AN EVALUATION OF RAINFALL-RUNOFF DATA FOR THE DENVER FEDERAL CENTER, LAKEWOOD, JEFFERSON COUNTY, COLORADO

By Robert D. Jarrett and Jack E. Veenhuis

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4050

Prepared in cooperation with the

GENERAL SERVICES ADMINISTRATION

Lakewood, Colorado
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

William P. Clark, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Colorado District Chief
U.S. Geological Survey, MS 415
Box 25046, Denver Federal Center
Lakewood, CO 80225

For sale by:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey, MS 306
Box 25425, Federal Center
Denver, CO 80225
Phone: (303) 236-7476

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

METRIC CONVERSION FACTORS

Inch-pound units used in this report may be converted to SI (International System) units by using the following conversion factors:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per acre ($ft^3/s/acre$)	0.0700	cubic meter per second per hectare
feet per mile (ft/mi)	0.1894	meter/kilometer
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
mile per hour (mi/h)	1.609	kilometer per hour
square mile (mi^2)	2.590	square kilometer

AN EVALUATION OF RAINFALL-RUNOFF DATA FOR THE DENVER FEDERAL CENTER, LAKEWOOD, JEFFERSON COUNTY, COLORADO

By Robert D. Jarrett and Jack E. Veenhuis

ABSTRACT

An investigation was made to measure the storm runoff in McIntyre Gulch basin to determine the rainfall-runoff characteristics. Results may now be used to evaluate the effects of future development on storm runoff from the Denver Federal Center, which is located in the McIntyre Gulch basin in Lakewood, Colo. Rainfall and runoff data were collected at eight streamflow stations and three auxiliary rainfall stations in and adjacent to the Denver Federal Center. The outflow peak discharges from McIntyre Gulch basin in the Denver Federal Center were higher than the inflow peak discharges for 11 of 19 storms by an average of 38 percent. Outflow peak discharges for eight of the storms were lower by an average of 12 percent. The study demonstrated that runoff varies with location of a storm--even for a relatively small basin. Peak discharges of McIntyre Gulch outflow from the Denver Federal Center were 27 percent greater than the inflow for all storms, but only 15 percent greater for evenly distributed storms. Runoff from the Denver Federal Center increased storm-runoff volumes in McIntyre Gulch by an average of 46 percent. To maintain peak flows at their present levels, onsite design considerations are needed for future development.

INTRODUCTION

Rapid increases in land development in Lakewood, Colo., have resulted in dramatic changes in storm-runoff characteristics. A potential flood hazard was created on the Denver Federal Center (DFC) in the summer of 1974 when development was started on property adjacent to the northwest corner of the Center in the North Avenue drainage. For developed conditions, peak discharges produced could have resulted in damaging flooding to buildings, roads, and property (Grozier and others, 1975).

In 1975 there were no precipitation or streamflow records for the McIntyre Gulch basin, which drains the DFC, to assess the storm-runoff characteristics. A study on storm runoff for McIntyre Gulch (McCall-Ellingson and Morrill, Inc., 1975) based on The Colorado Urban Hydrograph Procedure (Wright-McLaughlin Engineers, 1969a) was used to compute storm-runoff characteristics. This study indicated that the DFC contributed greatly to the storm runoff in McIntyre Gulch. However, these methods were not based on data representative of a watershed as steep as that draining to McIntyre Gulch. The General Services Administration (GSA), aware of the problems of the effects of development on storm runoff, asked the U.S. Geological Survey to conduct a study of the storm runoff of the Denver Federal Center. This report provides a description of the Denver Federal Center drainage areas and an evaluation of all rainfall-runoff data.

Purpose and Scope

The purpose of this study was to measure storm-runoff conditions and to provide GSA planners with information to evaluate the effect of future DFC development on storm-runoff characteristics. This information was to be used in the near future and long-range planning efforts. This study would provide input to the DFC Master Plan (General Services Administration, 1979a; 1979b). The goals of GSA are to limit runoff resulting from DFC development to the amounts existing under present conditions.

The objectives of this study were met by (a) providing a data base of storm runoff for the DFC, (b) determining the relation between rainfall and runoff for the DFC, (c) defining the effects of the DFC runoff on McIntyre Gulch, and (d) providing GSA planners with information for future design of drainage systems on the DFC.

Acknowledgments

The authors would like to express their appreciation to Robert Tirrell and Richard Grozier for permission to operate recording rainfall gages on their property. The authors also appreciate the efforts of Marge Buteau, Carolyn Jarrett, Rulon Christensen, Dennis Hall, Ed Novak, and Jack Simpson in reading nonrecording rain gages. The authors also thank the Agricultural Ditch and Reservoir Co. for permission to operate streamflow gages on the Agricultural Ditch on the DFC.

DESCRIPTION OF STUDY AREA

The Denver Federal Center, located in the McIntyre Gulch basin in Lakewood, Colo., has an area of slightly more than 1 square mile, and is about 7 miles west of downtown Denver (fig. 1; see also fig. 5). The only major drainage on the DFC is McIntyre Gulch, which drains the eastern flank of Green Mountain with a high point of about 6,700 feet and flows easterly through the DFC. McIntyre Gulch, a tributary to Lakewood Gulch, has a drainage area of 4.8 square miles at its confluence, at an altitude of approximately 5,400 ft.

McIntyre Gulch is a steep, incised channel, in many places cut into bedrock (fig. 2). The soils of the basin are derived from underlying shale, sandstone, and conglomerate and generally are poorly drained.

Runoff through the North Avenue Storm Drain, at the northwest corner of the DFC, flows northeasterly toward Lakewood Gulch. Welch Ditch and Agricultural Ditch (fig. 1) are irrigation ditches that convey water from north to south through the DFC. The Agricultural Ditch is shown in figure 3. Since much of the DFC is undeveloped, rainfall and streamflow gages were operated to evaluate runoff characteristics of a small undeveloped watershed. This watershed, Denver Federal Center Field, is shown in figure 4.

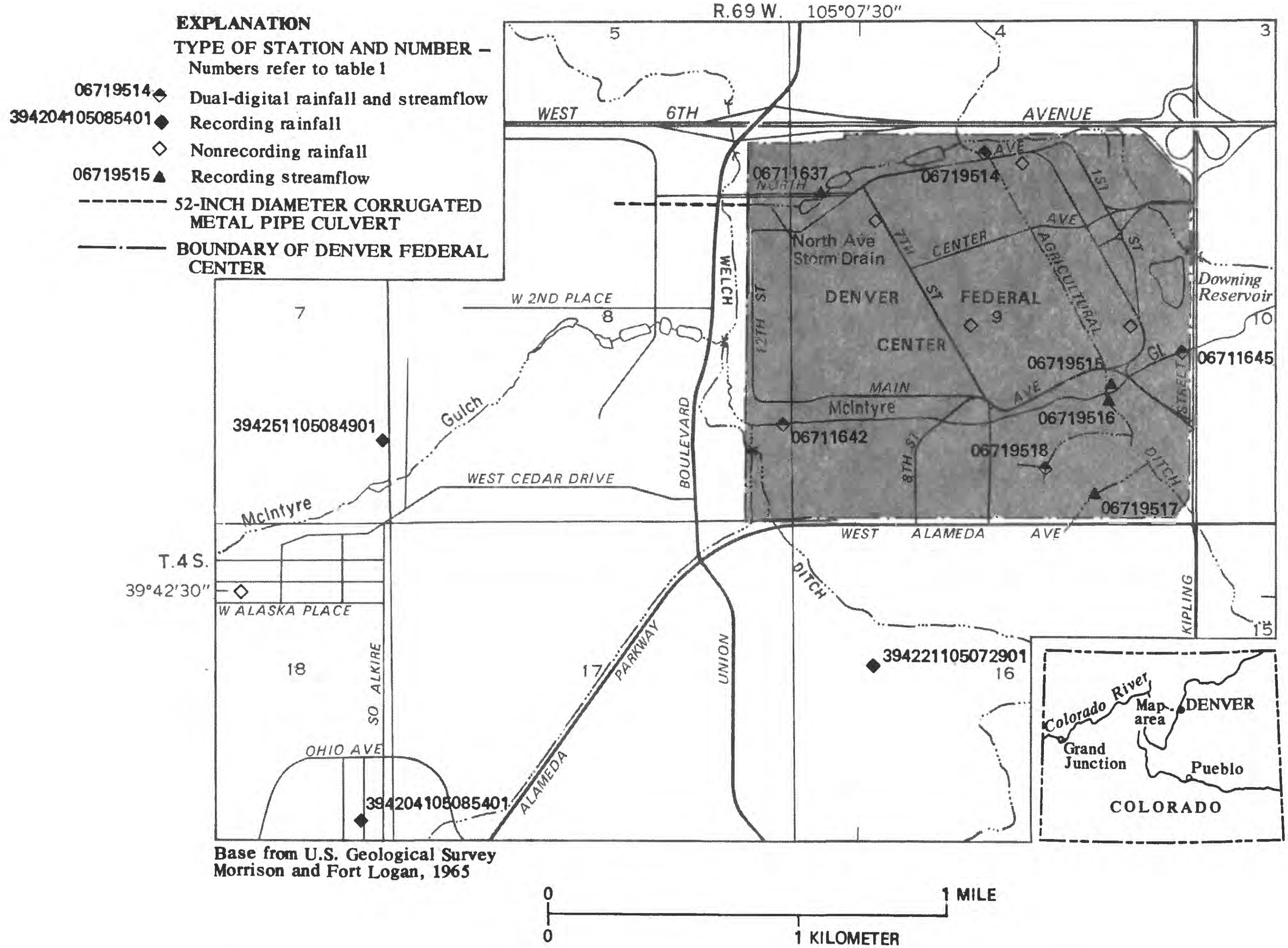

Figure 1.--Distribution of rainfall-runoff stations for the Denver Federal Center study.

