# PEAK-FLOW CHARACTERISTICS OF SMALL URBAN DRAINAGES ALONG THE WASATCH FRONT, UTAH

By K. L. Lindskov and K. R. Thompson

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CONVERSION FACTORS

Most values in this report are given in inch-pound units. The conversions factors are shown to obtain metric equivalents to four significant figures.

| Multiply | By | To obtain |
|---|---|---|
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| foot (ft) | 0.3048 | meter (m) |
| inch (in.) | 25.40 | millimeter (mm) |
| mile (mi) | 1.609 | kilometer (km) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |

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## ABSTRACT

Designers and planners for local, State, and Federal agencies need up-to-date methods for determining peak-flow frequency relations for urban drainages along the Wasatch Front, Utah. This report summarizes methods used to develop equations that estimate peak flows for small urban drainages along the Wasatch Front.

Rainfall and runoff data collected from eight urban drainages along the Wasatch Front during 1984-86 were used to calibrate a Distributed Routing Rainfall-Runoff model called DR3M-II for each drainage. Long-term rainfall data collected during 1948-83 at the National Weather Service station at the Salt Lake City Airport were used with the calibrated models to estimate peak-flow data for 1948-83 for each of the eight drainages. Log-Pearson fits were made to the peak-flow data and were used to estimate peak-flow frequency relations for each drainage.

Mathematical equations were developed that relate peak flows for recurrence intervals of 2, 5, 10, 25, 50, and 100 years for small urban drainages, to basin characteristics. Data entry to the equations requires determination of basin slope, drainage area, and percentage of impervious area.

Paired stations on Little Cottonwood Creek near Salt Lake City were used to help determine the effects of intervening urban drainage on peaks of larger streams that originate in the mountains. In general, peaks on larger streams caused by snowmelt and peaks caused by rainfall (where urban areas may have a significant effect) did not occur simultaneously.

## INTRODUCTION

Population increases and urban expansion have increased concern about adequate design of highway and street drainage structures within the urban environment. About two-thirds of Utah's population resides along the Wasatch Front, which extends from Brigham City on the north to Nephi on the south (fig. 1). The Wasatch Front includes the western flank of the Wasatch Range and the densely populated eastern part of adjoining valleys at the base of the range. Population along the Wasatch Front has increased considerably since 1960. In Salt Lake County (fig. 2), which includes a large part of the population, there was a 61-percent increase from 1960 to 1980 (U.S. Bureau of the Census, 1963; 1980). Population increased 13 percent from 1980 to 1985, and a similar future increase is anticipated (Utah Office of Planning and Budget, Data Resources Section, 1987).

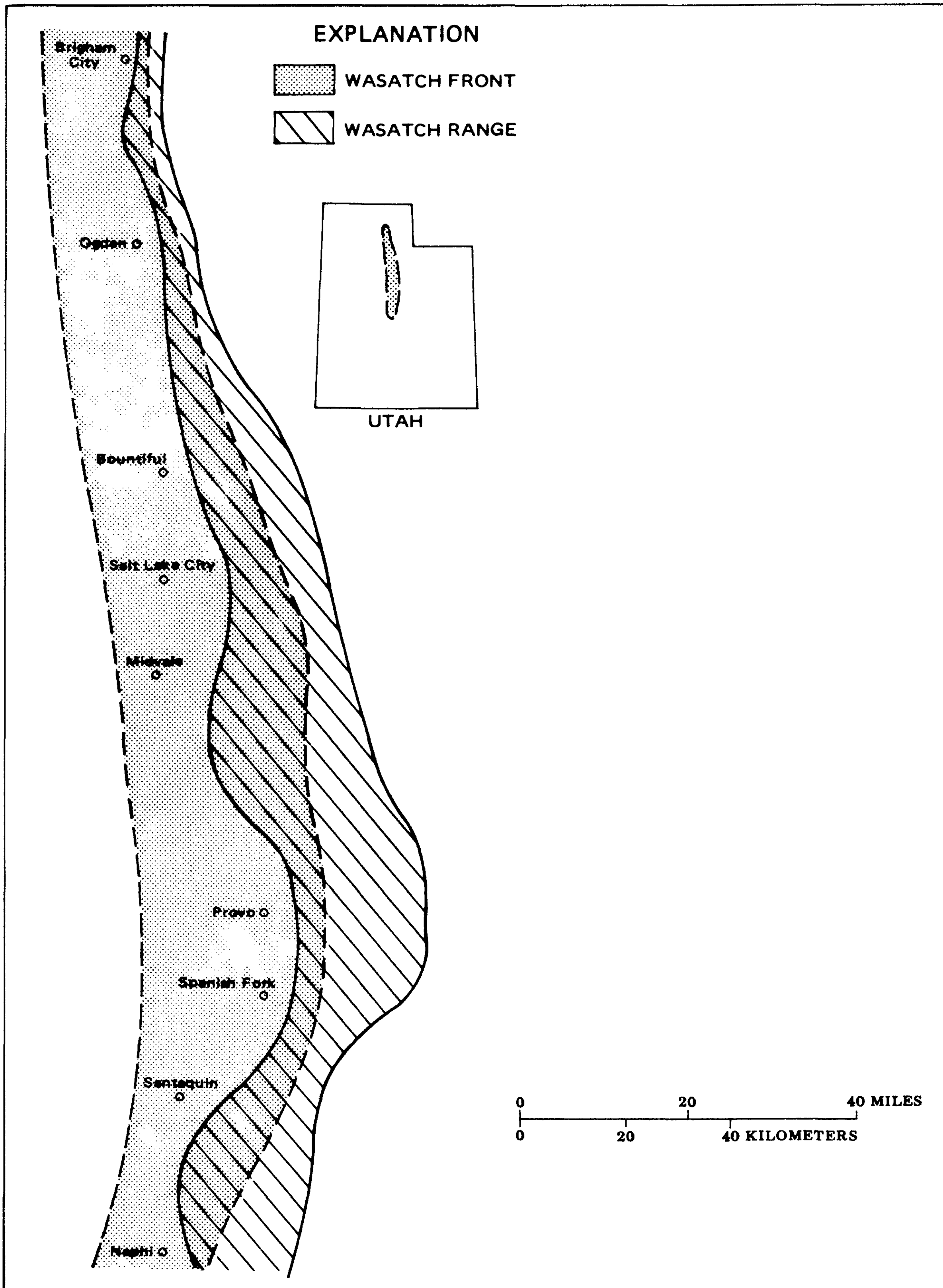


Figure 1.--Location of the Wasatch Front and the associated part of the Wasatch Range.

Two types of flooding are common in urban areas of the Wasatch Front. Intense rainfall produces most of the peak flows for urban drainages that originate below an altitude of 5,500 feet, and snowmelt produces most of the peak flows in streams that originate above an altitude of 7,000 feet. The higher-altitude streams originate in mountainous areas east of the Wasatch Front. Equations listed in Thomas and Lindskov (1983) were developed for natural streams in rural areas and are useful for computing peak-flow characteristics for the mountain streams. However, adequate hydrologic data were not available in 1983 to develop equations for computing peak-flow characteristics for urban drainages.

Designers and planners for local, State, and Federal agencies need up-to-date methods of determining peak-flow characteristics for urban drainages along the Wasatch Front. The Utah Department of Transportation, an agency responsible for design of many drainage structures in the area, recognized this need for improved methods and, because adequate local hydrologic data were not available for developing the methods, entered into a cooperative agreement with the U.S. Geological Survey to obtain these data.

## Purpose and Scope

This report describes the results of a study to obtain and interpret hydrologic data for representative urban drainages along the Wasatch Front for use in determining peak-flow frequency relations needed for adequate design of drainage structures. The specific objectives are: (1) Establish short-term streamflow partial-record gages on selected urban drainages and use the data to calibrate rainfall-runoff models that can be used with long-term rainfall records to estimate the long-term peak flows needed to develop peak-flow frequency relations for the gaged drainages, (2) develop methods for determining peak flow for selected recurrence intervals for ungaged urban drainages by relating peak-flow values for the gaged drainages to basin characteristics, and (3) compare peak flow at two existing continuous-record gaging stations in order to determine whether peak flow resulting from snowmelt in the mountains occurs simultaneously with that resulting from rainfall on the intervening urban areas.

## Approach

As part of this study, 11 small urban drainages were instrumented to obtain rainfall and flow data during the summers of 1984-86 for use in calibrating rainfall-runoff models. However, problems with instrumentation and the short time period resulted in insufficient data for two of the drainages, and the contributing area could not be defined adequately for one drainage. Thus, data from only 8 of the 11 drainages were used for this report.

The U.S. Geological Survey rainfall-runoff model (DR3M-II)(Alley and Smith, 1982) was calibrated for each of the eight drainages. The drainages ranged from 0.085 to 0.87 square mile and had different degrees of relief and impervious area. The eight calibrated models then were used to generate peak flows for each drainage. Rainfall data were digitized in 5-minute intervals from charts for one to four storms per year during 1948-83 for the National

Weather Service station at the Salt Lake City Airport, and these data were entered into the model for each drainage. Log-Pearson Type III distribution (U.S. Water Resources Council, 1981) was used to estimate annual peak-flow data for each drainage. Peak flows having recurrence intervals ranging from 2 to 100 years were calculated and are presented in this report.

Peak-flow values for selected recurrence intervals for the eight drainages were related to basin characteristics to develop equations for computing peak-flow frequency relations for ungaged, urban drainages along the Wasatch Front. Equations developed for the urban drainages represent small urban drainages originating below an altitude of 5,500 feet where most peak flow results from intense rainfall. Another situation exists in streams that originate in the mountainous areas above 5,500 feet. These streams, which have annual peak flows resulting mostly from snowmelt, flow through urban areas to larger rivers or directly to Great Salt Lake. Downstream reaches of these streams can receive large peak flows from either snowmelt in the mountains or from rainfall runoff on the intervening urban areas. Peak streamflow data for two continuous-record gaging stations on Little Cottonwood Creek were compared to determine whether the two types of peak flow occur simultaneously.

## DATA USED FOR ANALYSIS OF PEAK-FLOW CHARACTERISTICS

### Short-Term Network Instrumented to Obtain Rainfall and Flow Data for Calibrating Models

Eleven urban drainages were instrumented to obtain 5-minute rainfall and flow data during the summers of 1984-86 for use in calibrating the rainfall-runoff models. However, problems with instrumentation and the short time period resulted in insufficient data for two drainages, and the contributing area could not be defined adequately for one drainage. Thus, data from only eight of the drainages were used in model calibration. Location for each of the eight partial-record stations is shown in figure 2. Contributing drainage area and location of station are shown in figures 3 to 10.

Rainfall data and stage data (for determining flow) were recorded by digital recorders in 5-minute intervals for the summer months. Between 10 to 29 flow hydrographs were available for analysis. Daily mean flows were not computed for any of the stations. Concurrent rainfall data generally were obtained near the flow-measuring station for each of the drainages. The drainage area, basin slope, effective impervious area, and number of storms used for model calibration are summarized in table 1 for the eight drainages for which rainfall-runoff models were calibrated. Basin characteristics and how they were determined are explained in the "Definitions of Selected Basin Characteristics" section. Descriptions for each of the drainages are given in the "Physical and Basin Characteristics of Eight Urban Drainages" section.

