WRIGHT-McLAUGHLIN ENGINEERS
ENGINEERING CONSULTANTS
2420 ALCOTT STREET
DENVER, COLORADO 80211
(303) 458-6201

December 9, 1980

Mr. Bill DeGroot
Urban Drainage and Flood
Control District
2480 W. 26th Avenue, Suite 156-B
Denver, Colorado 80211

Re: Lena Gulch Flood Hazard
Warning Program

Dear Bill:

We have completed our contract No. 80-8.1 with the submission of this report. The report contains the following:

Section I	Summary
Section II	Review of Hydrology and Related Flood Hazard Information Needs
Section III	Stream Gaging Sites
Section IV	Flow Predictions

The system proposed for determination of probable flood hydrology uses a simplified synthetic hydrograph procedure which is founded on our earlier MITCAT computer model work. On an interim basis next season the tables provided may be used for predictive information regarding Maple Grove Reservoir.

These tables and others for determining predictive flows at other points in the basin will need to be developed by further analysis with the MITCAT model (or a similar effort).

We have enjoyed working on this interesting assignment. If we can provide further assistance please feel free to call.

Very truly yours,

WRIGHT-McLAUGHLIN ENGINEERS

By *William C. Taggart*
William C. Taggart

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802-070

SECTION I
SUMMARY

The purpose of this report is to review the Lena Gulch watershed hydrology and Maple Grove Reservoir operating procedures in the light of a flood hazard warning program; to analyze the possible locations for stream flow gages; and to investigate decision aide concepts.

LENA GULCH HYDROLOGY

The Lena Gulch watershed is a long, relatively narrow 13.84 square mile basin running from Lookout Mountain to Clear Creek near Kipling. The basin response from rainfall is quick and peak flows occur almost simultaneously along the Gulch. The only exception to this is a delay caused by waters flowing through Maple Grove Reservoir. This reservoir routing creates a situation in Wheat Ridge downstream where two peaks can occur.

Because of this quick response, the primary information required for a flood hazard warning system is rainfall predictions through radar and rainfall confirmations by rainfall gages in the basin. Because of the need to have hydrograph information for Maple Grove Reservoir, routings and flow predictions downstream and the likely error range in runoff predictions based soley on rainfall data, stream gaging is required.

There are many areas of special concern which need observation and flood hazard warning actions. These include:

1. Apex Gulch - A potential overflow out of the basin can occur near Heritage Square Shopping Center.

2. Jackson Gulch - Magic Mountain Dam No. 1 should be periodically observed (also near Heritage Square).

3. Jefferson County and Lakewood - Trailer courts near US 40 and US 6 should be monitored since they are in the floodplain; also there are numerous potential road crossing and undermining problems near structures.

4. Maple Grove Reservoir - See the discussion in Section II.

5. Wheat Ridge - Lena Gulch can carry only limited capacity until the floodway project is completed. Overflows leave the channel area and flow through a large neighborhood. There are also numerous tributary inflows that present a flood hazard.

STREAM GAGING

There are numerous potential stream gaging sites. Table III-1 presents a recommended system which is based in part on the recommended decision aid concept. Basically, telemetered (gages that are capable of automatically transmitting data to an interpretative/recording center) gages are recommended at the inflow to the reservoir of Maple Grove Dam. US 6 presents a good site for a telemetered or simple staff gage (to be reported by a field observer). This will monitor flow from the mountainous headwater area. The spillway flows of Maple Grove will need to be monitored to confirm flow predictions. Two interim staff gages are recommended in Wheat Ridge which will measure the total flow before overflows leave the channel area and to measure the flow left in the channel after overflows occur.

INTERPRETATIVE SYSTEM

For a variety of reasons such as: 1) The error range of rainfall predictions, 2) The basin's sensitivity to rainfall patterns, 3) The significant effect of infiltration and 4) The need to have information regarding timing and volume for Maple Grove Reservoir routings and flow predictions downstream the only type of system that was found to have a reasonable level of reliability was a simplified synthetic hydrograph procedure. Two tables were derived which would allow a technician to input rainfall data (predicted and/or recorded) and calculate the resulting hydrograph. A table was also developed for Maple Grove Reservoir routings. Figure IV-1 illustrates the basic mechanics of the system. We have also noted that all calculations could be put on a hand held programable calculator so that hydrographs could be determined quickly.

SECTION II
REVIEW OF HYDROLOGY
AND RELATED FLOOD HAZARD INFORMATION NEEDS

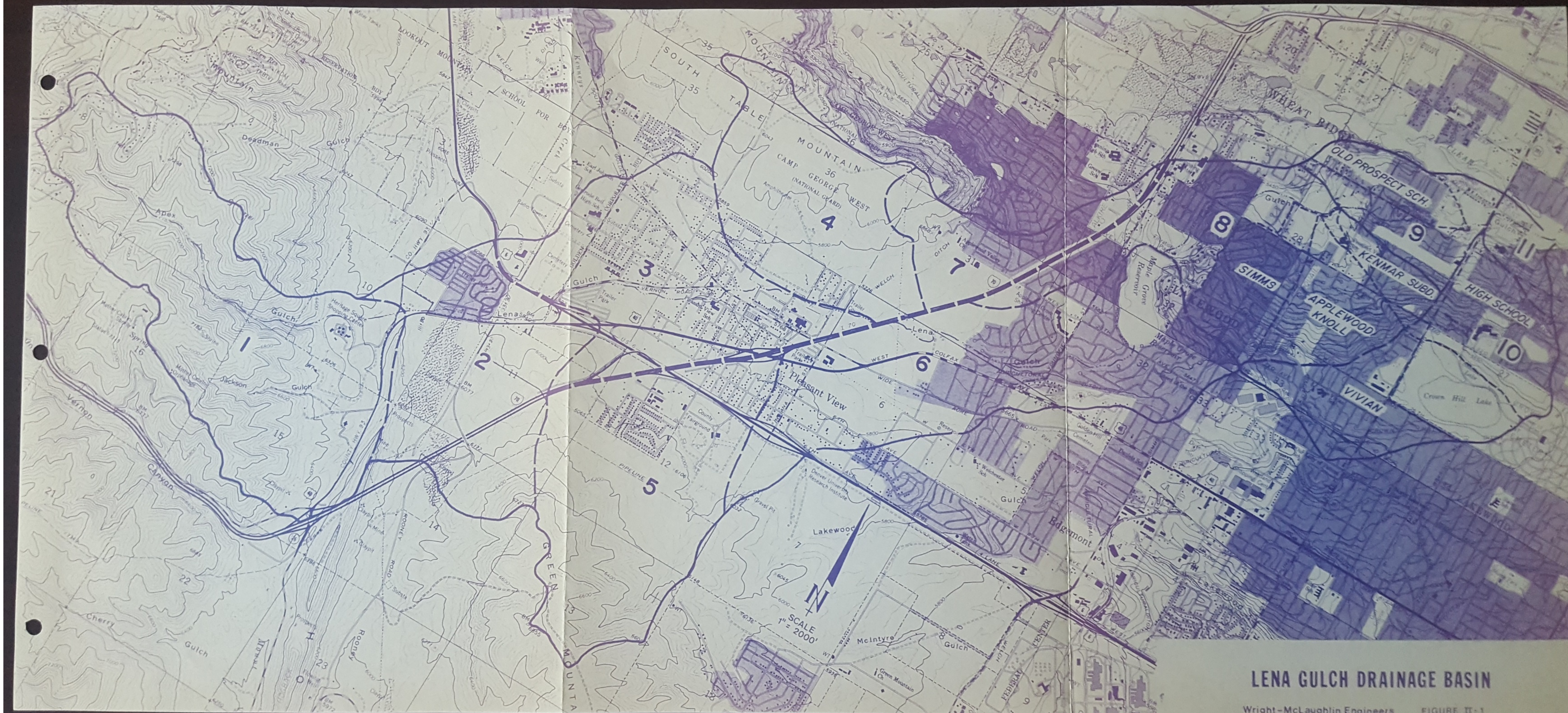
INTRODUCTION

The purpose of this section is to review the hydrology of the Lena Gulch watershed with emphasis on response characteristics that will affect the design of a flood hazard warning system. Besides the watershed hydrology, the operation and response characteristics of Maple Grove Reservoir are reviewed.

Lena Gulch as depicted on Figure II-1 is a 13.84 square mile basin. It has a tributary area which extends into a wide variety of topographic and land use features. It includes Lookout, South Table and Green Mountains, and areas of South Golden, Jefferson County, Northwest Lakewood, and Wheat Ridge. Lena Gulch flows approximately eleven miles from its headwaters on Lookout Mountain eastward to its confluence with Clear Creek near Kipling Street. The stream in the foothills, called Apex Gulch, is a rugged and natural stream with frequent bedrock outcrops. Below Heritage Square at the toe of the foothills, Jackson Gulch joins Apex Gulch and the major stream becomes Lena Gulch.

BASIN DESCRIPTION

The following descriptions present the hydrological characteristics of the basins and flood hazard problems. For simplicity, any given reach will be identified by the same number as the basin it is flowing through. (i.e., reach 2, 3, 6, 8, 9 and 11 form Lena Gulch).Also noted are the nearest streets at the lower end of the basin.



LENA GULCH DRAINAGE BASIN

Wright-McLaughlin Engineers FIGURE II-1

<u>Basin 1</u> (US 40 and County Hwy. 93)

Basin 1 as depicted on Drawing No. 1 is the western-most, mountainous area of Lena Gulch. Apex Gulch and Jackson Gulch join to form Lena Gulch at the bottom of the basin in the vicinity of Heritage Square. Light residential development is located on the higher ridges of the basin, and commercial development in the lower portion. At the Heritage Square development there is the potential for heavy floods to overflow out of the basin towards Golden.

<u>Basin 2</u> (US 6)

Basin 2 is a geologically complex basin located generally south of Lena Gulch and between the Hogback and Green Mountain. It does not contribute significantly to runoff flows because much of the basin has natural or man-made retention.

Lena Gulch runs eastward through trailer courts. The natural streambed has been replaced by a system of man-made ditches and underground conduits that are either eroded or filled with sediment and debris. In some locations, large amounts of sediment have been deposited whereas in other areas the channel has eroded vertical banks in claystone-type material.