Figure 2.--Downstream view of McIntyre Gulch showing rainfall and streamflow gages (station no. 06711642). Note deeply incised channel.

Figure 3.--Upstream view of Agricultural Ditch looking from Center Avenue toward North Avenue.

Figure 4.--Upstream view of Denver Federal Center Field rainfall and streamflow gages (station no. 06719518). Note undeveloped area.

FLOOD HISTORY

Runoff in the study area can result from any of three processes or combinations of any of these processes: snowmelt, frontal-system rainstorm, and thunderstorm or cloudburst. Snowmelt and frontal-system rainstorms can result in large-volume storm runoff, but do not result in severe flooding because the duration of the runoff is long, and precipitation intensities are only small to moderate. The storms of May 5-6, 1973 (occurred prior to data collection), and April 30, 1980, are examples of frontal-system rainstorms. It is the thunderstorm that produces intense precipitation of short duration that results in the most severe and damaging storm runoff or flooding. The June 15, 1963, flood, which had a peak discharge of 968 cubic feet per second (ft^3/s) in McIntyre Gulch at the Agricultural Ditch, resulted from an intense thunderstorm and is the largest flood known to have occurred. Interestingly, this storm took place before there was any significant development in the McIntyre Gulch basin west of Union Boulevard. The occurrence of this storm runoff indicates large flows occurred on the steep watershed before development. Other thunderstorms resulting in moderate to large storm runoff in McIntyre Gulch monitored as part of this study included the storms of July 20, 1975, June 6, 1977, and July 20, 1977. Precipitation data for these three storms and their occurrence within 2 years indicate that storms of this size are not that infrequent.

McIntyre Gulch is incised deeply through the DFC and generally contains the 100-year flood within the main channel (Hydro-Triad, Ltd., 1977b). The North Avenue Storm Drain has been improved by channel modifications, two detention ponds, and one retention pond to convey storm runoff through the DFC. Fortunately, these channel improvements were made just before a potentially damaging thunderstorm in 1975.

The Welch and Agricultural Ditches have drainage spills to major drainages, such as the one at McIntyre Gulch, to release intercepted storm runoff. However, these spills may be, and usually are, closed during a thunderstorm due to the storm's characteristic short warning time. Localized shallow-depth flooding can result from overtopping of the ditches, but generally should not result in serious flooding unless sufficient overtopping results in erosion of the bank. Although breaching of the bank is unlikely, breaching would result in significant shallow-depth flooding east of Agricultural Ditch between North Avenue and Main Avenue.

DATA COLLECTION

Rainfall and runoff data have been collected at three auxiliary rainfall stations and eight streamflow stations in the DFC and adjacent areas. Rainfall and streamflow stations are listed in table 1; their locations are shown in figure 1. The streamflow stations in table 1 are listed in downstream order by the assigned U.S. Geological Survey eight-digit streamflow gaging-station number. All stations were operated seasonally during the intense thunderstorm season (generally April through October). The period of record for each station is shown in table 1. The precipitation and streamflow data collected are published in reports by Cochran and others (1979, 1983). The purpose of the hydrologic-data network was to measure runoff entering the DFC and to measure the net DFC contribution to storm runoff, particularly to McIntyre Gulch.

Instrumentation

Rainfall, recorded in hundredths of an inch, was measured inside a 3-inch pipe by a small float connected directly to a digital recorder (fig. 4); rainfall entered the pipe from a 5- by 10-inch rectangular collector located on top of the shelter. The digital recorders punched all data on 16-channel paper tape at 5-minute intervals. Streamflow stage, recorded in hundredths of a foot, was measured inside a 4-inch stilling well by a small float connected directly to a digital recorder (fig. 4); runoff entered the pipe through numerous 1/4-inch holes drilled at several levels in the pipe. Although a single cam-type timer was used to activate dual rain and stage recorders, assuring time-synchronous data, there were slight nontime-synchronous differences between stations because of different timers at each station.

In addition, daily precipitation data were collected at six sites throughout the study area. The purpose of these data was to supplement the recording precipitation data to evaluate areal distribution and to provide backup data should the recording gages malfunction during a storm.

Stage-Discharge Relations

Current-meter measurements to determine discharge were used to define the lower flow part of the stage-discharge relation (rating curve) for all sites except the Denver Federal Center Field. Conventional discharge measurements generally could not be made at high flows due to rapidly changing stage and

Table 1.--*Rainfall-runoff stations in the Denver Federal Center in Lakewood, Colo., runoff study*

U.S. Geological Survey station no.	Station name[1]	Period of record[2]
	Auxiliary precipitation stations	
394204105085401	851 South Arbutus Street	June 1975 to Sept. 1981
394221105072901	11310 West Glennon Drive	Sept. 1975 to Sept. 1981
394251105084901	Zinnia Way near Warren Occupational Technical Center	June 1975 to Sept. 1981
	Streamflow stations	
06711637	North Avenue Storm Drain at Denver Federal Center	Apr. 1978 to Sept. 1981
06711642	McIntyre Gulch No. 1 at Denver Federal Center	June 1975 to Sept. 1981
06711645	McIntyre Gulch No. 2 at Denver Federal Center	June 1975 to Sept. 1981
06719514	Agricultural Ditch Inflow to Denver Federal Center	Aug. 1975 to Sept. 1981
	Auxiliary precipitation stations	
06719515	Agricultural Ditch Spill at Denver Federal Center	May 1975 to Sept. 1981
06719516	Agricultural Ditch below Spill at Denver Federal Center	Aug. 1975 to Sept. 1981
06719517	Alameda Avenue Inflow to Denver Federal Center	Apr. 1977 to Sept. 1981
06719518	Denver Federal Center Field	Sept. 1975 to Sept. 1981

[1]See figure 1 for station locations.
[2]Gages operated from about April 1 through September 30 (no winter record).

debris. Therefore, alternate theoretical methods were used to supplement the measured rating curve where required. For the Denver Federal Center Field, North Avenue Storm Drain, and McIntyre Gulch No. 2 stations, the upper part of the rating curve was determined by flow-through-culvert analysis as described by Bodhaine (1968). The upper part of the rating curve for the McIntyre Gulch No. 1 station was determined by step-backwater analysis, as described by Bailey and Ray (1966), and by the slope-area method of indirect determination of peak discharge for significant high peak flows, as described by Dalrymple and Benson (1967).

DESCRIPTION OF DRAINAGE BASINS

Of the eight partial-record stage discharge recorders operated as part of the Denver Federal Center study, five recorders measured storm runoff and three, located along the Agricultural Ditch, measured a combination of regulated irrigation flow and storm runoff. The five storm-runoff gaging stations and their contributing drainage areas are shown in figure 5 and listed in table 2, along with field estimates of effective impervious percentages for each basin (Alley and Veenhuis, 1979). Effective impervious areas are impervious areas which have direct connection to some means of conveying the runoff out of the areas, such as roofs which drain onto driveways, streets, sidewalks, and paved parking lots. The terms onsite and offsite in table 2 refer to whether the area is on or off the DFC. The total study area encompassed 2,721 acres, of which 2,455 acres are gaged. Estimates of ungaged Federal Center land and the impervious percentages also are listed in table 2 for future design considerations.

North Avenue Storm Drain

North Avenue Storm Drain (table 1, station 06711637) on the Denver Federal Center drains a mixed light commercial and multifamily residential area. The basin consists of 80 acres, of which 69 acres are offsite and 11 acres are on DFC property (table 2 and fig. 5). Development outside the DFC boundary of this basin has changed the effective impervious area from 29 percent in 1975 to 46 percent in 1981. The basin is approximately 30-percent multifamily housing. Light commercial land use increased from 20 to 30 percent, and open space decreased from 50 to 40 percent during the period of record. Additional basin and channel characteristics such as the area, centroid, channel length, channel slope, basin slope, total relief and elevation of the gaging site are given in table 3 (Alley and Veenhuis, 1979). Several studies of the offsite drainage have been published including one study of potential flood hazard by Grozier and others (1975); three hydrologic-data reports by Ellis and Alley (1978), Gibbs (1981), and Gibbs and Doerfer (1982); two hydrologic simulation reports by Ellis and Alley (1979) and Ellis and others (1983); and three drainage studies (Hydro-Triad, Ltd., 1973; 1974; 1983).

