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FLOOD POTENTIALITY OF THE SKUNK RIVER AND SQUAW CREEK BASINS AT THEIR CONFLUENCE BELOW AMES, IOWA

by

Richard Marshall Wells

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
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1956

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I. INTRODUCTION

A. Purpose and Objective

The Skunk River and its tributaries occupy a long narrow basin that lies wholly within the State of Iowa. Below the City of Ames, Iowa, Skunk River is joined by Squaw Creek, one of the major tributaries in the upper portion of this basin. The runoff from the 565 square miles of basin area above the confluence of the two streams can greatly influence the river flow for a considerable distance downstream. This is the area that will be considered in this thesis. A map showing the location of this area with respect to the entire Skunk River Basin is shown in Figure 1.

The Skunk River and its tributaries cause an estimated average annual flood damage of $1,810,380 based on 1950 prices (1). Damages to crops and pastures account for $1,660,260 while the remaining $150,120 is due to property damage. Thus, this is a basin that is accustomed to experiencing regular flood damage of sizable magnitude.

Flood damage varies with the area, depth, and duration of flooding. These factors are in turn a function of the quantity of flow in the stream and of the duration of a flow capable of producing flooding for the given valley cross-section. The flood potentiality of a basin is thus determined by the maximum quantity of flow that the basin might

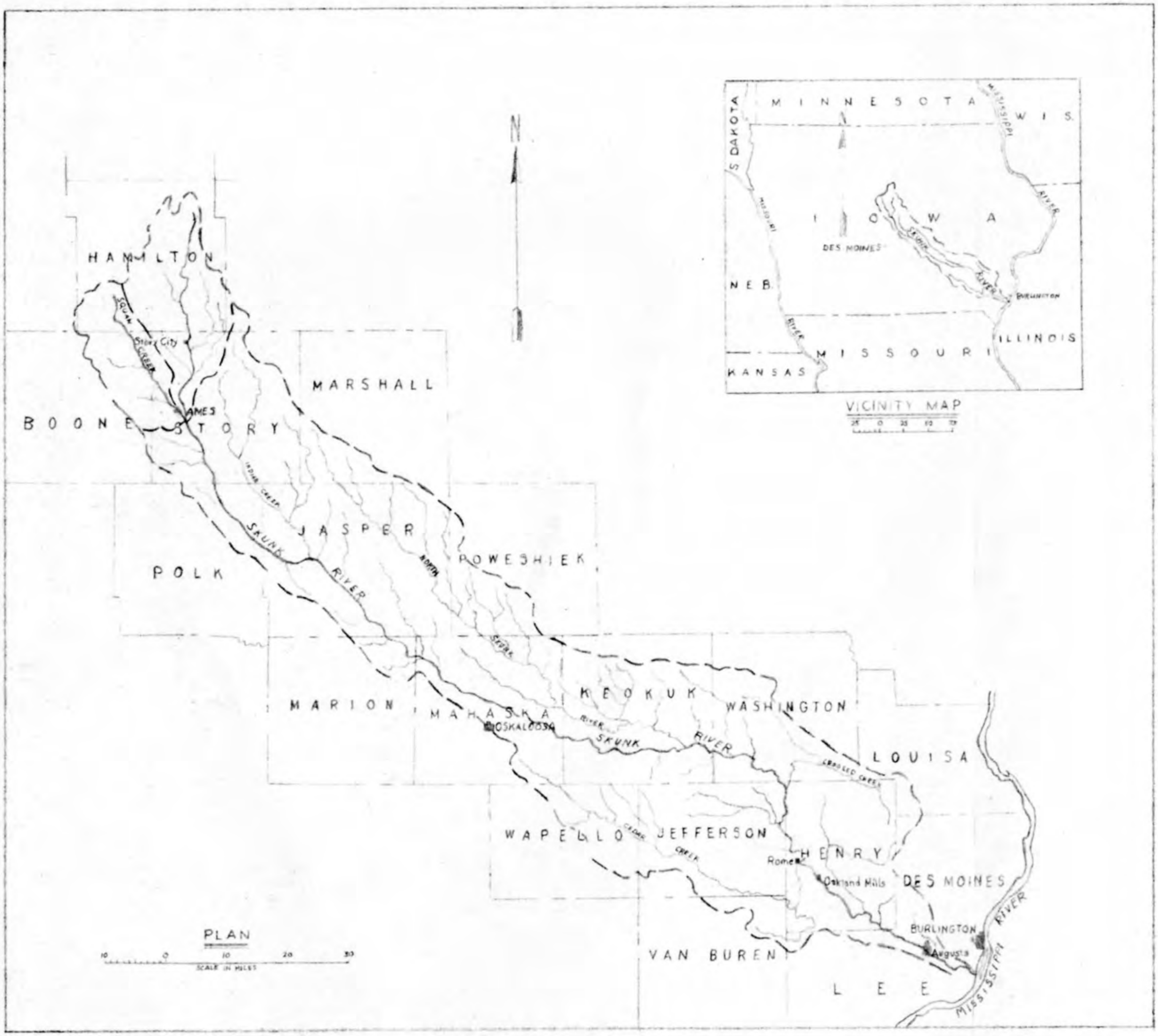

Figure 1. The Skunk River Basin (1)

be expected to produce in the river at the point considered and the period of time which this flow would exceed flood stage.

In addition to the potential for causing floods below the Squaw Creek confluence, these two streams cause flooding in the area around the City of Ames. Of particular interest is the low flat area between the main section of Ames and Iowa State College. If the college were to expand in the future, this would be a probable area for expansion; however, this area is part of the Squaw Creek flood plain and is subject to inundation.

The most generally used and perhaps most logical method of determining the flood potentiality of a basin is that of transposing storms of record over the basin in such a way as to produce maximum rainfall over the basin. In doing this, all rules governing transposition of storms must be followed as will be outlined later in the paper. The objective of this thesis is to determine the flood potentiality of the Skunk River and Squaw Creek Basins at their confluence below Ames, Iowa by transposition of storms of record.

B. Record of Past Floods

Three gaging stations operated by the U. S. Geological Survey have been used to measure streamflow in the area considered (2). The first station was placed on Squaw Creek 1700 feet above the Chicago and Northwestern Railroad bridge in Ames. Discharge records from this staff-gage station which operated from May 1919 to March 1925 are rated as good. From March 1925 to April 1927, the station was located at the Lincoln Highway bridge over Squaw Creek in Ames, two miles above the junction with the Skunk River. Readings at this location were taken with a chain gage and the discharge records are rated as fair. Since April 1927, a record of the flow in Squaw Creek has not been maintained.

The second gaging station is on the Skunk River two and a half miles north of Ames and five miles north of its junction with Squaw Creek. This station, installed in July 1920, operated with a staff-gage until August 1921 and with a water stage recorder thereafter. Between August 1927 and March 1933 the station was not operated; but it has been in continuous operation since that time. In July 1934, a concrete control was installed at the site.

The third gaging station is located on the right bank of the Skunk River one quarter of a mile downstream from Squaw Creek and about fifteen feet downstream from a highway bridge. This station, which was established in October, 1952, uses a water stage recorder and a concrete control. The period of record is too short to be of much use in this study.

Streamflows necessary to produce damaging floods in the two flood plains above their junction and in the flood plain below the junction have been determined (1). Damage occurs in the Skunk River flood plain above the junction, when the flow is greater than 3490 cfs. Damage occurs in the Squaw Creek flood plain, when the flow is greater than 3400 cfs. The Skunk River channel capacity below the mouth of Squaw Creek is only 2400 cfs. Greater flows cause some inundation of unprotected areas.

Tables 1 and 2 show all flood flows recorded at the first two gaging stations. All flows greater than 2400 cfs are recorded since they are of sufficient magnitude to produce flooding in the area below the intersection.

Table 1. Damaging floods on the Squaw Creek at Ames, Iowa, 1919 to 1927 (2)

Year	Flood period	Maximum mean daily discharge cfs	Maximum observed discharge Date	cfs	cfs per sq ft	Maximum observed stage ft
1918			6/4	6,900	32.9	14.5
1922	7/17	3,220	7/17	3,920	18.7	10.4

During the spring and summer of 1954, record streamflow occurred in the area considered. Table 2 shows that the maximum flow on the Skunk River was 8,630 cfs. As would be expected, this flow caused the river to overtop its banks both above and below Ames.

Flooding of the Squaw Creek in the Ames area also occurred in May and August of 1954. The heaviest flooding occurred during the period of 26 August to 28 August. Areas in Ames that were flooded during this period included Brook-

Table 2. Damaging floods on the Skunk River at Ames, Iowa, 1920-1927, 1933-present (2)

Year	Flood period	Maximum mean daily discharge cfs	Maximum observed discharge Date	cfs	cfs per sq mi	Maximum observed stage ft
1921	9/17	2,910	9/17	3,540	11.1	9.20
1943	7/31	2,490	7/31	4,500	14.0	10.33
1944	5/19-5/20	5,650	5/20	8,060	25.0	13.90
1945	6/2	3,070	6/2	4,010	12.4	9.71
1947	6/13	5,450	6/13	5,900	18.3	11.95
1947	6/23	4,350	6/23	4,920	15.3	- -
1949	3/4	1,700	3/4	2,700	8.4	10.52*
1951	3/29	4,600	3/29	5,320	16.5	10.90
1951	6/2	4,360	6/2	4,920	15.3	10.35
1954	6/1	2,380	6/1	3,180	9.9	7.84
1954	6/10-6/11	5,760	6/10	8,630	26.8	13.66
1954	7/27	2,120	7/27	3,520	10.9	8.27

*Stage discharge relation affected by ice.

side Park and the area around South Maple Street. Some overtopping of the stream banks occurred in the area between the City of Ames and Iowa State College. Although the flow was not measured in Squaw Creek at this time, a rough estimate of the magnitude of the flow can be made from readings taken on the Skunk River gages. The gage above Ames recorded a peak of 3,520 cfs at 6:30 P.M. on 27 August while the gage below Ames recorded a peak of 8,700 cfs at 2:30 A.M. on 28 August. These readings would indicate that the flow from Squaw Creek contributing to the gage reading below Ames was between 5,000 and 6,000 cfs. Although this estimate is not accurate, it does give a reasonable basis for future comparisons.

C. Storms Considered

Storms that are useful in determining the flood potentiality of a river basin of this size must have certain characteristics. The transposition of the storm must be feasible. In other words, the area over which the storm occurred and the area to which the storm is to be transposed must be meteorologically homogenious. A storm caused by moist air rising over the Cascade Mountains in the Pacific Northwest would have little significance transposed over Iowa. The Hydrometeorological Section of the U. S. Weather Bureau sets limits of transposition for various major storms of record and will calculate estimates of the percent of the original precipitation that would have occurred in the new location. This will be discussed further in a later section of the thesis.

The storm must be one that will produce unusually heavy precipitation over the area considered. As the area of a basin increases, the average precipitation over the entire area decreases. The 565 square mile area used in this study represents a comparatively small basin, so relatively high values of average storm precipitation could be expected. The storm should also have a high average intensity. A storm that spreads ten inches of rainfall over five days would produce less flooding than one in which ten inches of rainfall fell in one day. During the longer duration, the channel would carry away some of the runoff before the later precipitation arrived.

With these factors in mind, five storms were chosen for transposition over the basin (3). These storms are designated as Storms MR 4-24, UMV 1-22, UMV 2-5, MR 7-2B, and MR 6-15. These designations are those used by the U. S. Army Corps of Engineers. MR storms occurred over the Missouri River Valley. UMV storms occurred over the Upper Mississippi Valley.

The first storm, MR 4-24, occurred in September, 1926 with centers near Boyden and Maurice, Iowa. Figure 2a shows the area of this storm inclosed by the four-inch isohyet. This storm had a effective duration of twenty-four hours, lasting from eight o'clock in the morning on 17 September until eight o'clock in the morning on 18 September. Transposed over the Skunk River and Squaw Creek Basins, this storm produced an average total rainfall of 13.9 inches.

The second storm, UMV 1-22, occurred in August, 1941 with centers at Haywood and Moose Lake, Wisconsin. Figure 2b

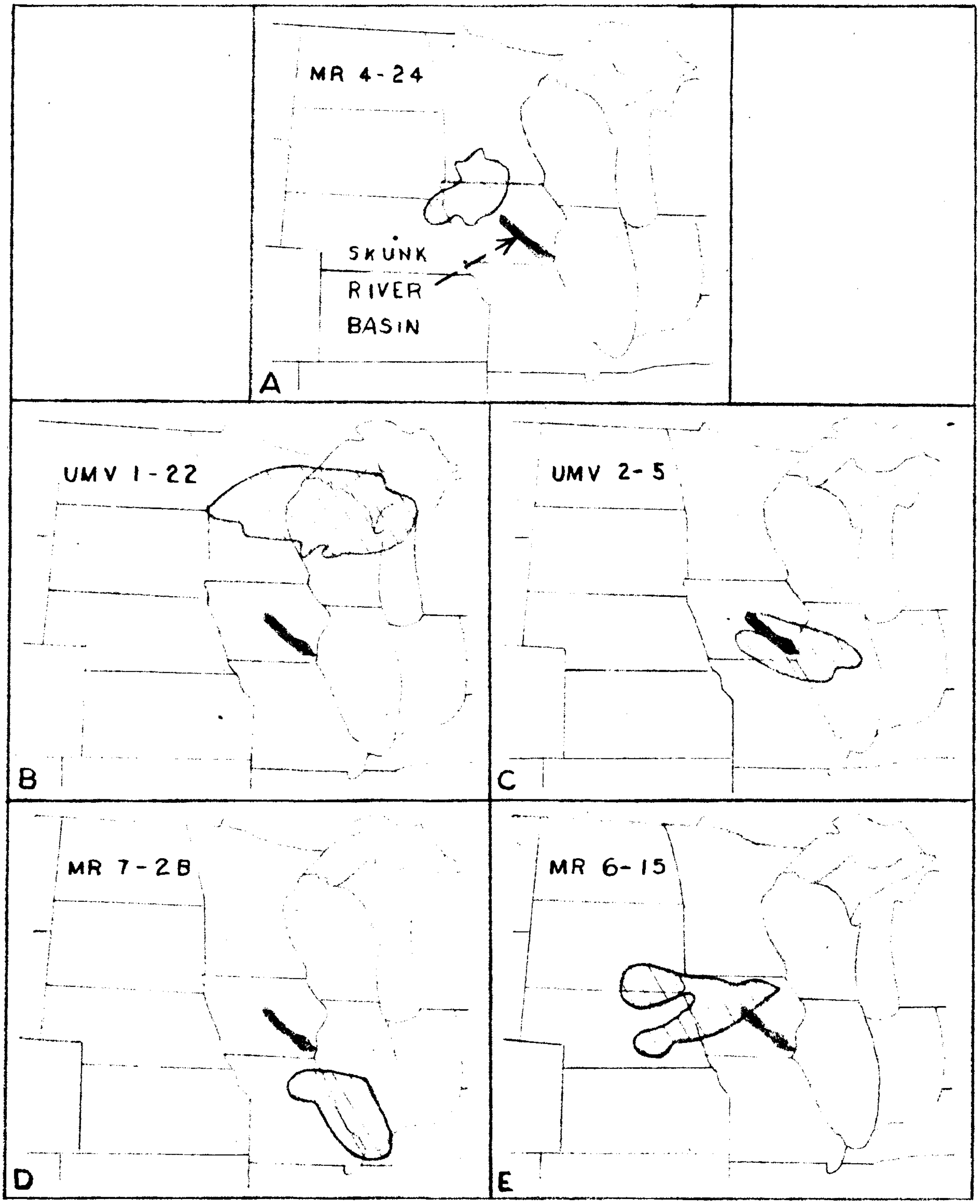

Figure 2. Rainfall maps of Storms MR 4-24, UMV 1-22, UMV 2-5, MR 7-2B, and MR 6-15 (3)

shows the area inclosed by the two-inch isohyet of this storm. Precipitation continued for seventy-eight hours. More than half of the rainfall, however, occurred in a twelve hour period from six o'clock in the afternoon on 29 August to six o'clock in the morning on 30 August. The total storm period was from six o'clock in the morning on 28 August to 12 o'clock noon on 31 August. This storm, when transposed, produced an average total rainfall of 13.6 inches over the basin.

The third storm, UMV 2-5, occurred in June, 1905 with a center near Bonapart, Iowa. Figure 2c shows the area inclosed by the two-inch isohyet of this storm. The storm lasted twelve hours from eight o'clock in the evening on 9 June to eight o'clock in the morning on 10 June. When transposed, it produced an average total rainfall of 9.9 inches over the basin.

The fourth storm, MR 7-2B, occurred with a center near Collinsville, Illinois in August, 1946. The storm had a thirty-six hour duration, lasting from nine o'clock in the evening on 14 August to nine o'clock in the morning on 16 August. The boundary of the storm as marked by the three-inch isohyet is shown in Figure 2d. This storm, when transposed, yielded an average total rainfall of 11.9 inches over the basin.

The last storm, MR 6-15, occurred in June, 1944 with a center near Stanton, Nebraska. Figure 2e shows the area covered by this storm inclosed within the three-inch isohyet.

Effective rainfall lasted twelve hours from six o'clock in the evening on 10 June until six o'clock in the morning on 11 June. After transposition, this storm produced an average total rainfall of 9.5 inches over the basin.

Many people living in the Skunk River Basin in Iowa are familiar with the Floyd River Storm of 8 June, 1953. This storm caused heavy flooding in much of northwestern Iowa. Damages were estimated to be nearly $50,000,000 (4). The damages were heavy due to the fact that the storm was well oriented over the Floyd River Basin and was of heavy intensity. The storm lasted sixteen hours from six o'clock in the morning until ten o'clock at night. Figure 3 shows the total storm isohyetal map of this storm transposed over the Skunk River and Squaw Creek Basins. This transposition yields a total average rainfall over the basin of only 7.9 inches. This is less than that of any of the five storms considered.