<u>Basin 3</u> (I 70)

This area is largely residential with strip commercial areas along the major roads. The trailer court development, Mountain Side Mobile Estates, moved Lena Gulch north to a small low capacity channel. The undercapacity of this channel is quite apparent when compared with the State Highway crossing upstream which has two 10-foot wide by 10-foot high culverts whereas the trailer court trapezoidal channel is only 11 to 12 feet wide and 3-1/2 to 4 feet deep. Below this area, the channel is more natural and slower flowing.

The entire reach of Lena Gulch in Basin 3 has undersized culverts. As the stream passes through Camp George West, it travels in a fairly well defined swale that has rock-lined banks. The Welch ditch crosses just below Camp George West in a concrete structure that has a 16-foot wide opening. As Lena Gulch passes through the remainder of Basin 3, it begins to cut a deeper channel. Near the culvert passing through I-70, the channel is approximately 15 feet deep.

Basin 4 (I 70)

Basin 4 is the portion of South Table Mountain that drains to Lena Gulch from above Camp George West. It includes the site of the Solar Energy Resource Institute facility.

Basin 5 (I 70 and US 40-Colfax)

Basin 5 is the portion of Green Mountain that drains to Lena Gulch above I-70. This area also has a variety of geological formations and the highest landslide hazards. This basin includes a wide range of development.

Several tributary streams exist that join together above I-70 near the Colfax Interchange and then flow into Lena Gulch.

Basin 6 (W. 20th Ave.-Maple Grove Resevoir)

This basin is the area below I-70 that drains into Lena Gulch above Maple Grove Reservoir.

The lower two-thirds of this basin is developed in residential dwellings, with the upper third being developed in both commercial and residential usage.

Some erosion control measures have been installed along the lower reaches of the basin. The channel capacity, however, is somewhat insufficient. Below Alkire Street and above Youngfield Street, the channel conditions fluctuate. Some areas have fair channel capacity and condition. Other locations exhibit erosion problems. The culvert under Youngfield Street is usually heavily silted, but tends to self clean due to the high head over the culvert. From Youngfield to Maple Grove Reservoir, Lena Gulch has fair channel capacity with erosion being the most serious problem as several homes are quite near the stream.

Basin 7 (W. 32nd Ave. and I-70)

This basin has the same general geological setting as Basin 4 but sheds runoff to Lena Gulch in a multitude of outfalls such as 20th Avenue, Rocky Mountain Ditch, 32nd Avenue, and various highway culverts. There is some undeveloped area on the South Table Mountain and residential development in the area below.

Basin 7 was simulated as flowing into Lena Gulch below the Maple Grove Reservoir.

Basin 8 (Quail St.)

This basin represents the portion of the watershed that is tributary to Lena Gulch below Maple Grove Reservoir and above the general location of Quail St. where the carrying capacity is considerably diminished and widespread flooding occurs.

The channel generally has reasonable capacity with the exception of undersized culverts and a few locations where sedimentation exists.

To better simulate the hydrologic response of Basin 8 during the final design phase of the Wheat Ridge Lena Gulch drainageway, three subbasins were delineated. These three subbasins are called Simms, Applewood Knolls, and the Kenmar Subdivision. Drainage from these areas, which can be a significant problem, enters Lena Gulch at many points, mostly in overland sheet and stream flow.

<u>Basin 9</u> (Kipling)

This basin is almost entirely developed with the exception of some open fields near Kipling Street.

The primary problem in this basin is that Lena Gulch has been constricted to such a severe degree that any significant flow floods an extremely wide area north of the stream.

For example, the Red Barn Store near 38th Avenue and Miller Court is actually built over Lena Gulch. The natural drainageway has been replaced by a 5-foot diameter concrete pipe which daylights to the east in about a 4-foot square box culvert. Besides the small capacity, the entrance conditions to the conduit and a trash rack result in restriction of most of the water flow.

Overflow which leaves Lena Gulch flows to the north. With the drainageway improvements this overflow will be eliminated except for events greater than the 100-year flood. The area to the north where flooding now occurs will ultimately be a separate subbasin and has been referred to as the Old Prospect School Subbasin.

The flow down through Old Prospect Subbasin largely stays in the streets where there are actually three outfall routes. One is on the north side of the basin and is generally parallel to 41st generally headed in a line towards the Seven-Eleven food store at Kipling. Another is an old irrigation ditch that drains most of the area. The third drainage will probably flow in 38th Place and traverse across the school grounds and join Lena Gulch.

Basin 10 (W. 38th Ave. and Kipling)

This is the area south of Lena Gulch along Kipling.

The immediate area around Crown Hill Lake has a delayed runoff response in regard to Lena Gulch flows. For this reason, this area was removed from the model schematic. The remaining portion of the basin logically divides into two subareas because the upper portion is much flatter than the lower portion. The upper and lower subbasins are respectively called Vivian and Highschool Subbasins. The importance of recognizing these basins is that significant overland flood problems can be caused by their flows traveling towards Lena Gulch.

Vivian Subbasin: Of the upper basin, it appears that the majority of the area south of 26th drains to a point east of Kipling near Crown Hill Lake. The triangle of the area to the northwest of the intersection of 26th and Kipling drains to a park area that is depressed at least six feet below all adjacent buildings and property. In Kipling adjacent to this park, there is a storm sewer system which outfalls directly to Clear Creek. From field inspection, it appears that the drainage area south of 26th also winds its way to this location. This is confirmed on the topographic maps of the Crown Hill area. This area of Kipling then becomes a sump, drained only by infiltration and what is carried off by the storm sewer system. As such, this basin is modeled with an ultimate outfall of a 48-inch RCP under surcharged conditions.

Highschool Subbasin: The Kipling roadway tends to be the major drainage route for this subbasin. As flow approaches 38th and Kipling it has the opportunity to travel in several directions.

It is also possible for the Rocky Mountain Ditch to intercept flow and carry it to other locations and overflow points.

Basin 11 (Clear Creek)

This is the small area below Kipling Street tributary to Lena Gulch immediately before its confluence with Clear Creek. The flatter northern portion along Lena Gulch and Clear Creek is subject to flooding. It is apparent that the stream alignment has been moved in the past 50 years to its present east-west direction. This has resulted in a flat streambed that has silted to such a degree that the channel capacity is quite low.

SUMMARY OF SPECIAL CONCERNS

Lena Gulch has six areas of concern which can be singled out. These are Apex Gulch, Jackson Gulch, floodplain trailer courts, Maple Grove Reservoir, Reach 9, and Reach 11.

Apex Gulch

Apex Gulch is susceptible to heavy flash flooding with eroded materials deposited downstream. It is possible for some portion of heavy flows to actually leave the watershed and travel towards Golden near Heritage Square. This situation should be monitored.

Jackson Gulch

A small pond, listed as Magic Mountain Dam No. 1 by the State Engineer's Office, is located on the mainstream of Jackson Gulch. The dam itself is approximately 30 feet high with a top width of 15 feet and a crest length of 540 feet. The spillway is essentially a broad crested wier 28 feet wide with a clearance of 4 feet before the low chord of the railroad bridge passing over it. The approximate safe discharge capacity of the spillway is estimated to be 700 cfs. This would be capable of handling more than 100-year peak flow from this portion of the basin. However, the condition of the dam should be monitored.

Trailer Courts

The trailer courts in Basin 2 and 3 have been built so that they have brought hazard upon themselves. The channel alignment has been moved significantly from historical conditions. It has also been constricted as a result of varying degrees of filling and siltation.

This area is of particular concern since the floods will probably occur with little warning because of the rather quick hydrological response of the mountainous areas above.

Basins 9 and 11

The lower reach of Lena Gulch has been restricted, realigned and abused by development to such an extent that almost the entire lower area of the watershed is subject to flooding. Two major items cause this flooding:

1. The channel has been restricted to a minimum capacity by development.

2. The Red Barn Store was built over Lena Gulch, and the watercourse replaced with a small conduit, resulting in the backup and diversion of the major portion of the flood flows to the north.

Maple Grove Dam and Reservoir

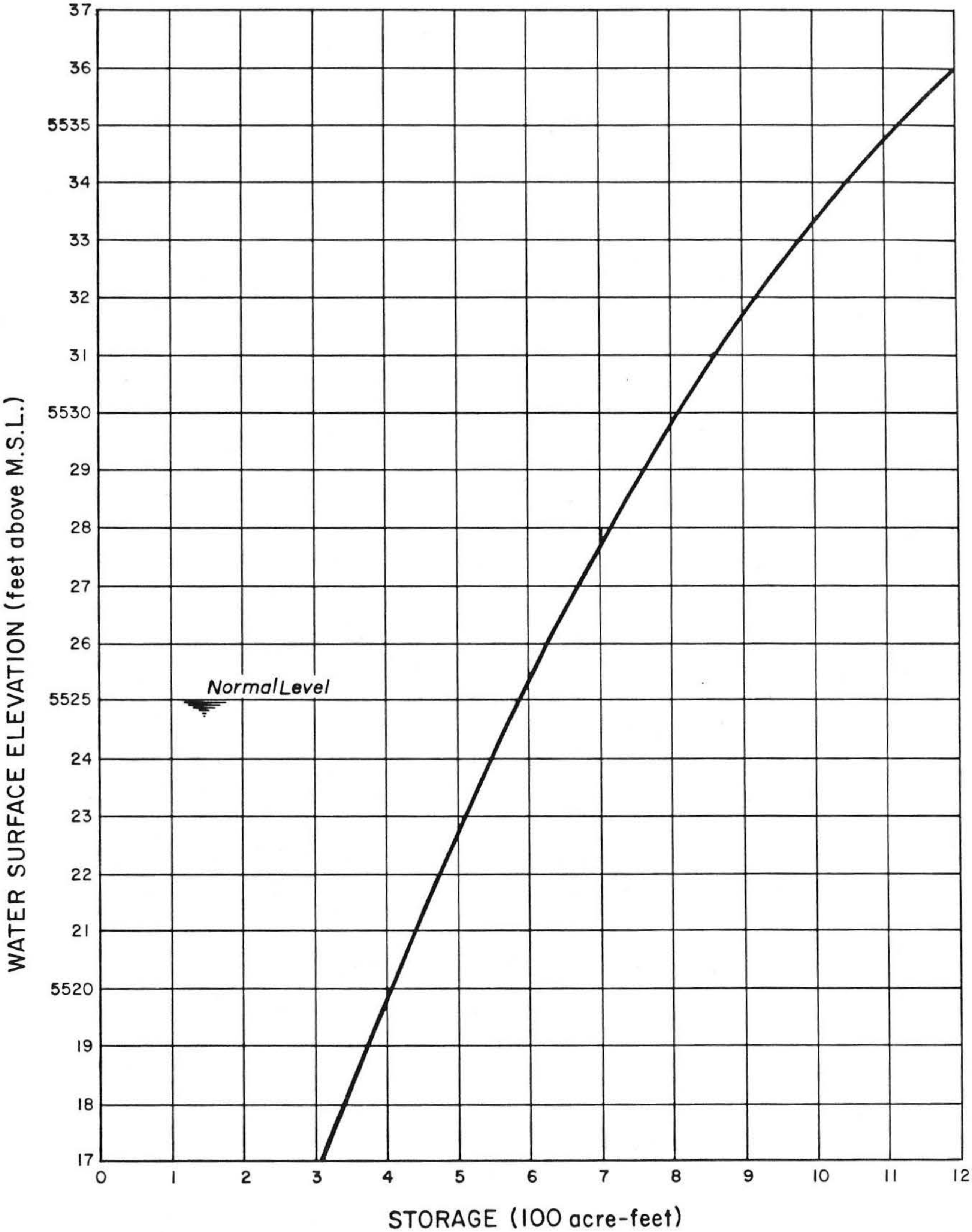
Improvements have been made to the dam and spillway which allow safe passage of the Standard Project Flood (SPF), flood peak reduction for events up to the 100-year flood, and optimal reservoir operations. The following information is taken from documents supplied by Consolidated Mutual Water Company.

