UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

POTENTIAL FLOOD HAZARD--NORTH AVENUE AREA
DENVER FEDERAL CENTER, LAKEWOOD, COLORADO

By Richard U. Grozier, Jerald F. McCain,
and G. Louis Ducret, Jr.

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CONVERSION TABLE

The following report uses the English system of units. The units are frequently abbreviated, using the notations shown below. English units can be converted to metric units by the following conversion factors:

English unit	*Multiply by*	*Metric unit*
acres	0.4047	hectares (ha)
cubic feet per second (ft^3/s)	2.832×10^{-2}	cubic metres per second (m^3/s)
feet (ft)	0.3048	metres (m)
inches	25.4	millimetres (mm)

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ABSTRACT

A potential flood hazard has been created on the Denver Federal Center by development of property adjacent to the northwest corner of the Center. This report describes the results of a study to evaluate the magnitude and areal extent of flooding in the vicinity of North Avenue west of Agricultural Ditch.

Prior to development of the property, the 100-year 1-hour rainfall of 2.10 inches would produce a peak discharge of 140 cubic feet per second at the west side of Union Street. This discharge would enter Welch Ditch and the combined discharge of 205 cubic feet per second would flow south into McIntyre Gulch without overflowing the east bank of the Ditch. Under developed basin conditions, the same rainfall would produce a peak discharge of 212 cubic feet per second. The total storm runoff would enter the Center through a 54-inch corrugated metal pipe recently constructed under Union Street and Welch Ditch. The 100-year flood discharge for developed basin conditions would cause damages to Buildings 67, 56, and 48 on the Center.

THE PROBLEM

Recent development of property immediately west of the northwest corner (herein referred to as the Fourth Avenue area) of the Denver Federal Center (fig. 1) has created a potential flood hazard to the Center. Officials of the General Services Administration noted the construction in the area and initiated a series of meetings at which the problem was discussed. Representatives of the U.S. Geological Survey attended the meetings at the request of General Services Administration. The U.S. Geological Survey was requested to conduct a study of the magnitude and areal extent of potential flooding in the area of the Denver Federal Center west of the Agricultural Ditch.

This report describes the results of the study by the U.S. Geological Survey and is arranged in three major sections:

