OPEN-FILE REPORT 78-10

GEOLOGIC HAZARDS OF THE GLENWOOD SPRINGS METROPOLITAN AREA - GARFIELD COUNTY, COLORADO

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This report is the result of a cooperative effort by the City of Glenwood Springs, Garfield County and the Colorado Geological Survey. It was prepared by Lincoln-DeVore, Engineers and Geologists, under the direction of the Colorado Geological Survey.

Copies of this report (Open-file 78-10) and a set of 14 accompanying maps may be purchased from the Colorado Geological Survey, 1313 Sherman Street, Denver, Colorado, 80203.

An additional publication, Debris-flow Hazards Analysis and Mitigation, An Example from Glenwood Springs, Colorado, by A. I. Mears (Information Series 8) is an excellent supplement to this report and is also available from the Colorado Geological Survey.

GEOLOGIC HAZARDS OF THE GLENWOOD SPRINGS METROPOLITAN AREA, GARFIELD COUNTY, COLORADO

by

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INTRODUCTION:

Glenwood Springs, county seat of Garfield County, Colorado, lies at the junction of the Roaring Fork and Colorado Rivers near the west-central edge of the Southern Rocky Mountains. Surrounded on the north, east, and south by high, steep mountains, the city occupies a narrow canyon at an elevation of about 5800 feet and possesses a mild, semi-arid climate. Due to its setting of abrupt topography and complex geology, both the city and its surroundings are subject to a variety of geologic processes that in the presence of human settlement constitute natural hazards.

The presence of geologic hazards in the area was graphically illustrated on the evening of July 24, 1977, when a major thunderstorm swept enormous quantities of mud, rock, tree limbs, and other debris into a city residential district. In less than a half hour, about 200 acres of the city was covered to depths ranging between four inches and 14 feet; reliable estimates placed the total damage at about $300,000. This event led to a recognition of the local importance of such debris flows, together with ground subsidence, mass wasting, and other processes, to the inhabitants of the area. As a result, Colorado Geological Survey, in cooperation with the planning departments of the City of Glenwood Springs and Garfield County, co-funded a study of the nature, extent, and severity of geologic hazards active within a study area defined in Figure 1. The results of that study are summarized in this report.

GENERAL GEOLOGY:

The location of the study area at the western edge of the mountains creates considerable geologic complexity. Every member of the sedimentary rock section, from the Cambrian Sawatch Quartzite to the Upper Cretaceous Mancos Shale, occurs within the boundaries of the study area; also found are structural features such as monoclines, thrust faults, high-angle faults, and evaporite diapirs, together with evidence of volcanic and hydrothermal activity. Most of the significant geologic hazards, however, concern the unconsolidated deposits of Quaternary age which cover the lowlands.

From the standpoint of stratigraphy and structure, the study area can be divided into four zones. North of the Colorado River, the White River Uplift (a major division of the Southern Rocky Mountains) rises in a deeply eroded, intricately faulted sequence of older sedimentary rocks. The series exposes rocks of the Sawatch Quartzite, Manitou Dolomite, Peerless Formation, Chaffee Formation, Leadville Limestone, Molas Formation, Belden Shale, and Eagle Valley Evaporite, and is bounded on the south by the trace of the Storm King Thrust Fault. To the east of the city, the ground rises rapidly to form the west limb of the great Sawatch Range anticline, another major feature of the Southern Rocky Mountains. This zone is the least complex of the four; only three formations--the Eagle Valley Evaporite, the Maroon Formation, and a basaltic lava flow--exist within the project boundaries, and no significant faults or other notable structural features alter the section. To the west of the city lies a system of high, steep ridges which form a part of the Grand Hogback. The Hogback, which forms the geologic boundary between the mountains and the Colorado Plateau, is made up of a thick section of formations which become increasingly younger toward the west. Included in the section are the Eagle Valley Evaporite, Maroon Formation, Weber Sandstone, Chinle Formation, Entrade Sandstone, Morrison Formation, Dakota Sandstone, and Mancos Shale. The ridge system, which forms a structurally simple, west-dipping monocline, is locally capped by basaltic lava flows which are related to the flows on the east side of the study area.

The fourth zone--the most significant from the standpoint of geologic hazards--is the valley bottoms of the Colorado and Roaring Fork rivers. Both valleys are controlled by geologic factors; the Colorado River locally follows the trace of the Storm King Thrust Fault, and the Roaring Fork follows the trend of the easily-eroded Eagle Valley Evaporite. Both valleys are underlain by stream alluvium and terrace deposits, composed of water-transported boulders and cobbles resting in a finer-grained matrix. In most of the Glenwood Springs area, terrace and alluvial deposits are found at elevations below about 5800 feet. However, remnants of high-level terraces do exist, notably north of the Colorado River, just west of the city limits. The high-level terraces are sometimes locally cemented by travertine, a form of calcium carbonate which has been deposited by hot springs associated with the Storm King Thrust Fault. The terrace deposits and alluvium generally present few hazards; many of the larger buildings in the city are founded on terraces. However, the areas mapped as alluvium usually fall within the floodplains of major streams.

Most of the other unconsolidated deposits in the valleys are of colluvial origin; that is, they have been formed by downslope movement, or slope wash, under the influence of gravity, of loose rock and soil debris. Included in this category are the large "fans" formed by debris flows. Debris fans cover the greater part of the developed portions of the study area and grade into sheets and wedges of undifferentiated colluvium. Both the debris fans and the colluvium deposits are actively accumulating material. Known thicknesses of these materials range from less than one foot to well over 50 feet. Another class of colluvial deposits include large bodies of rock and soil debris on the surrounding mountainsides. These bodies are believed to be the remnants of ancient debris flow, landslide, and colluvial deposits. The most prominant of these now-inactive deposits is Cemetary Hill (between basins E-3 and E-4, see Figure 1), which may be the eroded remnant of a debris fan or mudflow deposit. It is likely that the ancient debris flow and colluvial deposits are of late Pliocene or early Pleistocene age, and that they are roughly contemporaneous with both the series of very large, old landslides on the flank of the Grand Hogback (just above County Road 117 and Midland Avenue) and the very large landslide which is believed to underlie the coalesced debris fans of basins W-18, W-19, W-20, W-21, and W-22.

The bedrock and structural geology of the study area is shown on Sheet 1 of the map series; the surficial geology is shown in greater detail on Sheets 2, 3, 4, and 5, as well as on the stream profile sheet (Sheet 14).

DEBRIS FLOW HAZARDS:

Debris flows are masses of water and rock, soil, and other materials which move rapidly downhill--usually, though not always, along an existing drainage channel--and lose velocity and are redeposited on gentle, low-lying slopes, where they ultimately form characteristic fan-shaped deposits. Unlike landslides, which deform in plastic shear, and debris-laden floods, which flow as low-viscosity liquids, debris flows behave as Bingham substances; that is, they combine viscous flow with plastic strength in a manner similar to lava flows and glaciers. As a rule, debris flows can form whenever loose soil, rock, and other debris on steep slopes become entrained with water in such a way that mobilization occurs. In other words, the debris mass must become essentially saturated with water, and that water must exert pore pressures which are approximately equal to, or greater than, the normal intergranular stresses ("effective stresses") acting within the debris mass. The "neutral stress" of the pore water, which cannot withstand shearing, counteracts the effective stress of the debris and reduces the shear strength of the mass to negligible proportions. The debris mass is then free to deform and flow.

It is often theorized that a high clay content in the debris mass is essential to debris flow formation. This theory arises, in part, from a well-known association of clay, high pore water pressures, and slope stability problems and, in part, from the controlling role played by clays in certain intensively-studied debris flows, mainly in southern California. However, debris flows have been reported in materials ranging from silts to rock talus which possess very low (and sometimes insignificant) clay contents. In the Glenwood Springs study area, debris flows are associated primarily with outcrops of the Maroon Formation and secondarily with outcrops of the Eagle Valley Evaporite. The Maroon Formation consists of brilliant red and orange beds of shale, siltstone, sandstone, and conglomerate, with a little limestone. The sandstones and conglomerates are usually arkosic and micaceous, and are often rather coarse-grained. Although some beds within the formation are clayey, debris weathered from Maroon Formation outcrops does not usually have a very high clay content. The Eagle Valley Evaporite does contain considerable clay, together with soluble gypsum and halite, and beds of sandstone and siltstone. However, debris flows originating in areas of Eagle Valley Evaporite outcrop are usually smaller and less frequent than those originating on Maroon Formation outcrops.

As a result of this investigation, it was concluded that debris flows in the Glenwood Springs study area probably do not result from the gradual buildup of pore pressures in clayey soils as a consequence of rainfall precipitation, as is the case with southern California debris flows. A different model, involving the rapid introduction of water to debris, with a sudden increase in pore water pressure producing liquifaction, is therefore proposed. Debris flows in the study area are commonly caused by the sudden introduction of large quantities of loose debris into rapidly moving flash flood waters. The required quantities of debris result from rockfall, debris avalanching, and ground failure on very steep slopes; the situation is aggravated by the very high suspended sediment load of the flood waters, which results from sheet flooding and accelerated erosion in the upper drainage basin. In areas of Maroon Formation outcrop, it is likely that a great deal of debris is contributed by rapid, progressive failure of sheets of low-density residual and colluvial soil; the failure mechanism involves sudden saturation of the loose soil, followed by collapse of the soil structure and immediate liquifaction of the soil mass.

The relationship between flow magnitude and frequency in a given drainage basin is a function of many variables. Among those variables are rainfall intensity and magnitude, slope aspect, basin length, area, and slope, rock type, amount of available debris, and vegetation type and density. Several of these variables are summarized on Sheet 14 of the map series for 11 basins within the study area. Once a flow is mobilized, it will move downhill, either accelerating or decelerating as a function of the ground slope, the channel geometry, and the physical properties of the flow. A moving flow possesses considerable potential for destruction; impact pressures are directly proportional to the square of the flow velocity, and may exceed 2000pounds per square foot. While the flow is moving, the positions of the soil and rock grains within the flow continually adjust to maintain the high pore pressures which permit liquifaction. However, the flowing mass retains sufficient shear strength to transport large boulders and other objects, which are picked up by the advancing "snout" of the flow and transported on the upper surface of the flow. Due to the combination of viscous flow and plastic shear characteristics in debris flows, it is not uncommon for flows to be diverted from their channel or path by obstructions, which may be other, demobilized debris flow lobes. When diversion occurs, the flow will "jump" its channel and find a new path; the diverted flow then builds its own channel as it goes by leaving behind levees and medial deposits.

As the channel gradient decreases, the advancing debris flow will decelerate and, finally, come to a halt. Deceleration results from the reduced gradient of the slope, from the loss of energy consumed in fluid friction (both within the flow and at the interface with the ground surface), and from the internal friction resulting from growing effective stresses as the high pore pressures are dissipated by drainage. After a flow has demobilized, it may be extensively modified by water flooding and later erosion. Within the study area--especially in the large basins on the east bank of the Roaring Fork River--debris flows are usually immediately followed by large runoff flows which rework the debris and spread thin layers of mud over very large areas.

Although the debris flows of July, 1977 took many residents by surprise, review of old newspaper files and storm records shows that at least 12 damaging debris flow events have affected the study area since 1920. In addition, two other large flows are known to have occurred between 1900 and 1920, one of which (1903) resulted in a fatality after a train wreck. Nearly half of the reported events affected areas within the present city limits of Glenwood Springs. It appears that news accounts of debris flows were published only when the flows affected settled areas or transportation lines; recent population growth and urbanization of the West Glenwood district has been accompanied by a substantial increase in the number of reported flows.