The improved spillway is 70 feet wide and has two inflatable fabri-dams separated by a wall. The invert elevation of the concrete spillway is 5,520.0. The smaller fabridam is 6-feet high (max.) by 30-feet long and controls the reservoir to a normal operating level of 5,525.0. The larger fabridam is 10-feet high by 40-feet long and would only deflate during severe emergencies greater than the 100-year flood.

An erodible cofferdam, located upstream of the fabri-dams, has an overall elevation of 5,527 with a pilot channel which has an invert elevation of 5,526. In the event of an emergency failure or malfunction of the fabri-dam this would prevent the sudden release of the water stored between elevation 5,520 and 5,526. This cofferdam has no appreciable effect on the flood related characteristics of the dam and spillway.

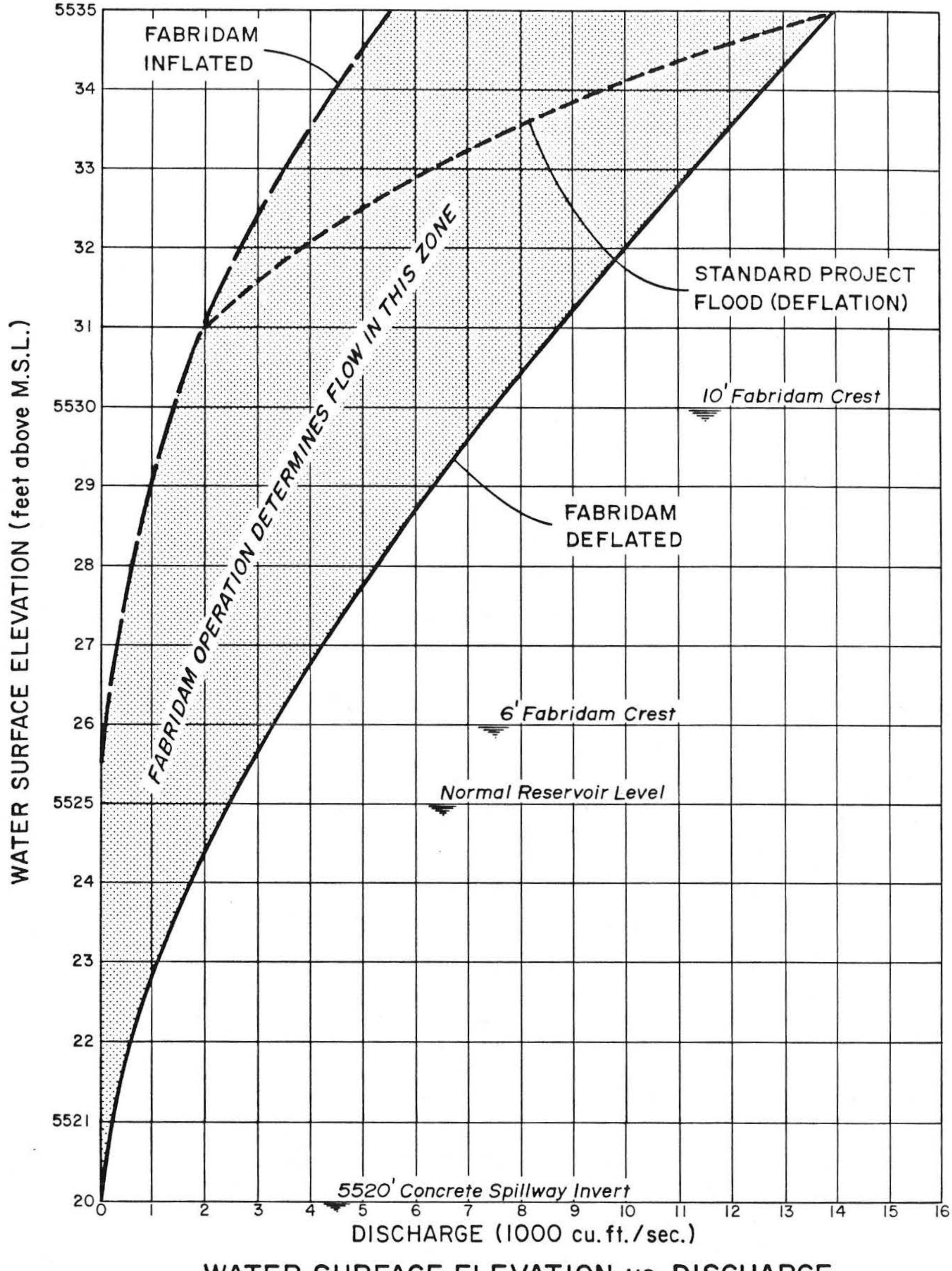
Figure II-2 presents the elevation-storage curve for Maple Grove Reservoir. Figure II-3 presents the water surface elevation - discharge curve for the spillway. Shown as the solid line is the discharge curve with the fabri-dams deflated. The long dash line is the discharge curve when the fabri-dams remain inflated. The zone between these two curves represents the discharge relationships that are possible depending on the dam control settings.

To achieve optimal flood storage benefits for floods in the 0-100 year frequency range, the fabri-dams would remain inflated until the water surface in the reservoir reached 5,531.0. When the water surface reaches this elevation then the fabri-dams would begin deflating and continue until completely deflated as long as the water surface elevation continued rising. If the water surface elevation in the reservoir began dropping after the dams had deflated to some level, then the fabri-dams would cease deflating and begin inflating, continuing until completely inflated as long as the water surface elevation continued to drop. The short dash line in Figure II-3 represents the assumed stage-discharge relation (provided by Consolidated Material) when the fabri-dams are deflating for the occurrence of a Standard Project Flood.



WATER SURFACE ELEVATION vs. STORAGE
MAPLE GROVE RESERVOIR

FIGURE II - 2



WATER SURFACE ELEVATION vs. DISCHARGE

MAPLE GROVE RESERVOIR SPILLWAY (70' WIDTH)

FIGURE II - 3

The maximum water surface elevation in the reservoir during the occurrence of a Standard Project Flood in Lena Gulch will be 5,534.9. The dam embankment is 5,535.0, thus providing minimal freeboard during the occurence of the SPF inflow design flood.

LENA GULCH FLOOD HYDROLOGY

The primary hydrology tool used for Lena Gulch was a computer model called the Massachusetts Institute of Technology Catchment Model (MITCAT). The model uses basic fluid mechanics to separately analyze the overland flow and stream flow portions of surface runoff. The design rainfall in Table II-1 is the basic input to the overland flow area, (catchment) which then inputs to the stream.

A more detailed explanation of the hydrology and backup data is presented in the "Lena Gulch Master Plan" and other references.