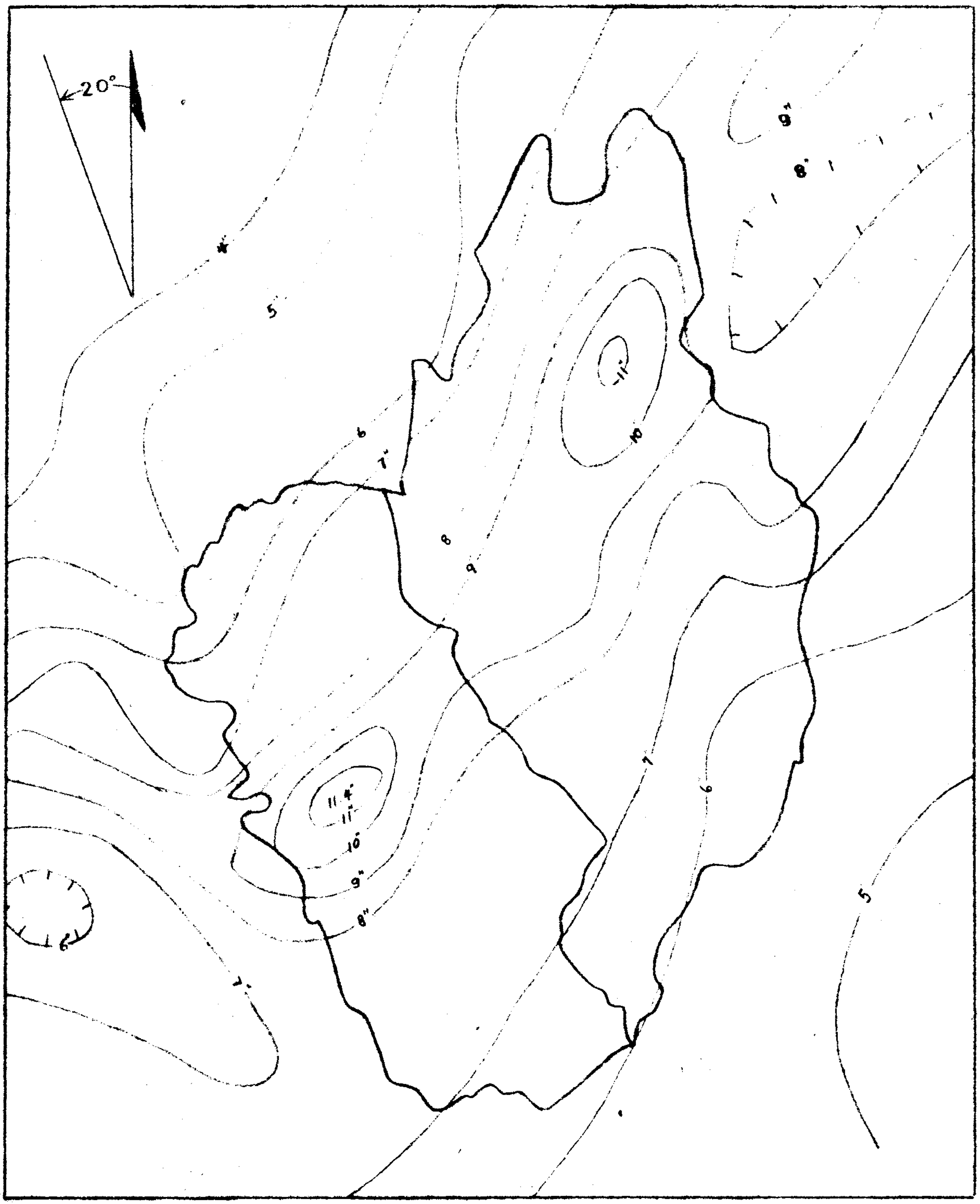

Figure 3. Transposition of the Floyd River Storm of 1953 over the Skunk River Basin above the Squaw Creek junction

II. CHARACTERISTICS OF THE SKUNK RIVER BASIN

A. General

The Skunk River lies in a relatively long, narrow basin that extends from north-central to southeastern Iowa. The basin has an area of 4,325 square miles and is composed of parts of twenty counties in the State of Iowa (1). The basin is approximately 180 miles long, has an average width of 24 miles, and a maximum width of about 40 miles. A map of the basin is shown in Figure 1. The basin lies between the watersheds of the Des Moines River to the southwest and the Iowa River to the northeast.

The source of the Skunk River is in northern Hamilton County, Iowa. From here the river flows approximately 264 miles south and southeast to a point about nine miles below Burlington, Iowa where it discharges into the Mississippi River. The river's total fall from its source to the Mississippi River is about 680 feet. Average stream slopes for the various reaches of the Skunk River are given in Table 3. At low water stage in the Skunk River, water from the Mississippi River backs up the Skunk River about 6.4 miles. The river profile is shown in Figure 4.

The major tributaries of the Skunk River are Big Creek, Cedar Creek, Crooked Creek, North Skunk River, Indian Creek, and Squaw Creek. The drainage areas of the Skunk River and

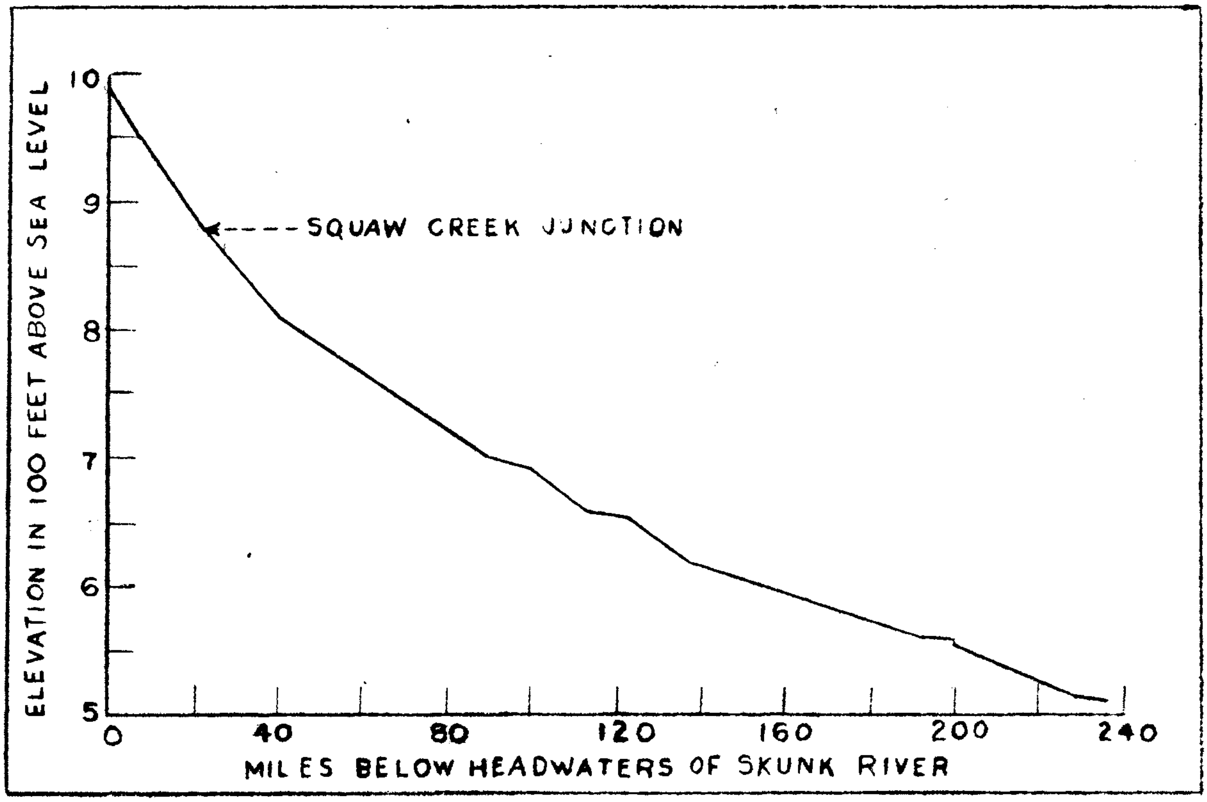

Figure 4. Profile of the Skunk River water surface at low water stage (1)

Table 3. Stream slopes in the Skunk River (1)

Portion of river*	Length in miles	Average slope feet per mile
Miles 231.4 near Story City to mile 213.3, jct. Squaw Creek	18.1	5.0
Mile 213.3 to mile 179.5, jct. Indian Creek	33.8	2.9
Mile 179.5 to mile 154.8	24.7	2.1
Mile 154.8 to mile 138.6, Oskaloosa gage	16.2	1.4
Mile 138.6 to mile 123.2, downstream end of straightened channel	15.4	2.1
Mile 123.2 to mile 38.3, tailwater, Oakland Mills dam	84.9	1.3
Mile 38.3 to mile 6.4, Mississippi River backwater	31.9	1.1

*Distance given in miles above mouth.

its tributaries are shown in Table 4. Cross-sectional dimensions and channel flow capacities at several points within the Skunk River Basin are given in Table 5. The bankful flow was selected as the flow that occurs when the water surface level reaches the adjacent bottom land elevation.

The Skunk River and Squaw Creek Basins above their confluence are shown in Figure 5. This section of the Skunk River Basin has an area of 333 square miles while the Squaw Creek Basin has an area of 232 square miles. Both basins are about three times as long as they are wide. Their combined areas are roughly pear shaped with a maximum length of 38

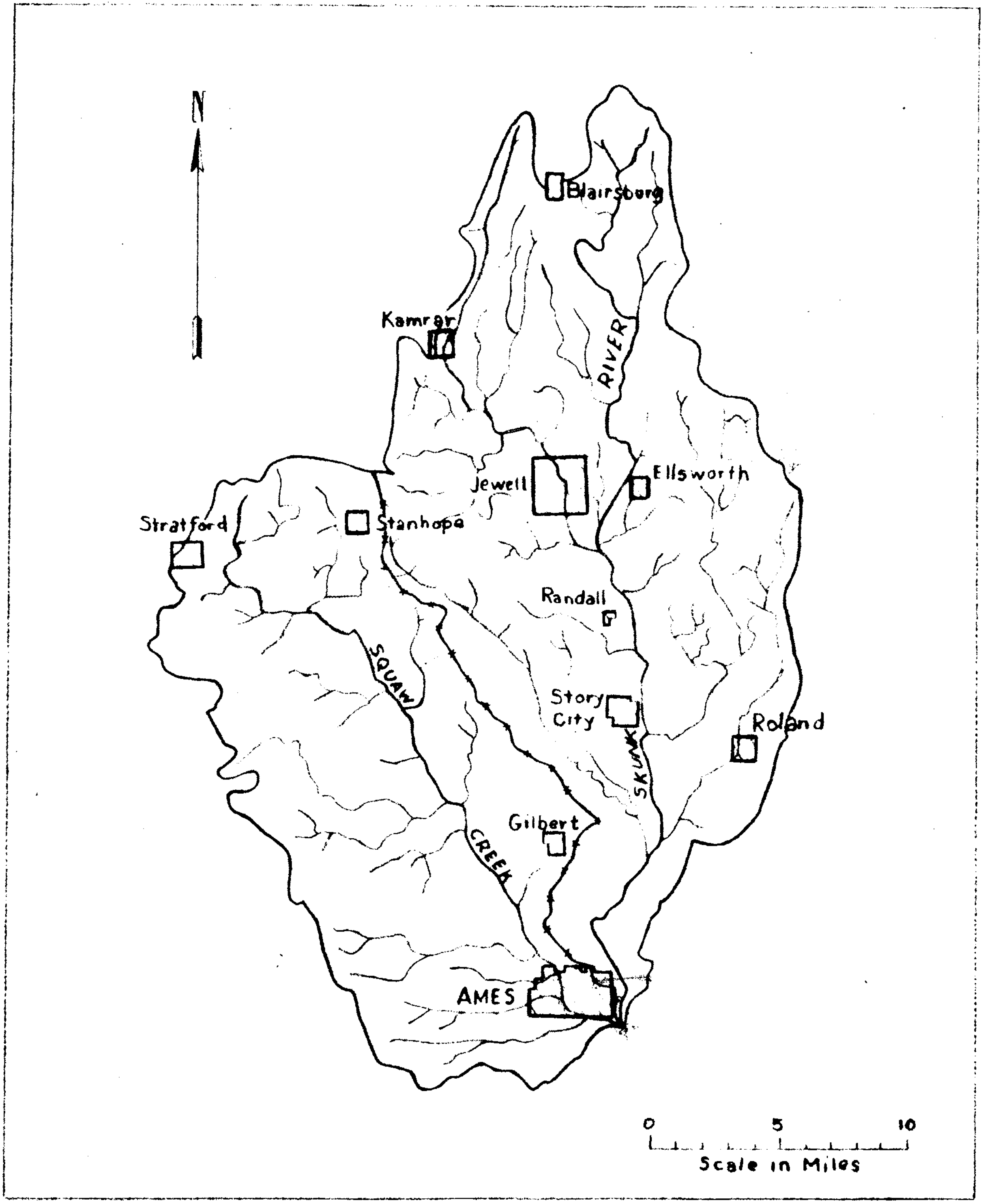

Figure 5. The Skunk River and Squaw Creek Basins above their junction

Table 4. Drainage areas of Skunk River and tributaries (1)

River miles above mouth	Description of point on river	Tributary	Tributary drainage area in sq. mi.	Main-stream drainage area in sq. mi.
0	Jct. Mississippi River	- - -	- -	4,325
12.2	U.S.G.S. gage, Augusta	- - -	- -	4,290
26.8	Below jct. Big Creek	Big Creek	162	4,207
43.1	Below jct. Cedar Creek	Cedar Creek	560	3,980
66.4	Below jct. Crooked Creek	Crooked Creek	284	3,200
93.1	Below jct. North Skunk	North Skunk	860	2,715
104.1*	U.S.G.S. gage, Sigourney	North Skunk	750	- - -
138.6	U.S.G.S. gage, Oskaloosa	- - -	- -	1,640
179.5	Below jct. Indian Creek	Indian Creek	421	1,231
213.3	Below jct. Squaw Creek	Squaw Creek	232	565
216.9*	U.S.G.S. gage, Ames	Squaw Creek	210	- - -
219.0	U.S.G.S. gage, Ames	- - -	- -	322

*Gages located on tributaries.

miles and a maximum width of 25 miles. The two basins have a good drainage net that is both natural and man made. With this favorable shape and drainage net "flashy" runoff hydrographs with quick, high peaks would be expected and do occur. Two small areas where the drainage flows into large depressions have been excluded from the basin drainage area since they do not contribute to surface runoff.

Table 5. Cross-sectional dimensions and channel flow capacities (1)

Cross section location	Miles above mouth	Bankful flow, (cfs)	Cross-sectional area at bankful flow, (sq ft)	Stream width at bankful flow, (ft)	Mean depth, (ft)
Augusta	12.2	17,000	4,610	427	10.8
Oskaloosa	138.6	6,500	3,340	297	11.2
Polk Co.	195.8	4,000	1,480	180	8.2
Story Co.	206.8	2,400	960	143	6.7

B. Topography

From its source the Skunk River flows south in a narrow postglacial valley to a point a few miles north of Ames. Although bluffs rise 75 to 100 feet above the river bed, in the lower five miles of this valley, the remainder of the valley is shallow. The river then enters a preglacial channel which widens below Ames and remains wide through Story, Polk, Jasper, and Marion Counties. From near Ames to Mahaska County, the river which formerly meandered in this reach flows through an artificially straightened channel. This improvement was undertaken piecemeal by local drainage districts. In much of the straightened reach, the stream has reestablished a meandering course within the bed of the channel by undercutting banks and depositing bars. In Keokuk, Washington, Jefferson, and Henry Counties the river meanders through a narrow valley and near Rome enters a narrow, steep-walled, postglacial valley. This valley continues to a point a few miles below Augusta where it widens and then merges with the flood plain of the Mississippi River.

In the upper third of the basin, the topography is gently rolling with shallow valleys except where streams cross morainal features. The natural drainage in this area is poor, but runoff is accelerated by artificial drainage. In the lower two-thirds of the basin, the topography is mature, characterized by gently sloping, interstream areas and steep slopes near the watercourses. Relatively wide flood plains have developed in the preglacial valleys; whereas, the postglacial valleys are narrow and sometimes rock-floored. The flood plain is widest and flood damages are generally greatest in the reach between Ames and the mouth of Indian Creek.

Squaw Creek flows in a southeastly direction from its source in southwestern Hamilton County until it joins the Skunk River below Ames. The upper valley is narrow and shallow. In Story County the valley becomes somewhat deeper and wider.

C. Geology

Bedrock beneath most of the Skunk River Basin is of the Des Moines series of the Pennsylvanian system which is chiefly shale but which contains some sandstones, limestones, and coal. Limestones of the Mississippian system outcrop along the valley walls of the Skunk River about Ames, as well as at many places downstream.

Materials were deposited on the basin during three glacial stages. Most of the basin is covered by Kansan drift, which in the lower part of the basin is covered by the Illinoisan glacial deposits. The upper third of the basin is covered by Cary and Mankato deposits. The Cary and Mankato are substages of the youngest glacial stage, the Wisconsin. The Kansan and Illinoisan drift is covered by a blanket of loess.

Deposits from the Cary and Mankato cover both the Skunk River and Squaw Creek Basins above the confluence of the two waterways. In the uplands of this area, the thickness of the Wisconsin and Kansan till varies considerably, reaching a hundred feet or more. These tills consist of stiff, heavy clay mixed with pebbles and boulders and with occasional lenses of sand. Borings in the postglacial valley of the Skunk River above Ames reveal a few feet of silt, about 30 feet of sand and gravel, and then Mississippian limestone (1). The Squaw Creek Valley is superimposed upon a pre-Wisconsin valley. Borings in this valley floor reveal a thin layer of silt, about 40 feet of sand, about 60 feet of what is apparently Kansan glacial till, and then another layer of sand. No rock outcrops occur in this valley.

D. Climatology

Table 6 shows precipitation data for Ames, Iowa. The published monthly precipitation records for five stations in the area indicate that about 71 percent of the precipitation occurs from April to September, 18 percent during October, November, and March and 11 percent during December through February. The records show that the record flow in the Skunk River of 8630 cfs was caused by an average rainfall of 2.98 inches over the Skunk River Basin during a twenty-four hour period.

Table 6. Precipitation in inches for Ames, Iowa
1876-1954 (5)

Average annual	Maximum		Maximum 2 year		Maximum 3 year		Maximum 5 year	
	Depth	Year	Depth	Year	Depth	Year	Depth	Year
31.1	51.9	1881	90.7	1943 to 1944	124.3	1943 to 1945	199.2	1940 to 1944

United States Weather Bureau records of average annual snowfall for seven stations in or near the Skunk River Basin show an average annual depth of snowfall over the basin of about 26 inches. Table 7 lists temperature data for Ames, Iowa.

