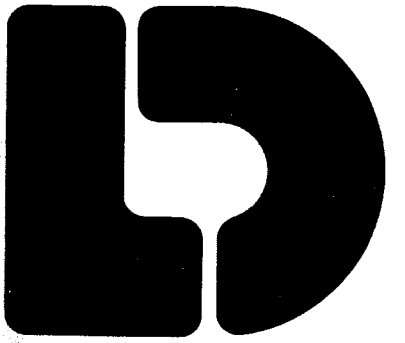
Library Copy

Do Not Remove

Dec 1984



Lincoln DeVore

Testing Laboratory, Inc.
1000 West Fillmore St.
Colorado Springs, Colorado 80907
(303) 632-3593
Home Office

December 26, 1984

City of Colorado Springs
Director of Public Works and Drainage Board
30 South Nevada Avenue
Colorado Springs, CO 80903

Re: TECHNICAL APPENDIX
to
ENGINEERING STUDY
of
SOUTHWEST AREA DRAINAGE BASIN
(UPPER CHEYENNE CREEK)
COLORADO SPRINGS, COLORADO

Gentlemen:

Enclosed is a Technical Appendix and Discussion of the engineering study of the Southwest Area Drainage Basin, authorized by the City Council of the City of Colorado Springs, the Colorado Springs Drainage Board and the Public Works Department of the City of Colorado Springs.

This Technical Appendix discusses hydrologic factors affecting the two upper basins of Cheyenne Creek. It includes soil types and mapping, basin geology, soil condition, varying rainfall effects, ground cover and gradient. A number of assumptions concerning these items were used as calibration data to determine the most likely runoff to be expected. The resulting most likely case hydrograph was used as the starting hydrograph for Cheyenne Creek in the Engineering Study of the Southwest Drainage Basin.

Respectfully submitted,
LINCOLN-DeVORE TESTING LAB., INC.

GEORGE D. MORRIS REGISTERED PROFESSIONAL ENGINEER STATE OF COLORADO

By: George D. Morris, P. E.
President

By: Richard N. Morris
Engineering Geologist

GDM/sc
LD Job No. 47623

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Contract 83-84 between the City of Colorado Springs and the Lincoln-DeVore Testing Laboratory required Lincoln-DeVore to perform a study in support of a master drainage plan for the Southwest Area of Colorado Springs. The Southwest Area consists of the watersheds of Cheyenne Creek and Spring Run. It thus includes the newly-annexed parts of Broadmoor, Skyway, Cheyenne Canyon, and Ivywild, as well as Stratton Meadows and other suburban areas. Preparation of the study is part of the City's policy of developing master drainage plans for each watershed affecting the community.

At the outset, both the City and Lincoln-DeVore recognized that the Southwest Area presents drainage problems not found in other watersheds within the city. Many of these relate to physical differences between the mountainous watershed of Cheyenne Creek and the plains watersheds that exist elsewhere in Colorado Springs. The topography, geology, climatology, and hydrology of the Southwest Area vary greatly from those of basins for which the City's drainage criteria were developed. Other problems involve the degree of urban development in the Southwest Area. Much of this development is old; none occurred within the context of a master drainage plan. There are thus both existing drainage and flooding problems and a fixed urban setting within which those problems must be faced. While the problems are the concern of Lincoln-DeVore's main

report to the City, space there does not permit thorough discussion fo the technical issues. The Technical Appendix covers those issues in greater depth.

The hydrologic procedures used in analysis of drainage basins within Colorado Springs are set forth in a report titled "Determination of Storm Runoff Criteria". This document was prepared by the City Engineering Division in March, 1977, with subsequent revisions. Most of the criteria reflect the city's growth onto the foothills and prairie lands east of the mountains. This is a region characterized by small watersheds drained by intermittent and ephemeral streams, by scant snowfall and limited total precipitation, and by cloudburst-fed floods in the summer. Accordingly, the criteria are a product of the City's cumulative experience in this hydrologic setting.

Watersheds in the Southwest Area -- particularly that of Cheyenne Creek -- lie partly or entirely within the mountains. These basins can be relatively large with steep gradients. They also contain perennial streams fed by snowmelt. Furthermore, they display storm and runoff patterns that differ markedly from those of plains basins. Although the City's criteria are a realistic approach to drainage design in the plains and foothills, their applicability to mountain basins is uncertain.

Both the City and Lincoln-DeVore agreed that the validity of the criteria should be checked with regard to the Southwest Area. For purposes of analysis,

Lincoln-DeVore's report divides the Southwest Area into four primary basins. These are:

Basin I -- North Cheyenne Creek
Basin II -- South Cheyenne Creek
Basin III -- Lower Cheyenne Creek and Cheyenne Run
Basin IV -- Spring Run

Basins III and IV are primarily foothills watersheds. Consequently, the City's drainage criteria are probably appropriate for them. Basins I and II, on the other hand, lie entirely within the mountains and require further study.

A related issue affecting the study is that of floodplain management. Federal, state, and local policies all require special management of land subject to inundation by specified flooding events (usually the 100-year flood). Floodplain studies have been performed on Cheyenne Creek by the U. S. Army Corps of Engineers and by contractors for the Federal Emergency Management Agency (FEMA). The results of these studies have generated much controversy. In part, the controversy arises from apparent conflict of the results with historic experience. Another factor is the economic and social impact of floodplain designation on the densely-developed neighborhoods that adjoin the creek. For these reasons, the City requested that Lincoln-DeVore evaluate the flood hydrology of Cheyenne Creek in enough detail to clarify the issues involved in floodplain management.

The Technical Appendix describes in some detail the physical and climatologic properties of Basins I

and II. It also describes the hydrologic assumptions and procedures used in Lincoln-DeVore's analyses. Finally, it sets forth the results of the analyses, draws conclusions from them, and explores some of the implications of those conclusions. Lincoln-DeVore emphasizes that this appendix is far from being the ultimate hydrologic analysis of the Southwest Area. Nevertheless, it should help to clarify the hydrologic setting of the mountainous basins.

PHYSICAL CHARACTERISTICS OF BASINS I AND II

Topography, Geology, and Geomorphology:

General. Basins I and II comprise the watersheds of North and South Cheyenne Creeks. The two forks join at the east boundary of North Cheyenne Canyon Park (Point 12 of this study). This is roughly at the intersection of Evans Avenue and Cheyenne Road. Basin I -- North Cheyenne Creek -- drains about 7372 acres (11.52 square miles) and Basin II -- South Cheyenne Creek -- drains about 6361 acres (9.94 square miles), for a total contributing area of about 14,733 acres (21.46 square miles). From Point 12, which is at the boundary between the mountains and the foothills, the two forks extend west into the mountains southeast of Pikes Peak. Both basins

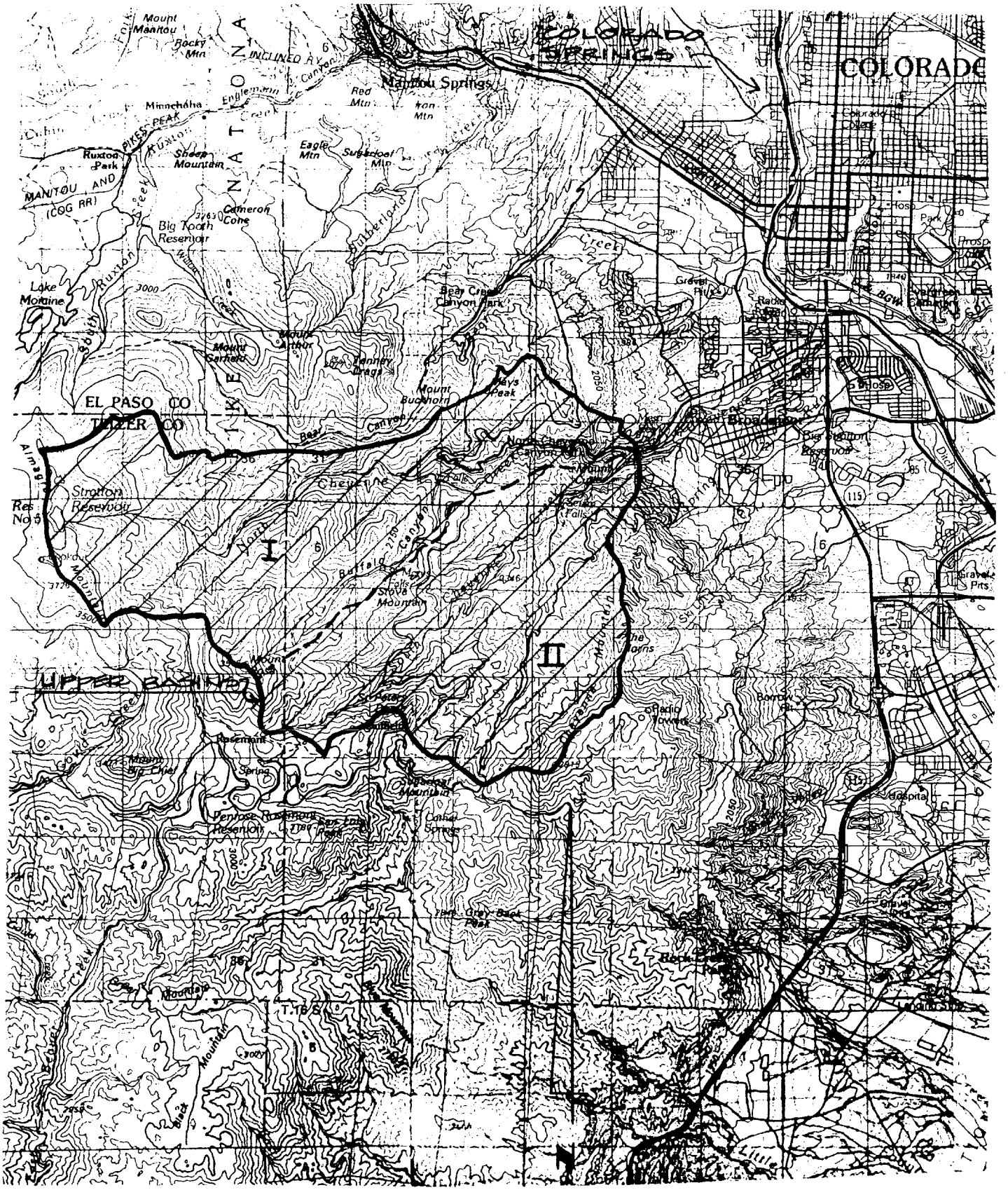


FIGURE 1

SCALE 1:100,000

GENERAL SITE LOCATION DIAGRAM
SOUTHWEST UPPER DRAINAGE BASIN
LD# 47623

LINCOLN DeVORE ENGINEERS GEOLOGISTS

COLORADO: COLORADO SPRINGS
GRAND JUNCTION, PUEBLO,
GLENWOOD SPRINGS

contain rugged terrain, with steep, rocky mountainsides and narrow, high-gradient canyons.

Geology. Basins I and II lie almost entirely within the Pikes Peak Batholith, a large body of granitic rock that forms this section of the Southern Rocky Mountains. The batholith was emplaced more than one billion years ago, and has repeatedly been the foundation of mountain ranges through much of geologic time. Pikes Peak and the surrounding mountains are only the most recent highlands to occupy this area, having initially formed during the Laramide orogeny of about 75 to 65 million years ago. After being worn down and then rejuvenated, the mountains were eroded by water and glacial ice to their present form.