The available evidence suggests that the various small drainage basins of the study area each possess a characteristic "style" of debris flow behavior. In general, the basins can be grouped on the basis of their styles, as shown on Sheets 6, 7, 8, and 9 of the map series. While both larger and smaller flows are not unknown, each basin tends to produce flows of a fairly consistent magnitude range. This is probably because of limitations imposed on the energy and mobility of the flowing mass by the physical characteristics of the source material and by the geometry of the basin and fan. While the total number of debris fan lobes and the total volume of debris involved can vary greatly, the actual area covered by flow deposits in the valley fluctuates within a much narrower range. On undisturbed fans, the zone of normal debris flow deposition is often distinguished from an outlying zone of eroded and reworked material by a distinct break in slope. Although the mechanics of flow deposition can be altered by both human development and long-term changes in the fan geometry, it is possible to subdivide the study area into low, moderate, and severe hazard zones on a semi-quantitative basis. These zones are shown on Sheets 6 through 9, together with the outlines of areas affected by recent debris flows and with other information about those flows. It should be noted that the outlined areas include both the zone of flow deposition and the zone of erosion and reworking.

Although approximate methods for the quantitative evaluation of debris flow hazards exist, the data necessary for that evaluation is usually unavailable. The analysis of hazards on specific tracts of land is therefore qualitative only. In the absence of an actual known history of flow deposition on a tract, clues to past behavior may be found in the presence of a fan, the presence of surface boulders and quantities of coarse-grained materials, and the lack of a well-developed surface soil profile. Subsurface investigations in high-hazard zones may disclose stratified, alternately coarse- and fine-grained beds (see Figure 2a), in which the coarse beds represent old flow deposits, or buried soil horizons. Due to the tendency for flows to change their path, the presence of a defined drainage channel on a fan does not guarantee the safety of the remainder of the fan. An example may be found in the 12th Street Floodway, which was built in 1938 to protect the downtown district from flows in basin E-3 (Cemetary Gulch). Although the floodway has sometimes functioned as planned (i.e. 1977), the 1943 flow left the channel near its head and spread through the city, causing widespread damage.

As can be seen from the maps, almost the entire urbanized part of the study area is subject to some degree of hazard from debris flows. Simple avoidance of the hazard is not always possible, and alternate mitigation methods must be employed.

Avoidance should be practiced at the apices of fans, where the high velocities of flows exiting from the gulches result in impact pressures which cannot reasonably be resisted by conventional residential and commercial structures. Elsewhere in the city, the only useful mitigation technique on the fans involves the design of flow-resistant buildings; such buildings require heavily-reinforced lower walls and should not have low windows or other openings on the uphill side. In some cases, it may be possible to grade a site so as to create an island which will split slowly-moving flows. This measure will, however, increase damage to surrounding property. Damage to structures and their contents by debris flows is covered under the flood insurance program of the Federal Insurance Administration. However, coverage does not extend to damage to landscaping and open ground. As most of the reported damage in the 1977 event involved landscaping and cleanup of open areas, it does not appear that fan-level mitigation techniques are sufficient to alleviate the problems posed by debris flows.

The place for truly effective mitigation is above the fan, in the lower reaches of the source basins. One possible technique requires the construction of detention dams to completely retain the flowing mass. A dam of this type is in successful operation in basin W-21, and others have been proposed in the small basins of West Glenwood. Detention dams must be cleaned out after every flow event. Furthermore, it will be difficult to construct dams of a sufficient size to retain the very large debris flows and floodwater volumes generated by larger basins, such as those along the Roaring Fork River. Overtopping or failure of a very large dam could be catastrophic. Therefore, dams cannot be recommended on other than small basins. For the larger basins, debris fences of the type discussed by Mears (1977, p. 38-41) are probably the best control alternative. These fences are designed to demobilize debris flows and permit drainage of water from the debris mass. The water can then be controlled by conventional storm drainage techniques. Debris fences are expensive, must be designed to withstand high impact pressures, must be high enough to prevent overtopping, and must be cleaned out after each flow event. However, they represent the most effective means of control yet devised for the study area.

HYDROCOMPACTION AND RELATED HAZARDS:

A second major geologic hazard affecting the Glenwood Springs study area is the susceptibility of colluvial surficial deposits to settlement or subsidence. The most spectacular incidences of subsidence are due to hydrocompaction, which is the sudden collapse of low-density soils upon wetting. Other, more gradual subsidence is attributed to complex ground failure and, to a very limited degree, to solution of soluble rocks in the Eagle Valley Evaporite. True consolidation, which requires the expulsion of pore water from a soil under load, is relatively uncommon, although it is not unknown. Although the limestones which outcrop in the study area are cavernous, the outcrops are in rugged, unpopulated areas and subsidence of caverns is not a significant hazard.

True hydrocompaction is known to occur at a few locations in Glenwood Springs; most reports have so far come from the south end of the study area. Although collapses in excess of 10 feet deep have been reported a short distance south of the study area, hydrocompaction subsidence in the Glenwood Springs area is usually much less. Hydrocompactive soils, according to one theory, are usually low-density silts or very fine sands which have been deposited by colluvial or aeolian (windblown) processes. The in-place void ratio of the soil must be greater than the void ratio of the same soil remolded at the liquid limit. A small amount of clay, occurring as thin coatings on the individual silt and sand grains, is vital to the process; otherwise, the presence of large quantities of clay or cementing compounds such as calcium sulfate and calcium carbonate tends to reduce or eliminate the potential for hydrocompaction. When a susceptible soil is saturated, the water tends to weaken the clay film bonds which have formed at intergranular contacts. Simultaneously, expansive pressures generated by the wetted clays tend to force the silt and sand grains apart. The weakened soil structure then collapses, either spontaneously or under load, to a denser, more stable configuration. Other theories implicate either surface tension effects in pore water or the pressure of small quantities of intergranular cementing compounds. In the Glenwood Springs area, most hydrocompactive soils are colluvial materials derived from the Marcon Formation; rarely, limited hydrocompaction may occur in colluvium derived from the Eagle Valley Evaporite.

Techniques for the evaluation of hydrocompactive soils are discussed in review papers by Dudley (1970) and Lofgren (1969). A preliminary indication of hydrocompactive potential may be obtained from theoretical considerations involving the specific gravity, liquid limit, and in-place density of the soil. Other techniques involve field tests and variations on the conventional consolidometer (oedometer) test. In terms of mitigation, total avoidance of highly hydrocompactive soils is advisable but not always practical. Other fairly successful techniques include pre-wetting or complete removal and replacement with compacted fill. A less satisfactory technique requires the construction of deep foundations which bear on a non-hydrocompactive material, combined with careful control of both surface and subsurface drainage.

A more widespread cause of subsidence in the study area is a hydrocompaction-related phenomenon here termed complex ground failure. Most of the unconsolidated deposits in Glenwood Springs contain sufficient clay and cementing compounds to preclude hydrocompaction. The clay and cementation may have been present in the material when it was deposited; more often, in-place weathering and infiltration by percolating waters has altered the material after deposition in debris fans and colluvial bodies. Nevertheless, the soil retains its low density and high void ratio. As long as the soil remains dry and undisturbed, it will display very high strength and almost no tendency to settle under light to moderate building loads.

If, however, the soil is wetted for an extended period of time, the clay and cementing compounds will soften and the cementing compounds will at least partially dissolve. Destruction of the intergranular bonds by this gradual process tends to drastically reduce the strength of the soil, as shown in the Mohr failure envelopes for typical Glenwood soils (Figure 3). Although no appreciable subsidence will occur in unloaded soils, the addition of building loads can result in gradual failure of the soil skeleton and densification of the entire soil mass. If the soil is completely saturated, piping erosion in the weakened soil can further reduce bearing capacity; furthermore, densification of the saturated soil will induce very high pore pressures and possible local liquifaction. Key distinctions between hydrocompaction and complex ground failure revolve around both the extended period of time and the actual physical changes in soil structure required for complex ground failure.

The potential for complex ground failure can be recognized from the interpretation of conventional consolidation test data if the tests are performed under conditions which permit the dissolution of the clay/cement bonds and if proper consideration is given to the possible effect of complications such as piping. Buildings and other facilities can then be designed on the basis of the reduced soil strength and compressibility values. A great many of the buildings in the study area have undergone some movement and damage as a consequence of complex ground failure. Most of the affected structures, however, are older frame buildings which are capable of adjusting to the movement without suffering much visible damage. Buildings constructed from concrete, masonry, and glass often undergo considerable cracking and structural movement. In cases where the affected soil underlies a slope, the mechanism carries with it the potential for local slope failure--complex ground failure is suspected in a small circular landslide occurring in an otherwise stable slope on the west side of Midland Avenue.

Other causes of ground subsidence are relatively minor within the study area. Some of the fine-grained soils, particularly in lower-lying areas, have the potential for true consolidation under load. This potential can, however, be detected by conventional geotechnical engineering techniques. Gradual solution of the gypsum and halite in the Eagle Valley Evaporite is known to cause large-scale subsidence. However, this subsidence is not usually accompanied by the differential movements which prove damaging to structures. The low permeability and mechanical incompetence of the soft, plastic evaporite combine to preclude the formation of voids and sinkholes.

The potential for subsidence of all types is shown on Sheets 10, 11, 12, and 13 of the map series. Also, Figure 2b illustrates a typical soil profile in a material subject to complex ground failure over a long period of time. Figure 2c shows a typical soil profile in a material subject to severe, short-term complex ground failure; the very low blow counts shown in parts of the profile may reflect piping erosion.

OTHER GEOLOGIC HAZARDS:

Although most of the geologic hazards found in the study area are associated with either debris flows or subsidence, a few other, lesser hazards are encountered. These include landsliding, rockfall, and corrosive soils.

A number of rather large landslides have been mapped on the hillsides in the west and north parts of the study area. Most of these are very old slides in the Maroon Formation which now exist in a metastable condition. These old slides, together with most of the old debris flow and mudflow deposits, seem to be related to unusual stress and hydrogeologic conditions associated with the contact between the Maroon Formation and the underlying Eagle Valley Evaporite. It is likely that these features may have been initiated when the downcutting Colorado and Roaring Fork Rivers first exposed the contact between the two formations. Of unusual interest is the very large coalesced debris fan of basins W-18 through W-22. This fan is probably developed upon the remains of a very large slope failure controlled both by the Maroon/Eagle Valley contact and by the Storm King Thrust Fault.

At the present time, all of the large landslides and related features appear to be stable. In fact, the roadway of County Road 117 cuts the toe of one of the largest of the slides, apparently without problems. Prudence would dictate that extreme care be used, however, whenever one of the old slides is affected by development or construction. Total avoidance of slide areas is strongly recommended. Known ancient landslides and slope failures are shown on Sheets 10 through 13.

A more pressing hazard involves rockfall. Most of the developed portions of the study area are ringed by steep hillsides and cliffs upon which resistant beds of the Maroon Formation outcrop. These outcrops serve as source areas for repeated falls of rocks of all sizes. Other rockfall source areas are found in other formations in the mountains surrounding the study area; however, few of these rockfalls affect developed area. Although the conventional remedy for rockfall is simple avoidance of the hazard zone, it is not always feasible to avoid the problem in Glenwood Springs--many of the hazard areas are already developed. At least one damaging rockfall occurred in a residential district during 1977; in addition, rockfalls create perpetual maintenance problems along transportation routes. The problem can be minimized by careful building site location and by grading building areas to provide catchment, impact absorbing, or deflection features. In critical areas, periodic scaling of loose rock on the slopes may be necessary. Rockfall areas are shown on Sheets 10 through 13 of the map series.

A final hazard is attributable to soils derived from, or modified by, rocks of the Eagle Valley Evaporite. These rocks contain substantial quantities of gypsum (calcium sulfate), which is corrosive to concrete and most metals. Structures and facilities located in areas of corrosive soil must be built in such a way that the construction materials in contact with the soil are protected. Concrete should be made with Type II or Type V cement, which is inherently resistant to sulfate attack. Metal installations should be coated with protective substances or be made of heavy-gauge stock to prevent or minimize rapid damage. Cathodic protection may, under certain circumstances, be a feasible means of protecting critical installations. Areas in which corrosive soils are expected are also shown on Sheets 10 through 13.

