DRAINAGE AND FLOOD CONTROL

FLASH FLOOD WARNING PLANNING, Lena Gulch

June 1981

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT-69-

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Treasurer

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June 29, 1981

MEMORANDUM

TO : Dick Cook - Jefferson County
Tom Palmer - Wheat Ridge
Brian Nielson - Lakewood
Virgil Hill - Consolidated Mutual Water Co.

FROM : Bill DeGroot

SUBJECT: Lena Gulch Warning Planning

Attached please find the report entitled "Flash Flood Warning Planning, Lena Gulch." This report constitutes partial fulfillment of the obligation of the Urban Drainage and Flood Control District under Agreement No. 79-10.5, "Flash Flood Warning Planning, Lena Gulch." Much of the background work for this report was done under subcontract by GRD Weather Center, Inc. and Wright-McLaughlin Engineers. I acted as Project Director and, in that capacity, formulated the alternative detection systems and completed the evaluation and cost estimates.

I have written the report to basically stand on its own, as if the Lena Gulch basin was the only area being considered for a detection system. However, as you know, a similar study has been completed for Bear Creek, and we have previously discussed the possibility of combining the two detection networks.

My recommendation, which is based on the results of the two studies and our previous discussions at progress meetings, is to proceed with Alternative 1, which is the Combined Automated and Manual System, for both Lena Gulch and Bear Creek. GRD Weather Center would be designated as the Situation Information Center (SIC) and would therefore be the primary data collection and analysis center.

Implementation of the two systems could be staged, with the Lena Gulch system and the SIC at GRD being established first, followed by the Bear Creek system (which would also utilize the SIC at GRD) at a later time. Other drainageways in Jefferson County could also be added to the system over time at the option of other local governments. For example Golden may have an interest in Clear Creek. Other local governments wanting to join the system would have to buy into the SIC.

The District's current Five-Year Capital Improvements Program for the 1980-1984 period contains a line item for 1981 for Bear Creek and Lena Gulch Early Warning in the amount of $75,000. These funds would have to be matched by local governments, which means a project in the area of $150,000 is conceivable. I recognize that a 1981 project is not very likely at this point. I have therefore recommended that the new Five-Year Capital Improvements Program for 1981-1985 allocate $75,000 in 1982 and an additional $25,000 in 1983 for the two warning systems. I have estimated the total cost for the combined systems at about $180,000. Therefore, figuring on some increased cost due to inflation, the District funds, matched by the local governments', should be sufficient.

Of course the above recommendation is subject to concurrence of your entities. If the local sponsors desire one of the other alternatives we can certainly move in that direction. What we need to do now is to make a decision on which alternative to pursue. I will be contacting you to arrange a meeting to determine a procedure to arrive at a decision. In the meantime, if you have any questions about the study, please contact me.

WGD/is

Enclosure

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SUMMARY

This study was completed under the direction of the Urban Drainage and Flood Control District in accordance with Agreement No. 79-10.5, "Flash Flood Warning Planning, Lena Gulch" which was executed by the District, Jefferson County, Wheat Ridge, Lakewood and Consolidated Mutual Water Company. Subcontractors on this study were GRD Weather Center, Inc. and Wright-McLaughlin Engineers.

Three alternative flood detection systems have been developed and evaluated. The systems vary in complexity from the present system which consists primarily of informal rainfall and stream flow, observations by employees of the sponsors of this study, to a more sophisticated system which includes both observers and automated rain and stream gages. Each alternative includes provisions for the use of weather radar and meteorologists from the National Weather Service and GRD Weather Center. Each of the three alternatives have been evaluated in terms of the lead time provided, credibility, reliability, non-flood warning benefits, ease of phased implementation, flexibility, first cost and annual operation and maintenance cost.

This report presents three basic alternatives for flood detection networks in the Lena Gulch drainage basin. Many different permutations and combinations can be developed from these three basic alternatives.

RECOMMENDATION

Jefferson County, Wheat Ridge, Lakewood and Consolidated Mutual Water Company, with the assistance of the Urban Drainage and Flood Control District, should evaluate and consider the three basic alternatives presented in this report as well as potential modifications to these three basic alternatives, and should then make a determination as to which of the alternatives or modified alternatives they wish to pursue. The Urban Drainage and Flood Control District will be available to provide further assistance upon request.

INTRODUCTION

PURPOSE AND SCOPE

This study was undertaken to evaluate the feasibility and costs of alternative flood detection networks which could be utilized in the Lena Gulch drainage basin to provide warning of impending floods to occupants of the Lena Gulch floodplain. The purpose of this report is to document the results of this study and to present an evaluation of alternative systems, including costs, in such a manner that the local sponsors can determine which alternative is most appropriate for Lena Gulch.

STUDY PROCEDURE

The Urban Drainage and Flood Control District contracted with Jefferson County, Wheat Ridge, Lakewood and Consolidated Mutual Water Company to complete this study. The District in turn retained GRD Weather Center, Inc. (GRD) and Wright-McLaughlin Engineers (WME) to provide professional advice regarding meteorological and hydrologic aspects, respectively, of the Lena Gulch drainage basin and various flood detection alternatives.

The District, in cooperation with the City of Boulder and Boulder County, had previously investigated flood detection networks for Boulder Creek. The results of that investigation and the experience gained from implementation of the selected alternative for Boulder Creek have been utilized in this study.

GRD Weather Center was retained to determine the appropriate number and approximate location of self reporting rain gages which would be necessary to detect flood producing rainstorms in an automated detection network. GRD's letter report is enclosed as Attachment 1.

WME was retained to review the Lena Gulch hydrology, review operating procedures for Maple Grove Reservoir, determine the optimum number and location of self reporting stream gages necessary to enable decisions to be made concerning flood potential, and to suggest concepts for decision aides to evaluate the flood potential at Maple Grove Reservoir. Their report is enclosed as Attachment 2.

Following completion of the analyses by GRD and WME, the District, after consultations with the local sponsors, developed and analyzed three alternative flood detection systems and prepared this summary report.

FLOOD HISTORY

A detailed history of flooding on Lena Gulch is not readily available in the literature. However, there have been several instances of relatively minor flooding since 1973. The U.S. Geological Survey estimated the peak discharge for a flood on May 5-6, 1973 at 820 cfs at Taft Street. That discharge corresponds to about a 10-year recurrence interval flood at that location.

On March 17-18, 1979, one of the fabri-dams on the Maple Grove Reservoir spillway was vandalized, causing an accidental release of water which resulted in a peak discharge of 720 cfs at 32nd Avenue (estimated by the USGS) Minor flooding also occurred on May 5, 1980, as a result of an intense thunderstorm. The USGS estimated the peak discharge at 32nd Avenue at about 500 cfs. Inadequate drainage facilities at points along the gulch have resulted in minor, localized problems on an almost annual basis.

EXISTING SITUATION

DESCRIPTION OF THE DRAINAGE BASIN

Lena Gulch is a tributary of Clear Creek. It has a drainage area of approximately 13.8 square miles. The drainage basin, which is shown in Figure II-1 of Attachment 2, is located in Jefferson County, Golden, Lakewood and Wheat Ridge. A more detailed discussion of the drainage basin is presented in Attachment 2.

PREVIOUS HYDROLOGY STUDIES

The most recent hydrology study for Lena Gulch was completed in 1975 by WME as a part of a master planning effort for Lena Gulch. The hydrology is summarized in Attachment 2.

MAPLE GROVE RESERVOIR

Maple Grove Reservoir is located on Lena Gulch at 27th Avenue. The reservoir, which is owned by Consolidated Mutual Water Company, is a water supply reservoir, although it does provide some flood protection, particularly for the smaller, more frequent events. A discussion of the reservoir is contained in Attachment 2.

The reservoir dam was inspected by Rocky Mountain Consultants, Inc. on August 6, 1979, as a part of the National Dam Safety Program. Their report* indicates that the spillway can safely pass 50% of the Probable Maximum Flood and the dam is therefore not classified as unsafe. The report also states that it is "extremely unlikely" that the embankment

*"Phase 1 Inspection Report, National Dam Safety Program, Maple Grove Reservoir Dam, Jefferson County, Colorado" by Rocky Mountain Consultants, Inc.

would be breached by overtopping during the Probable Maximum Flood. Therefore the flood detection alternatives do not address dam embankment failure.

EXISTING FLOOD DETECTION SYSTEM

The existing flood detection system for Lena Gulch ~~Bear Creek~~ incorporates the Denver officer of the National Weather Service (NWS), GRD Weather Center (GRD), and an informal group of observers who are employees of the study sponsors.

The NWS has responsibility for issuing flash flood watches and warnings for the area. A watch means that flooding is imminent or is occurring within the warning area.

Because the NWS Has such a large area of responsibility (29 counties in Colorado) the Urban Drainage and Flood Control District has retained GRD to assist the NWS within the District's area of responsibility. GRD has the capability to provide additional information to local governments by virtue of their smaller area of responsibility. They have access to the same radar, satellite and other data as the NWS and maintain close coordination with the NWS. In addition, their office location provides a good vantage point for observation (during daylight hours) of rainfall events which could impact Lena Gulch.

GRD provides information to Jefferson County Communications by telephone using standardized messages (Attached). These messages are then relayed to Wheat Ridge and Lakewood by Jefferson County. Message 1 is issued whenever weather conditions are such that flood producing rainfall could occur. This message is intended to allow key personnel in each jurisdiction to prepare for a possible flood situation. It is not intended for public dissemination because it is too early in the storm development process to concern the public. Whenever the NWS issues a flash flood watch GRD will issue Message 2 and will add any additional information pertinent to Lena Gulch. Whenever the NWS issues a flash flood warning GRD will issue Message 3 and again will add any additional information pertinent to Lena Gulch. When the hazard described by any previous message has passed, GRD will issue Message 4 which cancels previous messages. GRD also has an Update Message which is used when the situation described in a previous message has changed but another type of message is not appropriate.

Employees of the sponsors of this study have on occasion acted as observers during heavy rainfall events by reporting excess rainfall and runoff to GRD and/or the local sponsors. However, no formal arrangements exist to insure that observers will be available when needed; and no specific observation sites have been established.

The decision to warn or evacuate the flood hazard areas would be based upon the input of the meteorologists and observations of heavy rainfall and rising stream levels. Such a decision could be made unilaterally by a local jurisdiction or upon the issuance of a flash flood watch or warning by the NWS.

CENTERS OF POSSIBLE LIFE AND PROPERTY LOSS

The report "Lena Gulch Master Drainage Plan" by WME delineates the 100-year floodplain which is the primary area of concern. Within the 100-year floodplain WME has identified areas of special concern including the floodplain between Clear Creek and Maple Grove Reservoir, and the mobile home parks in the vicinity of Sixth Avenue and Colfax. The extent of the 100-year floodplain is shown in "Lena Gulch Master Drainage Plan."

Larger floods can also occur but their frequency of occurrence is smaller. In the event of a larger flood the 100-year floodplain will still be the area of highest hazard.