Table 7. Temperatures in degrees Fahrenheit at Ames, Iowa (5)

		Temperatures		
Station	Length of record	Maximum	Minimum	Average
Ames, Iowa	74 years	109°	-37°	48.7°

III. PROCEDURE

A. General

Determining flood potentiality of one of more basins involves many considerations and the handling of several problems. Hydrologists have in some cases developed different methods of coping with the same problem. The procedure used by this paper is outlined in general terms in this section and will be developed, step by step, in proceeding sections. Storms MR 4-24, UMV 1-22, UMV 2-5, MR 7-2B, and MR 6-15 were each treated in similiar manner.

The first step was the development of unit hydrographs for the Squaw Creek Basin and for the Skunk River Basin above the junction of the two streams. The unit hydrograph has been defined by Sherman as: "the hydrograph of surface runoff (not including groundwater runoff) on a given basin, due to an effective rain falling for a unit of time" (6-p308). In this study, effective rain was assumed to be a rainfall sufficient to produce one inch of rainfall excess or surface runoff over the entire basin. The unit of time was assumed to be six hours.

The second step was the development of a groundwater hydrograph for each of the two basins. Water below the water table in the soil is called groundwater (6). This groundwater acts as a vast sub-surface reservoir from which streams, lakes, and swamps are fed between rainstorms when no surface runoff is available (7). A groundwater hydrograph of a basin is a graphical plot of stream discharge derived from groundwater sources as ordinate and time intervals as abscissa.

The next step was the transposition of each storm in turn to a position over the two basins to produce maximum average rainfall on the basins. Total-storm isohyetal maps, which are maps of the original storms showing contours of equal precipitation, were used for making the transposition (8). The total-storm isohyetal map overlays were rotated over a map of the two basins to a position of maximum average precipitation. The United States Weather Bureau has determined that the major axis of a storm may be rotated up to twenty degrees in either direction. The geographic limits of the area over which a certain storm could have occurred and the amount of precipitation that would fall in a new storm location are affected by many conditions. The possibility of these storms occurring over the Squaw Creek and Skunk River Basins and the percentage of original rainfall that would fall in the new location had to be determined.

The fourth step was the determination of the average precipitation that would fall on each of the two basins in six-hour increments for the total length of the storm. This was accomplished by placing a series of six-hour isohyetal maps over the two basins in the position determined previously using the total-storm isohyetal map. Average precipitation over the basin for each six-hour period was then determined using the isohyetal method. In cases where precipitation was too light for this method to be used accurately, the Thiessen method was employed. This latter method gives equal weight to the areal distribution of the various precipitation recording stations (8). Each of these average precipitation values were modified using figures obtained from the U. S. Weather Bureau to account for the increase or decrease in rainfall due to the transposition.

The next step was the determination of the amount of runoff from each basin during each time period using the average precipitation values found above. Runoff, in this case, was the total runoff minus the groundwater flow. The portion of the precipitation that reaches the stream as runoff was calculated using a graph of rainfall-runoff relations developed for this region.

As a last step, streamflow hydrographs observed at the junction of the two streams were developed. Unit graph ordinates were multiplied by the previously determined values of rainfall excess for each period. This produced a series of hydrographs representing runoff from a six-hour increment of rainfall. These hydrographs were staggered with respect to time and summed along with the groundwater hydrograph to produce a total hydrograph for each stream. The ordinates of the two separate stream hydrographs were added to produce a total hydrograph of flow at the stream junction.

B. Development of Unit Hydrographs

In studies of this type, the unit hydrograph is the basic tool of the engineer. The unit hydrographs developed for the Skunk River and Squaw Creek Basins are hydrographs of surface runoff caused by a rainfall excess of one inch over the respective basin during a six-hour period of precipitation. There are several methods of developing unit hydrographs for small basins of this type. The best method is to use available precipitation and runoff data of the basin to derive the hydrograph directly. This is the method that was used in this paper. Other methods which could have been used include transferring a unit graph from a similiar basin and deriving a synthetic graph by mathematical means.

In developing unit hydrographs for the basins, actual hydrographs resulting from storms were obtained where possible. Where such records were not readily available, hydrographs were developed from published values of mean daily flow (1).

The groundwater flow was then separated from the total flow under the hydrograph. Since this is a difficult quantity to estimate, many arbitrary methods of separation have been developed (8). Most are satisfactory when used consistently throughout the study. One of the better methods involves the development of a groundwater recession curve which is fitted to the recession limb of the observed hydrograph. This recession curve is extended back to a point under the second point of inflection of the observed hydrograph. From here a straight line is drawn to the point where the hydrograph first begins to rise as a result of the rainfall.

The area under the hydrograph after the groundwater flow was excluded was next calculated. This area represents the volume of runoff derived from three sources. These are channel precipitation, surface runoff, and interflow. Interflow is water that travels in the zone beneath the surface of the earth and above the water table during some period in its movement to the stream. The volume of runoff was next converted to inches of runoff over the basin. Runoff ordinates of the hydrograph were divided by this figure to produce a hydrograph resulting from one inch of runoff over the entire basin.

Precipitation records were examined to determine the duration of rainfall that each graph represented. Unit hydrographs representing like durations of rainfall were averaged to provide the best unit graph. If no storms of the duration desired were recorded, a unit hydrograph for another duration could be derived and converted to the proper duration using an S-curve hydrograph (9). For example, to convert a twelve-hour unit hydrograph to a six-hour unit hydrograph, a series of twelve-hour unit hydrographs spaced twelve hours apart are added to form an S-curve. An S-curve will rise to a point where inflow equals discharge and the curve becomes horizontal. Ordinates of two twelve-hour S-curves would then be lagged six hours and subtracted. The new ordinates are those of a hydrograph caused by one half of an inch of rainfall excess in six hours. Multiplying these ordinates by two produces the desired six-hour unit hydrograph.

The derived unit hydrograph was then used to reproduce the hydrographs resulting from past storms. Discrepancies in the unit hydrograph indicated by comparing the observed and reproduced hydrographs were then adjusted.

Six-hour unit hydrographs were developed for both basins at their respective gages (1). Figure 6 shows the observed hydrograph of the flood of 19 to 20 May 1944 at the Skunk River gage and the hydrograph reproduced using the unit hydrograph. The Squaw Creek unit hydrograph was used to reproduce the hydrograph observed during the storm of July 17, 1922 as shown in Figure 7.

To obtain unit hydrographs for each stream at the junction, the ordinates of each unit hydrograph at the gage had to be routed downstream and increased to allow for the increased drainage area. The ordinates of each graph were multiplied, therefore, by a ratio of the basin area above the stream junction to the basin area above the gage. Since the increase in area is not large, the results are within desired accuracy. Figure 8 shows the unit hydrographs at

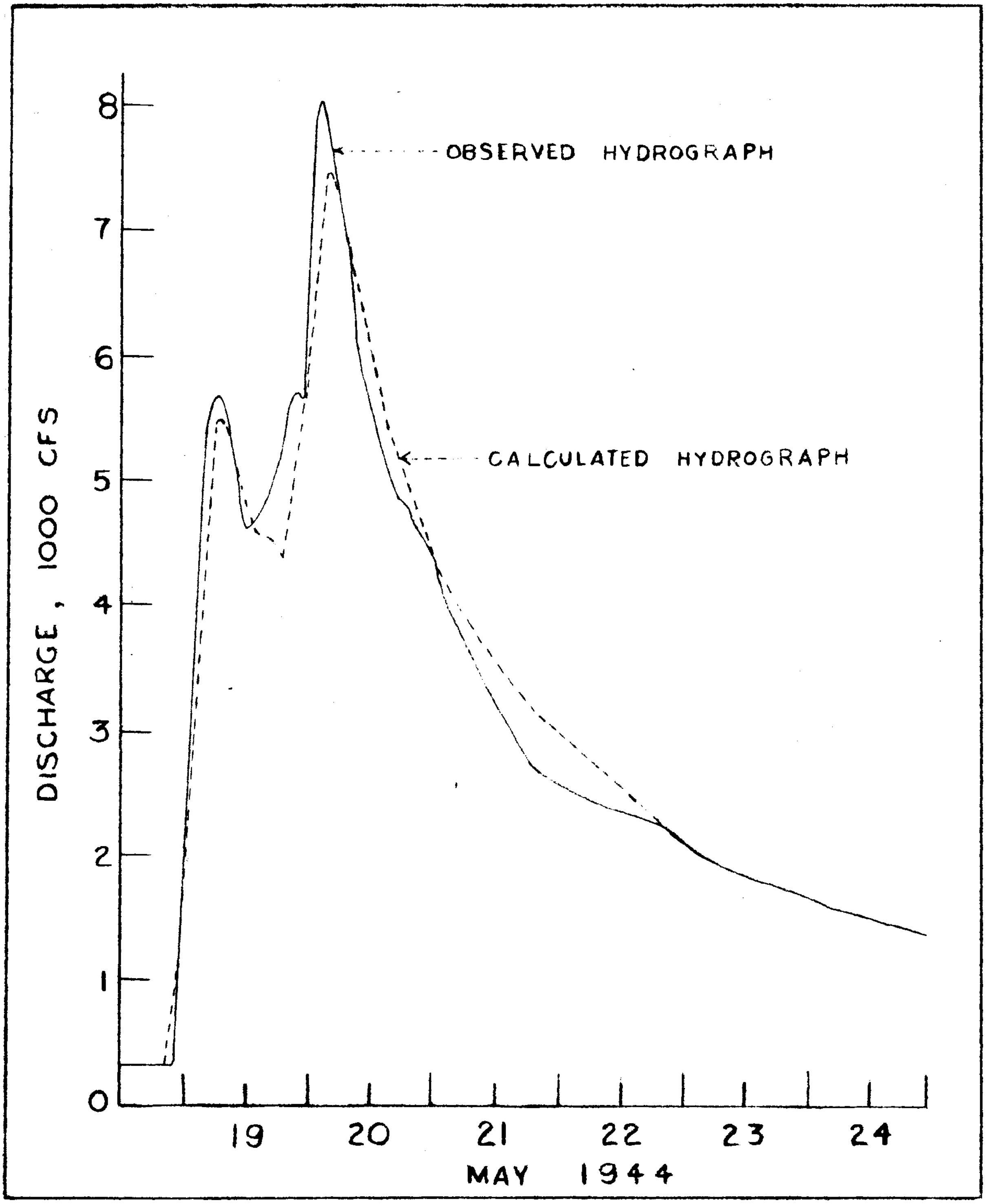

Figure 6. Comparison of the calculated and observed hydrographs for the 19 to 20 May 1944 flood at the Skunk River gage above Ames, Iowa (1)

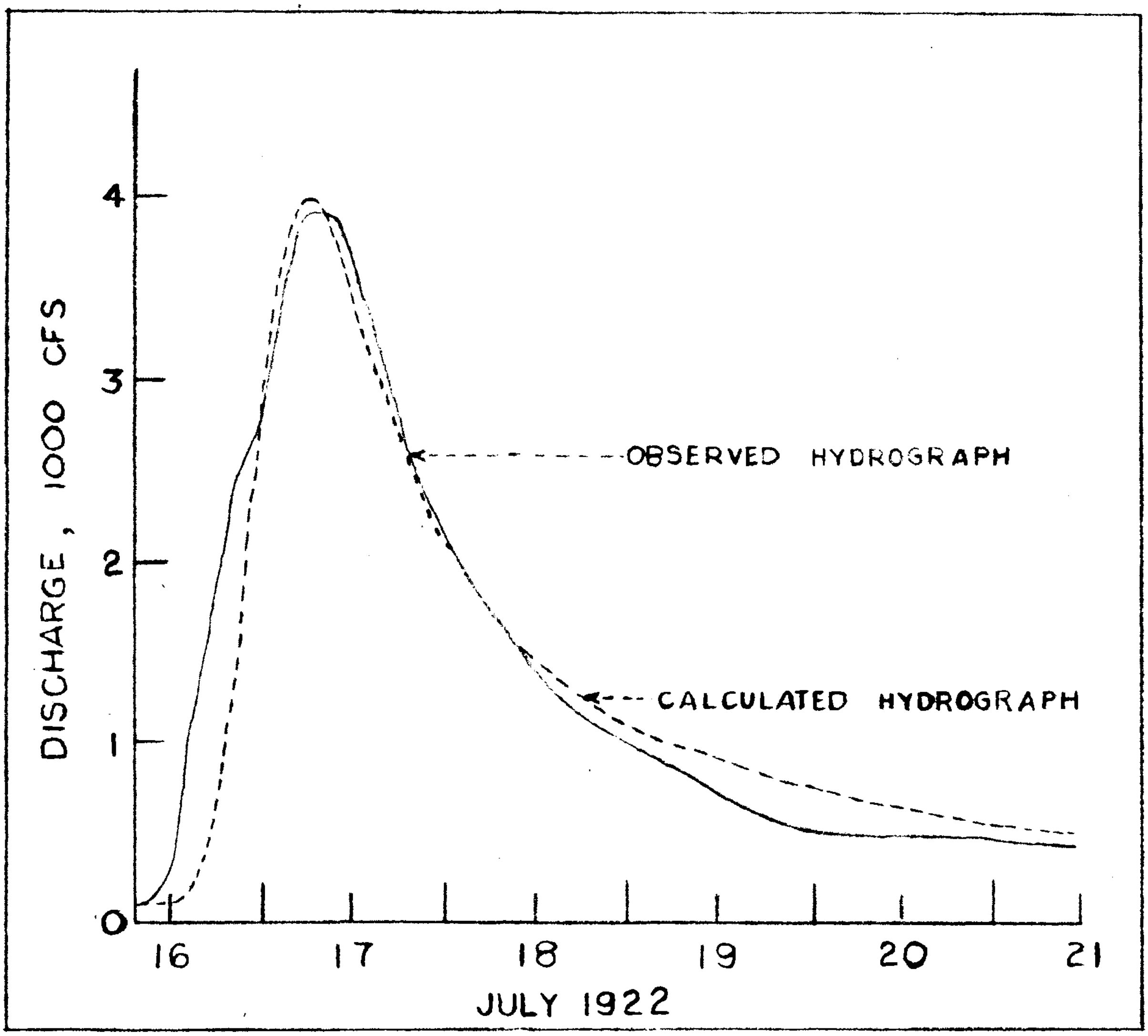

Figure 7. Comparison of the calculated and observed hydrographs for the 17 July 1922 flood on Squaw Creek at the gage at Ames, Iowa (1)

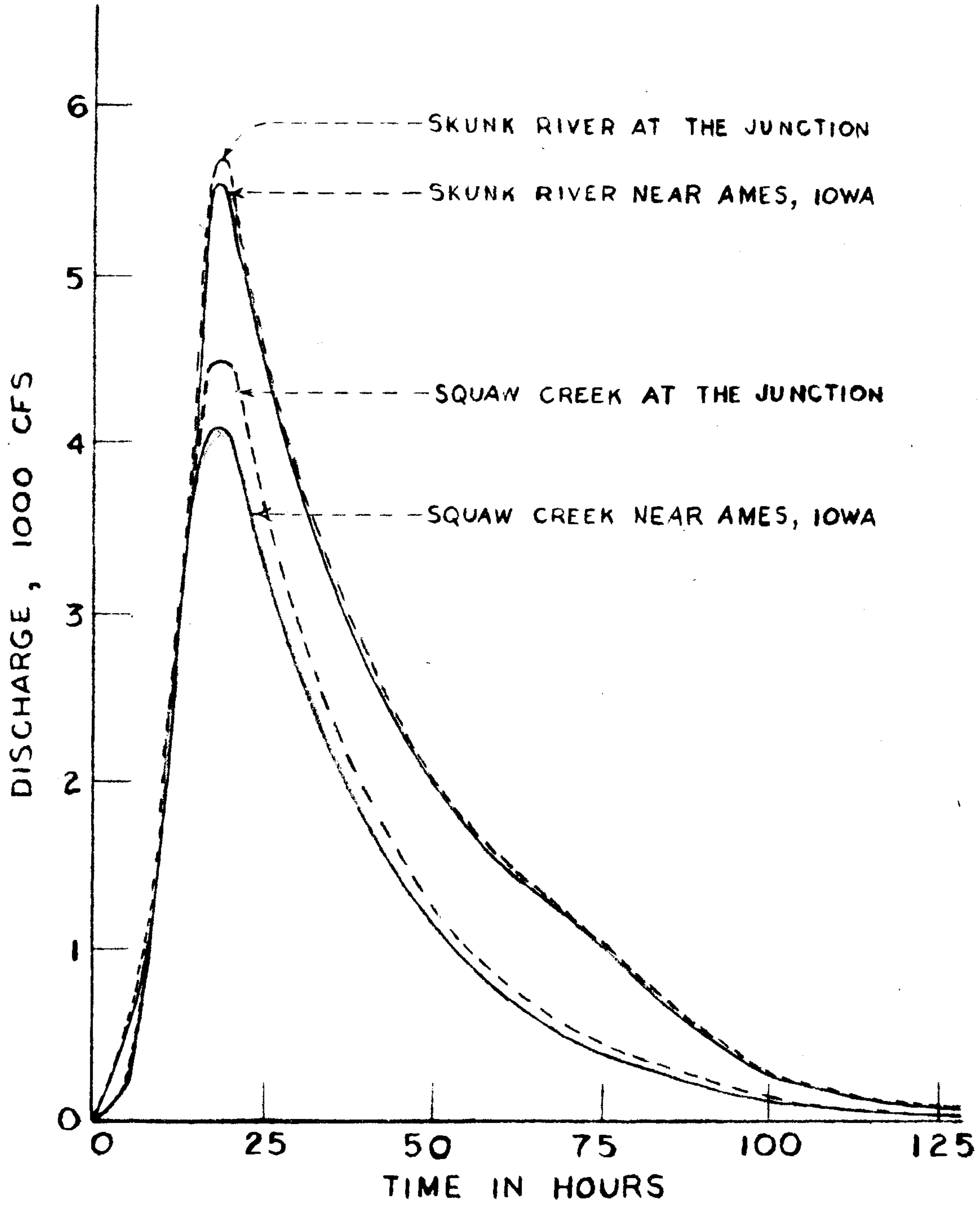

Figure 8. Comparison of the Skunk River and Squaw Creek unit hydrographs

the gages and at the junction. The ordinates of the unit hydrographs at the junction are shown in two-hour increments in Tables 8 and 9.