The Ute Pass Fault, which crosses both basins just above Point 12, is the east boundary of the batholith. Starting as a high-angle fault in Ute Pass, the fault is a low-angle thrust fault where it crosses Cheyenne Creek and passes below Cheyenne Mountain. Other faults associated with the Ute Pass Fault occur at various places within the mountains. They usually form systems of side canyons and aligned, ridgetop saddles, often along alignments nearly parallel to that of the main fault. East of the Ute Pass Fault, the geology changes abruptly. There, beds of sedimentary rock have been tilted sharply upwards by uplift of the mountains and movement along the fault. The rocks along the fault -- mostly clay shales -- have been locally altered to metamorphic hornfels by the intense

deformation. Nevertheless, this geologically interesting area is only a very small part of the two basins.

Of as much interest as the bedrock units are the surficial deposits. Although both basins contain significant areas of exposed bedrock, most of the ground surface is covered by soil and weathered rock debris. A thin, poorly-developed soil -- consisting mostly of weathered granite fragments, or grus -- covers the mountaintops and upland slopes. This soil is mostly sand and gravel, and ranges in thickness from an inch or less to as much as several feet. It may be either covered by a thin layer of organic litter, or bare to the elements. Along the margins of canyons and on lower slopes, wedges of colluvium form relatively thicker deposits of loose material. The colluvial deposits are masses of the same thin soil that have washed, slid, or fallen off the mountainsides, coming to rest on the flatter lower slopes. Both the residual soil and the colluvium are widespread throughout both Basins I and II.

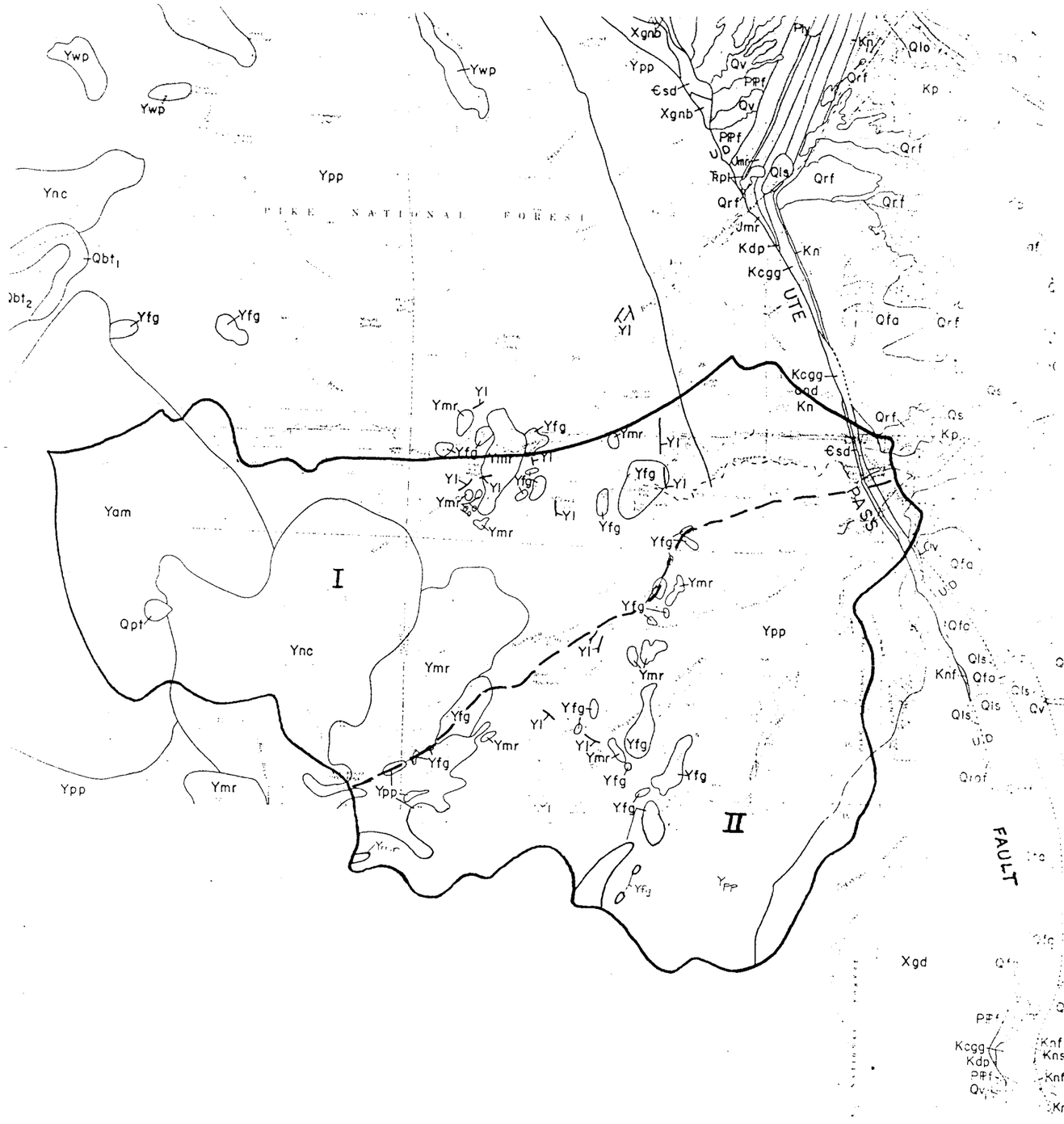
A second class of surficial deposits includes materials generated by mass movement processes. These processes include landsliding, rockfall, debris flow, and a variety of related mechanisms. All have in common the tendency to abruptly and quickly transport large amounts of soil and rock downslope, and to deposit them in large masses. Small deposits, such as those produced by smaller rockfalls and debris avalanches, are quite common. Likewise, the fan-shaped deposits left by debris flows and torrential floods are relatively common wherever small drainageways and tributary streams join larger

valleys. The deposits left by large landslides and rockfalls are relatively rare. However, they may exert an influence on drainage patterns that is disproportionately large with respect to their frequency. Mass movement processes are hydrologically significant in that they may generate enormous amounts of sediment and debris to be transported by streams. Furthermore, they can locally block or obstruct channels -- either temporarily, during a flood event, or more permanently, forming a lake or marsh.

Yet a third group of deposits are those laid down by water. Most of these are alluvium, or stream-laid deposits. These occur, to varying extents and thicknesses, in almost every larger valley and canyon. Alluvial deposits vary from a few tens of feet to a few hundred feet wide, and may be anywhere from a few feet to a few tens of feet thick. They are likely to be discontinuous along the length of a drainageway, occurring only where stream gradient and valley geometry are favorable. Isolated areas of valley floor may contain deposits laid down in small lakes, ponds, and marshes. These are most likely to occur where a landslide or debris fan has blocked a valley, allowing water to accumulate. Valley-bottom deposits generally contain significant amounts of organic matter. In addition, they are more-or-less stratified and are likely to be finer-grained than the hillside deposits. However, they tend to be silty rather than clayey, largely because the source rocks contain very little clayey matter.

The bedrock, regardless of its detailed character, tends to act as an impermeable barrier to infiltrating water. While faulted and fractured rock may, indeed, be able to transmit some groundwater, the volumes of water thus removed from the surface water system are trivial with respect to the total volume of a flood event. The surficial deposits are sufficiently thin over most of the uplands that their hydrologic behavior is controlled by that of the underlying bedrock. Although the sandy and gravelly soils may have very high infiltration rates, runoff waters must move downslope, back to the stream, along the impermeable rock surface. Virtually all of the soils contain only minor amounts of clay to impede drainage of water. However, the weathered granite soils generally contain large amounts of small, platy, mica flakes. These flakes tend to block soil pores, thereby reducing permeability below the levels usually found in sandy and gravelly soils. This effect is most pronounced in soils that already contain quantities of silt and fine- to medium-grained sand. Such finer-grained soils are often complexly interlayered with coarse-grained soils, thereby complicating the drainage behavior of the soil mass.

Fluvial Geomorphology: The drainage networks of both North and South Cheyenne Creeks consist of a handful of perennial streams, up to a few dozen intermittent streams, and innumerable small ephemeral streams, draws, and sidehill channels. These are, without exception, very steep and rocky; many are at least partially blocked by debris and



LEGEND:

Opt - PINEDALE TILL (PLEISTOCENE PINEDALE GLAGIATION) - Gray non-sorted, non-stratified firmly compacted bouldery sandy till on steep east flank of Almagre Mountain.

Kn - NIOBRARA FORMATION (UPPER CRETACEOUS)

Yl - LAMPROPHYRE (PRECAMBRIAN Y) - Black finely crystalline tabular masses in the Pikes Peak batholith interpreted as dikes that are discontinuous at the surface, but probably continouos at depth.

Ymr - MOUNT ROSE GRANITE (PRECAMBRIAN Y) - Light-gray granite. Contains riebackite in rosette clusters; generally medium but locally finely crystalline or pegmatitic; age relative to Windy Point Granite unknown, but approximately correlative.

Ync - GRANITE OF NELSON CAMP (PRECAMBRIAN Y) - Tan to greenish-brown medium-crystalline biotite granite. Contains minor astrophyllite and riebeckite.

Yam - GRANITE OF ALMAGRE MOUNTAIN (PRECAMBRIAN Y) - Pink equigranular medium-crystalline biotite granite. Contains interlocking tabular microcline crystals and prominent rounded quartz grains.

Ypp - PIKES PEAK GRANITE (PRECAMBRIAN Y) - Pink to reddish-tan medium to coarsely crystalline biotite granite or quartz monzonite. Encloses many pegmatites that locally contain crystal-lined miarloitic cavities; weathers to coarse grus. Contains some gabbroic or diabasic dikes.

Yfg - FAYALITE GRANITE (PRECAMBRIAN Y) - Dark-green medium-crystalline biotite granite. Contains small amounts of fayalite or its psuedomorphs. Occurs as xenolithic segregations in Pikes Peak Granite.

Esd - Sandstone dike (Cambrian?) - Reddish-brown hard quartzitic fine grained sandstone filling parts of Ute Pass fault and subsidiary parallel fractures.

SCALE 1: 62,500

FIGURE 2

GEOLOGIC MAP
SOUTHWEST UPPER DRAINAGE BASIN
LD# 47623

LINCOLN DeVORE ENGINEERS · GEOLOGISTS
COLORADO: COLORADO SPRINGS, GRAND JUNCTION, PUEBLO, GLENWOOD SPRINGS

DRAWN BY: D.O.	SCALE: SHOWN	DATE:
CHECKED BY:	CONT. INTERVAL:	REV.

vegetation. Structural and other geologic controls are evident throughout the two basins. The control may manifest itself in the orientation of canyons -- particularly where faults and shear zones associated with the Ute Pass Fault control the drainageways of tributaries flowing in north-south directions. Other controls include the very steep gradients and cataracts produced by resistant rock units, valley and canyon constructions arising from the same cause, and the large volumes of sediment injected into th system by weak rock units, landslides, and debris flows. Secondary impacts of geology upon the streams include the marshy areas and alpine bogs that sometimes exist, especially above valley constrictions.

The rugged terrain gives both basins hydraulic characteristics that differ greatly from those of more typical urban watercourses. Of paramount importance are the steep slopes and high roughness coefficients of the channels. The average basin slopes range from 0.123 to 0.297; corresponding values for mainstream channel reaches range from 0.074 to 0.204. Channel gradients vary greatly from the average values, of course. Short reaches may contain relatively level pools; conversely, cataracts have gradients well in excess of 1.000. Considering only the average gradients, though, it is apparent that the two forks of Cheyenne Creek are steep to very steep. The primary result of the steep slopes is high flow velocities in the channels.