CONSTRUCTION OF FLOOD CONTROL FACILITIES

At the present time construction of an enlarged channel from Clear Creek to upstream of Kipling is in progress. Additional channel construction in future years will, when completed, contain the 100-year flood between Clear Creek and Maple Grove Reservoir. The danger of flooding from larger events will still exist but the frequency of flooding will be reduced. In the consideration of flood detection alternatives the impact future construction will have on the flood hazard should be considered.

Received By________________

Date________________

GRD WEATHER CENTER

Time________________

MESSAGE NUMBER 1

This is the GRD Weather Center calling.

I have information concerning the possibility of flooding later today. Please prepare to fill in the blanks on GRD Weather Center Message Number 1. I will read the message to you when you are ready.

This is meteorologist ______________________________.
(name)

We have determined that the potential for flooding exists for ________________

____
(geographical area)

____

____

____

from ________________ until __________________.
(time) (time)

The type of flooding which may occur is (check appropriate boxes):

1. ___ Slow rising flooding of intersections, low-lying areas, and small streams
2. ___ Flash flooding of intersections, low-lying areas and small streams
3. ___ Slow rising flooding of major streams
4. ___ Flash flooding of major streams
5. ___ Other (describe) ____

   ____

   ____.

This is an internal alert and not for public dissemination. Please pass this information along to affected cities and towns within your area.

Also please take appropriate actions to prepare for possible flooding.

Further information will be provided to you as it becomes available.

This is ________________________________.
(name)

Received By ____________

Date ____________

Time ____________

GRD WEATHER CENTER

MESSAGE NUMBER 2

This is the GRD Weather Center calling.

I have information concerning the possibility of flooding later today. Please prepare to fill in the blanks on GRD Weather Center Message Number 2. I will read the message to you when you are ready.

This is meteorologist ____________________ (name).

The National Weather Service has issued a Flash Flood Watch for ____________________ (geographical area), which means that flash flooding is possible within the watch area.

We have determined that the possibility for flooding exists for ____________________ (geographical area)

____

____

____

from ____________ (time) until ____________ (time).

Please pass this information along to affected cities and towns within your area.

Also, please take appropriate actions to prepare for possible flooding.

Further information will be provided to you as it becomes available.

This is ____________________ (name).

Received by ______________

Date ______________

Time ______________

GRD WEATHER CENTER

MESSAGE NUMBER 3

This is the GRD Weather Center calling.

I have information concerning the probability of flood later today. Please prepare to fill in the blanks on GRD Weather Center Message Number 3. I will read the message to you when you are ready.

This is meteorologist ______________________________.
(name)

The National Weather Service has issued a Flash Flood Warning for __________

____________________________________ which means that flooding is imminent
(geographical area)

or has been reported within the warning area.

We have determined that the probability of flooding exists for ______________

____
(geographical area)
____

____

____

from __________________ until ____________________.
(time) (time)

Please pass this information along to affected cities and towns within your area.

Also, please take appropriate actions to deal with this flood threat.

Further information will be provided to you as it becomes available.

This is ________________________________.
(name)

(March, 1980)

Received by ____________________

Date ____________________

Time ____________________

GRD WEATHER CENTER

MESSAGE NUMBER 4

This is the GRD Weather Center calling.

Please prepare to fill in the blanks on GRD Weather Center Message Number 4. I will read the message to you when you are ready.

This is meteorologist ______________________________.
(name)

The potential for flooding in ______________________________
(geographical area)

____

____

____

has passed.

Message Number(s) ______________________________ are rescinded.

We will keep you advised of any changes.

Please pass this information along to the cities and towns you have previously notified.

This is ______________________________.
(name)

(March, 1980)

Received by ______________

Date ______________

Time______________

GRD WEATHER CENTER

UPDATE MESSAGE

This is the GRD Weather Center calling.

I have information concerning the possibility of flooding in your area. Please prepare to fill in the blanks on the GRD Weather Center UPDATE Message. I will read the message when you area ready.

This is meteorologist ______________________________.
(name)

This is an update to Message(s) __________________ concerning possible

flooding for ____
(geographical area)

____

____

We have the following additional information: __________________________

____

____

____

____

____

Please pass this information along to the cities and towns you have previously notified.

Also, please take appropriate action in response to the current flood potential.

Further information will be provided to you as it becomes available.

This is ____________________________.
(name)

(March, 1980)

ALTERNATIVE FLOOD DETECTION SYSTEMS

GENERAL

A complete flood warning system consists of three elements:

1. Detection of the flood threat,
2. Dissemination of the flood warning to the population at risk,
3. Proper response of the population at risk.

All three elements of the warning system must function properly or the warning system will fail.

While all three elements are equally important, the purpose of this study is to evaluate only the detection element. Once a detection alternative is selected it should be implemented in conjunction with the other two elements.

EVALUATION CRITERIA

During the Boulder Creek Flood Warning Study, which was mentioned earlier, the following criteria were selected to evaluate the various flood detection systems:

1. Lead Time
2. Credibility
3. Reliability
4. Non-flood Warning Benefits
5. Implementation
6. Flexibility
7. First Cost
8. Annual Operation and Maintenance Cost

These criteria are defined in the following paragraphs.

Lead time is the time from knowledge of an approaching flood to the time flooding begins at a specific location. In other words, lead time is the length of time between the time when the decision center determines that a flood will strike a certain location and the time when flooding begins at that location.

Credibility describes the certainty with which a flood detection system predicts a flood event. A credible system allows accurate flood prediction. A system with low credibility may issue a high percentage of false alarms, or may miss significant floods.

Reliability refers to the dependability of a system's component parts. A system would be reliable if all the components of the system functioned properly during a flood event.

Non-Flood Warning Benefits include the system's usefulness for purposes other than flood detection. These could include the accumulation of rainfall and streamflow records or assistance in forest fire prediction.

Implementation refers to how well a system adapts to phased installation.

Flexibility rates a system's convenience in adjusting locations of observation points once operating procedures have been established and operating experience gained.

First Cost is the initial expenditure required to set up a detection system and make it operational. This includes design, installation and right-of-way acquisition.

Annual Operation and Maintenance Costs include salaries for personnel to operate and maintain the system and costs to replace or repair equipment.

ELEMENTS COMMON TO ALL ALTERNATIVES

Three basic alternative flood detection systems are described later in this section. There are several elements which are common to all three alternatives and which will be discussed here.

1. Rain and stream gages and radar should all be used in any flood detection system. Weather radar can give the earliest indication of potential flood producing rainfall within a given drainage basin. It is also helpful in determining the speed and direction of rainfall events, which can be critical. For example, a slow moving storm will drop more rain within a drainage basin than a fast moving storm which moves rapidly from basin to basin. Likewise, a storm that is moving across a drainage basin will drop less rain within the basin than a storm moving up or down the basin. Even with these advantages radar is not the answer by itself. Radar can only provide approximate rainfall amounts which are subject to interpretation by the radar observer. The reasons for this will not be discussed here, although the problems are widely known and accepted. Therefore, "ground truth" is required to help the radar observer calibrate the radar image.

This is where the rain gages are important. Rain gages spread throughout the drainage basin give a clearer picture of how much rain is actually reaching the ground. The radar observer can use the rain gage measurements of rainfall to calibrate the radar image. Rain gage measurements can also be used, in conjunction with hydrology models, to estimate peak stream discharges based on the amount of rainfall already measured. While this information is helpful there are certain drawbacks. One is that rain gages cannot predict future rainfall. The hydrology model must then use measured rainfall to the present and estimated rainfall for the future. This is where the radar and the meteorologist (discussed below) can help with rainfall predictions. Another problem is that hydrology is still an inexact science. Therefore it is entirely possible for a hydrology model to predict a peak stream discharge which would differ from what actually occurs, thus resulting in an incorrect assessment of the flood hazard. For example, the hydrology model could predict a non-hazardous peak discharge when in actuality the area of concern is flooded.

Stream gages can reduce the possibility of an incorrect assessment of the flood hazard because they measure the actual amount of water in the stream. They can confirm that rainfall has been converted to runoff and whether the hydrology predictions are accurate or not. Stream gages can provide the final confirmation that a flood problem has developed.

The above discussion illustrates the inter-relationship of rain and stream gages and radar and the need for all three in a flood detection system.

2. Meteorologists should be a part of any flood detection system. Meteorologists can utilize weather radar, satellite photographs and other weather data to make predictions of possible flood producing storms. They can provide the earliest indication of a potential flood as well as updated forecasts as the storm progresses. Meteorologists have proven to be very useful in the Boulder Creek system. Meteorologists from the National Weather Service and GRD Weather Center are available to participate in a Lena Gulch flood detection system, and, in fact, are already participating in the existing Lena Gulch system (see earlier discussion of the existing flood warning system).

3. A situation information center (SIC) should be established. This is the location where all data would be collected and analyzed, decisions on the extent of the flood hazard made, and warnings disseminated. For the Boulder Creek system the SIC is located adjacent to the communications center, which is jointly run by the City of Boulder and Boulder County. No similar arrangement is possible for Lena Gulch because each local government's public safety and communications operations are located separately from the others, and Consolidated Mutual is also separate from the others. This problem has been discussed with the local sponsors, and it was agreed to approach the SIC on the basis of hiring GRD Weather Center or a similar organization to perform the functions of the SIC.

GRD is a logical selection for this role because of their current involvement in the existing warning system; and they have indicated a willingness to perform this function.

4. An emergency services group should be established to collect and analyze data received from the flood detection system. GRD can perform this function, with the aid of some data handling equipment, should the SIC be located at their office. If another location is selected the emergency services group should be composed of people who have expertise in all aspects of the flood situation, including a basic knowledge of hydrology, communications and public safety. For example, the Boulder Creek system has an emergency services group composed of the following people:

- Sheriff's Dept. Fire Liaison
- Communications representative
- Boulder Police Dept. representative
- Boulder Fire Dept. representative
- University of Colorado Police Dept. representative
- Boulder County hydrologist

- Boulder Public Works Dept. representative

These people carry pagers and are called in whenever a flood potential exists. They are cross-trained so that each is capable of performing any of the tasks necessary to detect a flood hazard and disseminate necessary warnings.

5. A written warning plan should be developed. The plan would contain all of the actions which must be taken for the plan to be carried out successfully. Responsibilities for each action would be assigned. This plan is necessary to insure that all tasks are carried out as required.

AUTOMATED vs. MANUALLY OBSERVED GAGES

As indicated above, radar, rain gages and stream gages each have drawbacks when utilized individually. However, when used in combination they complement each other. The same can be said for automatic versus manually observed gages.

Manually observed gages require people to make an effort to observe a gage, in bad weather and quite often in the dark; communicate that observation to someone else; and to then continue observation and repeat the process. This requires a sacrifice on the part of the observer. Also, there are times when the observer is not available, thus eliminating that gage from the detection network.

On the other hand observers can provide descriptions of what is happening, whereas automated gages cannot. The verbal descriptions can be of great assistance to those people trying to determine the flood potential. For example, an observer can tell the decision makers that a bridge is blocked by debris whereas an automated stream gage could only relay the depth of water at the bridge, thus giving a false impression of the flood discharge.

