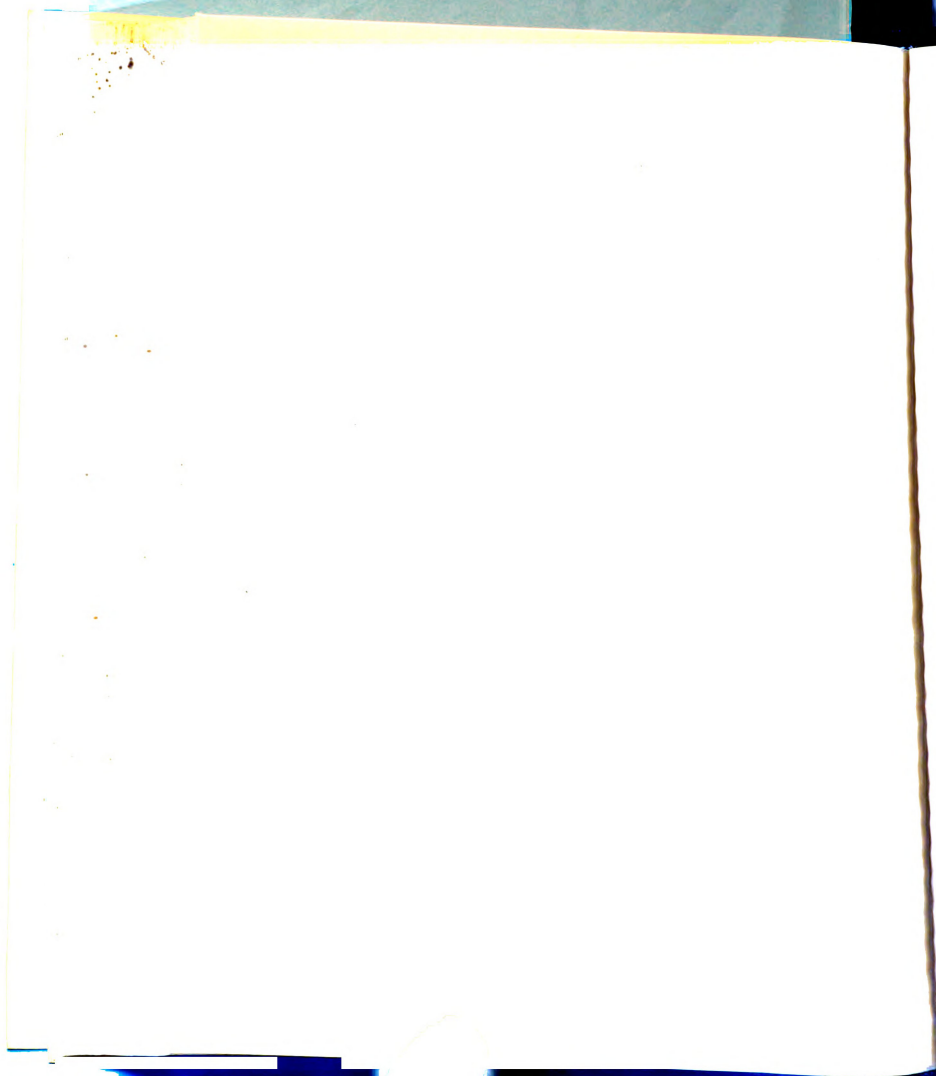
Time	Total flow CFS	Base flow CFS	Run- off CFS	Unit graph CFS	Time	Total flow CFS	Base flow CFS	Run- off CFS	Unit graph CFS
July 4-7, 1957					August 16-19, 1959				
4-18	1.1	1.1	0.0	0	16-14	5.6	5.6	0.0	0
19	2.4	1.2	1.2	4	15	6.6	5.6	1.0	7
20	3.6	1.4	2.2	8	17	40	5.7	34.3	240
21	5.5	1.5	4.0	14	18	51	5.7	45.3	318
22	18	1.6	16.4	57	19	57	5.7	51.3	359
23	82	1.7	80.3	281	20	61	5.8	55.2	387
24	90	1.8	88.2	308	21	57	5.8	51.2	358
5- 1	88	1.9	86.1	301	22	52	5.8	46.2	323
2	83	2.0	81.0	284	24	44	5.9	38.1	267
3	79	2.2	76.8	269	17- 3	34	5.9	28.1	197
7	65	2.8	62.2	218	8	26	6.0	20.0	140
13	48	3.5	44.5	156	12	21	6.0	15.0	105
21	33	4.5	28.5	100	18	16	6.1	9.9	69
24	29	4.8	24.2	85	24	13	6.2	6.8	48
6-10	21	6.2	14.8	52	18-12	9.3	6.4	2.9	20
16	18	7.1	10.9	38	24	7.8	6.6	1.2	8
24	14	8.0	6.0	21	19-12	6.7	6.7	0.0	0
7-12	9.6	9.6	0.0	0					

