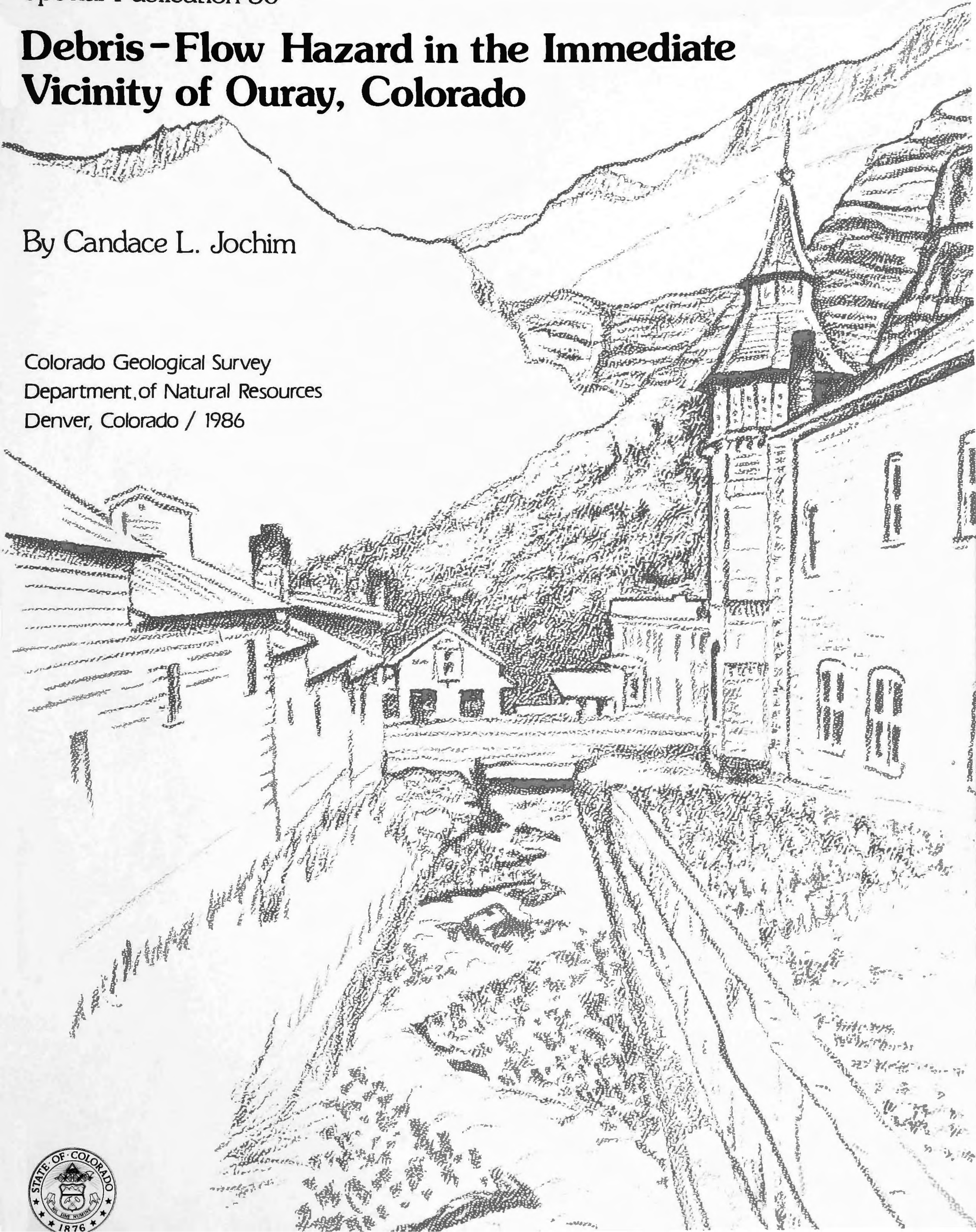
Special Publication 30

Debris-Flow Hazard in the Immediate Vicinity of Ouray, Colorado

By Candace L. Jochim

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado / 1986



Cover: Looking west down Portland Creek flume. Elk's Lodge on right.
Sketch by Cheryl Brchan (from photograph).

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INTRODUCTION

Debris flows are among the most destructive geologic processes that occur in mountainous areas. While modern land-use planning should prevent construction in areas subject to debris-flow hazard, debris fans have historically been enticing places to build. They often provide the only apparently "suitable" construction sites between areas of steep valley sides and riverine flooding. Most of Colorado's mountain towns were founded during the mining-boom era from 1860 to 1900 and were built without the benefits of land-use planning or much understanding of the debris-flow process. The existence of communities in geologically hazardous areas presents a potential threat to the inhabitants, as well as a financial burden on local and state governments.

Ouray, Colorado, is a small mountain city that has periodically experienced damaging debris flows since it was founded in 1875. Although there have been no recorded human fatalities within the city itself, recurring damages to buildings, roads, and water and sewer systems and attempts at structural control have been very costly.

There are eight sizable creeks and several smaller basins and gullies that can directly affect the city of Ouray or the areas of potential growth associated with it. All of these creeks and gullies were studied in order to evaluate the debris-flow problem that confronts the city. The eight major creeks studied were Portland, Cascade, Skyrocket, Canyon, Oak, Bridalveil, Corbett, and Dexter.

The main part of the city is located on the debris fans of Portland, Cascade, and Oak Creeks (the corporate limits include Skyrocket and Bridalveil Creeks). The geologic processes that formed these fans are still active today. Intense summer thunderstorms occur over the basins of the creeks. The creek beds range from 7,600 feet to 12,800 feet elevation. High rates of runoff result. In the process of falling 5000 feet, the water can pick up fine silt and clay as well as sand, gravel, boulders, and dislodged timber and combine them to form a debris flow.

The size and frequency of debris-flow events are dependent upon several factors including the amount of loose material available for redistribution in the basins, the magnitude and frequency of the storms, and the antecedent soaking rainfall and/or snowmelt in the basin.

Systematic hydrologic records have never been kept for the creeks in the study area. Therefore, the relative magnitude of past events must be estimated from newspaper reports, pictures, and physical field evidence. Although it appears that some minor flooding may occur every few years, the most significant events occurred in 1909, 1927, 1929, 1951, 1965, 1971, 1973, 1981, and 1982 (Table 1). In historical accounts, the terms "flood", "flash flood", and "mudflow" were used to describe the events. From descriptions, pictures, and physical evidence it is apparent that most of the reported large events included debris flows. The effects of these events were studied, and their probable mechanisms interpreted, in order to make a map of hazardous areas and recommendations for mitigation measures.

Based on the frequency of events in the past, Ouray can expect damaging storms at intervals of approximately 10 to 25 years. Because of the certainty of future debris-flow events and the limited success of past remedial measures, additional measures have been developed to minimize potential damage to existing development. Through careful land-use planning and the use of improved engineering methods to design structural solutions, future debris-flow damage to the city of Ouray and the areas of population associated with it can be reduced, but probably not eliminated.

In this study the geology and flood history of each basin are discussed, and a generalized map of areas subject to debris-flow and flooding hazard is presented. The map also includes the 100-year flood plain of the Uncompahgre River as determined by A & S Consultants, Inc., in 1978 and designated by the Colorado Water Conservation Board (CWCB) in 1981.

Acknowledgments

Sincere appreciation is extended to Pat Rogers of the Colorado Geological Survey and William P. Stanton of the Colorado Water Conservation Board for their critical reviews of the manuscript and their innumerable constructive suggestions for its improvement; and Cheryl Brchan for drafting.

Table 1. Dates of major debris-flow events and the creeks affected.

YEAR	DATE	PORTLAND	CASCADE	SKYROCKET	CANYON	OAK	BRIDALVEIL	CORBETT	DEXTER	SOURCES OF INFORMATION	
1874	?							●		The Ouray Herald	6/09/06
1878	7-22	●								The Times	7/27/1878
1909	7-21	●	●						●	The Ouray Herald	7/23/09
1909	8-17		●						●	The Ouray Herald	8/20/09
1909	8-22	●	●							The Ouray Herald	8/27/09
1909	8-23	●	●							The Ouray Herald	8/27/09
1923	7-20			●						Follansbee and Sawyer	7/20/23
1927	7-27		●	●	●	●		●	●	The Ouray Herald The Montrose Press	7/29/27 7/28/27
1927	9-(?9-12)			●	●					The Ouray Herald	9/16/27
1929	7-25	●	●	●	●	●		●	●	The Ouray Herald The Montrose Daily Press	8/02/29 7/26/29
1929	7-26	●	●	●	●			●		The Ouray Herald The Montrose Daily Press	8/02/29 7/27/29 7/29/29
1951*	8-2		●	●			●		●	The Ouray Herald	8/10/51
1965	7-11	●	●							The Ouray County Herald	7/15/65
1965	7-12	●								The Ouray County Herald	7/15/65
1971	8-27				●	●		●		The Ouray County Plaindealer and Herald	9/02/71
1973	7-8		●							The Ouray County Plaindealer and Herald	7/12/73
1981	7-14	●	●	●						The Ouray County Plaindealer	7/16/81
1981	7-15	●	●	●						The Ouray County Plaindealer	7/16/81
1982	8-20	●	●							The Ouray County Plaindealer	8/26/82
1982	8-21	●	●							The Ouray County Plaindealer	8/26/82
1982	8-22	●	●							The Ouray County Plaindealer	8/26/82
1982	8-23	●	●							The Ouray County Plaindealer	8/26/82

Creeks on which debris flows occurred during a single event.

* The evidence for a debris flow having occurred on Bridalveil Creek in 1951 is based on a 1955 airphoto that shows a wide, fresh-looking debris-flow track to the north of the current (1986) channel. According to the 1955 USGS topographic map, the creek is running in that channel. There is some evidence on the photo that a channel also existed where the channel is now. This indicates that the creek switched channels sometime prior to 1955 and again since then. In addition, the 1951 newspaper account states that all creeks in that area were "running" during the 1951 event.

DEBRIS FANS AND THEIR DEPOSITIONAL PROCESSES

Debris Fans

Debris fans are usually triangular-shaped landforms that are created as a result of the deposition of a heterogeneous mixture of clay, silt, boulders, and organic debris at the confluence of a tributary with the valley floor of a larger stream. The debris deposited originates in the basin of the tributary and is transported to the fan by debris flows, mudflows, and water floods.

The triangular shape of the debris fan is due to sudden deposition caused by the decrease in gradient and increase in area as the tributary leaves it's constricted channel and enters the main valley floor; and the consequent decrease in depth and velocity and increase in internal friction of the flowing debris (Fig. 1, A).

The specific shape, size, and slope of individual fans are determined by the type and amount of sediment available and the transport capacity of the flow medium.

The relative activity of a fan can be estimated by the amount, type, and maturity of vegetative growth on the fan and by whether or not the fan is truncated, incised, or receding.

If activity on the fan is infrequent and/or of low intensity, trees and shrubs will have the opportunity to establish themselves. Mature stands of evergreens such as fir and pine trees indicate low intensity events or infrequent activity (Figs. 1, C, D). Stands of aspen, however, may indicate a recent flow (or an avalanche) since aspen are the first trees to establish themselves in a denuded area (Fig. 1, E).

Incision at the fan apex, or in the tributary channel, indicates erosive activity. This is usually the result of water-dominated events and indicates low sediment supply to the fan (Fig. 1, B). It does not necessarily indicate low activity.