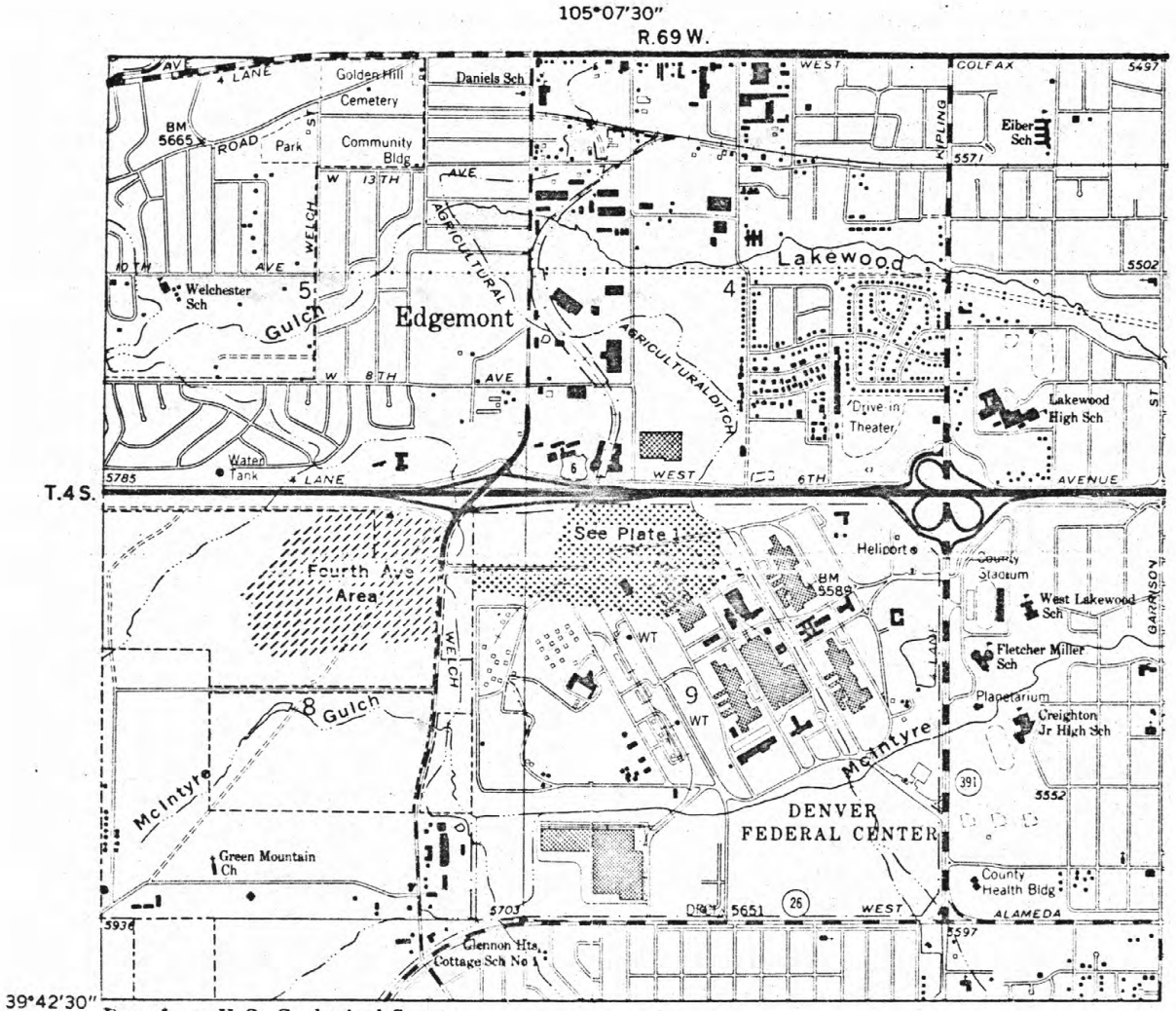

Figure 1.--Location map showing Denver Federal Center and vicinity, Lakewood, Colo.

(1) Historical factors and events affecting storm runoff from the area.
(2) Computations of flood hydrographs for the 100-year design rainfall under both pre-developed and developed conditions.
(3) Presentation of maps showing areas of the Federal Center west of the Agricultural Ditch which are subject to inundation by the 100-year flood from the Fourth Avenue area under both pre-developed and developed conditions.

Several assumptions were required during the course of the study. These assumptions are listed below:

(1) All culverts and channels in the flooded area of the Federal Center will be clear of debris during the flood.
(2) Flood runoff from the area within the Federal Center will be discharged before the arrival of runoff from the Fourth Avenue area.
(3) Surface storage in the flooded area will be filled by residual local runoff within the Center.
(4) Distribution of floodflows along the flooded area will be proportional to the water-carrying capacities of the channel.

DESCRIPTION OF STUDY AREA

Location

The study area is located in NE¼ sec. 8 and NW¼ sec. 9, T. 4 S., R. 69 W., in the western part of Lakewood, Colo. This report divided the area into two parts; the Fourth Avenue area and the potential flood-hazard area on the Denver Federal Center. The Fourth Avenue area consists of 104 acres bounded on the north by the Sixth Avenue Expressway and on the east by the Center. The potential flood-hazard area on the Center is located along North Avenue in the northwest corner of the Center as shown on plate 1.