Continued on next page

Year	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950	2951	2952	2953	2954	2955	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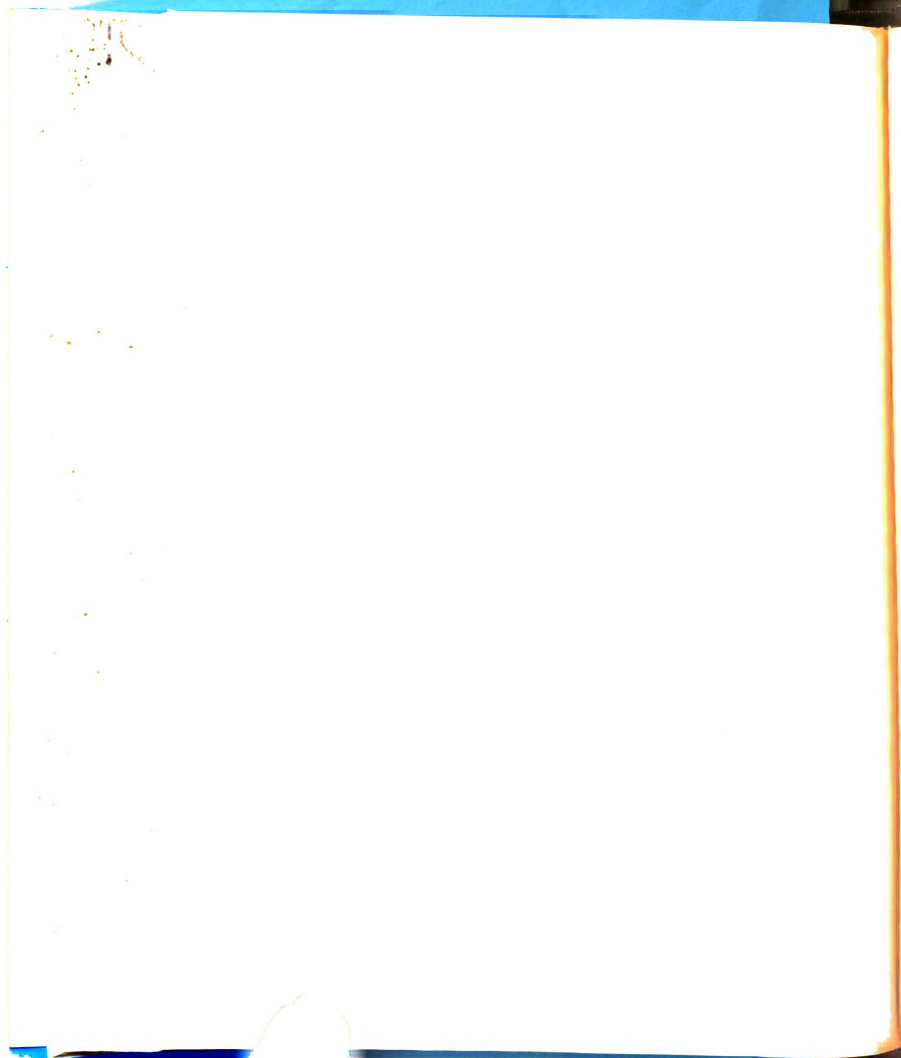
Appendix 5 Data for comparsion of calculted and actual
2 Hr. unit graphs.