A truncated fan (Figs. 1, C, D), may indicate a low or infrequent sediment supply since the mainstream is able to erode away the edge of the fan

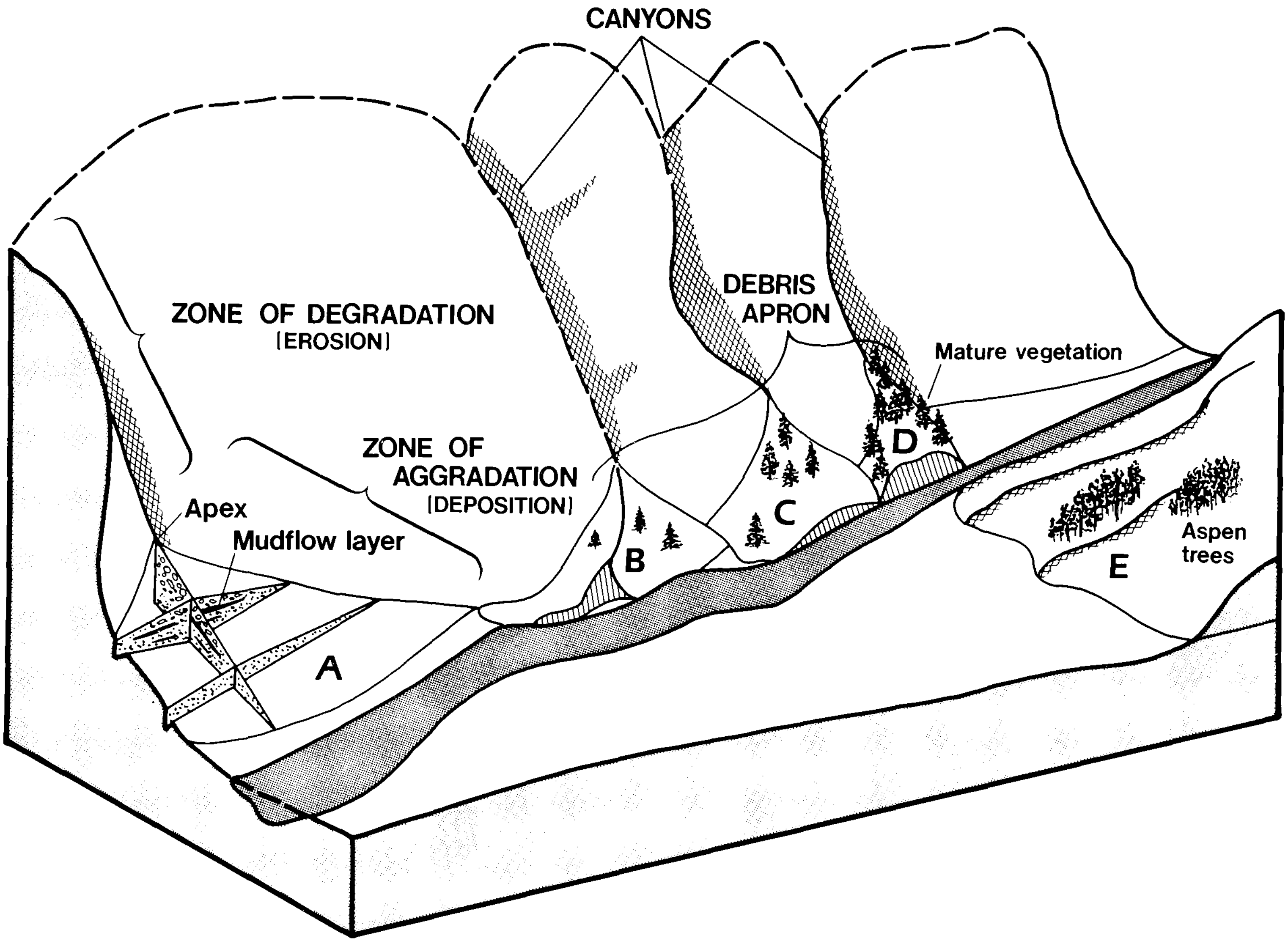


Figure 1. Internal structure of a typical debris fan (modified from Rachocki, 1981). Particle size decreases towards the fan base. B, Incised fan; indicates water-dominated events or low sediment supply to the fan. C, D, truncated fans resulting from low or infrequent sediment supply or due to erosion by a recent large mainstream flood. E, Active debris fan. An active fan can push the mainstream towards less active fans.

faster than it is being built-up. It can also be the result of a great and relatively recent mainstream flood event (Soule, 1976: Fig. 2), or the lack of a valley floor on which to establish a fan, as in the case of Canyon Creek.

Depositional Processes

Debris flows, mudflows, hyperconcentrated flows, and water floods are all part of the spectrum of events that can occur when loose rock material, water, and steep slopes are combined. Frequently, these terms are used interchangeably. However, even though the causes of these events and their resultant damage are similar, it is very important to distinguish among them before attempting hazard evaluation and costly mitigation measures, since the measures effective for one type of event may not be very effective for another.

The formal classification of sediment-water flow events has changed over time. In 1978 Varnes distinguished debris flows from mudflows on the basis of particle size. Now, types of flows are distinguished more on the basis of viscosity and shear strength (e.g. Pierson and Costa, 1984), which are controlled by the composition, texture, and sorting of the sediments.

A debris flow is a form of rapid mass movement in which a body of granular solids combines with entrained air and water to form a slurry that then flows downslope. Generally speaking, five conditions must be met for debris flows to occur; (1) steep slopes, (2) loose rock and soil material, (3) clay minerals, (4) saturated soil conditions, and (5) rainfall of sufficient intensity and duration to initiate slope movement.

In debris flows, solids may constitute 70 to 90 percent by weight (Costa, 1984). The solids and water move together as a single visco-plastic body (Johnson, 1970) and there is no separation into solid and liquid components during deposition as in water floods, although dewatering of coarse debris flows may occur shortly after deposition (Mears, 1977).

The presence of clay in the debris-flow slurry is very important. The clay fraction, even if minor, plays a critical role in determining strength properties of the debris. The mixture of clay plus water provides a cohesive slurry that supports fine-grained particles within the debris, as well as reducing the effective normal stresses between particles (Rodine and Johnson,

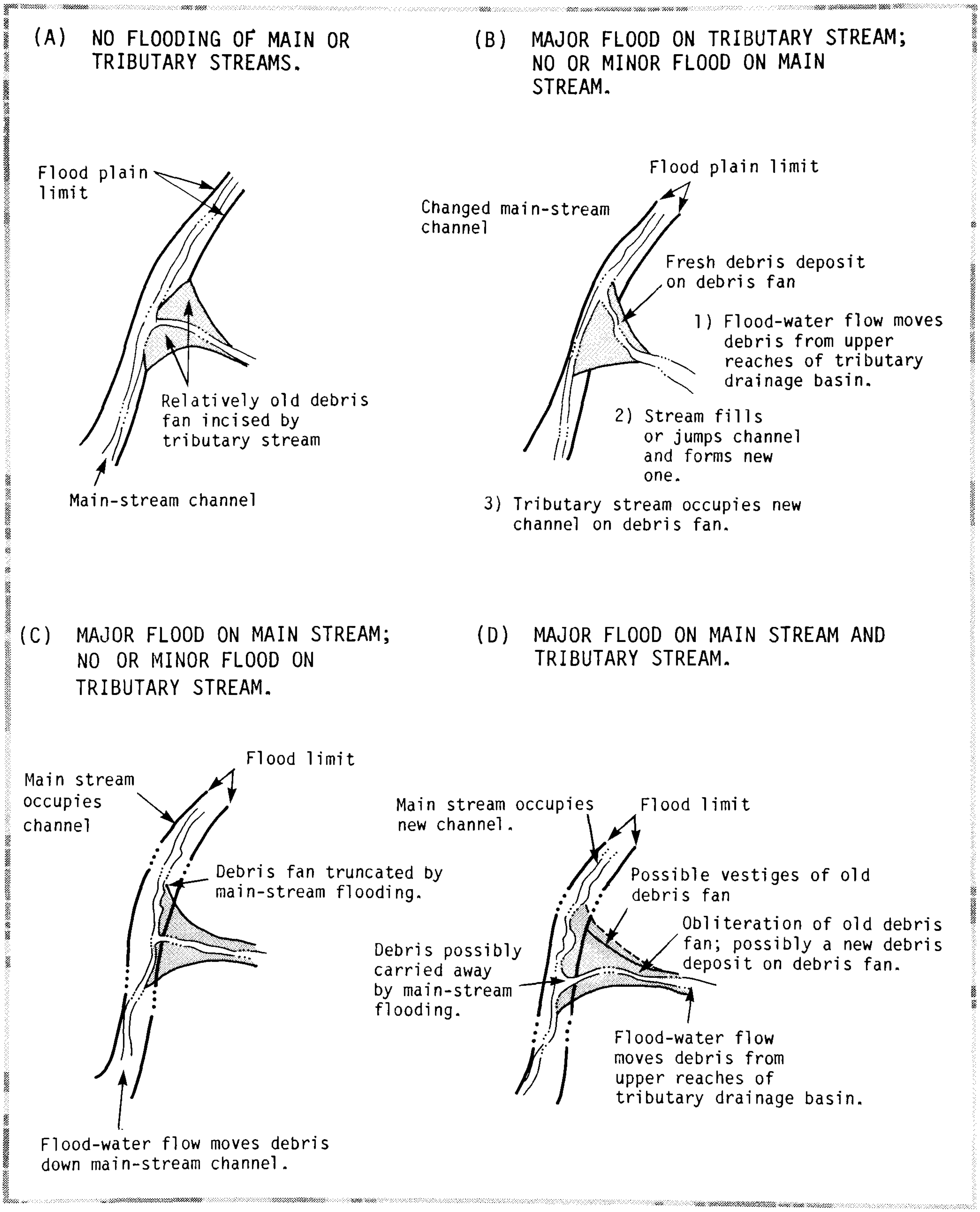


Figure 2. Effects of mainstream and tributary flooding on debris fan shape. (modified from Soule, 1976.)

1976). The presence of even a small percentage of clay in the slurry will greatly increase mobility by reducing permeability and increasing pore pressure (Rodine, 1974; Hampton, 1975; Pierson, 1981).

Debris flows move downvalley in a series of plugs or surges. The surging effect results from the temporary damming of channels by the debris. The flows usually follow pre-existing drainageways, but can move any direction across fan surfaces because the flows tend to build their own channels as levees form at the lateral boundaries of the flow (Mears, 1977).

Debris-flow surges can be divided into two parts. The front or snout of the surge is usually higher than the trailing portion and appears to be armoured since it contains the largest boulders. The trailing portion is a turbulent mixture of silt, clay, boulders, and water (Costa, 1984).

As debris flows progress downslope, dispersive forces can cause migration of large particles to the margins of the flow. Lateral areas of the flow mass are pushed to the sides and sheared from it as the rigid plug passes through the middle of the flow, leaving distinctive levees (Mears, 1977). Damage is heaviest in the center of the flow path and diminishes outward toward the low velocity zones at the edges of the flow (Costa, 1984).

Water floods consist primarily of water with minor amounts of entrained debris and sediment. Solids may constitute 1 to 40 percent by weight (Costa, 1984). During water floods, sediment and water are two distinct and separate phases. Sediment moves by suspension and by the transfer of energy from the moving water to the sediment particles (Costa, 1984).