A number of factors combine to partially offset the high flow velocities. First among these is the high boundary roughness of almost every channel in the two basins. The channels contain roughness elements at every scale from moderately small to very large. At the small scale, several reaches of channel have beds consisting of corase-grained sand and gravel, with scattered cobbles. Other reaches, though, are dominated by cobbles and boulders; dimensions of the boulders may be in excess of 10 feet. While all of these roughness elements serve to retard flow, the larger elements constitute actual obstructions to flow and are massive enough to be effective even during floods of low to moderate magnitude. Added to the normal boundary roughness is the additional roughness contributed by bank vegetation, downed timber, and debris. Still more retardance comes from the form roughness associated with channel irregularity, sinuosity, and bedforms such as bars. Steeper stretches of channel have sequences of chutes and pools (corresponding roughly to the pools and riffles of less steep streams) that significantly affect flow.

Other factors that modify flow velocity include the retardance caused by vegetation outside the channel. This effect is, obviously, most pronounced during flood episodes that involve overbank flow. Additionally, it has the greatest impact in flat, boggy reaches and in areas that are densely overgrown with vegetation -- particularly brush and small

trees. In large floods, however, the energy of the flow may suffice to destroy the vegetation. This will produce a sudden decrease in roughness, with an abrupt increase in flow velocity. Yet another factor, and one that is present for all high flow stages, is the effect of erosion and sediment transport. In reality, few steep gradient streams flow at very high velocities. Instead, they expend energy in erosion and in the transport of sediment and debris. Major floods on mountain streams thus tend to carry unusually high concentrations of solids. As a consequence, flood discharges in streams like North and South Cheyenne Creeks tend to hover near critical flow, oscillating between sub-critical and super-critical flow as they pass down the channels.

Watershed Descriptions:

Characteristics of Basin I. The watershed of North Cheyenne Creek is long and narrow, with considerable relief. Beginning at the summit of Almagre Mountain (elevation 12,360 feet), the basin extends about seven miles eastward to its confluence with South Cheyenne Creek at Point 12 (elevation 6260 feet). At no point is the basin wider than about 2.5 miles; through much of its length , it is only about 1.1 miles wide. Through the lower three-quarters, the creek flows through a canyon having walls as high as 1500 feet or more. The

only major tributary is Buffalo Creek, which joins North Cheyenne Creek just below Helen Hunt Falls (Point 4; elevation 7190 feet).

Buffalo Creek heads at the summit of Mounta Rosa (elevation 11,500 feet) and passes through an equally narrow and deep canyon. In its final one-third mile, Buffalo Creek passes over Silver Cascade Falls, dropping some 250 feet to Point 4. Further upstream, the creek passes over Saint Mary's Falls. At this cataract, the creek drops about 200 feet in about 0.2 miles. The main stem of North Cheyenne Creek does not branch into tributaries until very high in the basin -- above about 9700 feet in elevation. While the stream has several very steep reaches and minor cataracts, the primary waterfall is Helen Hunt Falls.

Normally, streamflow in North Cheyenne Creek is dominated by snowmelt. The effect is either direct, in the spring and early summer, or indirect, as a consequence of interflow and groundwater discharge. Summer rainstorms cause rapid rises in stream stage. However, this effect is only temporary -- although it has the greatest potential for generating damaging floods. The hydrologic effect of summer thunderstorms is increased by the overall orientation of the drainage basin, which has its long axis aligned downstream along the probable storm path. Man-made impacts on the stream's hydrology include the presence of Stratton Reservoir in the creek's extreme headwaters, and both the diversion of water and

the maintenance of minimum streamflows by the City of Colorado Springs Department of Public Utilities.

Characteristics of Basin II. South Cheyenne Creek has a drainage basin with a crude triangular shape; its relief, although high, is generally less than that of North Cheyenne Creek. Much of the difference in basin shape between the two creeks is due to the branching of South Cheyenne Creek into two forks at Point 11, just above Seven Falls. The north, or main, branch heads at the summit of Mount Rosa, while the south branch begins at a low divide (elevation 8500 feet) where the Cripple Creek Stage Road crosses into the drainage of Little Fountain Creek. However, many tributaries of the south branch head at much higher elevations on Cheyenne Mountain and on the ridge to the west. Overall, the basin is about 5.5 miles long and, at most, about 3.1 miles wide. The north branch is about 4.4 miles long and about 1.6 miles wide; the south branch is about 3.2 miles long and 1.9 miles wide. From the confluence at Point 11 (elevation 6740 feet) to the junction of North and South Cheyenne Creeks at Point 12, the basin length is about 1.2 miles.

Unlike North Cheyenne Creek, the highest points in Basin II are not necessarily at the most distant parts of the basin, nor are they representative of the basin as a whole. Although the north branch heads on Mount Rosa, the drainage divide at the end of the watershed is a pass east of the ghost town of Rosemont, at elevation 10,030 feet. The highest points in the watershed of the south branch are the south

summit of Cheyenne Mountain (elevation 9570 feet) and the ridge behind Saint Peters Dome (elevation 9750 feet). The latter peak, together with Stove Mountain (elevation 9750 feet), marks a zone of resistant bedrock. This results in a steep and rugged reach of canyon, marked by cataracts and falls similar to those at Saint Mary's Falls on Buffalo Creek. Below this point, the valley of the north branch opens up and becomes distinctly less rugged. In this it imitates the south branch, whose basin is a relatively wide valley possessing a narrow, but distinct, alluvial floodplain. This valley which is distinctly different from that of Basin I, reflects geologic control of South Cheyenne Creek's path by faults and shear zones related, and sub-parallel, to the Ute Pass Fault. Both branches of South Cheyenne Creek have a number of short tributaries. Below Point 11, though, another zone of highly resistant bedrock produces the cataract at Seven Falls, where the creek drops 170 feet in about 0.1 miles. The creek then passes through a narrow, winding, steep-walled canyon for about 0.8 miles before emerging from the mountains just above Point 12.

Streamflow in Basin II is also dominated by snowmelt. The relative absence of very high elevations, though, reduces both the amount and the seasonal duration of snowfall relative to Basin I. This effect is partially offset by the superior groundwater properties of the wider valleys, which tend to retain snowmelt and release it gradually to the stream. Like Basin I, summer thunderstorms cause stream stage to rise and fall rapidly. The basin axis is not oriented as favorably along

probable storm paths. However, the two branches join in such a manner that flood peaks will tend to arrive at the confluence almost simultaneously. This tends to increase the magnitude of peak discharges from Seven Falls to Point 12. Unlike North Cheyenne Creek, South Cheyenne Creek has been relatively free of man-made structures and other water developments.

Characteristics of the Canyon Mouth Area. In the reach immediately upstream from Point 12, both creeks leave their mountain canyons to flow short distances in a relatively open, common valley. The transition occurs abruptly where the Ute Pass Fault separates the highly-resistant granitic rocks from the erodible shales. In many respects, the canyon mouth area is a zone of adjustment. Both creeks rapidly flatten their gradients, with a consequent loss in the potential energy available to the flowing water. As a result, the streams must drop most of their sediment load while developing first a braided, and then a meandering, channel form. The area above Point 12 is thus a depositional landform, half alluvial fan and half stream terrace. Although the land surface possesses considerable relief, it is so much flatter than the adjoining mountainsides that it appears gentle. In a major flood, the canyon mouth area will act as an energy dissipator and sediment trap. Floodwaters will tend to leave the channels and spread out over a broader area. Some of the water will-re-concentrate in the channel of Cheyenne Creek. The remainder will flow down streets, abandoned channels, and similar paths of minimum resistance.

Soils and Vegetation:

General. Soils in the study area are uniform to the extent that most of them consist of weathering debris from granitic rocks. The thickness of the soils does vary greatly from place to place, as do their condition and vegetative cover. Areas of alluvial soil do exist, as do areas of frozen soil at high elevations. Because of a lack of solid hydrological data, very little is actually known about the hydrologic properties of the soils. The manner in which soil will affect runoff and groundwater movement is thus a matter of surmise and interpretation. Varying interpretations are a major source of uncertainty in deriving synthetic hydrographs for both basins.

At the time of our study, the only detailed soil mapping available for Basins I and II was unpublished data compiled by the U.S. Forest Service. This information was available only in the form of unchecked, annotated aerial photographs at the office of the Forest Supervisor for the Pike and San Isabel National Forests. To use this information, it was necessary to compile it into a map (included with the main report) resolving inconsistencies and doing limited checking and reinterpretation in the process. It was also necessary to estimate hydrologic properties for some mapping units that had not yet had those properties officially defined by either the Forest Service or the U.S. Soil Conservation Service. Limited areas along the east edge of Basins I and II were covered on the Soil Conservation Service maps for El Paso County. While

this provided useful supplementary information, the different level of precision at which the two sets of soils mapping were done necessitated further interpretation to resolve inconsistencies where the two sets joined.

Our hydrologic analyses were performed using both the Forest Service soils mapping -- modified as described above -- and a set of soil properties independently estimated by Lincoln-DeVore hydrologists. As such, the soil properties used are subject to modification, either when final maps are prepared by the Forest Service or when additional, site-specific soils information becomes available. As detailed study of the infiltration and runoff properties of the basin's soils is far beyond the scope of our work, there is thus a residual uncertainty associated with this part of the hydrologic analysis. Nevertheless, the soil properties -- together with the associated vegetative cover and condition properties -- represent the best information available at the time of the study.

Hydrologic Soils Groups. As is well known, the Soil Conservation Service classifies all soils into one of four hydrologic soil groups. These groups are used to establish soil -- cover complexes that can be used to estimate a rainfall-runoff relationship. According to Appendix B of the SCS Technical Release No. 55 (U.S.D.A. Soil Conservation Service, 1980), the four groups are defined as follows:

A. (Low runoff potential). Soils having a high infiltration rate even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels.

B. Soils having a moderate infiltration rate when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils within moderately fine to moderately coarse texture.

C. Soils having a slow infiltration rate when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine texture.

D. (High runoff potential). Soils having a very slow infiltration rate when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material.

The hydrologic soil groups are used directly in selecting a runoff curve number (CN) for a watershed. Consequently, the choice of soil group (or composite soil group for an entire basin) has a dramatic impact on the expected runoff in a flood.

The Forest Service mapping assigns almost all soils in Basins I and II to groups C and D. The only exceptions are mapping units of limited extent, such as the Tecolote very stoney sandy loam in the valley bottom of South Cheyenne Creek's south branch. The reasoning of Forest Service mappers in so classifying the soils is not entirely clear. Because almost all the soils are sandy and gravelly, it would appear reasonable to place many of the mapping units in groups with lower runoff potential. However, the fact that the basins do contain large areas of rock outcrop and that the permeable soils are thin and overlie low-permeability bedrock may partly explain the groupings. This combination of factors can lead to rapid movement of <u>interflow</u>, or water that infiltrates into the soil but then moves laterally to a surface stream. Furthermore,

the thin soils over bedrock are prone to landsliding and other mass-wasting processes that move the entire mass -- water, soil, and all -- rapidly downhill into watercourses. Either of these phenomenae tend to produce high runoff, with limited storage of water in the soil. Yet another factor tending to increase runoff is the effect of mica and other platey minerals in plugging soil pores and reducing permeability.