Hours from peak	Comp. 1 hour un. gr. C.F.S.	Un. gr. shifted 1 hour C.F.S.	Double 2 hour un. gr. C.F.S.	Calc. 2 hour un. gr. C.F.S.	4-7 July 57 2 hour un. gr. C.F.S.
- 5					0
- 4	0		0	0	4
- 3	10	0	10	5	8
- 2	90	10	100	50	14
- 1	307	90	397	198	57
0	521	307	828	414	281
+ 1	447	521	968	484	308
+ 2	365	447	812	406	301
+ 3	290	365	655	327	284
+ 4	256	290	546	273	269
+ 5	228	256	484	242	255
+ 6	208	228	436	218	240
+ 7	190	208	398	199	229
+ 8	174	190	364	182	218
+11	148				
+12	139	148	287	143	174
+17	109				
+18	102	109	211	105	123
+24	78				
+25	74	78	152	76	85
+31	54				
+32	50	54	104	52	60
+43	26				
+44	24	26	50	25	30
+49	15				
+50	13	15	28	14	19
+54	9				
+55	7	9	16	8	10
+59	1				
+60	0	1	1	0	0



Appendix 6 Data for comparsion of calculated and actual
hydrographs.

Hours from peak	Comp. unit graph CFS	July 4-7, 1957		Calc. Run off CFS	Act. Run off CFS	Hours from peak
		1st. hour CFS	2nd. hour CFS			
					0	- 6
- 4	0	0		0	1	- 5
- 3	10	2	0	2	2	- 4
- 2	90	15	1	16	4	- 3
- 1	307	52	11	63	16	- 2
0	521	88	36	124	80	- 1
+ 1	447	75	61	136	88	0
+ 2	365	61	53	114	86	+ 1
+ 3	290	49	43	92	81	+ 2
+ 4	256	43	34	77	77	+ 3
+ 5	228	38	30	68	73	+ 4
+ 6	208	35	27	62	69	+ 5
+ 7	190	32	25	57	65	+ 6
+ 8	174	29	22	51	62	+ 7
+ 9	164	28	21	49	59	+ 8
+10	155	26	19	45	56	+ 9
+11	148	25	18	42	53	+10
+12	139	23	17	40	50	+11
+13	133	22	16	38	47	+12