Automated gages have several advantages. They measure what they are supposed to and immediately report it to the decision makers. They are always present at their designated location. Automated data collection centers can quickly collate and display data from many gages for the decision makers. Disadvantages of automated gages include the possibility of a malfunction, the lack of the descriptive capability observers have, and the cost of maintenance.

ALTERNATIVE 1 -- COMBINED AUTOMATED AND MANUAL SYSTEM

Alternative 1 is the most complex system presented. It also offers the greatest capability to detect flood threats and is the most expensive. Alternative 1 is patterned after the Boulder Creek system. This alternative consists of the following components:

1. Six automated rain gages dispersed throughout the drainage basin which would report by radio to a central base station. The approximate locations for the rain gages were determined by GRD Weather Center (Attachment 1), but would be subject to change during final design.
2. Two automated stream gages which also would report by radio to a central base station. The approximate locations for these gages were determined by Wright-McLaughlin Engineers. (Attachment 2). This alternative considers one gage at 20th Avenue with another location to be determined during final design, should this alternative be selected.
3. Base station equipment to receive and handle the automated gage data. The actual amount and type of equipment which could be used in a base station would be subject to decisions during final design of the overall system. A representative list of base station equipment includes a radio receiver, data terminal and display, data

printer and a mini-computer to collect, collate and display data.

4. Manual rain gage observers in the vicinity of each automated rain gage.
5. Up to three manual stream gage observers located on Lena Gulch. Exact locations would be determined during final design of the system.
6. Continued participation of meteorologists from GRD Weather Center and the National Weather Service, to include their observations of weather radar and other meteorological tools.
7. Establishment of the situation information center at GRD as described earlier.
8. Formulation of decision aides to assist the decision makers in their evaluation of a potential flood threat. See Attachment 2 for one example of a possible decision aide.
9. Formulation of a written plan which ties together all of the above components of the system.

The combination of radar, rain gages and stream gages helps to offset the weaknesses that any one of these components has. Likewise, the use of both automated and manually observed gages tend to offset their respective weaknesses.

The rain gage and stream gage observers can be either volunteers who live at or near the gage locations, or they can be employees of, or members of, government or quasi-government organizations within the drainage basin. For example, in the Boulder Creek system, the gages have been assigned to volunteer fire departments. When gage readings are desired by the emergency services group, the fire departments are paged and they in turn dispatch observers to their assigned gages. This approach for reading gages seems to be working well. It has the advantage of institutionalizing responsibility for reading the gages, which increases the likelihood that someone will be available to read the gages when needed. The problem with the pure volunteer is that he or she may not be available when needed.

Another problem faced in the observer portion of this system is the problem of communications. Phone lines are sometimes unreliable during periods of severe weather, which is exactly when they would be needed by observers in a flash flood detection system. To overcome this problem it is preferable to equip all, or at least some, of the observers with radios. In the Boulder Creek warning system, the existing communications capabilities of the volunteer fire departments were upgraded by the provision of pagers, pack units and base station units. In return for receipt of these communications tools the fire departments agreed to observe their assigned gages. Of course, the radio equipment is used for all other legitimate activities of the fire departments; thereby enhancing their overall effectiveness. Radios could also be provided to volunteer observers, but they would then not be available for other uses and the effectiveness would diminish. A discussion of how Alternative 1 meets the evaluation criteria established earlier follows.

Lead time - Lead time for this or any system will vary for different points of interest within the basin. However, the combination of meteorological support and automated rain gages will give the earliest indication of flood producing rainfall of any alternative considered. This information in turn allows the emergency services group (unless GRD is fulfilling this function) to be called in and observers to be put on notice. All of this activity helps to increase the lead time available.

Credibility - This alternative has the highest credibility of any of the alternatives considered, again because of the combination of radar, rain gages, and stream gages; and automatic and manual observations. The stream gage observations enhance credibility by confirming that rainfall has in fact been converted to runoff which has reached the stream. One factor with regard to the credibility of any system which cannot be judged is the human factor. In other words, how will the data be analyzed and utilized by the decision makers.

Reliability - The reliability of this alternative is high because of the redundancy between automated and manually observed gages, and because of the number of gages scattered throughout the drainage basin.

Non-Flood Warning Benefits - Many types of automated gages can be equipped with additional sensors, at small additional cost, to provide information such as temperature and wind speed and direction which may be of value to fire fighting efforts. Also, as mentioned above, if radios are provided to organizations such as volunteer fire departments, those radios can be used for other useful purposes. As far as the Boulder Creek system is concerned, Boulder and Boulder County have used their preparations for that system as a springborad to develop plans and procedures to deal with other potential problem areas such as hazardous material spills.

Implementation - This alternative is extremely flexible in that it can be installed in phases or all at once. It also has the capability to be expanded to other drainage basins if desired. For example, in the Boulder Creek system the automated rain gages have been installed for approximately two years while the automated stream gages will be installed in 1981. Also, the Boulder Creek system is now going to be expanded into the South Boulder Creek drainage basin.

Flexibility - Although it is not desirable to move gages once a historical rainfall-runoff record has been established, the gages in this alternative could be moved if necessary. Of course, it would be much easier to move the manually observed gages than it would be to move the automated gages.

First Cost - This alternative is without question the most expensive alternative considered.

Annual Operation and Maintenance Cost - Again, this alternative will have the highest costs, by virtue of the amount of automated equipment including gages and radios which is involved.

The estimated cost for this alternative is presented in Table 1. It should be pointed out that there are many options within the alternative which could raise or lower the total cost. For example, the number of automated gages could be raised or lowered, the number of radios for observers could be raised or lowered, or the base station could be more or less sophisticated. The total cost given in Table 1 is an estimate which is considered sufficiently refined for this level of planning and decision making, but which will undoubtedly change somewhat should this alternative be selected and implemented.

ALTERNATIVE 2 - EXPANDED MANUAL SYSTEM

Alternative 2 is essentially Alternative 1 without the automated equipment. This alternative consists of the following components:

1. Six or more rain gage observers dispersed throughout the drainage basin in locations approximating those designated for automated rain gages in Alternative 1.
2. Up to five stream gage observers on Lena Gulch and its major tributaries. Approximate locations would be the same as for Alternative 1.
3. Continued participation of meteorologists from GRD Weather Center and the National Weather Service to include their observations of

weather radar and other meteorological tools.

4. Establishment of an emergency services group and a situation information center, as described earlier.

5. Formulation of decision aides to assist the decision makers in their evaluation of a potential flood threat. See Attachment 2 for one example of a possible decision aid.

6. Formulation of a written plan which ties together all of the above components of the system.

GRD could not function as the SIC for this alternative since the manpower requirements for collecting, collating and analyzing the data would exceed their reasonable staffing levels. These activities would, for the most part, be done by machine in Alternative 1. Therefore another SIC would have to be selected, and an emergency services group would have to be formed. Previous discussions with the local sponsors have indicated that this would be a difficult task to accomplish.

As with Alternative 1, it is recommended that some, if not all, of the observers be equipped with radios in order to get away from the problem of unreliable phone lines. It is also recommended that responsibility for observing the various gages be delegated to governmental or quasi-governmental organizations, such as volunteer fire departments, whenever possible in order to institutionalize the requirement for timely observations. A discussion of how Alternative 2 meets the evaluation criteria as established earlier follows.

Lead Time - The lead time will be similar to that in Alternative 1 because observers will be located in a density equal to the automated gage density. However, there could be some reduction in lead time due to delays in taking readings and/or relaying those readings to the base station.

Credibility - Alternative 2 will have good credibility, again because of the number of observers spread throughout the drainage basin.

Reliability - Reliability is somewhat questionable. If an observer is not available or elects not to participate, the data is lost. Likewise, if phone lines are depended upon instead of radios, outages can cause a loss of data.

Non-Flood Warning Benefits - If radios are provided to organizations such as volunteer fire departments which act as observers, those radios can be used for other useful purposes. Also, the preparations which go into the emergency services group and situation information center and writing of the written plan can be used as a springboard to develop plans and procedures to deal with other potential problems such as hazardous materials spills.

Implementation - This alternative can be implemented fairly quickly provided that the observers, whether pure volunteers or organizations, can be located and brought into the program and a location for the SIC can be agreed upon.

Flexibility - Although, as stated previously, it is not desirable to move gages once a historical rainfall-runoff record has been established, the gages in this alternative could be moved fairly easily if necessary. Again the problem would be whether or not observers could be provided at the new locations.

First Cost - This alternative is much less expensive than Alternative 1. If observers are equipped with new radios the cost will obviously be higher than if phone lines are used. In either event, the cost will be much less than Alternative 1.

Annual Operation and Maintenance Cost - Again, this alternative will have lower costs than Alternative 1, by virtue of the fact that automated equipment, with the possible exception of radios, will not be included.

Estimated costs for this alternative are presented in Table 2. The estimate is based upon providing radios for one half of the observers' sites, the same assumption as was used for Alternative 1. Therefore, a comparison of the cost estimates for the first two alternatives will give a relative difference in costs, but if this Alternative 2 is selected for implementation, the cost could go up or down.

ALTERNATIVE 3 - UPGRADED EXISTING SYSTEM

Alternative 3 consists of some relatively inexpensive modifications to the present or status quo situation. The workings of this system have been described earlier in this report. The modifications would include a written plan agreed to by all the sponsors and the formulation of decision aides as discussed for Alternatives 1 and 2.

A discussion of how Alternative 3 meets the evaluation criteria established earlier follows.

Lead Time - Lead times will usually be less than for Alternatives 1 and 2 because of the lack of ground data other than the informal system described earlier.

Credibility - The credibility of this alternative is less than the other two, again because of the lack of observers throughout the basin. The lack of stream gage observations also decreases the credibility by increasing the possibility that a flood warning based solely on radar estimated rainfall data may be incorrect.

Reliability - The reliability of this alternative is lower than the other two, again because of the same problems with the lack of observers.

Non-Flood Warning Benefits - The preparations taken to prepare a formal written plan acceptable to all local sponsors may have some side benefits with regard to local cooperation for other emergency situations.

Implementation - It would be fairly simple and straightforward to implement the additions required to bring the current system up to a full Alternative 3 level.

Flexibility - This alternative is quite flexible since there are no "fixed" components.

First Cost - The preparation of a written plan and decision aides is estimated at $10,000.

Annual Operation and Maintenance Cost - There would be no additional operation and maintenance costs beyond any current costs.

Alternative 3 obviously does not fare as well as Alternatives 1 or 2 in many of the evaluation criteria. However, it is the least expensive alternative and it is partially in effect.

TABLE 1
ALTERNATIVE 1 - COST ESTIMATE

DESCRIPTION		NO.	UNIT COST	TOTAL COST
1.	Base Station (Primary site to be at GRD Weather Center)			
	Receiver	2	$2400	$4800
	Data Terminal	1	3900	3900
	Printer	2	1100	2200
	Mini-Computer	1	8000	8000
	Map Display	1	2500	2500
	Radio	1	1000	1000
	Emergency Generator	1	5000	5000
2.	Rain Gage Site (Automated)			
	Gage	6	2620	15720
	Right-of-Way	6	100	600
3.	Stream Gage Site (Automated)			
	Gage	2	5000	10000
	Right-of-Way	2	100	200
4.	Manual Observer Sites			
	Rain Gage	6	10	60
	Stream Gage	3	50	150
	Radios	5	1000	5000
5.	Repeater Site			
	Repeater	2	2650	5300
	Right-of-Way	2	500	1000
	Site Preparation	2	2000	4000
6.	Engineering	-		15000
	SUBTOTAL			84,430
	15% Allowance for Contingencies			12,670
	TOTAL			$97,100

MAINTENANCE COSTS - Boulder Creek experience indicates a start-up maintenance cost of approximately 1/2 man-year of a technician's time plus $2800.