Historical Background

Prior to the construction of the Welch Ditch in the 1860's, storm runoff from the Fourth Avenue area flowed in a northeasterly direction and entered Lakewood Gulch in SW¼ sec. 3, T. 4 S., R. 64 W., just west of the present location of Garrison Street. After the Welch Ditch was constructed, storm runoff was intercepted by the ditch and flowed southward to McIntyre Gulch where it was discharged through an overflow structure into the Gulch. When Union Street was constructed, a 30-inch corrugated metal pipe was placed under Union Street and water discharged

into Welch Ditch. Because of the long-standing precedent of interception of storm runoff by Welch Ditch, subsequent design of drainage structures along the channel east of Welch Ditch did not consider the total storm runoff from the Fourth Avenue area. Local runoff from the Federal Center is intercepted by the Agricultural Ditch and flows southward to McIntyre Gulch.

Prior to development of the Fourth Avenue area, three physical features of the area had significant effects on the storm runoff. An old railroad fill constructed about 1940 crossed the Fourth Avenue area about 800 feet west of Union Street. This embankment created a large storage area with no outflow structure. A storage area was also created by the construction of Union Street but the outflow was controlled by the 30-inch culvert under Union Street. During the development of the Fourth Avenue area, these storage areas were filled and are no longer available for storing storm runoff. The other feature of the area affecting storm runoff is the corrugated metal pipe-arch culvert on Welch Ditch under Sixth Avenue. North of Sixth Avenue, Welch Ditch averages about 4.5 feet in depth and will overflow at greater depths. The water that overflows the ditch will flow northeastward toward Lakewood Gulch and will not enter the study area. This condition essentially creates a maximum discharge through the Sixth Avenue culvert and has an important bearing on the utilization of the capacity of Welch Ditch south of Sixth Avenue.

Two other factors noted during this study also aid in the evaluation of the flooding situation prior to the construction of the Fourth Avenue area. These factors are as follows:

(1) Discussions with personnel of various government agencies on the Federal Center established that no significant flooding in the study area has occurred since the Center was con structed. The only problems have been caused by minor local flooding from areas within the Center.

(2) At the time of the survey in September 1974, the watercourse east of Welch Ditch consisted of a very small channel with no evidence of degradation which would be associated with large flood discharges. This indicates that no significant overflows of Welch Ditch have occurred since the construction of North Avenue.

STUDY APPROACH

Data Collection and Processing

A topographic map of the Denver Federal Center (scale: 1 inch = 50 feet; contour interval = 1 foot) prepared by Ralph D. Peterson and Associates (1964) was provided by the General Services Administration. The U.S. Geological Survey made studies to define channel cross-sections, channel roughness characteristics, and drainage structure details within the problem area. Several topographic modifications, including new buildings, new streets, and land surface changes, have been made since the map was prepared. These changes were added to the map. The survey data and the topographic map were used to prepare a plan layout (pl. 1) of the problem area. Channel cross-sections and profiles were plotted for use in the analysis.

Methods of Computation

The description of methods used in computing the various hydrologic and hydraulic factors are described below. These descriptions are provided at this point in the report to avoid cumbersome details in later parts.

Flood Hydrographs

The flood hydrographs from the Fourth Avenue area for the 100-year rainfall were computed using the Colorado Urban Hydrograph Procedure. This method is described in detail in the Urban Drainage Criteria Manual, which was prepared by Wright-McLaughlin Engineers (1969). The only departure from this method was in the distribution of the 100-year 1-hour rainfall which was based on a method described by Eagleson (1970). This distribution removed some of the subjective arrangement of rainfall as recommended in the manual. Basin characteristics of the Fourth Avenue area such as drainage area, channel slope, and channel lengths were extracted from a report by Hydro-Triad, Ltd. (1973).

Stage-Discharge Relations

Stage-discharge relations were required at two cross-sections in the problem area to portray the increase in discharge with increasing water surface elevation. Discharges were computed using the Manning equation,

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2},$$

where

Q = discharge in cubic feet per second,
n = channel roughness coefficient,
A = cross-section area in square feet,
R = hydraulic radius defined as area of a cross-section divided by the wetted cross-section perimeter in feet, and
S = slope of energy gradient assumed to equal the average slope of the channel between adjacent cross-sections.