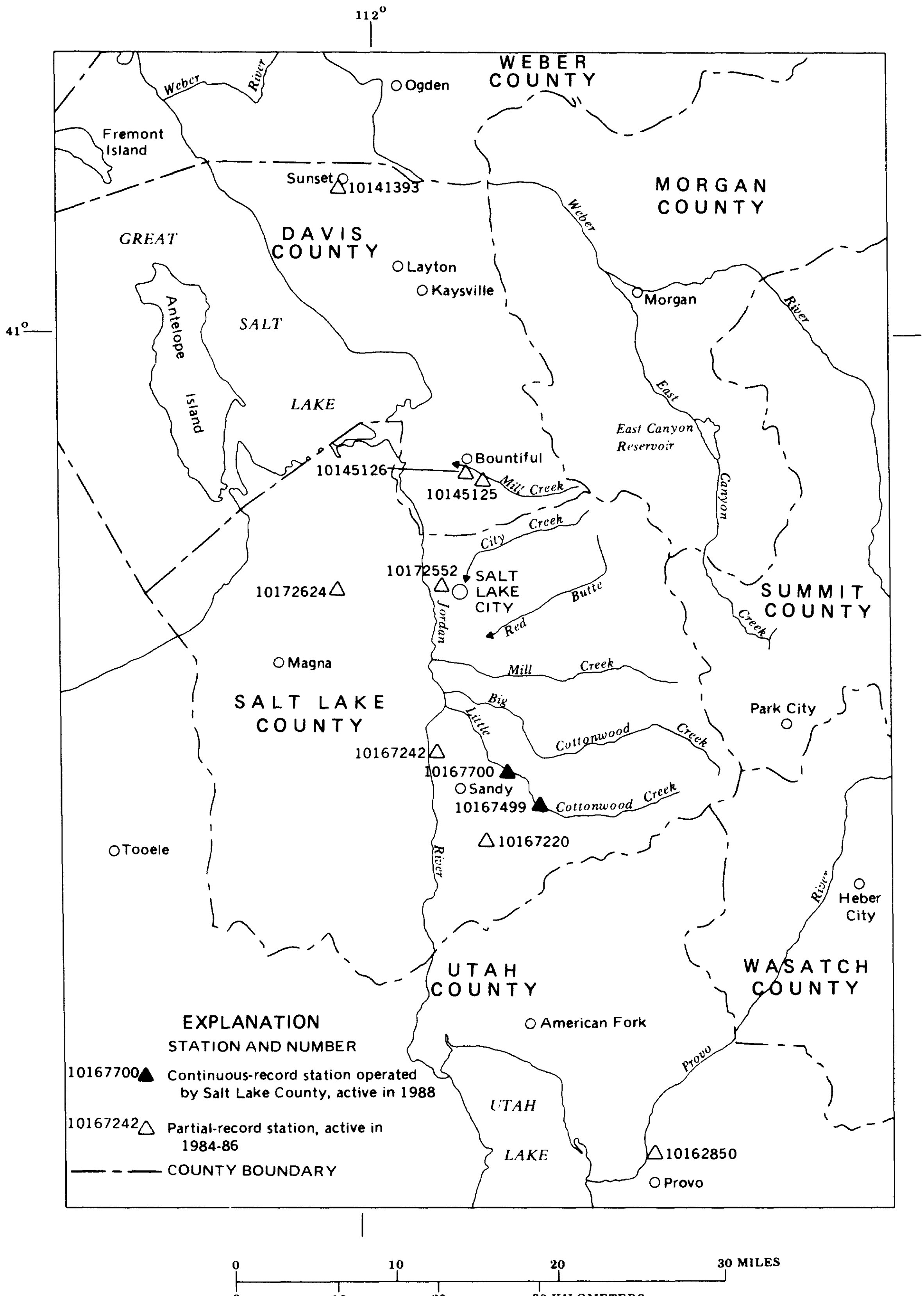


**Figure 2.—Location of two stations on Little Cottonwood Creek and eight stations on storm drains.**

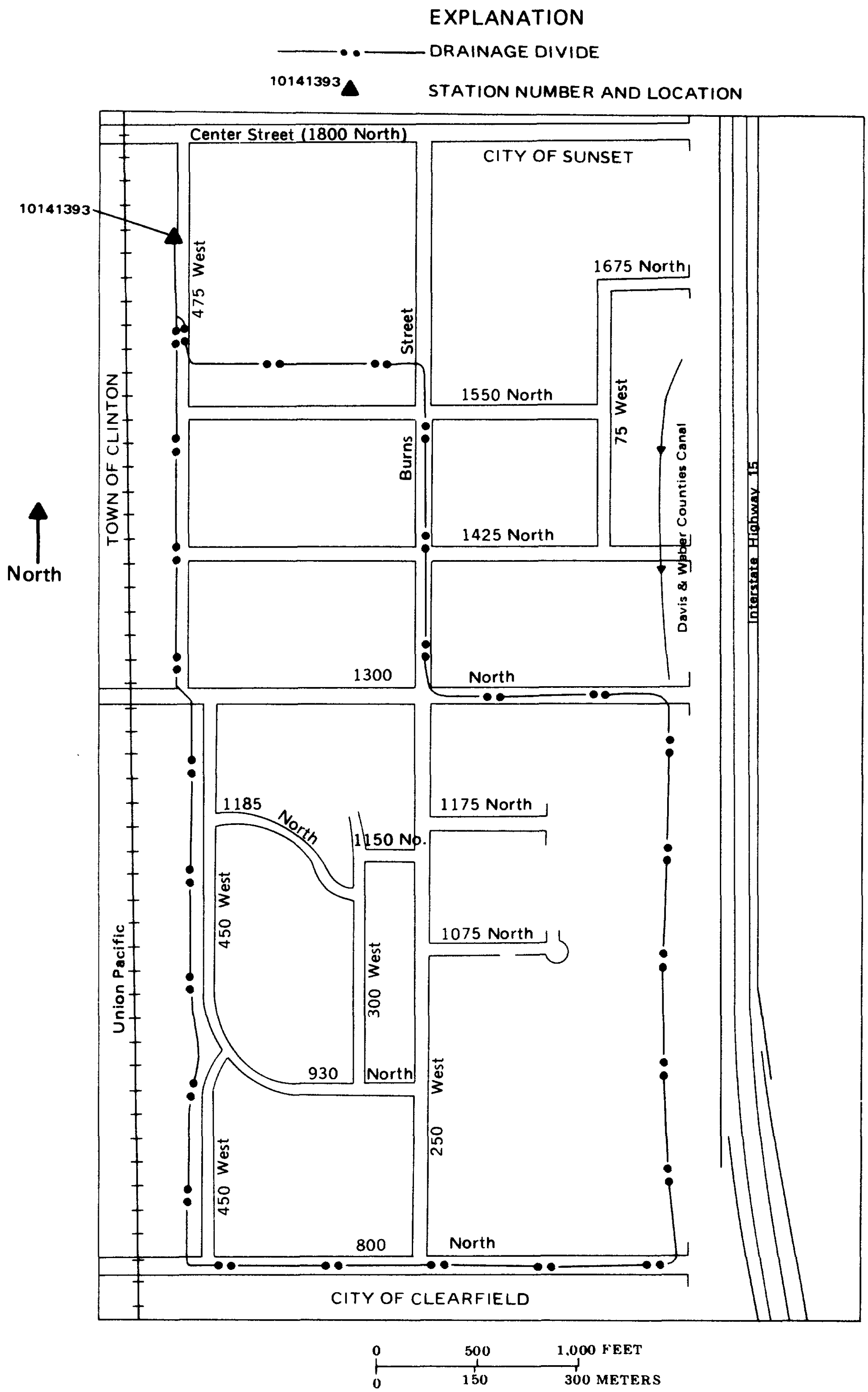


Figure 3.—Contributing drainage area and location of station 10141393.

EXPLANATION

DRAINAGE DIVIDE

10145125 STATION NUMBER AND LOCATION

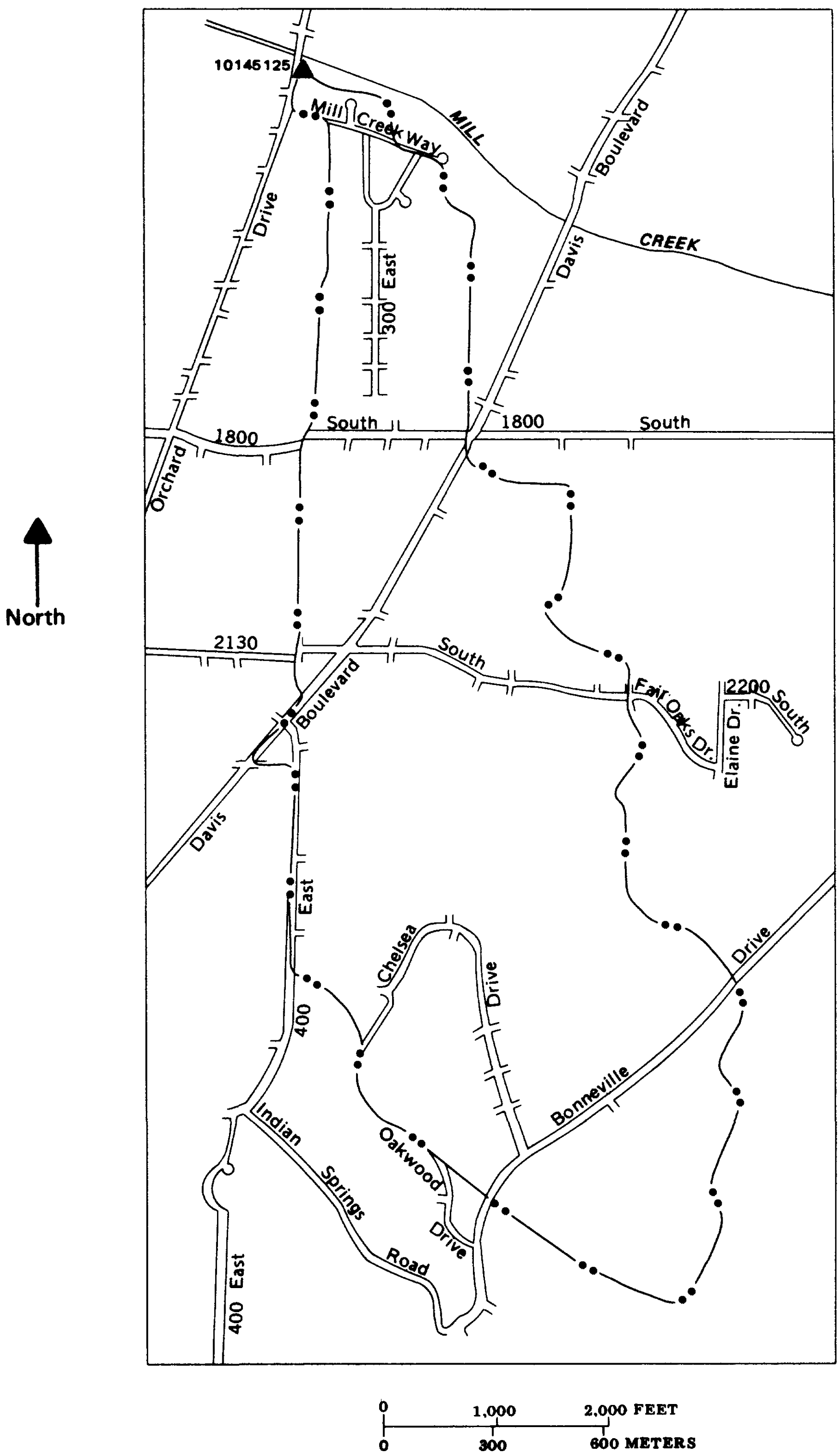


Figure 4.—Contributing drainage area and location of station 10145125.

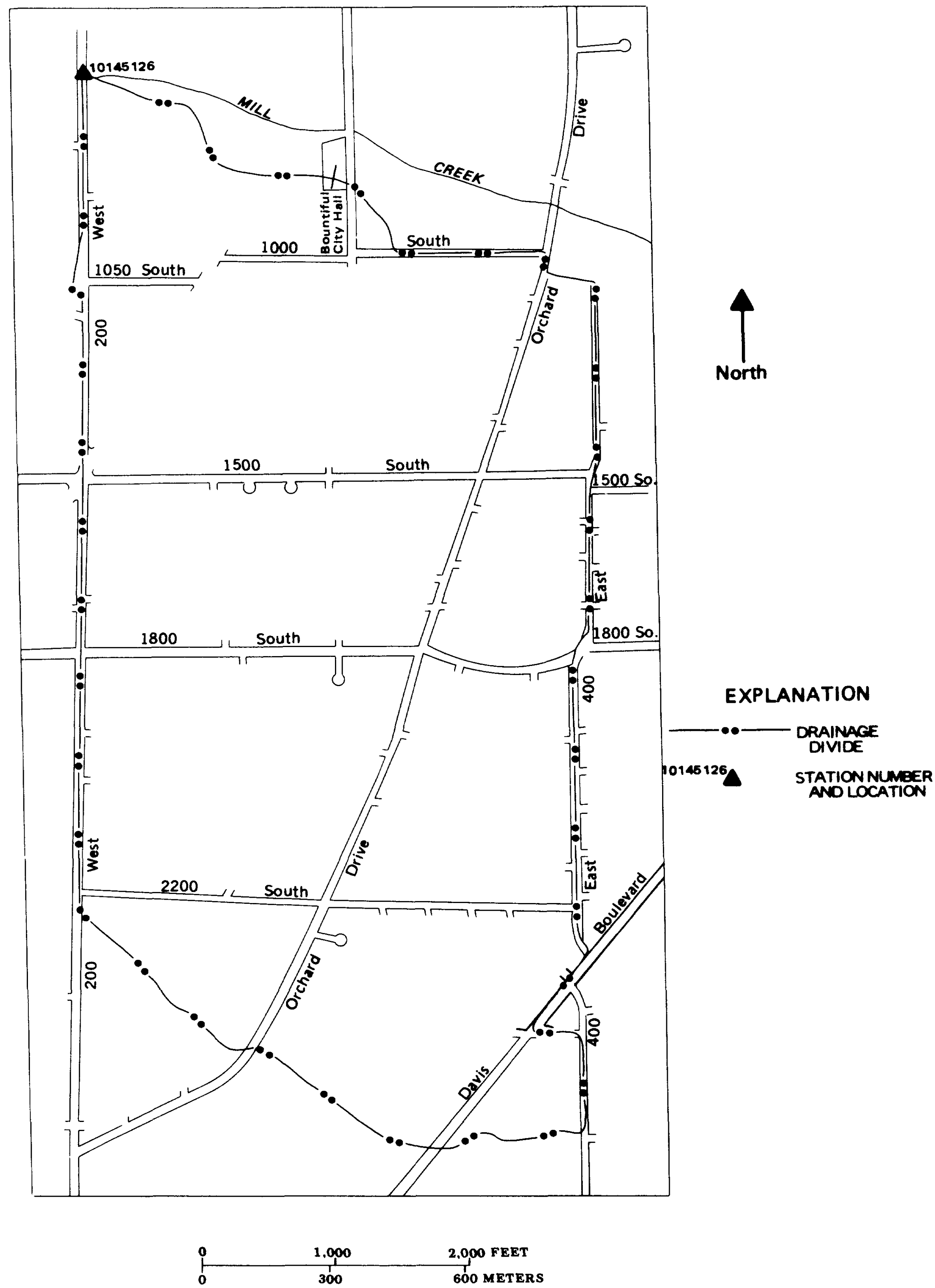


Figure 5.—Contributing drainage area and location of station 10145126.