The alternative estimates of soil groupings made by Lincoln-DeVore yielded less severe classifications. Our estimates gave greater weight to the sandy character of the soils. In addition, they took into consideration the fact that historic flows in the two Cheyenne Creeks do not reflect the high runoffs that would be expected from C and D soils. Extrapolation of Soil Conservation Service mapping units into the study area also suggests that the soils should be assigned a lower runoff potential. Accordingly, our hyrdologists placed most soils into the B and C groups. The resulting decrease in predicted runoff was partially offset by separate consideration of impervious areas (rock outcrops and the like) in computing hydrographs. Both sets of soil groupings were used in our analyses for purposes of comparison.

Antecedent Moisture Conditions. Another soil property having a major impact on predicted runoff is the antecedent moisture condition. The infiltration rate of a given soil varies greatly as a function of the moisture content of that soil. A granular soil in a dry state will have a very

FOREST SERVICE EQUIV. HYDROLOGIC CLASSIFICATIONS

SOIL NO.	HYDRO. CLASSIF.
1	D
3	C
6	D
10	C
13	C
14	D
22	D
23	D
24	D
25	C
28	D
29	D
31	B

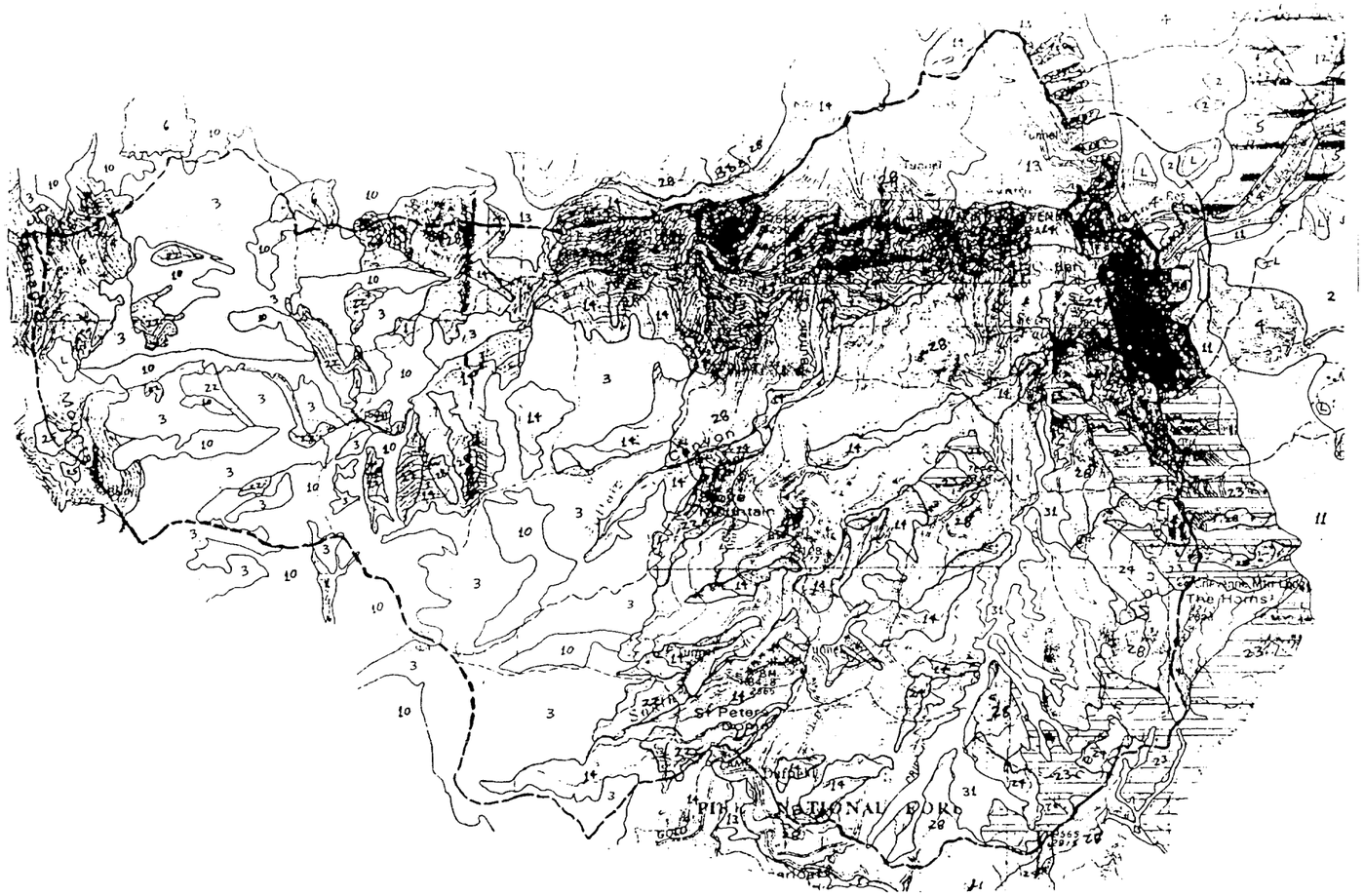


FIGURE 3

SOUTHWEST UPPER RAIN SOIL DIAGRAM
INTERPRETATION OF FOREST SERVICE MAP.
LD #47623

LINCOLN DeVORE ENGINEERS · GEOLOGISTS

COLORADO: COLORADO SPRINGS, GRAND JUNCTION, PUEBLO, GLENWOOD SPRINGS

DRAWN BY: KD	SCALE:	DATE: 12-17-84
CHECKED BY:	CONT. INTERVAL:	REV.

LINCOLN DeVORE TESTING LAB INC.

BY:

high infiltration rate because of the very high capillary potentials that work to draw water into the soil. The same soil will usually exhibit lower infiltration rates upon attaining saturation; the capillary potential then approaches zero, leaving only the gravitational potential to govern water movement. In clayey soils, saturation produces swelling of clay minerals, with a consequent drastic reduction in permeability and infiltration rate. The moisture content of the soil must, therefore, be considered in any attempt to predict runoff from storm events.

The antecedent moisture condition (AMC) is an index of soil moisture. It is defined (U.S.D.A. Soil Conservation Service, 1980) in terms of the depth of precipitation occurring in the five days prior to the flood-producing storm:

	Five-day Precipitation, inches	
AMC	Growing Season	Dormant Season
I	Less than 1.4	Less than 0.5
II	1.4 - 2.1	0.5 - 1.1
III	More than 2.1	More than 1.1

Most flood-hydrology studies assume the AMC II, or "average", condition. The AMC I condition is non-conservative and is usually employed only for special-purpose studies. Conversely, AMC III assumes very wet conditions and yields dramatically high discharges when used. As with the choice of hydrologic soil group, the choice of antecedent moisture condition greatly affects the magnitude of the computed flood.

Intuitively, AMC II seems reasonable for thunderstorm floods in both Basins I and II. The semiarid to subhumid climate of the area implies that five-day precipitation is unlikely to exceed 2.1 inches except on rare occasions. It might be argued, however, that it is precisely on such rare occasions that flooding will most likely occur. As there are not precipitation gauges within the study area, there is no reliable data from which the antecedent moisture condition can be directly estimated. Our hydrologic computations were made using AMC as a calibration parameter to resolve this problem. From this, we concluded that AMC II is indeed the most reasonable condition. Most hydrographs computed using AMC III over part or all of the combined watershed yielded peak discharges far in excess of any historically-experienced flows. Discharges computed for five-year recurrence interval were significantly greater than any known or believed to have occurred in the 125-year period of settlement for Cheyenne Creek. Consequently, we used AMC II for the remainder of our analyses.

Vegetation: The greatest part of the two basins is forested, either with conifers or with deciduous brush. Although the forest can be relatively dense, there are large areas--particularly in Basin II--where tree cover is thin and in only fair condition. Moreover, the sandy and gravelly soils often do not support extensive understory and ground

cover vegetation. Both the extent and the quality of the vegetative cover affect not only the rainfall - runoff relation, but also the sediment and debris yield.

Perhaps the most common tree species is Douglas fir. Ponderosa pine is quite common at lower elevations; Englemann spruce and Bristlecone pine occur at high elevations. Groves of aspen are widespread, often indicating areas disturbed by fire, landsliding, and erosion. Subbasins I-A and I-B, on the higher parts of Almagre Mountain, contain significant areas of tree-free tundra above timberline, while subbasins I-H and I-J include extensive areas of rangeland and scrub oak (Gambel's oak) groves. Virtually the entire study area has been affected in the historic past by fire, logging, and recreational disturbance. These effects combine with the inherent erodibility and limited soil development of the mountainsides to generate large areas in which forest condition is poor or fair. At higher elevations, such areas are often extensive slopes of bare rock and exposed gravel. These slopes support little or no vegetation and continually deliver large amounts of sediment and debris to the streams by means of erosion and shallow landslides.

Less spectacular, but probably more common and more significant, are rapidly-eroding mountainsides that retain their tree cover. These mountainsides, which are commonly the east and south facing slopes in areas that have been logged, possess only a sparse ground cover consisting largely of clumps of kinnikinnik and common juniper. The bare soil between clumps erodes readily. Furthermore, this process is aggravated by

the many abandoned roads and trails that cross the slopes on steep grades. Extensive aras in this condition occur on the middle slopes of Mount Rosa and on the west side of Cheyenne Mountain. In many cases, further deterioration has resulted from recreational overloading and from the unrestrained use of off-road vehicles. Such man-caused abuse is most apparent, of course, along the principal roadways--the Cripple Creek Stage Road, the Gold Camp Road, and the High Drive. Road construction itself contributes to the problem, especially when coupled with poor maintenance. For example, a failing and eroding embankment on the Gold Camp Road almost singlehandedly produces recurring debris flows at Mine Hill in North Cheyenne Park.

For our analyses, we classified Basins I and II into both land cover and condition categories. Cover classes used included tundra, bedrock outcrop, talus slopes, woodland, and pasture. Condition categories used were good, fair, and poor. These groupings were used in conjunction with the hydrologic soil groups to estimate hydrologic soil--cover complexes analogous to those defined by the SCS for determination of runoff curve number (U.S.D.A Soil Conservation Service, 1980). We defined the cover and condition classes using interpretation of aerial photographs, supplemented by limited field checking. Our work was simplified by the fact that Forest Service soil scientists had apparently used vegetation type and density as major mapping criteria. It was thus often possible to use soil mapping units as hydrologic soil cover complexes directly.

Erosion and Sediment Production. An essential fact in understanding the flood hydrology of North and South Cheyenne Creeks is that the mountainside soils are highly erodible and will inevitably deliver large volumes of sediment to the streams during a rainfall-caused flood. This fact has been alluded to previously in this report, but is here described in detail. Most soils are thin, poorly-developed, and underlain by weathered bedrock. The slopes themselves are at or near their angle of repose. This makes it very easy for either a slight increase in energy or a slight decrease in resisting forces to place large volumes of soil in motion downslope. An intense rainfall event both contributes energy and decreases resistance. The history of flooding in Bsins I and II, and in surrounding areas, emphasizes the point that sediment production is a major phenomenon in flooding. In some cases, it is a leading cause of damage and disruption.

Erosion and sediment production would be high in these basins under any circumstances. However, the poor condition of the mountainsides consequent to forest fires, timbering, mining, water development, and recreation severely aggravates the situation. The relative importance of disturbed lands in sediment production is a matter of some interest. While the slopes of bare rock and gravel place large amounts of sediment in the streams as discrete pulses, the aggregate amount of sediment produced is probably dwarfed by that produced by the less-disturbed, but still actively eroding, slopes.

In the latter case, sediment production is somewhat more continuous and takes place throughout the watershed.