C. Development of a Groundwater Hydrograph

That water flowing in the soil below the water table that emerges as streamflow is known as groundwater flow or base flow. Precipitation infiltrating through the soil to the water table can cause the water table level to rise considerably. An increase in the water table level eventually causes an increase in groundwater flow although the two do not vary directly. In developing a groundwater hydrograph, the shape of the rising limb and the location of the peak groundwater flow are largely indeterminate (8). It follows that any assumptions made regarding the groundwater hydrographs are arbitrary; however, the relative magnitude of this portion of the total flow is small enough that it should not introduce serious error in the runoff computations.

A groundwater flow of one cubic foot per second per square mile of basin area was assumed in each basin at the beginning of each storm. The flow was then assumed to rise at an increasing rate to a peak of two cubic feet per second per square mile at the end of 42 hours where it then remained constant. An examination of streamflow records for these streams during the months of May through September revealed

Table 8. Skunk River unit hydrograph ordinates in cfs at the junction with Squaw Creek

Two hour period	Hydrograph ordinates	Two hour period	Hydrograph ordinates	Two hour period	Hydrograph ordinates
0	0	24	2180	48	300
1	67	25	2060	49	269
2	454	26	1935	50	238
3	1141	27	1840	51	212
4	1731	28	1737	52	176
5	2221	29	1635	53	165
6	2930	30	1541	54	155
7	4260	31	1459	55	147
8	5350	32	1386	56	140
9	5710	33	1323	57	132
10	5490	34	1271	58	125
11	5000	35	1220	59	118
12	4720	36	1158	60	111
13	4320	37	1095	61	103
14	4080	38	1023	62	96
15	3820	39	951	63	89
16	3570	40	879	64	82
17	3360	41	816	65	75
18	3155	42	735	66	66
19	2958	43	661	67	58
20	2790	44	579	68	49
21	2630	45	496	69	32
22	2481	46	414	70	17
23	2315	47	351	71	0

Table 9. Squaw Creek unit hydrograph ordinates in cfs at the junction with Skunk River

Two hour period	Hydrograph ordinates	Two hour period	Hydrograph ordinates	Two hour period	Hydrograph ordinates
0	0	32	682	64	47
1	30	33	625	65	44
2	176	34	576	66	40
3	537	35	529	67	36
4	1173	36	486	68	33
5	2160	37	446	69	33
6	3139	38	411	70	30
7	3900	39	377	71	27
8	4310	40	346	72	23
9	4500	41	318	73	21
10	4390	42	292	74	19
11	4080	43	268	75	17
12	3755	44	247	76	17
13	3442	45	228	77	17
14	3160	46	209	78	17
15	2900	47	191	79	17
16	2681	48	176	80	17
17	2441	49	162	81	14
18	2243	50	149	82	11
19	2060	51	137	83	8
20	1890	52	126	84	7
21	1735	53	113	85	6
22	1592	54	106	86	6
23	1463	55	97	87	6
24	1343	56	90	88	6
25	1225	57	83	89	6
26	1133	58	76	90	6
27	1041	59	71	91	6
28	956	60	64	92	6
29	880	61	61	93	4
30	807	62	55	94	2
31	742	63	52	95	0

that an assumption of a base flow of one cubic foot per second per square mile prior to a stream rise was reasonable.

D. Transposition of Storms

Transposition of a storm from one area to another generally involves three considerations. The first entails determining whether the new area is within the areal limits in which the storm may be transposed. The second entails determining whether any change in the shape or orientation of the isohyetal pattern of the storm is permissible (8). Finally, the change in the magnitude of the storm that the transposition might cause is determined.

The limits of transposition of a storm are generally determined by an investigation of the type of storm involved. The five storms considered in this thesis belong to the class of wave-type cyclones that occur in the north-central United States below the Great Lakes (10). Due to a decrease in the air-mass temperature contrast with movement of the storm to the south, a general limit for occurrence of storms of this type is set at the southern borders of Kansas and Missouri. The area of occurrence is further bordered to the west by the Rocky Mountains, to the east by the Appalachian Mountains, and to the north by the Great Lakes. The U. S. Weather Bureau has verified the fact that these storms could have occurred over the Skunk River Basin (1).

A change in the shape or orientation of a storm pattern could greatly affect the total amount of precipitation falling on a basin. All storms were transposed, however, without altering their original shape. Rotation of the major axes of the storm patterns was limited to a twenty degree maximum in either direction. This follows a general rule set by the Weather Bureau.

Transposition of a storm can change the probable amount of precipitation caused by the storm. If the dynamic features of the storm are assumed to be unchanged, then the change would be mainly due to a difference in available moisture in the two localities (8). The Weather Bureau has developed charts from which the amount of precipitable water available in each locality can be estimated using representative surface dewpoints as a parameter. Altitude is used as another parameter in these charts since a difference in altitude affects atmospheric pressure. These factors were taken into account in calculating the relative magnitude of precipitation from each storm over the basins considered (1). The relative magnitude of each storm is expressed below as a percentage of the original:

MR 4-24	104%
UMV 1-22	119%
UMV 2-5	96%
MR 7-2B	89%
MR 6-15	101%

Each of the five storms was transposed in turn to a position over the two basins. This position was chosen by rotating an isohyetal overlay of the total precipitation in each storm over a map of the two basins to a position of maximum precipitation over the total area. Figures 9 through 13 show the five storms superimposed upon the two basins. The number of degrees that each storm axis was rotated are indicated below:

MR 4-24 - - - - - - - - - - - 20° counterclockwise
UMV 1-22 - - - - - - - - - - 20° clockwise
UMV 2-5 - - - - - - - - - - - 20° clockwise
MR 7-2B - - - - - - - - - - - 17° clockwise
MR 6-15 - - - - - - - - - - - 20° clockwise

E. Determination of Average Rainfall

Average rainfall over the basins was determined using two methods. The isohyetal method was used in all cases except where the rainfall was very light. In this case, the Thiessen method was used. Precipitation amounts were determined for six-hour periods of rainfall for use with the unit hydrographs. The positions of the isohyetal and Thiessen short-period storm patterns were fixed by the position of the total-storm transposition.

Isohyets in an isohyetal pattern act as contours of equal precipitation. The isohyet pattern is derived by interpolation between points of known precipitation. Any recording type of precipitation station will show how the

Figure 9. Transposition of Storm MR 4-24 over the Skunk River Basin above the Squaw Creek junction

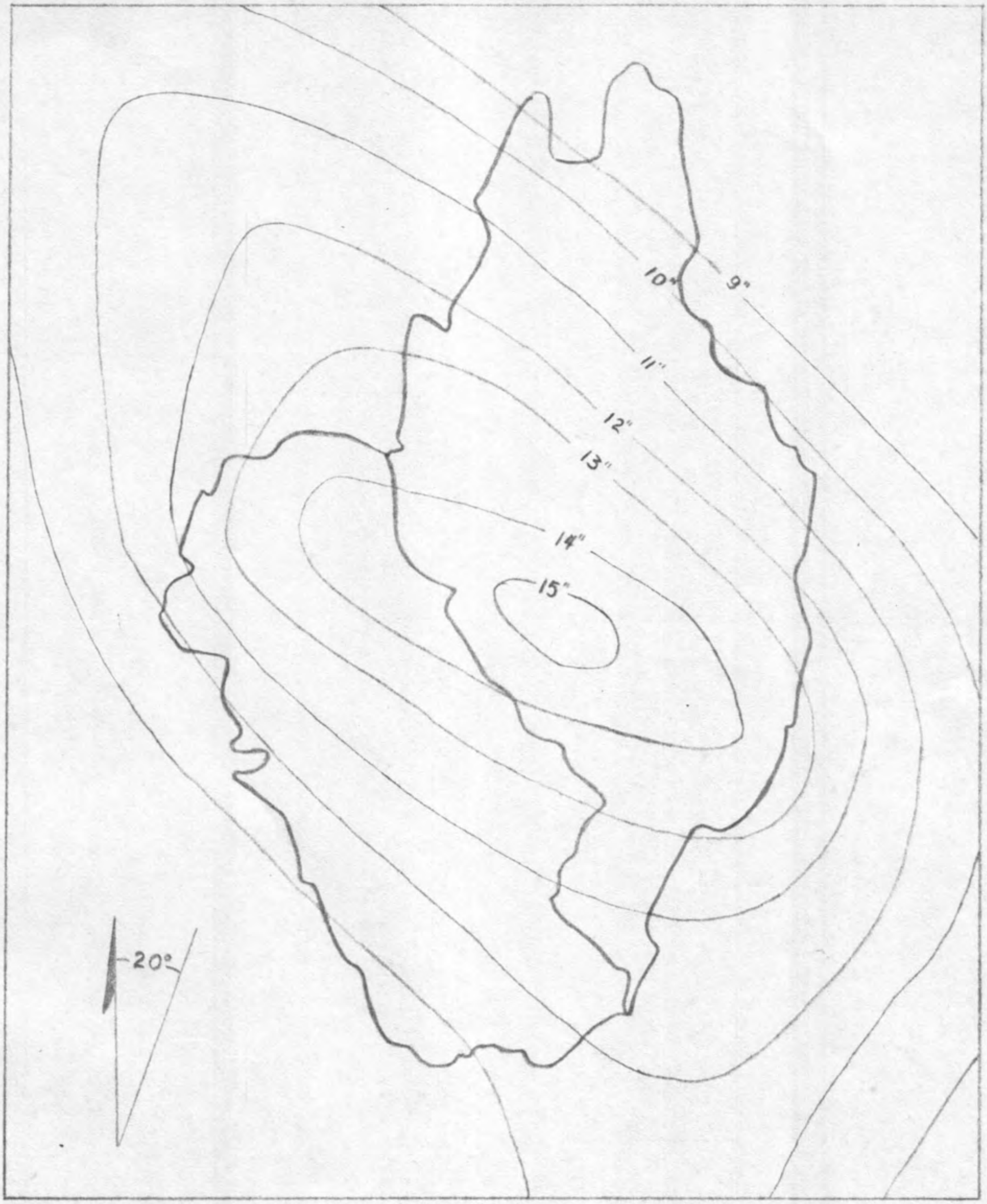

Figure 10. Transposition of Storm UMV 1-22 over the Skunk River Basin above the Squaw Creek junction

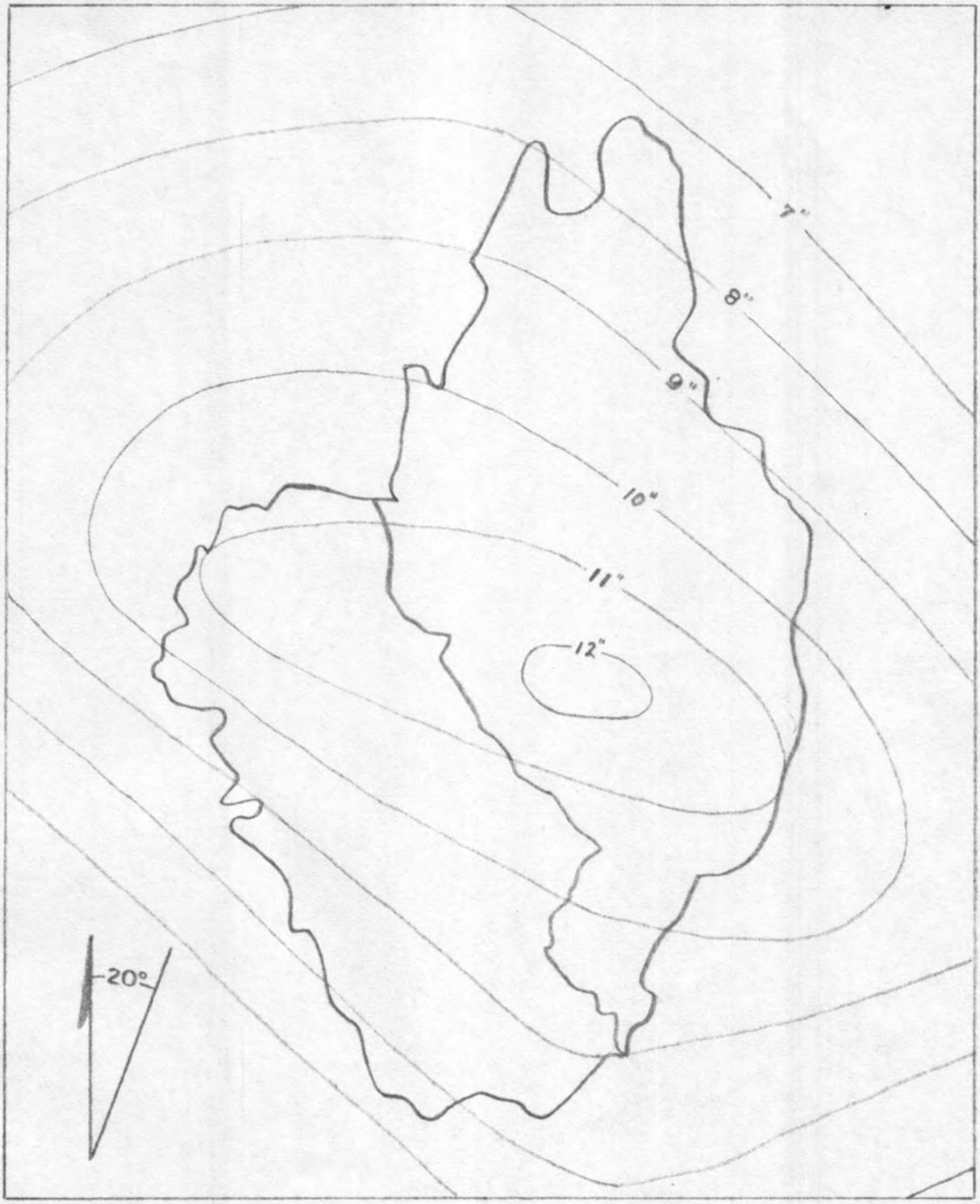

Figure 11. Transposition of Storm UMV 2-5 over the Skunk River Basin above the Squaw Creek junction

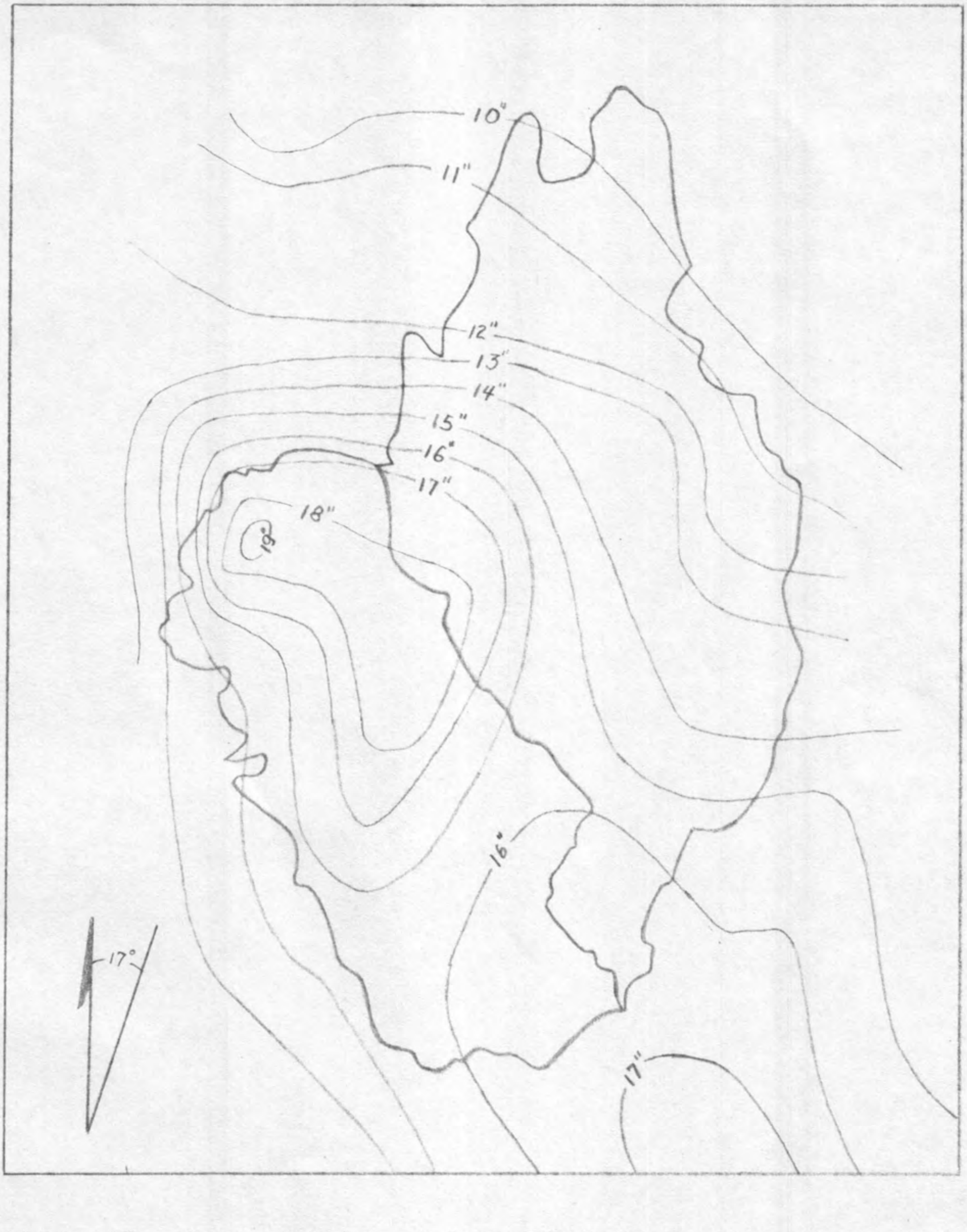

Figure 12. Transposition of Storm MR 7-2B over the Skunk River Basin above the Squaw Creek junction