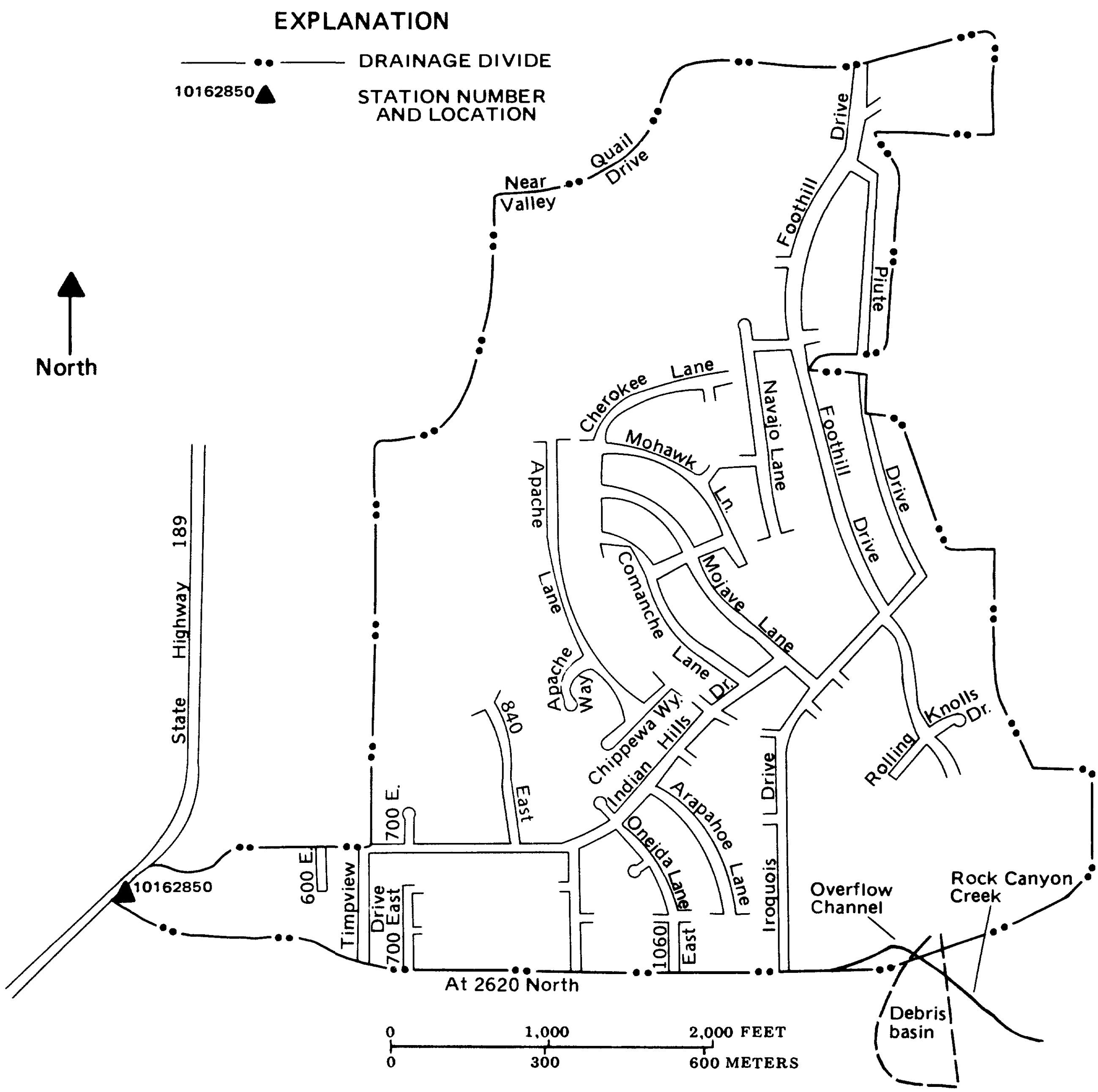


Figure 6.--Contributing drainage area and location of station 10162850.

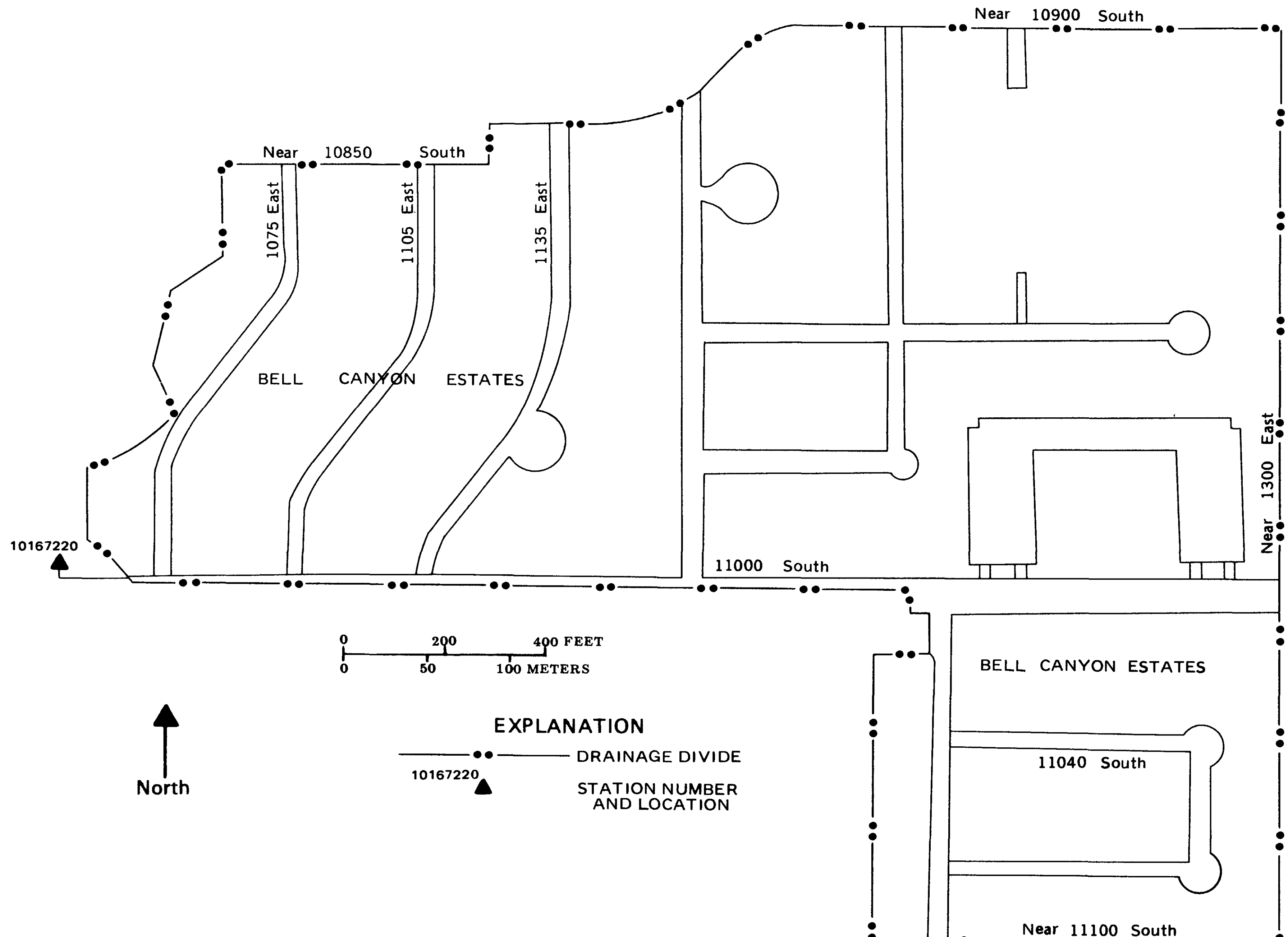


Figure 7.--Contributing drainage area and location of station 10167220.

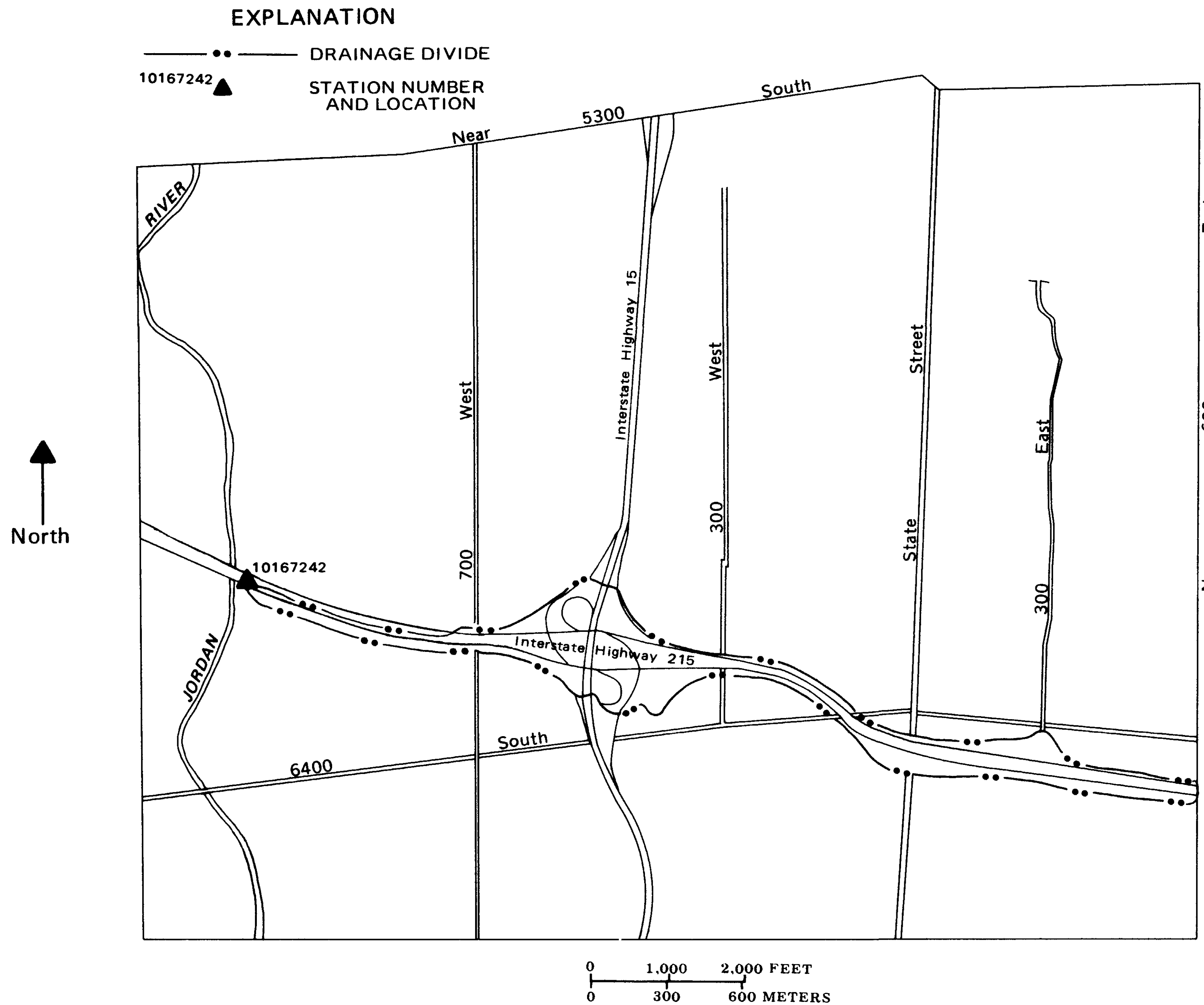


Figure 8.--Contributing drainage area and location of station 10167242.

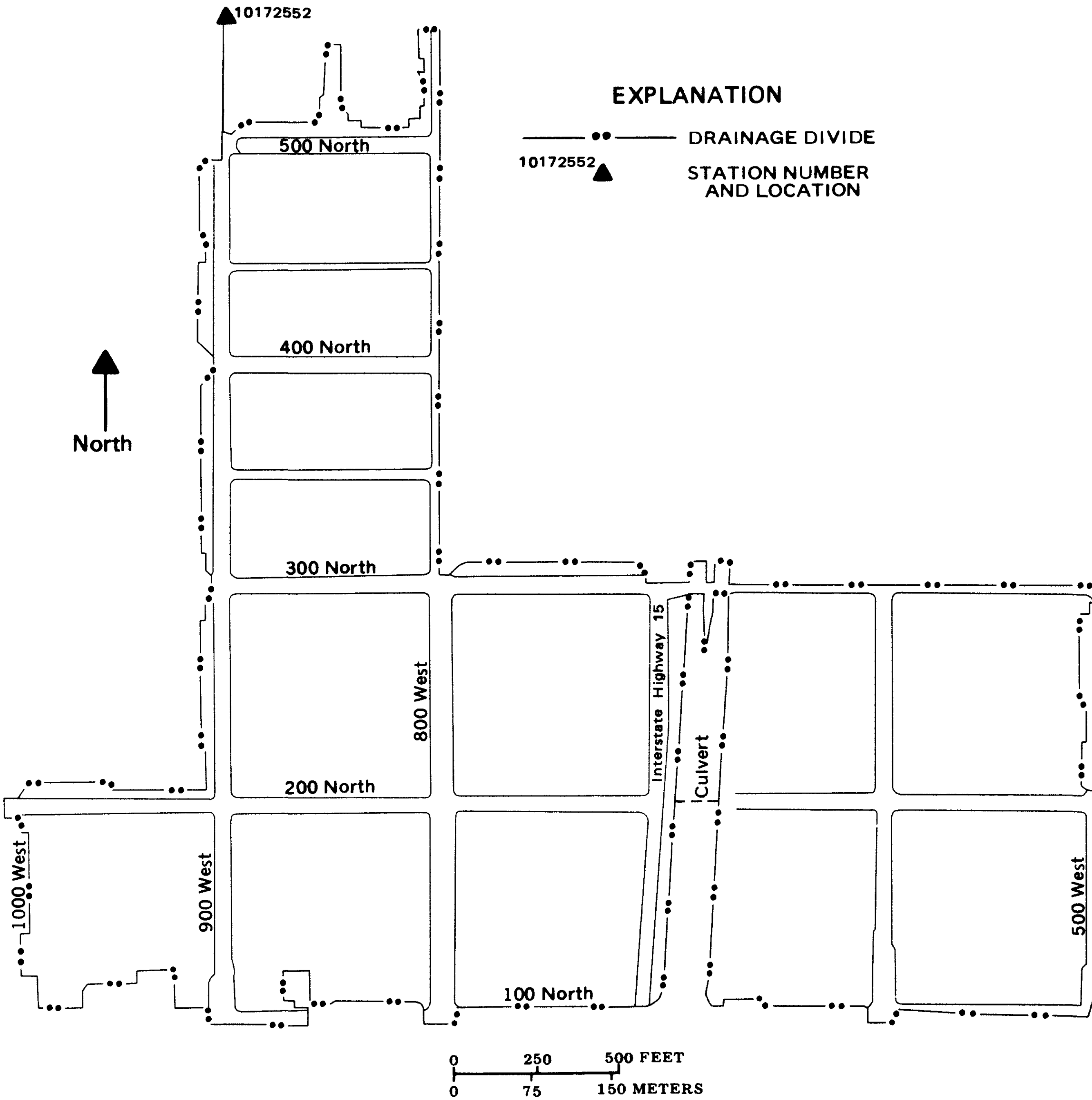


Figure 9.--Contributing drainage area and location of station 10172552.