The occurrence of past debris flows and past water floods can usually be distinguished by the type of damage caused, the character of materials deposited, and the resulting landforms. A water flood will deposit boulder bars or splays of debris while, because of the strength of its matrix, a debris flow can deposit levees and lobes. Water-flood deposits are better sorted than those of debris flows and will usually have primary sedimentary structures such as stratification and cross-bedding (Costa, 1984). Debris-flow deposits are poorly sorted and sometimes exhibit reverse-grading. When a debris flow is followed by a water flood, the evidence that would distinguish the deposits may be destroyed.

Beverage and Culbertson (1964) used the category "hyperconcentrated flows" for sediment-laden waters where solids account for 40 to 70 percent by weight. This category includes those events between debris flows and water floods. Hyperconcentrated flows include "noncohesive mudflows", "turbulent mudflows", "intermediate flows", and "mud floods" (Costa, 1984). The deposits of hyperconcentrated flows are difficult to distinguish from those of water floods, since solids and water are separate components of the flow (Costa, 1984).

GEOLOGY

The regional geology directly affects the debris-flow events in Ouray because the geologic formations provide both the materials that feed the flows and the geomorphic conditions that produce the events.

Three of the five conditions necessary for debris flows to occur: (1) steep slopes, (2) loose rock and soil material, and (3) clay minerals, are adequately met by the geography and geology in the Ouray area. Steep slopes and cliffs are formed in the indurated sandstones and volcanics, while the shales and volcanics provide aluminosilicates and other clay-forming minerals. Abundant loose rock material is supplied by the weathering of the highly fractured and faulted formations and the glacial deposits and mine tailings. Also, vegetation is scarce on the volcanics and sandstones, making them easily erodible; the last two conditions for debris-flow occurrence: (4) sufficient antecedent soil moisture, and (5) rainfall of sufficient intensity and duration to initiate slope movement, are provided by snowmelt and intense summer thunderstorms.

The following brief discussion of the geology of the Ouray area is adapted from Luedke and Burbank, 1962.

The city of Ouray is located on the northwest flank of the San Juan Mountains (Fig. 3). This region underwent intense deformation during four major episodes of mountain building. Each episode coincided with the end of a major division of geologic time; the Precambrian, Paleozoic, Mesozoic, and Cenozoic. In general, the intensity of deformation decreased with time while the associated volcanic activity increased.

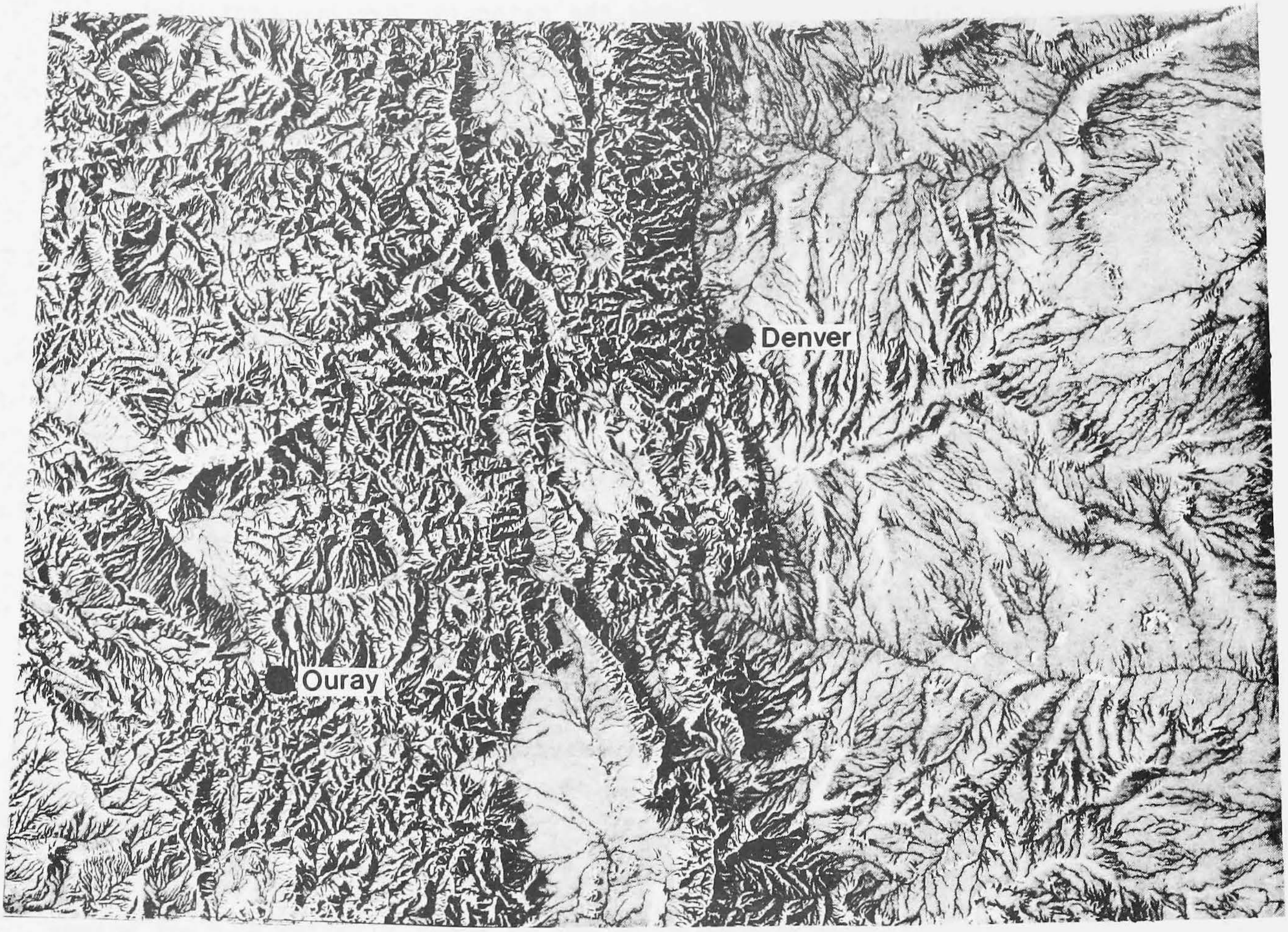


Figure 3. Index map of Colorado showing location of city of Ouray. (U.S.G.S.)

During Precambrian time, the rocks were deformed by strong compression and tight folding. In Late Paleozoic time, a domal uplift occurred with resulting monoclinal folds and faults. In the Late Mesozoic and Early Cenozoic, there was a renewal of domal uplifting and additional monoclinal folding and faulting occurred. Deformation during this period was accompanied by intrusive activity and some mineralization. During the Late Tertiary, there was widespread volcanic activity, igneous intrusion, faulting, and mineralization. Each period of deformation was followed by extensive erosion which resulted in local gaps in the normal stratigraphic sequence.

Structurally, the city is situated between a west-plunging syncline on the south and a north-dipping monocline on the north.

The stratigraphic section consists of a series of metasedimentary, sedimentary, and layered volcanic rocks ranging in age from Precambrian to Tertiary (appendix A). Much of the area is blanketed by Quaternary age surficial deposits of glacial drift and colluvium.

The topography of the basins is the result of both Pleistocene glacial erosion and postglacial mechanical weathering.

Portland Creek

The main part of the city of Ouray is located on the coalescing debris fans of Portland and Cascade Creeks.

Portland Creek's basin is called The Amphitheater, because of its circular shape (Plate 1, A). The upper portion of the basin is formed by precipitous cliffs of San Juan Tuff. The debris from this formation is composed of tuff, breccia, conglomerate, and reworked, bedded volcanics. The creek's headwaters originate in the tuff and then flow through a large deposit of glacial drift. The glacial material consists of rounded cobbles, gravel, sand, and some boulders (Fig. 4). After crossing the glacial drift, the creek traverses a section of Leadville Limestone.

Although some debris is supplied by mass wasting in the highly fractured and faulted volcanic tuff, the major source of debris in this basin is the sheet of glacial drift. Relatively little debris is contributed by the limestone, but the creek has worn a deep, narrow channel through it, and it is through this gorge that the debris flows and floods are funneled before breaking out onto the fan.

Portland Creek drains an area of approximately 2.4 square miles. Average slopes in the basin range from thirty to one hundred percent with the steeper slopes in the upper basin. The elevation of the creek ranges from about 7,700 feet above sea level at the mouth to about 12,400 feet above sea level at the head. The estimated average fan slope is approximately eight percent.

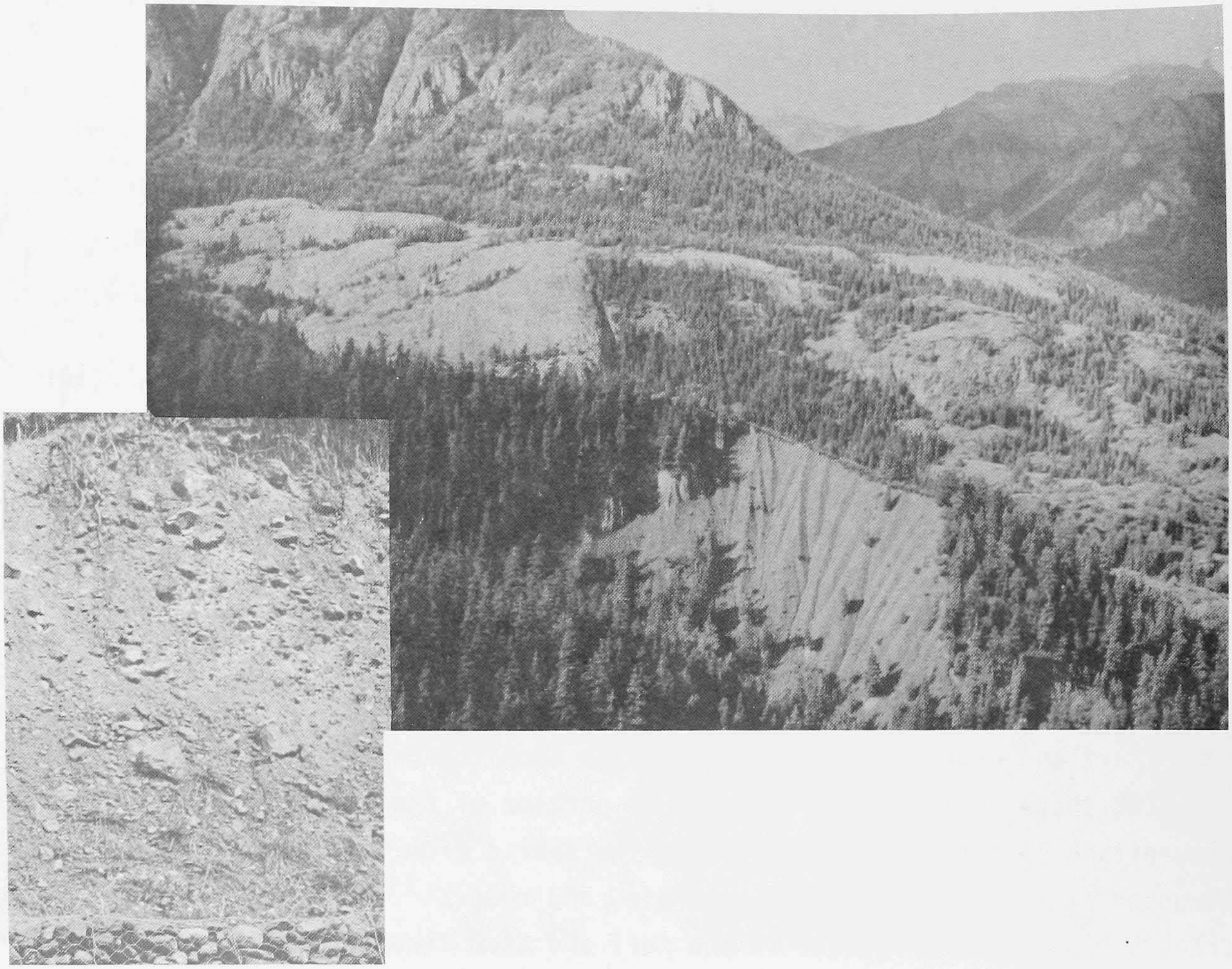


Figure 4. Glacial drift deposit in Portland Creek basin. Boulders shown in inset average about one foot in width.