NOTES:

1. Costs are equipment costs only and assume installation by city or county forces.
2. The repeaters will be necessary only if it is determined that direct transmission from the gages to the base station is not possible.
3. One receiver and printer at a minimum should be established at another location for redundancy. A second repeater should also be established for redundancy.
4. Radio costs are based on equipping half the observers.
5. It is assumed that no right-of-way acquisition will be required for the manual gages.
6. Engineering costs consist of final site selection, development of stage-discharge relationships and development of decision aides.

TABLE 2

ALTERNATIVE 2 - COST ESTIMATES

DESCRIPTION		NO.	UNIT COST	TOTAL COST
1.	Manual Observer Sites			
	Rain Gage	6	$10	$60
	Stream Gage	5	50	250
	Radios	6	1000	6,000
2.	Engineering	-	-	15,000
	SUBTOTAL			$21,310
	15% Allowance for Contingencies			3,190
	TOTAL			$24,500

MAINTENANCE COSTS - Estimated at 1/6 man-year of a technician's time + $1,000

NOTES:

1. Costs are equipment costs only and assume installation by city or county forces.
2. No costs are included for the Situation Information Center.
3. Radio costs are based on equipping half the observers.
4. It is assumed that no right-of-way acquisition will be required for the manual gages.
5. Engineering costs consist of final site selection, development of stage-discharge relationships and development of decision aides

WEATHER CENTER, INC.
PHONE: 303-986-9557
IRONGATE EXECUTIVE PLAZA II • 777 S. WADSWORTH BLVD. • DENVER, COLORADO 80226

ATTACHMENT 1

October 7, 1980

Mr. Bill DeGroot
Urban Drainage & Flood Control District
2480 W. 26th Avenue
Denver, Colorado 80211

Dear Bill:

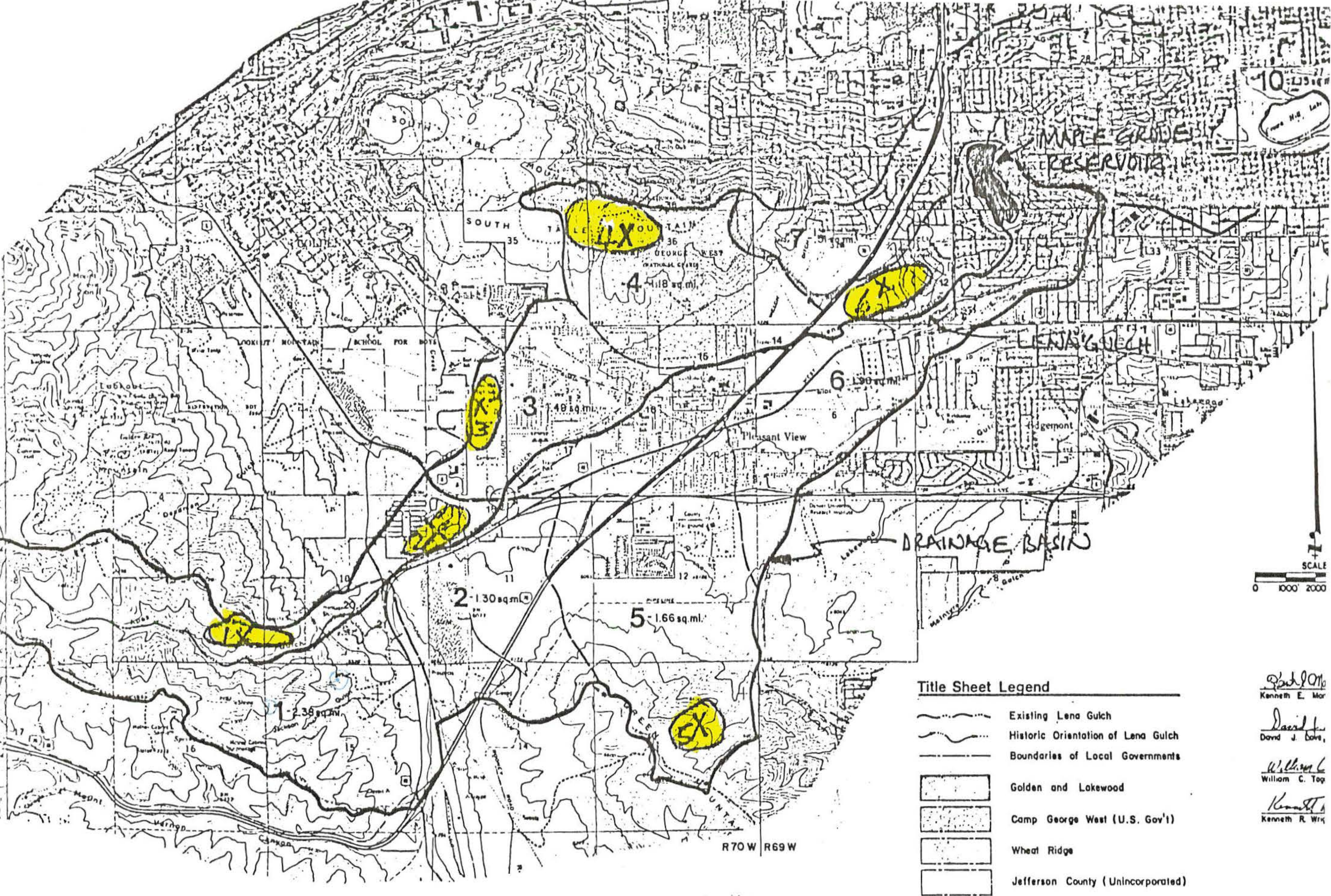
The rain gage site selection is shown on the enclosed map. There were six sites chosen; one in each of the six Lena Gulch sections. We consider this to be the optimum/maximum number since the Lena Gulch drainage basin is small. A seventh site would have been chosen on the south side of section 1, however, the Mt. Vernon Canyon (Bear Creek) site is suggested as an adequate substitute.

We hope you find the enclosed site selections useful. We believe that the sites selected will be more than adequate to catch a flash flood event.

Sincerely,

John F. Henz
President

Edward W. Pearl
Executive Vice President



WRIGHT-McLAUGHLI IGINEERS

URBAN DRAINAGE AND FLOOD CONT OL DISTRICT

CITIES of GOLDEN LAKEWOOD and WHEAT RIDGE JEFFERSON COUNTY

MASTER PLANNING
LENA GULCH

L TION MAP

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

ATTACHMENT 2

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

WCT:hes

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

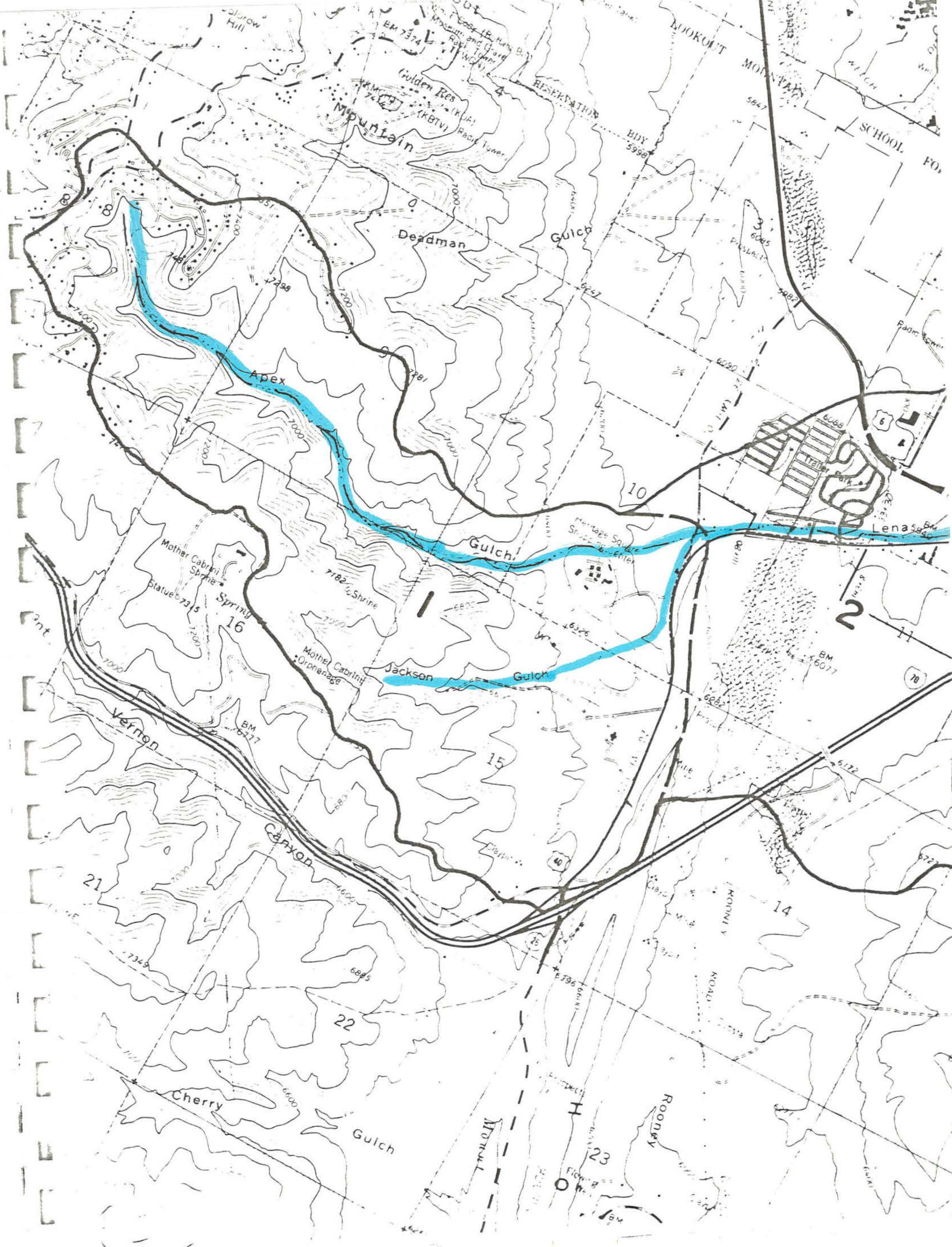
INTRODUCTION

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.