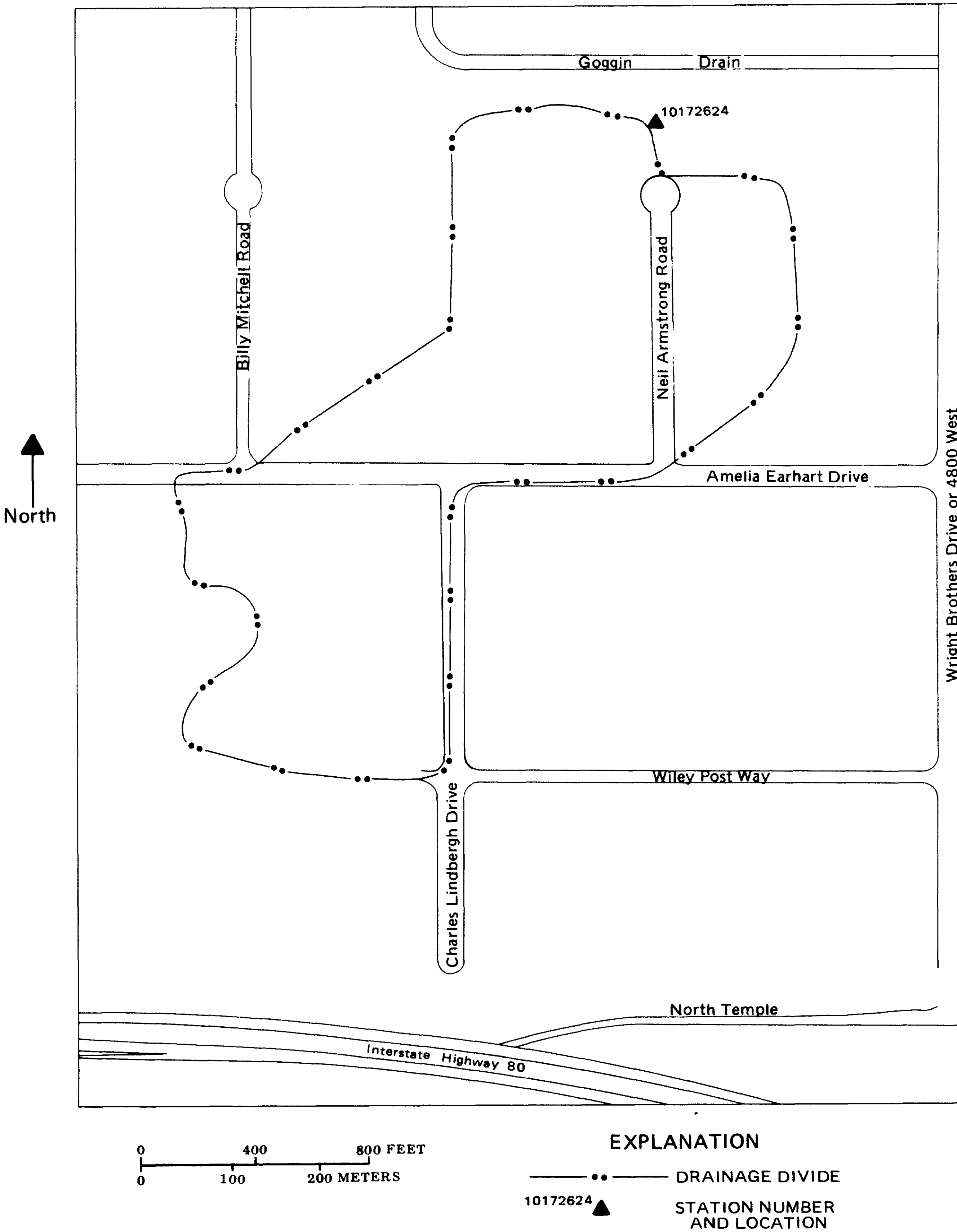


Figure 10.--Contributing drainage area and location of station 10172624.

*Table 1.--Summary of selected basin characteristics, selected DR3M-II model parameters, and statistical comparison of measured and model-simulated volumes and peaks*

| Station number | Drainage area (square miles) | Basin slope (percent) | Effective impervious area (percent) | Number of storms used for model calibration | Number of overland-flow segments | Number of pipe and channel segments | Average standard error of estimate (percent) | | R-squared (percent) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Volumes | Peaks | Volumes | Peaks |
| 10141393 | 0.28 | 3.5 | 30 | 27 | 3 | 3 | 39.0 | 45.5 | 87.6 | 81.1 |
| 10145125 | .80 | 15 | 22 | 19 | 6 | 7 | 29.0 | 36.0 | 91.4 | 86.6 |
| 10145126 | .87 | 5.0 | 25 | 24 | 4 | 5 | 39.5 | 50.0 | 87.0 | 80.3 |
| 10162850 | .66 | 9.5 | 23 | 18 | 7 | 5 | 37.5 | 37.0 | 91.2 | 86.9 |
| 10167220 | .093 | 8.6 | 27 | 10 | 3 | 3 | 69.5 | 53.0 | 70.7 | 65.9 |
| 10167242 | .20 | 7.9 | 38 | 29 | 3 | 4 | 31.0 | 41.0 | 90.7 | 71.4 |
| 10172552 | .23 | .6 | 31 | 20 | 2 | 3 | 30.5 | 39.5 | 94.8 | 89.3 |
| 10172624 | .085 | .3 | 57 | 20 | 3 | 6 | 23.5 | 30.5 | 88.4 | 77.8 |

## Definitions of Selected Basin Characteristics

Drainage area (DA).--Drainage area is the area, in square miles, of the drainage basin planimetered from city and county maps depicting topography, storm-drain networks, streets, and aerial photography. Scales range from 1 inch equals 200 feet to 1 inch equals 1,000 feet. Onsite determinations were made for boundaries when drainage-area divides were not readily identifiable from using the maps.

Basin slope (BS).--Basin slope is the average slope for the drainage basin, in percent. City and county aerial photographs having 2- to 5-foot contour intervals were used to determine this characteristic. The formula described by Wisler and Brater (1959) was used to determine the basin slope for each of the eight drainages gaged for this study. For the larger drainages, a grid was used to segment the entire drainage area into smaller subareas of equal size, and the basin slope was calculated as an average of the slopes of 20 or more randomly selected subareas.

Another simplified method for estimating the basin slope is to establish a grid over a map of the drainage area. The grid should have 20 or more intersections within the drainage area. The slope of a short segment of line normal to the contours can be determined at each grid intersection, and the basin slope can be estimated as an average of the individual values.

Effective impervious area (EIA).--Effective impervious area is that part of the drainage area, in percent, that is impervious to the infiltration of rain and drains directly by curb, gutter, or channel to a storm drain. It does not include the area of rooftops that discharge on lawns. It does include areas of paved roads and streets, paved parking lots and driveways, and some rooftops and sidewalks. Aerial photographs having scales ranging from 1 inch equals 200 feet to 1 inch equals 1,000 feet were used to determine this characteristic.

## Physical and Basin Characteristics of Eight Urban Drainages

Station 10141393, storm drain, 480 feet south of 1800 North 475 West Sunset.--Station 10141393 (fig. 3) is at lat 41°08'27", long 112°02'04", in NW¼NW¼SE¼ sec. 26, T. 5 N., R. 2 W., Davis County, Hydrologic Unit 16020102. The drainage area, which is outlined in figure 3, is 0.28 square mile. The area is bounded by about 475 West on the west, by about 800 North on the south, by a line near Interstate Highway 15 on the southeast, by about 250 West on the northeast, and by about 1550 North on the north. The area is mostly residential except for a park and some open fields in the southeast part. The basin slope is 3.5 percent, and the effective impervious area is 30 percent.

Station 10145125, storm drain to Mill Creek, east of Orchard Drive, Bountiful.—Station 10145125 (fig. 4) is at lat 40°52'49", long 111°52'19", in SW¼SW¼NW¼ sec. 29, T. 2 N., R. 1 E., Davis County, Hydrologic Unit 16020102, about 100 feet upstream of Mill Creek at Orchard Drive. The drainage area, which is outlined in figure 4, is 0.80 square mile. The area is bounded by about 400 East on the west, by a line near Oakwood Drive and extending just beyond Bonneville Drive on the south, by a line extending from Davis Boulevard near 1800 South to the southeast corner beyond Bonneville Drive on the east, and by a line near Mill Creek on the north. The area is mostly residential except for the southern part near Bonneville Drive. The basin slope is 15 percent, and the effective impervious area is 22 percent.

Station 10145126, storm drain to Mill Creek, 620 South 200 West, Bountiful.—Station 10145126 (fig. 5) is at lat 40°52'59", long 111°53'06", in SW¼NE¼NW¼ sec. 30 , T. 2 N., R. 1 E., Davis County, Hydrologic Unit 16020102, 10 feet upstream from Mill Creek at 200 West. The drainage area, which is outlined on figure 5, is 0.87 square mile. The area is bounded by about 200 West on the west, by a line across Orchard Drive beyond 2200 South on the south, by about 400 East on the east, and by a line just south of Mill Creek on the north. A large part of the area is residential, and the remainder is mostly large office buildings and parking lots. The basin slope is 5.0 percent, and the effective impervious area is 25 percent.

Station 10162850, Rock Creek overflow channel, east of State Highway 189, Provo.--Station 10162850 (fig. 6) is at lat 40°16'11", long 111°39'08", in SE¼SW¼NW¼ sec. 30, T. 6 S., R. 3 E., Utah County, Hydrologic Unit 16020203, just upstream of the confluence with a storm drain, 55 feet upstream of State Highway 189, about 2 miles north of Brigham Young University Campus, Provo, Utah. The drainage area, which is outlined in figure 6, is 0.66 square mile. The area includes the urban area downstream of the debris basin on Rock Canyon Creek. Flow from snowmelt in Rock Canyon Creek will fill the debris basin and contribute to the overflow channel. However, for this study, Rock Canyon Creek did not contribute to the overflow channel for any of the summer storms used to calibrate the model. The drainage area is bounded by about 2620 North on the south, by a line beyond Iroquois Drive on the southeast, by developments along the mountain front on the east and northeast, by a line south of Quail Valley Drive on the north, by a line near Timpview Drive on the west, and by a line near State Highway 189 on the southwest. Most of the area is residential except for a few open fields. The basin slope is 9.5 percent, and the effective impervious area is 23 percent.

Station 10167220, Bells Canyon conduit, 1000 East 11000 South, Sandy.—Station 10167220 (fig. 7) is at lat 40°33'07", long 111°51'41", in SW$\frac{1}{4}$SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 17, T. 3 S., R. 1 E., Salt Lake County, Hydrologic Unit 16020204, 100 feet east of the 1000 East and 11000 South intersection in Sandy. The drainage area, which is outlined in figure 7, is 0.093 square mile. The area is bounded by a line near 1075 East and 11000 South on the southwest, by a line near 11100 South and 1300 East on the southeast, by a line near 1300 East and 10900 South on the northeast, and by a line near 10850 South and 1075 East on the northwest. The area is mostly residential except for some open fields in the northwest part. The basin slope is 8.6 percent, and the effective impervious area is 27 percent.

Station 10167242, Interstate Highway 215 median storm drain to right bank of Jordan River, near Salt Lake City.--Station 10167242 (fig. 8) is at lat 40°38'19", long 111°55'13", in NE$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 23, T. 2 S., R. 1 W., Salt Lake County, Hydrologic Unit 16020204, in the median strip of Interstate Highway 215 about 250 feet upstream from where the drain discharges to the Jordan River. The drainage area, which is outlined in figure 8, is 0.20 square mile. The area includes the eastbound lanes of Interstate Highway 215 and the median strip from near the gage east for about 3,000 feet, both the eastbound and westbound lanes and the median east for another 400 feet to near 700 West, most of the Interstate Highway 215 interchange with Interstate Highway 15 and State Street from about 700 West to 300 East, and both the eastbound and westbound lanes and the median from 300 East to about 600 East. The segment of Interstate Highway 215 completed since 1986 to 1300 East was not used for this study. The area is mostly highway right-of-way, and consists of pavement, grass, and bare soil in the median and on some embankments. The basin slope is 7.9 percent, and the effective impervious area is 38 percent.

Station 10172552, Ninth West conduit, 536 North 900 West, Salt Lake City.--Station 10172552 (fig. 9) is at lat 40°46'53", long 111°54'58", in SE$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 35, T. 1 N., R. 1 W., Salt Lake County, Hydrologic Unit 16020204, on the east side of 900 West, 300 feet north of the 500 North and 900 West intersection in Salt Lake City. The drainage area, which is outlined in figure 9, is 0.23 square mile. The area is bounded by about 500 North and 900 West on the northwest; by about 200 North, 1000 West, and 100 North on the southwest; by 100 North, east across Interstate Highway 15 to 500 West on the south; by 500 West between 100 North and 300 North on the southeast; and by 800 West and 500 North on the northeast. Most of Interstate Highway 15 that crosses the area does not contribute. More than one-half of the area is residential, about one-quarter is commercial, and the remainder is mostly open fields including one small park. The basin slope is 0.6 percent, and the effective impervious area is 31 percent.