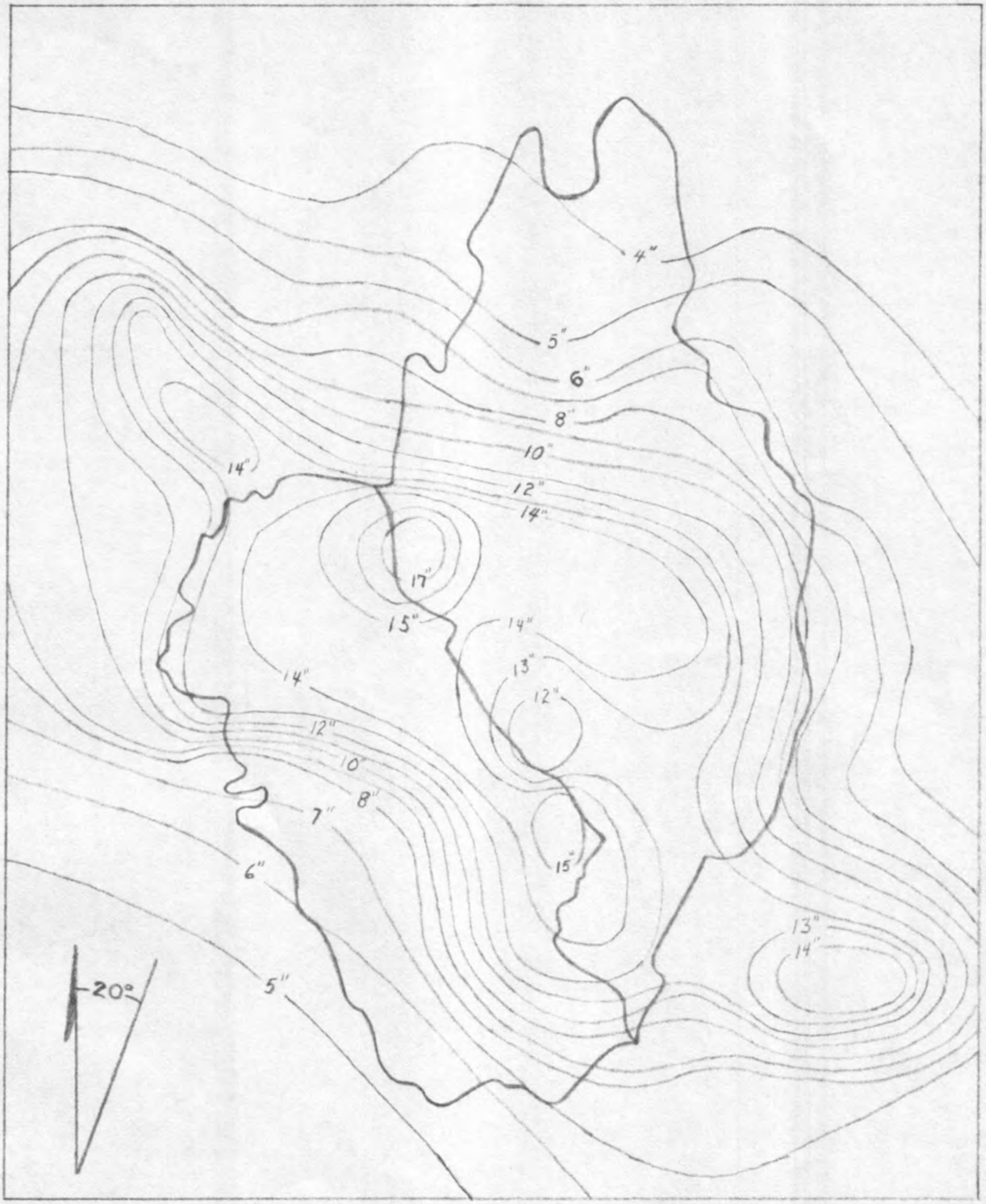

Figure 13. Transposition of Storm MR 6-15 over the Skunk River Basin above the Squaw Creek junction

precipitation varied with time. Data from all non-recording sources is broken down into incremental periods by comparing it with data from nearby recording stations.

Six-hour isohyetal maps were obtained for the five storms discussed in this thesis (1). Each isohyetal map was converted to the same scale as that of a map of the two basins. Each six-hour isohyetal map was positioned over the two basins in the same position determined with the total-storm isohyetal map described in the previous section. Figure 14 shows the second six-hour period of Storm MR 6-15 placed over the two basins in the position determined by the total-storm map in Figure 13.

Each of the short-period isohyetal maps was used to determine a value of average rainfall for that period. Table 10 shows an example of the determination of average rainfall over the Skunk River Basin using the same period that was illustrated in Figure 14. Individual areas enclosed between ischyets were considered in turn. A planimeter was used to determine areas between isohyets. Column 1 of the table shows the values of the emclosing isohyets, and Column 2 shows the intial average planimeter reading for each area. The Skunk River Basin area is equivalent to 81.0 planimeter units so Column 3 represents the initial planimeter readings adjusted such that their total will equal 81.0 units. The error in planimetering was divided according to area. Column 4 lists the enclosed area in

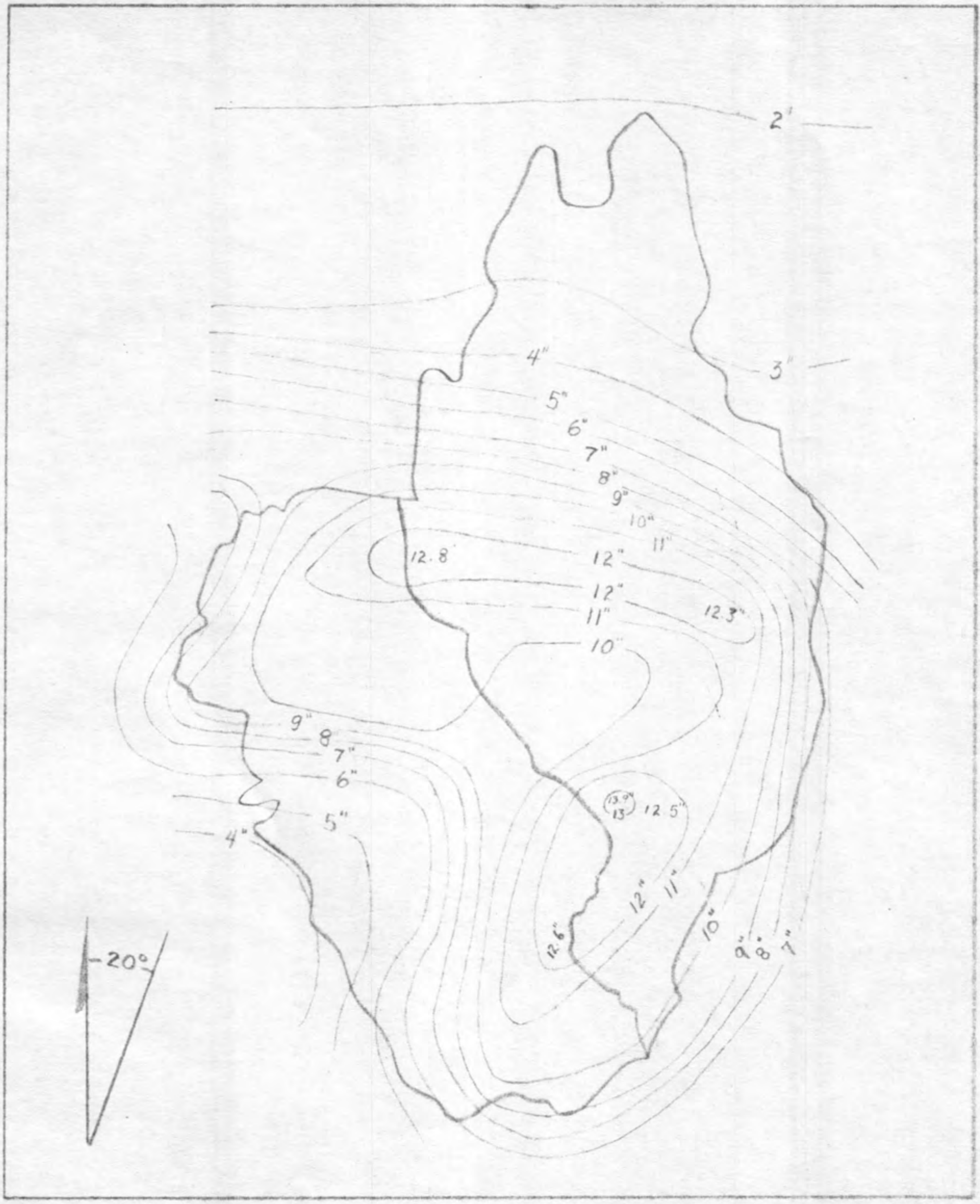

Figure 14. Transposition of the second period of Storm MR 6-15 over the Skunk River Basin above the Squaw Creek junction

Table 10. Sample determination of average rainfall over the Skunk River Basin using the second period of Storm MR 6-15

	Planimeter readings				
Enclosing isohyets (1)	Initial (2)	Adjusted (3)	Area, sq mi (4)	Average rain, in. (5)	Depth area in.-sq mi (6)
13.9-13.0	.25	.25	1.03	13.3	13.7
13.0-12.0	4.30	4.26	17.55	12.5	219.5
12.8-12.0	5.25	5.19	21.35	12.27	262.0
12.0-11.0	10.40	10.28	42.23	11.5	486.0
11.0-10.0	15.55	15.36	63.10	10.55	666.0
10.0- 9.5	5.05	4.99	20.50	9.75	199.5
10.0- 9.0	4.75	4.70	19.33	9.5	183.3
9.0- 8.0	4.00	3.96	16.28	8.5	138.2
8.0- 7.0	3.25	3.21	13.20	7.6	100.3
7.0- 6.0	3.40	3.36	13.82	6.5	89.9
6.0- 5.0	3.10	3.07	12.62	5.5	69.4
5.0- 4.0	5.60	5.54	22.77	4.5	102.3
4.0- 3.0	7.10	7.03	28.92	3.5	104.6
3.0- 2.1	9.90	9.80	40.30	2.65	106.9
Total	81.90	81.00	333.00		2741.6

square miles, using the relation that one planimeter unit equals 4.12 square miles.

With reasonably parallel isohyets, an arithmetic average of the two values was used to represent the average precipitation over the area between isohyets. Circular and other irregular isohyetal patterns required that this procedure be varied to give a more realistic value. Column 5 of Table 10 lists the values of average rainfall used for the respective areas. The depth-area product of Colums 4 and 5 is shown in Column 6. When the total of Column 6, 2,741.6

inch-square miles, is divided by the total 333 square-mile area, an average rainfall value over the basin of 8.23 inches is obtained. Other average rainfall values were determined in a similiar manner.

During periods of very light precipitation, points of precipitation records were transposed instead of isohyetal patterns. Perpendicular bisectors of lines between these points were joined to form a Thiessen pattern. Figure 15 illustrates a Thiessen pattern that was used for the second period of rainfall during Storm UMV 1-22. Average precipitation equal to the station record was assumed to occur over the area enclosed around each station by the perpendicular bisectors. Here again, depth-area values were calculated, summed, and divided by the total basin area to provide a value of average precipitation over the basin.

F. Rainfall-Runoff Relationships

The volume of runoff from a basin produced by a rainfall of given magnitude is affected by many variables. Satisfaction of interception, depression storage, and soil moisture demands of the basin uses up much of the early rainfall and some of the later rainfall. Since each of these sources of loss is affected by many factors, a direct scientific determination of the amount of runoff from a basin of this size is impossible at this time. For this reason many empirical methods of estimating runoff have been devised. The best

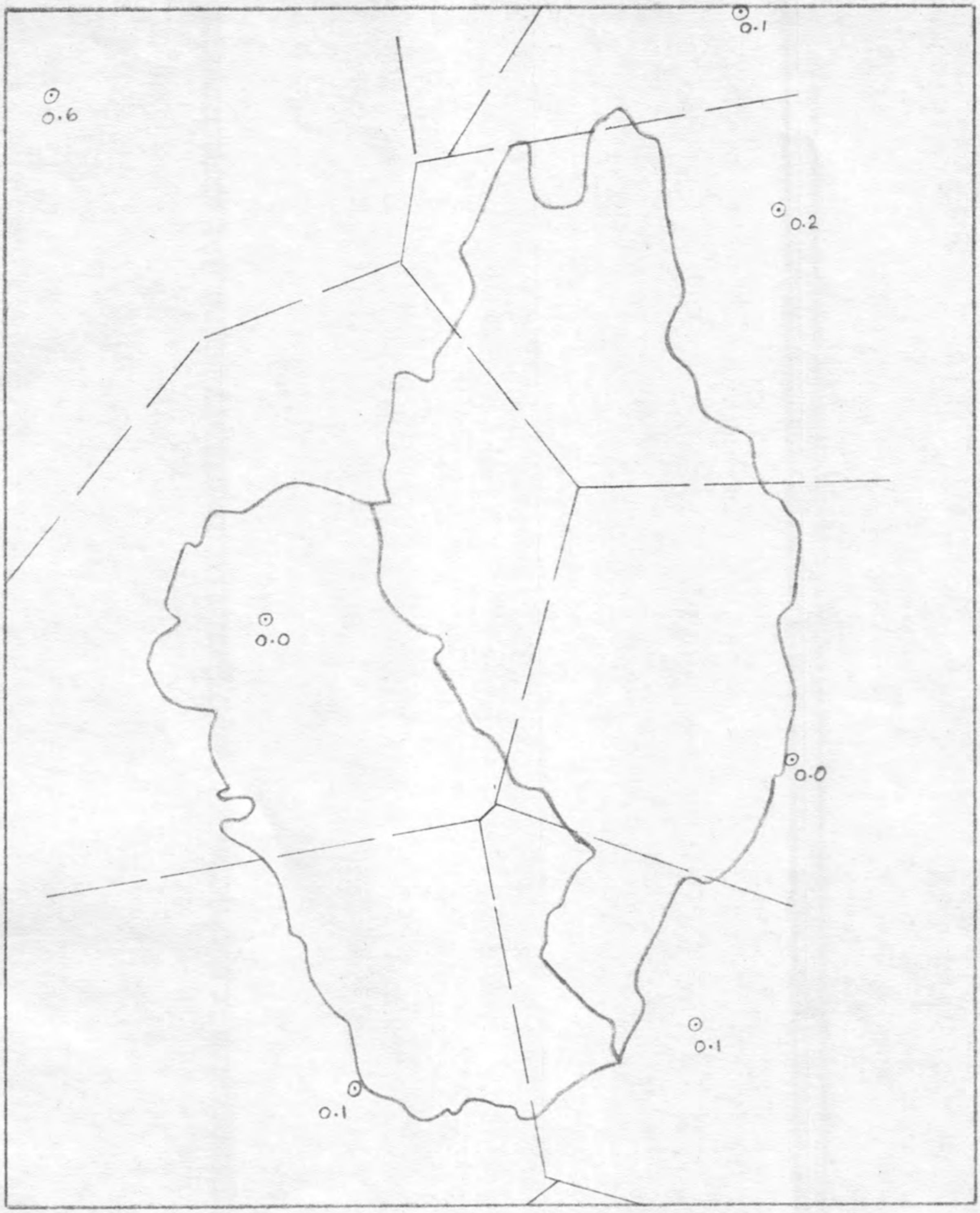

Figure 15. Thiessen pattern used with the second six-hour period of Storm UMV 1-22

method to use for a certain basin depends on the records available for that basin.

In the humid and subhumid basins of this country, streamflow prior to a storm has been found to be a good index to the moisture deficiency of the basin (8). Assuming that runoff from previous rains has been discharged, this streamflow would result from groundwater flow entirely. A graph of rainfall-runoff relations that uses initial groundwater flow as a parameter has been developed for the Iowa River Basin (11). This basin borders the Skunk River Basin on its northeast side. Due to the similarity and proximity of the two basins this graph was considered suitable for use in this study. No other relationship between rainfall and runoff for the basins under study was available or easily determinable for use in this study. The relationship used in the study is shown in Figure 16. Use of this graph is limited to the months of April through October since freezing temperatures alter any relation between precipitation and runoff during other periods.

In a previous section the groundwater flow at the start of each of the transposed storms was assumed to be one cubic foot per second per square mile. This groundwater flow was used as the index flow in the graph in Figure 16. The graph was used by entering on the left hand side with a value of average rainfall. By reading down from the point where this value intersected the groundwater parameter, a

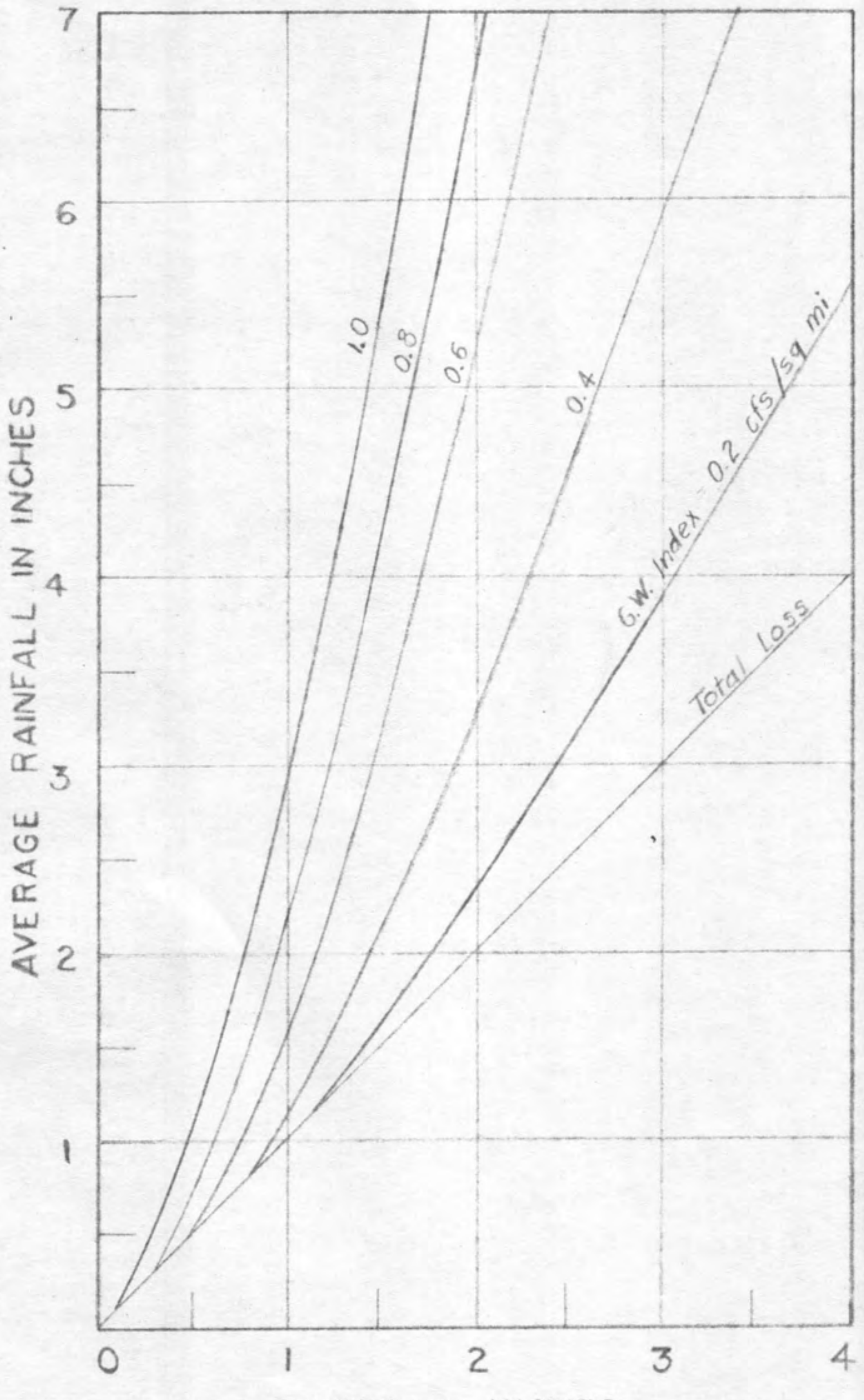

Figure 16. Rainfall-runoff relationship graph (11)

value of rainfall loss was obtained. This graph was used to determine rainfall loss resulting from the first seven inches of rainfall. After seven inches of rain had fallen, ninety percent of all additional rainfall was assumed to reach the stream as runoff.