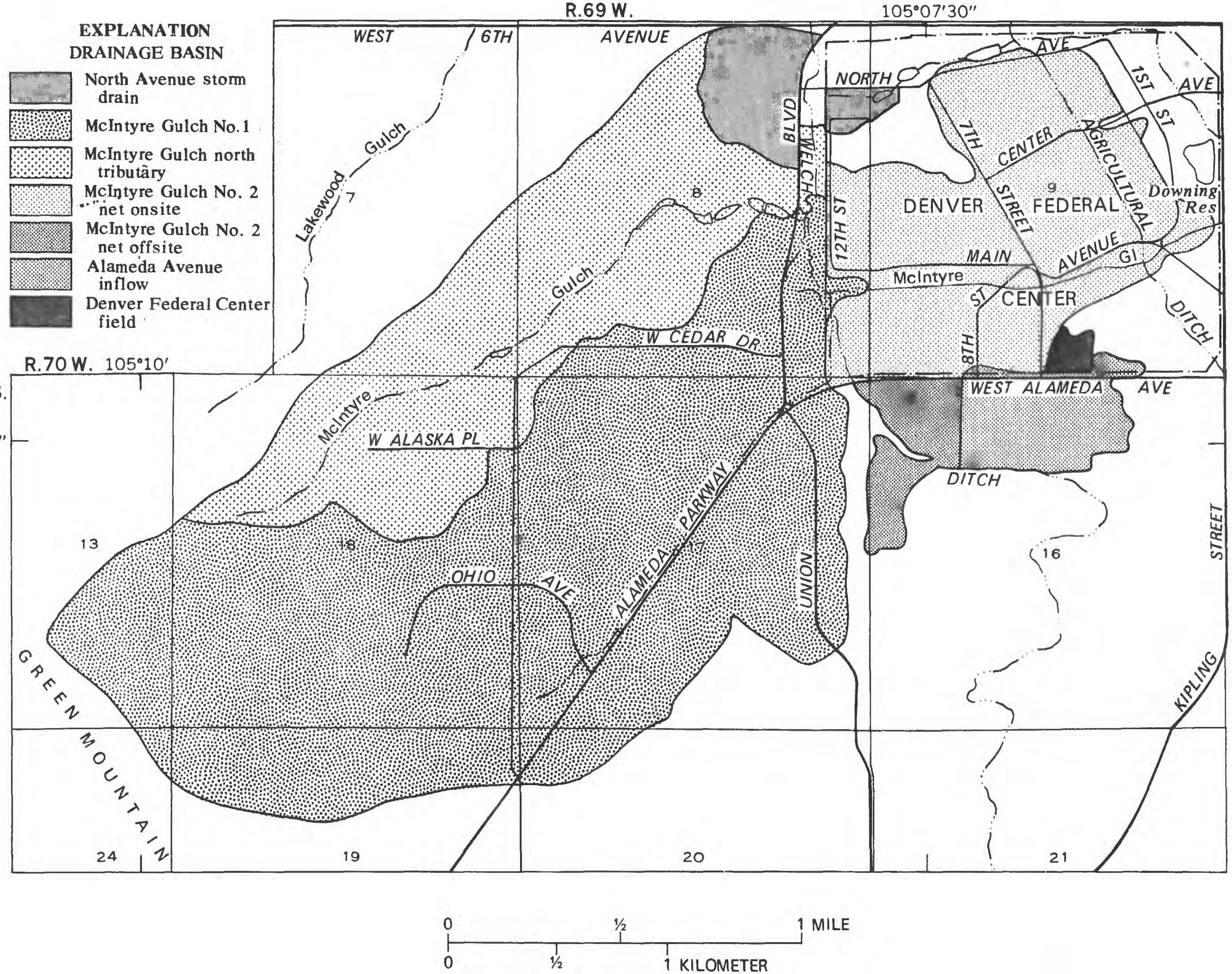

Figure 5.--Location of Denver Federal Center drainage basins.

Table 2.--*Denver Federal Center drainage basin areas and percentages of effective impervious areas*

Gaged Drainage Basins[1]	Onsite[2] Effective impervious area, in acres	Onsite[2] Effective impervious area, in percent	Offsite[2] Effective impervious area, in acres	Offsite[2] Effective impervious area, in percent	Total Effective impervious area, in acres	Total Effective impervious area, in percent
North Avenue Storm Drain	11	24	69	30-50	80	29-46
McIntyre Gulch No. 1	---	---	1256	17-21	1256	17-21
McIntyre Gulch No. 1 including North Tributary	---	---	1805	15-20	1805	15-20
McIntyre Gulch No. 2	422	42	1310	17-21	1731	23-26
McIntyre Gulch No. 2 including North Tributary	422	42	1858	15-20	2280	20-24
Net McIntyre Gulch	422	42	53	25	475	40
Agricultural Ditch Inflow	([3])	([3])	([3])	([3])	([3])	([3])
Agricultural Ditch Spill	([3])	([3])	([3])	([3])	([3])	([3])
Agricultural Ditch below Spill	([3])	([3])	([3])	([3])	([3])	([3])
Alameda Avenue Inflow	6	0	77	28	83	26
Denver Federal Center Field	12	0	----	-----	12	0
Total gaged drainage basins	451	40	2004	16-21	2455	20-25
Agricultural Ditch below Spill	58	0	20	25	78	6
Southeast Area Draining Offsite	25	10	--	--	25	10
North Avenue Detention Ponds	78	10	6	32	84	12
Northeast Area Draining Offsite	59	29	--	--	59	29
East Pond	20	22	--	--	20	22
Total ungaged area	240	13	26	27	266	14
TOTAL AREA	691	31	2030	16-21	2721	20-24

[1]See figures 1 and 5 for locations.
[2]Percent effective impervious area values for 1975 and 1981.
[3]Not applicable because these stations measure a combination of regulated and storm flow.

Table 3.--*Denver Federal Center drainage basin characteristics*

Streamflow station name[1]	Elevation of streamflow station, in feet	Channel length, in miles	Centroid, in miles[2]	Channel slope, in feet per mile	Basin slope, in feet per mile	Total relief, in feet
North Avenue Storm Drain-----	5,654	0.57	0.36	174	375	148
McIntyre Gulch No. 1---------	5,668	2.90	1.25	385	929	1,097
McIntyre Gulch No. 2---------	5,543	3.95	1.80	243	824	1,222
McIntyre Gulch net drainage[3]------------------	5,543	1.05	.62	84	549	125
Alameda Avenue Inflow--------	5,612	.52	.21	127	253	85
Denver Federal Center Field--	5,615	.20	.066	158	227	32

[1]See figures 1 and 5 for locations.
[2]Channel length upstream from streamflow station.
[3]See figure 5 for McIntyre Gulch net drainage area.

McIntyre Gulch No. 1

McIntyre Gulch No. 1 (table 1, station 06711642) on the Denver Federal Center measures the major drainage inflow to the DFC from the Green Mountain area of the city of Lakewood. Four tributaries join just before entering the DFC, draining an area which is 25-percent single-family residential and 10-percent multifamily residential. During the study period (1975-81), the area drained by the three southernmost tributaries underwent continued development, and the commercial land-use percentage increased from 12 to 17 percent, reducing the amount of open space from 53 percent to 48 percent. Of this open space, 31 percent of the 1,256 acres at the upper end of the basin, excluding the noncontributing north tributary, are permanently classified as open space. The north tributary accounts for an additional 549 acres that drain to a series of retention storage ponds. This pond system is designed to retard storm runoff from the north tributary, so storm runoff from this tributary does not contribute to peak discharge at the same time as runoff from the other three tributaries. The percentage of effective impervious area ranged from 17 to 21 percent during the study for the immediately contributing area and from 15 to 20 percent for the whole drainage. Basin characteristics are listed in tables 2 and 3; figure 5 shows the two subareas of offsite drainage to this station. The McIntyre Gulch channel profile from the basin divide through the DFC (fig. 6) illustrates how steep the basin is, particularly upstream from the DFC. Several drainage studies have been published for McIntyre Gulch, including McCall-Ellingson and Morrill, Inc. (1975) and Hydro-Triad, Ltd. (1977a, 1977b).