Station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City.—Station 10172624 (fig. 10) is at lat 40°46'46", long 112°00'29", in NW$\frac{1}{4}$SE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 36, T. 1 N., R. 2 W., Salt Lake County, Hydrologic Unit 16020204, on the right bank at the north end of Neil Armstrong Road (4955 West) in the International Center, 2 miles west of Salt Lake City International Airport. The drainage area, which is outlined in figure 10, is 0.085 square mile. The general area is bounded by a line between Neil Armstrong Road and Goggin Drain on the north near the station, by a line extending west between Billy Mitchell Road and Neil Armstrong Road and then south-southwest to near the intersection of Billy Mitchell Road and Amelia Earhart Drive, by a line extending from Amelia Earhart Drive south to near Wiley Post Way, by near Wiley Post Way east to Charles Lindberg Drive, by Charles Lindberg Drive north to Amelia Earhart Drive, by Amelia Earhart Drive east to Neil Armstrong Road, and by a line extending beyond Neil Armstrong Road northeast about one-half block and then north and west to the station. The area is mainly commercial and has large parking lots and warehouses. However, there are considerable lawns and some unlined drains. The basin slope is 0.3 percent, and the effective impervious area is 57 percent.

## Long-Term Rainfall and Evaporation Data Used to Simulate Peak Flow

Long-term daily rainfall and evaporation data are required for use with the calibrated model for each drainage basin to simulate peak flow for a longer period of record for frequency analysis. For this study, daily rainfall data were obtained for 1948-83 for the National Weather Service Forecast Center station at the airport. Daily pan-evaporation data also were entered for the National Weather Service stations at Utah Lake at Lehi and Brigham Young University at Provo.

Long-term rainfall data for durations less than a day also are needed for use with the calibrated model for each drainage basin. For this study, copies of the original precipitation charts for major storms at the Salt Lake City International Airport station were obtained from the National Climatic Data Center in Asheville, N.C., for 1948-83. First, the major storms, 1 to 4 per year, were selected from a list provided by Robert W. Lichty (U.S. Geological Survey, written commun., 1985). Second, the major-storm dates and precipitation totals that Lichty provided were compared with the dates and values of hourly precipitation, published monthly since 1951. All storms having 0.1 inch of rain or more per hour were examined to make sure all major storms were considered, and a few additional storms were included. Storm-rainfall data on the hourly precipitation charts were tabulated at 5-minute intervals, and a total of 63 storms were used in the analysis.

## Long-Term Data for Little Cottonwood Creek Used for Comparing Peak Flow at Canyon Mouth with That at a Downstream Station Including Urban Drainage

Peak-flow data for stations 10167499, Little Cottonwood Creek (channel only) near Salt Lake City, and 10167700, Little Cottonwood Creek at 2050 East, near Salt Lake City were selected to compare the magnitude of peak flow at the canyon mouth, which results primarily from snowmelt, with that at a downstream station, which includes runoff from intervening urban drainage. This comparison is discussed in the "Comparison of Peak Flow for Little Cottonwood Creek at Canyon Mouth with That at a Downstream Station Including Urban Drainage" section.

## DATA ANALYSIS

### Description of Rainfall-Runoff Model

Storm-flow hydrographs were simulated for all urban drainages using the Distributed Routing Rainfall-Runoff model called DR3M-II. DR3M-II is a deterministic, distributed-parameter model that combines rainfall-excess components developed by Dawdy and others (1972) with kinematic-wave routing presented by LeClerc and Schaake (1973). The DR3M-II model is described in detail by Alley and Smith (1982). Daily and unit rainfall and daily pan evaporation are used in the simulation of storm-flow hydrographs.

Rainfall-excess components in DR3M-II include soil-moisture accounting, impervious and pervious area rainfall excess, and parameter optimization. Infiltration and soil-moisture accounting parameters used by DR3M-II to account for the effect of antecedent conditions on infiltration are listed in table 2.

*Table 2.--Parameters for infiltration and soil-moisture accounting for the DR3M-II model*
(Alley and Smith, 1982, p. 18)

Infiltration parameters

KSAT—Effective saturated value of hydraulic conductivity, in inches per hour.
PSP—Suction at wetting front for soil moisture at field capacity, in inches.
RGF—Ratio of suction at wetting front for soil moisture at wilting point to that at field capacity.

Soil-moisture-accounting parameters

BMSN—Available soil water at field capacity, in inches.
EVC—Pan coefficient for converting measured pan evaporation to potential evapotranspiration.
RR—Proportion of daily rainfall that infiltrates soil for period of simulation, excluding unit days.

Rainfall excess is routed over pervious areas and two types of impervious areas: (1) Effective impervious areas where flow is routed directly into the channel drainage system, and (2) noneffective impervious areas where flow is routed onto the surrounding pervious areas. A user-specified rainfall, usually ranging from about 0.02 to 0.05 inch, is retained on impervious areas. Rain falling on noneffective impervious areas is assumed to instantaneously run off uniformly onto the surrounding pervious area.

The optimization procedure for calibrating the soil-moisture and infiltration parameters is based on a trial-and-error procedure that changes a parameter value and recomputes an objective function using the revised parameter value. If results at the end of an iteration show a decrease in the value of the objective function, an improvement in model calibration is assumed and the new parameter value is accepted; if not, the previous value is retained.

The routing components of the DR3M-II model are determined by the kinematic-wave theory for routing flows over a given drainage basin. A basin is approximated by the DR3M-II model by a set of segments that jointly represent the drainage features of the basin. Two types of segments are used in this report: (1) Overland-flow segments and (2) channel segments. Overland-flow segments receive uniformly distributed lateral inflow from rainfall excess and represent a rectangular plane of a given size, slope, roughness, and percent imperviousness. Channel segments are used to represent natural or manmade conveyances, such as gutters or storm-sewer pipes.

Several assumptions are necessary for the kinematic-wave equations for overland-flow and channel routing, according to Alley and Smith (1982). The major assumptions are listed below:

1. Disturbances are allowed to propagate only in the downstream direction. The model, therefore, does not account for backwater effects or flow reversal.

2. The capacity of circular-pipe segments is limited to nonpressurized flow.

3. Rainfall excess is uniformly distributed over an overland-flow segment.

4. Pervious and impervious parts of a segment are uniformly distributed over the segment.

5. The complex uneven topography of the natural catchment can be approximated by rectangular planes.

6. Rainfall excess does not infiltrate as it moves overland. Once rainfall excess is computed, it must end up in a channel.

7. When rainfall ceases, infiltration ceases.

8. Lateral inflows to channels are uniformly distributed. In an urban environment, however, lateral inflows may enter through a gutter rather than uniformly.

9. Changes in flow from laminar to turbulent or vice versa will not occur.

10. Rainfall on noneffective impervious areas is instantaneously and uniformly distributed over the pervious area of the segment.

## Calibration and Verification of Models

Each basin was divided into overland-flow and channel segments that represented a simplified description of the basin topography and drainage system. Basin characteristics, such as drainage area, basin slope, and effective impervious area, and a roughness coefficient, similiar to

Manning's n (Alley and Smith, 1982, p. 25), were entered into the model. Rainfall and flow data, processed in 5-minute intervals, were entered into the model as well as daily rainfall and daily evaporation. Effective impervious area and soil-moisture-accounting parameters were then optimized by the model. Simulated storm-flow hydrographs for each basin were calibrated and verified by comparing simulated runoff volume and peak flow with measured runoff volume and peak flow.

### Detailed Description of Model Calibration for Station 10172624

A detailed description of model calibration for station 10172624 is presented in this section. Model calibration procedures for the other stations were similiar to that presented here.

Station 10172624, in an area known as the International Center, measures flow from an industrialized area. Basin characteristics, such as drainage area, basin slope, effective impervious area, and a roughness coefficient, were determined for the area using aerial photographs, maps, engineering drawings, and on-site inspections. Once basin characteristics were determined and entered into the model, the optimization procedure for the effective impervious area and the infiltration and soil-moisture-accounting parameters began.

All optimization was completed using a single overland-flow segment and a single channel segment that represented the entire basin as recommended by Alley and Smith (1982, p. 63). Only one parameter was optimized at a time. EAC was optimized first using only small storms that contribute runoff largely from the effective impervious areas. EAC is a factor by which the initial value of effective impervious area is multiplied. The final optimized value of EAC was 0.76 for this station. The initial value of the effective impervious area was multiplied by the EAC factor, resulting in a new effective impervious area value. Any adjustment to the effective impervious areas is offset in the model by an adjustment to the noneffective impervious areas in order to maintain a constant total drainage area. The model uses a factor called a RAT value to make this adjustment. The RAT value is the sum of the noneffective impervious and pervious areas divided by the pervious areas. The RAT value for this basin was 1.64 after EAC was optimized.

Infiltration and soil-moisture-accounting parameters were optimized one at a time, holding the remaining parameters constant. Values for parameters held constant were either best estimates or previously optimized values. The optimized value for KSAT was 0.49 and that for PSP was 4.45. Values suggested by Alley and Smith (1982) were used for the remaining parameters. These values are 10 for RGF, 5 for BMSN, 0.70 for EVC, and 0.80 for RR. These parameters were not optimized.

Routing is the final step of calibration. Overland-flow and channel segments were determined for the basin. Each segment represented a simplified description of the basin topography and drainage system. Overland flow was divided into three segments, and the drainage system was divided into six segments, two pipe segments and four channel segments (figs. 11 and 12). Physical characteristics for each segment were determined and entered into the model. Twenty storms, collected over a 2-year period, were used for model calibration and verification. The storms were divided into two representative data sets of 10 storms each. The first data set was used in model calibration, and the second was used in model verification. The model was calibrated using the first data set by comparing measured peaks and volumes with simulated peaks and volumes. The model was adjusted until it produced the best approximation of the measured peaks and volumes. The second data set was entered to the model to verify model calibration. Generally accepted error criteria for simulated runoff volumes and peaks are within 50 percent if the simulated volume or peak is less than that measured and within 100 percent if the simulated volume or peak is greater than that measured (Doyle and Miller, 1980, p. 18; Shade, 1984, p. 12). For the 20 storms used in model calibration and verification, the only peak exceeding this criteria was for a storm on September 21, 1984 (table 3).

### Model Calibration for the Other Stations

Models for the other stations were calibrated using the same techniques described for station 10172624. Several factors affected how well different basins could be calibrated. Summer rainstorms in the Wasatch Front area typically are small in areal extent and intense. Rain from a storm may be recorded at the rain gage, but not fall on major parts of a basin or vice versa. This was particularly noticeable for basins on the bench areas near the Wasatch Mountains. Also, snowstorms or hailstorms interfered with the rain-gage operation. During intense rainstorms, water may flow into or out of a drainage segment by overflowing gutters or crossing the crown in a street, ordinarily the boundaries of drainage segments. This was particularly noticeable in basins that had steep overland-flow segments. Some basins, such as the section of Interstate Highway 215 (station 10167242), had complex drainage systems that were greatly simplified for inclusion in the model.

A summary of selected basin characteristics and model parameter results is presented in table 1. The standard error and R-squared values for volumes and peaks were derived after the data had been log transformed.

## Estimating Peak Flow for 1948-83

Long-term rainfall data for 1948-83, including all daily and 5-minute interval values for major storms (1 to 4 per year), and daily evaporation data, were used with each calibrated model to simulate estimates of long-term peak flows for each of the eight urban drainages. All data used to calibrate the models and the data used with the calibrated models to simulate peak flows for 1948-83 are discussed in the "Data Used for Analysis of Peak-Flow Characteristics" section.

Peak flows simulated for major storms during 1948-83 for station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City, are listed in table 4. Peak flows also were simulated for each of the other seven urban drainages. Peak-flow data for all eight drainages were entered into the Peak-Flow File of the U.S. Geological Survey's National Water-Data Storage and Retrieval System (WATSTORE) for use in frequency analysis. The WATSTORE system consists of several computer files in which data are grouped and stored by common characteristics and data-collection frequencies. Instruction on the use of the Peak-Flow File appears in U.S. Geological Survey, 1979.

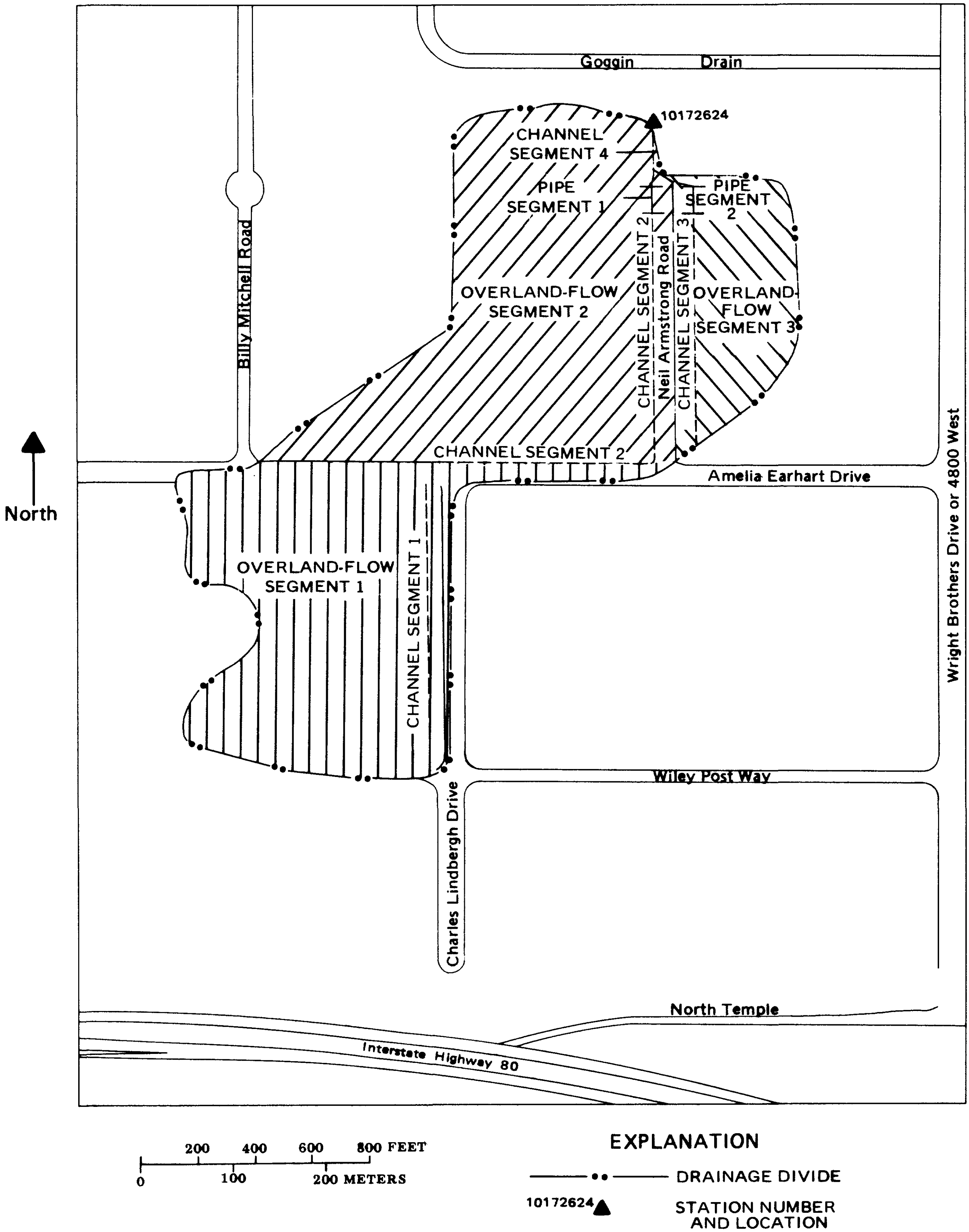


Figure 11.--Generalized outline of drainage features, overland-flow segments, and pipe and channel segments used to develop model for station 10172624.