Flood Elevations

Flood elevations at cross-sections were computed by an iterative solution of the Manning equation. The flood elevations are reported to the nearest 0.1 foot.

Culvert Discharges

Culvert discharges were computed by methods described by Bodhaine (1968).

RESULTS

Flood hydrographs were computed for both pre-developed and developed conditions of the Fourth Avenue area to study the effects of the respective floods on the problem area within the Denver Federal Center. The development of the Fourth Avenue area has been in progress for several years but the distinction of basin conditions for purposes of this report is assumed to be 1974. During this period the previously mentioned storage areas were filled and a 54-inch corrugated metal pipe culvert was placed under both Union Street and Welch Ditch. An evaluation of each basin condition is discussed.

Pre-developed Basin Conditions

The maximum discharge from the 100-year rainstorm under pre-developed basin conditions was computed to be 155 ft^3/s. The primary question relating to the flooding of the Denver Federal Center prior to development of the Fourth Avenue area is: Would Welch Ditch overflow near North Avenue during a flood of this magnitude? This question was prompted by the fact that during extreme flood events in the Denver area, irrigation ditches usually are filled by runoff from areas at higher elevations along the ditches, and hence have little or no capacity left to intercept local runoff. This usually precludes the utilization of irrigation ditch capacities in drainage design. In order to answer the above question, several related questions also had to be answered.

(1) What would be the maximum discharge of the culvert on Welch Ditch under Sixth Avenue?
(2) How would the storage area upstream from the old railroad fill modify the pre-development flood hydrograph?
(3) What maximum discharge would occur through the 30-inch corrugated metal pipe culvert under Union Street?
(4) Would the discharge through the 30-inch culvert and the storage area upstream from Union Street be sufficient to prevent overtopping of Union Street?
(5) Would the flow in Welch Ditch from upstream and the maximum discharge through the 30-inch culvert cause Welch Ditch to be overtopped?
(6) Could water stored upstream from Union Street flow along the west side of the embankment toward the south and enter McIntyre Gulch?

Officials of Agricultural Ditch Company (who own Welch Ditch), Colorado Division of Highways, and Hydro-Triad, Ltd., were contacted to gather information relating to the above questions. A topographic map by Hydro-Triad, Ltd. (1973) (scale: 1 inch = 200 feet, contour interval = 2 feet) was used to obtain much of the required data. Computations were made of storage, culvert discharge, Welch Ditch capacities, and Union Street profiles. The results are:

(1) Maximum discharge through the Welch Ditch culvert under Sixth Avenue was computed to be 65 ft^3/s. The upstream stage for the culvert was selected at a depth which would overtop the banks of Welch Ditch by 1.2 feet. Further increase in depth would result in significant overflow with only minor increase in culvert discharge. The downstream stage was selected at the top of the culvert pipe which would produce a maximum head on the culvert with both ends flowing full.
(2) The storage area upstream from the old railroad fill would contain 63,870 ft^3/s of water at an elevation of 5,748 feet. This storage would reduce the pre-development maximum discharge from 155 to 140 ft^3/s.
(3) Based on an inflow-outflow analysis of the storage area upstream from Union Street, the maximum discharge through the 30-inch culvert would be 60 ft^3/s at an upstream elevation of approximately 5,719 feet and a downstream elevation in Welch Ditch of 5,708.5 feet.

(4) With a discharge of 60 ft^3/s through the 30-inch culvert, the maximum water surface elevation of the storage area upstream from Union Street would be 5,719 feet. The minimum elevation of Union Street at this location is 5,718.4 feet. Thus, the 100-year pre-development flood would create flow over Union Street with a depth of 0.6 foot and a maximum discharge of approximately 80 ft^3/s. Based on the map by Hydro-Triad, Ltd. (1973), the Union Street overflow would enter Welch Ditch just east of Union Street.