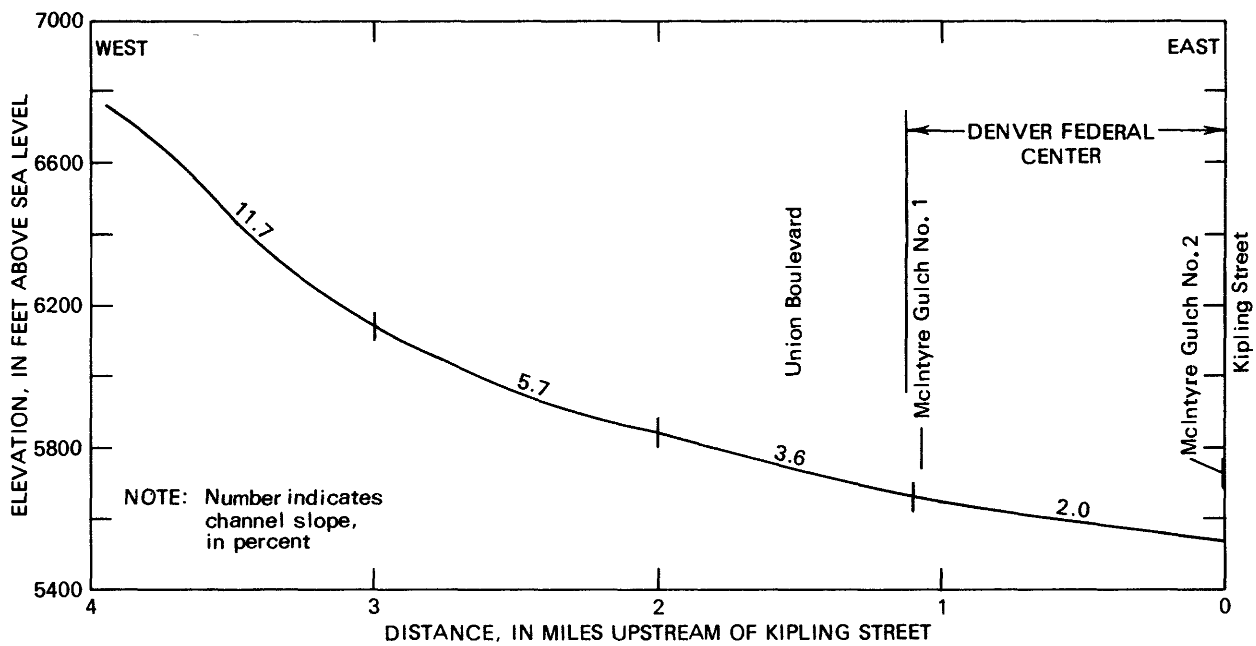

Figure 6.--Channel profile of McIntyre Gulch.

McIntyre Gulch No. 2

McIntyre Gulch No. 2 (table 1, station 06711645) on the DFC measures the major drainage outflow from the DFC complex. This area drains 475 acres, in addition to the flow at McIntyre Gulch No. 1, of which only 53 acres are offsite. Approximately 60 percent of this additional drainage area is light commercial land use, 30 percent is open space, and about 10 percent is single-family residential located entirely on the offsite area south of the DFC. Basin characteristics for this drainage basin are listed in tables 2 and 3, and the net onsite and offsite areas that contribute to the McIntyre Gulch No. 2 outflow from the DFC are shown in figure 5. The outflow station, McIntyre Gulch No. 2, measures the drainage from a 38-percent larger contributing area than the inflow station, McIntyre Gulch No. 1. This additional 38 percent of drainage contributing to flow past the outflow station, excluding the north tributary, has an effective impervious cover of approximately 40 percent. A flow routing chart for the McIntyre Gulch and Agricultural Ditch gages to determine DFC storm runoff to McIntyre Gulch gages is schematically shown in figure 7.

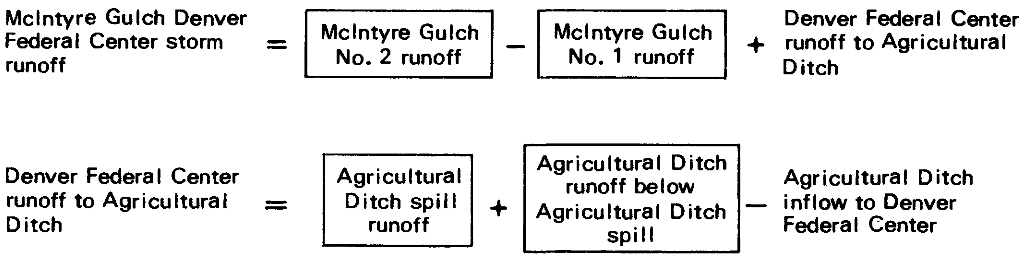

Figure 7.--Flow routing chart for McIntyre Gulch. (Boxes indicate a drainage basin gaged during the study.)

Agricultural Ditch

Agricultural Ditch (fig. 1) extends from the north-central DFC border to the southeastern corner. The data shown in table 1 for inflow (station 06719514), outflow (station 06719516), and the Spill (station 06719515) to McIntyre Gulch upstream from McIntyre Gulch No. 2 gage were measured and their contributions to storm runoff computed. Because these three gages reflect a combination of regulated irrigation and varying amounts of storm-runoff flow, the drainage areas and percentage of impervious area shown for other sites in table 2 are not applicable to these sites. Depending on the intensity of rainfall, some of the DFC storm runoff may contribute to McIntyre Gulch through the Agricultural Ditch Spill. In cases of high runoff an indeterminate amount of the flow will cross the Agricultural Ditch at North Avenue, at Center Avenue, and at Main Avenue. The flow chart (fig. 7) diagrams the routing of flow for these three gages on Agricultural Ditch. During the period of data collection, the contribution of storm runoff from the DFC to the Agricultural Ditch and the Agricultural Ditch Spill to McIntyre Gulch were insignificant.

Alameda Avenue Inflow

Alameda Avenue Inflow (table 1, station 06719517) to the DFC drains an 83-acre residential area with some open space and light commercial development. This drainage area is approximately 78-percent single-family residential, 8-percent open space, and 14-percent light commercial development. Basin characteristics are listed in tables 2 and 3, and figure 5 shows the contributing drainage. Approximately 26 percent of the drainage is effective impervious area, which has not changed significantly for the 1977-81 period of record. The original estimate of the drainage area included 100 acres, the water from which actually drains into Welch Ditch and subsequently contributes to runoff only if the ditch is full, and 53 acres, the water from which drains under Alameda Avenue at Eighth Street (fig. 5) and is recorded by the outflow station--McIntyre Gulch No. 2.

Denver Federal Center Field

Denver Federal Center Field (table 1, station 06719518) in Lakewood drains an undeveloped open space near the south end of the DFC. The basin consists of 12 acres of pervious open space. Basin characteristics are given in tables 2 and 3, and the drainage basin is outlined in figure 5.

Ungaged Drainage Area

Listed in table 2 after the gaged rainfall-runoff basins are several ungaged drainage areas on the DFC described by location or the direction of drainage. Field estimates of total area and percentages of effective impervious area are included to aid in future design. The ungaged part of the DFC drainage encompasses 266 acres of the study area and is denoted by the unshaded sections within the DFC boundary lines in figure 5.

ANALYSIS OF STORM-RUNOFF DATA

Rainfall-Runoff Analysis

Annual Peaks at Smaller Basins

Of the eight partial-record stage-discharge recorders, three were subbasins, which either drain onto the DFC property or drain a small part of the DFC property itself, located on small drainages that are not tributary to McIntyre Gulch. The annual peak discharges of these smaller drainages are given in table 4.

North Avenue Storm Drain and Alameda Avenue Inflow have similar drainage areas--80 and 83 acres, respectively (table 2)--although both channel slope and basin slope are about 40 percent steeper for North Avenue Storm Drain. North Avenue Storm Drain also has a higher percentage of effective impervious area. These factors combine to produce larger peak discharges for similar storms at the North Avenue Storm Drain station than at the Alameda Avenue station. A comparison of the peak discharges from four storms with nearly the same rainfall on both of these drainages is shown in table 5. For these storms, North Avenue Storm Drain produced twice the instantaneous peak discharge, probably due to its higher percentage of impervious area and its steeper slopes.

The station for the Denver Federal Center Field in Lakewood has recorded flow only three times during the 6 years of record. Since this is a completely undeveloped site, only in April and May of 1980 did the soil become saturated enough by several days of frontal-type rainfall for runoff to occur. Peak flows were recorded of 0.82 ft^3/s on April 25, 0.98 ft^3/s on April 30, and 0.78 ft^3/s on May 1, 1980.

McIntyre Gulch

The primary objectives of this storm-drainage analysis are to determine the effects of the DFC storm runoff on McIntyre Gulch, to assess both past and current runoff conditions, and to try to assess future problems so that storm runoff can be managed. Accordingly, since basin characteristics have considerable effect on storm runoff, a comparison of the two gaging stations on McIntyre Gulch might be beneficial in understanding the effects of the DFC storm runoff.

The contributing drainage area of McIntyre Gulch No. 2 station is 38 percent larger than McIntyre Gulch No. 1, excluding the noncontributing north tributary (table 2). In 1975 the effective impervious area (contributing area times percentage of effective impervious area) was 86 percent higher for the McIntyre Gulch No. 2 drainage area than for the area draining to McIntyre Gulch No. 1. By 1981 the continued upstream development had reduced this difference in impervious area to 71 percent. The increases in both drainage area and effective impervious area would tend to increase the peak discharges and volumes of runoff from the inflow to the outflow station. On the other hand, values of the area, length, centroid, and total relief are larger for the outflow gage than the inflow gage, and the channel slope (fig. 6) and basin slope are less (table 3). The channel slope, basin slope, and total relief of the net McIntyre Gulch drainage between the inflow and outflow stations (89 percent of which is DFC property) also indicate a flattening of slope. This decrease in slope as McIntyre Gulch drainage proceeds from the inflow to the outflow station (fig. 6) would tend to cause instantaneous peak discharges to lessen slightly as they pass through the DFC property.