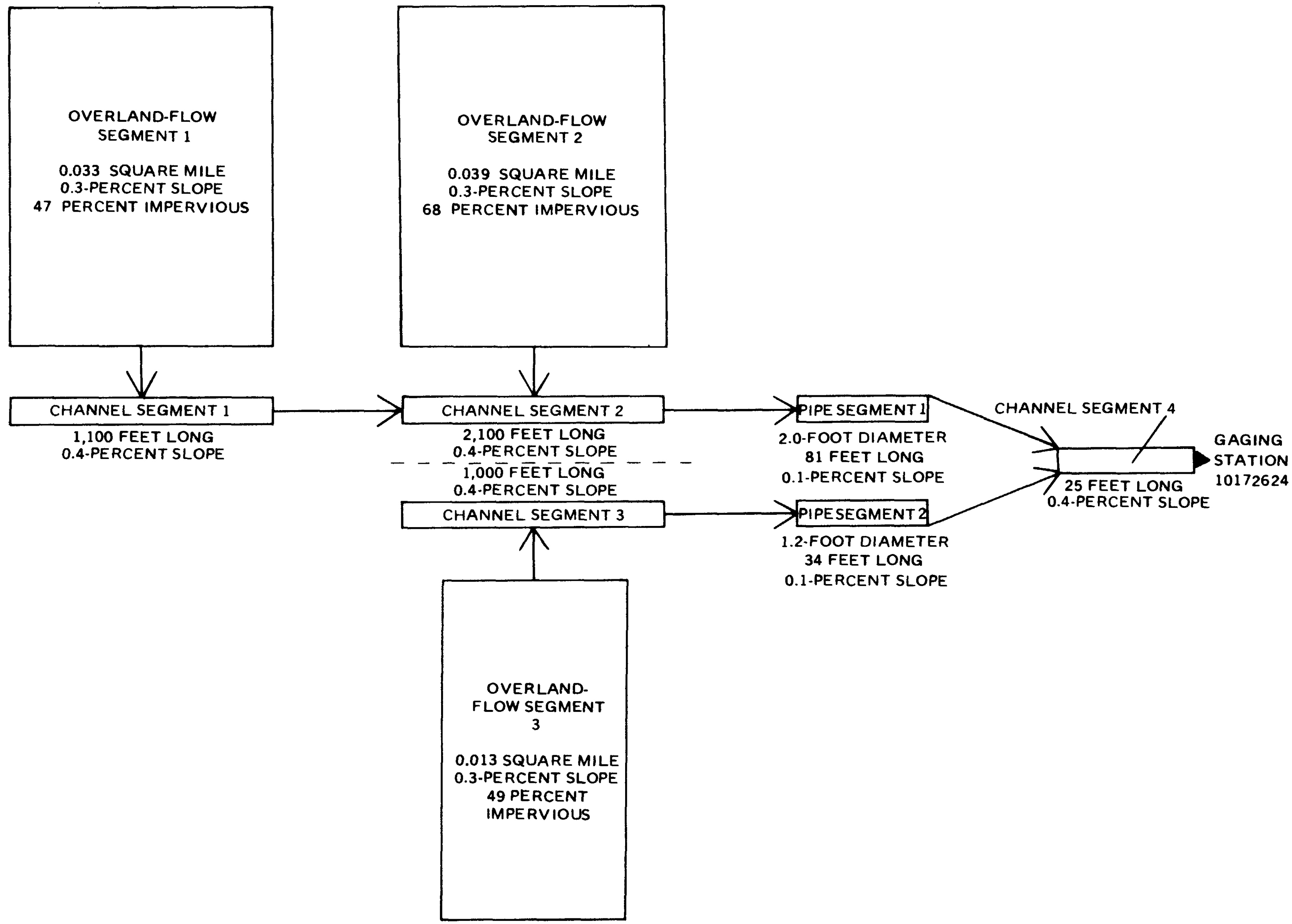


Figure 12.—Schematic of drainage features, overland-flow segments, and pipe and channel segments used to develop model for station 10172624.

*Table 3.—Measured and simulated volumes and peaks at station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City*

| Storm date | Volumes | | | Peaks | | |
|---|---|---|---|---|---|---|
| | Measured (inches) | Simulated (inches) | Percent error | Measured (inches) | Simulated (inches) | Percent error |
| 06/07/84 | 0.204 | 0.226 | 10.8 | 6.37 | 6.29 | -1.3 |
| 06/09/84 | .111 | .109 | -1.8 | 2.77 | 2.70 | -2.5 |
| 07/28/84 | .229 | .208 | -9.2 | 6.45 | 6.6 | 2.3 |
| 08/16/84 | .393 | .334 | -15.0 | 10.97 | 9.76 | -11.0 |
| 09/06/84 | .106 | .135 | 27.4 | 1.62 | 2.07 | 27.8 |
| 09/11/84 | .121 | .114 | -5.8 | 3.02 | 2.52 | -16.5 |
| 09/20/84 | .058 | .074 | 27.6 | 1.74 | 2.02 | 16.1 |
| 09/21/84 | .073 | .044 | -39.7 | 2.32 | 1.03 | -55.6 |
| 09/23/84 | .198 | .185 | -6.6 | 3.85 | 4.10 | 6.5 |
| 10/01/84 | .104 | .071 | -31.7 | 2.52 | 1.55 | -38.5 |
| 10/02/84 | .081 | .112 | 38.3 | 3.15 | 4.71 | 49.5 |
| 10/11/84 | .521 | .652 | 25.1 | 6.95 | 9.75 | 40.3 |
| 10/26/84 | .185 | .183 | -1.1 | 2.68 | 3.08 | 14.9 |
| 07/17/85 | .093 | .127 | 36.5 | 4.04 | 5.95 | 47.3 |
| 07/22/85 | .277 | .268 | -3.2 | 9.12 | 9.76 | 7.0 |
| 09/11/85 | .332 | .362 | 9.0 | 4.84 | 5.59 | 15.5 |
| 09/18/85 | .460 | .462 | .4 | 4.84 | 4.13 | -14.7 |
| 10/06/85 | .281 | .310 | 10.3 | 4.89 | 5.08 | 3.9 |
| 10/21/85 | .231 | .317 | 37.2 | 3.24 | 4.24 | 30.8 |
| 11/05/85 | .132 | .167 | 26.5 | 3.14 | 3.97 | 26.4 |

*Table 4.--Peak flows simulated for 63 storms during 1948-83 for station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City*

| Date | Simulated peak flow (cubic feet per second) |
|---|---|
| 06/21/48 | 13.1 |
| 09/18/48 | 2.74 |
| 11/16/48 | 4.79 |
| 03/23/49 | 4.54 |
| 08/23/49 | 2.22 |
| 09/09/49 | 7.63 |
| 02/06/50 | 7.85 |
| 07/09/50 | 13.7 |
| 09/03/51 | .94 |
| 07/30/52 | 28.8 |
| 07/26/53 | 2.78 |
| 08/01/53 | 8.56 |
| 08/08/54 | 49.9 |
| 07/24/55 | 14.0 |
| 06/15/56 | 12.0 |
| 08/29/57 | 18.8 |
| 04/22/58 | 17.6 |
| 08/19/59 | 8.21 |
| 08/22/60 | 20.0 |
| 08/15/61 | 13.5 |
| 10/27/61 | 3.39 |
| 07/12/62 | 72.2 |
| 03/15/63 | 8.58 |
| 09/23/64 | 9.28 |
| 04/23/65 | 9.51 |
| 07/21/65 | 11.5 |
| 09/14/66 | 7.46 |
| 07/16/67 | 23.9 |
| 08/08/68 | 25.8 |
| 08/13/68 | 12.1 |
| 07/29/69 | 24.6 |
| 09/04/70 | 8.72 |
| 08/29/71 | 22.4 |
| 09/30/71 | 7.73 |
| 09/28/72 | 6.03 |

*Table 4.--Peak flows simulated for 63 storms during 1948-83 for station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City--Continued*

| Date | Simulated peak flow (cubic feet per second) |
|---|---|
| 09/01/73 | 3.05 |
| 09/07/73 | 11.3 |
| 04/09/74 | 7.55 |
| 08/06/74 | 8.12 |
| 03/22/75 | 9.00 |
| 04/25/75 | 5.43 |
| 10/07/75 | 5.93 |
| 04/25/76 | 9.61 |
| 07/17/76 | 15.9 |
| 07/30/76 | 19.2 |
| 08/05/77 | 15.3 |
| 08/26/77 | 3.92 |
| 09/14/77 | 21.6 |
| 03/31/78 | 5.30 |
| 09/17/78 | 9.04 |
| 07/22/79 | 3.70 |
| 10/19/79 | 3.14 |
| 01/14/80 | 11.6 |
| 05/14/80 | 4.49 |
| 07/01/80 | 16.6 |
| 06/02/81 | 2.97 |
| 10/07/81 | 6.32 |
| 10/10/81 | 2.70 |
| 10/28/81 | 5.57 |
| 07/28/82 | 41.3 |
| 09/26/82 | 11.3 |
| 05/11/83 | 6.60 |
| 08/17/83 | 5.75 |

## Peak-Flow Frequency Relations for Eight Gaged Drainages

The 63 peak flows generated from the calibrated models, using long-term rainfall records for 1948-83, were stored in the Peak-Flow File of WATSTORE. However, only the 36 annual peak flows were considered in developing frequency relations for each of the eight urban drainages. A log-Pearson Type-III frequency distribution was fitted to each series of simulated peak flows in accordance with U.S. Water Resources Council (1981) recommendations. Graphical fits were compared to mathematical fits (log-Pearson Type-III) and were used for two of the eight drainages. The weighted skew option was chosen using the generalized skew coefficient map in U.S. Water Resources Council (1981). The generalized skew on this map was developed for data from rural drainages and may not be representative of peak flows for some urban drainages. However, more data for urban drainages along the Wasatch Front are needed to define representative skew coefficients for peak flow from rainfall.

The peak-flow frequency relation shown in figure 13 is an example for station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City. Only 35 points are plotted in figure 13 because one low outlier was not used. Peak-flow frequency relations for the eight urban drainages are summarized in table 5 for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. As shown in table 5, the 100-year peak flow ranged from 68 cubic feet per second for station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City, to 222 cubic feet per second for station 10145125, storm drain to Mill Creek, east of Orchard Drive, Bountiful.

## Developing Relations for Estimating Peak-Flow Frequency for Ungaged Urban Drainages

Multiple-regression techniques were used to develop relations between the 2-, 5-, 10-, 25-, 50-, and 100-year peak-flows (table 5) and the basin characteristics of drainage area, basin slope, and effective impervious area. This type of multiple-regression analysis provided a mathematical equation of the relation between a single dependent variable (peak-flow for indicated recurrence interval) and one or more independent variables (basin characteristics). This analysis also provides a measure of the accuracy of the relation (the standard error of estimate). The resulting equations (table 6) have the following form:

$$Q_T = a(DA)^{b1}(BS)^{b2}(EIA)^{b3}$$

where $Q_T$ = peak-flow, in cubic feet per second, for indicated recurrence interval T, in years;
DA = drainage area, in square miles;
BS = basin slope, in percent;
EIA = effective impervious area, in percent.

$Q_T$ is the dependent variable, and DA, BS, and EIA are the independent variables (see "Physical and Basin Characteristics of Eight Urban Drainages" section). The constant, a, and coefficients, b1-b3, are derived from the regression analysis.