Cascade Creek

Cascade Creek's basin is relatively long and narrow (Plate 1, A). The creek heads in the San Juan Tuff and continues cutting down through the stratigraphic section, exposing Tertiary granodiorite porphyry, and the Dakota, Morrison, Wanakah, Entrada, Dolores, Cutler, and Hermosa formations. The source material in this basin is predominantly angular blocks of sandstone, tuff, and limestone with some cobbles from reworked older formations, and some clays and other fines from the volcanics and shales.

Cascade Creek drops over Cascade Falls (Fig. 5) and into a small intermediate basin before entering a broad channel leading to its fan. The drop over the falls causes a loss in momentum and allows some of the larger material to settle out.

Figure 5. Cascade Falls (photo courtesy CWCB).

Cascade Creek drains an area of approximately 1.4 square miles. Slopes in the upper portion of the basin average forty-five percent. The lower portion of the basin averages about eighty percent. The elevation of the creek ranges from about 7,700 feet above sea level at the mouth to about 12,400 feet above sea level at the head. The estimated average fan slope is fifteen percent.

Skyrocket Creek

Skyrocket Creek's basin is relatively short and wide (Plate 1, A). The creek heads in the San Juan Tuff and cuts down through Tertiary granodiorite porphyry, and the Dakota, Morrison, Cutler, and Hermosa formations. The basin also has large deposits of talus and landslide debris and the Wanakah, Entrada, and Dolores formations are present in the southeast part of the basin. Coarse material deposited on the surface of the fan is predominantly angular blocks of tuff (Fig. 6).

Skyrocket Creek drains an area of approximately 0.7 square mile. Slopes in the basin average eighty percent. The fan slope is approximately thirteen percent. The creek ranges in elevation from about 7,600 feet above sea level at the mouth to about 10,400 feet above sea level at the head.

Canyon Creek

Canyon Creek emerges from a sandstone canyon (Box Canyon) and discharges directly into the Uncompahgre River (Plate 1, A). There is no fan because

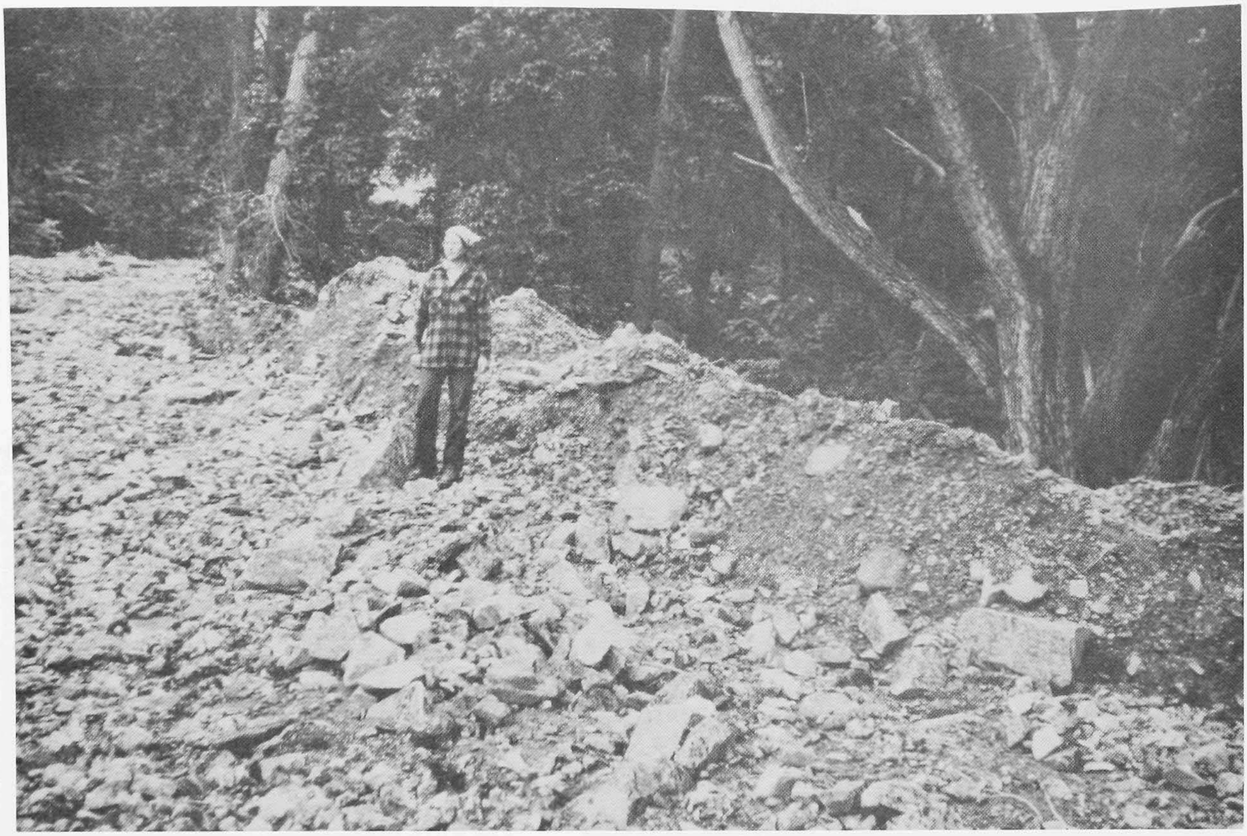


Figure 6. Debris on Skyrocket Creek fan, 1982.

events at the canyon mouth are relatively infrequent and any debris is rapidly washed away.

The creek heads in the San Juan Tuff and then cuts down through the stratigraphic section exposing the Dakota, Morrison, Wanakah, Entrada, Dolores, Cutler, Hermosa, Molas, Leadville Limestone, Ouray Limestone, Elbert, and Uncompahgre formations. There are thick accumulations of detritus in the basin in the form of talus, rock glaciers, debris fans, landslide deposits, and mine tailings.

Canyon Creek drains an area of approximately 26.2 square miles, and contains several subbasins. There is a wide range of slopes. Because the basin is so large, isolated storm cells have less effect than in small basins where a storm may completely cover the entire basin; the large size of the basin allows a significant proportion of the moisture to be absorbed, making it difficult for the basin as a whole to reach a saturated condition. Debris flows within the subbasins are known to have occurred.

Oak Creek

The small portion of the city that lies on the west side of the Uncompahgre River is located on the debris fan of Oak Creek (Plate 1, A).

The creek heads in the San Juan Tuff and then cuts down through the stratigraphic section exposing the Dakota, Morrison, Wanakah, Entrada, Dolores, Cutler, and Hermosa formations. There are thick accumulations of rock detritus in the basin in the form of talus, rock glaciers, and landslide deposits.

Oak Creek drains an area of approximately 2.1 square miles. Slopes in the basin average about sixty percent. The elevation of the creek ranges from about 7,760 feet above sea level at the mouth to about 12,200 feet above sea level at the head. The fan has been truncated by the river and modified by the excavation of the railroad bed.

Bridalveil Creek

The Bridalveil Creek basin is relatively long and narrow (Plate 1, A). The creek heads in the San Juan Tuff and cuts down through Tertiary granodiorite porphyry, and the Dakota, Morrison, Wanakah, Entrada, Dolores, and Cutler formations. The average slope of the basin is about sixty percent. The slope of the fan is about thirty percent. Material deposited on the fan is predominantly derived from volcanics. The area of the basin is approximately 0.75 square mile. The elevation of the creek ranges from about 7,620 feet above sea level at the mouth to about 11,400 feet above sea level at the head.

Corbett Creek

Corbett Creek drains an area of approximately 3.0 square miles (Plate 1, A). The creek heads in the San Juan Tuff and traverses Tertiary granodiorite porphyry and an extensive landslide deposit before cutting down through the Dakota, Morrison, Wanakah, Entrada, Dolores, and Cutler formations.

Slopes at the head of the basin average around seventy percent, while the rest of the basin averages about thirty-five percent. The slope of the fan is about fifteen percent. The material deposited is predominantly volcanics. The elevation of the creek ranges from about 7,440 feet above sea level at the mouth to about 11,600 feet above sea level at the head.

Dexter Creek

Dexter Creek drains an area of about 6.7 square miles (Plate 1, A). The creek heads in the San Juan Tuff and cuts down through the Mancos, Dakota, Morrison, Wanakah, Entrada, Dolores, and Cutler formations. The basin also contains granodiorite porphyry and large deposits of landslide material, glacial drift, and lake deposits. Slopes in the basin average sixty percent. The elevation of the creek ranges from about 7,420 feet above sea level at the mouth to about 11,800 feet above sea level at the head. The fan is relatively small and flat. This could be the result of having predominantly erosive, water-flood type events.

Examination of the Dexter Creek basin showed that the lower basin is fairly well vegetated, while the upper basin, consisting of volcanics, is relatively barren. Large amounts of mine tailings are present in the basin.

Gullies and Small Basins

In addition to the eight major creeks described, six smaller unnamed gullies and basins were briefly studied. These gullies all have debris or talus fans and the potential for debris flows. For convenience they are numbered one through six on the hazard map (Plate 1, B).

(1) Gully number 1 is also called the Rotary Park debris fan. It is located on the north side of the Rotary Park. This fan is fairly steep and well vegetated. Significant mine tailings are located in the gully and basin above the fan and have contributed to past debris flows.

(2), (3) Gullies 2 and 3 are located immediately south of Rotary Park. Both are predominantly talus fans associated with mine workings.

(4), (5) Gullies 4 and 5 are also located south of Rotary Park and north of the Bridalveil Creek fan. Four is mainly a talus fan associated with mine workings. Five is a debris fan, but is also associated with mine workings.

(6) Gully number 6 is located on the south edge of the Bridalveil Creek fan. This is mainly a talus fan.

HISTORY OF FLOODING AND DEBRIS-FLOW EVENTS

Ouray, Colorado, is situated on coalescing debris fans in the narrow canyon formed by the Uncompahgre River. At an elevation of 7,700 feet above sea level, the city is surrounded by the rugged San Juan Mountains, with individual peaks reaching up to 12,800 feet (Fig. 7).

Figure 7. View looking south toward Ouray, Colorado, 1982.

Originally a mining town, Ouray was founded in 1875. From the beginning it was apparent that flooding in the creeks could be a problem. Prospectors going to Ouray in 1875 noted that a flood had swept down Corbett Creek (Fig. 8), probably the previous summer, at a level ten feet above normal (The Ouray Herald, June 9, 1906).