It is a truism in geomorphology that most of the actual work in erosion takes place via processes that act continuously, but not usually in spectactular manner. Landslides, episodes of massive erosion, and the like actually contribute only a small percentage of the total sediment moved through a watershed, despite their dramatic appearance. In a major flood on either fork of Cheyenne Creek, most of the sediment will come from small-scale debris avalanches on mountainsides and from the colluvium already "stored" on the channel banks and in the valley bottoms. However, large-scale pulses of sediment proudced by landslides and other discrete events will be of great importance in locally blocking streams and in generating debris flows and debris floods. This gives them an importance in flood hydrology that belies the relatively minor volumes of sediment involved in those events.

Sediment, as well as the large debris that accompanies it, appreciably affects the hydraulic properties of floods. One of the major effects occurring at high sediment concentrations is <u>flow bulking</u>. To each cubic foot of floodwater must be added the volume of sediment transported by that water. This sediment volume is trivial at low concentrations. But if moderate and high concentrations are being transported, the total volume of the flood becomes significantly

greater than the volume of the water alone. At extreme concentrations, the total volume may be two, three, or more times the water volume. Flow bulking can thus have a drastic effect on the adequacy of both natural channels and hydraulic structures.

Other effects include the development of internal dissipative stresses and yield strength within the flow. As floodwaters change from clear water to very muddy water, and then into thicker and thicker mud, an increasing amount of energy is needed to transport the solid particles. Much of this energy is lost as heat, noise, and other irreversible phenomenae. In addition, the mud gradually develops a finite shear strength that must be exceeded before the material can flow at all. Both the unit weight and the viscosity of the fluid increase, the latter at an exponential rate. While this has significant engineering consequences in itself, it also means that the flow changes from a Newtonian fluid to some kind of plastic substance. Not only do the hydraulic properties change, but many of the basic principles of hydraulics gradually become invalid.

Sediment also implies the existence of both erosional and depositional processes. Disregarding erosion on the mountainsides, which has already been discussed, it must be recognized that major floods will severely scour the stream channels. In the Big Thompson flood of 1976, many tributary streams were scoured all the way to intact bedrock. Furthermore, scour and bank erosion will produce major changes in valley bottoms and in the canyon mouth area. These will include

channel migration, where the stream channel erodes laterally and thereby destroys dry land in the valley bottoms. Also included are channel avulsions, in which a stream completely abandons a reach of channel and picks a new path. Both effects have serious consequences for people and structures, and for the successful operation of hydraulic structures.

Deposition effects are equally important; in fact, deposition of sediment can induce migration and avulsion. Sediment deposits can obstruct or completely block culverts, bridges, channels, and other structures. The impact loadings of sediment and debris can be highly destructive. Moreover, removal of sediment deposits can easily be a major part of the cost associated with flood damage. Depositional effects and their impacts on channel migration and avulsion are severely aggravated by the presence of large debris. Such things as large boulders, tree trunks and branches, automobile bodies, fragments of structures, and even trash, are very likely to block channels, bridges, culverts, and other constrictions. When they do so, both destruction of the blocked hydraulic structure and a diversion of the floodwater usually occur. It was precisely such blockages at small bridges that caused much of the damage in the July, 1965, flood on Cheyenne Creek.

As important as sediment transport and deposition are in a watershed like that of North and South Cheyenne Creeks, it must be remembered that conventional engineering methods in flood hydrology completely disregard them. The hydrologic methods in common use--including that of the City

of Colorado Springs--assume that floods consist of clear water flowing down a channel with fixed, unchangeable boundaries. While these assumptions are probably invalid for almost every drainage basin in the city, they are glaringly so for the two Cheyenne Creeks. The magnitude of this problem depends somewhat on the flood being considered. For floods with short return periods--the annual floods and perhaps those up to the five or ten year flood--the event is most likely to be a sediment-laden water flood. Conventional methods apply to this type of flood as long as some consideration is given to sedimentation.

Larger floods, however, are likely to fall into the category of debris floods. Events of this type have major erosion and deposition consequences that must be considered. In addition, the hydraulic effects of high sediment concentrations begin to be important. Beyond this range is that of debris flow. In the debris flow range, conventional hydraulic analyses are inapplicable and the deposition of sediment and debris is the principle consideration. Debris flows are unlikely to occur in the main streams. However, they are highly likely to occur on small, steep tributaries during flood events of almost any return period. Such small debris flows are locally important in their own right if they affect structures or transportation routes. Furthermore, they may be important sources of sediment for the main streams.

Addition of large amounts of sediment to a flood can have major impacts on the hydrograph. The processes involved in eroding sediment and mobilizing heavy

debris tend to retard floodwaters somewhat. Consequently, the hydrograph tends not to rise smoothly. Instead, the flood becomes more "flashy"; the hydrograph rises very sharply and the flood may display a distinct frontal wave. The bulking effect also tends to put prominent spikes in the observed hydrograph, with each spike corresponding to an injection of sediment and debris into the flow. Very little is known about the hydraulic behavior of such pulses of sediment-laden water. It is not certain as to whether the pulses will tend to damp out or to persist, and the physical processes that control this behavior are very poorly understood. It is not the purpose of our study to analyze the effects of sediment and debris in detail. The limitations of both the study scope and the analytical methods available force us to consider only water hydrographs explicitly. However, we emphasize that the behavior of sediment and debris is of vital importance to the flood hydrology of Basins I and II. Any attempt to control floods, design hydraulic structures, or develop plans for hazard avoidance and mitigation must be devised with the sediment and debris problem in mind. Measures taken without such consideration are unlikely to be effective and may actually aggravate the damage and disruption caused by floods.

STORM HYDROLOGY OF THE BASINS

General Considerations:

The analysis of flood conditions in Basins I and II is an exercise in uncertainty. This is true to a degree of all hydrologic studies. In this case, however, a higher than usual level of uncertainty results from the near-total lack of both input and calibration data. The accuracy of the analysis is, therefore, entirely dependent on the quality of the analyst's judgement. Our attempt to provide reliable flood hydrographs required that we take great care in making realistic assumptions for the analysis. It also required that we perform some parametric studies to check the appropriateness of those assumptions, and that we carefully compare our analytical results with the limited calibration data available.

In addition to the uncertainties regarding soils conditions, sediment impacts, and the other factors already discussed, very little is known about either the magnitude or characteristics of a design storm in the mountain area. There are no rain gauges of any description within Basins I and II. Although a few gauges do exist elsewhere in the surrounding mountains--mostly operated by the City of Colorado Springs Department of Public Utilities--none of these are recording gauges. Although these gauges may give some information about total rainfall in a 24-hour period, they tell nothing about the distribution or intensity of the rainfall. The

closest recording rain gauge is at the Colorado Springs Municipal Airport. This gauge, though, is some 11 miles from the center of the Cheyenne Creek watershed, is several thousand feet lower in elevation, and lies in an entirely different physiographic region. Data from this gauge cannot be reliably extrapolated to the study area.

Morever, the relief and terrain of the study area can be expected to produce storms with highly site-specific properties. No data exists to assess those properties in more than a very broad, qualitative sense. Such things as the intensity and duration of storms, their spatial extent, and the timing of storm events over both the various subbasins and the elevation zones greatly affect the properties of the flood hydrograph. However, our understanding of these phenomenae is little more than speculative.

In this context, it is also true that virtually all of the accepted procedures for hydrologic analysis of a watershed were developed for geographic regions and basin properties much different than those of Cheyenne Creek. Extrapolation of a hydrologic model from, say, a corn-producing watershed in Iowa to the rugged terrain of the Southern Rocky Mountains is a questionable practice at best. It can be justified only by the facts that such models are widely accepted and used as standard in the profession, and that no models developed for mountainous terrain have been sufficiently developed

and verified to achieve general usage. Consequently, our analyses employed those methods, though with due consideration to their probable limitations.

Design Storm Properties:

Factors Studied: Our assumptions for the design storms concerned five major factors. The most fundamental, and perhaps the easiest to assess, are storm duration and total storm precipitation. Two factors that are more dependent on site-specific conditions involve distribution of rainfall in time, and of the overall storm in space. Finally, the rate and direction of storm movement constitutes an important factor that is, however, difficult to quantify.

Storm duration and total precipitation could be chosen using standard techniques. However, the other three factors required parametric study before appropriate assumptions could be made. Our studies mainly involved the computation of trial hydrographs using various assumptions and combinations of assumptions. In some cases, only a single subbasin, or fraction thereof, was modeled. In other cases, complete hydrographs for both basins were generated. The resulting hydrographs were then studied in an attempt to put together a "most probable", or "most realistic" set of assumptions for the actual engineering analysis of the Cheyenne Creek watershed.

Storm Duration: The selection of a duration period for the design storms was relatively straightforward. As a matter of convention, storms of 24-hour and six-hour duration are widely used by hydrologists. While a different duration might be more appropriate for this study, there is absolutely no data available on which to base a different duration. Our choice was thus confined to the two "standard" durations.

In general, six-hour durations yield somewhat larger peak discharges than do 24-hour durations. This is a consequence of higher precipitation intensities during the shorter storm. However, the 24-hour duration yields larger runoff volumes. The choice of duration thus depends, in part, on the likely importance of retention and detention in the watershed. We felt that, for this watershed, the estimation of the maximum likely peak discharge was of greater importance than the estimation of volumes to be stored. As noted in the main report, detention sites on North and South Cheyenne Creeks are rare, of limited volume, and in locations that render them essentially undevelopable. Use of the six-hour duration is also consistent with local practice and with the City's drainage criteria. Consequently, a six-hour storm duration was used for basic analyses.

Total Storm Precipitation: The depth of precipitation for the design storms was estimated from appropriate maps in the National Oceanic and Atmospheric Administration's Precipitation - Frequency Atlas of the Western United States (Miller and others, 1973). This technique was in

accordance with accepted engineering practice. The depths chosen were 2.20 inches for a storm with a five-year recurrence interval, and 3.60 inches for a storm with a 100-year recurrence interval. A precipitation depth - duration - frequency curve and a plot of the partial-duration series for precipitation depth and return period are shown on Figure 4.

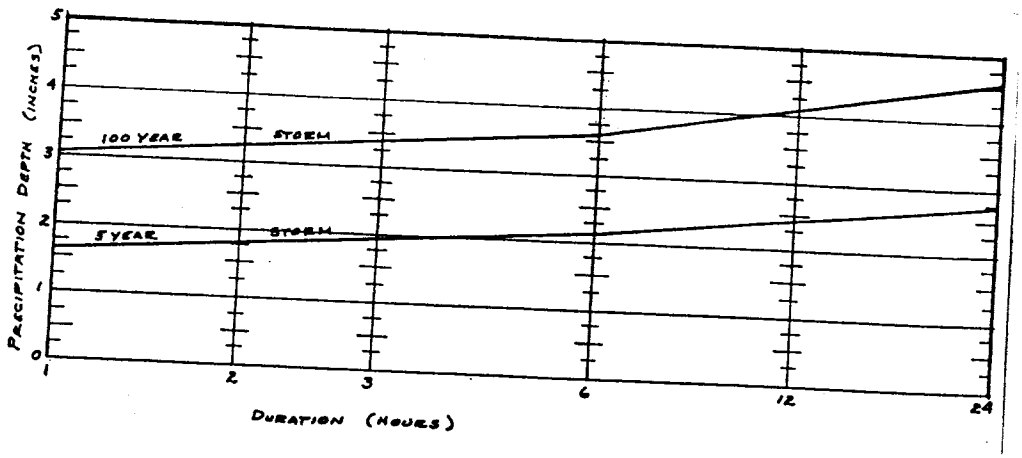
Time Distribution of Rainfall: The selection of an appropriate distribution of rainfall over time is critical to development of a realistic hydrograph. In very steep watersheds, minor changes in rainfall intensity can have very dramatic effects on both the peak discharge and the shape of the hydrograph. At least some of these effects are probably artifacts of the hydrologic modeling procedure being used. Others, though, are quite real. The hydrologic models developed by the USDA Soil Conservation Service employ a number of standard rainfall distributions, based on statistical analysis of a large number of storm measurements taken nationwide. For Colorado, the standard distributions in use are the Type II and Type IIA.