(5) The combined discharges of Welch Ditch from upstream and that through the 30-inch culvert plus the Union Street overflow would total 205 ft^3/s. This discharge in Welch Ditch would occur at an elevation of 5,708.5 feet which would not overtop the east bank.

(6) Based on profiles of the centerline and west ditch of Union Street, water could not flow south into McIntyre Gulch along the west embankment. For this to occur, flow over Union Street would have to exceed a depth of 4 feet.

Developed Basin Conditions

The maximum discharge from the 100-year rainstorm for developed basin conditions was computed to be 212 ft^3/s at the west boundary of the Denver Federal Center. The calculations were made using a factor of 60 percent for basin impervious area and by assuming the availability of 60,000 ft^3/s of upstream storage as recommended in the report by Hydro-Triad, Ltd. (1973). The computed discharge checked reasonably closely with the discharge of 193 ft^3/s computed by Hydro-Triad, Ltd. The flood discharge from the 100-year rainstorm would enter the Federal Center through the recently constructed 54-inch corrugated metal pipe culvert under Union Street and Welch Ditch and would flow eastward along the south side of North Avenue for a distance of approximately 1,000 feet. At this point the flood discharge would divide with part flowing through the culvert under North Avenue and the remainder flowing to the east over Eighth Street.

Distribution of Flood Discharge

In order to evaluate the potential flood damages to existing facilities, the distribution of discharge was required at the North Avenue culvert and at several other locations along the path of the flood water.

North Avenue culvert.--The capacity of the corrugated metal pipe culvert under North Avenue would control the distribution of flood discharge to downstream areas. In order to compute the distribution of discharge, an iterative solution was required with two constraints being placed on the solution. The first constraint was that the discharge through the culvert must equal that through cross-section No. 23 at the downstream end of the culvert, and the second constraint was that the sum of discharges through the culvert and through cross-section No. 20A (South channel) must equal the total discharge. Repeated trials were made assuming various combinations of water-surface elevations until the two constraints were satisfied. The division of discharge is tabulated below.

Condition of basin	Total discharge (ft^3/s)	Culvert discharge (ft^3/s)	South channel discharge (ft^3/s)
Pre-developed	0	0	0
Developed	212	48	164

Sixth Street.--The peak discharge at the driveway to the Building 67 north parking lot would consist of 97 ft^3/s from the parking lot and 43 ft^3/s flowing south along Sixth Street from overflow of channels on each side of the railroad track for a total discharge of 140 ft^3/s. The remainder of the 164 ft^3/s from upstream would be discharged through the culverts at the railroad on Sixth Street. The culverts would each discharge about 12 ft^3/s to the east along each side of the railroad track.

The discharge of 140 ft^3/s at the driveway of Building 67 would again divide with part flowing south along Sixth Street and part crossing Sixth Street into the north parking lot of Building 56. Although relative amounts of discharge could not be determined because of the complex hydraulic conditions, the following general comments can be made. The discharge south along Sixth Street would cause water to enter the loading ramps of Building 67 and would fill the area between Buildings 56 and 67. Based on relative elevations along Sixth Street and the north parking lot of Building 56, the temporary storage area would fill to an elevation of about 5,619.0 feet, thereby reducing the maximum discharge to the east from about 140 ft^3/s to about 126 ft^3/s based on a subjective reduction of 10 percent. At this elevation no water would overflow along Sixth Street south of Building 56. The temporary storage in this area would be discharged to the east through the north parking lot of Building 56 and through storm drains.