Peak Discharges

Because storm-runoff drainage design is usually concerned with damage caused by peak discharges, most of the emphasis of this analysis was on peak flows resulting from thunderstorm runoff at the inflow and outflow sites. A summary of rainfall and its return period, instantaneous peak discharge at McIntyre Gulch No. 1 and No. 2 (the inflow and outflow stations), and percent increase or decrease between the two stations is given in table 6 for storm runoff greater than about 50 ft^3/s. The return period is the average time interval between actual occurrences of a hydrologic event of a given or greater magnitude. Of the 19 storms only three were frontal-system storms (table 6); these generally were the smaller storms. Many other frontal-system storms occurred; however, peak discharges were less than 50 ft^3/s and of no concern in this study. The lag time (in this case, the time from the center of the maximum 5-minute rainfall to the time of peak discharge) for McIntyre Gulch No. 1 and the peak travel time between McIntyre Gulch No. 1 and No. 2 streamflow gages also are listed in table 6.

Table 4.--*Annual peak discharges for North Avenue Storm Drain, Alameda Avenue Inflow, and Denver Federal Center Field streamflow stations*

Streamflow station name[1]	Date	Peak discharge, in cubic feet per second	Gage height, in feet
North Avenue Storm Drain at Denver Federal Center at Lakewood--------------------	May 17, 1978	32	12.26
	June 23, 1979	15	11.47
	August 8, 1980	15	11.51
	June 3, 1981	37	12.47
Alameda Avenue Inflow to Denver Federal Center at Lakewood--------------------	June 6, 1977	24	12.44
	May 5, 1978	11	11.54
	August 19, 1979	5.5	11.01
	April 30, 1980	8.5	11.30
	May 27, 1981	13	11.73
Denver Federal Center Field at Lakewood-----------------	1976	No Recorded Flow	
	1977	No Recorded Flow	
	1978	No Recorded Flow	
	1979	No Recorded Flow	
	April 30, 1980	98	10.15
	1981	No Recorded Flow	

[1]See figures 1 and 5 for locations.

Table 5.--*Peak discharges for comparable storms for Alameda Avenue Inflow and North Avenue Storm Drain streamflow stations*

	Station[1]	
Date	Alameda Avenue Inflow peak discharge, in cubic feet per second	North Avenue Storm Drain peak discharge, in cubic feet per second
May 17, 1978	11	32.0
June 7, 1979	4.3	9.0
August 19, 1979	5.6	9.6
July 26, 1981	12.0	23.0

[1]See figures 1 and 5 for locations.

The outflow peak discharge was higher than the inflow peak discharge for 11 of the 19 storms by an average of 38 percent. Outflow peak discharge was lower for eight of the storms by an average of 12 percent. A difference of 27 percent was noted for the 19 storms that recorded peak discharges at both sites.

During the 7 years of data collection, the largest peak discharges were 0.48 $ft^3/s/acre$ at McIntyre Gulch No. 1 and 0.34 $ft^3/s/acre$ at McIntyre Gulch No. 2. For comparison, during the 4 years of data collection at the North Avenue Storm Drain, the largest peak discharge similar in magnitude was 0.46 $ft^3/s/acre$. A plot of the instantaneous peak discharge at McIntyre Gulch No. 1 (DFC inflow) versus McIntyre Gulch No. 2 (DFC outflow) is shown in figure 8, with a straight line representing equal peak discharges for the same storm. The greater peak discharges at McIntyre Gulch No. 2 plot above the line, while the greater peak discharges at McIntyre Gulch No. 1 plot below the line and show the effect of the DFC contribution to runoff. If data are used from all storms regardless of rainfall distribution, the correlation coefficient between the inflow and outflow peak discharges is 0.95.

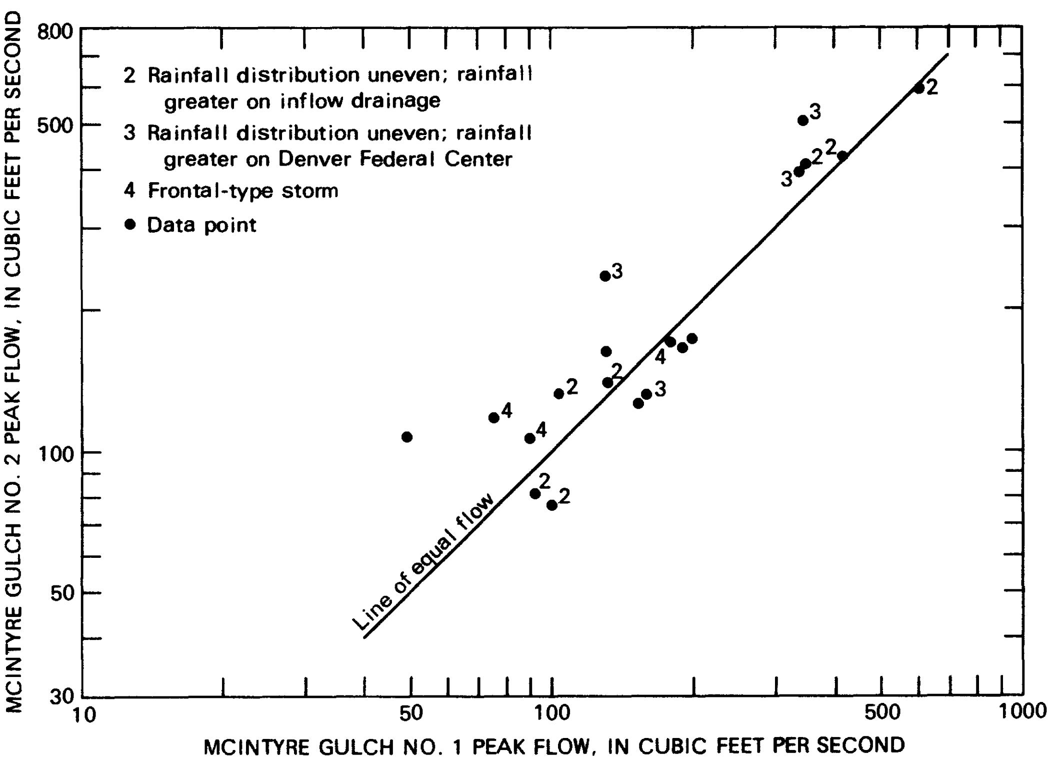

Figure 8.--McIntyre Gulch No. 1 peak flow versus No. 2 peak flow for the Denver Federal Center.

Table 6.--*Rainfall and peak discharges, lag time, and time of travel of streamflow at McIntyre Gulch stations No. 1 and No. 2 on the Denver Federal Center*

	Weighted mean maximum 30-minute rainfall,		Peak discharge, in cubic feet per second			Lag	Peak travel
Date	In inches	Return period, in years	McIntyre Gulch No. 1	McIntyre Gulch No. 2	Percent change	time, in minutes	time, in minutes
July 20, 1975	[2]0.73	~4	415	421	+1	28	10
July 26, 1976	[2].39	<2	100	77	-23	28	25
June 6, 1977	[2].66	~3	347	410	+18	22	15
July 20, 1977	[2].84	~5	600	596	-1	28	5
May 17, 1978	[3].28	<2	130	236	+82	18	20
May 2, 1979	[4].14	<2	75	117	+56	--	--
June 7, 1979	[4].18	<2	90	106	+18	42	8
August 10, 1979	[2].36	<2	131	141	+8	28	20
August 19, 1979	[2].34	<2	103	132	+28	28	5
April 30, 1980	[4].22	<2	130	162	+25	18	10
May 1, 1980	[4].19	<2	179	172	-4	32	10
May 5, 1980	.23	<2	49	107	+118	42	--
May 7, 1980	.17	<2	190	167	-12	12	10
August 14, 1980	[3].34	<2	158	132	-16	12.5	10
May 27, 1981	.37	<2	198	172	-13	22.5	15
May 28, 1981	.15	<2	154	129	-15	27.5	15
June 3, 1981	[3].52	~2	344	510	+48	22.5	15
July 15, 1981	[2].33	<2	92	81	-12	22.5	25
July 26, 1981	[3].70	~3	340	400	+19	17.5	15
Averages					27	25	14

[1]See figures 1 and 5 for locations.
[2]Rainfall distribution uneven; rainfall greater on inflow drainage.
[3]Rainfall distribution uneven; rainfall greater on Denver Federal Center.
[4]Frontal-type storm.