Golden Res
Mountain
RESERVATION
BDY
LOOKOUT MOUNTAIN
SCHOOL
Radio Tower
Deadman
Gulch
Apex
Gulch
Heritage Square
Trailer Park
Lena
Mother Cabrini Shrine
Statue
Spring
Shrine
Mother Cabrini Orphanage
Jackson
Gulch
Vernon
Canyon
Cherry
Gulch
Rooney
8
9
10
3
2
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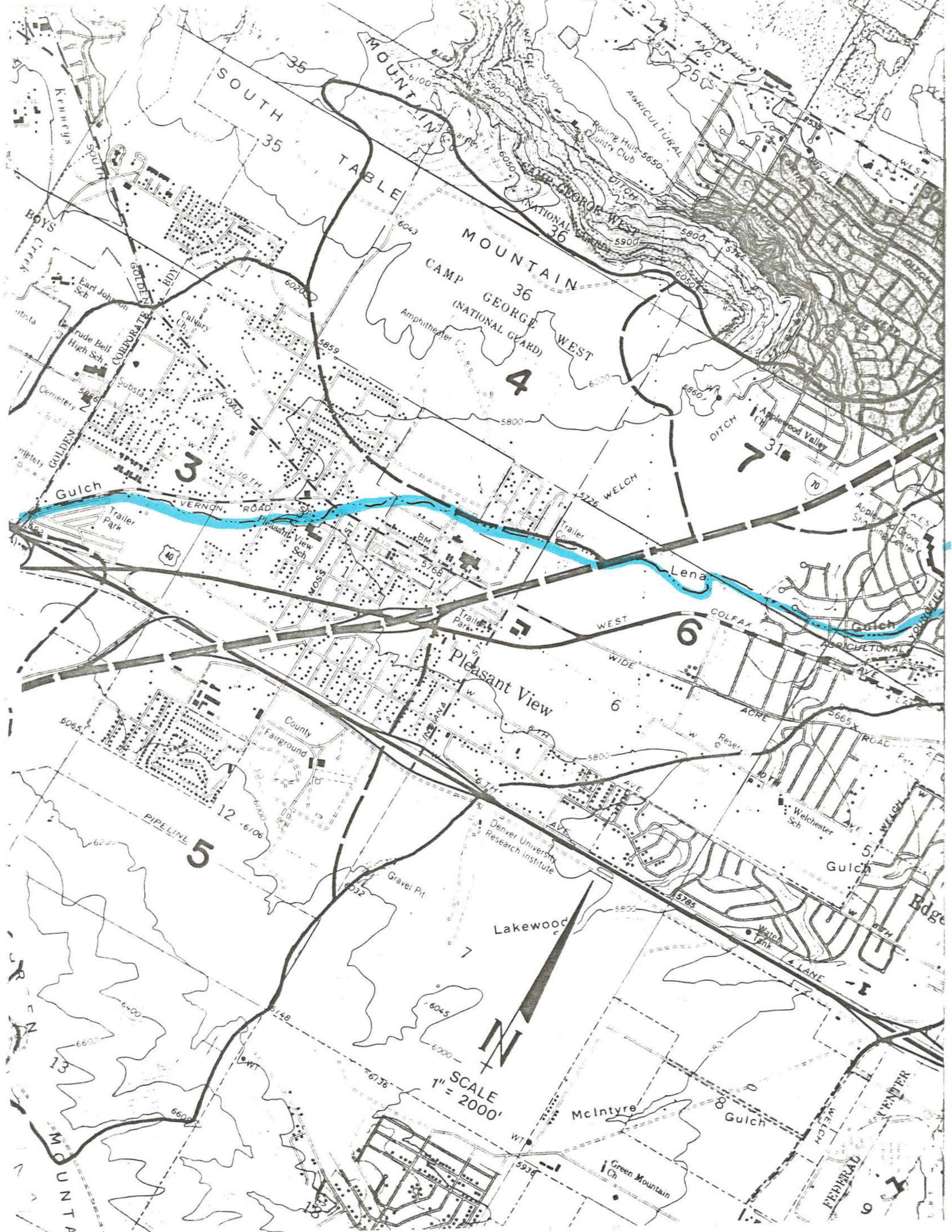
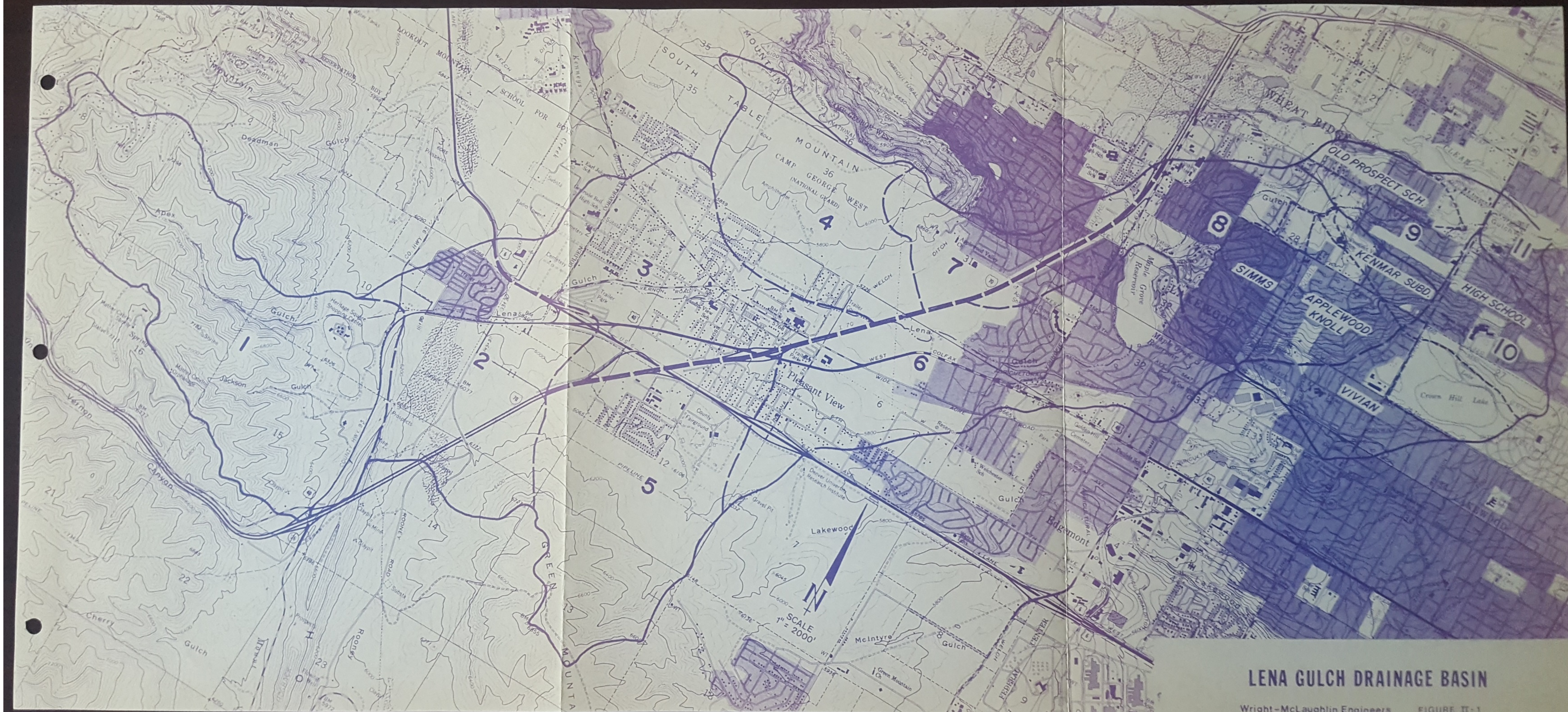
14
21
22
23



SOUTH TABLE MOUNTAIN
MOUNTAIN
CAMP GEORGE WEST (NATIONAL GUARD)
Amphitheater
Rolling Hills Country Club
AGRICULTURAL
DITCH
Applewood Valley
Applewood Grove Shopping Center
Earl Johnson Sch
Gertrude Bell High Sch
Calvary Ch
Cemetery
Substa
GOLDEN CORPORATE BDY
BOYS Creek
Gulch
VERNON ROAD
Trailer Park
Pleasant View Sch
MOSS ST
BM 5768
Lena
Gulch
WEST COLFAX
WIDE ACRE ROAD
Pleasant View
County Fairground
PIPELINE
6TH AVE
8TH AVE
Welchester Sch
Denver University Research Institute
Gravel Pit
Lakewood
Water Tank
4 LANE
SCALE 1" = 2000'
McIntyre Gulch
Green Mountain
FEDERAL CENTER
WELCH
MOUNTAIN
3
4
5
6
7

LENA GULCH DRAINAGE BASIN

Wright-McLaughlin Engineers FIGURE II-1



LENA GULCH DRAINAGE BASIN

Wright-McLaughlin Engineers FIGURE II-1

Basin 1 (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.

Basin 2 (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.

Basin 3 (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.

Basin 9 (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

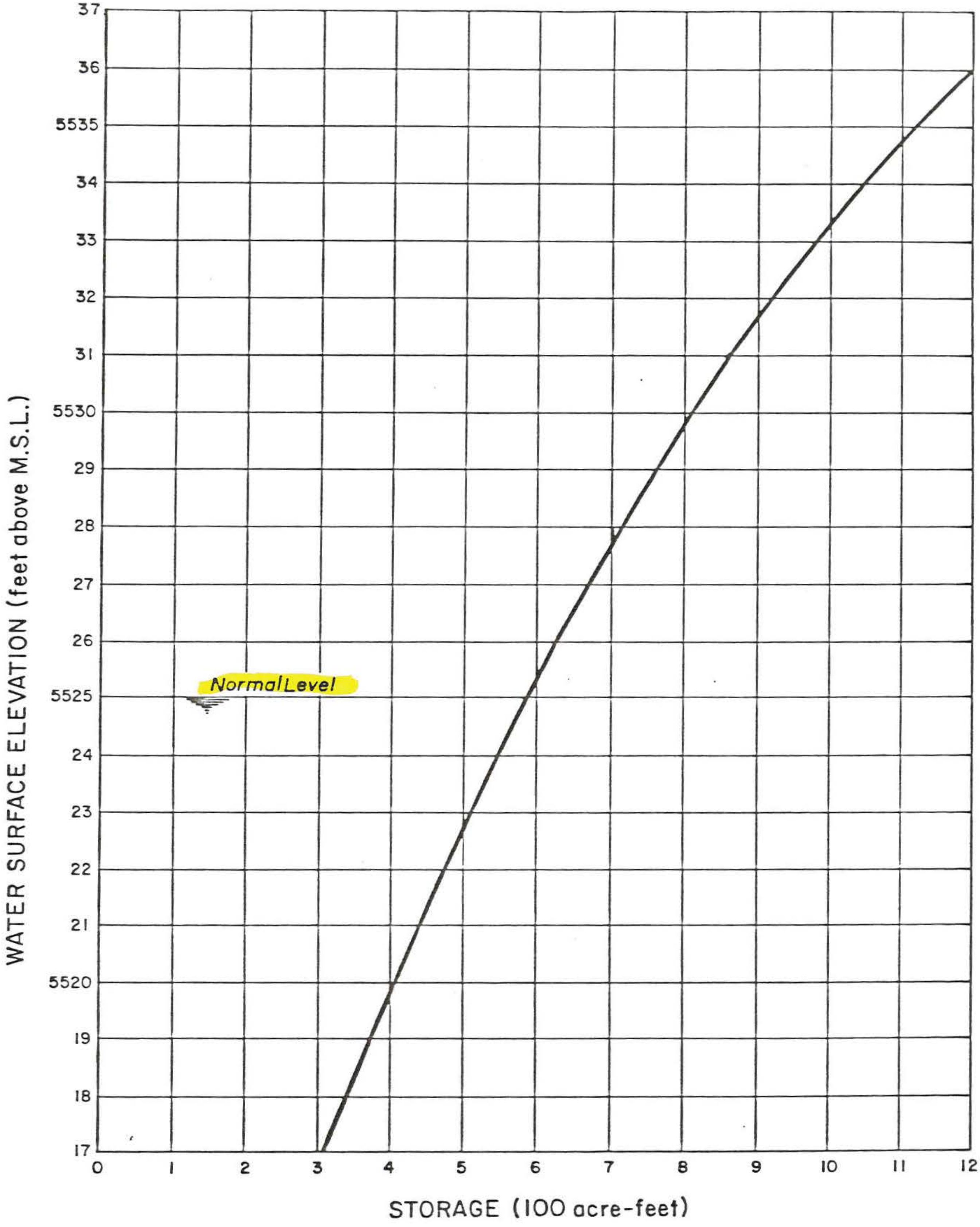
Improvements have been made to the dam and spillway which allow safe passage of the Standard Project Flood (SPF), flood peak reduction for events up to the 100-year flood, and optimal reservoir operations. The following information is taken from documents supplied by Consolidated Mutual Water Company.