One of the earliest recorded incidents of damage in the city itself occurred on July 22, 1878, when it was reported that,

> "On Monday afternoon all the denizens [residents] of Ouray were startled by a tremendous and continuous roar as of a large body of water, evidently coming from Portland creek. . . In the channel where usually runs an insignificant stream was a rushing, roaring torrent, bearing on its surface large logs and immense quantities of driftwood, and the rattling of huge boulders as they came in contact with each other beneath the rushing stream could be distinctly heard above the roar of the water. So thick was it with soil and sand that it was barely admissible to denominate it a liquid. . . The cause of the trouble is believed to have been the bursting of a waterspout [thunderstorm] at the head of Portland creek." (The Times, July 27, 1878)

Although the damage was minor, consisting of one flooded house and damage to the Second and Third Street bridges, the people recognized that if the channel had been blocked at any point, the consequences could have been disastrous.

Even though Ouray was initially located on the coalescing debris fans of Portland and Cascade Creeks, the rectilinear street system did not make special allowances for the creeks when the city was platted in 1875. In the early years they were allowed to flow without interference through the city to the river. However, they wandered over a fairly wide expanse, moving mud, rocks, and water (Figs. 9, 10). As the city grew, property owners adjacent to the creeks attempted to confine them into narrower, more definite channels. By 1909 short stretches of narrow wooden flume had been constructed on Portland Creek and houses were being built up to the edges of the newly constricted channel.

The first serious flood occurred on July 21, 1909, when both Portland and Cascade Creeks went on a rampage. The Ouray Herald, July 23, 1909, reported that where Portland Creek had been flumed, the timbers were knocked

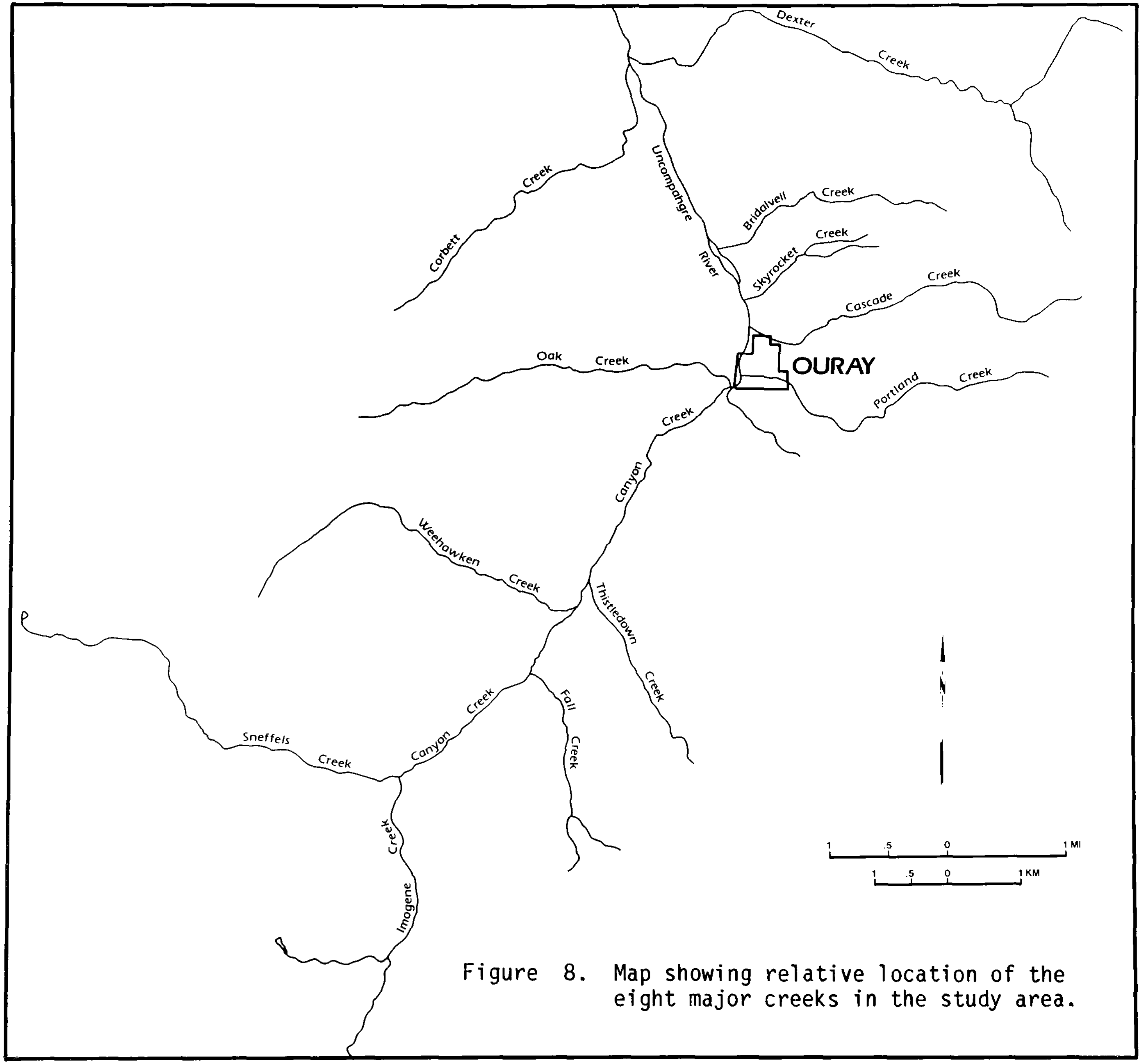


Figure 8. Map showing relative location of the eight major creeks in the study area.

Figure 9. Ouray, Colorado, before 1886. Portland Creek in foreground. (Photo courtesy Colorado Historical Society)

out and the creek flowed into yards and streets. Small buildings were undermined and fell into the channel, causing further blockage and threatening wagon and foot bridges as the debris worked its way down the channel. Damages multiplied when the mouth of Portland Creek became clogged with debris, which caused the channel to back-up as far as Fourth Street (Fig. 11). Once the lower channel was blocked, the creek spread out and cut a new one. Sewer and water pipes were destroyed, cutting off the water supply to many residences.

On Cascade Creek, considerable damage was caused by debris and mud. Some houses were crushed and an estimated thirty to forty were filled with mud and rock.

On Dexter Creek, bridges were washed out and the compressor house at the Calliope Mine was filled with three feet of mud and rock.

Figure 10. Ouray, Colorado, 1886. Portland Creek center (see arrow). (Photo courtesy Colorado Historical Society)

The day after the storm, the city council held a special meeting to plan cleanup and repair of the storm damage. It was also decided at this time that steps should be taken toward permanently fluming the channels of Portland and Cascade Creeks with concrete.

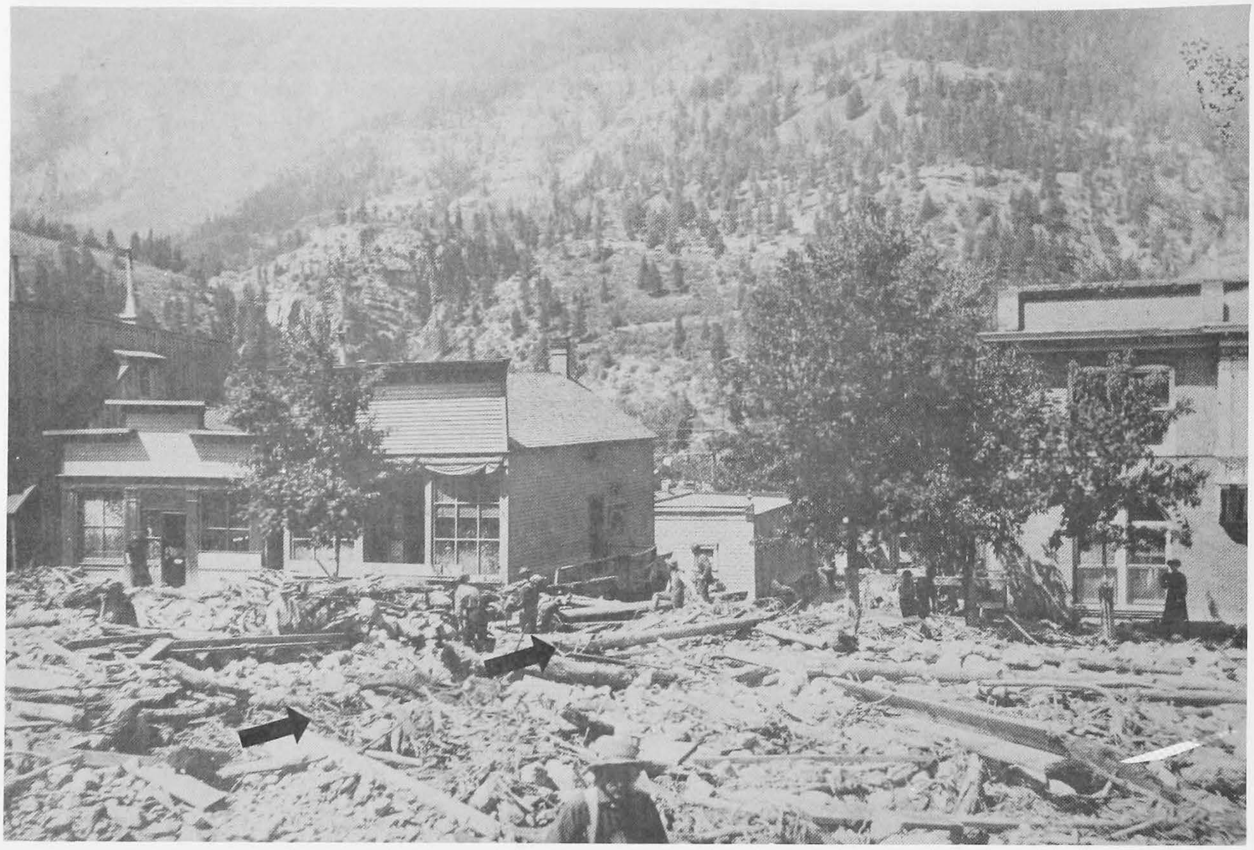


Figure 11. Debris flow on Portland Creek, 1909. Looking west across Main Street. Flume passes between buildings on left and tree (see arrows). (Photo courtesy Denver Public Library Western History Collection)

Once it had been decided to permanently flume the creeks, the only remaining issues were where the channels would be and who would pay for the improvements. Eventually, two improvement districts were formed, one for each creek, with those property owners receiving the greatest benefit (those closest to the flumes) paying the greatest share of the costs. The location of the channels was more controversial. It was proposed that new channels be made so as to divert Portland Creek down Fourth Avenue and Cascade Creek down Eighth Avenue. To build along the avenues was thought to be cheaper and more efficient than building along the old channels. However, it was also considered unfair to those living along the avenues to relocate the creeks, thus exposing them to flooding and potentially devaluing their property. It was eventually decided to run the flumes down the old channels as nearly as possible. The city engineer was especially concerned about using Cascade's old channel since the lower 300 feet had (and still has) almost no grade (The Ouray Herald, September 24, 1909).

While the city council was settling the details of the improvement districts and the channel routes, two more storms struck the area. The first, on August 17, 1909, centered over the Dexter Creek watershed. Reports say a wall of muddy water twenty to twenty-five feet high came down the creek, causing heavy damage at the Bachelor Mine, where the stables were swept away, part of the boarding house knocked out, and the area deluged with mud. Several bridges across the creek were also carried away.

On August 22 and 23, 1909, a storm more severe than the one in July struck Ouray. The destruction of this flood was perhaps even greater than it might have been, since the channels were still filled with debris from the previous storm.