Typical storm hydrographs of discharge at McIntyre Gulch No. 1 and No. 2 for a storm of relatively even rainfall distribution over the study area are shown in figure 9. For this rainfall distribution for a thunderstorm, peak discharges at McIntyre Gulch No. 2 averaged 15 percent larger than those at McIntyre Gulch No. 1 (although it could be less as shown for this storm). The Agricultural Ditch Spill to McIntyre Gulch also was monitored; only minor contribution to the peak flows (usually less than 10 ft^3/s) could be attributed to this source during the period of record. This is due primarily to the spill being closed unless opened by the Agricultural Ditch Runner, by which time the peak flows have passed this location on McIntyre Gulch. Although the storm hydrographs in figure 9 generally are similar except for time of discharge, the recession limb of the McIntyre Gulch No. 2 hydrograph reflects the majority of the storm-runoff contribution from the DFC contributes to the upstream storm runoff well after the peak. This was typical of most larger storms.

Seven storms (indicated with a 2 in fig. 8 and table 6) had greater rainfall on the upper part of the basin, resulting in a smaller or only slightly greater peak discharge at the outflow gage than at the inflow gage. Typical hydrographs for McIntyre Gulch No. 1 and No. 2 of discharge resulting from a storm centered upstream from the DFC are shown in figure 10. The figure represents the translation of a hydrograph from the western to the eastern boundaries of the DFC and shows the effects of attenuation on the hydrograph due to channel storage between the two stations. Also note that the DFC storm-runoff contribution is after the peak in the later stages of the hydrograph. For storms centered over the upper basin, resulting peak discharges were the greatest of any type of rainfall distribution, and peak discharges increased on the average of 3 percent from the inflow station to the outflow station.

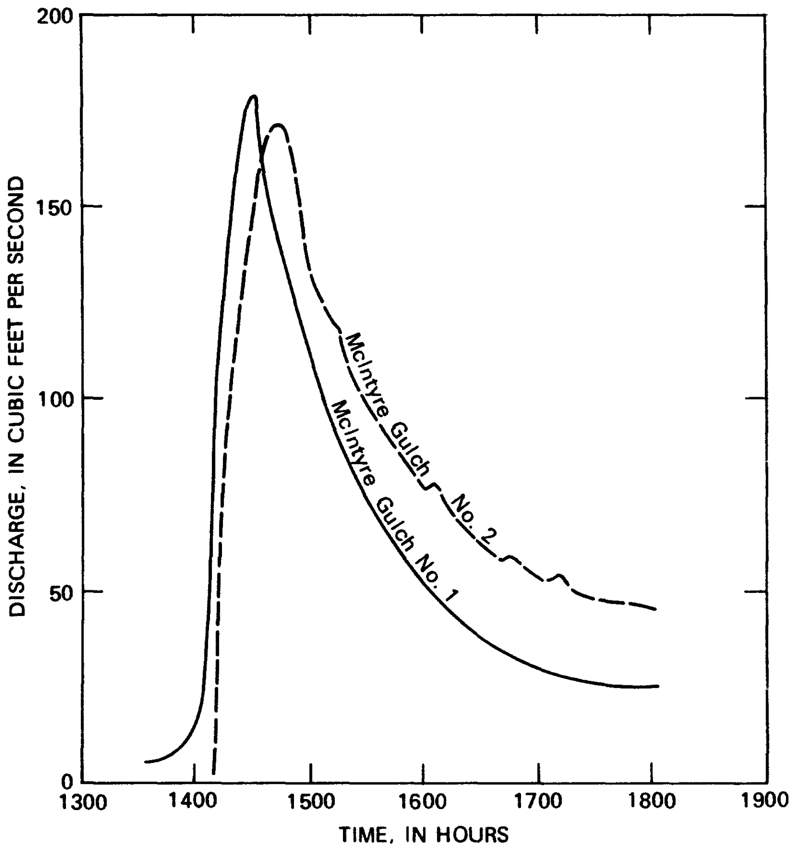

Figure 9.--Typical McIntyre Gulch storm hydrographs for evenly distributed rainfall, May 1, 1980.

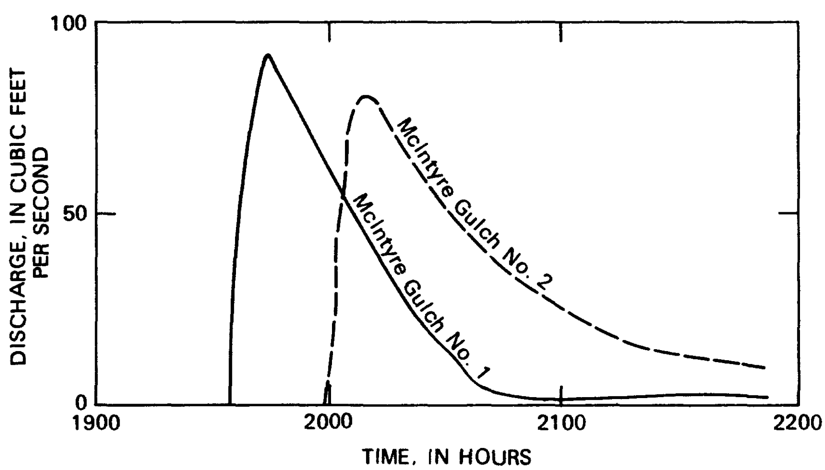

Figure 10.--Typical McIntyre Gulch storm hydrographs for rainfall centered upstream from the Denver Federal Center, July 15, 1981.

The four storms (indicated by a 3 in fig. 8 and table 6) that had greater rainfall on the net drainage area between the two stations (primarily on the DFC) resulted in an average increase of 33-percent in peak discharge. This is slightly larger than the percent increase that would be expected if rainfall from three of the storms had been uniform.

Typical storm hydrographs of discharge at the McIntyre Gulch No. 1 and No. 2 gages for a storm that had greater precipitation on the DFC are shown in figure 11. This rainfall distribution occurred infrequently (in only four of the documented storms). The most common rainfall distribution appeared to have greater intensities and volumes over the upper McIntyre Gulch basin, probably due to an orographic effect from Green Mountain. The volume of discharge shown on the hydrograph is larger at McIntyre Gulch No. 2 than at McIntyre Gulch No. 1 (fig. 11); however, the peak discharge may not always be larger.

The lag between the time of the peak discharge (table 6) at the McIntyre Gulch No. 1 station and the time (at the centroid) of the highest intensity 5-minute rainfall averaged about 25 minutes. The time of travel (table 6) for the peak from McIntyre Gulch No. 1 to McIntyre Gulch No. 2 averaged about 14 minutes (4.5 miles per hour) for the 1.05-mile distance between the two stations. Generally, the more intense and larger the storm, the faster the travel time through the DFC.

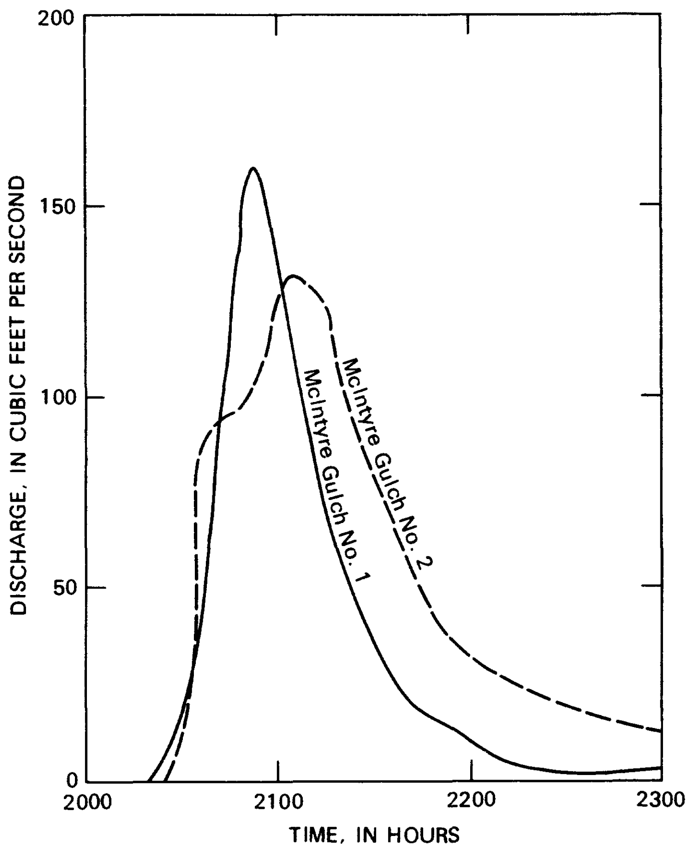

Figure 11.--Typical McIntyre Gulch storm hydrographs for rainfall centered on the Denver Federal Center, August 14, 1980.

Runoff Volumes

The location of the McIntyre Gulch No. 1 gage on bedrock, at the west side of the DFC allowed for a full range of streamflow data to be collected. McIntyre Gulch No. 2 was located on a sand channel just upstream of a large box culvert under Kipling Street. The sand tended to plug the intakes of this gage when flows were less than about 25 ft^3/s. The DFC area tends to drain very slowly compared to the upper basin, and much of the DFC storm runoff was contributed when flows at the outflow station were less than 25 ft^3/s. Because of the difficulty in accurately determining values of flow less than 25 ft^3/s at the outflow station, accurate total storm-runoff volume is difficult to determine, and for some storms was approximated. To further complicate comparison of runoff volumes, the north tributary of McIntyre Gulch No. 1 also contributes low runoff during the larger frontal-type storms as the storage ponds overflow.