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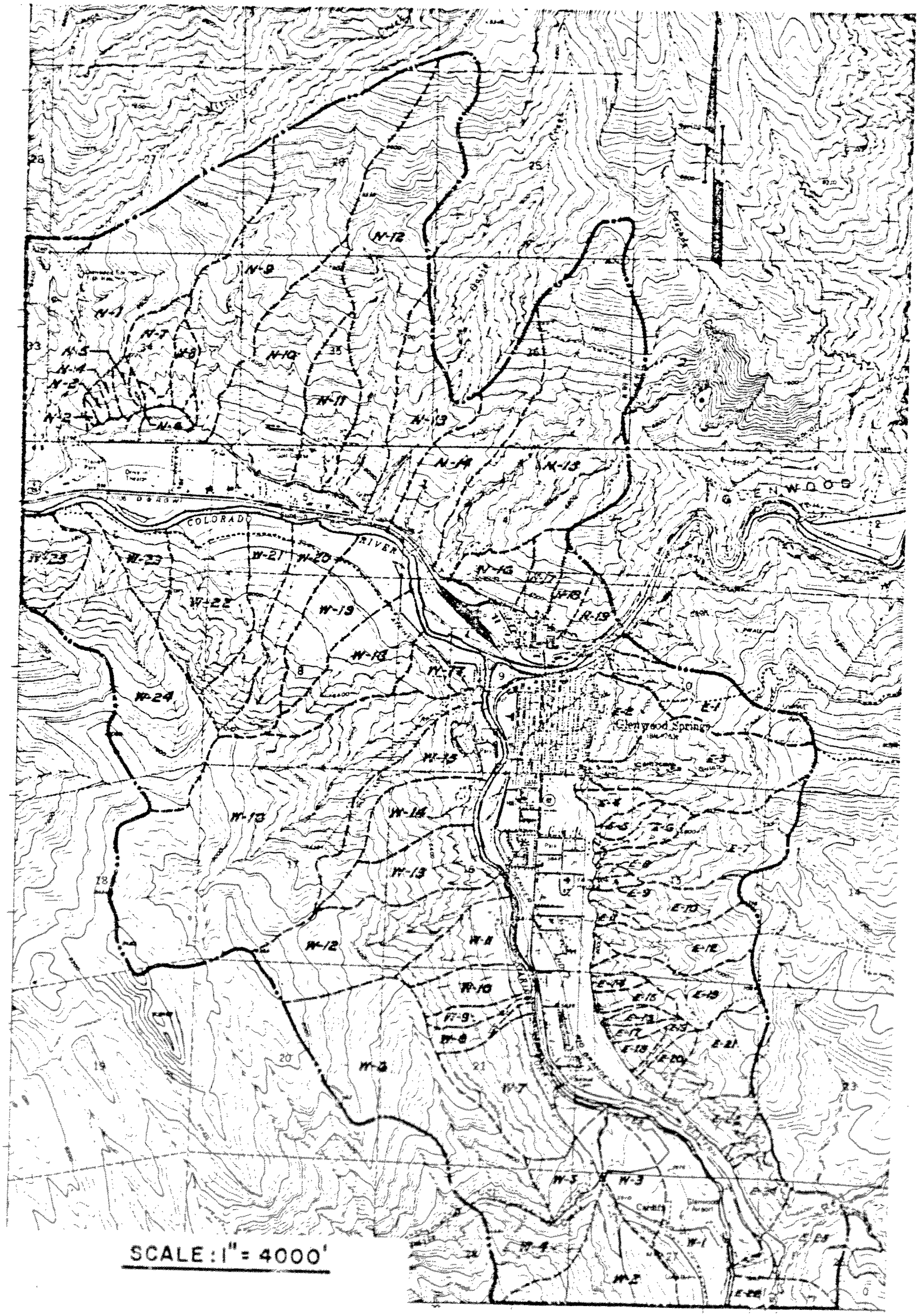


FIGURE 1: PROJECT LOCATION MAP
SHOWING DRAINAGE BASIN BOUNDARIES

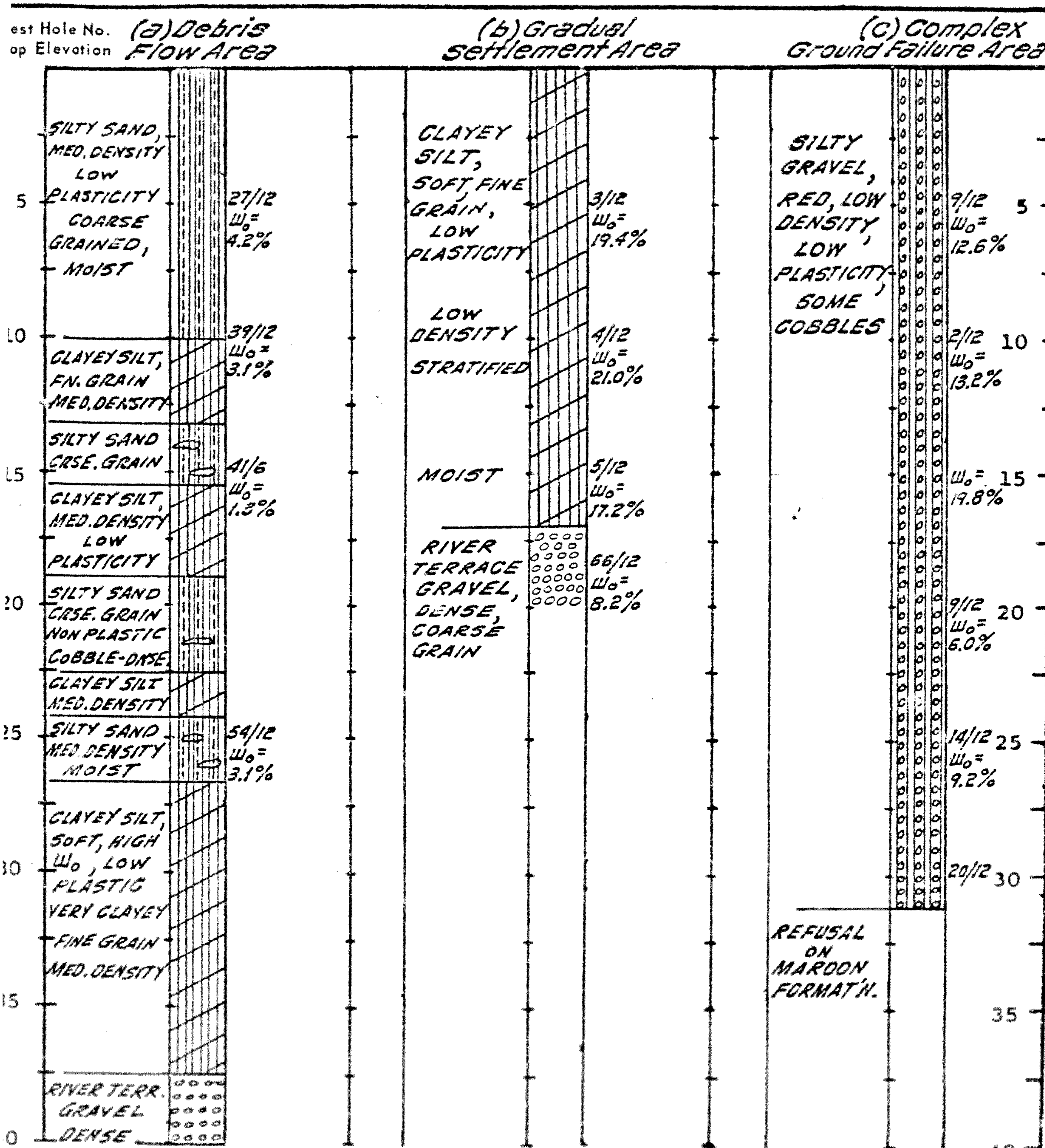


FIGURE 2: TYPICAL SOIL PROFILES (10/12 INDICATES STANDARD PENETRATION TEST RESULTS FOR 12" OF PENETRATION – ω_o INDICATES MOISTURE CONTENT)

DRILLING LOGS	LINCOLN–DeVORE TESTING LABORATORY COLORADO SPRINGS–PUEBLO, COLORADO

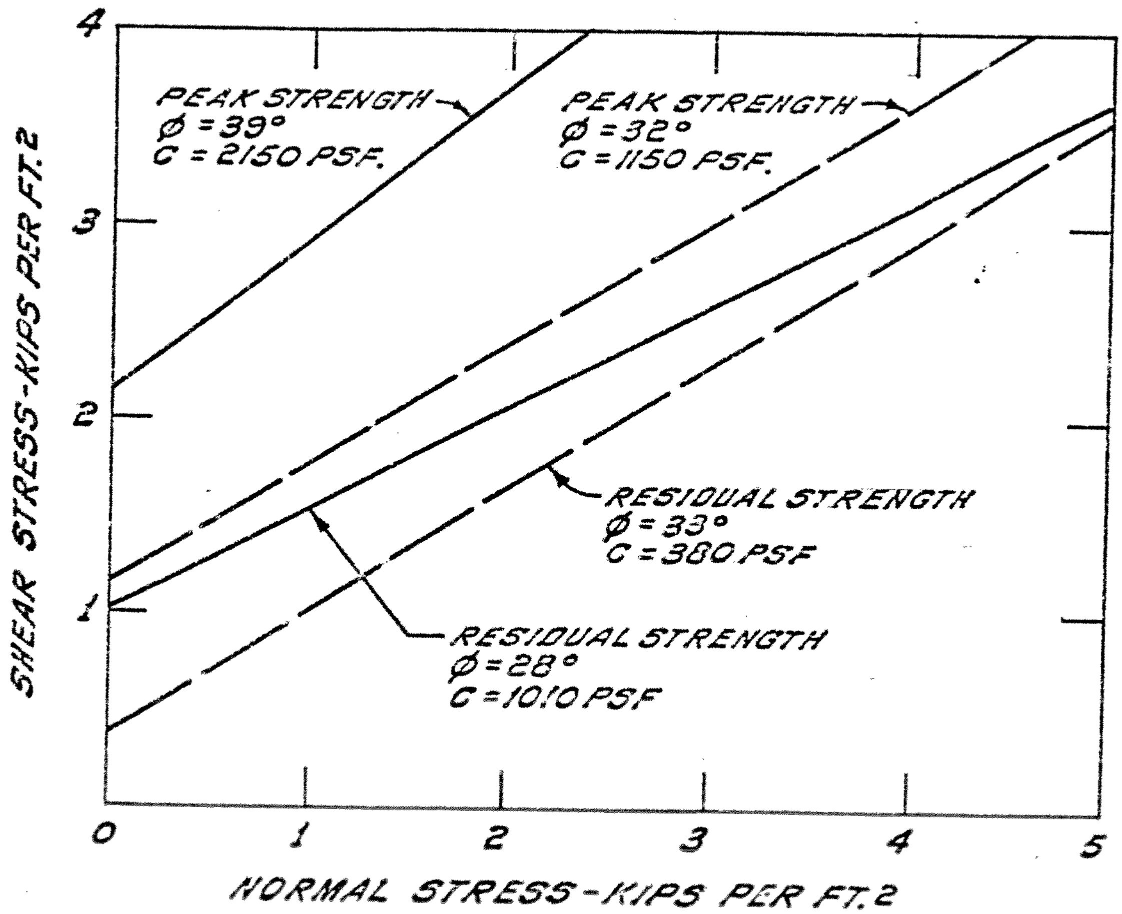
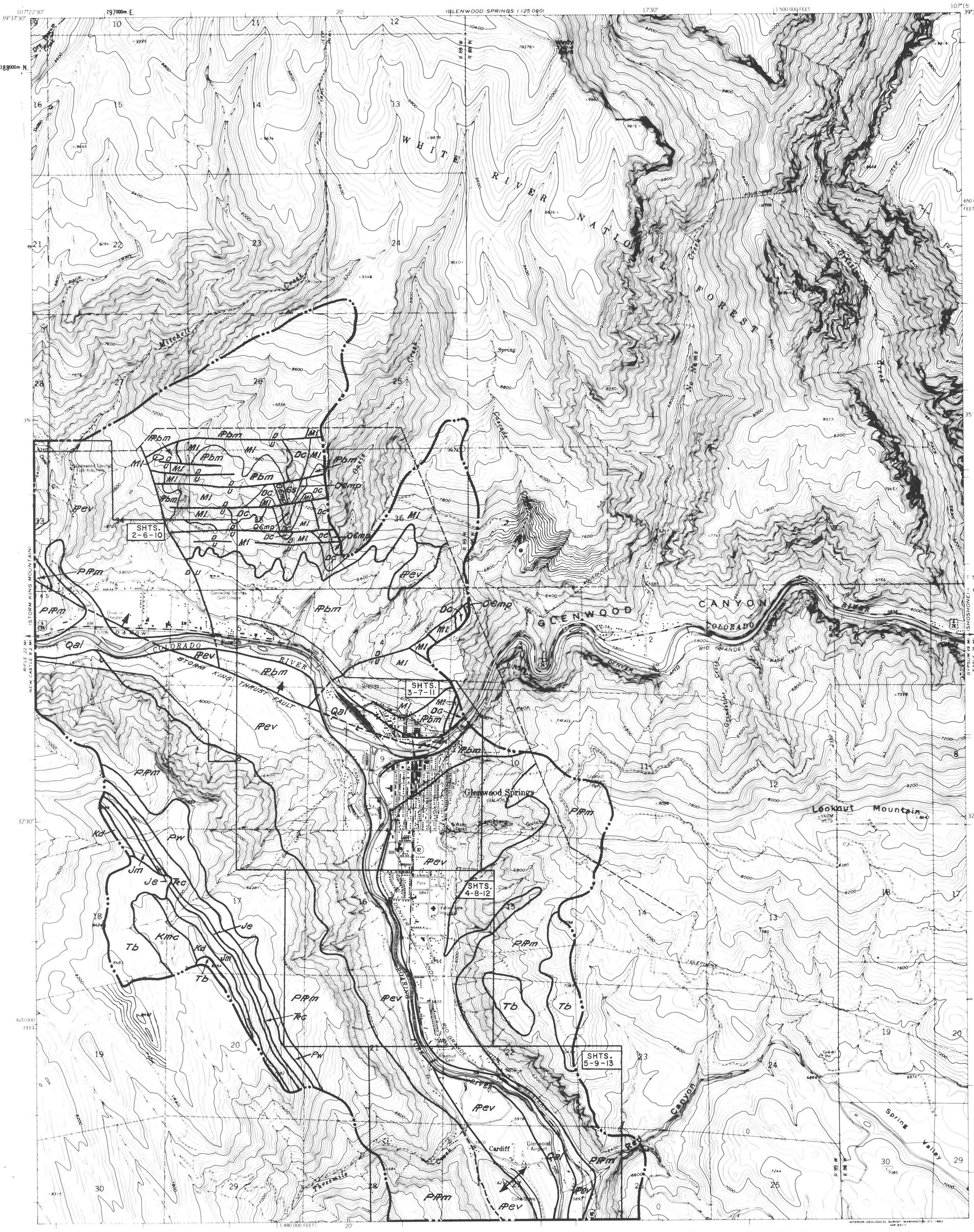