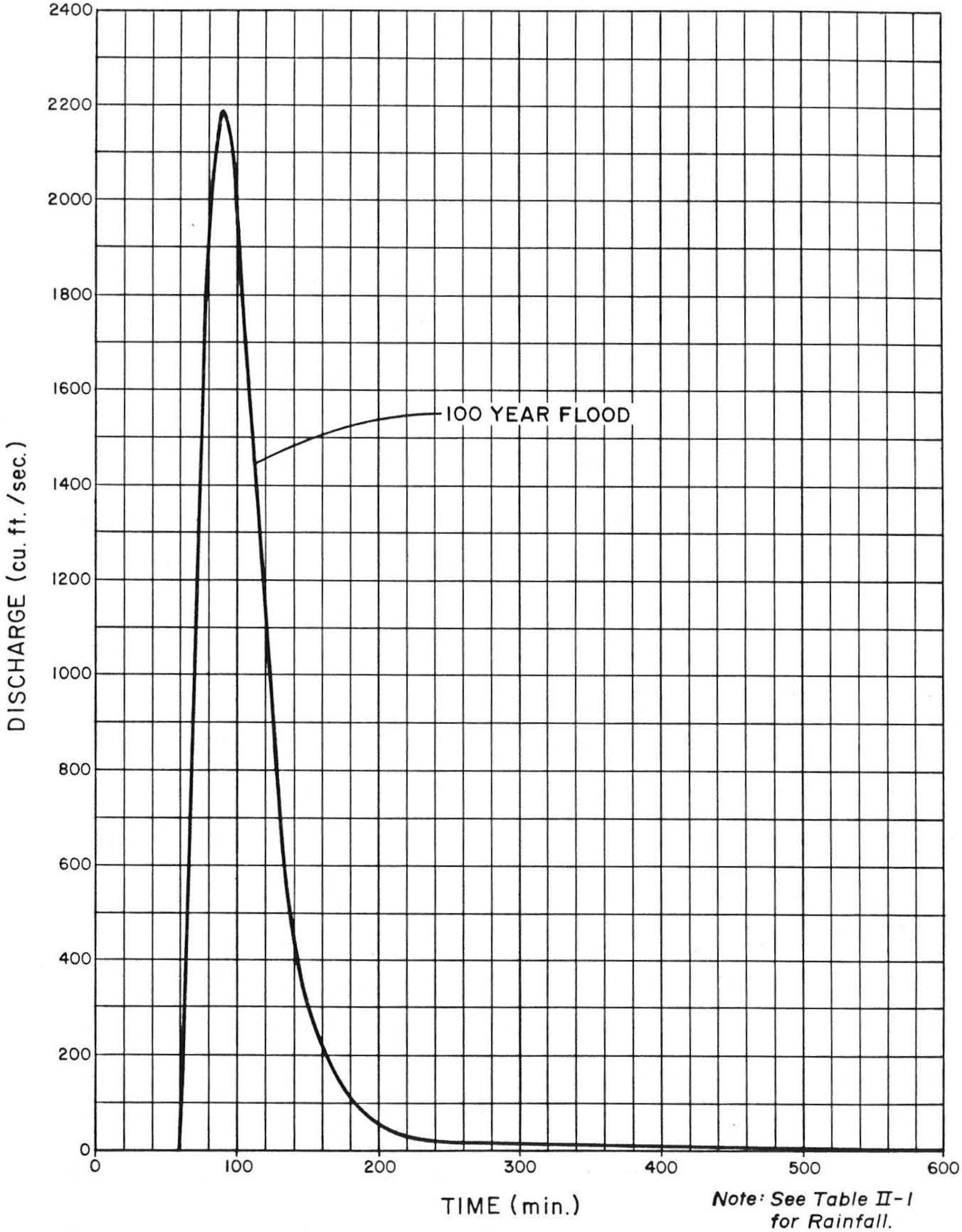
Figure II-4 presents a 100-year discharge hydrograph at U.S. 6. Figure II-5 and II-6 present hydrographs at Maple Grove Reservoir. Shown first are the 100-year flood hydrographs in and out of the reservoir and the 10-year flood hydrograph out of the reservoir. The 100-year floodpeak is reduced from 3,800 cfs to 1,725 cfs and the 10-year floodpeak is reduced from 1,650 cfs to 825 cfs. The second graph illustrates that the reservoir has no substantial reduction in the Standard Project Flood of 14,000 cfs but delays the peak 20 to 30 minutes.

Figures II-7 and II-8 illustrate discharge hydrographs for the 10- and 100-year floods at the upstream end of Basin 9 and the confluence with Clear

TABLE II-1

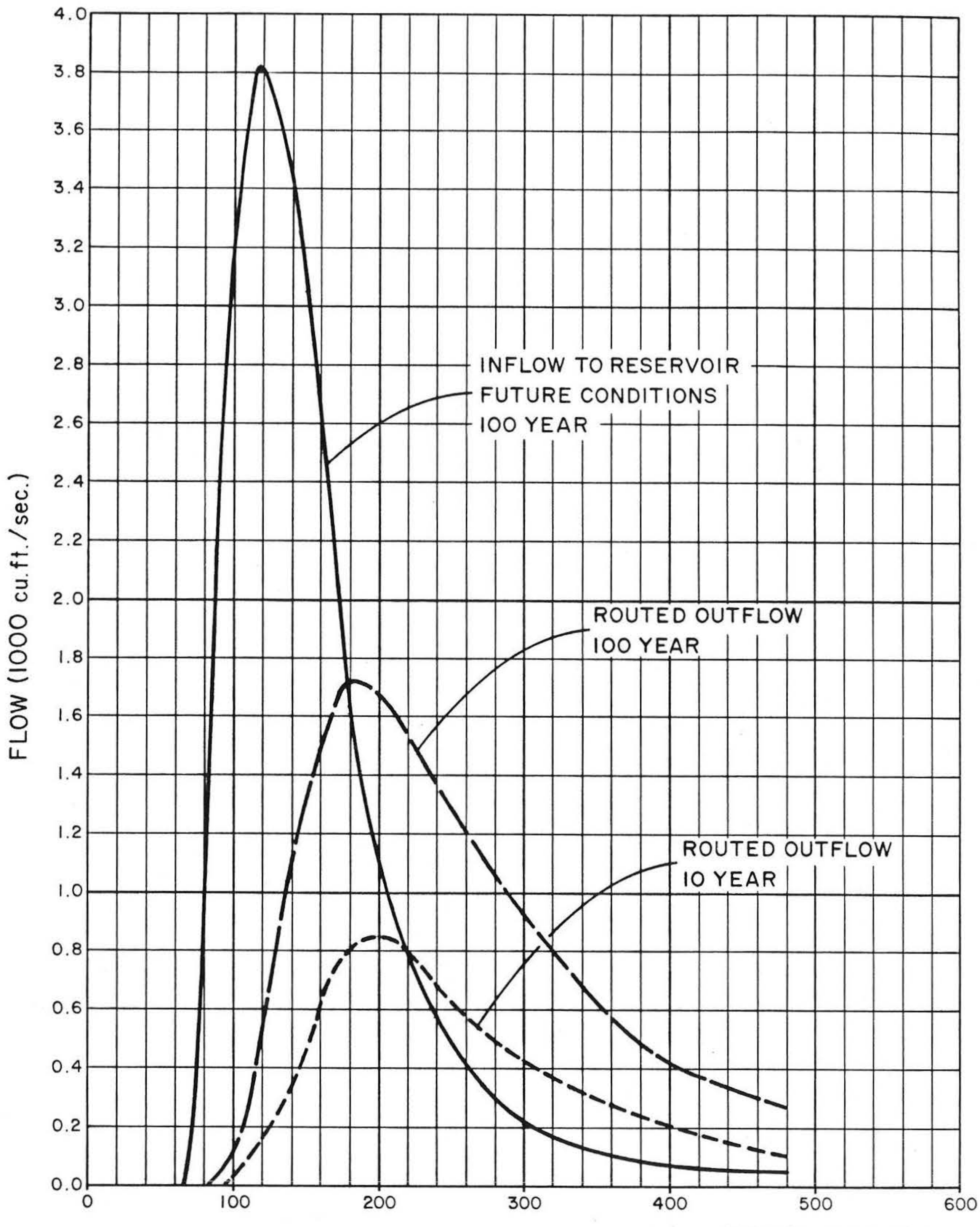
LENA GULCH WATERSHED DESIGN RAINFALL
(INCHES)

Time from Beginning of Storm Minutes	Design Frequency		
	1 year	10 years	100 years
0	.03	.00	.00
10	.04	.04	.05
20	.04	.06	.07
30	.06	.07	.10
40	.06	.10	.18
50	.18	.17	.26
60	.08	.70	1.04
70	.06	.28	.35
80	.04	.15	.17
90	.03	.10	.10
100	.02	.06	.09
110	.02	.06	.06
120	.02	.05	.06
130	.02	.05	.06
140	.02	.05	.06
150	.02	.04	.06
160	.02	.03	.04
170	.02	.03	.04
180	0	.03	.04
190	0	.03	.04
200	0	.03	.04
210	0	.03	.04
220	0	.02	.04
230	0	.02	.03
240	0	.02	.03



INFLOW TO BASIN 3 (US 6)

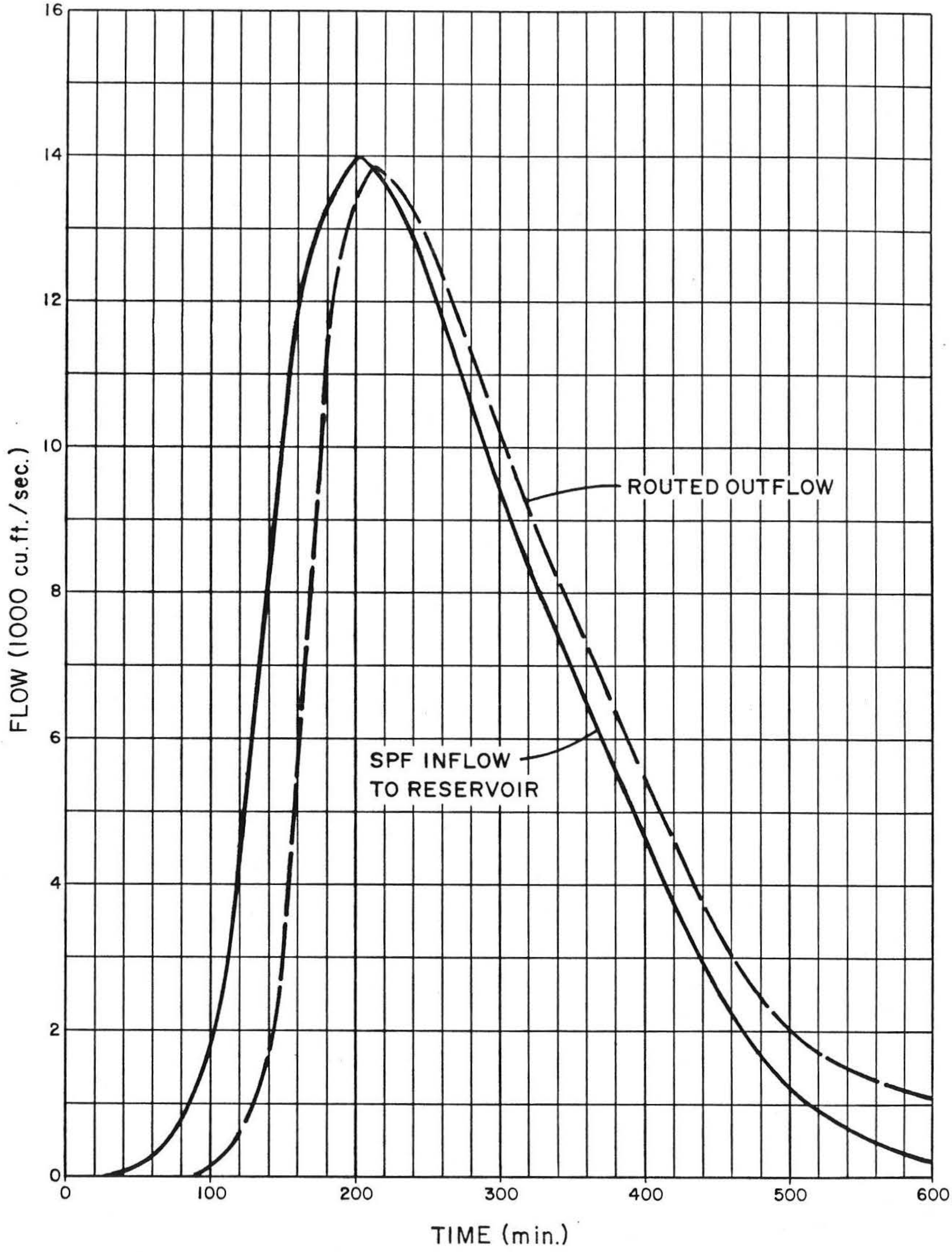
FIGURE II-4



Note: See Table II-1 for Rainfall.