The contract for construction of the flumes was awarded in October of 1909 with a scheduled completion date of December 31, 1909. The Portland Creek flume, as constructed, was reported to be approximately 2,450 feet long, 10 feet wide, 6 feet deep, and had a v-shaped bottom. The Cascade Creek flume was reported to be 2,300 feet long, 8 feet wide, and 5 feet deep. Concrete wedges were added later to give a v-shaped bottom (Fig. 12). Actual dimensions of the flumes varied along their length.

The city was spared serious flooding again until 1927. In that year heavy runoff from snowmelt, combined with cloudbursts, produced severe flooding. The storm that struck on July 27, 1927, caused simultaneous flooding in Cascade, Skyrocket, Canyon, Oak, Corbett, and Dexter Creeks.

During this storm Oak Creek changed its course, cutting a new path east of its old outlet into Canyon Creek. Cascade Creek blocked at the mouth and filled with large boulders and timber. The debris backed-up three blocks, causing the water to form a new channel outside the flume and flooding many homes. Skyrocket ran so heavily that it pushed a dam of rocks and mud across the Uncompahgre, forcing the river to use the railroad tracks as a temporary channel. The Radium Springs fish ponds and pool were filled with mud. Corbett Creek tore out a section of the railroad tracks and a bridge before joining Dexter Creek and the Uncompahgre River to wash out the road to Ridgway (US 550). The pipeline conveying water from the big reservoir was broken and for several days residents used the limited supply from the old Oak Creek reservoir.

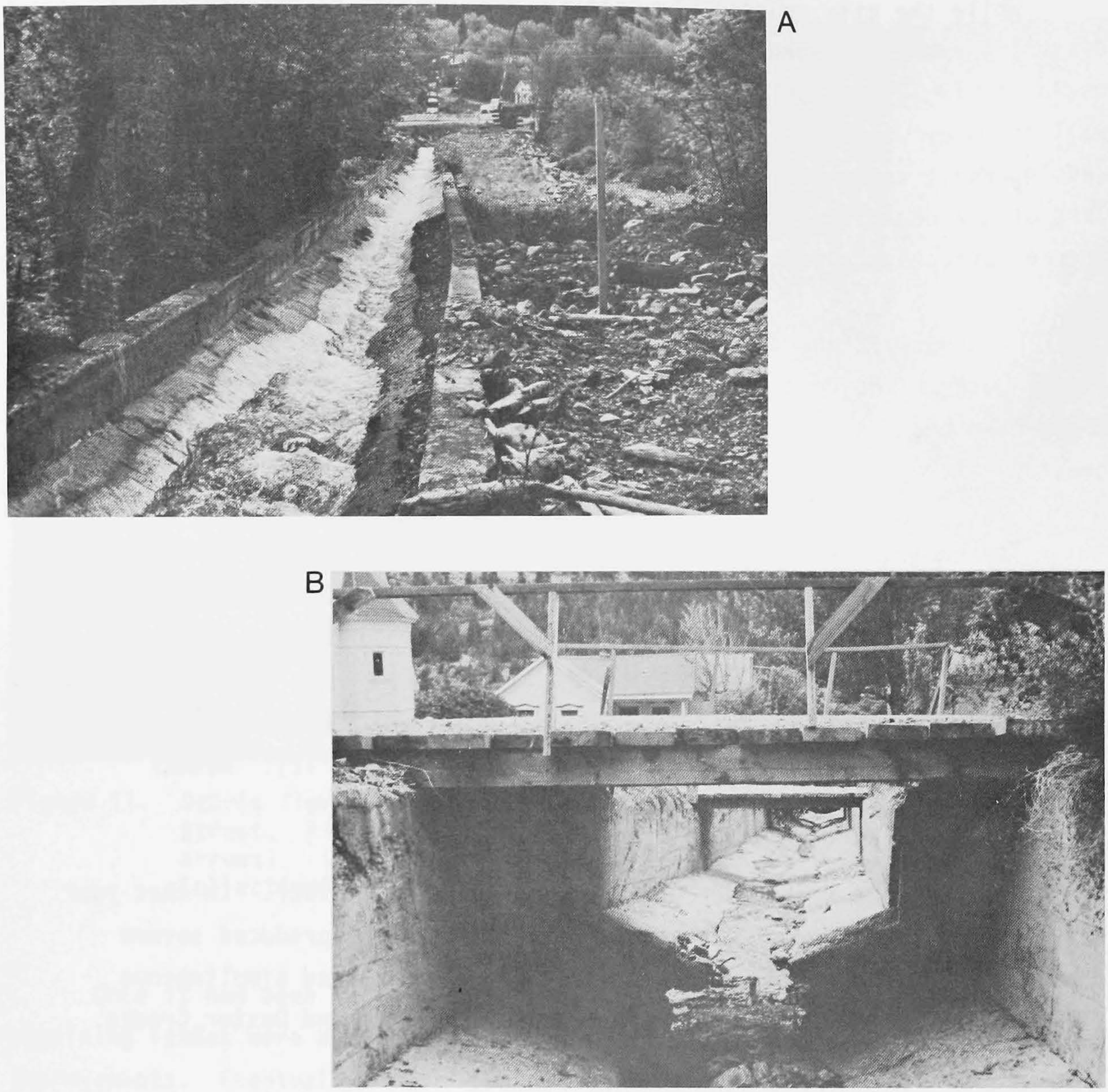


Figure 12. A, Cascade Creek flume. B, Portland Creek flume. (Photo courtesy CWCB)

In the spring of 1929, a wooden diversion dam was built on Skyrocket Creek to protect the highway and park from flooding (Fig. 13). The dam blocked the creek's historic entrance onto the fan and shunted it to the northern side of the fan through a new channel which had been blasted into the rock.

The most devastating storms in Ouray's history to date occurred on July 25 and 26, 1929. These storms caused flooding in Portland, Cascade, Canyon,

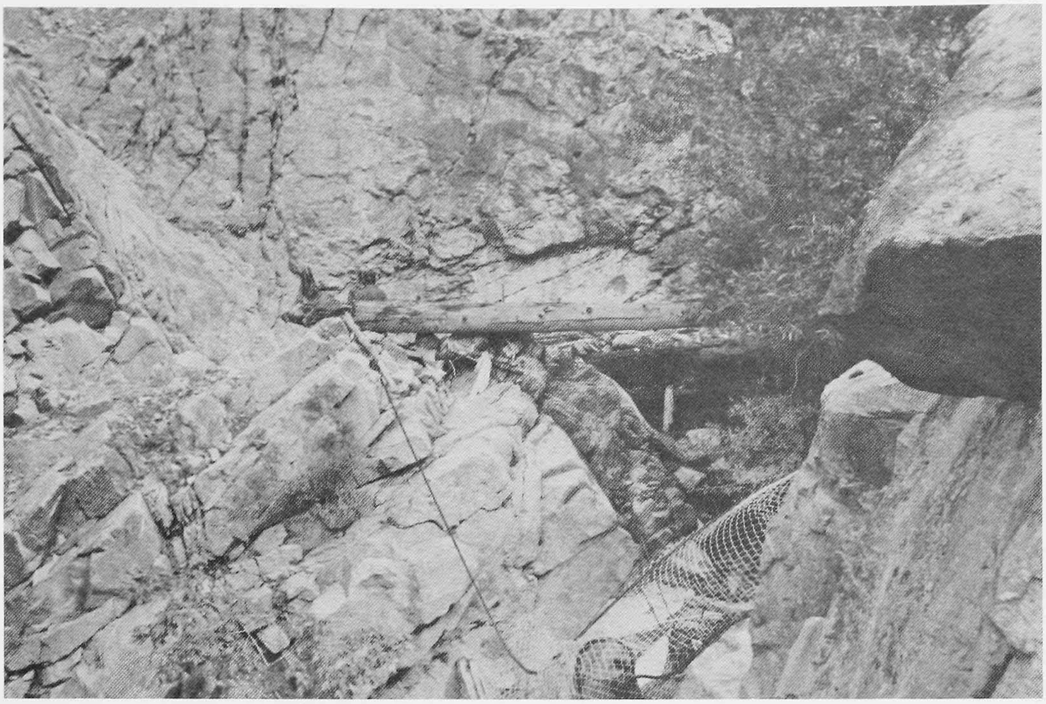


Figure 13. Remains of wooden diversion dam constructed on Skyrocket Creek in 1929. (Photo courtesy William P. Stanton, CWCB)

Oak, Skyrocket, Corbett, and Dexter Creeks and, subsequently, the Uncompahgre River.

Skyrocket Creek broke through the diversion dam built that spring and plunged down the mountain side and into the park. A drift of rock, almost forty feet high, covered the road at that point.

Cascade became clogged with the first wave of debris. During the storm debris was piled twelve to fifteen feet high and at least one house was swept from its foundation.

> "As soon as it became clogged, the raging torrent spread all over that territory, with waves of water several feet high, carrying logs, trees, and huge boulders. In its mad rush, nothing was spared. Rocks broke through the walls of houses, broke doors and windows, and debris filled the homes, some of them to within a foot of the ceiling." (The Ouray Herald, August 2, 1929).

There was a shortage of water after the first storm rendered the city's old reservoir useless, cutting off half the population from its water supply. The second storm broke the pipeline from Weehawken Creek, a tributary of

Canyon Creek, to the new reservoir, cutting off water supply to the rest of the city.

It was noted that Cascade Falls looked different after the storm. Huge boulders dropping down from great heights had knocked off a projecting ledge which had divided the falls. They now appeared higher, being one continuous drop.

Eleven more floods occurred after the one in 1929. In 1951 a large "mudflow" came down Dexter Creek piling debris six feet high on the road and inundating the house located next to the creek. "Muck" was piled four to five feet deep on the inside and to the eaves on the outside. Skyrocket Creek blocked the road and filled the fish ponds with mud again and Cascade Creek was "a slow moving mass of mud..." (The Ouray Herald, August 10, 1951). One hundred and twenty-five feet of the flume below Main Street were destroyed and the flow hit one house "crushing it like matchwood and heaving it into the street." (The Ouray Herald, August 10, 1951).

In 1965 there were two days of noteworthy events. The first storm on July 11 "washed down tons of rocks, trees and mud..." (The Ouray County Herald, July 15, 1965). Both the Portland and Cascade Creeks flumes became plugged with debris, spreading water through a number of houses. The second day, Portland Creek flooded again. Boulder sizes were estimated to be from 300 to 1,000 pounds.

In the 1971 storm, Oak Creek dammed the Uncompahgre River with debris, forming a temporary lake. A local resident observed that at one point, Oak Creek rose above its banks without overflowing (The Ouray County Plaindealer and Herald, September 2, 1971).

In the 1973 event, after Cascade's flume plugged, water ran about two feet above ground level in a neat path, as if between invisible walls, before spreading out where the land leveled off (The Ouray County Plaindealer and Herald, July 12, 1973).

In July of 1981 Portland, Cascade, and Skyrocket Creeks flooded on two successive days. On the first day, four pedestrian bridges were destroyed on Portland Creek, and several others heavily damaged. The Portland Creek flume plugged at the mouth and backed-up, depositing a huge pile of debris. This caused flooding of the lumber yard and the Baptist Church adjacent to the river. A side of the flume was deliberately knocked out to allow the flood waters to take another course to the river (Fig. 14). When Cascade's flume plugged on the second day (from the river to Fourth Street), the city diverted the water and debris down Main Street, contributing to the flooding at the Radium Springs Park, where the goldfish pond, swimming pool, and park were already being inundated by mud and water from Skyrocket Creek. Both flumes sustained heavy damage during this storm.