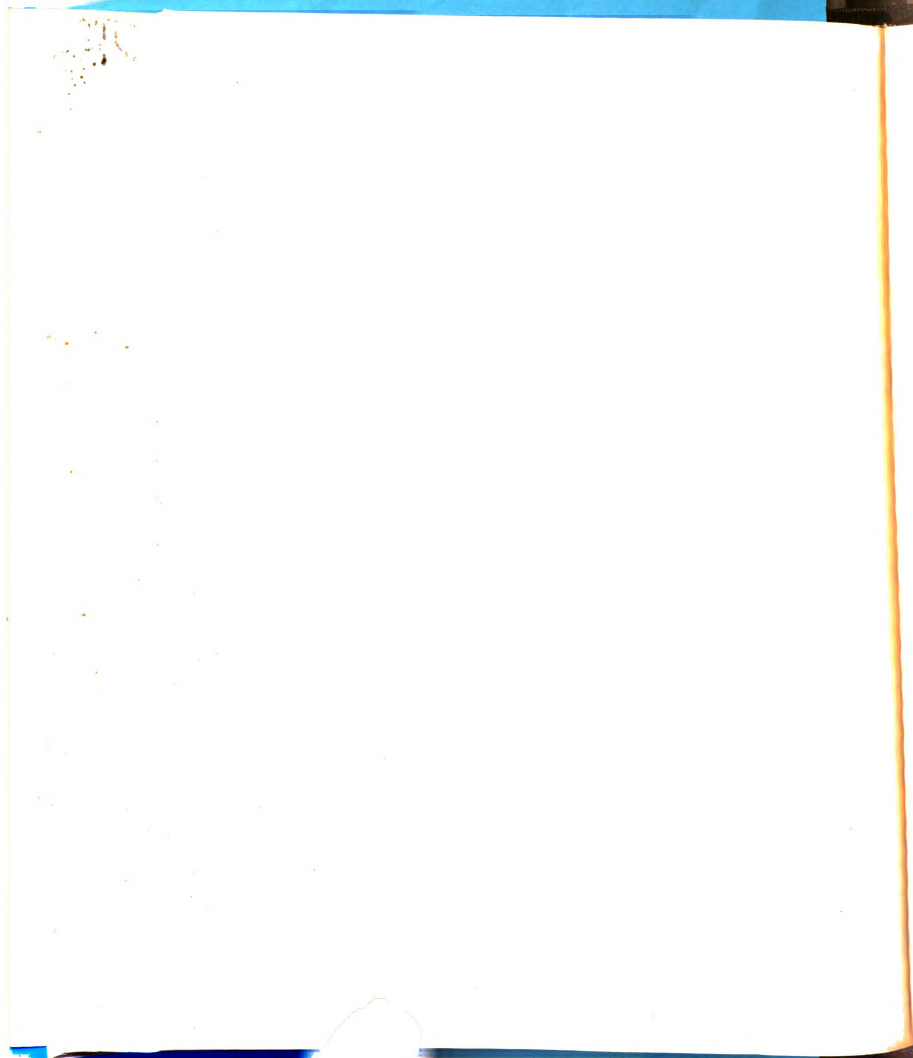
Appendix 6 Continued

Hours from peak	Comp. unit graph CFS	July 8-11, 1957				Calc. Run- off CFS	Act. Run- off CFS	Hours from peak
		1st. hour CFS	2nd. hour CFS	3rd. hour CFS	4th. hour CFS			
							0	- 8
							4	- 7
- 4	0	0				0	26	- 6
- 3	10	1	0			1	29	- 5
- 2	90	12	0	0		12	35	- 4
- 1	307	42	2	0	0	44	45	- 3
0	521	71	7	3	0	81	47	- 2
+ 1	447	61	11	9	3	84	51	- 1
+ 2	365	50	10	15	9	84	54	0
+ 3	290	40	8	13	15	76	52	+ 1
+ 4	256	35	6	11	13	65	49	+ 2
+ 5	228	31	6	8	11	56	47	+ 3
+ 6	208	29	5	7	8	49	45	+ 4
+ 7	190	26	5	7	7	45	44	+ 5
+ 8	174	24	4	6	7	41	42	+ 6
+ 9	164	22	4	6	6	38	40	+ 7
+10	155	21	4	5	6	36	39	+ 8
+11	148	20	3	5	5	33	37	+ 9
+12	139	19	3	5	5	32	36	+10
+13	133	18	3	4	5	30	35	+11