A comparison of the runoff volumes at McIntyre Gulch No. 1 and No. 2 streamflow gages is shown in table 7. For the 15 storms for which runoff volumes were computed, there was an average increase of 46 percent from the inflow to the outflow stations. There did not seem to be a major difference in the increase in volume due to the location of the maximum rainfall in the basin. For the last six storms most of the outflow volume was determined, so an indication of the volume increases can be seen for different types of rainfall distributions. The contributing drainage between the McIntyre Gulch inflow and outflow gages increases 38 percent for most storms and 26 percent for those frontal storms with durations long enough to include flow from the McIntyre Gulch north tributary detention ponds. These differences must be considered in evaluating the increases. All data collected indicated that runoff volumes increased from the inflow to the outflow stations. Most of this increased volume of runoff was added after the peak discharge had passed (figs. 9, 10, and 11).

Rainfall-Runoff Frequencies

Up to now, the discussion has focused on the magnitude of storm runoff in the study area. Of equal interest are the relative frequencies of the storm runoff. Unfortunately, runoff frequencies cannot be determined from the available data, for several reasons. First, the period of record, generally 7 years, is too short to make reliable flow-frequency analyses. The Interagency Advisory Committee on Water Data (1981) recommends that at least 10 years of data be used for statistical analyses. Second, all the drainages have undergone varying degrees of development during the study. The resulting urbanization and its changes in land use and stream channels make assigning a frequency to any of the peak discharges questionable. Finally, regional methods of determining the magnitude and frequency of peak discharges cannot be applied to the data collected during this study.

Table 7.--*Runoff volumes at McIntyre Gulch No. 1 and No. 2 streamflow stations*

Date	Maximum rainfall location	McIntyre Gulch No. 1 No. 1 runoff volume (inflow), in acre-feet[1]	McIntyre Gulch No. 2 No. 2 runoff volume (outflow), in acre-feet[1]	Percent increase[2]
July 26, 1976	Inflow basin	5.83	7.02	20.4
June 6, 1977	Inflow basin	20.4	28.2	38.2
May 1, 1979 to May 2, 1979[3]	Even	47.1	103	119
June 7, 1979 to June 8, 1979[3]	Even	41.3	60.5	46.5
August 10, 1979	Inflow basin	9.55	15.1	58.1
August 19, 1979	Inflow basin	8.95	15.9	77.6
April 30, 1980[3]	Even	70.0	95.0	35.7
May 1, 1980[3]	Even	22.3	28.2	26.5
May 7, 1980	Even	6.79	8.67	27.7
August 14, 1980	Outflow basin	9.02	13.0	44.1
May 27, 1981	Even	8.13	9.63	18.4
May 28, 1981	Even	7.56	9.26	22.5
June 3, 1981	Outflow basin	18.9	35.3	86.8
July 15, 1981	Inflow basin	4.45	5.55	24.7
July 26, 1981	Outflow basin	20.9	29.9	43.1

[1]See figures 1 and 5 for locations.

[2]$\frac{\text{Outflow-Inflow}}{\text{Inflow}} \times 100$

[3]Frontal-type storm.

For these reasons a simplified method was used of interpreting the relative frequencies of the peak discharges by evaluating the frequency of the rainfall associated with each storm. Although this simplified approach assumes that rainfall frequency equals runoff frequency (which is not always the case), it does give an idea of relative peak discharge frequency. The analyses of the McIntyre Gulch rainfall and runoff data indicated that the maximum 30-minute rainfall probably produced the peak discharges. Therefore, the weighted mean maximum 30-minute rainfall associated with each peak discharge at McIntyre Gulch No. 1 was selected for this analysis. The weighted mean maximum 30-minute rainfall was computed as the sum of the maximum 30-minute rainfall for each gage in the McIntyre Gulch No. 1 basin weighted areally with the Thiessen method. This station was selected because it is located fairly near the center of the developed part of McIntyre Gulch which contributes the majority of storm runoff. The weighted mean maximum 30-minute rainfall and the associated frequency in terms of return period in years (Denver Regional Council of Governments, 1972) are shown in table 6. Fifteen of the storms have had a return period of 2 years or less; two storms had a return period of 3 years; one storm had a return period of 4 years; and one storm had a return period of 5 years.

MANAGEMENT OF STORM RUNOFF

One of the main objectives of this study was to provide GSA planners with information for the design of DFC drainage systems for future planning, either for proposed new developments or upgrading of existing storm-runoff systems. Analysis of the storm-runoff data indicates that the present drainage system retards storm runoff sufficiently that most of the DFC runoff enters McIntyre Gulch after the peak flows from upstream from the DFC. In the early phases of this study, rainfall-runoff computer modeling was planned to be used to evaluate the hydrologic impacts of proposed DFC development. However, during this study, results of the analysis of the data and complexities of the hydraulics of the DFC physical system and hydrology (rainfall occurrence and distribution) indicated that alternative methods (Hydro-Triad, Ltd., 1983) had been revised to provide adequate definition of storm runoff. These alternative methods will evaluate runoff conditions for existing and proposed DFC development so that onsite controls can be designed to maintain existing storm-runoff peak discharges.

Complexity of Denver Federal Center Physical System

Both McIntyre Gulch No. 1 and No. 2 drain areas which present several complex hydraulic and computer-simulation problems. The inflow gage records drainage from a rapidly developing basin of changing land use and a resulting increase in impervious surface. A storm over the southern end of the upper basin would cause an entirely different effect from one over the north tributary where the storage ponds near Union Boulevard modify storm runoff. The area above the outflow gage , which includes most DFC property, contains two irrigation ditches that collect runoff in varying amounts, depending on rainfall intensity. In addition, several areas in the middle of the DFC drainage collect significant amounts of standing water due to local depressions, storm-drainage system that retards flow, and drainage boundaries that vary with rainfall intensity. Because the McIntyre Gulch channel is on the southern end of the DFC, a storm located there would produce a higher peak than a storm located in the northern part of the DFC, where roof and parking-lot storage, undersized drains, and the distance from the main channel delay the runoff. The difficulties and cost of setting up a rainfall-runoff computer-simulation model of such a hydrologically complex drainage led to the alternative suggestion of designing onsite storm-runoff controls to reduce the hydrologic impact of further DFC development.

Onsite Design Considerations

Because McIntyre Gulch is the major drainage passing through the DFC property, storm-runoff management of this drainage is of major concern. A storm-runoff control system already has been installed for the North Avenue drainage (Hydro-Triad, Ltd., 1973). As noted previously, the increase in both actual drainage area and impervious area between the inflow and outflow gaging stations on McIntyre Gulch would normally increase peak flows as the storm runoff passed through the DFC. Fortunately, a decrease in channel slope, channel storage, and the less developed condition of the area surrounding the channel reduces this tendency. Continuing development of the upper basin probably will lead to higher peak flows at the inflow station unless upper basin drainage planning considers the hydrologic impact of this development. The storm runoff entering the south end of the DFC near Eighth Street between the inflow and outflow stations (fig. 5 and table 2) also must be considered, although land use in this mostly residential area should be stable.

During this study, it seems that the average peak discharge at the McIntyre Gulch No. 2 station increased only slightly more than the peak discharge at the McIntyre Gulch No. 1 station (fig. 8). Only significant increases of peak discharge from inflow to outflow are shown in figure 8 for the storms having discharges less than about 130 ft^3/s and for storms producing greater rainfall on the DFC property itself than on the upstream drainage.

Given the current drainage characteristics of the study area and their effects on the differences in storm runoff between the McIntyre Gulch inflow and outflow stations, several aspects of the present and future management of storm runoff on the DFC need to be considered. Most of the DFC drainage to the north of McIntyre Gulch already is developed. There, roof and parking-lot storage, undersized drains, and the distance from the drainageway delay the runoff until the peak discharge from McIntyre Gulch No. 1 has passed. A storm centered on the less developed southern end of the DFC currently adds very little storm runoff to McIntyre Gulch because of the ability of the relatively flat terrain to absorb rainfall. Records from the Denver Federal Center Field station showed that only after several days of continuous rainfall will undeveloped areas actually contribute to storm runoff. Storm runoff from any development in the southern part of the DFC could be maintained at existing levels by combining roof and parking-lot storage with undersized drains, in spite of the proximity to the drainageway. Existing levels also could be maintained by a system of retention and detention storage basins designed to minimize the impact of any increases in impervious area, as was done for the development of the North Avenue drainage (Hydro-Triad, Ltd., 1973). Similar onsite design needs to be incorporated in any improvements to existing DFC drainage facilities. The channel of McIntyre Gulch needs to be adequately maintained in the event that increased storm peak flows from the upper basin require more channel capacity. Likewise, drainage plans for new development along the west border need to be carefully evaluated in regard to the total DFC storm-management plan.