FIGURE 3 - COMPARISON OF PEAK AND RESIDUAL STRENGTH ENVELOPES
SOLID LINES: MAROON FORMATION - DERIVED CLAYEY SILT, CEMETARY HILL
DASHED LINES: MAROON FORMATION - DERIVED SILTY CLAY, 1600 BLAKE AVE.



EXPLANATION:

- [2-6-10] .... MAP SHEET BORDER AND INDEX NUMBER
- PROJECT BOUNDARY
- BEDROCK CONTACT
- U/D FAULTS (NORMAL AND THRUST)
- ANTICLINE AXIS

SYMBOL	AGE	UNIT
Qal	QUATERNARY	RIVER ALLUVIUM
Tb	TERTIARY	BASALT (LAVA FLOW)
Kmc	CRETACEOUS	MANCOS SHALE
Kd	CRETACEOUS	DAKOTA SANDSTONE
Jm	JURASSIC	MORRISON FORMATION
Je	JURASSIC	ENTRADA SANDSTONE
T̄Rc	TRIASSIC	CHINLE FORMATION
Pw	PERMIAN	WEBER SANDSTONE
PPm	PERMIAN – PENNSYLVANIAN	MAROON FORMATION
Pev	PENNSYLVANIAN	EAGLE VALLEY EVAPORITE
Pbm	PENNSYLVANIAN	BELDEN AND MOLAS FORMATIONS
Ml	MISSISSIPPIAN	LEADVILLE LIMESTONE
Dc	DEVONIAN	CHAFFEE FORMATION
O-Ꞓmp	ORDOVICIAN-CAMBRIAN	MANITOU AND PEERLESS FORMATIONS
Ꞓs	CAMBRIAN	SAWATCH QUARTZITE

Base map from U.S. Geological Survey "Glenwood Springs" 7.5' Quadrangle, 1961
Geology adapted from Morris et al., 1976.

GEOLOGIC REFERENCES:
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OLANDER, LAMM AND FLORQUIST, 1974, ROARING FORK AND CRYSTAL VALLEYS – AN ENVIRONMENTAL AND ENGINEERING GEOLOGY STUDY, EAGLE, GARFIELD, GUNNISON AND PITKIN COUNTIES, COLORADO: COLO. GEOL. SURVEY ENV. GEOL. No. 8

PREPARED FOR
THE COLORADO GEOLOGICAL SURVEY
JOHN W. ROLD, DIRECTOR
DEPARTMENT OF NATURAL RESOURCES
STATE OF COLORADO

IN CO-OPERATION WITH
THE CITY OF GLENWOOD SPRINGS, COLORADO AND THE COUNTY OF GARFIELD, COLORADO

SURFICIAL GEOLOGY AND DATA INDEX MAP
SHEET NUMBERS 2-3-4-5

DEBRIS FAN DEPOSITS AND HAZARDS
SHEET NUMBERS 6-7-8-9

GENERAL GEOLOGIC HAZARDS MAP
SHEET NUMBERS 10-11-12-13

COMPARATIVE STREAM PROFILES
SHEET NUMBER 14

NOTE: THESE MAPS ARE INTENDED FOR USE IN CONJUNCTION WITH THE REPORT, "DEBRIS FLOWS, HYDROCOMPACTION, AND GEOLOGIC HAZARDS IN GLENWOOD SPRINGS, COLORADO."

PROJECT BOUNDARY AND SHEET INDEX MAP
WITH GENERALIZED BEDROCK GEOLOGY
GEOLOGIC HAZARDS
OF THE
GLENWOOD SPRINGS METROPOLITAN AREA
GARFIELD COUNTY, COLORADO

LINCOLN DeVORE TESTING LABORATORY
COLORADO: Colorado Springs, Pueblo, Glenwood Springs, Montrose, Gunnison, Grand Junction – WYO. Rock Springs

2000 0 2000 4000
SCALE IN FEET
CONTOUR INTERVAL = 40 FEET

DECEMBER 1977

EXPLANATION:

SYMBOL	AGE	UNIT
Qdf	QUATERNARY	DEBRIS FAN, ACTIVE
Qcw	QUATERNARY	COLLUVIUM AND COLLUVIAL WEDGE, ACTIVE
Qal	QUATERNARY	STREAM ALLUVIUM, RECENT AND MODERN
Qt	QUATERNARY	STREAM TERRACE, VARIOUS AGES
Qtr	QUATERNARY	STREAM TERRACE, TRAVERTINE-CEMENTED, OLDER
Qls	QUATERNARY	LANDSLIDE DEPOSITS, MOSTLY OLDER
adf	TERTIARY-QUATERNARY	DEBRIS FLOW, MUDFLOW AND LANDSLIDE DEPOSITS, OLD
Tb	TERTIARY	BASALT LAVA FLOWS
PPm	PERMIAN-PENNSYLVANIAN	MAROON FORMATION
Pev	PENNSYLVANIAN	EAGLE VALLEY EVAPORITE
Pbm	PENNSYLVANIAN	BELDEN SHALE AND MOLAS FORMATION (UNDIVIDED)
Ml	MISSISSIPPIAN	LEADVILLE LIMESTONE
Dc	DEVONIAN	CHAFFEE FORMATION
O€mp	ORDOVICIAN-CAMBRIAN	MANITOU AND PEERLESS FORMATIONS (UNDIVIDED)

CONTACT BETWEEN GEOLOGIC UNITS

U/D FAULT, DASHED WHERE CONCEALED

THRUST FAULT, SHOWING OVERTHRUST PLATE, DASHED WHERE CONCEALED

①............DRILL HOLES

△............OTHER FIELD TESTING

□............BOULDER SIZE STUDIES

●............MISCELLANEOUS INFORMATION - DEPTH TO TERRACE, LIQUID LIMIT (LL), DRY DENSITY (γ)

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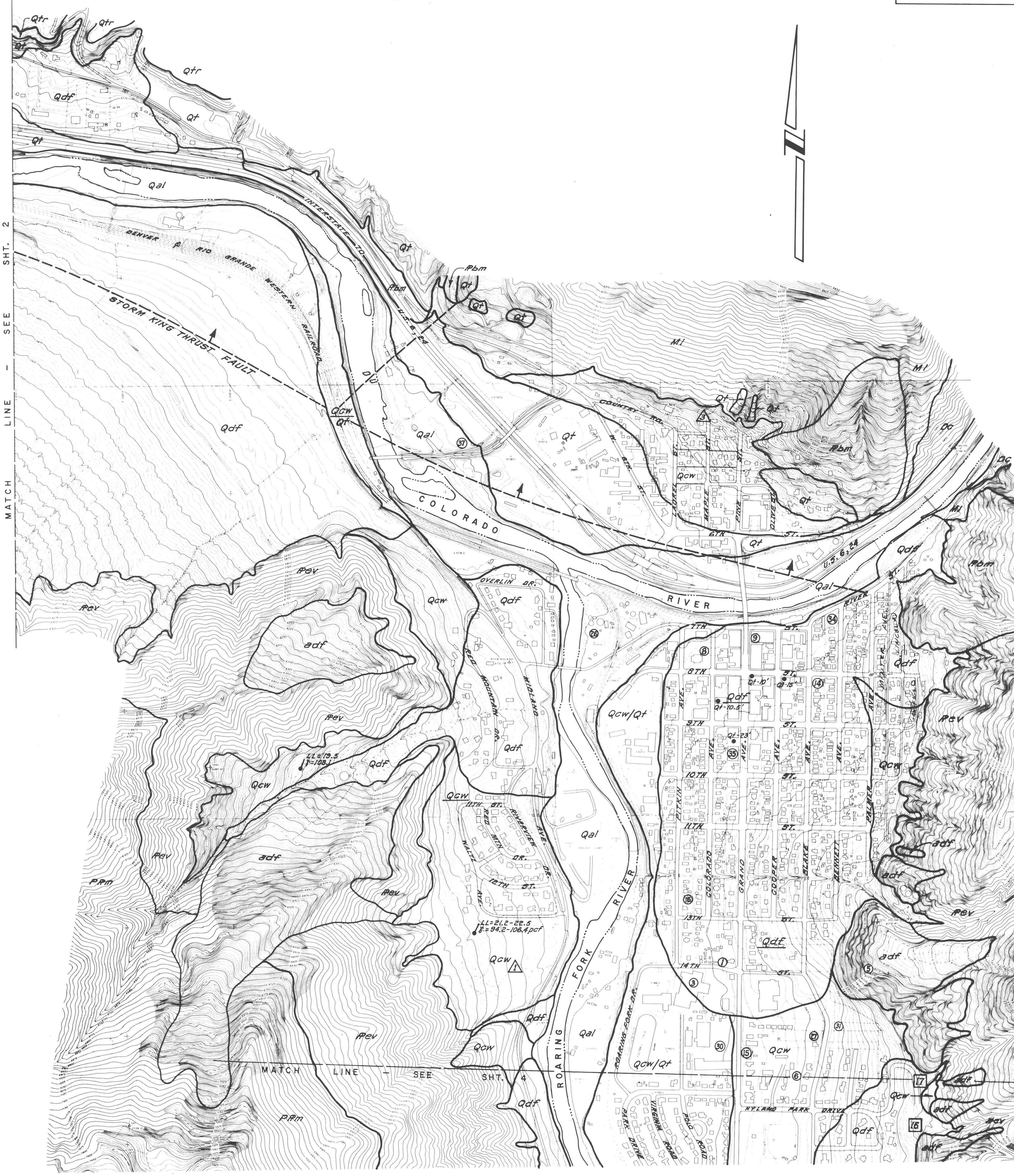
400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

SURFICIAL GEOLOGY AND DATA INDEX MAP

GEOLOGIC HAZARDS OF THE GLENWOOD SPRINGS METROPOLITAN AREA

GARFIELD COUNTY, COLORADO

DECEMBER 1977



SEE SHEET NO. 2 FOR EXPLANATION OF SYMBOLS AND NOTE.