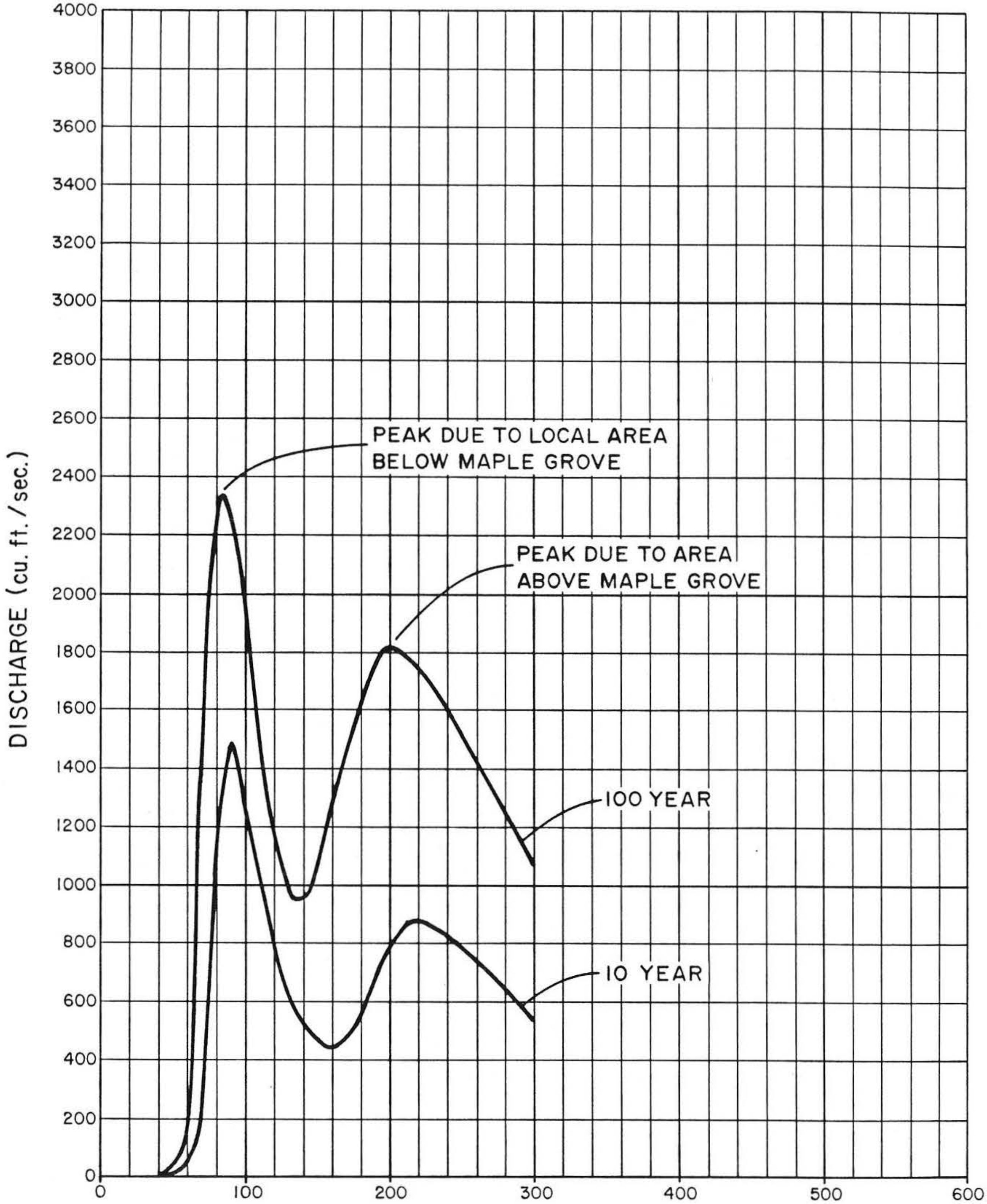
MAPLE GROVE RESERVOIR HYDROGRAPHS

FIGURE II-5



STANDARD PROJECT FLOOD (SPF)
MAPLE GROVE RESERVOIR

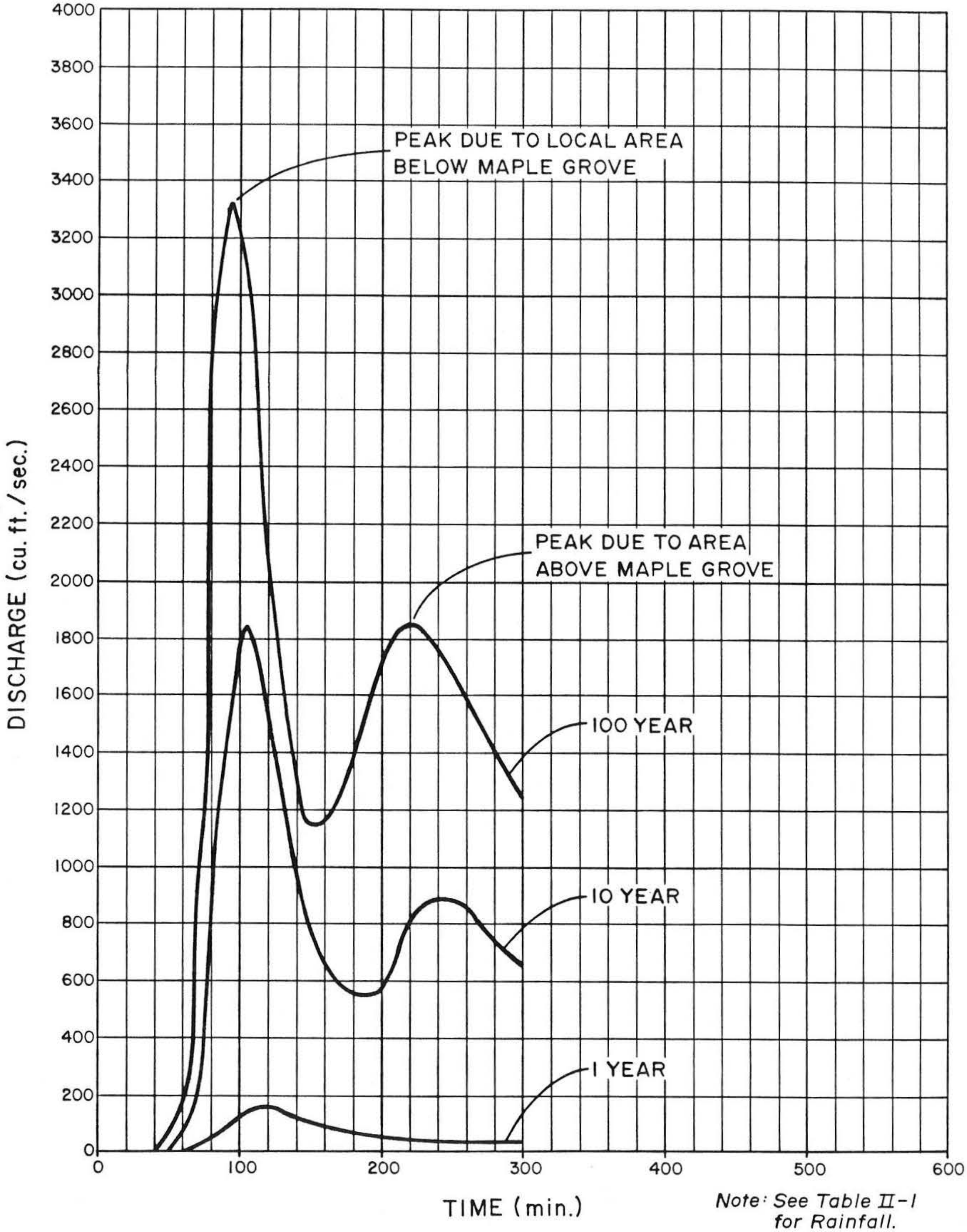
FIGURE II - 6



Note: See Table II-1 for Rainfall.

INFLOW TO BASIN 9

FIGURE II-7



Note: See Table II-1 for Rainfall.

LENA GULCH AT CLEAR CREEK

FIGURE II - 8

Creek. Both illustrate an initial peak at 90 to 100 minutes due to the drainage area below Maple Grove and a second peak at 200 to 240 minutes due primarily to the drainage area above Maple Grove. Also a 1-year frequency flood is shown on Figure II-8 which is primarily caused by the area below Maple Grove.

Figure II-9 is an approximate peak discharge profile along Lena Gulch for the 10- and 100-year floods.

ANALYSIS

Review of the preceding information indicates a short time interval between the occurance of peak rainfall and the peak runoff. Table II-2 presents this response timing at several points.

Unfortunately, this will require quick mobilization and a high likelihood of false warnings considering the 30 minute response of the basin and the existing low channel capacity in Wheat Ridge. Once the improvements in Wheat Ridge are made the situation will be more tolerable since there will be a higher threshold before flooding occurs.