Fifth Street.--The peak discharge of 126 ft^3/s would enter Fifth Street at the east driveway of the north parking lot of Building 56. The maximum elevation of Fifth Street south of the driveway is 5,614.1 feet and the ground elevation along the east side of Fifth Street north of Building 48 (cross-section No. 57) is 5,613.5 feet. Based on these elevations, water would flow northeast across Fifth Street, and then east along the north side of Building 48. The maximum water-surface elevation at cross-section No. 57 would be approximately 5,614.0 feet. Because of water impinging on the west wall of Building 48 east of the driveway, some water would discharge south along Fifth Street but depths would be very shallow. The flow north of the railroad track (about 12 ft^3/s) would discharge through the culvert under Fifth Street and would continue on the north side of the track into Agricultural Ditch. The flow of 12 ft^3/s through the south culvert under Fifth Street would rejoin the main flow east of Fifth Street.

Presentation of Computed Data

Water-surface elevations at several points along the south channel for developed basin conditions are listed in table 1. The elevations are also plotted on the cross-section and channel profile graphs which are available for inspection in the office of the Colorado District, U.S. Geological Survey, Building 53, Denver Federal Center. The areas subject to inundation by the 100-year flood for developed basin conditions are outlined on plate 1.

Table 1.--*Elevations for 100-year flood for developed conditions along south channel near North Avenue on Denver Federal Center*

Description	Distance along baseline (feet)	Elevation (feet)
	0	
Northeast corner of Building 48------	118	5,607.6
At 12-inch corrugated metal pipe near railroad----------	244	5,611.3
Northwest corner of Building 48------	389	5,614.0
Northwest corner of Building 56------	733	5,618.6
Centerline Sixth Street at entrance to Building 67 parking lot---------	1,000	5,624.0
At island in Building 67 parking lot-	1,181	5,629.0
East side of Seventh Street----------	1,425	5,635.4
Centerline Eighth Street------------	1,986	5,653.9

SUMMARY AND CONCLUSIONS

Flood discharge computations for both pre-developed and developed conditions of the Fourth Avenue area yield the following results:

100-year 1-hour rainfall	2.10 inches
Maximum discharge--developed conditions (with recommended basin storage)	212 ft^3/s
Discharge onto Federal Center	212 ft^3/s
Maximum discharge--pre-developed conditions (with storage)	140 ft^3/s
Discharge onto Federal Center	0
Maximum discharge in Welch Ditch--pre-developed conditions:	
Sixth Avenue culvert	65 ft^3/s
Union Street culvert	60 ft^3/s
Union Street overflow	80 ft^3/s
Total	205 ft^3/s
Maximum discharge through North Avenue culvert for developed conditions	48 ft^3/s
Maximum discharge along south channel for developed conditions	164 ft^3/s

Based on the information summarized above and other information contained in this report, the following conclusions can be made. Prior to development of the Fourth Avenue area, flood runoff for the 100-year 1-hour rainfall would be intercepted by Welch Ditch and would be transferred southward to McIntyre Gulch without overflows occurring along the east bank of the ditch. Because of the topography of the area, flood runoff could not flow south along the west embankment of Union Street into the McIntyre Gulch basin.

This study also indicates that during the maximum discharge from the 100-year rainstorm under developed basin conditions, three buildings on the Denver Federal Center, Buildings 67, 56, and 48, would receive severe water damage. Water would enter Building 67 through the loading ramps and equipment tunnel on the east side of the building. The driveway and grounds at the west entrance of Building 56 would be inundated, causing flooding inside Building 56. Part of the floodwater would flow along the north side of Building 48 and would enter the basement through the loading ramp at the east end of the building. A minor part of the floodwater would flow south along Fifth Street and some would flow eastward along North Avenue and enter Agricultural Ditch. These flows along Fifth Street and North Avenue would cause only minor damages to existing facilities. The peak discharge of 48 ft^3/s through the culvert under North Avenue would not cause damage to existing facilities.

This water would enter Agricultural Ditch at the north boundary of the Federal Center. Combined flows from Agricultural Ditch and from the Fourth Avenue area could cause flood problems east of the ditch, but evaluation of these problems is beyond the scope of this report.

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