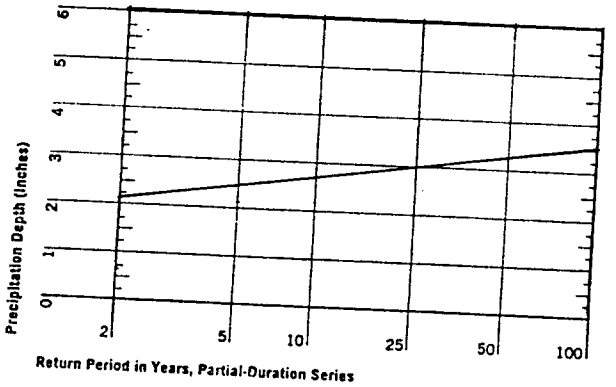
It is most unlikely that the actual pattern of rainfall in this study area actually fits either of these two distributions. For example, it is possible that the presence of the Pikes Peak mountain group induces local storm patterns that lead to anomalous rainfall depths and distributions. This is suggested by the apparent large discrepancy between predicted flood runoff and the actual history of flooding since 1859 in the mountain watersheds west of Colorado Springs. However, the site-specific data necessary to develop a typical

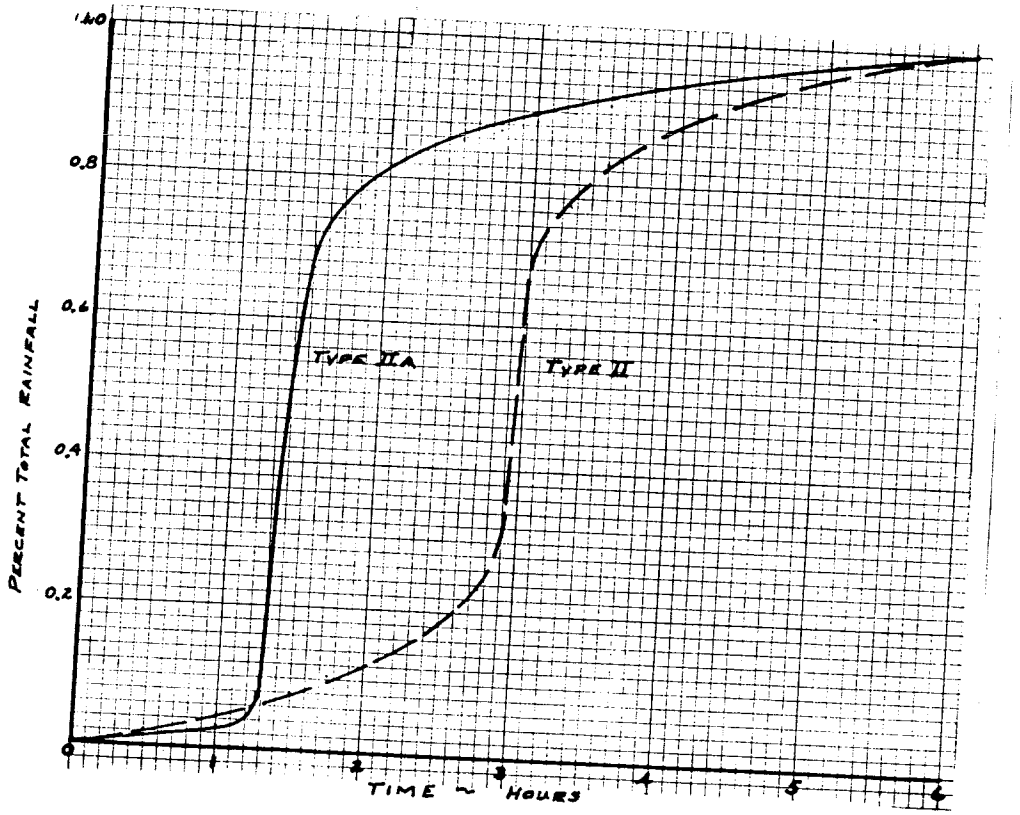
storm distribution for Cheyenne Creek is unavailable, even in qualitative form. Consequently, we studied both the Type II and the Type IIA distributions, as presented in the City's drainage criteria and the manual of the Pikes Peak Area Council of Governments (Gilbert, Meyer and Sams, Inc, 1979).

The Type IIA rainstorm is normally used in City drainage studies. This distribution defines a thunderstorm with a relatively brief "burst" of intense rainfall early in the storm. Figure 4 shows the distribution of the Type IIA storm, as modified by the City drainage criteria. This storm is appropriate for the cloudburst-like storms that occur on the high plains. It is, however, uncertain if this type of storm properly represents the general condition in the higher mountains. Research conducted after the 1976 Big Thompson Canyon flood suggests that large cloudbursts rarely occur above about elevation 7500 to 8000 feet (R.B. Jarrett, U.S. Geological Survey, personal communication, 1982). This apparent phenomenon may partly represent physical constraints on storm generation. The greatest effect, though, is that of terrain. Cells of intense precipitation tend to localize in individual canyons, so that only small percentages of a high mountain watershed receive intense rainfall at the same time.

It thus may be that the less-intense Type II storm better simulates events over much of Basins I and







RAINFALL DATA -
SOUTHWEST BASIN - COLORADO SPRINGS

LINCOLN DeVORE ENGINEERS GEOLOGISTS

FIGURE 4

COLORADO: COLORADO SPRINGS
GRAND JUNCTION, PUEBLO,
GLENWOOD SPRINGS

II. To check the effect of rainfall distribution, three different design storms were modeled:

1. A Type II storm over the entire watershed;
2. A Type IIA storm over the entire watershed; and
3. A Type II storm over subbasins mostly in excess of 8000 feet, and a Type IIA storm over subbasins mostly lying below 8000 feet.

The final choice of design rainfall distribution was based on the overall reasonableness of the calibration results.

Area Distribution of Rainfall. Point values of rainfall intensity should be corrected for the area of the watershed. This is because the center of intense precipitation in a storm cell is unlikely to coincide exactly with the boundaries of the drainage basin. Standard reduction factors are available in the literature; a figure containing such factors is a part of the City drainage criteria. For Basins I and II, the factor is about 0.96. Hydrographs were computed with and without application of this factor to assess its significance. As noted above, mountainous terrain imposes its own constraints on the size and aerial distribution of rainstorms, and it remains to be seen if standard reduction factors are actually meaningful. Unfortunately, no data exists upon which a better set of factors can be based for this region.

Storm Movement and Timing. The direction in which the design storm moves, as well as the rate of motion, has substantial impact on the flood hydrograph. If the storm moves down a watershed axis, the center of intense rainfall may follow the rising peak of the hydrograph downstream toward

the axis. This generates a flood of short duration, with a sharp, high peak. Conversely, if the storm moves up the basin axis, the hydrograph stretches out and displays a relatively low, broad peak. It follows that a stationary storm usually gives an "average" hydrograph. (However, stationary conditions in 1976 also allowed development of the "superstorm" over the Big Thompson Canyon--a rare, but highly important event.)

In general, intense storms will tend to move down North and South Cheyenne Creeks, from west to east. The effect should be more pronounced along North Cheyenne Creek than in the other basin. Possible exceptions to this rule include storms arising from upslope conditions. Upslope storms, however, are usually not extremely intense; furthermore, they mostly affect only lower elevations.

It is apparent that the precise effect of any storm pattern upon the hydrograph depends heavily on the precise timing of rainfall. If the storm develops so that the hydrographs from individual subbasins are in phase as they join the main stream, the resulting peak discharge will be extremely high. The opposite conclusion holds if the subbasin hydrographs are all out of phase. To evaluate the effect of storm movement, albeit in a simplistic way, three different storm lag cases were modeled. These were:

1. No lag, with the entire basin receiving the same storm at the same time;

2. A Type IIA storm, timed to begin in the lower basin shortly after onset of a Type II storm at higher elevations; and

3. A Type IIA storm at lower elevations, timed so that its peak coincides with that of a Type II storm in the upper basin.

The in-phase/out-of-phase effect was especially pronounced when combinations of Type II and Type IIA storms were modeled. As might be expected, the second case (above) yielded bimodal, out-of-phase hydrographs with the lowest peak discharges. The third case gave the sharpest, highest hydrographs.

Antecedent Moisture. The role of the antecedent moisture condition (AMC) in flood hydrology has already been discussed. As AMC is related to the time distribution of rainfall, and as it was used as a calibration parameter, further discussion is merited here. Combinations of AMC used in calibration modeling included:

1. AMC II over the entire watershed;
2. AMC III over the entire watershed;
3. AMC II below 8000 feet and AMC III above 8000 feet; and
4. AMC III below 8000 feet and AMC II above 8000 feet.

PROBABILITY AND STORM HYDROLOGY

Much of this report up to now concerns the need to calibrate the storm hydrology model so that it gives "reasonable" results. Before proceeding further, it is necessary to discuss some probabilistic issues involved in defining that "reasonable" hydrograph.

Floods are normally described in terms of their return period; as a "100-year flood", for example. The City drainage criteria require computation of the five-year and the 100-year floods for drainage purposes. While the concept of return period is often confusing to lay persons, conditions in Basins I and II are less straightforward than usual. At the outset, there is a common fallacy that return period implies certainty of occurrence That is, it is widely believed that a 100-year flood occurs once, and only once, in each century. In fact, the term means only that such a flood has a chance of 1% (0.01, or 1/100) of being equaled or exceeded in any given year. The 100-year flood may occur ten times in a single year, or only once in 10,000 years -- it is all in the luck of the draw. Such extremes are unusual, and, on the average, about one such flood does occur for every 100 years of history. There is no certainty about the exact timing, though.

Because it is water discharge that defines a flood, the only direct way to define a return period is to measure streamflows over long periods. Methods of probability and statistics can then be applied to estimate the long-term flooding behavior of the stream. In many cases, as at Cheyenne Creek, no streamflow measurements exist. Indirect methods, such as rainfall/runoff models, must then be used.

While measuring streamflow yields relatively unambiguous data, each step of an indirect method requires making assumptions. For example, there is really no such thing as a 100-year storm that corresponds uniquely to a

100-year flood. A 100-year rainfall depth can be estimated from rain gauge measurements. All of the factors listed previously in this section, though, join with the rainfall to make up a design storm. Unless all the probabilities affecting distribution, timing, and intensity of rainfall (among other factors) are known, it is not possible to define precisely a 100-year storm. Instead, each factor must normally be assumed, in the hope of deriving a design storm that is reasonably similar to the real (but unknown) storm. As there are many sets of assumptions that can be made, there are many possible "100-year storms". The choice of assumptions ultimately depends on the degree to which the resulting hydrograph matches real stream behavior.

In the Cheyenne Creek watershed, only the return periods associated with precipitation depth are known even approximately. There are no streamflow measurements of any kind, and virtually nothing is known of the probabilities governing the other factors that influence storm behavior. While the rainfall depths used in modeling are reasonable estimates for the five- and 100-year return periods, the actual return period of the storm reflects the joint probability of the many factors that make up the storm. That is, the actual probability of the storm is the arithmetic product of the probability of the rainfall depth, the probability of the time distribution, the probability of the time distribution, and so on.