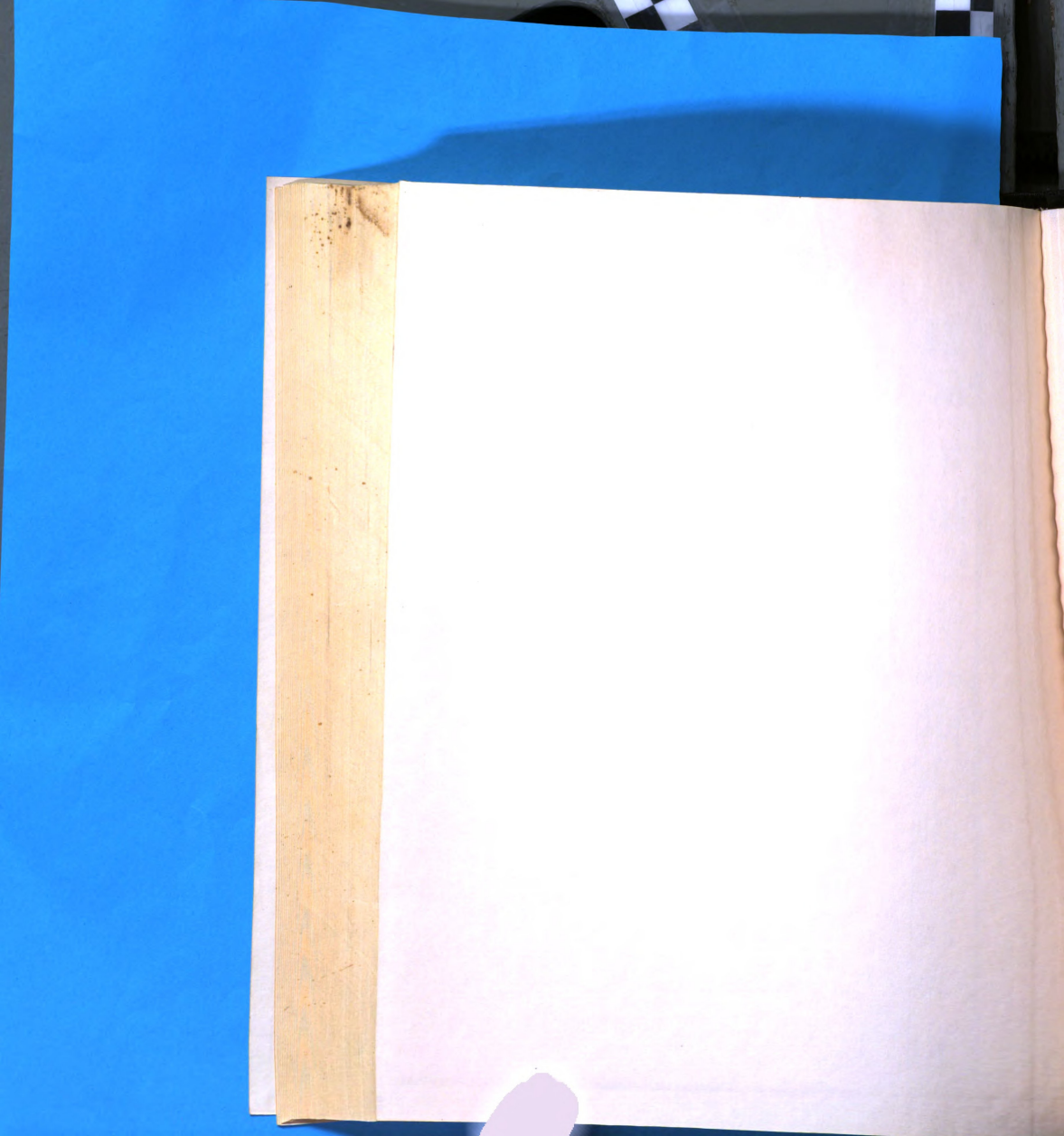


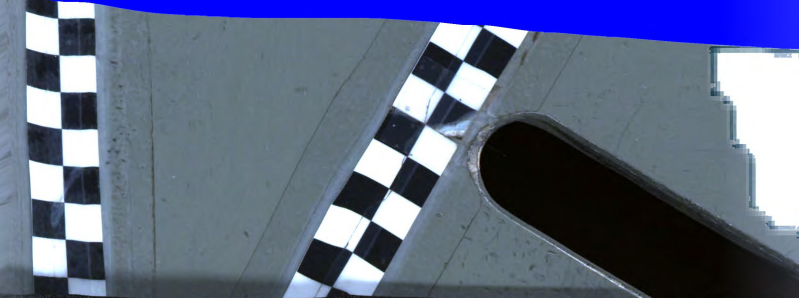
Appendix 6 Continued

Hours from peak	October 6-9, 1959										Calc.		Run-off CFS	Act. CFS	Hours from peak
	Comp. unit CFS	1st. hour CFS	2nd. hour CFS	3rd. hour CFS	4th. hour CFS	5th. hour CFS	6th. hour CFS	7th. hour CFS	8th. hour CFS	9th. hour CFS					
- 3	10	3	0								3	3			-11
- 2	90	26	3	0							29	12			-10
- 1	307	88	26	1	0						115	111			- 9
0	521	150	88	10	0	0					248	237			- 8
+ 1	447	128	150	33	3	1	0				315	249			- 7
+ 2	365	105	128	56	9	6	1	0			305	260			- 6
+ 3	290	83	105	48	15	20	7	0	0		278	274			- 5
+ 4	256	73	83	39	13	34	25	4	1	0	272	311			- 4
+ 5	228	65	73	31	11	30	42	13	9	3	277	372			- 3
+ 6	208	60	65	27	8	24	36	22	32	26	300	407			- 2
+ 7	190	55	60	25	7	19	29	19	55	88	357	419			- 1
+ 8	174	50	55	22	7	17	24	16	47	150	388	464			0
+ 9	164	47	50	21	6	15	21	12	38	128	338	418			+ 1
+10	155	45	47	19	6	14	18	11	30	105	295	379			+ 2
+11	148	43	45	18	5	13	17	10	27	83	261	338			+ 3
+12	139	40	43	17	5	11	15	9	24	73	237	302			+ 4
+13	133	38	40	16	5	11	14	8	22	65	219	273			+ 5