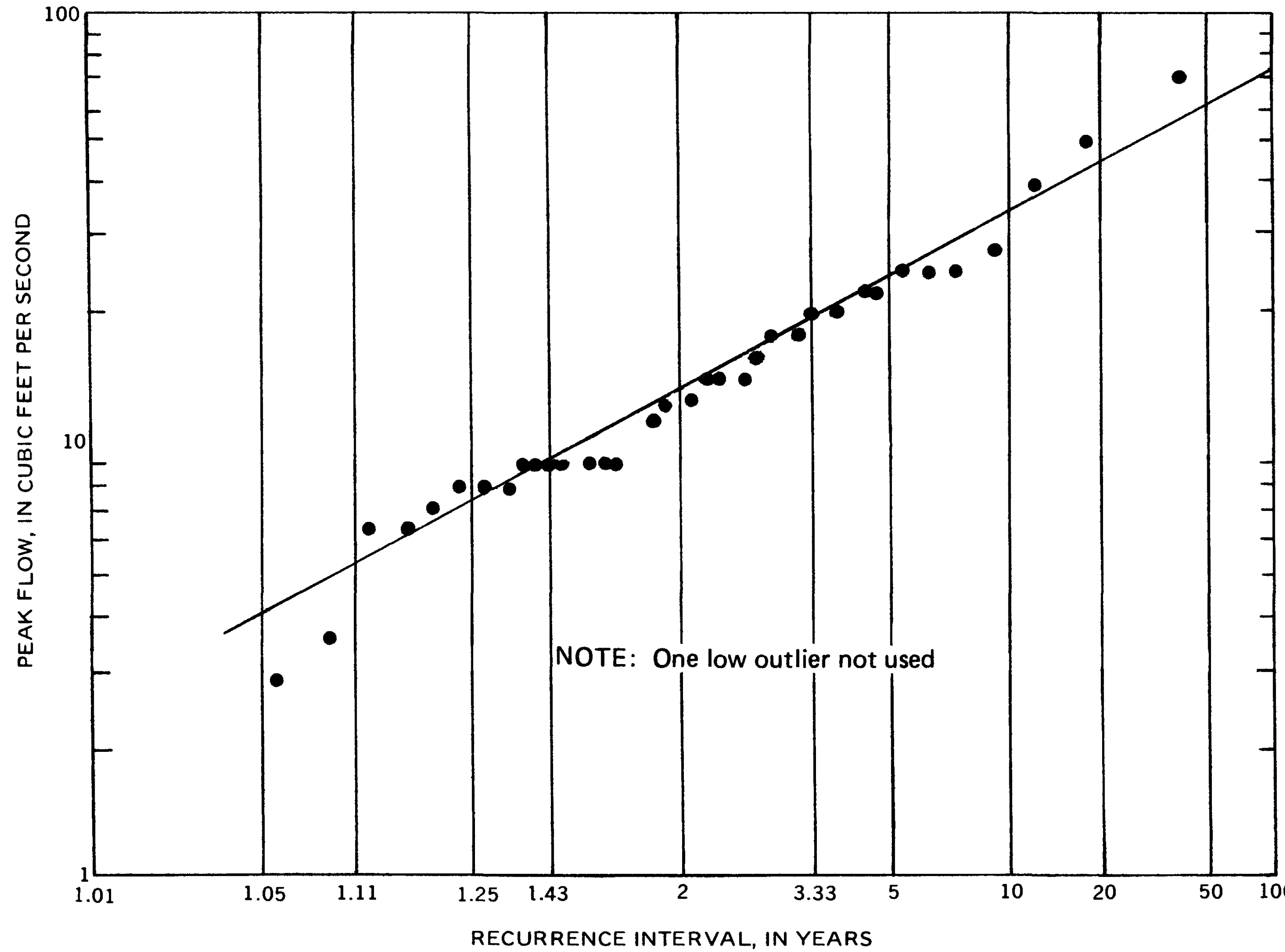


Figure 13.--Magnitude and frequency of simulated annual peak flows at station 10172624, storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City.

*Table 5.--Peak-flow frequency relations from simulated annual peak flows for eight urban drainages using record for 1948-83*

| Station number | Station name | Peak flow (cubic feet per second) for indicated recurrence interval (years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 25 | 50 | 100 |
| 10141393 | Storm drain, 480 feet south of 1800 North 475 West, Sunset | 28.3 | 61.0 | 88.7 | 129 | 163 | 200 |
| 10145125 | Storm drain to Mill Creek, east of Orchard Drive, Bountiful | 38.6 | 71.3 | 99.1 | 142 | 179 | 222 |
| 10145126 | Storm drain to Mill Creek, 620 South 200 West, Bountiful | 26.8 | 49.4 | 68.3 | 96.6 | 121 | 149 |
| 10162850 | Rock Creek overflow channel, east of State Highway 189, Provo | 21.1 | 39.1 | 55.0 | 80.7 | 104 | 132 |
| 10167220 | Bells Canyon conduit, 1000 East 11000 South, Sandy | 20.0 | 33.0 | 48.0 | 70.0 | 83.0 | 100 |
| 10167242 | Interstate Highway 215 median storm drain to right bank of Jordan River, near Salt Lake City | 33.0 | 58.7 | 78.7 | 107 | 130 | 155 |
| 10172552 | Ninth West conduit, 536 North 900 West, Salt Lake City | 7.1 | 15.0 | 22.0 | 37.0 | 50.0 | 70.0 |
| 10172624 | Storm drain, 250 feet above Goggin Drain, near Neil Armstrong Road, International Center, Salt Lake City | 13.0 | 23.4 | 32.0 | 44.8 | 55.8 | 68.0 |

*Table 6.—Regression equations for peak flows of selected recurrence intervals*

[Q, peak flow, in cubic feet per second; DA, drainage area, in square miles; BS, basin slope, in percent; EIA, effective impervious area, in percent]

| Recurrence interval (years) | Equation | Average standard error of estimate (percent) |
|---|---|---|
| 2 | $Q = 0.068\ DA^{0.282} BS^{0.488} EIA^{1.60}$ | 27 |
| 5 | $Q = 0.219\ DA^{0.319} BS^{0.432} EIA^{1.48}$ | 31 |
| 10 | $Q = 0.575\ DA^{0.285} BS^{0.410} EIA^{1.29}$ | 32 |
| 25 | $Q = 66.1\ DA^{0.093} BS^{0.243}$ | 33 |
| 50 | $Q = 89.5\ DA^{0.128} BS^{0.219}$ | 32 |
| 100 | $Q = 120\ DA^{0.158} BS^{0.194}$ | 29 |

The multiple-regression procedure (Ryan and others, 1985, p. 236), which is used to evaluate all possible combinations of the independent variables, was used to determine whether all three independent variables (drainage area, basin slope, and effective impervious area) provided the best equation. Because of the small range in the drainage area and effective impervious area values, some judgment was used to retain some of the variables even though there was little improvement in the relation for the larger recurrence-interval peak flows. Effective impervious area did not improve the relation for the 25-, 50-, and 100-year peak flows and, therefore, is not included in table 6 for these the equations.

Peak-flow values computed for the 2- and 100-year recurrence intervals from the equations in table 6 are compared in figures 14 and 15 to values in table 5 from frequency analysis of the station data. The average standard error of estimate was 27 percent for the 2-year peak flow and 29 percent for the 100-year peak flow. The equal-value lines in figures 14 and 15 indicate that errors are fairly evenly distributed throughout the range.

Regression equations in table 6 should provide reasonable estimates of peak-flows for urban drainages along the Wasatch Front with similar drainage areas, basin slopes, and effective impervious areas. However, the limitations in accuracy need to be considered when using the equations in table 6. The small number of drainages used to develop these equations may limit their accuracy. In addition, the equations may not provide accurate estimates for drainages having basin characteristics outside the range of those used to develop the equations. The range of basin characteristics used to develop the equations is summarized in table 7.

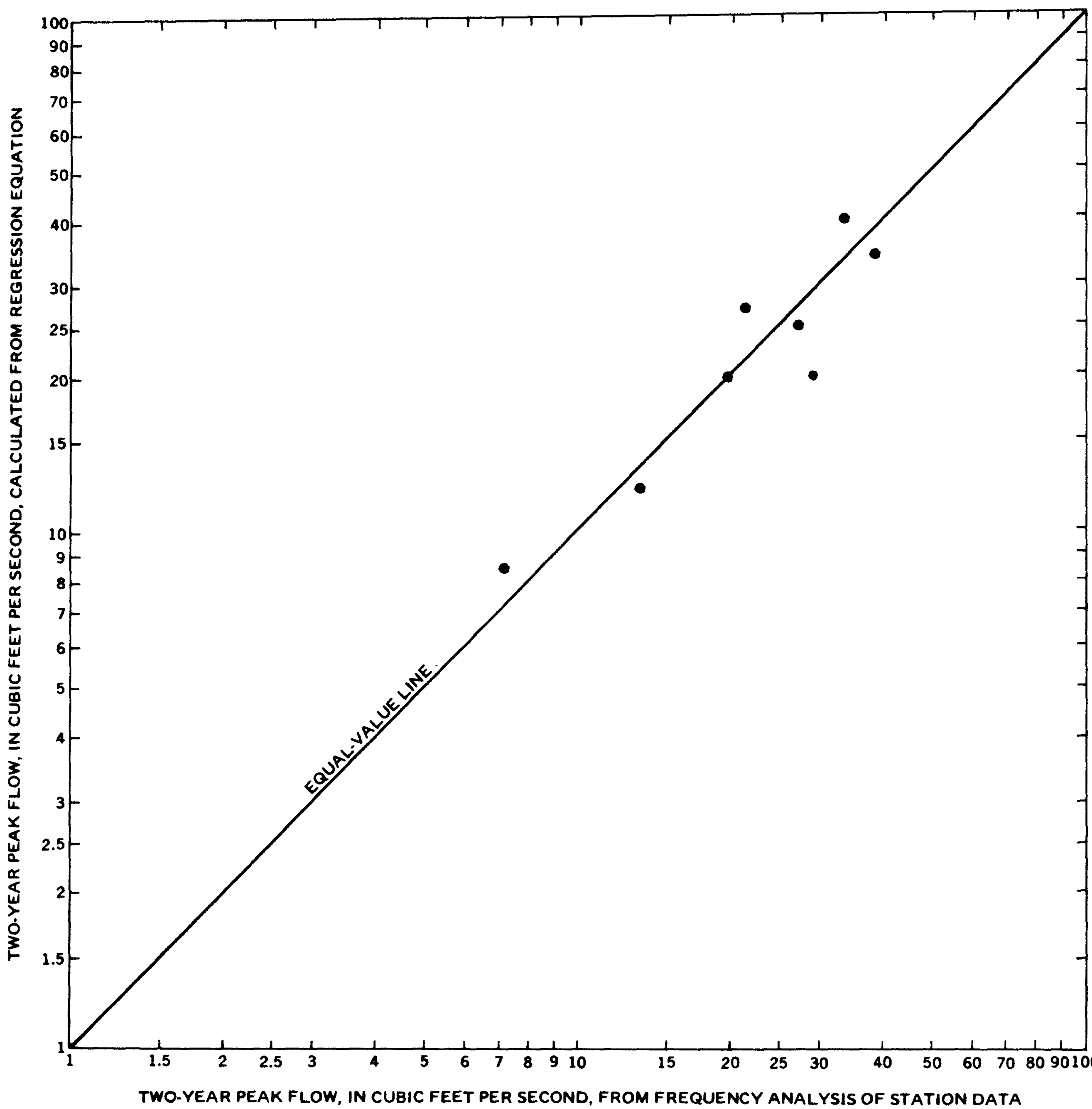


Figure 14.--Relation of 2-year peak flow from regression equation to that obtained from frequency analysis of station data for eight urban drainages.

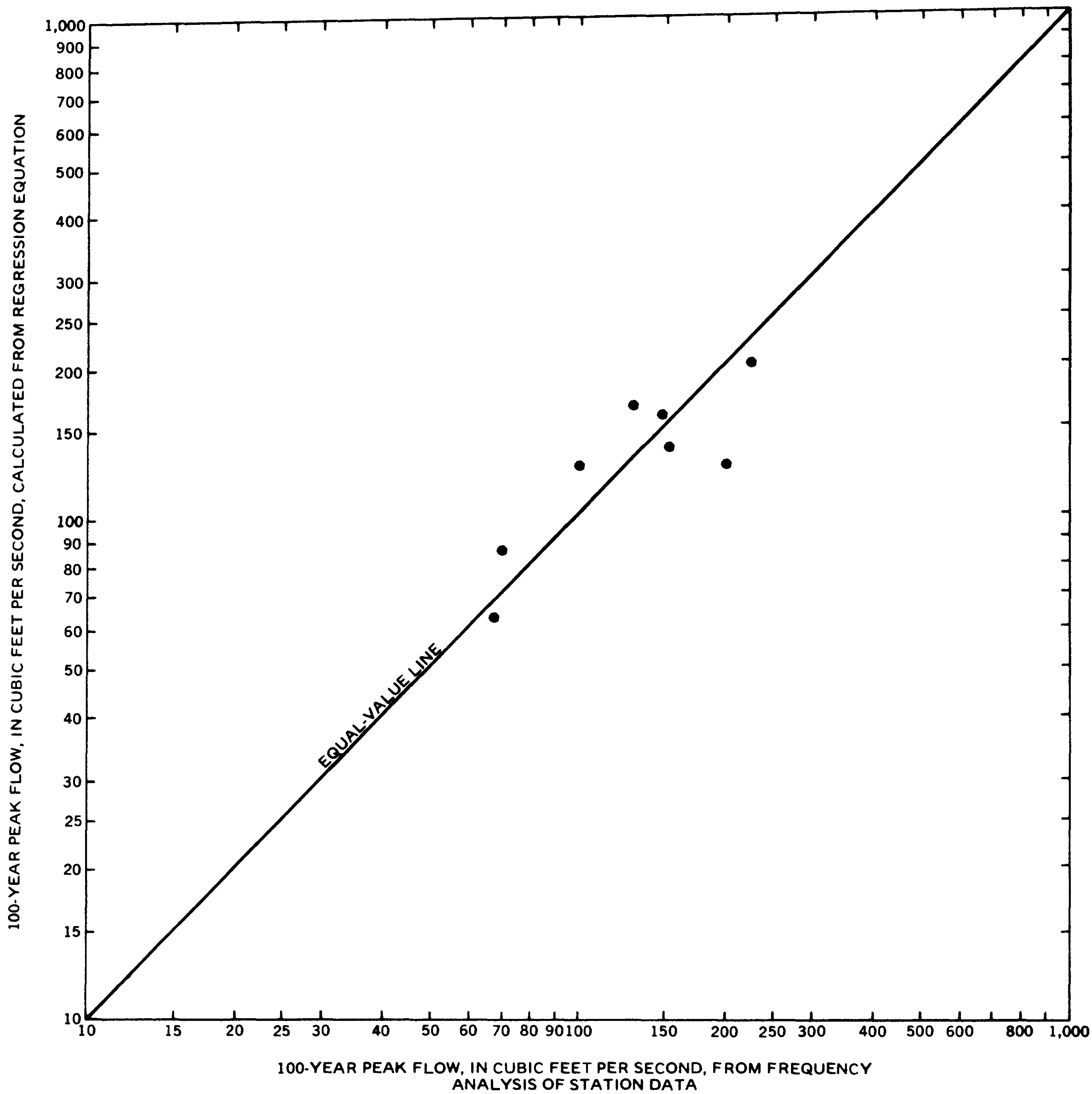


Figure 15.--Relation of 100-year peak flow from regression equation to that obtained from frequency analysis of station data for eight urban drainages.