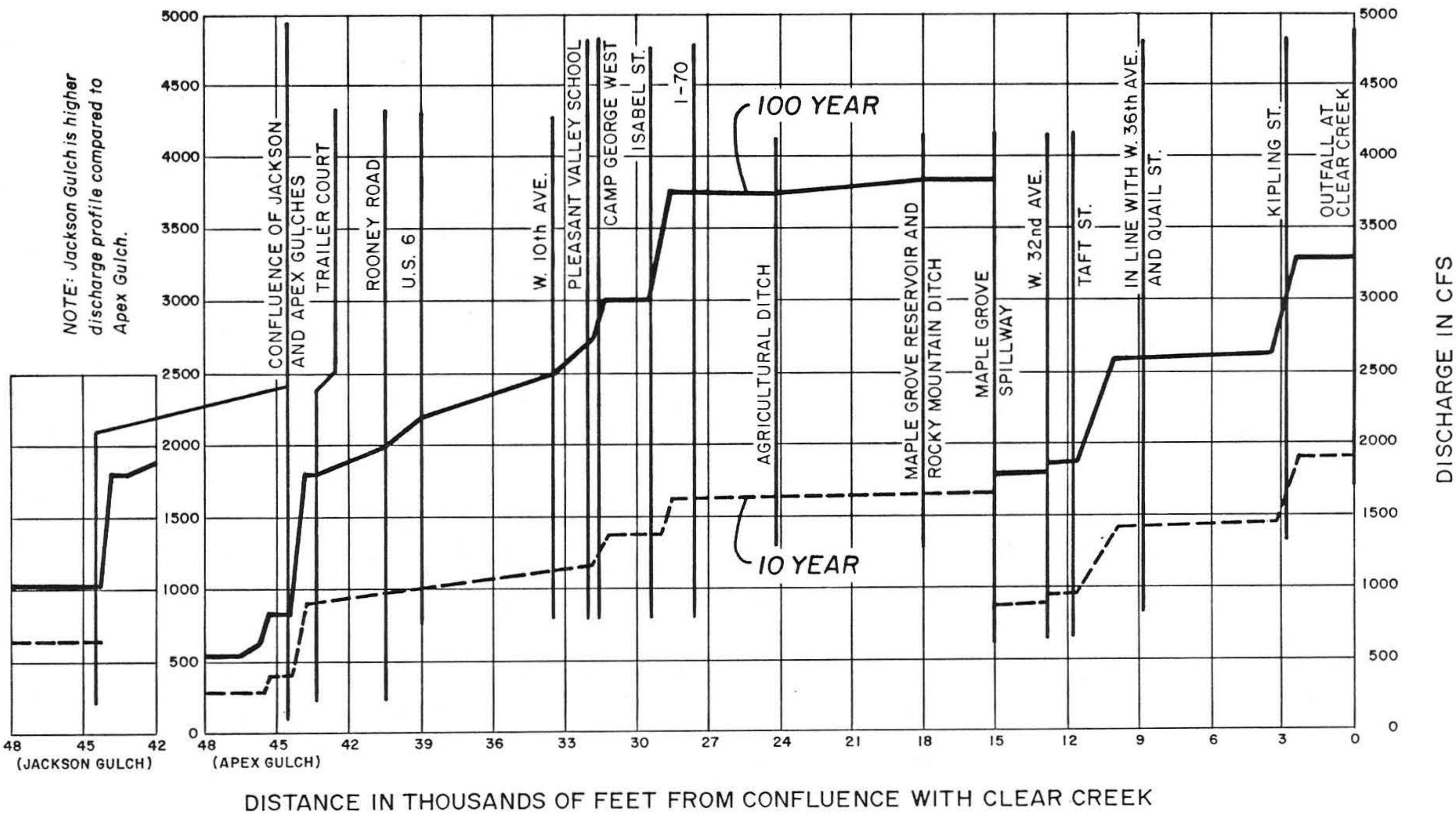
Note also that these "threshold" flood capacities should be better documented to help decide when and where to warn in priority.

There are three basic flood hazard situations as discussed following:

1. Floods Less than the 100-year Event

There are really three sub-situations of concern:

a. Rainfall events essentially occuring above Maple Grove
b. Rainfall events essentially occuring below Maple Grove
c. Rainfall events occuring over the entire basin



LENA GULCH PEAK DISCHARGE PROFILE

FIGURE II-9

TABLE II-2

TIME INTERVAL FROM PEAK RAINFALL TO PEAK RUNOFF

Location	Time(minutes)
U.S. #6	30
Maple Grove Reservoir In	60
Maple Grove Reservoir Out	120
32nd Avenue	Less than 20 minutes from area below reservoir -and- 125 minutes from area above reservoir
Parfet Street	25 minutes from area below reservoir -and- 140 minutes from area above reservoir
Clear Creek	30 minutes from area below reservoir -and- 150 minutes from area above reservoir

Flood Hazard warnings for situation b. should rely on rainfall and radar type warning systems. The area above Maple Grove should rely on rainfall and radar type warning systems for cases a. and c. However, the area below Maple Grove should additionally rely heavily on streamflow gaging as it will greatly enhance the accuracy of flood flow predictions.

Another important point is that once the Wheat Ridge Lena Gulch Drainageway improvements are largely implemented (Schedule I-IV of VI total) the need for flood hazard warnings for events less than the 100-year will be greatly reduced. However, there will still be the need to issue hazard warnings for more severe events.

2. Floods Greater than the 100-year Flood

In the event of greater floods both rainfall and stream gaging information will be useful, particuarly below Maple Grove Reservoir. The variance in what flood hazard will exist below Maple Grove varies dramatically between the 100-year and Standard Project Flood. A Standard Project Floodplain evaluation should probably be made for the area below Maple Grove to guide flood warning priorities. A troublesome point is the tendency for residents that will be taken out of the 100-year floodplain by channel improvements to be unaware of or complacent about the hazard of larger events.

Radar and rainfall information should reliably indicate an event of this magnitude and allow early warning. Stream gaging will provide the best information regarding volume that is flowing into the reservoir. Rainfall and radar information will also give the best guidance in projecting what further volume will come into the reservoir. The two can be used to predict discharge downstream and thus indicate appropriate flood hazard warning.

3. Malfunction of Maple Grove Reservoir Spillway

A key concern is rapid deflation of the fabri-dam due to punctures, vandalism, or system failure. When the dam is inflated with water rapid deflation is less likely than with air. Since air inflation is generally used only during the winter this situation is more likely during that season.This situation has been largely minimized with the installation of the erodible cofferdam.

The impact of this situation will also be lessened with the future drainageway improvements downstream.

Rainfall Gaging Recommendations

Because of the short response time involved and the tendency of the peak rainfall in a given basin to result in the peak runoff for that basin (as opposed to peaks being caused by streamflow from the area above the basin in question), the warning must be founded on radar information and interpretative predictions. However, because of the error range of these rainfall predictions and resulting large variations in runoff predicitions it is strongly advisable to incorporate a rainfall gaging system that can automatically report data to an interpretative center. These rainfall gage readings should be confirmed during the event by physical inspection.

Streamflow Gaging Recommendations

Stream gaging would be essential to flood hazard warnings with regard to Maple Grove Reservoir. A system which used stream gages midway above Maple Grove towards Lookout Mountain, above Maple Grove, below Maple Grove and possibly midway to Clear Creek would provide optimal information for both confirmation of Maple Grove hydrology and for overall accuracy, enhancement, and reliability of the predictive systems. It also provides a means of refining the predicted hydrograph based on comparison with the actual hydrograph. By this comparison one could decide whether the predicted hydrograph was likely to be high or low.

It is highly likely that direct runoff peaks will occur essentially simultaneously along the length of the gulch. This is to be expected in a long narrow basin. Thus, direct runoff flood warnings based on stream gaging upstream would be too late, except with regard to Maple Grove Reservior.

Stream gaging information midway in the basin, above Maple Grove and below, will be highly useful in predicting the probable magnitude of the second peak of the hydrograph for the area below Maple Grove. Also, in the case of a rainfall event occuring largely above Maple Grove, it will be much more reliable in predicting downstream flows and issuing warnings than depending on point-rainfall gages alone.

The types of streamflow gages to be selected would probably vary with the final system selected. Initial concepts have indicated the advisability of telemetered streamflow gages at the inflow to Maple Grove Reservior and recording or staff gages midway in the basin, in the reservior and on the spillway of Maple Grove Reservior and at a location near Quail or Simms in Wheat Ridge.

There are a few other notes of interest. Because the crest elevation of the spillway is variable due to the fabri-dams, a reservior gage will only give storage volume data. Unless one has information as to the elevation of the fabri-dams, reservior discharge cannot be determined as in a conventional dam with fixed spillway crest elevations. Practically, it is easier to have a gage downstream of the spillway.

As with rainfall gages, streamflow gages readings should be confirmed during the event by physical inspection.

SECTION III

STREAM GAGING SITES

The need for gaging stations and a discussion of general locations has been previously covered in this report.

Desirable features of a gaging station site would include easy accessibility, channel features that will contribute to a fairly permanent stage-discharge relation, and a drainage structure or channel reach that will lend itself to determining peak discharge rates by indirect measurement techniques.

A gaging station could be established on Lena Gulch where it passes under 6th Avenue. The drainage structure is a double 10 by 10 foot box concrete culvert. The gage could be attached to the upstream right wing wall. Channel features of the stream above and below the culvert are such that the stage-discharge relation at the gage could be computed from the hydraulic characteristics of the culvert. The rating curve (stage-discharge relation) would be very stable at medium and high stages.

Another site further upstream where the highway crosses Apex Gulch just above the confluence with Jackson Gulch would be a fairly good site. The flow at this point would not be greatly affected by man-made features and would monitor the flow from that part of the basin above Jackson Gulch on Lookout Mountain. The stage-discharge relation would be subject to some shifting and periodic checks of peak flow may be necessary. A 10-inch steel channel set in concrete just upstream from the bridge has been used as part of a gaging station installation. The rating curve has been defined by the USGS up to 450 cfs.