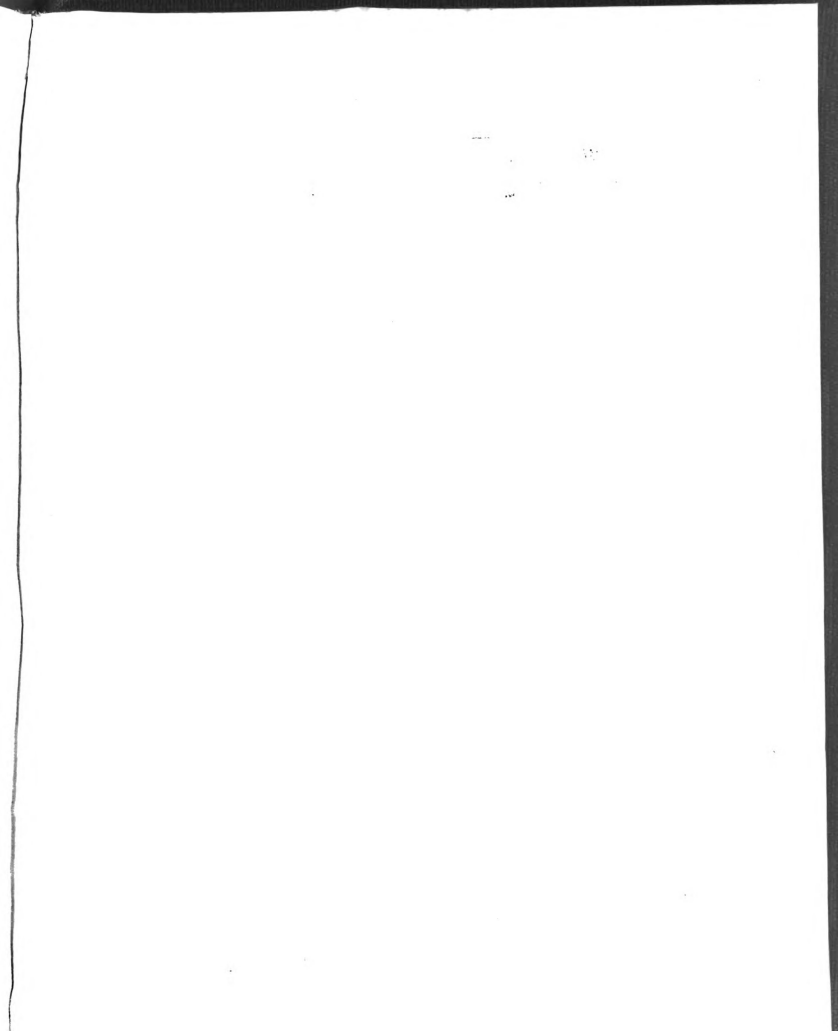
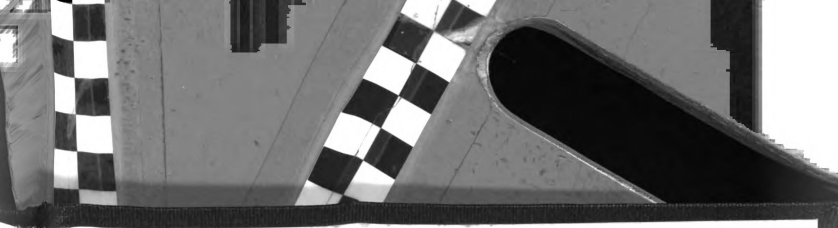
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