OTHER AVAILABLE INFORMATION

Additional records and data not published in this report are available from the U.S. Geological Survey, Water Resources Division. Aerial photography flown on May 13, 1976, was used to prepare maps of the study area. These maps include orthographic and topographic maps of the study area at a scale of 1 inch equals 400 feet with a contour interval of 10 feet and similar maps of the DFC at a scale of 1 inch equals 200 feet with a contour interval of 2 feet. Channel cross-sectional data were compiled from the aerial photography at 50- to 100-foot spacing on drainage channels on the DFC. Hydraulic geometry surveys also were made at bridges and at culverts greater than 1 foot in diameter on the DFC.

SUMMARY AND CONCLUSIONS

GSA planners, to avoid adverse effects on storm runoff from proposed development on the DFC, asked the U.S. Geological Survey to investigate the storm-runoff characteristics of the area. To provide data on existing storm runoff, McIntyre Gulch, which flows through and drains the DFC, was measured for 7 years.

The total study area encompassed 2,721 acres, of which 2,455 acres were measured for streamflow. About 20 percent of the study area in 1975 to 24 percent in 1981 was impervious due to residential, light commercial, and business land uses.

Rainfall and runoff data were collected at eight streamflow stations and three auxiliary rainfall stations in and adjacent to the DFC. Fifteen of the recorded storms had a return period of 2 years or less; two storms had a return period of 3 years; one storm had a return period of 4 years; and one storm had a return period of 5 years. Due to the short period of record and the changing land use in the basin, runoff frequencies were not determined.

The major drainage in the study area is McIntyre Gulch. The contributing drainage area for McIntyre Gulch is 38 percent larger at the outflow station than at the inflow station. The outflow peak discharges from McIntyre Gulch were higher than the inflow peak discharges by an average of 38 percent for 11 of the 19 storms where flows exceeded 50 ft^3/s. Outflow peak discharges were lower for eight of the storms by an average of 12 percent. The study indicated that runoff varies with the location of the storm even for a relatively small basin. An increase in outflow of 27 percent was noted for the 19 storms; however, for evenly distributed rainfall, peak outflow was only 15 percent greater than for peak inflow.

Most of the storm runoff generated on the DFC contributed to the flow in McIntyre Gulch after the inflow peak. All data collected indicated that McIntyre Gulch runoff volumes increased from the inflow station to the outflow station by an average of 46 percent. The distribution of storm runoff was dependent of the intensity and location of the rainstorm within the basin. Generally, the larger storms occurred upstream of the DFC, probably due to orographic effects of Green Mountain. The lag time of the peak discharge at the McIntyre Gulch inflow site from the center of the highest 5-minute rainfall averaged about 25 minutes. The travel time for the peak flow through the DFC averaged about 14 minutes for the 1.05 mile distance, or 4.5 miles per hour. A station on a small undeveloped field on the DFC recorded flow only after the soil became saturated by several days of rainfall. Although Agricultural Ditch Spill to McIntyre Gulch was measured, only minor contributions (usually less than 10 ft^3/s) were observed during the period of record.

A comparison was made of peak flows of two watersheds, of similar size with differing basin slope and effective impervious area. The steeper watershed with a greater effective impervious area had peak discharges about double in magnitude for storms of similar rainfall.

Management of storm runoff on the DFC is difficult due to the complexities of the occurrence of the storms over the basin and the hydraulics of the existing DFC drainage. The development in the North Avenue Storm Drainage has been designed to effectively maintain peak discharges at predevelopment levels. The design of onsite storm-runoff designs needs to include the storage of water on roof and parking lots, undersized storm drains, and a system of retention and detention storage basins to minimize the impact of any increases in impervious areas. Thus, onsite storm-runoff systems designed for any proposed development on the DFC need to maintain peak flows at their present levels. The currently accepted technique to evaluate storm runoff from changing land uses in the Denver Metropolitan area is the Colorado Urban Hydrograph Procedure (Wright-McLaughlin Engineers, 1969a). Onsite design based on results from the Colorado Urban Hydrograph Procedure should provide acceptable and effective means of controlling storm runoff from improvements to existing DFC development drainage facilities.

REFERENCES

Alley, W. M., and Veenhuis, J. E., 1979, Determinations of basin characteristics for an urban distributed routing rainfall-runoff model, in Stormwater Management Model (SWMM) Users Group Meeting, Montreal, Canada, May 24-25, 1979, Proceedings: Washington, D.C., U.S. Environmental Protection Agency Miscellaneous Reports Series EPA 600/9-79-026, 27 p.

Bailey, J. F., and Ray, H. A., 1966, Definition of stage-discharge relation in natural channels by step-backwater analysis: U.S. Geological Survey Water-Supply Paper 1869-A, 21 p.

Bodhaine, G. L., 1968, Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A3, 60 p.

Cochran, B. J., Hodges, H. E., Livingston, R. K., and Jarrett, R. D., 1979, Rainfall-runoff data from small watersheds in Colorado, October 1974 through September 1977: U.S. Geological Survey Open-File Report 79-1261, 673 p.

Cochran, B. J., Minges, D. R., Jarrett, R. D., and Veenhuis, J. E., 1983, Rainfall-runoff data from small watersheds in Colorado, October 1977 through September 1980: U.S. Geological Survey Open-File Report 82-873, 748 p.

Dalrymple, Tate, and Benson, M. A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter A2, 12 p.
Denver Regional Council of Governments, 1972, Rainfall/runoff information [Prepared in cooperaion with the Urban Drainage and Flood Control District]: Urban Systems Engineering Demonstration Program, Project No. COLO-USE-1, Project REUSE Final Report--Suplemental Publication DRCOG-72-003, 336 p.
Ellis, S. R., and Alley, W. M., 1978, Hydrologic data for urban storm runoff from three localities in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 78-410, 135 p.
_____1979, Quantity and quality of urban runoff from three localities in the Denver metropolitan area, Colorado: U.S. Geological Survey Water-Resources Investigations Report 79-64, 60 p.
Ellis, S. R., Lindner, J. B., and Patterson, D. A., 1983, Effects of increased urbanization on the storm runoff from a small urban basin in metropolitan Denver, Colorado, in International Symposium on Urban Hydrology, Hydraulics and Sediment Control, Lexington, Ky., July 23-28, 1983, Proceedings: Lexington, Kentucky University, p. 79-86.
General Services Administration, 1979a, Denver Federal Center master plan and environmental impact statement: Denver, Colo., Master Plan, v. 1, 59 p.
_____1979b, Denver Federal Center future development and master plan: Denver, Colo., Environmental Impact Statement No. ECO-78001, v. 2, 266 p.
Gibbs, J. W., 1981, Hydrologic data for urban storm runoff from nine sites in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 81-682, 142 p.
Gibbs, J. W., and Doerfer, J. T., 1982, Hydrologic data for urban storm runoff in the Denver metropolitan area, Colorado: U.S. Geological Survey Open-File Report 82-872, 553 p.
Grozier, R. U., McCain, J. F., and Ducret, G. L., Jr., 1975, Potential flood hazard--North Avenue area, Denver Federal Center, Lakewood, Colorado: U.S. Geological Survey Open-File Report 75-45, 12 p.
Hydro-Triad, Ltd., 1973, Drainage study for Union Square; prepared for Tri-Consultants, Inc.: Denver, Colo., 57 p.
_____1974, Drainage study for Tract I--Union Square development; prepared for Tri-Consultants, Inc.: Denver, Colo., 13 p.
_____1977a, McIntyre Gulch major drainageway planning, Addendum Phase A Report, April 1977; prepared for the Urban Drainage and Flood Control District and City of Lakewood, Colorado: Lakewood, Colo., 110 p.
_____1977b, McIntyre Gulch major drainageway planning, Phase B; prepared for Urban Drainage and Flood Control District, and City of Lakewood: Lakewood, Colo., 21 p., appendixes A-B.
_____1983, Fourth Avenue/Union Boulevard drainage study; prepared for the City of Lakewood: Lakewood, Colo., 104 p.
Interagency Advisory Committee on Water Data, 1981, Guidelines for determining flood flow frequency (2d ed., revised) [editorial corrections made March 1982]: Reston, Va., U.S. Geological Survey Office of Water Data Coordination, Hydrology Subcommittee Bulletin 17B, appendixes 1-14, 28 p.

McCall-Ellingson and Morrill, Inc., 1975, Phase A, Preliminary report on major drainage planning on Lakewood and McIntyre Gulches; prepared for Urban Drainage and Flood Control District, the City and County of Denver, and Jefferson County: Denver, Colo., 62 p.

Wright-McLaughlin Engineers, 1969a, Urban storm drainage criteria manual, volume 1; prepared for Denver Regional Council of Governments: Denver, Colo., 453 p.

_____1969b, Urban storm drainage criteria manual, volume 2; prepared for Denver Regional Council of Governments: Denver, Colo., 244 p.