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400 0 400 800
SCALE IN FEET
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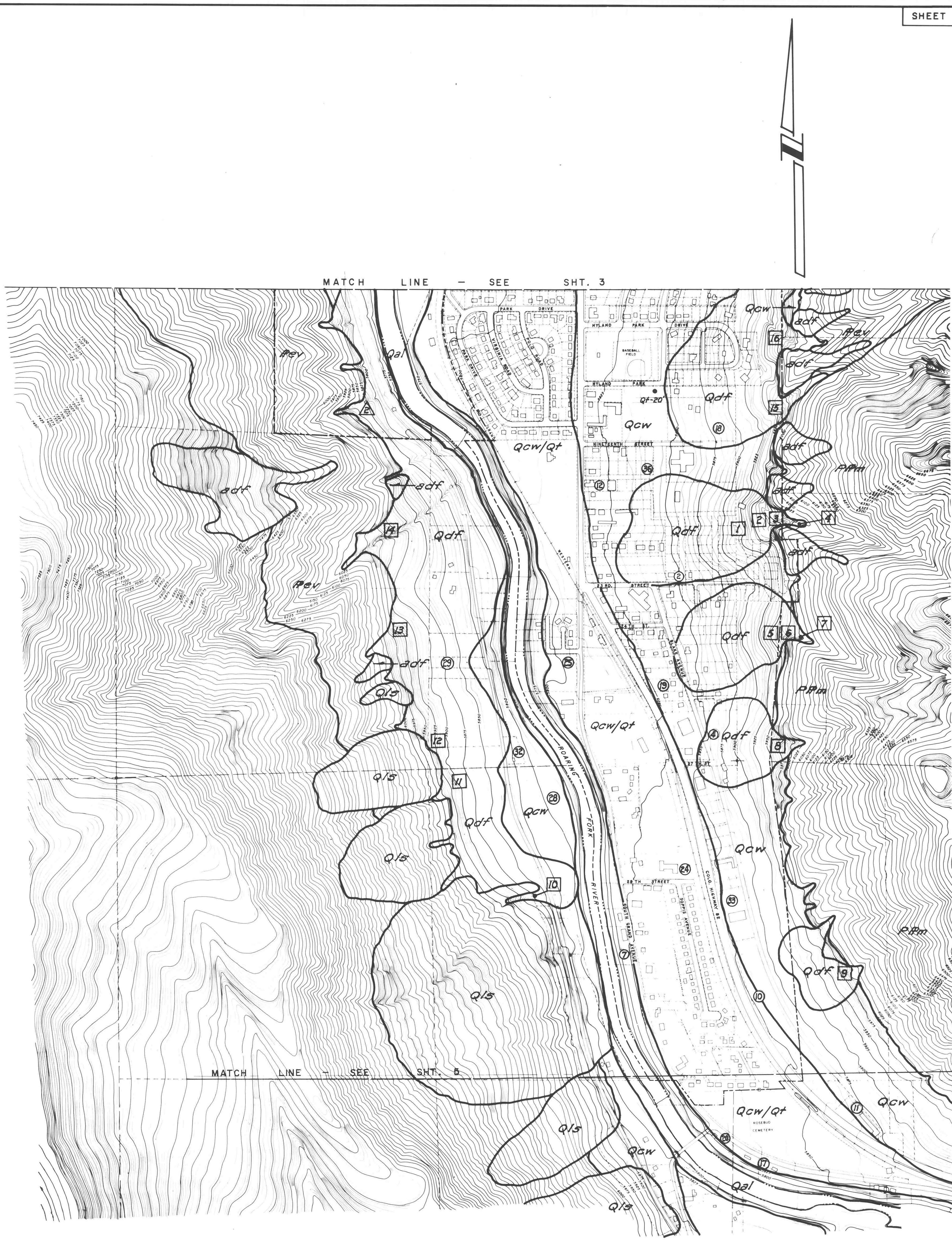
DECEMBER 1977



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400 0 400 800
SCALE IN FEET
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SURFICIAL GEOLOGY AND DATA INDEX MAP

GEOLOGIC HAZARDS
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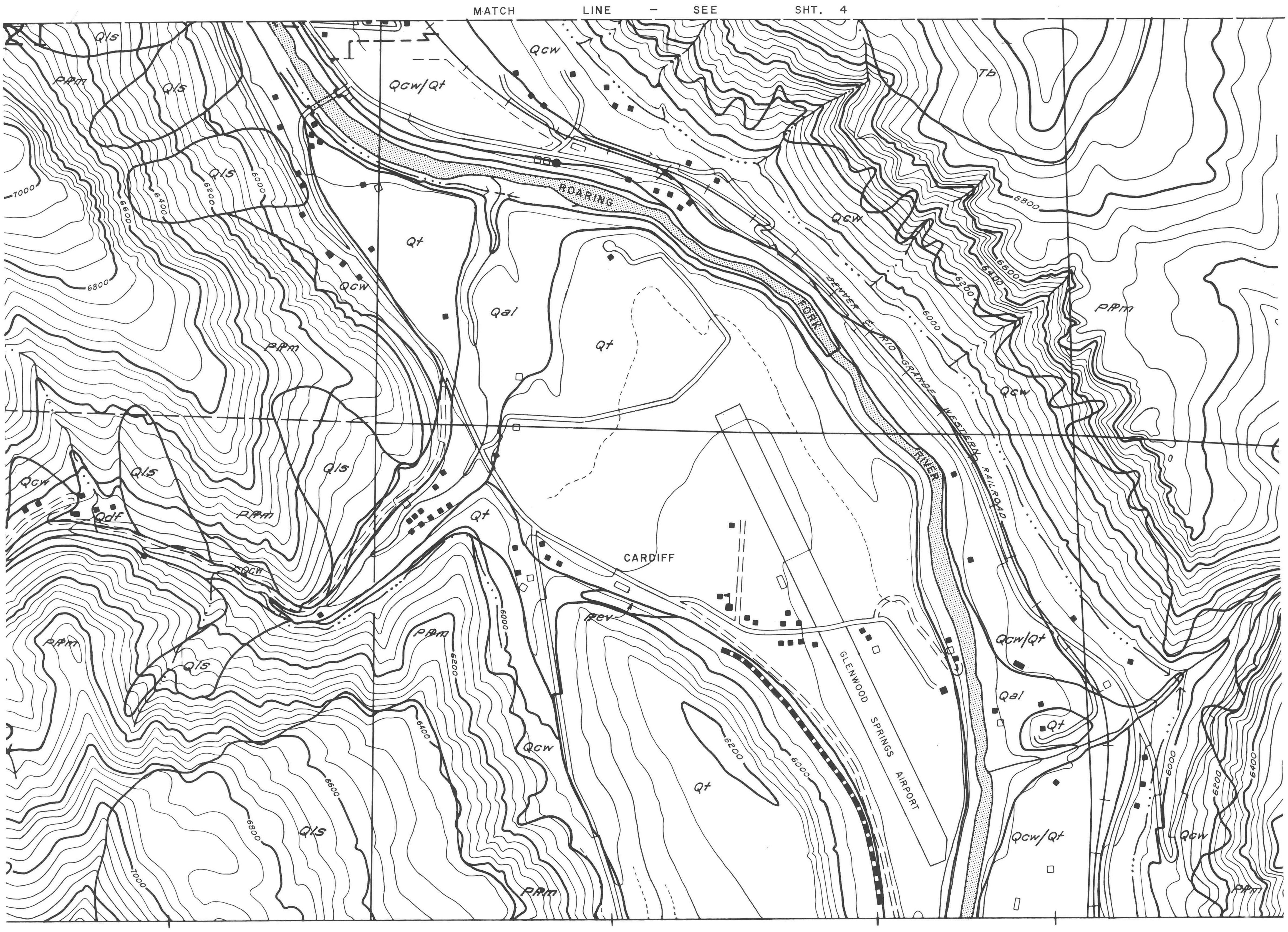
GLENWOOD SPRINGS METROPOLITAN AREA
GARFIELD COUNTY, COLORADO

DECEMBER 1977



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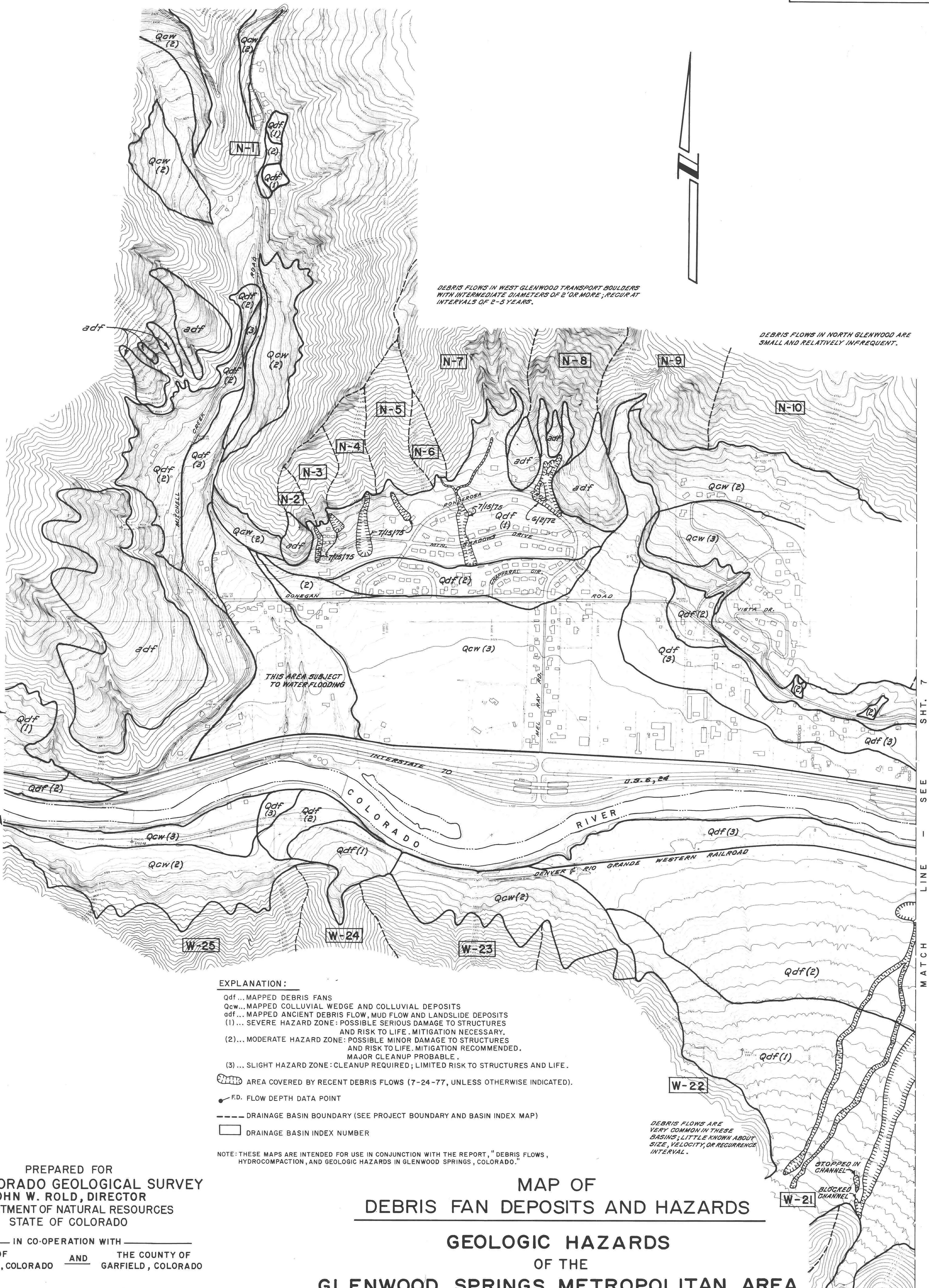
400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 40 FEET