Tables 11 and 12 illustrate the method of determining runoff from the two basins for each six-hour period of the five storms. The six-hour periods of each storm were numbered numerically beginning with the first period. These numbers are shown in the first column of each table. The second column lists the values of average six-hour rainfall that were determined by the method described in the preceding section of this thesis. The actual average rainfall values in Column 2 were adjusted to the values listed in Column 3 by multiplying the actual rainfall by the percentage increase or decrease in rainfall to be expected in the transposed location. The percentages used for each storm are listed on page 36. For example, values in the second column for Storm MR 4-24 were multiplied by 1.04 to give the values in the third column. The adjusted values are totaled cumulatively in the fourth column.

Values from Column 4 were used to enter the graph on Figure 16 to obtain values of total loss. The total loss figures were entered in Column 5 of each table. The values in Column 5 were subtracted from the values in Column 4 to give values of total runoff recorded in the

Table 11. Calculation of runoff from the Skunk River Basin

6-hour period (1)	Average 6-hour rain, in. (2)	Adjusted average rain, in. (3)	Total rain, in. (4)	Total loss, in. (5)	Total runoff, in. (6)	Incremental runoff, in. (7)
Storm MR 4-24						
1	0.09	0.09	0.09	0.09	0.0	0.0
2	8.69	9.04	9.13	1.98	7.15	7.15
3	3.35	3.48	12.61	2.33	10.28	3.13
4	0.10	0.10	12.71	2.34	10.37	0.09
Storm UMV 1-22						
1	0.029	0.035	0.035	0.035	0.000	0.00
2	0.065	0.077	0.112	0.100	0.012	0.01
3	0.534	0.635	0.747	0.370	0.377	0.36
4	0.065	0.077	0.824	0.410	0.414	0.04
5	0.000	0.000	0.824	0.410	0.414	0.00
6	0.819	0.975	1.799	0.720	1.079	0.66
7	5.040	5.990	7.789	1.860	5.929	4.85
8	2.290	2.725	10.514	2.130	8.384	2.46
9	0.203	0.242	10.765	2.150	8.606	0.22
10	0.919	1.093	11.849	2.260	9.589	0.98
11	0.770	0.916	12.765	2.350	10.415	0.83
12	0.350	0.416	13.181	2.390	10.791	0.38
13	0.048	0.057	13.238	2.400	10.838	0.05
Storm UMV 2-5						
1	7.75	7.44	7.44	1.82	5.62	5.62
2	2.48	2.38	9.82	2.06	7.76	2.14
Storm MR 7-2B						
1	4.09	3.64	3.64	1.17	2.47	2.47
2	1.93	1.72	5.36	1.50	3.86	1.39
3	0.00	0.00	5.36	1.50	3.86	0.00
4	1.12	1.00	6.36	1.67	4.69	0.83
5	2.57	2.29	8.65	1.94	6.71	2.02
6	1.90	1.69	10.34	2.11	8.23	1.52
Storm MR 6-15						
1	0.55	0.56	0.56	0.30	0.26	0.26
2	8.23	8.32	8.88	1.97	6.91	6.65

Table 12. Calculation of runoff from the Squaw Creek Basin

6-hour period (1)	Average 6-hour rain, in. (2)	Adjusted average rain, in. (3)	Total rain, in. (4)	Total loss, in. (5)	Total runoff, in. (6)	Incremental runoff, in. (7)
			Storm MR 4-24			
1	1.49	1.55	1.55	.65	.90	.90
2	10.01	10.41	11.96	2.28	9.68	8.78
3	3.28	3.41	15.37	2.62	12.75	3.07
4	0.10	0.10	15.47	2.63	12.84	.09
			Storm UMV 1-22			
1	0.000	0.000	0.000	0.000	0.000	0.00
2	0.045	0.054	0.054	0.054	0.000	0.00
3	0.344	0.409	0.463	0.250	0.213	0.21
4	0.012	0.014	0.477	0.252	0.225	0.01
5	0.000	0.000	0.477	0.252	0.225	0.00
6	0.531	0.631	1.108	0.510	0.598	0.37
7	6.020	7.160	8.268	1.900	6.368	5.77
8	2.350	2.795	11.063	2.180	8.883	2.52
9	0.033	0.039	11.102	2.180	8.922	0.04
10	0.975	1.160	12.262	2.300	9.962	1.04
11	1.020	1.213	13.475	2.420	11.055	1.09
12	0.51	0.607	14.082	2.490	11.592	0.54
13	0.014	0.017	14.099	2.490	11.609	0.02
			Storm UMV 2-5			
1	8.50	8.16	8.16	1.90	6.26	6.26
2	2.02	1.94	10.10	2.09	8.01	1.75
			Storm MR 7-2B			
1	4.43	3.94	3.94	1.23	2.71	2.71
2	1.67	1.49	5.43	1.52	3.91	1.20
3	0.00	0.00	5.43	1.52	3.91	0.00
4	2.00	1.78	7.21	1.80	5.41	1.50
5	5.10	4.54	11.75	2.25	9.50	4.09
6	2.58	2.30	14.05	2.48	11.57	2.07
			Storm MR 6-15			
1	1.34	1.35	1.35	0.59	0.76	0.76
2	9.00	9.09	10.44	2.12	8.32	7.56

sixth column of each table. The total runoff in Column 6 was broken down into incremental values for each six-hour period. Six-hour incremental values of runoff are shown in the last column of each table.

G. Development of Total Hydrographs

The final step in a study of this type involves the development of hydrographs of runoff from each storm considered. All of the information that has been developed in previous sections of the paper was used to produce flood hydrographs for both streams. The ordinates of the two hydrographs were then added to produce a total flood hydrograph.

In the preceding section, six-hour runoff values were developed for each basin. These values were used with the basin unit hydrographs and basin groundwater hydrographs to produce stream hydrographs at the junction of the two streams. Table 13 illustrates the development of a hydrograph for the Skunk River from the runoff values calculated for Storm MR 7-2B.

Values of the ordinates of the Skunk River unit hydrograph were broken down into two-hour periods in Table 8. These unit hydrograph values were used in the development of all Skunk River hydrographs. Column 1 of Table 13 divides the streamflow into two-hour periods for the total length of the rise to facilitate use of the unit hydrograph.

The ordinates of the unit hydrograph are those of a hydrograph of one inch of runoff over the basin. It was determined in Table 11 that from the first six hours of Storm MR 7-2B, 2.47 inches of runoff occurred. To get streamflow ordinates for this period of runoff, the unit hydrograph ordinates were multiplied by 2.47. These values were entered in Column 2 of Table 13.

It was determined that during the following six-hour periods of the storm 1.39 inches, 0.0 inches, 0.83 inches, 2.02 inches, and 1.52 inches of runoff occurred. Streamflow ordinates for each of these increments of runoff were calculated and entered in turn in Columns 3 through 6 of the table. The ordinates from each runoff period were staggered by three, two-hour periods or six hours to allow for the difference in time of occurrence. The zero inches of runoff in the third period caused no streamflow so that column was omitted.

A groundwater hydrograph was assumed earlier in the paper. The ordinates of that hydrograph were entered in Column 7 of Table 13. Columns 2 through 7 were totaled across to give the ordinates of the total flood hydrograph. These figures were entered in Column 8. Figure 17 illustrates this procedure graphically. In this figure, the groundwater hydrograph, the five six-hour hydrographs, and the total stream hydrograph are plotted.

The procedure outlined above was used to derive stream hydrographs for both basins for all five storms. For each

Table 13. Development of the Skunk River hydrograph ordinates in cfs for Storm MR 7-2B

2 hr per (1)	Period one (2)	Period two (3)	Period four (4)	Period five (5)	Period six (6)	Base flow (7)	Total flow (8)
0	0					333	333
1	165					333	498
2	1121					333	1454
3	2818	0				333	3151
4	4276	93				333	4702
5	5486	631				333	6450
6	7237	1586				333	9156
7	10522	2406				344	13272
8	13215	3087				344	16646
9	14104	4073	0			354	18531
10	13560	5921	56			354	19891
11	12350	7437	377			364	20528
12	11658	7937	947	0		374	20916
13	10670	7631	1437	135		395	20268
14	10078	6950	1843	917		425	20213
15	9435	6561	2432	2305	0	455	21188
16	8818	6005	3536	3497	102	485	22443
17	8299	5671	4441	4486	690	515	24102
18	7793	5310	4739	5919	1734	545	26040
19	7306	4962	4557	8605	2631	586	28647
20	6891	4670	4150	10807	3376	626	30520
21	6496	4385	3918	11534	4454	666	31453
22	6128	4112	3586	11090	6475	666	32057
23	5718	3878	3386	10100	8132	666	31880
24	5385	3656	3171	9534	8679	666	31091
25	5088	3449	2963	8726	8345	666	29237
26	4779	3218	2789	8242	7600	666	27294
27	4545	3030	2619	7716	7174	666	25750
28	4290	2863	2455	7211	6566	666	24051
29	4038	2690	2316	6787	6202	666	22699
30	3806	2558	2183	6373	5806	666	21392
31	3604	2414	2059	5975	5426	666	20144
32	3423	2273	1921	5636	5107	666	19026
33	3268	2142	1809	5313	4796	666	17994
34	3139	2028	1710	5012	4496	666	17051

Table 13. Continued

2 hr per (1)	Period one (2)	Period two (3)	Period four (4)	Period five (5)	Period six (6)	Base flow (7)	Total flow (8)
35	3013	1927	1606	4676	4241	666	16129
36	2860	1839	1527	4404	3998	666	15294
37	2705	1767	1442	4161	3771	666	14512
38	2527	1696	1357	3909	3519	666	13674
39	2349	1610	1279	3717	3314	666	12935
40	2171	1522	1211	3509	3131	666	12210
41	2016	1422	1150	3303	2941	666	11498
42	1815	1322	1098	3113	2797	666	10811
43	1633	1222	1055	2947	2640	666	10163
44	1430	1134	1013	2800	2485	666	9528
45	1225	1022	961	2672	2342	666	8888
46	1023	919	909	2567	2218	666	8302
47	867	805	849	2464	2107	666	7758
48	741	689	789	2339	2011	666	7235
49	664	575	730	2212	1932	666	6779
50	588	488	677	2066	1854	666	6339
51	524	417	610	1921	1760	666	5898
52	435	374	549	1776	1664	666	5464
53	408	331	481	1648	1555	666	5089
54	383	295	412	1485	1446	666	4687
55	363	245	344	1335	1336	666	4289
56	346	229	291	1170	1240	666	3942
57	326	215	249	1002	1117	666	3575
58	309	204	223	836	1005	666	3243
59	291	195	198	709	880	666	2939
60	274	183	176	606	754	666	2659
61	254	174	146	543	629	666	2412
62	237	164	137	481	534	666	2219
63	220	154	129	428	456	666	2053
64	203	143	122	356	409	666	1899
65	185	133	116	333	362	666	1795
66	163	124	110	313	322	666	1698
67	143	114	104	297	268	666	1592
68	121	104	98	283	251	666	1523
69	79	92	92	267	236	666	1432

Table 13. Continued

2 hr per (1)	Period one (2)	Period two (3)	Period four (4)	Period five (5)	Period six (6)	Base flow (7)	Total flow (8)
70	42	81	85	253	223	666	1350
71	0	68	80	238	213	666	1265
72		44	74	224	201	666	1209
73		24	68	208	190	666	1156
74		0	62	194	179	666	1101
75			55	180	169	666	1070
76			48	166	157	666	1037
77			41	152	146	666	1005
78			27	133	135	666	961
79			14	117	125	666	922
80			0	99	114	666	879
81				65	100	666	831
82				34	88	666	788
83				0	74	666	740
84					49	666	715
85					26	666	692
86					0	666	666

storm, the ordinates of the two stream hydrographs were added with respect to time to produce a total hydrograph at the junction of the two streams. Tables 14 through 18 in the Appendix list the ordinate values determined for the stream and total hydrographs for each of the five storms. The three hydrographs determined for each storm are plotted in Figures 18 through 22.

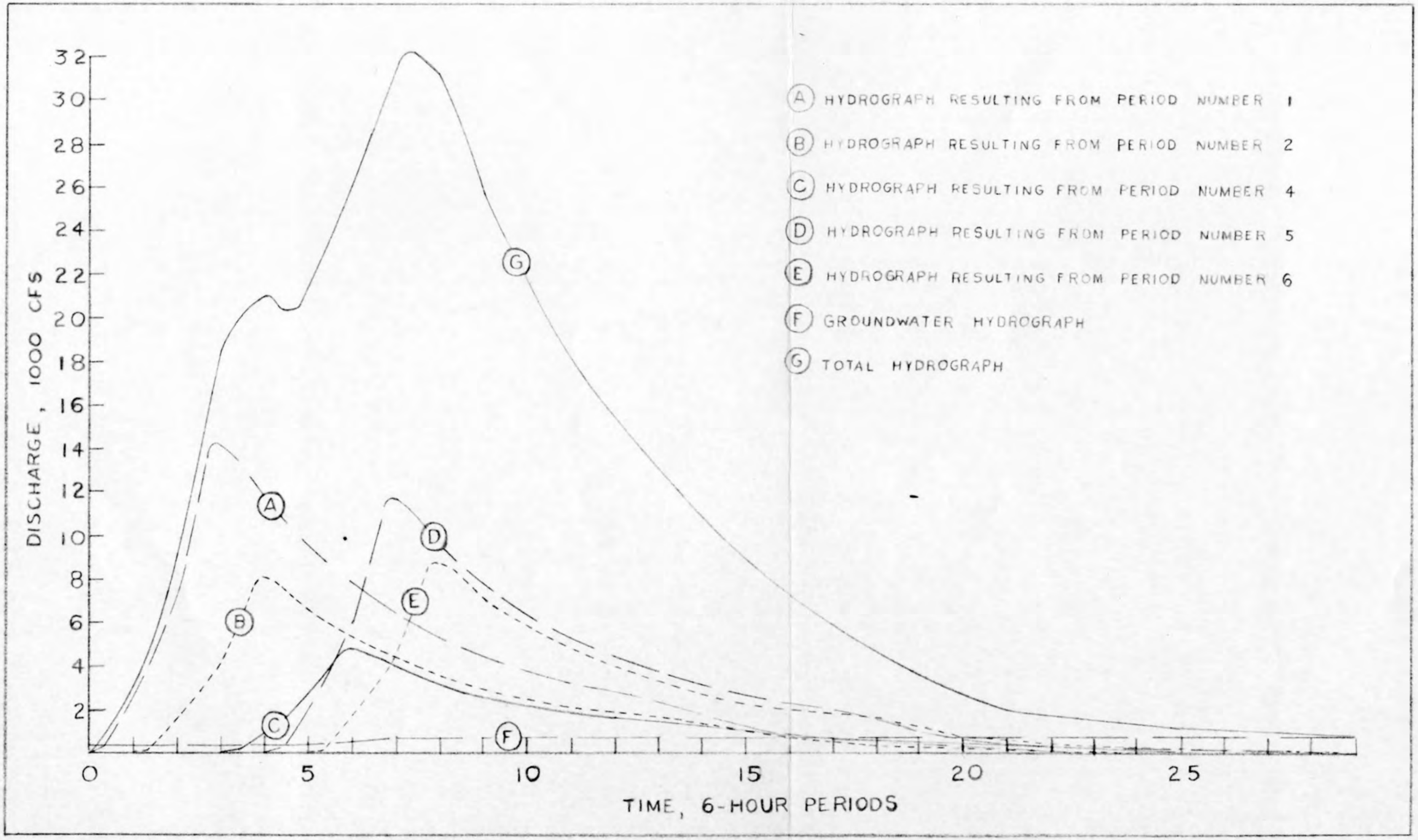

Figure 17. Development of the Skunk River hydrograph at the Squaw Creek junction for Storm MR 7-2B