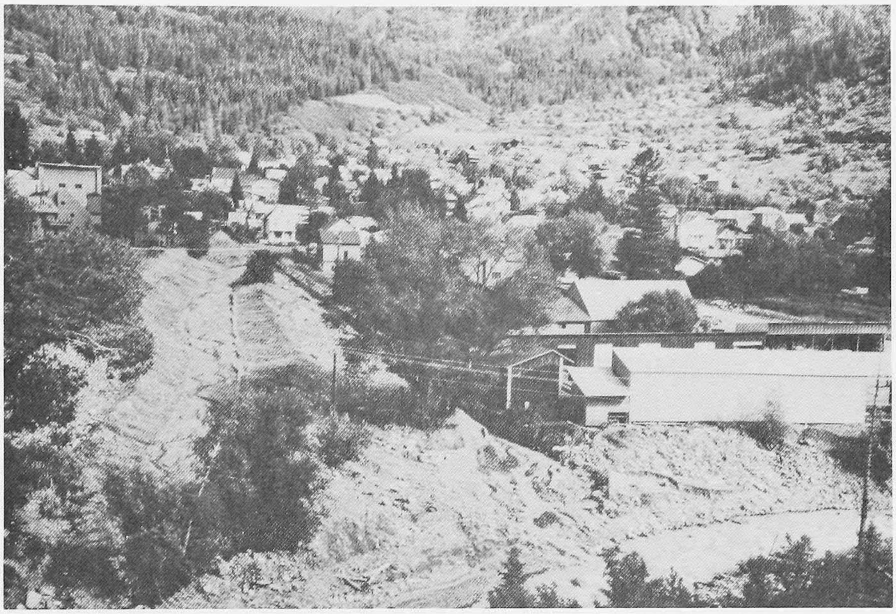


Figure 14. Portland Creek flume after 1982 event. Looking east from Oak Street. Debris is spread out where flume was broken in 1981.

In 1982 flooding occurred on four successive days in August. On the first day, Cascade Creek jumped its flume and ran down Eighth Avenue, depositing rocks and logs and causing minor water damage (Fig. 15). Once again, Cascade's flume plugged at the box culvert under Highway 550 (also called Third Street or Main Street) and filled with debris on both sides from Fourth Street down to Second Street (Fig. 16). Portland Creek's flume plugged below Second Street and backed-up to the east. During this storm, at least thirty-five homes and businesses received damage. Also, many foot and auto bridges were destroyed.

On the second day of flooding, both Portland and Cascade Creeks ran again. Because the flumes and culverts were still plugged, Portland's channel quickly filled and the flow fanned out over the piles of debris. Cascade flowed over the highway but was channeled back into its flume by banks of debris piled-up for that purpose.

Figure 15. Debris deposited on Eighth Avenue when Cascade Creek jumped flume in 1982.

Figure 16. Debris back-up caused by plugged culvert on Cascade Creek at intersection with Highway 550, 1982 Looking west. (Photo courtesy William P. Stanton, CWCB)

On the third day of flooding the flumes had been cleared, but the culverts were still blocked. Both Portland and Cascade Creeks were channeled over the highway by banks of debris and back into their flumes on the other side.

On the fourth day, there was much less debris washed down and both creeks stayed within their channels.

HAZARD ANALYSIS

Debris vs. Water

The success of any mitigation measure depends upon an accurate analysis and understanding of the problem. In the past, hydrologists and engineers developed techniques which tended to focus on riverine flooding by water alone. Although there is no question that water floods occur in Ouray, especially on the Uncompahgre River, evidence indicates that the major destructive events on the tributaries are primarily debris flows.

For example, of the 1878 event it was noted that the flow of the creek was "so thick...with soil and sand that it was barely admissible to denominate it a liquid." (The Times, July 27, 1878).

In the 1909 event there is evidence of a possible debris plug. "The debris piled up to such an extent before the torrent of water that it burst through the windows..." (The Ouray Herald, August 27, 1909).

In 1927 "Skyrocket creek carried such a heavy load of water that it forced a dam of rocks and mud clear across the Uncompahgre...An estimate of the rocks and dirt carried down by Skyrocket creek is very conservative at 5,000 tons." (The Ouray Herald, July 29, 1927).

In 1929 "Skyrocket creek broke through the dam built this spring, to divert the waters, and filled with rocks plunged down the mountain and into the park. A drift of rock, almost forty feet high covered the highway at this point." (The Ouray Herald, August 2, 1929).

The 1951 event on Cascade Creek is described as "Not a rushing mighty wall of water, but a slow-moving mass of mud four feet in depth, carrying logs and rocks as large as a ton or two in weight...pushed houses off their foundation, smashed in walls and crept like a limitless field of lava into houses." (The Ouray Herald, August 10, 1951).

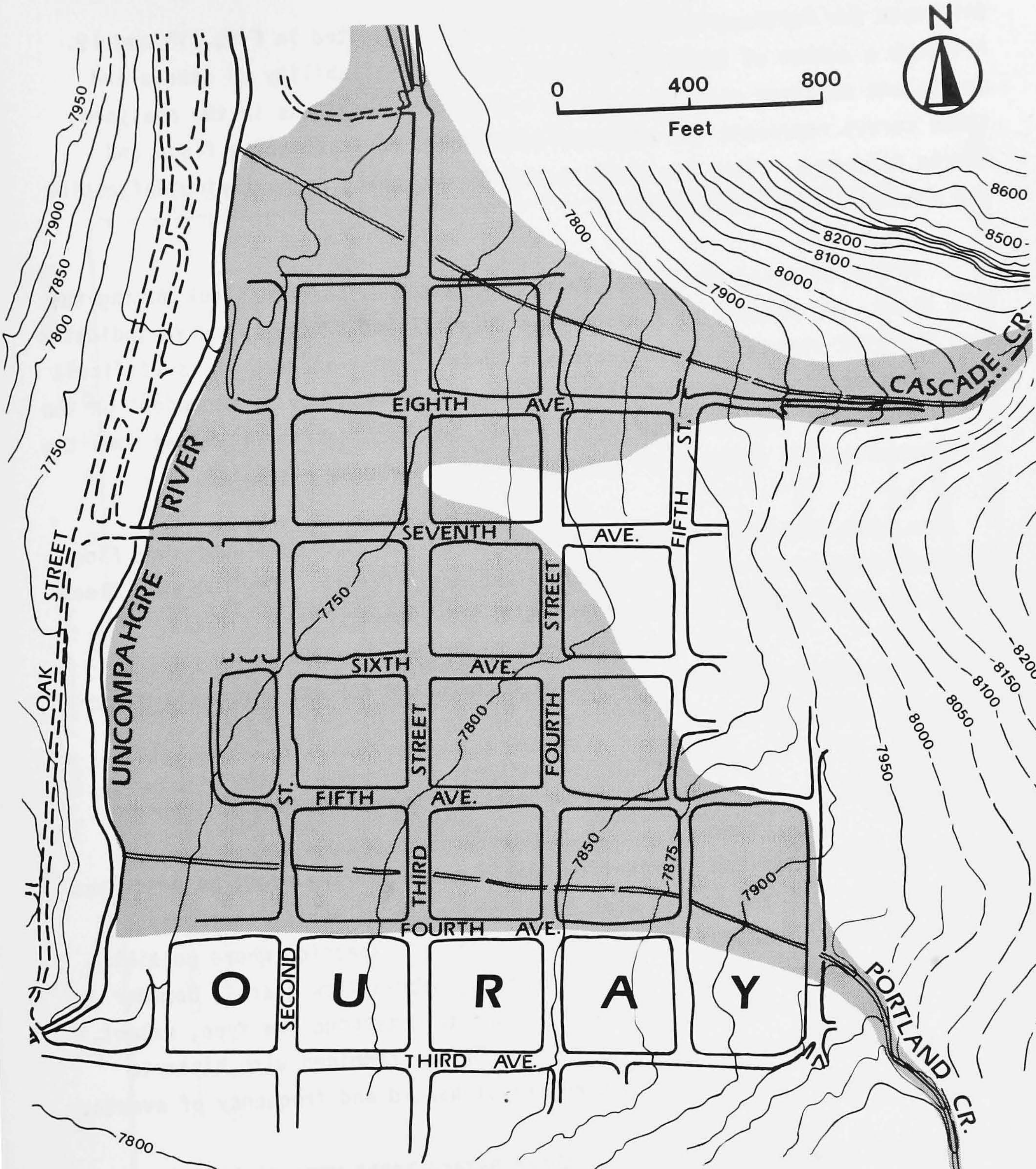
In 1971 Oak Creek's waters were "running higher than the banks, a distance before it overflowed..."(The Ouray County Plaindealer and Herald, September 2, 1971), and in 1973 in Cascade Creek "water was running about two feet above ground level in a neat path, as if between invisible walls." (The Ouray County Plaindealer and Herald, July 12, 1973).

All of these descriptions indicate that debris flows occurred during these storms. It should be recognized that all major events include heavily sediment- and debris-laden flood waters between the plugs or pulses of mud and debris. However, the water-dominant flooding is more predictable and controllable and thus potentially less damaging.

Hydrology

The detailed hydrology of Portland and Cascade Creeks was first studied by A & S Consultants, under contract to the CWCB and Ouray County, in 1977. The hydrology report, prepared by Grigg, determined the 10-, 50-, and 100-year flood water peaks for the creeks. It was recognized that the creeks did not behave as normal streams during flooding due to debris loads and that their flood plains could not be determined accurately by conventional hydraulic methods. Therefore, photographs of past floods, discussions with residents, and topographic mapping were used to determine an envelope "area of high hazard due to flooding". This area is illustrated in Fig. 17. Property located within the hazard envelope may be subjected to debris flows during future events. It is unlikely, however, that any single event would affect the entire area at once.

In 1982 a "Debris and Flood Control Plan for Portland and Cascade Creeks at Ouray, Colorado" was prepared by Simons, Li & Associates, under contract to the CWCB and the city. In this report, the original A & S hydrology was modified to account for the debris. The debris/flood frequency curves



Base modified from Pafford & Assoc.

Figure 17. A & S "envelope of hazard due to flooding" for Portland and Cascade Creeks. (A & S Consultants, 1978)

developed for Portland and Cascade Creeks are presented in Figs. 18 and 19. Although a number of limiting factors, such as availability of debris and antecedent moisture conditions require certain assumptions in the analyses, these curves represent the best available tools for estimating flood and debris discharge. They may prove useful in designing or modifying deflection and channelization structures.

Using estimated amounts of debris deposited by Cascade Creek during the 1982 flood, the Simons, Li & Associates debris/flood frequency curve indicates that the 1982 storm was approximately a 10-to 25-year storm. It is difficult to be more precise, since the calculation of the frequency is dependent on the amount of debris deposited during an event, and much debris is washed down the river or otherwise disposed of before its volume can be estimated.

In 1985, the Federal Emergency Management Agency (FEMA) published Flood Insurance Studies for the city of Ouray and Ouray County. The 100-year flood plains in these studies are based on the A & S report.

No hydrologic studies have yet been conducted for the other six major creeks that affect Ouray.

Hazard Mapping

In order to map the debris-flow hazard zones for the eight major creeks studied, their fans and basins were examined by use of aerial photographs, topographic maps, geologic maps, and actual field inspection where possible. The identification of levees, lobes, channels, debris-flow tracks, boulder splays, and tree burial and scarring was used to determine the type, extent, and severity of past events. This information was combined with historic newspaper accounts to determine the degree of hazard and frequency of events.