SURFICIAL GEOLOGY AND DATA INDEX MAP

GEOLOGIC HAZARDS
OF THE
GLENWOOD SPRINGS METROPOLITAN AREA
GARFIELD COUNTY, COLORADO

DECEMBER 1977



EXPLANATION:

Qdf ... MAPPED DEBRIS FANS
Qcw ... MAPPED COLLUVIAL WEDGE AND COLLUVIAL DEPOSITS
adf ... MAPPED ANCIENT DEBRIS FLOW, MUD FLOW AND LANDSLIDE DEPOSITS
(1) ... SEVERE HAZARD ZONE: POSSIBLE SERIOUS DAMAGE TO STRUCTURES AND RISK TO LIFE. MITIGATION NECESSARY.
(2) ... MODERATE HAZARD ZONE: POSSIBLE MINOR DAMAGE TO STRUCTURES AND RISK TO LIFE. MITIGATION RECOMMENDED. MAJOR CLEANUP PROBABLE.
(3) ... SLIGHT HAZARD ZONE: CLEANUP REQUIRED; LIMITED RISK TO STRUCTURES AND LIFE.

AREA COVERED BY RECENT DEBRIS FLOWS (7-24-77, UNLESS OTHERWISE INDICATED).

F.D. FLOW DEPTH DATA POINT

DRAINAGE BASIN BOUNDARY (SEE PROJECT BOUNDARY AND BASIN INDEX MAP)

DRAINAGE BASIN INDEX NUMBER

NOTE: THESE MAPS ARE INTENDED FOR USE IN CONJUNCTION WITH THE REPORT, "DEBRIS FLOWS, HYDROCOMPACTION, AND GEOLOGIC HAZARDS IN GLENWOOD SPRINGS, COLORADO."

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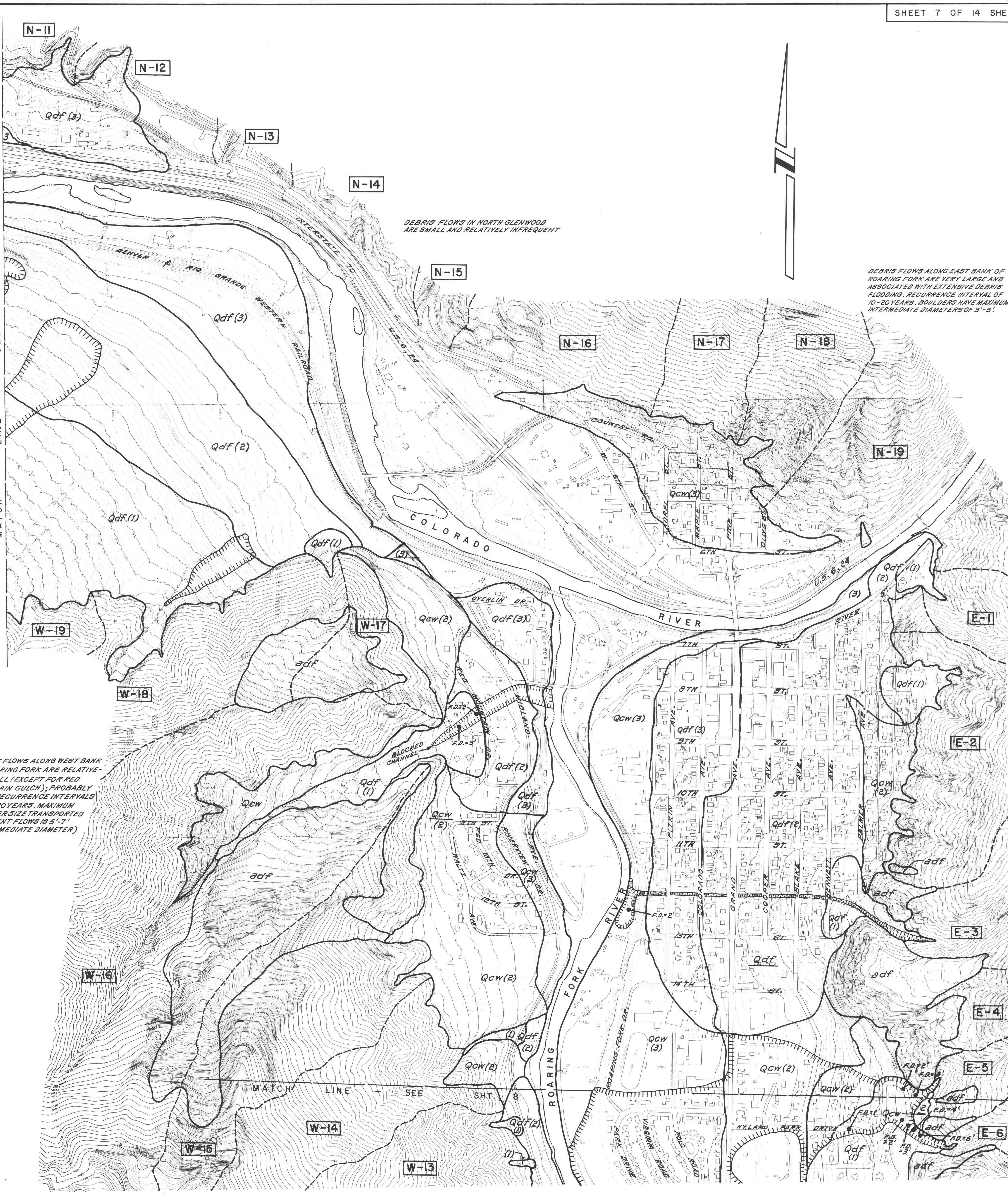
400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

MAP OF DEBRIS FAN DEPOSITS AND HAZARDS

GEOLOGIC HAZARDS OF THE GLENWOOD SPRINGS METROPOLITAN AREA

GARFIELD COUNTY, COLORADO

DECEMBER 1977



SEE SHEET NO. 6 FOR EXPLANATION OF SYMBOLS AND NOTE.

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400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

MAP OF DEBRIS FAN DEPOSITS AND HAZARDS

GEOLOGIC HAZARDS
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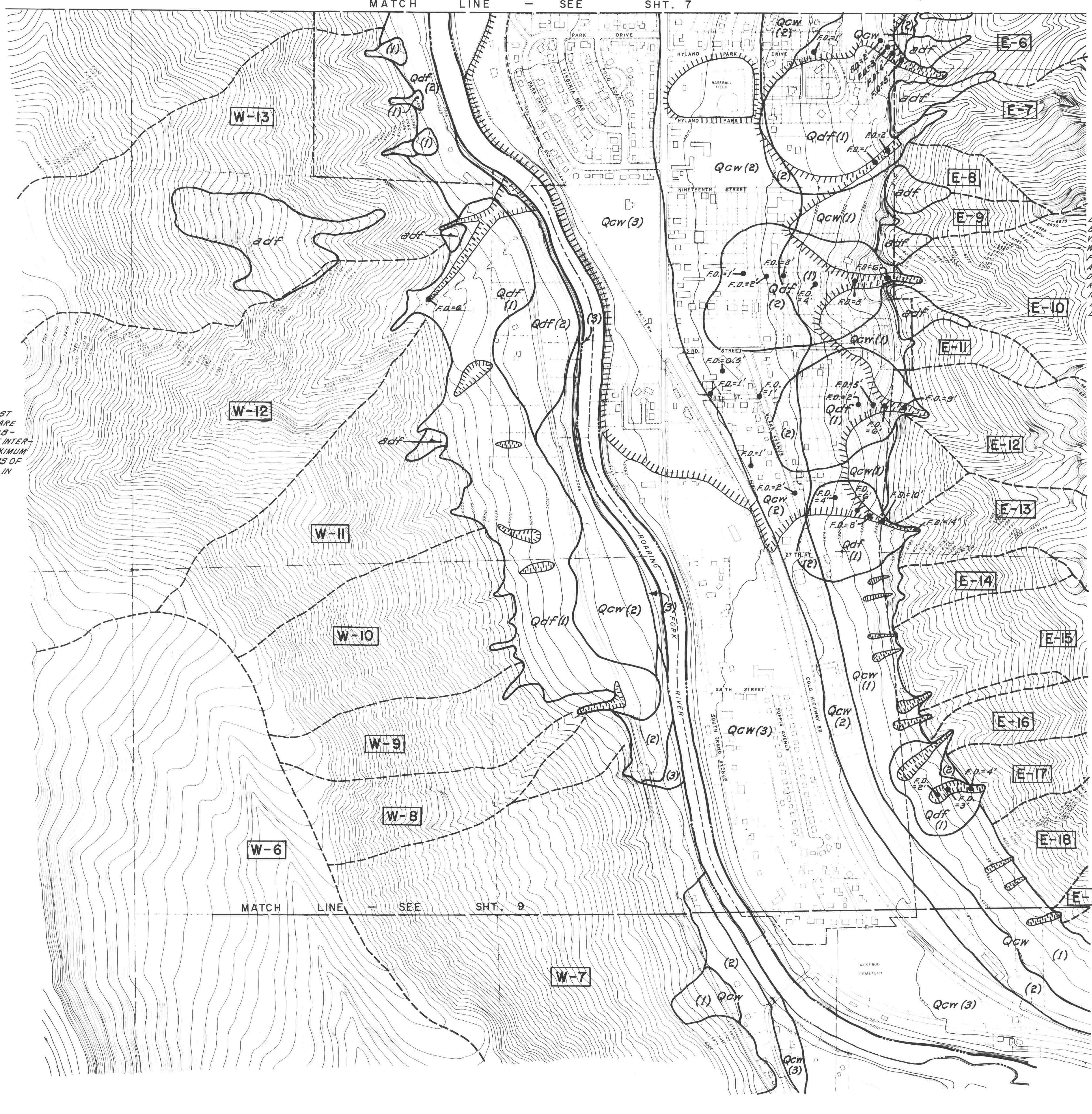
GARFIELD COUNTY, COLORADO

DECEMBER 1977



DEBRIS FLOWS ALONG WEST BANK OF ROARING FORK ARE RELATIVELY SMALL; PROBABLY HAVE RECURRENCE INTERVALS OF 10-20 YEARS. MAXIMUM INTERMEDIATE DIAMETERS OF BOULDERS TRANSPORTED IN RECENT FLOWS IS 5'-7'.

DEBRIS FLOWS ALONG EAST BANK OF ROARING FORK ARE VERY LARGE AND ASSOCIATED WITH EXTENSIVE DEBRIS FLOODING. BOTH FLOW SIZE AND MAGNITUDE OF FLOODING DECREASE TO THE SOUTH. RECURRENCE INTERVAL OF 10-20 YEARS. BOULDERS HAVE MAXIMUM INTERMEDIATE DIAMETERS OF 3'-5'.

SEE SHEET NO. 6 FOR EXPLANATION OF SYMBOLS AND NOTE.