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.

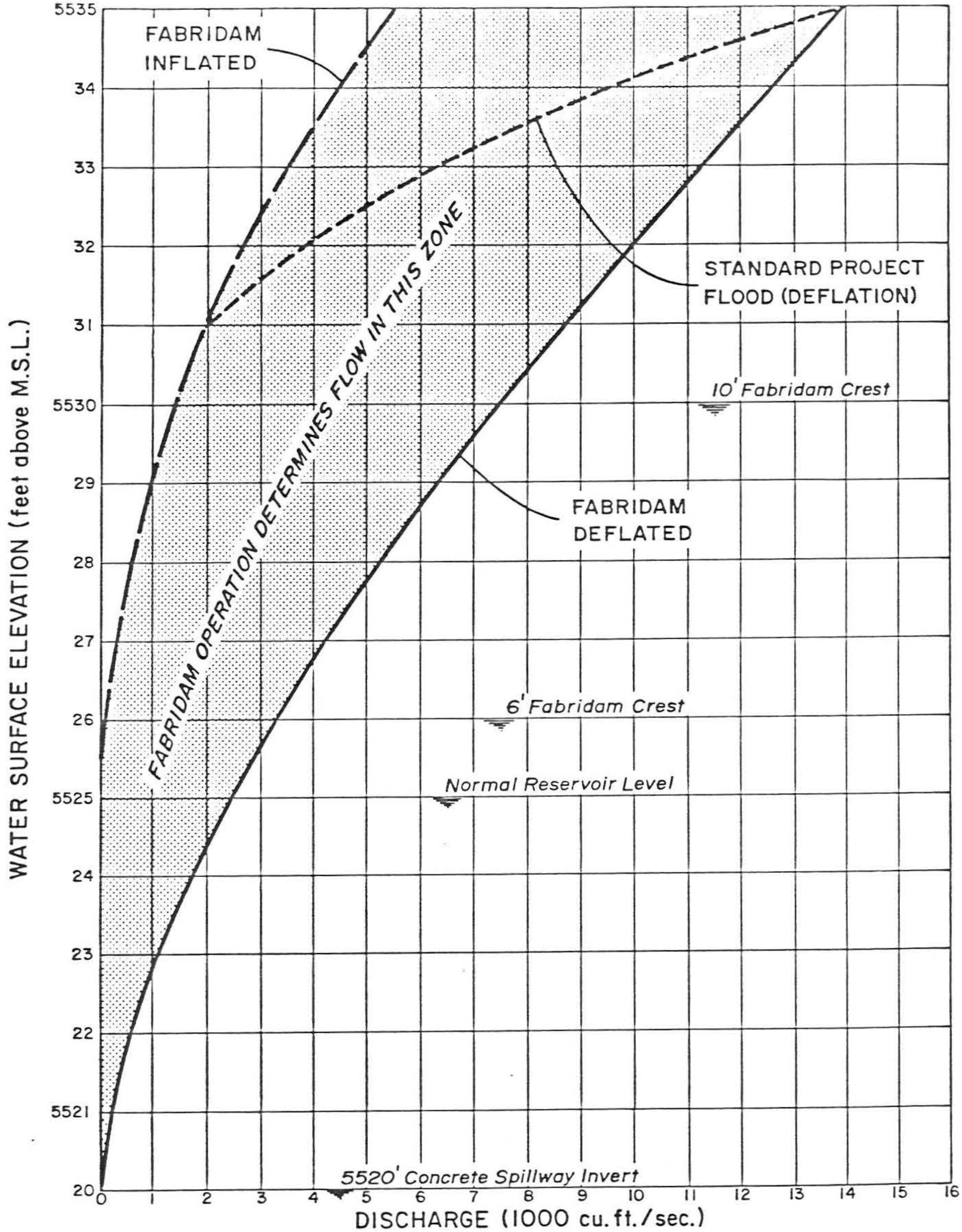
Figure II-2 presents the elevation-storage curve for Maple Grove Reservoir. Figure II-3 presents the water surface elevation - discharge curve for the spillway. Shown as the solid line is the discharge curve with the fabri-dams deflated. The long dash line is the discharge curve when the fabri-dams remain 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.

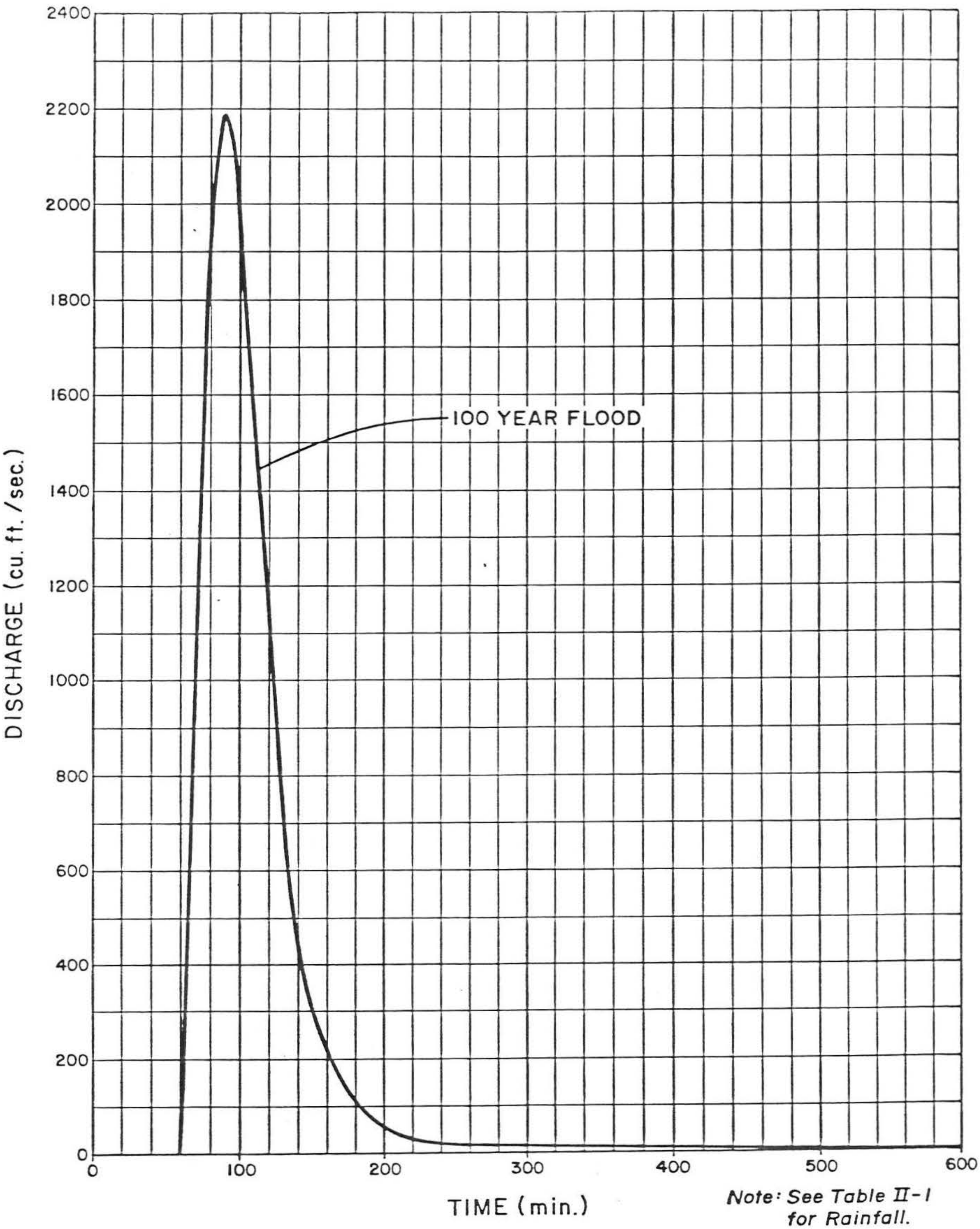
Figures II-7 and II-8 illustrate discharge hydrographs for the 10- and 100-year floods at the upstream end of Basin 9 and the confluence with Clear