*Table 7.--Range of basin characteristics used to develop regression equations*

| Basin characteristics | Range in values |
|---|---|
| Drainage area (DA) (square miles) | 0.085-0.87 |
| Basin slope (BS) (percent) | 0.3-15 |
| Effective impervious area (EIA)(percent) | 22-57 |

## Comparison of Peak Flow for Little Cottonwood Creek at Canyon Mouth with That at a Downstream Station Including Urban Drainage

Designers need to consider peak flow from intervening urban drainage to adjust the peak flow of larger streams at the canyon mouth in order to determine peak-flow frequency relations at downstream locations within the urban areas. Results from this study show that larger peak flows on small urban drainages generally occur during mid-July to mid-September from intense shorter-duration rainfall from thunderstorms. Results are supported by considering the 10 largest peak flows from the 63 simulated by the models (table 4); all these peak flows occurred between July and September. In contrast, annual peak flows in the larger streams generally occur during late May to early July (fig. 16). These peak flows generally result from mountain snowmelt.

A comparison of annual peak flow for Little Cottonwood Creek at the canyon mouth (drainage area = 27.4 square miles) to that for a downstream station (drainage area = 33.8 square miles) that includes 6.4 square miles of intervening urban drainage is shown in figure 16. Data in figure 16 show that annual peaks at the downstream station are similar to those at the upstream station and indicate that the intervening urban drainages do not substantially increase flows as compared to those at the canyon mouth. In contrast, data in figure 17, which compares peak flow for August-September, indicate that the intervening drainage may be the main source of peak flows at the downstream station during August-September when intense thunderstorms are likely to occur. The contrast is further explained by comparing the peak-flow data in figures 16 and 17 for 1987. During 1987, the annual peak flow (fig. 16) was 255 cubic feet per second at upstream station 10167499 and 231 cubic feet per second at downstream station 10167700. These annual peak flows occurred on May 18 as a result of mountain snowmelt and define a slightly greater annual peak flow for the upstream station. However, from August through September 1987 (fig. 17), the peak flow was 39 cubic feet per second at the downstream station compared to 12 cubic feet per second at the upstream station.

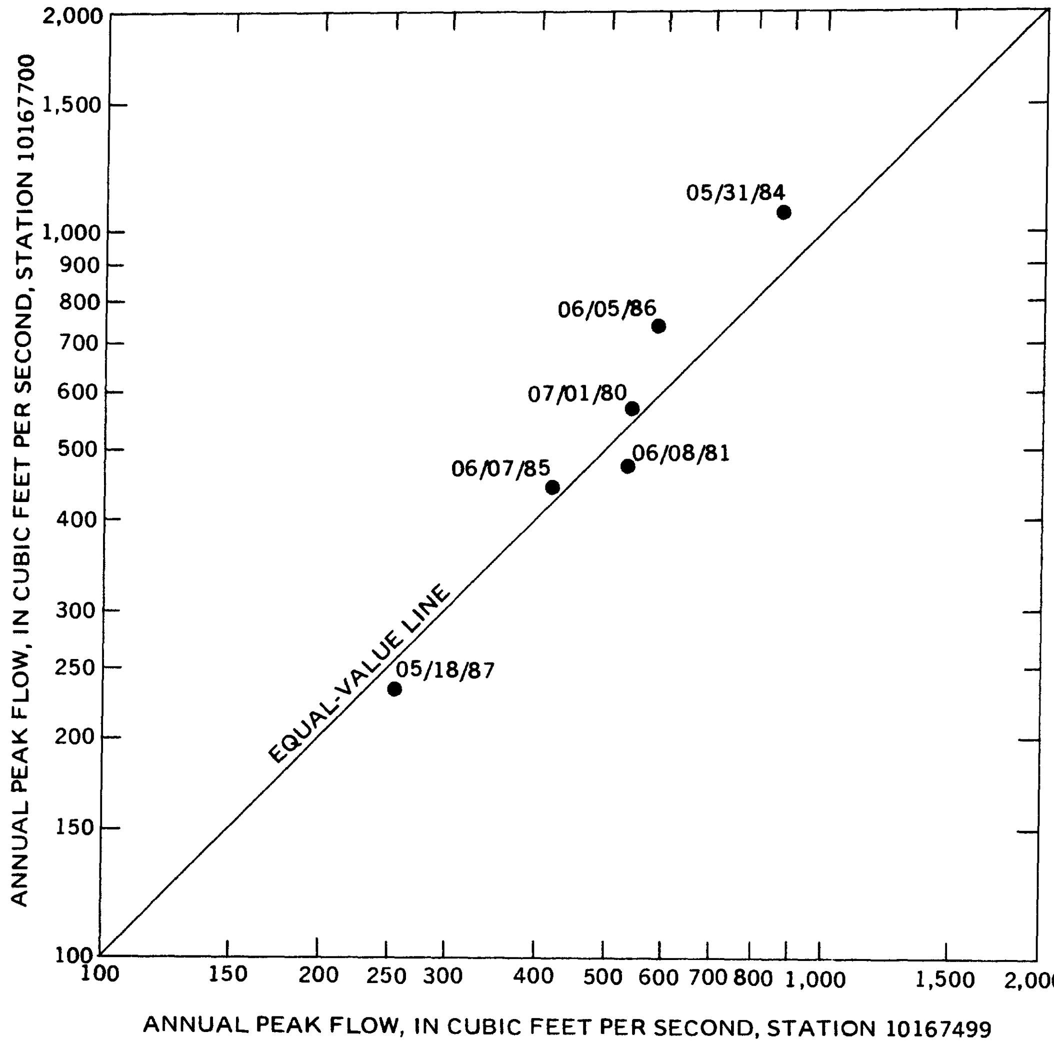


Figure 16.--Relation of annual peak flow at station 10167700, Little Cottonwood Creek at 2050 East, near Salt Lake City, to that at station 10167499, Little Cottonwood Creek (channel only) near Salt Lake City.

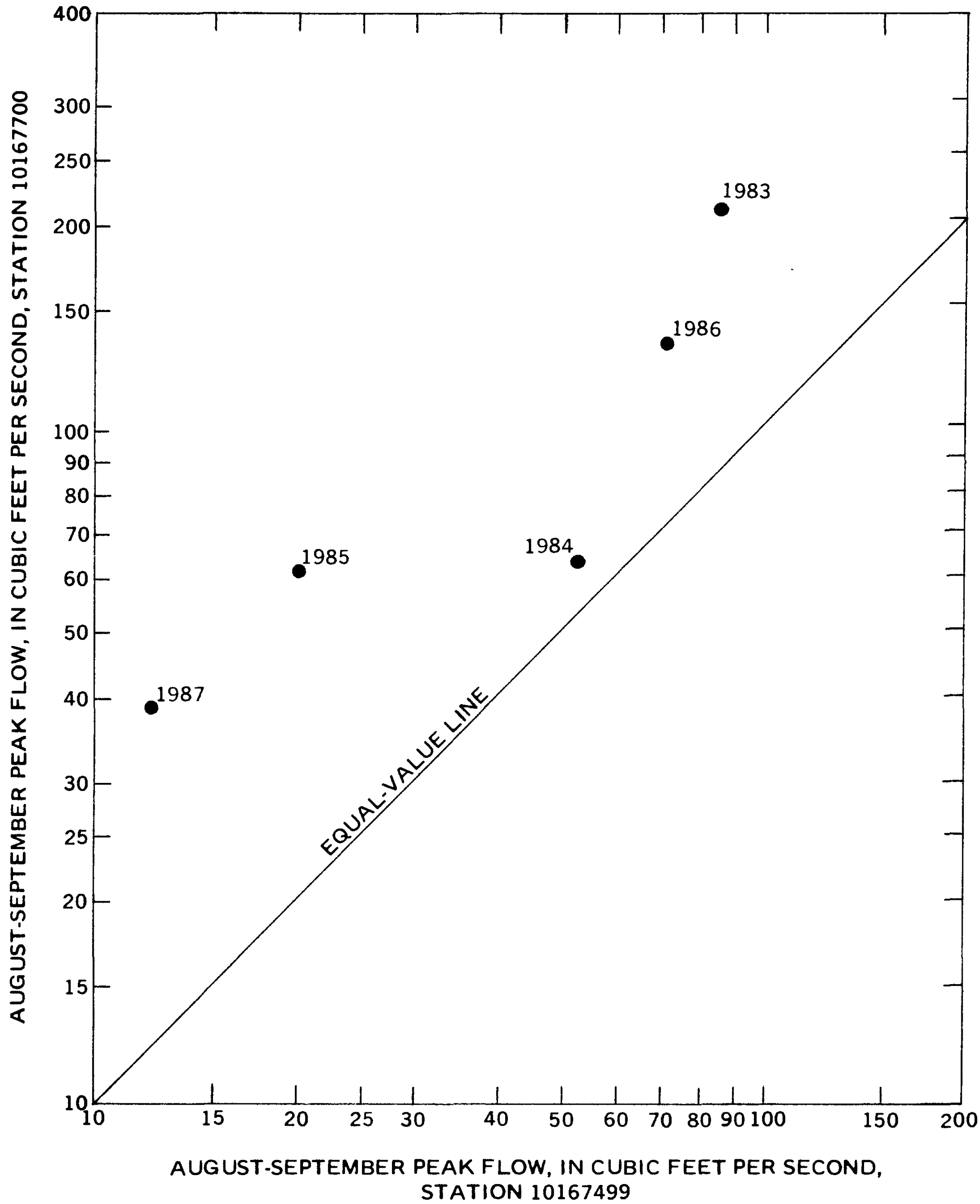


Figure 17.--Relation of August-September peak flow at station 10167700, Little Cottonwood Creek at 2050 East, near Salt Lake City, to that at station 10167499, Little Cottonwood Creek (channel only) near Salt Lake City.

## NEED FOR FUTURE WORK

Questions remain about how to combine rainfall- and snowmelt-derived peak flows. Streams that originate in the mountains above an altitude of 7,000 feet and flow through the urban areas can be expected to experience peak flows from both rainfall and snowmelt. Possibly, data need to be obtained from a network of two gages on a reach of one of the larger streams in combination with data from several gages that measure contributions from intervening urban drainages. These data and concurrent rainfall data could be used to calibrate hydrologic models at each gage, and the results could be used with a routing model to simulate longer records for use in frequency analysis.

Data for larger drainages within the urban area also would be useful in order to better define the equations in table 6. However, it is difficult to find large drainages that do not receive flow from major canals.

## SUMMARY

Designers and planners for local, State, and Federal agencies need up-to-date methods of determining peak-flow frequency relations for urban drainages along the Wasatch Front, Utah. Methods used to develop equations for estimating peak-flow frequency relations for small urban drainages along the Wasatch Front are summarized in this report.

Rainfall and flow data, collected during 1984-86 from eight urban drainages in the Wasatch Front area, were used to calibrate the Distributed Routing Rainfall-Runoff model (DR3M-II) for each of the eight drainages. Rainfall and flow data, available in 5-minute intervals, were used in the model because of the intense, short duration rainfall common in the area. The DR3M-II models then were used to generate 36 annual peak flows for the eight urban drainages using rainfall data collected from 1948-83 at the National Weather Service station at the Salt Lake City Airport. These rainfall data were digitized into 5-minute intervals from copies of original recorder charts. Log-Pearson type III distribution fits were made to these annual peak-flow data for each drainage, and peak flows for recurrence intervals of 2, 5, 10, 25, 50, and 100 years were calculated.

Multiple-regression techniques were used to develop relations between the 2-, 5-, 10-, 25-, 50-, and 100-year peak-flows and the basin characteristics of drainage area, basin slope, and effective impervious area. The eight drainage basins instrumented during this study had drainage areas ranging from 0.085 to 0.87 square mile, basin slopes ranging from 0.3 to 15 percent, and effective impervious area ranging from 22 to 57 percent.

The multiple-regression techniques produced a series of equations that can be used to estimate peak flows for recurrence intervals of 2, 5, 10, 25, 50, and 100 years at ungaged urban drainages in the Wasatch Front area. The average standard error of estimate for the regression equations ranged from 27 to 33 percent. The equations may not provide accurate results for drainages having basin characteristics outside the ranges used to develop the equations.

Peak flows resulting from snowmelt and peak flows resulting from intense rainfall on small urban drainages are compared at two stations on Little Cottonwood Creek near Salt Lake City. Generally, peak flows resulting from snowmelt and peak flows resulting from intense rainfall on urban drainages did not occur simultaneously. Questions remain about how to combine rainfall- and snowmelt-derived peak flows. Streams that originate in the mountains above an altitude of 7,000 feet and flow through the urban area can be expected to experience peak flows from both rainfall and snowmelt. Additional study is needed to address the effects of combining peak flows from snowmelt with peak flows from rainfall.

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