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400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

MAP OF DEBRIS FAN DEPOSITS AND HAZARDS

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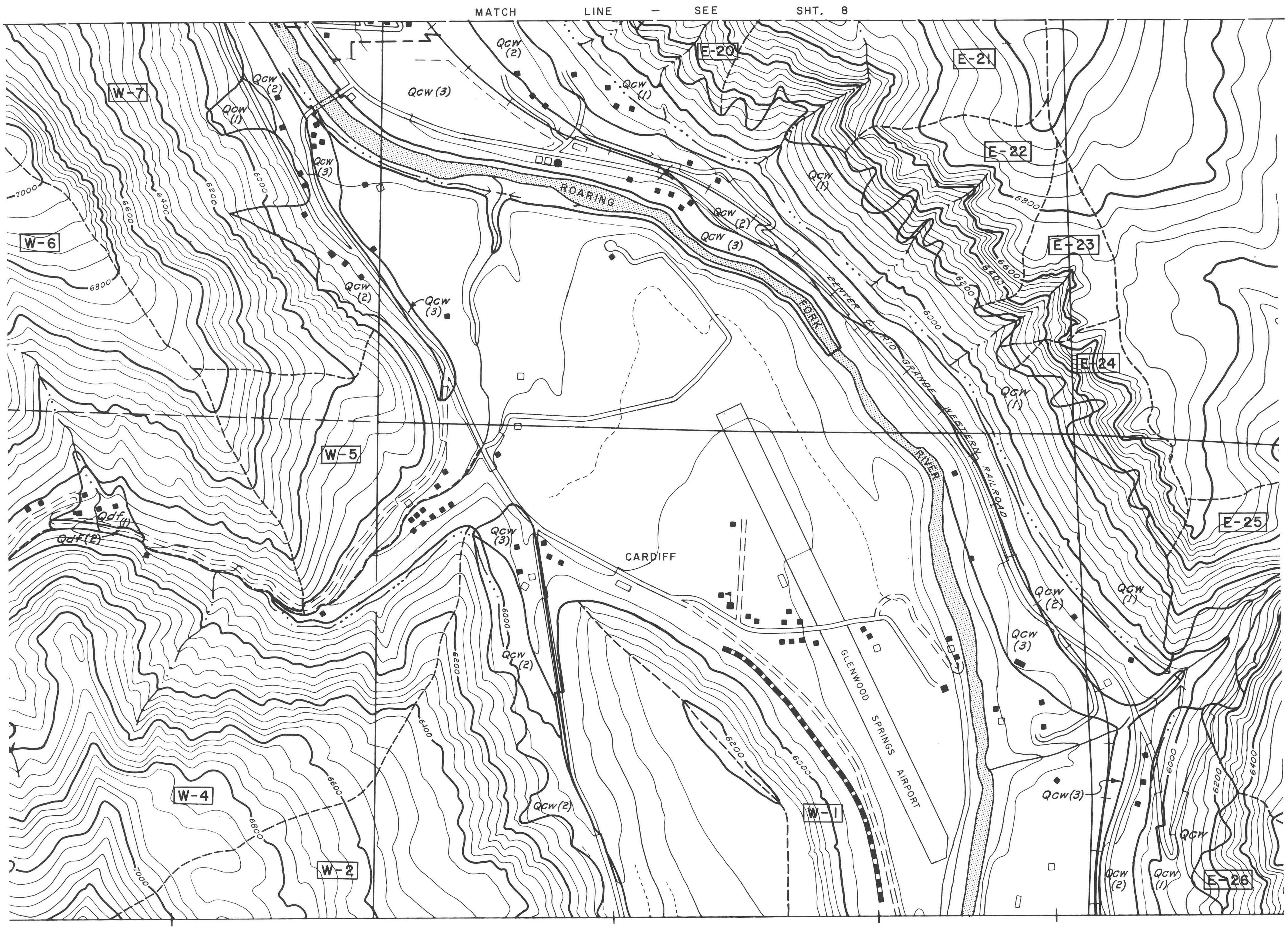
DECEMBER 1977



DEBRIS FLOWS ON THIS SHEET ARE NOT SUPPORTED BY RELIABLE RECORDS.
HAZARD ZONES ARE BASED ON CHARACTERISTICS INFERRED FROM REMAINDER OF STUDY AREA.

SEE SHEET NO. 6 FOR EXPLANATION OF SYMBOLS AND NOTE.

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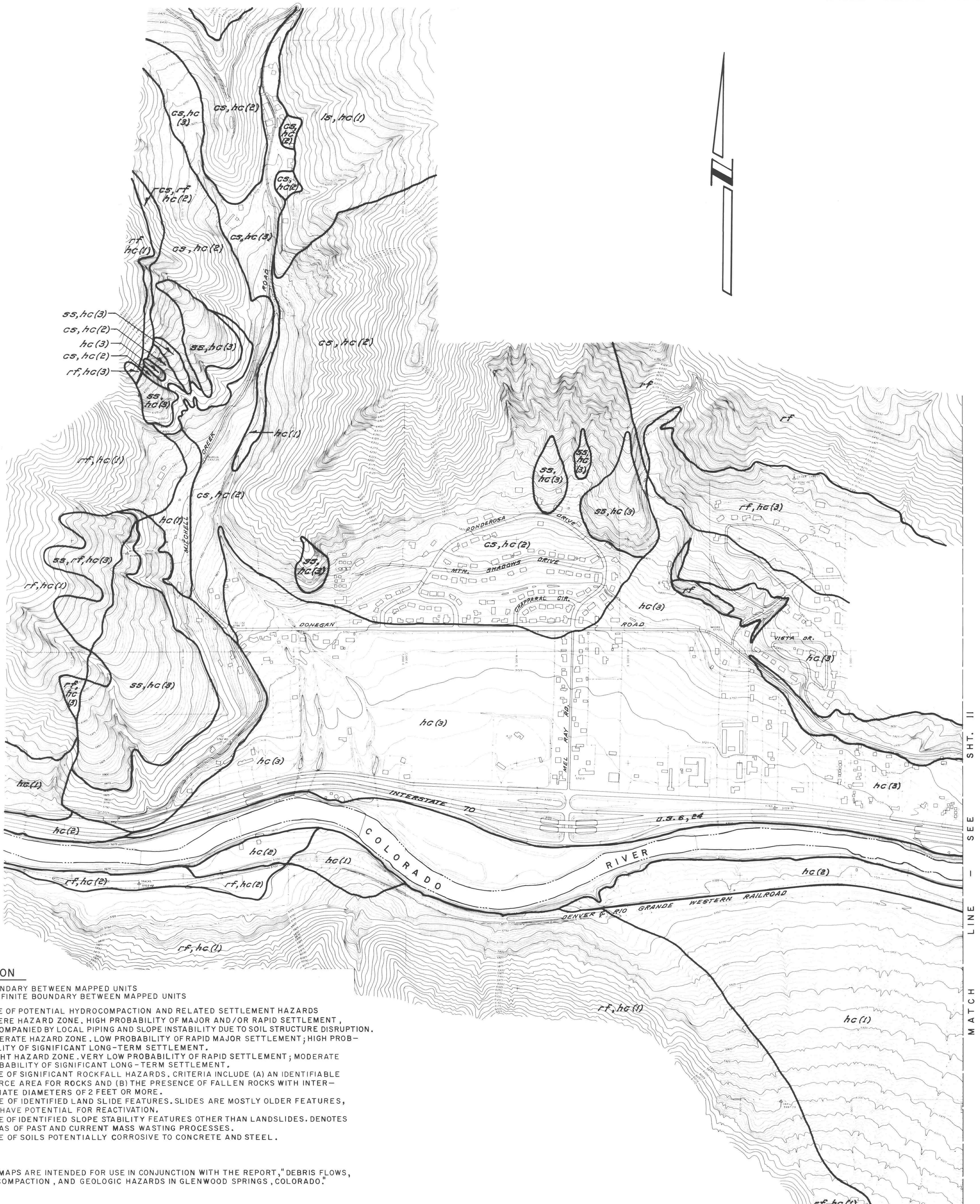
400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 40 FEET

MAP OF DEBRIS FAN DEPOSITS AND HAZARDS

GEOLOGIC HAZARDS OF THE GLENWOOD SPRINGS METROPOLITAN AREA

GARFIELD COUNTY, COLORADO

DECEMBER 1977



EXPLANATION

BOUNDARY BETWEEN MAPPED UNITS
INDEFINITE BOUNDARY BETWEEN MAPPED UNITS

hc ------ ZONE OF POTENTIAL HYDROCOMPACTION AND RELATED SETTLEMENT HAZARDS
(1) ------ SEVERE HAZARD ZONE. HIGH PROBABILITY OF MAJOR AND/OR RAPID SETTLEMENT, ACCOMPANIED BY LOCAL PIPING AND SLOPE INSTABILITY DUE TO SOIL STRUCTURE DISRUPTION.
(2) ------ MODERATE HAZARD ZONE. LOW PROBABILITY OF RAPID MAJOR SETTLEMENT; HIGH PROBABILITY OF SIGNIFICANT LONG-TERM SETTLEMENT.
(3) ------ SLIGHT HAZARD ZONE. VERY LOW PROBABILITY OF RAPID SETTLEMENT; MODERATE PROBABILITY OF SIGNIFICANT LONG-TERM SETTLEMENT.
rf ------ ZONE OF SIGNIFICANT ROCKFALL HAZARDS. CRITERIA INCLUDE (A) AN IDENTIFIABLE SOURCE AREA FOR ROCKS AND (B) THE PRESENCE OF FALLEN ROCKS WITH INTERMEDIATE DIAMETERS OF 2 FEET OR MORE.
ls ------ ZONE OF IDENTIFIED LAND SLIDE FEATURES. SLIDES ARE MOSTLY OLDER FEATURES, BUT HAVE POTENTIAL FOR REACTIVATION.
ss ------ ZONE OF IDENTIFIED SLOPE STABILITY FEATURES OTHER THAN LANDSLIDES. DENOTES AREAS OF PAST AND CURRENT MASS WASTING PROCESSES.
cs ------ ZONE OF SOILS POTENTIALLY CORROSIVE TO CONCRETE AND STEEL.

NOTE: THESE MAPS ARE INTENDED FOR USE IN CONJUNCTION WITH THE REPORT, "DEBRIS FLOWS, HYDROCOMPACTION, AND GEOLOGIC HAZARDS IN GLENWOOD SPRINGS, COLORADO."

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400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

GENERAL GEOLOGIC HAZARDS MAP

GEOLOGIC HAZARDS OF THE GLENWOOD SPRINGS METROPOLITAN AREA

GARFIELD COUNTY, COLORADO

DECEMBER 1977

SEE SHEET NO. 10 FOR EXPLANATION OF SYMBOLS AND NOTE.