It follows that, in general, the "100-year" design storm will not have a return period of exactly

100 years. Depending on the actual probabilities of the assumptions used, the true return period may be very much greater. The purpose of calibration is to develop assumptions that yield a return period as close as is practical to the ideal return period. This requires careful consideration of whatever information may be available on flood behavior and history. It also requires the application of much judgement, especially when the available information is inadequate, incomplete, or unreliable.

ENGINEERING ANALYSIS OF BASINS

Hydrologic Modeling. Two different, computerized models were used for hydrologic analysis of Basins I and II. The greatest part of the work employed "DABRO", a microcomputer-based set of hydrologic programs using methods set forth in the SCS National Engineering Handbook (USDA Soil Conservation Service, 1972). "DABRO" was developed by Bernard L. Golding, P.E. (Ret.). The well-known HEC-1 model of the Corps of Engineers was used as an independent check on DABRO, as well as for conducting some of the calibration studies.

The "DABRO" modeling used the hydrologic soil groups estimated by Lincoln-DeVore, rather than those of the Soil Conservation Service. Percentages of each group (mostly B and C soils) were estimated for different zones within each subbasin, and runoff curve numbers were then computed and

averaged over the subbasin. The percentage of impermeable surfaces, such as rock outcrops, was explicitly factored into the model. The design storms used were (a) the Type IIA storm overall, and (b) the combination of Type IIA below elevation 8000 feet and Type II at higher elevations. Antecedent moisture condition varied between II and III, both above and below 8000 feet. Channel routing was by the Muskingum method, with assumed coefficients.

For consistency with DABRO and the City criteria, the HEC-1 runs used the SCS unit hydrograph option. All hydrologic soils groups and runoff curve numbers were determined by SCS methods, using Forest Service soils mapping. Because almost all the soils fell into groups C and D, it was considered unnecessary to make further allowances for exposed bedrock and other impermeable areas. Design storms included (a) the Type II overall, (b) the Type IIA overall, and (c) the combination of Type IIA below 8000 feet and Type II above. For case (c), the Type IIA storm was lagged both 15 minutes and 105 minutes behind the Type II storm. The antecedent moisture conditions used included (a) AMC II overall, (b) AMC III overall, and (c) the combination of AMC II below 8000 feet and AMC III above. Channel routing was done by the kinematic wave method.

Discussion of Results. Computed hydrographs from the calibration runs differed greatly, with peak discharges ranging from about 6000 to about 40,000 cubic feet per second. Many of these hydrographs were clearly unreasonable; the

remainder had peak discharges varying from about 8000 to about 14,000 cubic feet per second. In general, hydrographs computed with DABRO were broadly similar to those obtained using HEC-1. DABRO did, however, tend to generate lower peak discharges. This probably resulted from the different procedures used to obtain runoff curve numbers and from the differing methods of channel routing.

The highest peak discharges (up to nearly 40,000 cubic feet per second) came from runs employing the AMC III assumptions. As the computed discharges for even the five-year flood greatly exceed any real flood known to have occurred on Cheyenne Creek since 1859, the use of AMC III appears unreasonable. While such very large floods can undoubtedly occur, their return period must be well in excess of 100 years.

Using HEC-1 with all other assumptions held constant, all design storms (except the Type IIA/Type II combination with 15-minute lag) gave about the same peak discharges at the confluence of North and South Cheyenne Creeks. Both the time-to-peak and the overall shape of the hydrograph varied significantly, though, with the latter ranging from just over two hours to nearly four hours. The similarity of the peak discharges suggests that the subbasin hydrographs are roughly in phase.

By contrast, the Type IIA/Type II combination with 15-minute lag yields a peak discharge only about two-thirds as high. This hydrograph is strongly bimodal; each of the two storm types produces a separate peak. In this case, the

Peak Flows at Point 12 (upper basin outfall) - SCS Method - Various Assumptions

Peak Flows in cfs (T_P)

Storm Type	Freq.	Lag	AMC II Entire Basin	AMC III Upper basin AMC II Lower basin	AMC III Entire Basin
II - Entire Basin	5 yr. 100 yr. 100 yr.	None 15 min.	1062 (4.4 hr.) 5680 (4.2 hr.) 5530 (4.2 hr.)	7360 (4.0 hr.)	
II - Above 8000' IIA- Below 8000'	5 yr. 100 yr. 100 yr.	15 min. 15 min. 60 min.	6595 (3.8 hr.) 6290 (4.1 hr.)	2680 (4.2 hr.) 10119 (3.7 hr.)* 10220 (4.0 hr.)	12880 (3.9 hr.)
IIA -Entire Basin	100 yr. 100 yr.	None 60 min.		11930 (2.8 hr.) 11375 (3.1 hr.)	14110 (2.8 hr.)

Peak Flows at Point 12 (upper basin outfall) - HEC-1 Method - Various Assumptions

Peak flows in cfs (T_P hrs)

Storm Type	Freq.	Lag	AMC II Entire Basin	AMC III Upper basin AMC II Lower basin	AMC III Entire Basin
II - Above 8000' IIA- Below 8000'	5 yr. 100 yr.	15 min. 15 min.	3007(3.92 hr.) 8997(3.75 hr.)	11438 (3.50 hr.) 22823 (3.42 hr.)	11420(3.50 hr.) 22495(3.42 hr.)
	5 yr. 100 yr.	105 min. 105 min.	4475(3.92 hr.) 13700(3.75 hr.)	11962 (3.50 hr.) 24391 (3.50 hr.)	19343(3.50 hr.) 37747(3.50 hr.)
IIA- Entire	5 yr. 100 yr.	None None	4215(2.33 hr.) 13283(2.17 hr.)	14111 (2.00 hr.) 30162 (1.92 hr.)	19675(1.92 hr.) 39917(1.92 hr.)

FIGURE 5

COMPARATIVE PEAK FLOWS
SOUTHWEST UPPER DRAINAGE BASIN
LD #47623

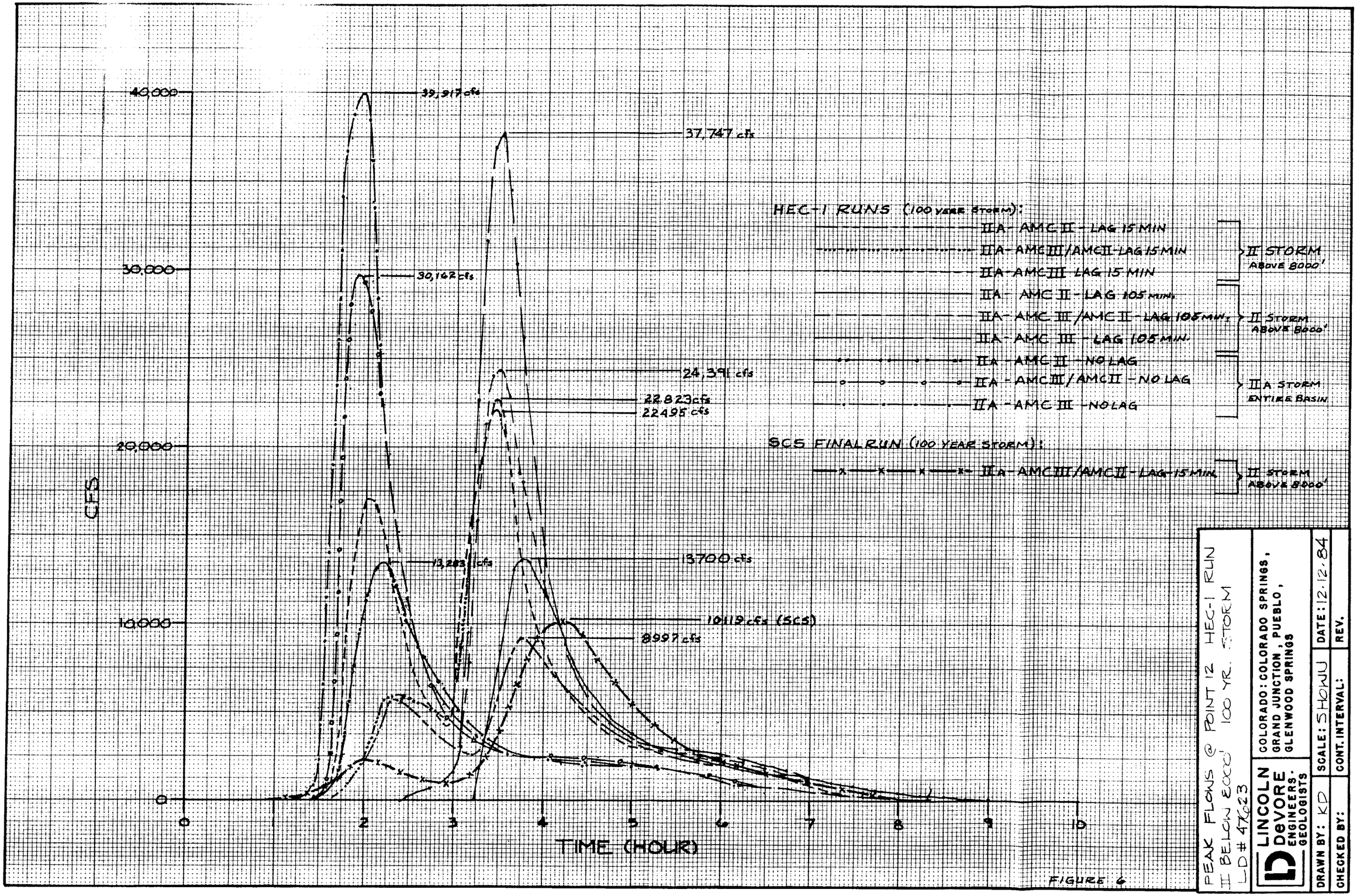


FIGURE 6

PEAK FLOWS @ POINT 12 HEC-1 RUN
II BELOW 8000' 100 YR. STORM
LD # 47623

LINCOLN DeVORE ENGINEERS. GEOLOGISTS

COLORADO: COLORADO SPRINGS, GRAND JUNCTION, PUEBLO, GLENWOOD SPRINGS

DRAWN BY: KD	SCALE: SHOWN	DATE: 12-12-84	
CHECKED BY:	CONT. INTERVAL:	REV.	