The reach of channel through and adjacent to Camp George West was inspected. Unfortunately a good site was not found. However, a gage located at a small bridge just upstream from the Welch Ditch crossing could be used. There is a staff gage at this location at the present time.

Two possible gage sites for determining the inflow to Maple Grove Reservoir were checked out. The first site considered was at Youngfield Street. The culvert at this site is partially filled with sediment but probably clears during periods of high flow.

Another site that has more desirable features is the site at the 20th Avenue crossing. It is close to the reservoir and the stage-discharge relation could be computed based on the hydraulic characteristics of the culvert and the road. The site will experience backwater from Maple Grove Reservoir during extreme flood events, but preliminary calculations show that it would have no effect on the gage except for measuring the downward leg of hydrographs for events like the Standard Project Flood.

A good site for monitoring the outflow of the reservor is in the tail race of the spillway section just downstream from the stilling basin at the bottom of the spillway. The weir downstream from the gage site would furnish a stable control section.

Acceptable sites were found at Parfet and Nelson Streets for monitoring the existing channel flow downstream in Wheat Ridge. These sites are in areas subject to flooding from fairly common discharges. A gage could be established on the upstream side of either culvert. The gage would provide data on the discharge and stage at that location and allow one to deduce the magnitude of overbank flows with the knowledge of the total upstream flow.

Recommendations

It would be advisable to make a field survey of several flood events at each site to refine the stage-discharge curves that are based on the hydraulic characteristics of the channel and culverts at the gage location.

Table III-1 presents our summary of site recommendations, which was arrived at after considering the likely flood warning system as discussed in Section IV. No readily adaptable sites for measuring the total flow in Wheat Ridge were found before the points where overflows begin. However an approximate interim channel staff gage could be located at Parfet Street which would allow monitoring of the total flows and better indicate flood warnings in overflow areas.

TABLE III-1
STREAMFLOW GAGING RECOMMENDATIONS

General Reach	Location	Types	Purpose
Midway Above Maple Grove	6th Avenue	Telemetered recording or staff gage reported manually	• Confirms flows from upper watershed tributary to Maple Grove Reservoir • Enhance local flood warnings and flood predictions
Above Maple Grove	20th Avenue	Telemetered recording	• Confirms flow predictions • Reservoir Routing update
Maple Grove	Reservoir	Telemetered recording	• Allows initiation of reservoir routing with predicted hydrograph • Allows refinement of reservoir routing with actual inflow data
Maple Grove Spillway	Spillway Tail Race	Staff gage if MG staff involved, otherwise Telemetered	• Allows confirmation of reservoir routing and predicted flows to Wheat Ridge
Wheat Ridge	Parfet	Interim Channel Staff Gage Interim Culvert Staff Gage	• Allows confirmation of other flows tributary that are adding to predicted Maple Grove flow • Allows confirmation of flow split and overflow flooding

SECTION IV
FLOW PREDICTIONS

The hydrology of the Lena Gulch Watershed mandates the use of predictive algorithms that are sophisticated enough to be able to give reliable peak flows and discharge volumes yet easily usable so that response is quick with a reasonable effort. In the process of investigating alternative schemes various constraints and concerns became apparent.

First, the range of error of rainfall predictions made through interpretation of radar and other information is important to understand, particularly with respect to the range of error of resulting flow predictions. John Henz of the GRD Weather Center has indicated that on a conceptual level rainfall amounts may be predicted within about 1/2 inch for an average 2-hour storm and that timing of the rainfall can be predicted within about thirty (30) minutes. Rainfall amounts may also be predicted for 30-minute intervals. The range of error resulting in predictive hydrographs can be significant. For example, in one test case for Basin 6 discharge of a 2-hour storm of 2-inches uniformly distributed, an error of an extra 0.5 inch of rainfall over 1 hour resulted in a peak of 2,250 cfs, while 0.5 inch less of rainfall in 1 hour resulted in a peak of 1,150 cfs. For the same duration storm rearranged to a more realistic pattern, an error of an extra 0.5 inch of rainfall over 1 hour resulted in a peak of 3,250 cfs while 0.5 inch less of rainfall in 1 hour resulted in a peak of 1,550 cfs. The GRD rainfall predictions will indicate the likely magnitude of the event, but ground observation and measurement is necessary to more reliably indicate probable flows and allow more reliable warning actions.

Actually, part of the apparent error range is due to the effect of infiltration. For lesser amounts of rainfall, effective precipitation comes largely from impervious areas since the infiltration rate in the basin is relatively high. But when the rainfall intensity is larger, runoff from the pervious area occurs. Thus, it becomes apparant that the storm pattern and infiltration characteristics are critical to reliable predictions.

If the rainfall prediction error was compounded with the error of a simplified rainfall-duration-runoff relationship, the consequence would be a total error that would probably result in a system that had no credibility (i.e. a serious flood was predicted and only a small flow occurred, or only a small event was predicted and a horrendous storm occured). For example, the above mentioned test indicated a range of 1,150 to 3,250 cfs was possible depending upon storm pattern and the error of rainfall predictions, while the predicted discharge from a simplified rainfall-duration-runoff relationship was about 1,400 cfs. The resulting peak outflows through Maple Grove Reservoir varied from 550 to 2,000 cfs, which would dictate significantly different actions.

The complexity of Maple Grove Reservoir leads to the need for knowledge of probable timing of flows from the reservoir in relation to the inflow resulting directly from the watershed tributary to Lena Gulch below the dam.

These concerns lead to the following criteria for a predictive hydrology system for flood hazard warning:

1. The system should be capable of working with 30-minute incremental rainfall predictions and varying rainfall patterns.

2. The system should be capable of inputing recorded rainfall data that has occurred along with future rainfall predictions.

3. The rainfall should be adjusted to reflect the portion that will actually become runoff (effective rainfall).

4. The predicted flow data should be provided with peak flow, volume and timing parameters.

5. The effects of Maple Grove Reservoir should be reflected.

6. The system should allow immediate adjustments dictated by actual stream flow data.

7. The system should be readily usable with a minimal knowledge of hydrology.

The last criterion initially leads to an evaluation of a system keyed to a recognition of similar storm patterns with typical runoff hydrographs. The testing done indicated that 30-minute increments of 1/2-inch rainfall blocks was the minimum necessary to have sensitivity between events like the 1, 10 and 100-year. Unfortunately, when a 2-hour event was used considering no rainfall block greater than 1-1/2-inches, 254 patterns resulted. Because of the number of patterns involved that still resulted in a gross error range, further investigation was discontinued in lieu of developing a simplified synthetic hydrograph procedure, which met the above criteria.

SIMPLIFIED SYNTHETIC HYDROGRAPH PROCEDURE

The MITCAT model which was used for the original Lena Gulch Master Plan can be used to develop unit hydrographs for various basins for 30-minute durations. These unit hydrographs can be simplified to a triangular or other prismatic shape. Basically, a flood hydrograph can be calculated quickly and easily from a given storm pattern after the rainfall has been corrected to effective rainfall (runoff).

Tables IV-1 and IV-2 represent typical calculation forms that could be provided or used in conjunction with a programable calculator. A set of these forms would be provided for several key locations.

Tables IV-3 and IV-4 present an example calculation. A 2-hour event predicted by GRD is entered in column 2 of Table IV-3. The effective precipitation from the impervious areas is determined as a simple percentage in column 3. The user is instructed that if wet conditions prevail to adjust the infiltration in column 4. The effective precipitation off of the

TABLE IV-1
(Effective Precipitation)
Inflow to Maple Grove

(1) Real Time at Time 0 below = : , / / TIME INTERVAL (minutes)	(2) Incremental Precipitation (inches)	(3) Effective Precipitation from Impervious 30% of (2)	(4) Maximum* Infiltration and pervious losses inches	(5) Effective Precipitation from pervious 70% of (2)-(4) unless negative then use zero	(6) Effective Precipitation (3+5) inches
0	-	-	-	-	-
30			1.8		
60			1.0		
90			0.8		
120			0.75		
150			0.75		
180			0.75		
210			0.75		
240			0.75		
270			0.75		

* If wet conditions prevail use 0.75 for all values.

TABLE IV-2

PREDICTIVE HYDROGRAPH TABLE
INFLOW TO MAPLE GROVE

(1) Real Time at time 0 below = ___:___, / / TIME INTERVAL (minutes)	(2) Unit Hydro-graph mult. for 0-30 precip.	(3) 30 min. effec. precip. from Table IV-1, 2nd row of column 6 is _______; mult. by value in column 2	(4) Unit Hydro-graph mult. for 30-60 precip.	(5) 60 min. effec. precip. from Table IV-1, 3rd row of column 6 is _______; mult. by value in column 4	(6) Unit Hydro-graph mult. for 60-90 precip.	(7) 90 min. effec. precip. from Table IV-1, 4th row of column 6 is _______; mult. by value in column 6	(8) Unit Hydro-graph mult. for 90-120 precip.	(9) 120 min. effec. precip. from Table IV-1,5th row of column 6 is _______; mult. by value in column 8	(10) (even) Unit Hydro-graph for next inter-val....move multiplier down	(11) (odd) Next effec. precip. from Table IV-1 next row in column 6 is _______; mult. by pre-vious even column	(12) Predicted Cummula-tive Hydro-graph (add rows) of val-ues in odd numbered col-umns except column 1	(13) Actual Gage Hydrograph Till Time____	(14) Possible Corrected Hydrograph
0	-	-	-	-	-	-	-	-	-	-	0		
30	0	0	-	-	-	-	-	-	-	-	0		
60	2050		0	0	-	-	-	-	-	-			
90	4100		2050		0	0	-	-	-	-			
120	3075		4100		2050		0	0	-	-			
150	2050		3075		4100		2050		0	0			
180	1025		2050		3075		4100		2050				
210	0	0	1025		2050		3075		4100				
240	-	-	0	0	1025		2050		3075				
270	-	-	-	-	0	0	1025		2050				
300	-	-	-	-	-	-	0	0	1025				
							-	-	0	0			
									-	-			

TABLE IV-3
(Effective Precipitation)
Inflow to Maple Grove

(1) Real Time at Time 0 below = 15:00 9/4/83 TIME INTERVAL (minutes)	(2) Incremental Precipitation (inches)	(3) Effective Precipitation from Impervious 30% of (2)	(4) Maximum* Infiltration and pervious losses inches	(5) Effective Precipitation from pervious 70% of (2)-(4) unless negative then use zero	(6) Effective Precipitation (3+5) inches
0	-	-	-	-	-
30	0.5	.15	~~1.8~~ 0.75	0	.15
60	1.0	.30	~~1.0~~ 0.75	.18	.48
90	0.5	.15	~~0.8~~ 0.75	0	.15
120	0	0	0.75	0	
150			0.75		
180			0.75		
210			0.75		
240			0.75		
270			0.75		

* If wet conditions prevail use 0.75 for all values.