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400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

GENERAL GEOLOGIC HAZARDS MAP

GEOLOGIC HAZARDS
OF THE
GLENWOOD SPRINGS METROPOLITAN AREA
GARFIELD COUNTY, COLORADO

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LINCOLN DeVORE TESTING LABORATORY	COLORADO: Colorado Springs, Pueblo, Glenwood Springs, Montrose, Gunnison, Grand Junction - WYO. Rock Springs

400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

GENERAL GEOLOGIC HAZARDS MAP

GEOLOGIC HAZARDS
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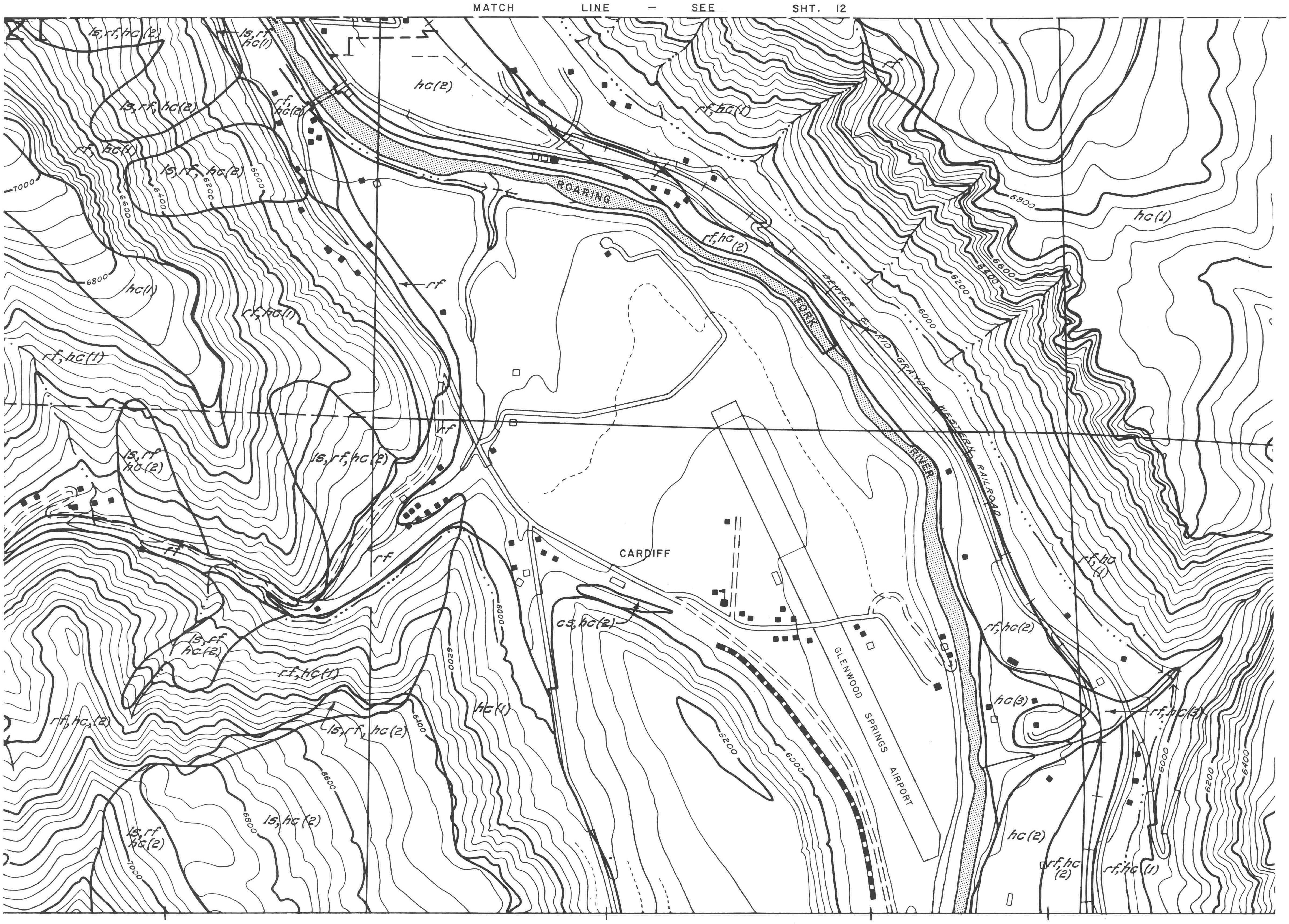
GARFIELD COUNTY, COLORADO

DECEMBER 1977

MATCH LINE — SEE SHT. 12



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400 0 400 800
SCALE IN FEET
CONTOUR INTERVAL = 5 FEET

GENERAL GEOLOGIC HAZARDS MAP

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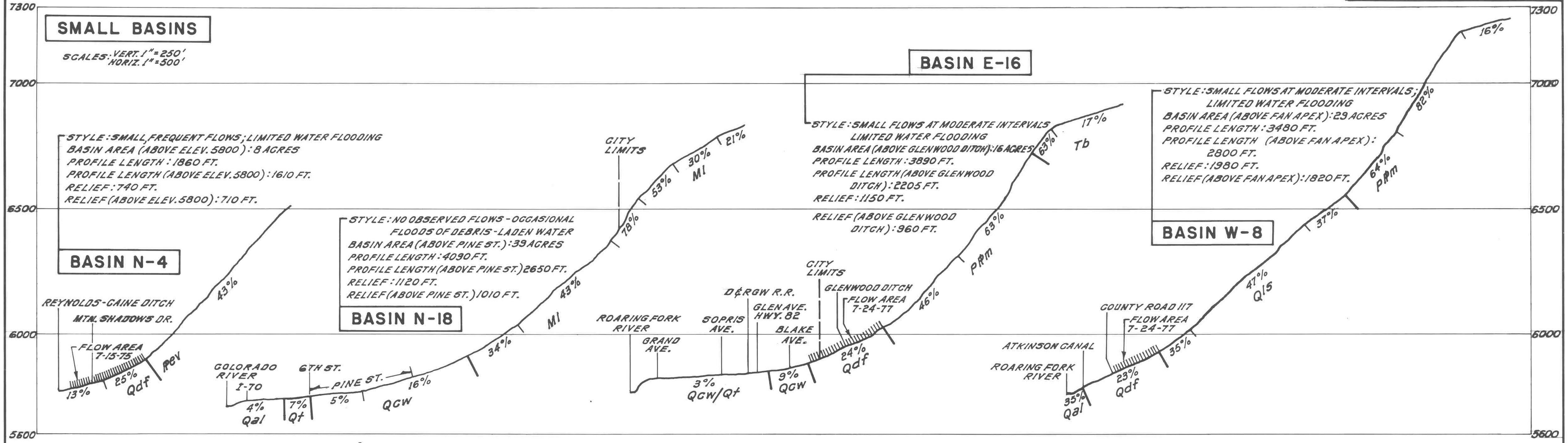
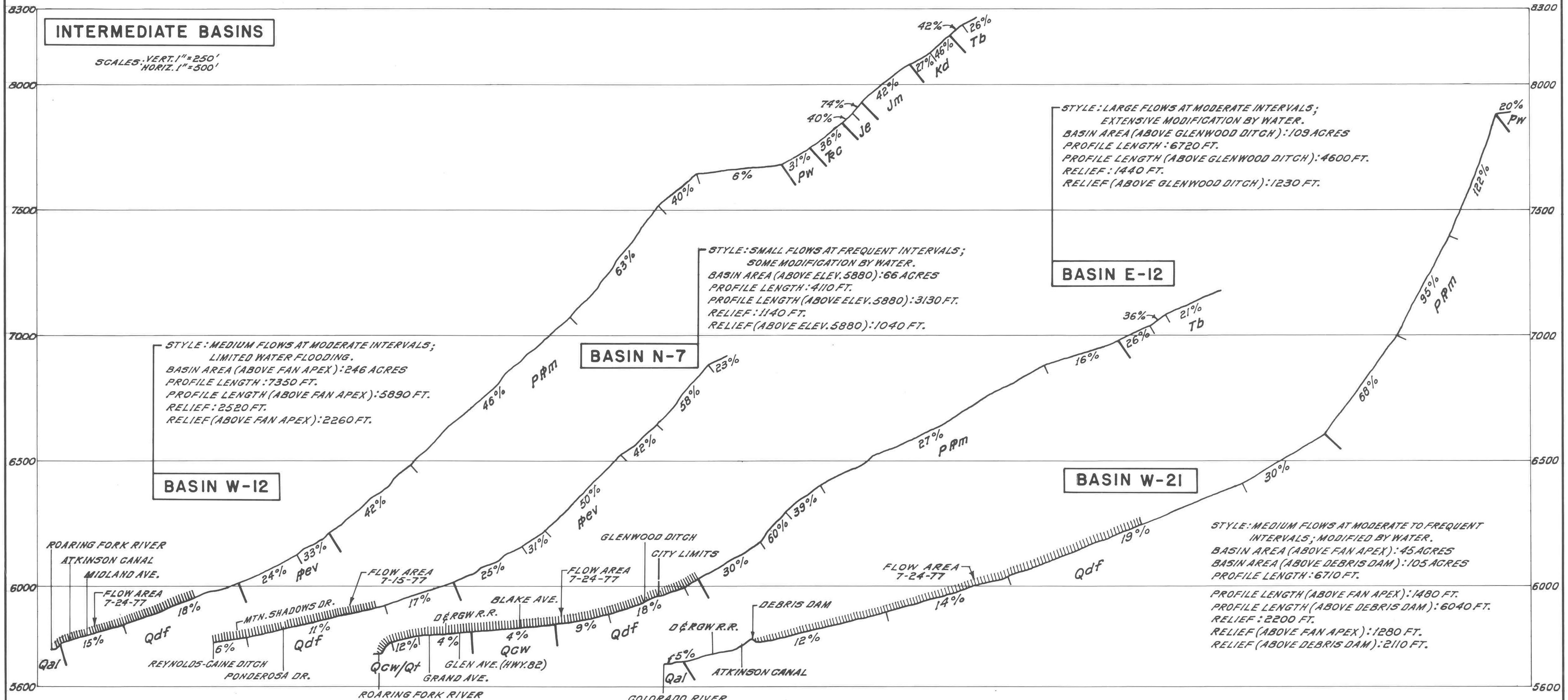
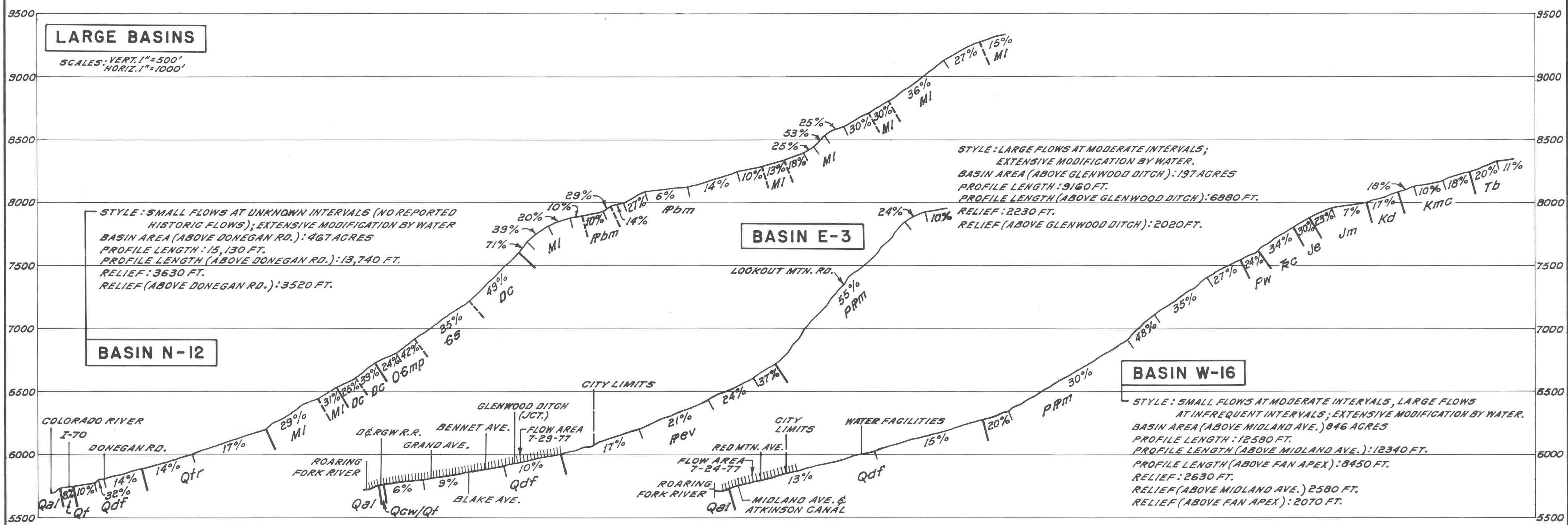
DECEMBER 1977







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EXPLANATION:

VERTICAL EXAGGERATION = 2X
BREAK IN SLOPE
GEOLOGIC CONTACT
FAULT
DEBRIS FLOW AREA

SURFICIAL DEPOSIT SYMBOLS:
Qal.... ALLUVIUM
Qt..... STREAM TERRACE
Qcw.... COLLUVIUM & COLLUVIAL WEDGE
Qdf.... DEBRIS FAN
Qls.... ANCIENT LANDSLIDE

FOR EXPLANATION OF BEDROCK SYMBOLS, SEE SHEET NO. 1

COMPARATIVE STREAM PROFILES SHEET

GEOLOGIC HAZARDS
OF THE
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GARFIELD COUNTY, COLORADO