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

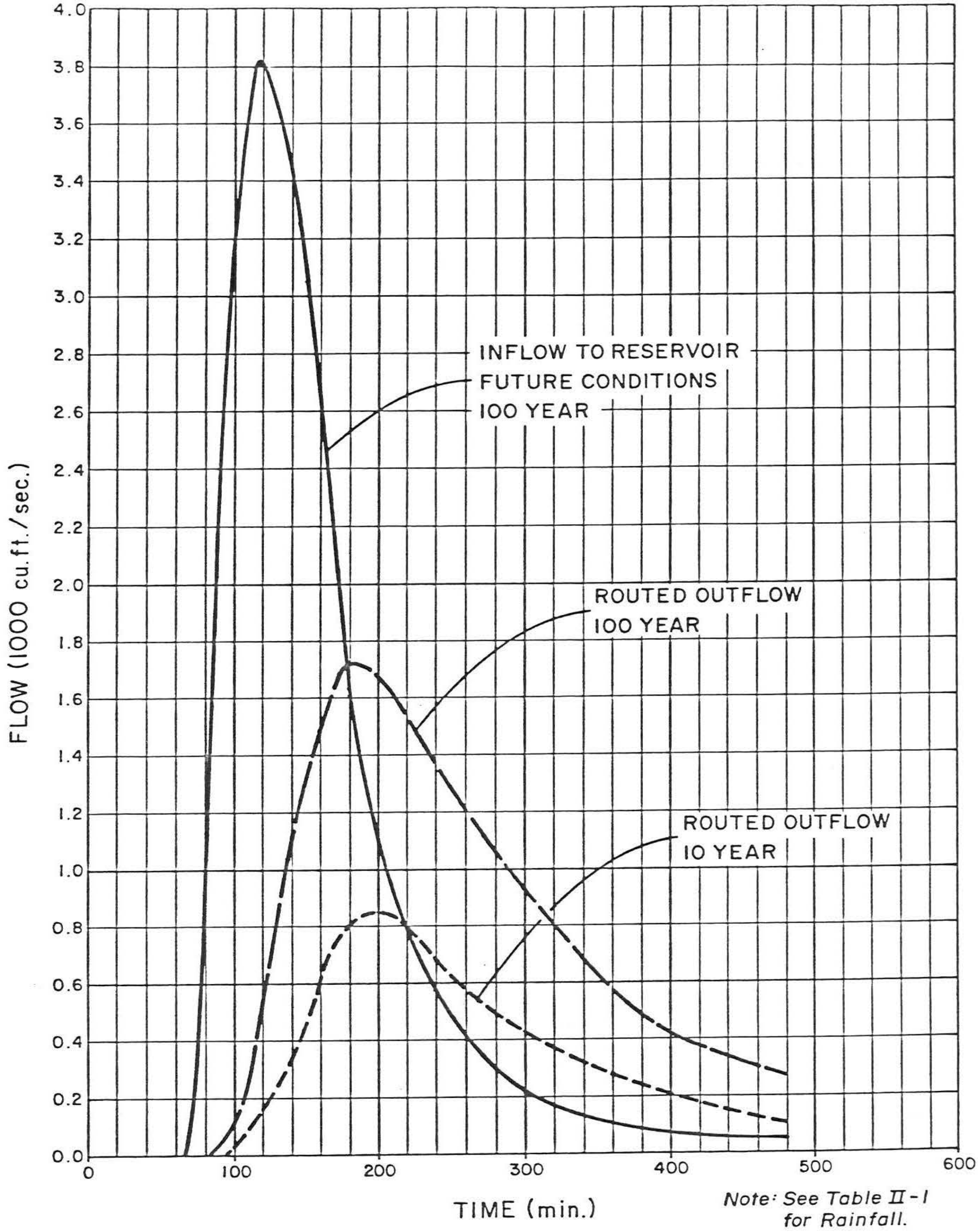
4/hr design storm



Note: See Table II-1 for Rainfall.

INFLOW TO BASIN 3 (US 6)

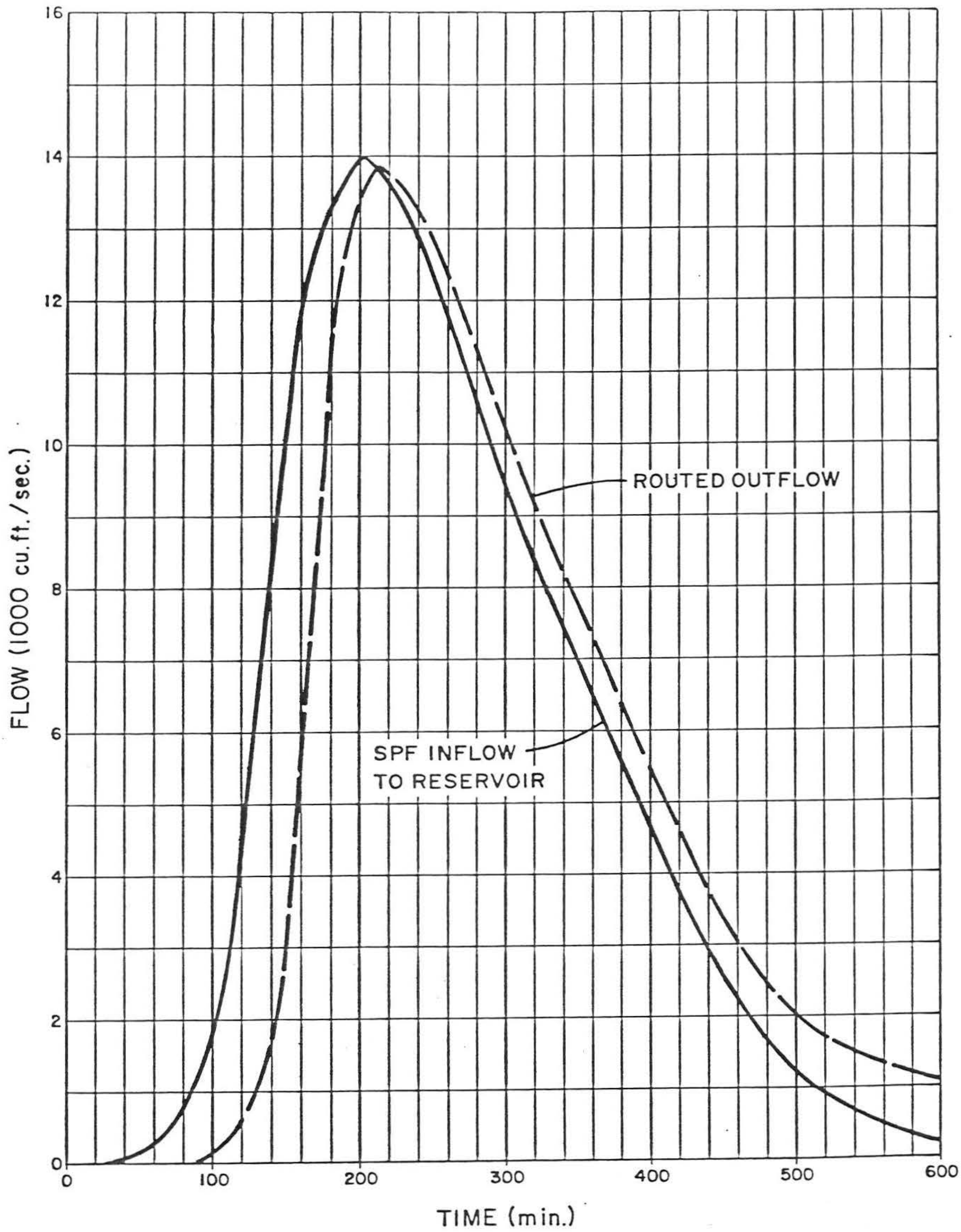
FIGURE II-4



Note: See Table II-1 for Rainfall.