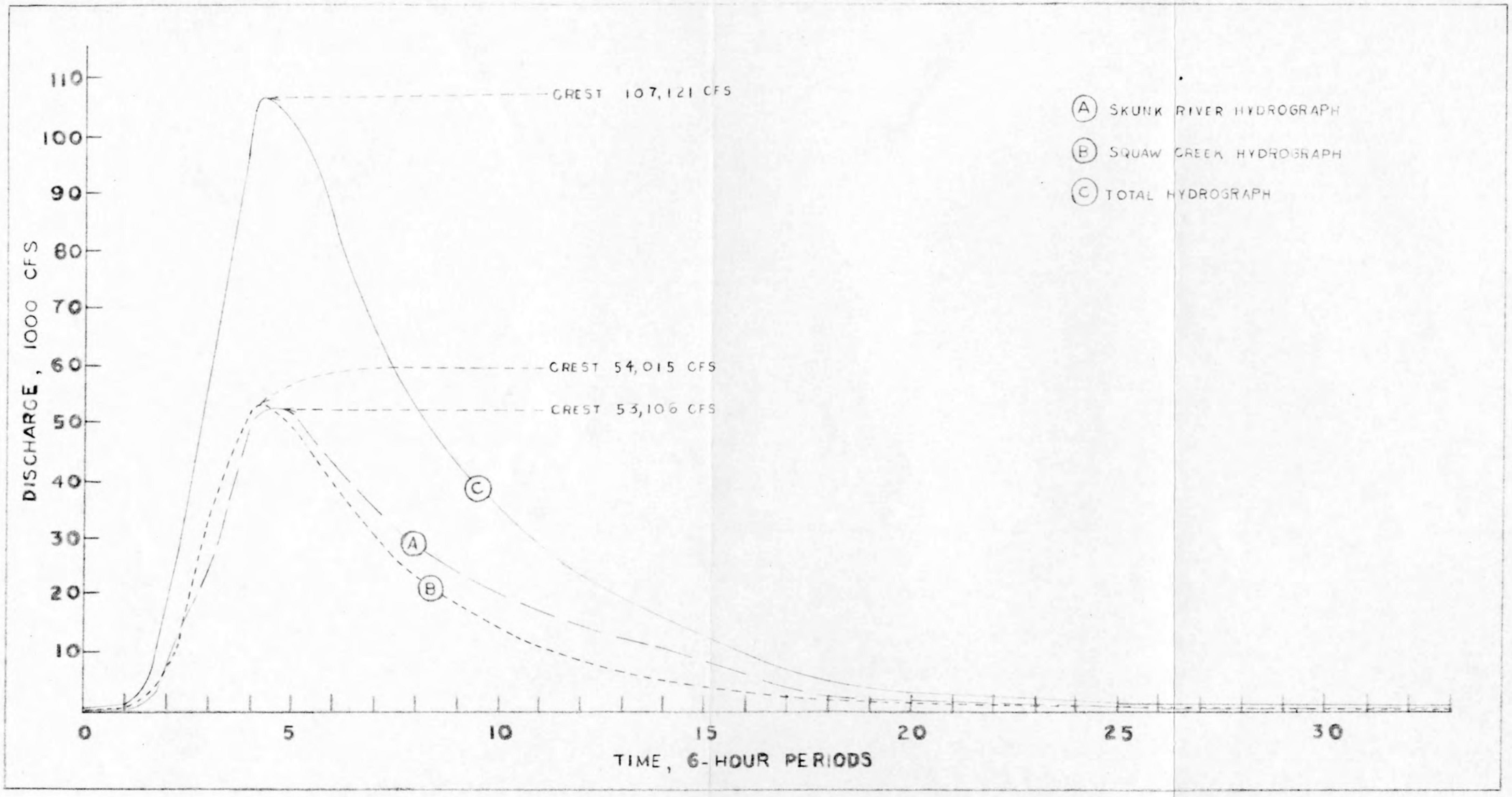

Figure 18. Hydrographs at the confluence of Skunk River and Squaw Creek resulting from Storm MR 4-24

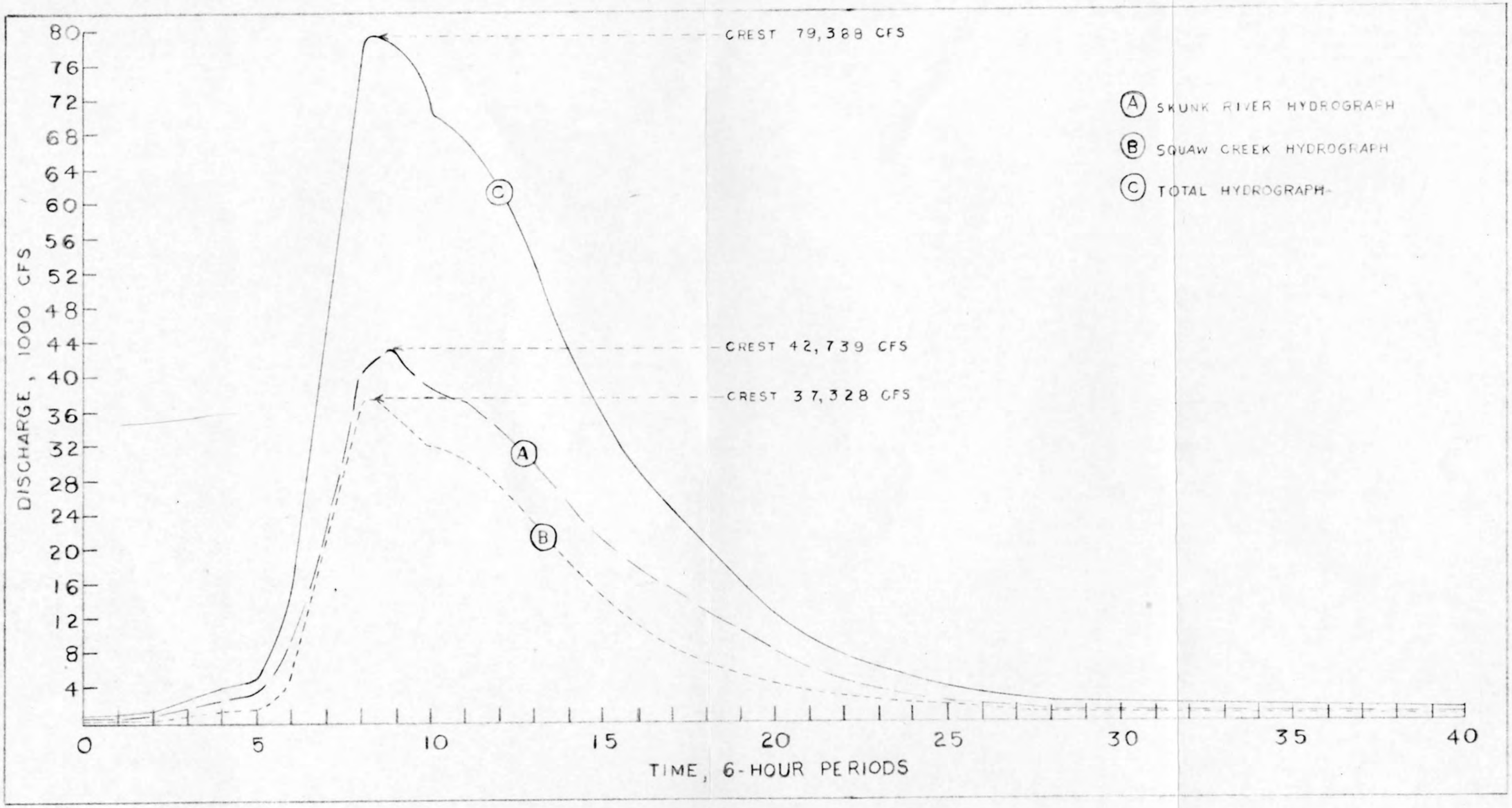

Figure 19. Hydrographs at the confluence of Skunk River and Squaw Creek resulting from Storm UMV 1-22

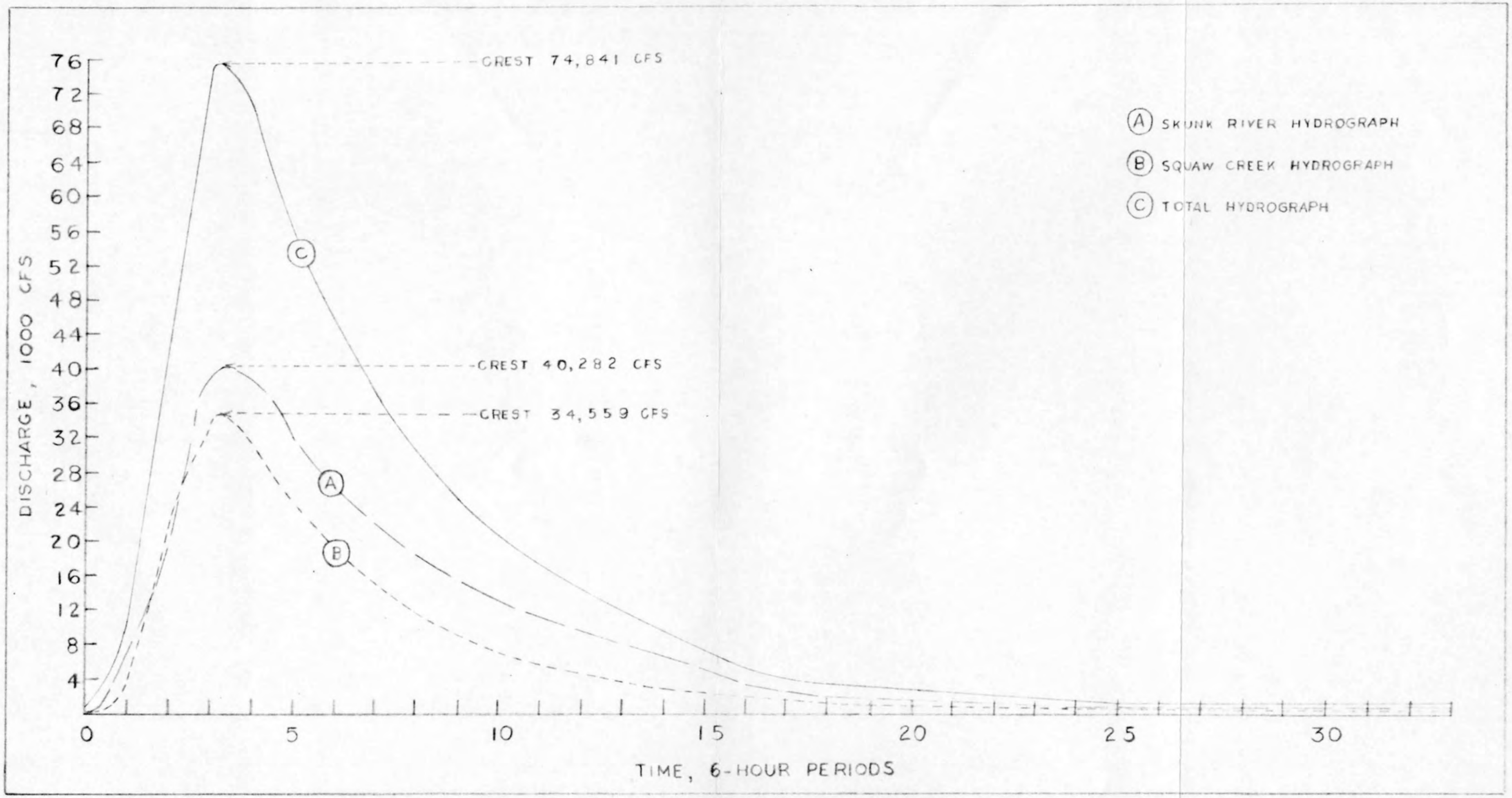

Figure 20. Hydrographs at the confluence of Skunk River and Squaw Creek resulting from Storm UMV 2-5

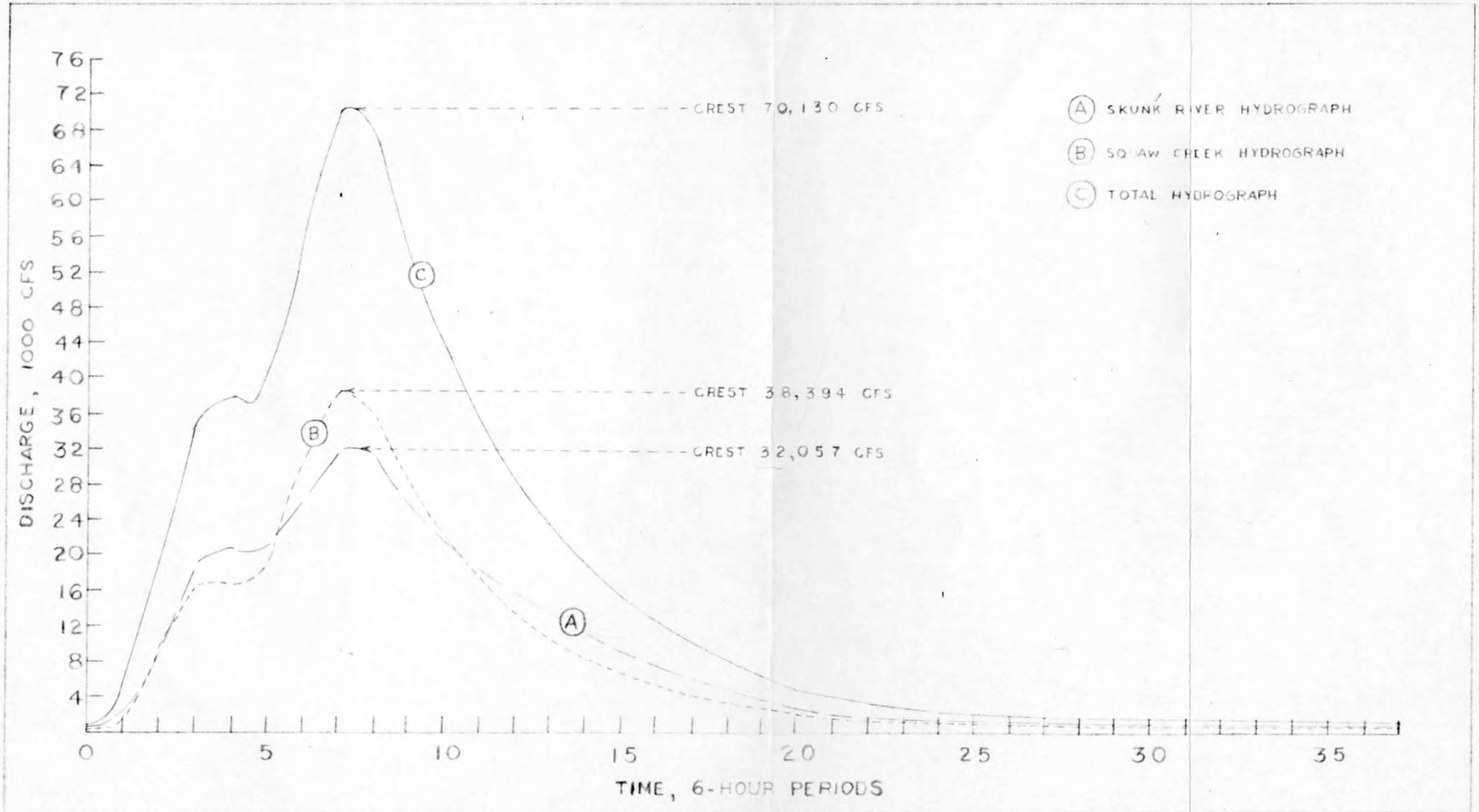

Figure 21. Hydrographs at the confluence of Skunk River and Squaw Creek resulting from Storm MR 7-2B

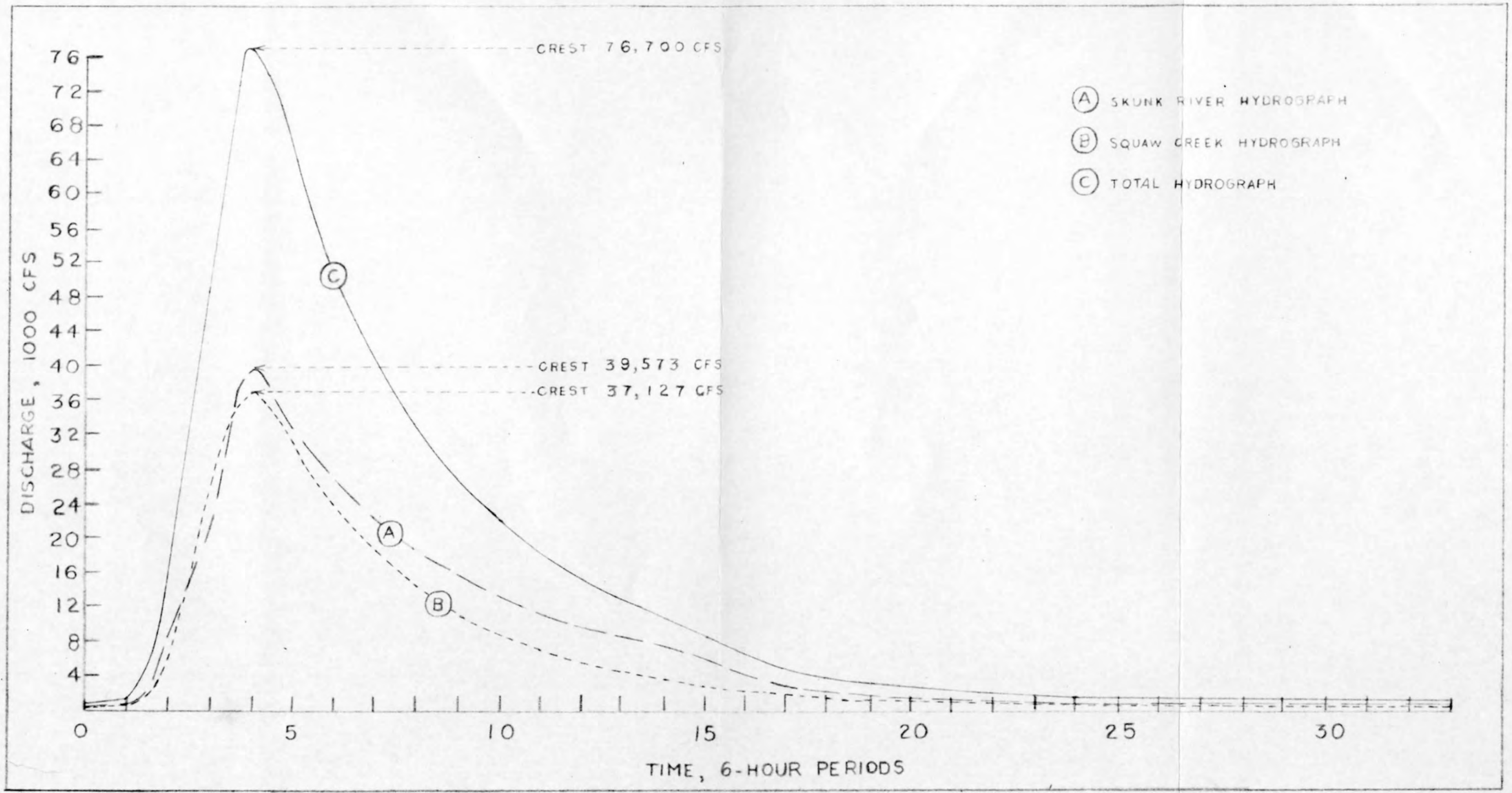

Figure 22. Hydrographs at the confluence of Skunk River and Squaw Creek resulting from Storm MR 6-15

IV. RESULTS

Tables 14 through 18 in the Appendix and Figures 18 through 22 were used to compare runoff resulting from the five storms considered. The peak discharges on the Skunk River resulting from each of the five storms are as follows:

MR 4-24 - - - - - - - - - 53,106 cfs
UMV 1-22 - - - - - - - - 42,739 cfs
UMV 2-5 - - - - - - - - - 40,282 cfs
MR 7-2B - - - - - - - - - 32,057 cfs
MR 6-15 - - - - - - - - - 39,573 cfs

The length of time that flood stage, 3490 cfs, would have been exceeded on the Skunk River for each of the storms is as follows:

MR 4-24 - - - - - - - - - 98 hours
UMV 1-22 - - - - - - - - 108 hours
UMV 2-5 - - - - - - - - - 90 hours
MR 7-2B - - - - - - - - - 108 hours
MR 6-15 - - - - - - - - - 88 hours

The peak discharges on Squaw Creek resulting from the five storms are as follows:

MR 4-24 - - - - - - - - - 54,015 cfs
UMV 1-22 - - - - - - - - 37,328 cfs
UMV 2-5 - - - - - - - - - 34,559 cfs
MR 7-2B - - - - - - - - - 38,394 cfs
MR 6-15 - - - - - - - - - 37,127 cfs

Flood stage, 3400 cfs, would have been exceeded on Squaw Creek for each of the five storms for the following periods of time:

MR 4-24 - - - - - - - - - 88 hours
UMV 1-22 - - - - - - - - 90 hours
UMV 2-5 - - - - - - - - - 76 hours
MR 7-2B - - - - - - - - -100 hours
MR 6-15 - - - - - - - - - 74 hours

The total peak discharges at the junction resulting from each of the five storms are as follows:

MR 4-24 - - - - - - - - - 107,121 cfs
UMV 1-22 - - - - - - - - 79,388 cfs
UMV 2-5 - - - - - - - - - 74,841 cfs
MR 7-2B - - - - - - - - - 70,130 cfs
MR 6-15 - - - - - - - - - 76,700 cfs

The length of time that flood stage, 2400 cfs or larger, would have been exceeded below the junction for each of the five storms is as follows:

MR 4-24 - - - - - - - - - 130 hours
UMV 1-22 - - - - - - - - 150 hours
UMV 2-5 - - - - - - - - - 120 hours
MR 7-2B - - - - - - - - - 138 hours
MR 6-15 - - - - - - - - - 120 hours

Storm MR 4-24 produced the largest flood on both the Skunk River and on Squaw Creek. A comparison of the record flow in the Skunk River of 8,630 cfs with the flow of 53,106 cfs shows how little of the flood potentiality of this river has been experienced to date.