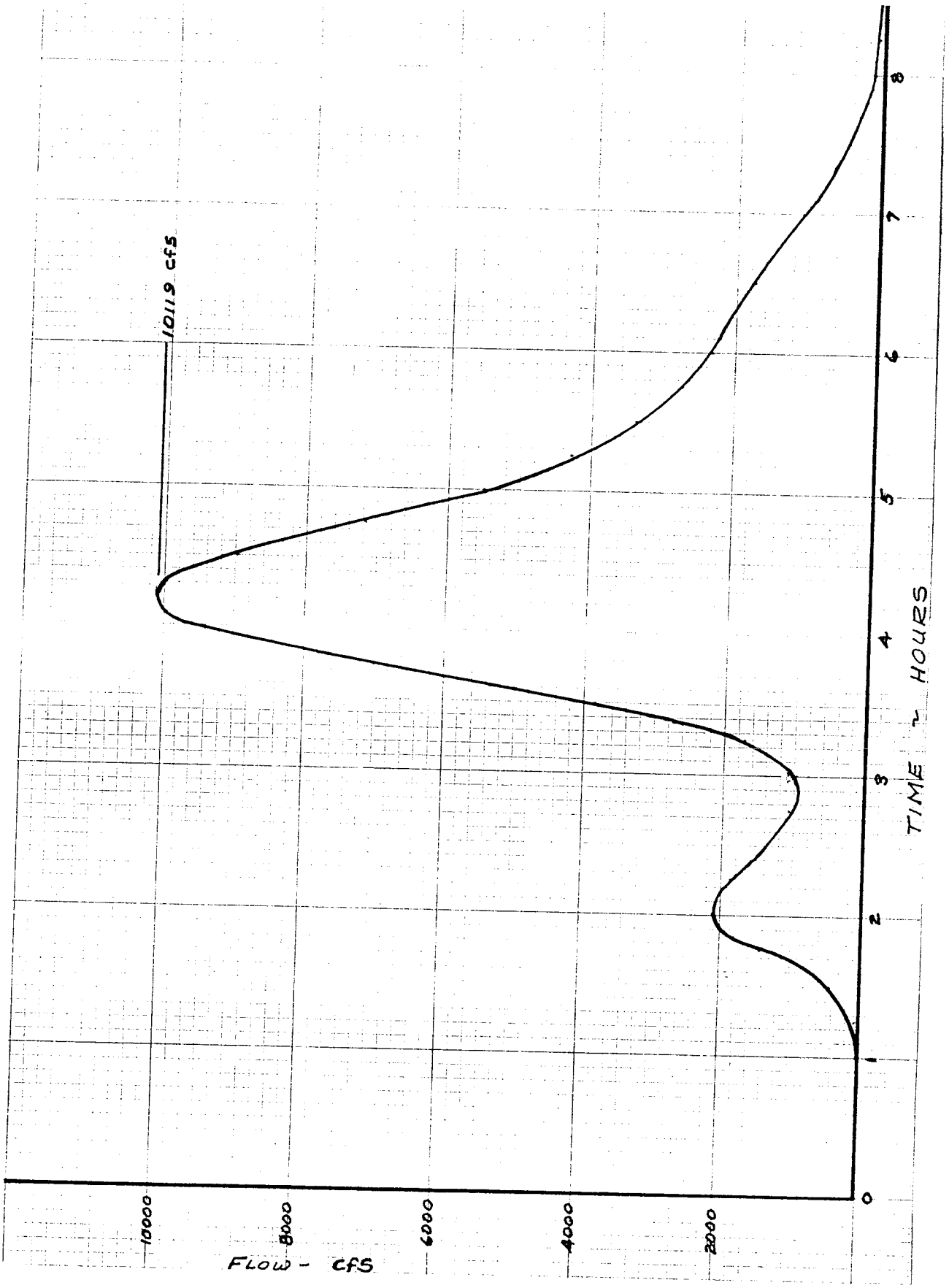


FIGURE 7

REPORT HYDROGRAPH AT POINT 12
SOUTHWEST-UPPER DRAINAGE BASIN
LD 47623

LINCOLN DeVORE
ENGINEERS
GEOLOGISTS

COLORADO: COLORADO SPRINGS
GRAND JUNCTION, PUEBLO,
GLENWOOD SPRINGS

hydrographs of contributing areas are well out of phase. More-subtle variations in the design storm across the various sub-basins will generate an even more-complicated hydrograph.

The computed times-to-peak are probably too short, especially for the HEC-1 models. The channel routing methods do not fully account for the effects of vegetation, obstructions, and blockages. Furthermore, much of the water's energy will be dissipated in erosion and transportation of sediment and debris, as well as in other irreversibilities. Although the computer models suggest that flow will be supercritical, the net effect of energy dissipation, obstructions, and the like will be to force the water into subcritical or critical flow. The probable effect on the hydrograph will be to delay the peak somewhat, but to generate a very steep rising limb -- essentially, to produce a "wall of water." Actually, this will not be a vertical "wall". It will simply be a rapid (but still gradually-varied) rise in stage, accompanied by large volumes of sediment and debris.

Comparison With Other Methods. Comparison of computed hydrographs with other, independent estimates of stream response was part of the calibration process. Source of other estimates included historical records and other indirect hydrologic procedures. By indicating the range over which realistic peak discharges may vary, the other estimates permitted judgement of the overall reasonableness of computed hydrographs. For this study, the comparisons yielded mixed results. Some computed hydrographs conflicted seriously with all

other estimates, and could be eliminated from further consideration. Another group of computed peak discharges agreed well with those of some alternate methods, but were at variance with others. The computed hydrographs were most difficult to reconcile with the limited historical data available.

Of greatest interest is comparison with the peak discharges established for flood insurance purposes by the Federal Emergency Management Agency (FEMA). This discharge is about 13,300 cubic feet per second at the confluence of Cheyenne Creek and Fountain Creek. As large amounts of water are lost to overbank storage below the junction of North and South Cheyenne Creeks, the FEMA peak discharge at the outlet of Basins I and II should be somewhat higher. This value is from previous HEC-1 modeling performed by the U.S. Army Corps of Engineers, as checked by the regionalization method of the Colorado Water Conservation Board's Technical Manual No. 1 (McCain and Jarrett, 1976).

The FEMA peak discharge is at the upper end of the "most credible" range of discharges modeled during the calibration runs. It is slightly higher than most of the HEC-1 runs, and substantially higher than most of the DABRO hydrographs. Most of the discrepancy between the Corps of Engineers' HEC-1 discharge and the present work is undoubtedly in some of the basic hydrologic assumptions. Unfortunately, the Corps assumptions were not available for comparison wth those used in this study. With the Technical Manual No. 1 (TM-1) regionalization methods, there is a question as to the overall

correctness and precision of the result. The regionalization equations were derived from records of gaged streams, few of which have properties similar to those of Cheyenne Creek and none of which occupy a similar physiographic position. Moreover, TM-1 places Basins I and II in the Southern Plains Region. This being an area dominated by large, cloudburst rainstorms, the problem of storm appropriateness -- discussed at length earlier in this report -- must be considered. While the method is undoubtedly useful for preliminary estimates of flood behavior, it is doubtful that the results are more reliable than those of the computed hydrographs.

Another regionalization procedure is found in Circular 32 of the Colorado Water Conservation Board. This might be better termed a "micro-regionalization" method, in that it breaks El Paso County into several small regions. Although the exact basis for this procedure is unknown, it apparently shows zones in the mountains where very low runoff can be expected. Use of appropriate curves from this source for Basins I and I gives a 100-year peak discharge of only about 1300 cubic feet per second. This is an order of magnitude lower than most of the computed hydrographs. While this peak discharge is highly non-conservative, it demonstrates the potential impact of some of the meteorologic and environmental factors discussed in this report.

The ultimate criterion is the observed record of flooding in the watershed. Unfortunately, as described earlier, the historical record is only qualitative and

anecdotal. However, it does not support the occurrence of large floods on Cheyenne Creek within the last 125 years. Cases in which the creek has been significantly out of its banks, as in July of 1965, are rare. Furthermore, the numerous old bridges and structures that impinge upon the stream testify to the absence of damaging floods during the period of settlement. This type of record possesses little credibility as a predictor of extreme events, such as the 100-year flood. However, the discharge discrepancy applies as well to frequent events, such as the five-and ten-year floods. FEMA's computed water surface profiles place the ten-year flood crest nearly three feet above the bridges on Cheyenne Creek. As a flood of this magnitude has apparently not occurred since the turn of the century (and probably not since at least 1859), it is likely that the discharge-frequency relationship implied by FEMA values is in error.

Conflicts between the various lines of evidence cannot be conclusively resolved with the existing data. However, the historical record cannot be disregarded despite its inadequacies. There appear to be factors operating to reduce peak discharges from runoff events to levels significantly lower than can be modeled using "standard" assumptions. The following factors are possibilities:

1. Soils possess infiltration and runoff properties different from those of the hydrologic soils groups to which they are assigned;

2. The Pikes Peak highland has topographic effects that significantly modify local storm patterns, rendering the conventional storm assumptions inaccurate;

3. Local topography effectively limits the percentage of a watershed that can simultaneously receive rainfall of very high intensity; and

4. A number of as-yet unidentified factors.

While it is not appropriate to reduce flood discharges to the levels predicted by the Circular 32 method, the use of a modeled hydrograph yielding a moderate peak discharge is a defensible alternative.

SUGGESTED FLOODING SCENARIO

The modeled hydrographs define a wide range of possible design floods for North and South Cheyenne Creeks. These vary, for the 100-year return period, from a small flood that barely overflows the channel to a major catastrophe larger than the 1976 Big Thompson Canyon flood. It is Lincoln-DeVore's opinion that many of the hydrographs overestimate flood magnitudes at a given return period, for reasons relating to the physical properties of the watershed and its environment. The flood discharges adopted by FEMA, although not among the most extreme possible, appear to be excessive in view of the known behavior of the stream over a 125-year period.

The flooding scenario selected for use in this study falls near the midrange of the "most-credible" modeled hydrographs. While the peak discharge is slightly lower

than the mean discharge for those hydrographs, it falls sufficiently near the midpoint to approximate an average. This suggested hydrograph is a compromise, reconciling defensible hydrologic assumptions with the historical record. The hydrograph for the 100-year flood, one of the DABRO models, is shown in Figure 7.

Briefly stated, the proposed flooding scenario has the following properties:

1. At Point 12 (the confluence of North and South Cheyenne Creeks), the 100-year flood has predicted peak discharge of 10,119 cubic feet per second, a time-to-peak of 4.25 hours, and a total runoff volume of approximately 2,110 acre-feet.

2. The corresponding values for the five-year flood are a peak discharge of 2,680 cubic feet per second, a time-to-peak of 4.30 hours, and a total volume of approximately 990 acre-feet.

3. Runoff curve numbers were estimated basin-wide, using hydrologic soil groups (mostly B and C) and land cover classes estimated by Lincoln-DeVore, and with impermeable areas considered separately.

4. Antecedent moisture conditions were assumed to be average (AMC II) over the entire watershed.

5. The assumed storm was the City-modified Type IIA below elevation 8000 feet and a corresponding Type II above 8000 feet, with the IIA storm lagged 15 minutes.

Incidental conclusions derived from the study include the following:

1. The HEC-1 modeling suggests that use of either a Type II or a Type IIA storm over the entire watershed will give roughly the same peak discharge as the combined storm. However, the time-to-peak and the shape of the hydrograph vary greatly. The combined storm actually used probably reflects reality better than either of the other assumptions, and yields the most appropriate hydrograph.

2. The proper selection of runoff curve numbers is critical to the end result and must be done with great care. The assignment of hydrologic soil groups to the watershed thus requires additional careful study if hydrologic predictions are to be significantly improved.

3. In view of the anomalous flooding behavior, not only on Cheyenne Creek but also in other watersheds draining the Pikes Peak massif, research should be conducted on the behavior of rainstorms in such environments.

4. As with most other hydrologic models, the suggested runoff hydrograph does not explicitly account for the effects of sediment and debris loading. The adverse impacts of sediment and debris should be carefully evaluated and allowed for in any use made of this hydrograph.

In closing, we emphasize that hydrologic analysis of basins like those of Cheyenne Creek is an exercise in uncertainty. The lack of quantitative data (and, in many cases, qualitative information as well) forces the hydrologist to rely upon judgement rather than rigorous analysis. Consequently, this report cannot pretend to be a definitive study of the problem. However, it does represent a reasonable approach, based on the state of the art and the available information, for use in plannning, scheduling of capital improvements, and flood hazard management.