TABLE IV-4

PREDICTIVE HYDROGRAPH TABLE

INFLOW TO MAPLE GROVE

(1) Real Time at time 0 below = 15:00, 9/4/83 TIME INTERVAL (minutes)	(2) Unit Hydrograph mult. for 0-30 precip.	(3) 30 min. effec. precip. from Table IV-1, 2nd row of column 6 is 0.15; mult. by value in column 2	(4) Unit Hydrograph mult. for 30-60 precip.	(5) 60 min. effec. precip. from Table IV-1, 3rd row of column 6 is 0.48; mult. by value in column 4	(6) Unit Hydrograph mult. for 60-90 precip.	(7) 90 min. effec. precip. from Table IV-1, 4th row of column 6 is 0.15; mult. by value in column 6	(8) Unit Hydrograph mult. for 90-120 precip.	(9) 120 min. effec. precip. from Table IV-1, 5th row of column 6 is 0; mult. by value in column 8	(10) (even) Unit Hydrograph for next interval....move multiplier down	(11) (odd) Next effec. precip. from IV-1, next row in column 6 is ____; mult. by previous even column	(12) Predicted Cummulative Hydrograph (add rows) of values in odd numbered columns except column 1)	(13) Actual Gage Hydrograph Till Time ___	(14) Possible Corrected Hydrograph
0	-	-	-	-	-	-	-	-	-				
30	0	0	-	-	-	-	-	-	-	0			
60	2050	307	0	0	-	-	-	-	-	307			
90	4100	615	2050	984	0	0	-	-	-	1599			
120	3075	461	4100	1968	2050	307	0	0	-	2736			
150	2050	307	3075	1476	4100	615	2050		0	2398			
180	1025	154	2050	984	3075	461	4100		2050	1599			
210	0		1025	492	2050	307	3075		4100	799			
240	-		0		1025	154	2050		3075	154			
270	-		-		0		1025		2050	0			
300	-		-		-		0	0	1025				
							-	0	0				

impervious area is determined in column 5 and the total in column 6.

In Table IV-4 the simplified triangular unit hydrograph is already tabulated in the even number columns which is multiplied by the effective precipitation for the appropriate time interval of Table IV-3. The cummulative hydrograph of column 12 is summed from the odd numbered columns.

As the actual event proceded, Table IV-1 would be adjusted to reflect actual recorded precipitation along with revised prediction for the future. This would result in new flow predictions on Table IV-2. These flow predictions would then be compared with actual stream flow measurements on column 13 and a revised hydrograph presented in column 14. The procedure for this adjustment will need to be developed with future studies and experience gained from monitoring actual events.

A short form reservoir routing procedure could be used for Maple Grove Reservoir, similar to Table IV-5. It requires usage of Figures II-2 and II-3, but this could be simplified by usage of a programable calculator. Table IV-6 presents an example routing using the hydrograph of Table IV-4. Flow predictions downstream of Maple Grove Reservoir would require two more columns to Table IV-2 to include the flow from Maple Grove Reservoir.

Figure IV-1 illustrates the framework that this system would work within. Computational time tests indicate that answers and interpretation would be available within minutes of receiving data. In cases where the only data available is predictive rainfall the other data steps can be omitted until available and Maple Grove assumed to be full at elevation 25 with 590 acre-feet of storage.

TABLE IV- 5

MAPLE GROVE RESERVOIR ROUTING

(1) TIME*	(2) Inflow (cfs - from Table IV-2)	(3) Average Inflow (average of column 2 values)	(4) Average Inflow Volume (acre-feet) column 3 X 0.041	(5) Reservoir Volume (previous values of columns 4 and 9	(6) Reservoir Elevation (enter col. 5 value into Fig. II-2)	(7) Reservoir Discharge (enter col. 6 value into Fig. II-3)**	(8) Average Outflow Volume (acre-feet) col. 7 X 0.041	(9) Corrected Reservoir Volume (col. 5 - col. 8)
0								
30								
60								
90								
120								
150								
180								
210								
240								
270								
300								

* Real Time at Time 0 above = ___:___, ___/___/___

** Check operation mode of Dam; use curve marked Fabri-Dam Inflated up to elevation 31, then curve marked SPF above.

TABLE IV-6

MAPLE GROVE RESERVOIR ROUTING

(1) TIME*	(2) Inflow (cfs - from Table IV-2)	(3) Average Inflow (average of column 2 values)	(4) Average Inflow Volume (acre-feet) column 3 X 0.041	(5) Reservoir Volume (previous values of columns 4 and 9	(6) Reservoir Elevation (enter col. 5 value into Fig. II-2)	(7) Reservoir Discharge (enter col. 6 value into Fig. II-3)**	(8) Average Outflow Volume (acre-feet) col. 7 X 0.041	(9) Corrected Reservoir Volume (col. 5 - col. 8)
0	0			590	25	0	0	590
		0	0					
30	0			590	25	0	0	590
		153	6.3					
60	307			596.3	25.2	10	.4	596
		953	39					
90	1599			635	26.2	100	4	631
		2167	90					
120	2736			721	28.2	600	25	696
		2567	106					
150	2398			802	29.9	1350	56	746
		1998	83					
180	1599			829	30.3	1600	66	763
		1199	50					
210	799			813	30.1	1500	62	751
		476	20					
240	154			771	29	1000	41	730
		77	3					
270	0			733	28.3	750	31	702
300								

* Real Time at Time 0 above = 15:00, 9/4/83

** Check operation mode of Dam; use curve marked Fabri-Dam Inflated up to elevation 31, then curve marked SPF above.

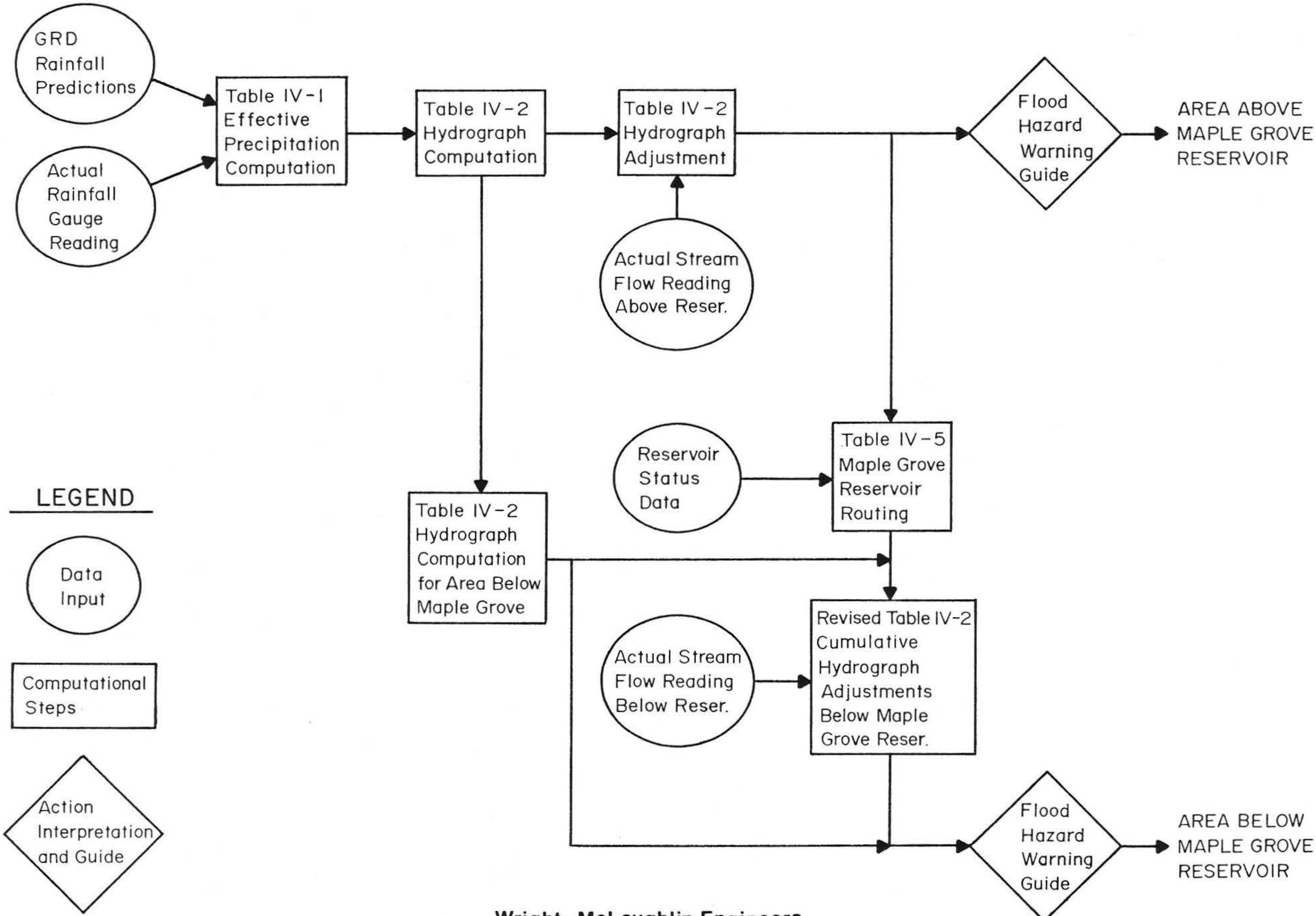


FIGURE IV-1

Wright-McLaughlin Engineers

LENA FLOOD HAZARD WARNING PROCEDURAL CHART