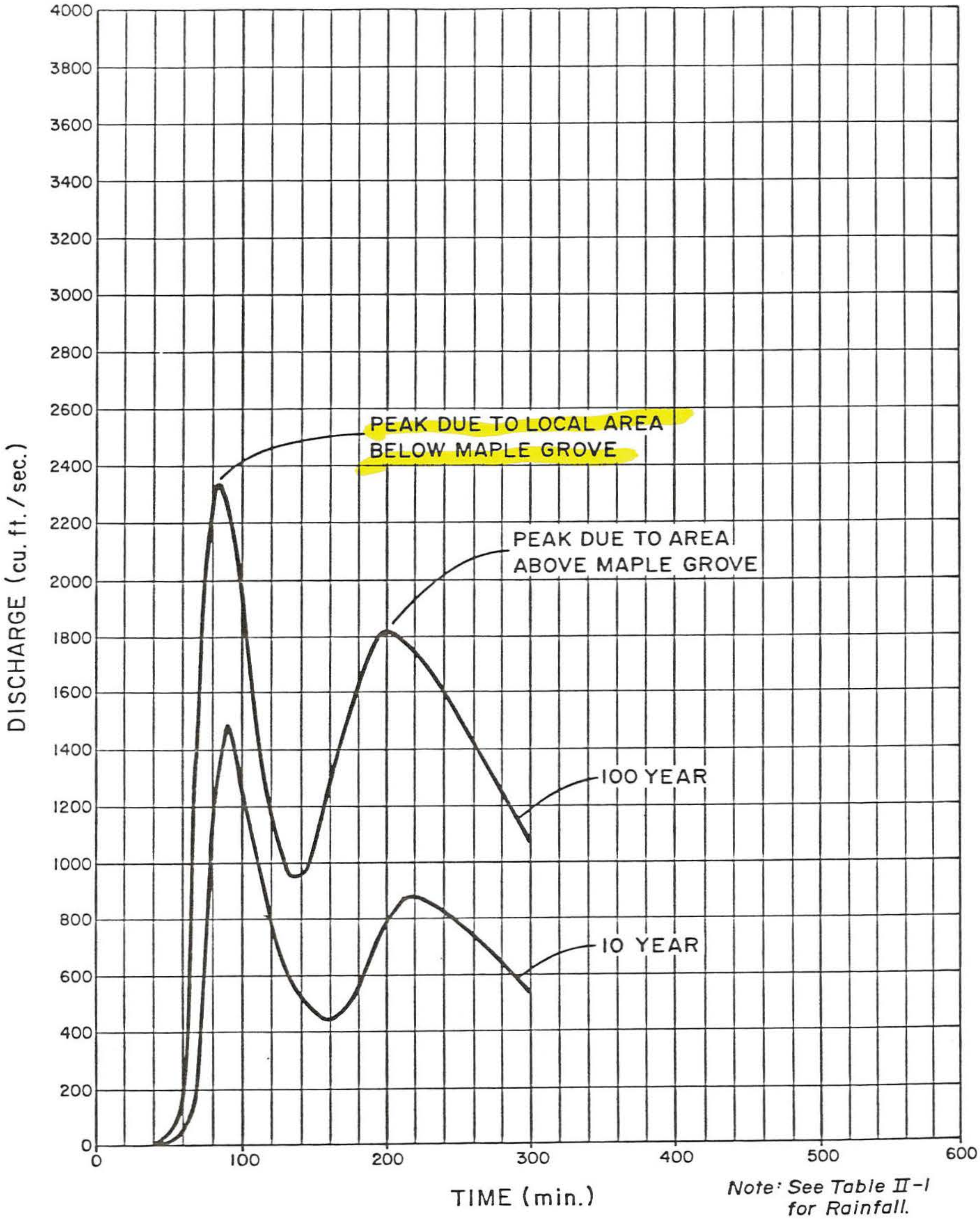
MAPLE GROVE RESERVOIR
HYDROGRAPHS

FIGURE II-5

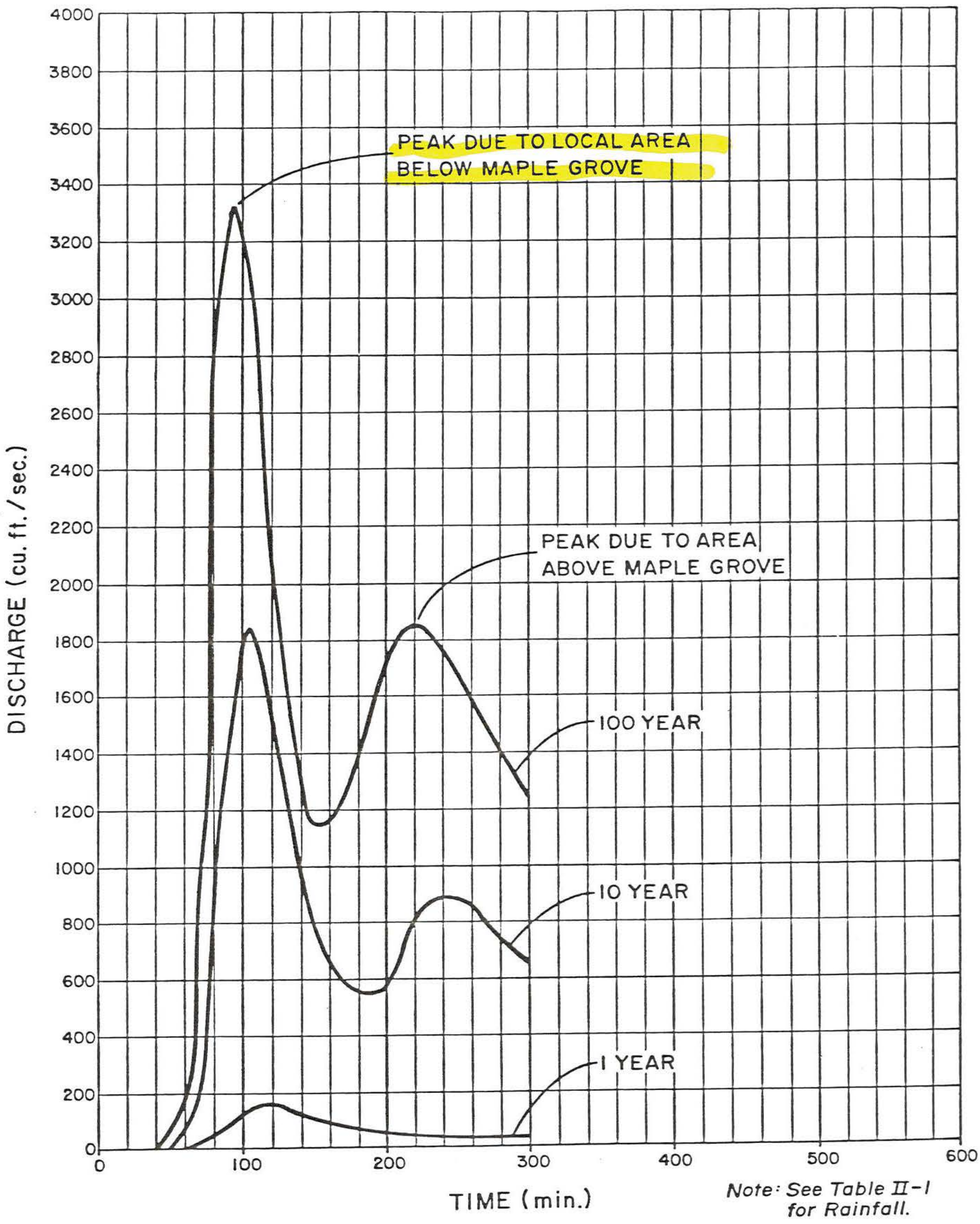


STANDARD PROJECT FLOOD (SPF)
MAPLE GROVE RESERVOIR

FIGURE II - 6



INFLOW TO BASIN 9



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.

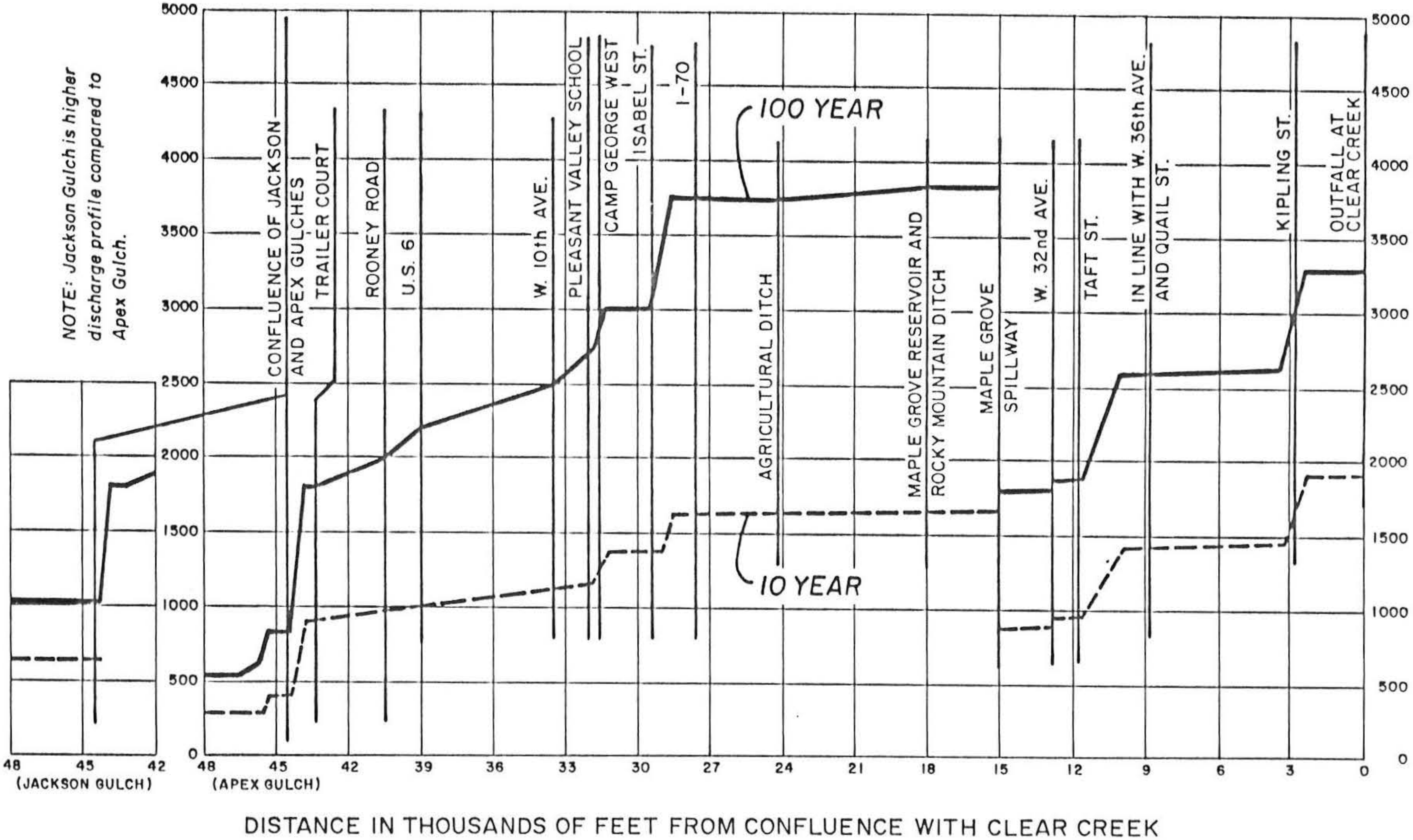
Note also that these "threshold" flood capacities should be better documented to help decide when and where to warn in priority.

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.

Yes, Prior to conc. channel construction

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

Alt: Cliff Nolte site

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 Hydrograph 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 Hydrograph 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 Hydrograph 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 Hydrograph 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 Hydrograph for next interval....move multiplier down	(11) (odd) Next effec. precip. from Table 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	-	-	-	-	-	-	-	-	-	-	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			636	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.

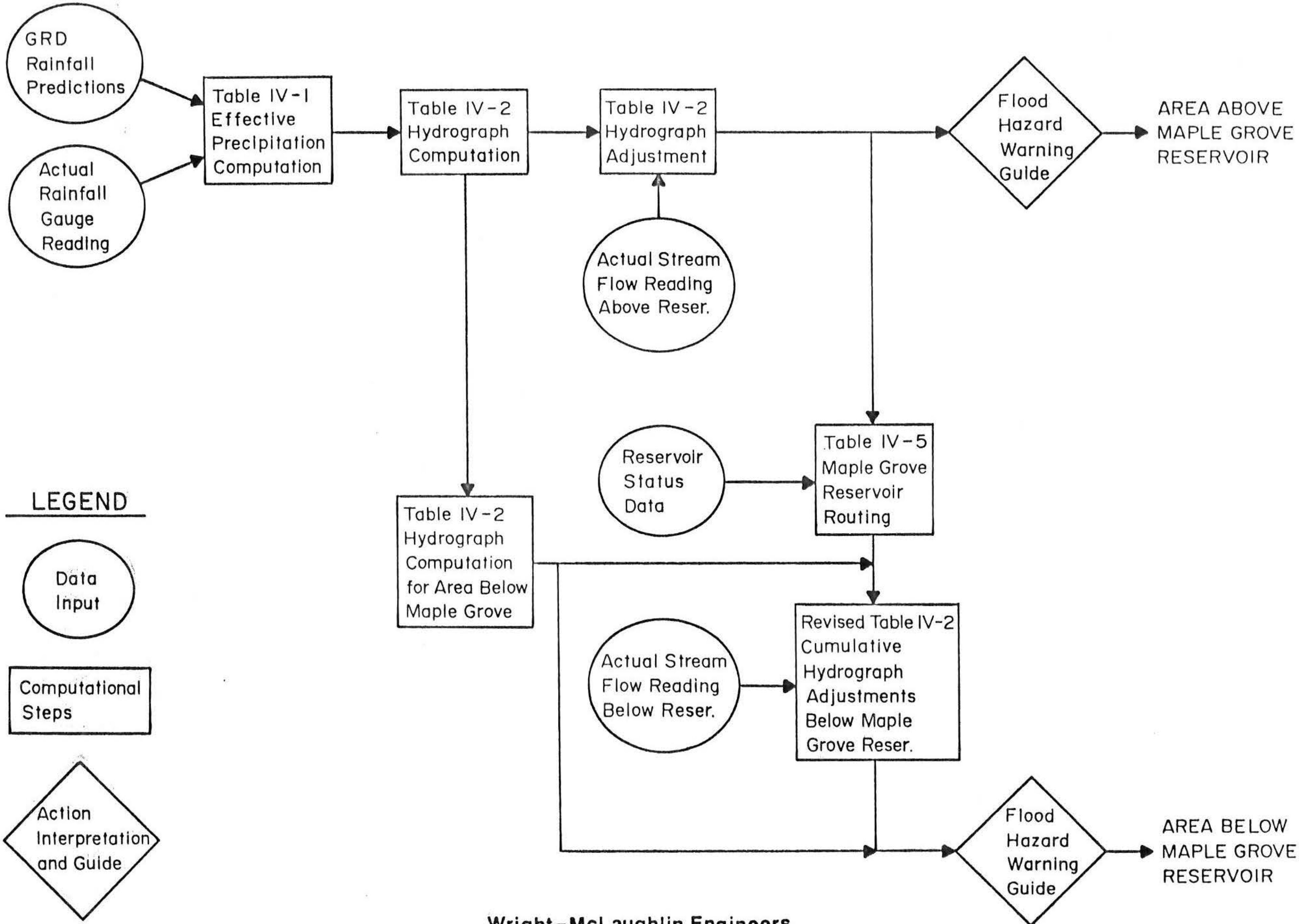


FIGURE IV-1

Wright-McLaughlin Engineers

LENA FLOOD HAZARD WARNING PROCEDURAL CHART