It was determined that flows in excess of 3400 cfs cause the Squaw Creek to flood and that flows in the neighborhood of 6,000 cfs cause considerable flooding in several areas in the City of Ames. The transposition of Storm MR 4-24 produced a streamflow of 54,015 cfs in Squaw Creek which would undoubtedly cause great damage in the City of Ames.

The effect of valley storage in the two flood plains above the confluence has not been considered in this study. This storage would tend to reduce the peak of each flood. A stage-discharge relation has only been established for flows of less than 9,000 cfs in either channel. Any dependable prediction of the stage height that would be reached at the crest of the flood caused by each of the transposed storms would be impossible without a great deal more data than is available at this time.

V. CONCLUSIONS

Although serious flooding has occurred from flow in the upper reaches of the Skunk River Basin, the flood potential of this region has by no means been realized. After transposition of Storms MR 4-24, UMV 1-22, UMV 2-5, MR 7-2B, and MR 6-15 to this area, the following conclusions are drawn:

1. The five storms could have occurred over the Skunk River Basin with some adjustment in their relative magnitudes.

2. If Storm UMV 2-5 had occurred only 150 miles northwest of its actual location in southeastern Iowa, and if Storm MR 4-24 had occurred only 150 miles southeast of its actual location in northwestern Iowa, the Skunk River could have experienced flood discharges of about 75,000 cfs and 107,000 cfs, respectively, below the confluence with Squaw Creek. Such discharges are approximately eight to twelve times greater than the present maximum discharge of 8700 cfs experienced in August 1954. Flood discharges resulting from the other three storm transpositions are likewise in this general magnitude.

3. Flows produced in both the Skunk River and Squaw Creek near Ames were many times greater than any flows previously experienced in these streams during the period of record.

4. Floods of this magnitude would cause severe overflow above and below the confluence for a period of from three and

one half to five and one half days with associated high damage.

VI. LITERATURE CITED

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VII. ACKNOWLEDGMENTS

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APPENDIX

Table 14. Hydrograph ordinates in cfs for Storm MR 4-24

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
0	333	333	565	35	15863	9736	25599
1	333	259	592	36	15119	8965	24084
2	333	390	723	37	14469	8292	22761
3	333	708	1041	38	13870	7655	21525
4	811	1556	2367	39	13228	7065	20293
5	3575	3732	7307	40	12606	6532	19138
6	8480	7787	16267	41	11925	6048	17973
7	12913	14163	27076	42	11210	5590	16800
8	17624	23647	41271	43	10496	5168	15664
9	24852	33510	58362	44	9811	4791	14602
10	36196	42093	78289	45	9003	4437	13440
11	45505	48426	93931	46	8244	4110	12354
12	50440	52843	103283	47	7456	3819	11275
13	53106	54015	107121	48	6606	3556	10162
14	53103	52397	105500	49	5776	5300	9076
15	52331	50001	102332	50	5064	3065	8129
16	48929	46814	95743	51	4432	2860	7292
17	45817	43243	89060	52	3947	2666	6613
18	43065	39817	82882	53	3519	2483	6002
19	40120	36808	76928	54	3167	2324	5491
20	37874	33668	71542	55	2773	2175	4948
21	35615	30979	66594	56	2623	2013	4636
22	33381	28554	61935	57	2466	1907	4373
23	31489	26172	57661	58	2291	1787	4078
24	29692	24083	53775	59	2205	1679	3884
25	27974	22123	50097	60	2115	1589	3704
26	26259	20362	46621	61	2037	1496	3533
27	24766	18733	43499	62	1963	1424	3387
28	23421	17163	40584	63	1888	1318	3206
29	22043	15870	37913	64	1807	1286	3093
30	20890	14626	35516	65	1734	1213	2947
31	19760	13438	33198	66	1661	1162	2823
32	18618	12422	31040	67	1586	1104	2690
33	17588	11438	29026	68	1514	1056	2570
34	16721	10550	27271	69	1426	1011	2437

Table 14. Continued

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
70	1347	957	2304	86	666	593	1259
71	1260	918	2178	87	666	575	1241
72	1109	903	2012	88	666	558	1224
73	977	861	1838	89	666	549	1215
74	827	823	1650	90	666	545	1211
75	772	786	1558	91	666	541	1207
76	724	758	1482	92	666	541	1207
77	671	732	1403	93	666	540	1206
78	669	702	1371	94	666	538	1204
79	668	696	1364	95	666	536	1202
80	666	689	1355	96	666	518	1184
81	666	680	1346	97	666	501	1167
82	666	677	1343	98	666	483	1149
83	666	674	1340	99	666	477	1143
84	666	647	1313	100	666	471	1137
85	666	620	1286	101	666	464	1130

Table 15. Hydrograph ordinates in cfs for Storm UMV 1-22

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
0	333	232	565	35	35564	28471	64035
1	334	232	566	36	34429	27426	61855
2	338	232	570	37	33016	26083	59099
3	344	232	576	38	31447	24471	55918
4	374	238	612	39	29945	22830	52775
5	518	269	787	40	28271	21120	49391
6	773	345	1118	41	26598	19498	46096
7	1013	488	1501	42	25178	17954	43132
8	1216	698	1914	43	23712	16522	40234
9	1512	906	2418	44	22351	15219	37570
10	2012	1084	3096	45	21122	14005	35127
11	2429	1180	3609	46	19960	12914	32874
12	2594	1230	3824	47	18873	11895	30768
13	2628	1234	3862	48	17889	10953	28842
14	2779	1248	4027	49	17014	10098	27112
15	3173	1336	4509	50	16236	9319	25555
16	3763	1697	5460	51	15342	8585	23927
17	5885	2874	8759	52	14565	7926	22491
18	9609	5290	14899	53	13747	7335	21082
19	13445	9298	22743	54	12939	6773	19712
20	17442	15491	32933	55	12142	6252	18394
21	22756	22094	44850	56	11380	5789	17169
22	29439	28008	57447	57	10579	5356	15935
23	36616	32714	69330	58	9788	4954	14742
24	39999	36136	76135	59	9022	4594	13616
25	42060	37328	79388	60	8216	4263	12479
26	42614	36631	79245	61	7458	3954	11412
27	42739	35526	78265	62	6770	3667	10437
28	40970	34060	75030	63	6132	3413	9545
29	39453	32744	72197	64	5591	3175	8766
30	38666	31751	70417	65	5115	2953	8068
31	38066	31114	69180	66	3671	2752	7423
32	37811	30503	68314	67	4240	2566	6806
33	37164	30082	67246	68	3925	2382	6307
34	36468	29462	65930	69	3617	2239	5856

Table 15. Continued

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
70	3304	2091	5395	98	688	624	1312
71	3072	1957	5029	99	681	604	1285
72	2842	1844	4686	100	675	589	1264
73	2639	1730	4369	101	668	576	1244
74	2458	1637	4095	102	668	569	1237
75	2296	1534	3830	103	667	563	1230
76	2138	1460	3598	104	666	562	1228
77	2018	1373	3391	105	666	558	1224
78	1904	1307	3211	106	666	553	1219
79	1791	1240	3031	107	666	549	1215
80	1701	1178	2879	108	666	533	1199
81	1598	1124	2722	109	666	518	1184
82	1504	1063	2567	110	666	503	1169
83	1412	1017	2429	111	666	496	1162
84	1288	985	2273	112	666	488	1154
85	1174	941	2115	113	666	481	1147
86	1054	899	1953	114	666	481	1147
87	994	861	1855	115	666	480	1146
88	938	828	1766	116	666	480	1146
89	881	797	1678	117	666	478	1144
90	859	764	1623	118	666	476	1142
91	838	747	1585	119	666	474	1140
92	818	732	1550	120	666	471	1137
93	790	720	1510	121	666	469	1135
94	766	708	1474	122	666	467	1133
95	739	699	1438	123	666	466	1132
96	720	676	1396	124	666	465	1131
97	705	649	1354	125	666	464	1130

Table 16. Hydrograph ordinates in cfs for Storm UMV 2-5

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
0	333	232	565	35	10474	4970	15444
1	710	420	1130	36	9992	4600	14592
2	2884	1334	4218	37	9527	4264	13791
3	6745	3594	10339	38	9014	3963	12977
4	10204	7628	17832	39	8478	3675	12153
5	13782	14062	27844	40	7938	3411	11349
6	19230	20822	40052	41	7431	3175	10606
7	27972	26709	54681	42	6823	2952	9775
8	35142	31003	66145	43	6253	2748	9001
9	38685	33905	72590	44	5658	2567	8225
10	40282	34559	74841	45	5020	2402	7422
11	39860	33337	73197	46	4401	2241	6642
12	39062	31634	70696	47	3872	2092	5964
13	36367	29493	65860	48	3408	1965	5373
14	34005	27205	61210	49	3060	1844	4904
15	31977	25028	57005	50	2752	1731	4483
16	29750	23130	52880	51	2496	1630	4126
17	28088	21165	49253	52	2228	1537	3765
18	26413	19500	45913	53	2100	1432	3532
19	24814	18002	42816	54	1989	1368	3357
20	23463	16547	40010	55	1867	1292	3159
21	22167	15250	37417	56	1804	1225	3029
22	20910	14031	34941	57	1738	1170	2908
23	19619	12930	32549	58	1682	1110	2792
24	18520	11907	30427	59	1627	1066	2693
25	17528	10919	28447	60	1571	1010	2581
26	16472	10117	26589	61	1511	979	2490
27	15650	9331	24981	62	1457	932	2389
28	14816	8593	23409	63	1402	902	2304
29	13977	7956	21933	64	1346	865	2211
30	13245	7338	20583	65	1292	835	2127
31	12566	6782	19348	66	1227	805	2032
32	11938	6273	18211	67	1167	771	1938
33	11383	5789	17172	68	1101	748	1849
34	10917	5369	16286	69	987	741	1728

Table 16. Continued

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
70	886	715	1601	85	666	521	1178
71	770	691	1461	86	666	516	1182
72	734	666	1400	87	666	514	1180
73	702	648	1350	88	666	513	1179
74	666	630	1296	89	666	513	1179
75	666	610	1276	90	666	513	1179
76	666	607	1273	91	666	513	1179
77	666	603	1269	92	666	513	1179
78	666	600	1266	93	666	500	1166
79	666	600	1266	94	666	488	1154
80	666	600	1266	95	666	475	1141
81	666	582	1248	96	666	471	1137
82	666	563	1229	97	666	468	1134
83	666	544	1210	98	666	464	1130
84	666	533	1199				

Table 17. Hydrograph ordinates in cfs for Storm MR 7-2B

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
0	333	232	565	35	16129	14312	30441
1	498	313	811	36	15294	13177	28471
2	1454	709	2163	37	14512	12103	26615
3	3151	1687	4838	38	13674	11195	24869
4	4702	3447	8149	39	12935	10318	23253
5	6450	6297	12747	40	12210	9496	21706
6	9156	9383	18539	41	11498	8786	20284
7	13272	12219	25491	42	10811	8101	18912
8	16646	14514	31160	43	10163	7483	17646
9	18531	16204	34735	44	9528	6920	16448
10	19891	16875	36766	45	8888	6387	15275
11	20528	16746	37274	46	8302	5913	14215
12	20916	16635	37551	47	7758	5471	13229
13	20268	16742	37010	48	7235	5063	12298
14	20213	17703	37916	49	6779	4689	11468
15	21188	19573	40761	50	6339	4350	10689
16	22443	22429	44872	51	5898	4032	9930
17	24102	26424	50526	52	5464	3739	9203
18	26040	30644	56684	53	5089	3472	8561
19	28647	34178	62825	54	4687	3231	7918
20	30520	36714	67234	55	4289	3004	7293
21	31453	38394	69847	56	3942	2799	6741
22	32057	38073	70130	57	3575	2617	6192
23	31880	37046	68926	58	3243	2439	5682
24	31091	35209	66300	59	2939	2280	5219
25	29237	32881	62118	60	2659	2135	4794
26	27294	30322	57616	61	2412	2005	4417
27	25750	27896	53646	62	2219	1872	4091
28	24051	25705	49756	63	2053	1765	3818
29	22699	23569	46268	64	1899	1660	3559
30	21392	21680	43072	65	1795	1554	3349
31	20144	19985	40129	66	1698	1477	3175
32	19026	18346	37372	67	1592	1390	2982
33	17994	16880	34874	68	1523	1315	2838
34	17051	15528	32579	69	1432	1255	2687

Table 17. Continued

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
70	1350	1192	2542	91	666	609	1275
71	1265	1136	2401	92	666	604	1270
72	1209	1078	2287	93	666	585	1251
73	1156	1034	2190	94	666	565	1231
74	1101	985	2086	95	666	548	1214
75	1070	943	2013	96	666	536	1202
76	1037	907	1944	97	666	523	1189
77	1005	877	1882	98	666	515	1181
78	961	852	1813	99	666	512	1178
79	922	819	1741	100	666	510	1176
80	879	797	1676	101	666	510	1176
81	831	775	1606	102	666	507	1173
82	788	744	1532	103	666	504	1170
83	740	713	1453	104	666	501	1167
84	715	688	1403	105	666	492	1158
85	692	667	1359	106	666	484	1150
86	666	650	1316	107	666	476	1142
87	666	632	1298	108	666	472	1138
88	666	626	1292	109	666	468	1134
89	666	622	1288	110	666	464	1130
90	666	613	1279				

Table 18. Hydrograph ordinates in cfs for Storm MR 6-15

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
0	333	232	565	35	10200	6022	16222
1	350	255	605	36	9765	5558	15323
2	451	366	817	37	9403	5158	14561
3	630	640	1270	38	9045	4775	13820
4	1229	1350	2579	39	8614	4425	13039
5	3929	3205	7134	40	8177	4099	12276
6	8683	6678	15361	41	7681	3813	11494
7	12963	12074	25037	42	7181	3536	10717
8	16505	19848	36353	43	6683	3284	9967
9	21324	27393	48717	44	6243	3056	9299
10	30110	33073	63183	45	5683	2845	8528
11	37242	35938	73180	46	5170	2649	7819
12	39573	37127	76700	47	4607	2476	7083
13	38027	36067	74094	48	4042	2322	6364
14	34736	33530	68266	49	3489	2167	5656
15	32836	30895	63731	50	3062	2021	5083
16	30141	28383	58524	51	2716	1899	4615
17	28521	26099	54620	52	2501	1785	4286
18	26768	24013	50781	53	2292	1676	3968
19	25096	22248	47344	54	2116	1581	3697
20	23695	20334	44029	55	1874	1491	3365
21	22331	18740	41071	56	1799	1386	3185
22	20982	17248	38230	57	1731	1328	3059
23	19822	15864	35686	58	1677	1255	2932
24	18723	14602	33325	59	1628	1198	2826
25	17701	13431	31132	60	1573	1140	2713
26	16564	12385	28949	61	1524	1085	2609
27	15641	11408	27049	62	1476	1043	2519
28	14816	10452	25268	63	1427	988	2415
29	13959	9698	23657	64	1372	961	2333
30	13303	8947	22250	65	1324	913	2237
31	12596	8255	20851	66	1275	887	2162
32	11899	7635	19534	67	1226	846	2072
33	11258	7040	18298	68	1178	822	2000
34	10698	6512	17210	69	1113	791	1904

Table 18. Continued

2-hr per.	Skunk River	Squaw Creek	Total flow	2-hr per.	Skunk River	Squaw Creek	Total flow
70	1056	759	1815	85	666	552	1218
71	992	734	1726	86	666	529	1195
72	879	730	1609	87	666	522	1188
73	779	707	1486	88	666	514	1180
74	666	682	1348	89	666	514	1180
75	666	651	1317	90	666	514	1180
76	666	636	1302	91	666	514	1180
77	666	621	1287	92	666	514	1180
78	666	606	1272	93	666	512	1178
79	666	606	1272	94	666	511	1177
80	666	606	1272	95	666	509	1175
81	666	604	1270	96	666	494	1160
82	666	601	1267	97	666	479	1145
83	666	599	1265	98	666	464	1130
84	666	575	1241				