For the purposes of this study three hazard zones were distinguished. The boundaries of all zones are estimates and should only be used as an approximation of the relative hazard at any particular location on or near a fan. Detailed geotechnical studies would be required for a more accurate determination of the degree of hazard in any particular area.

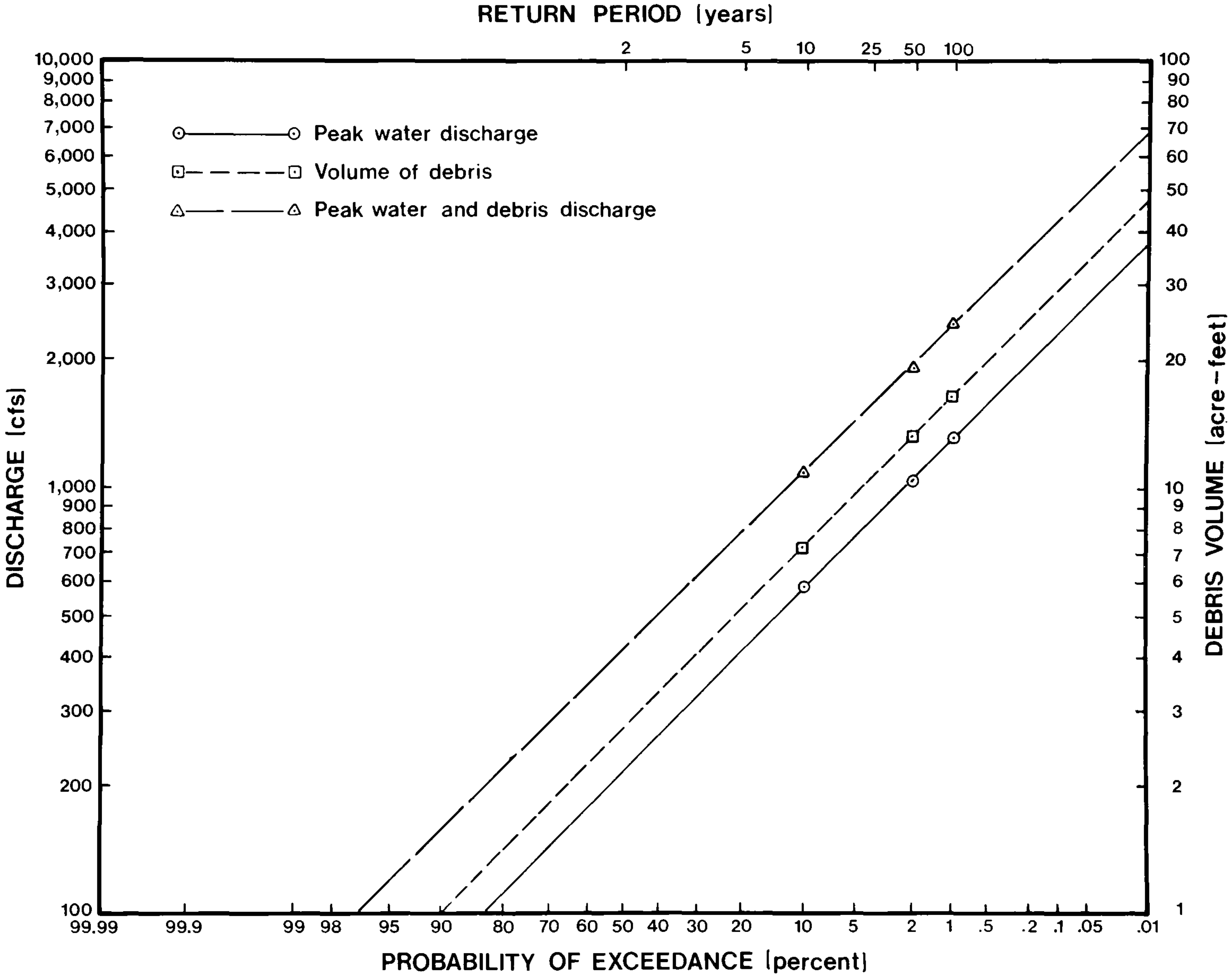


Figure 18. Portland Creek debris/flood frequency curve. (Simons, Li & Assoc., Inc., 1982)

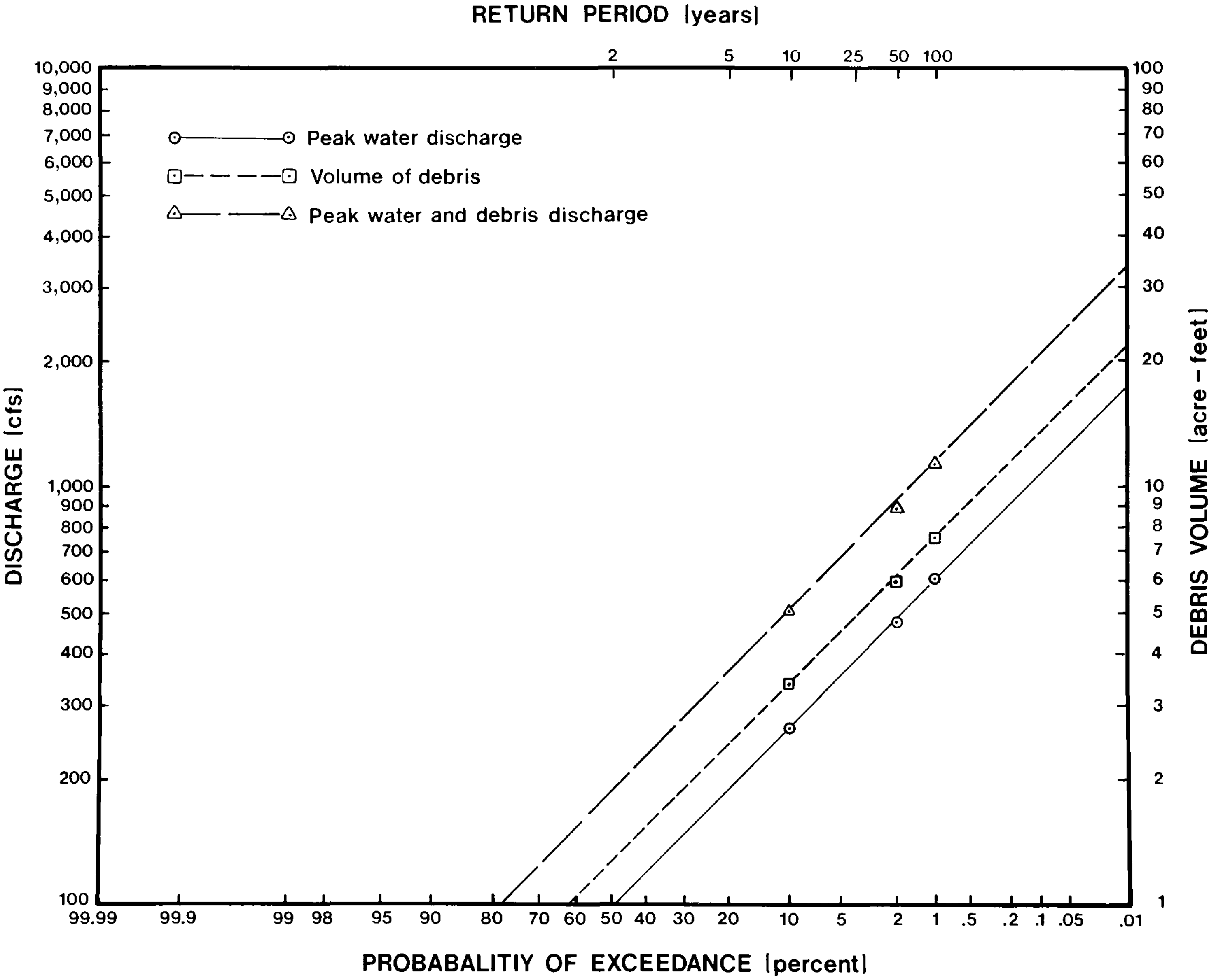


Figure 19. Cascade Creek debris/flood frequency curve. (Simons, Li & Assoc., Inc., 1982)

Very High Hazard Zone	This is the zone of greatest hazard. It is estimated that in this area the greatest impact from, and most frequent exposure to, debris flows and floods occurs. The zone is generally characterized by steep slopes, deposits of large boulders (greater than two feet in diameter), tree scars and burial, channels, levees, and lobes. Damage in this zone could include structural damage, such as buildings being moved off their foundations, walls and windows being broken, large accumulations of debris being piled in and around buildings, trees being toppled or severely damaged, and severe mud and water damage. Plugs of debris should be expected in this zone, and loss of life is possible.
High Hazard Zone	This is the zone of high hazard. This zone is subject to debris flows and floods, but does not experience the maximum impact of the events. However, events may be just as frequent as in the Very High Hazard Zone. The zone is generally characterized by moderate to steep slopes, boulders, levees, lobes, tree scars and burial, and channels. Damage in this zone could include moderate damage to structures resulting from the pounding of boulders and logs, broken windows, basements filled with mud and debris, piles of debris in and around structures and in yards and streets, and severe mud and water damage.
Moderate to Low Hazard Zone	This hazard zone is usually subjected primarily to mud and water flooding as a result of debris-flow events. This zone is characterized by low to moderate slopes, and deposits of abundant mud, and minor debris (small boulders, one foot or less, and logs). Damage is usually comparatively minor, consisting of mud and water damage to outer walls of buildings, basements, and yards.

Portland and Cascade Creeks: In determining the degree of hazard due to debris flows and floods in Portland and Cascade Creeks, it is important to note that on these creeks the events are influenced by manmade structures. This is because their stream channels and fans have been severely modified by the placement of concrete flumes and deflecting walls, buildings, and roads. Because of the flumes, the debris flows and floods always follow the same path onto the upper fan. This is different from the situation on an unmodified fan where the location of the stream channel may change from one event to the next.

Because of the flumes there is some amount of predictability in the range of the flows. Careful study of past events led A & S Consultants to determine an "envelope of hazard due to flooding". That envelope was developed in 1978. Improvements in the flumes since then should have reduced the hazard within the envelope. However, because of the structures on the fan, the behavior of the flows within the envelope is still unpredictable. An example of the erratic courses of flows within the envelope can be seen in Figs. 20, 21, and 22 where the CWCB has mapped the paths of flows on three successive days of flooding in 1982 (before improvements were made to the flumes).

Because of the unpredictability of debris-flow events within the hazard envelope, the entire envelope is placed within the High Hazard Zone on the map. This study recognizes that the areas near the apexes of the fans and the areas along the flumes are probably actually in the Very High Hazard Zone. However, it would be misleading, due to the unpredictability of the flows, to place them alone in that zone.

Skyrocket Creek: The recorded history of the Ouray area indicates that Skyrocket Creek has been very active in the past. According to the USGS, Skyrocket Creek has one of the highest measured rates of runoff per square mile in Colorado (Follansbee and Sawyer, 1948). Examination of aerial photography shows several debris-flow tracks on the fan. Because the fan has been extensively modified by man in recent years, field examination revealed little definitive information.

The manmade modifications include a catchment basin excavated at the foot of the cliff where the creek has historically entered onto the fan and berms that have been built to channel flows out of the basin (Fig. 23). The berms are formed entirely of debris from the fan. This debris is relatively unconsolidated, and the deflection channel veers off at a sharp angle. Small

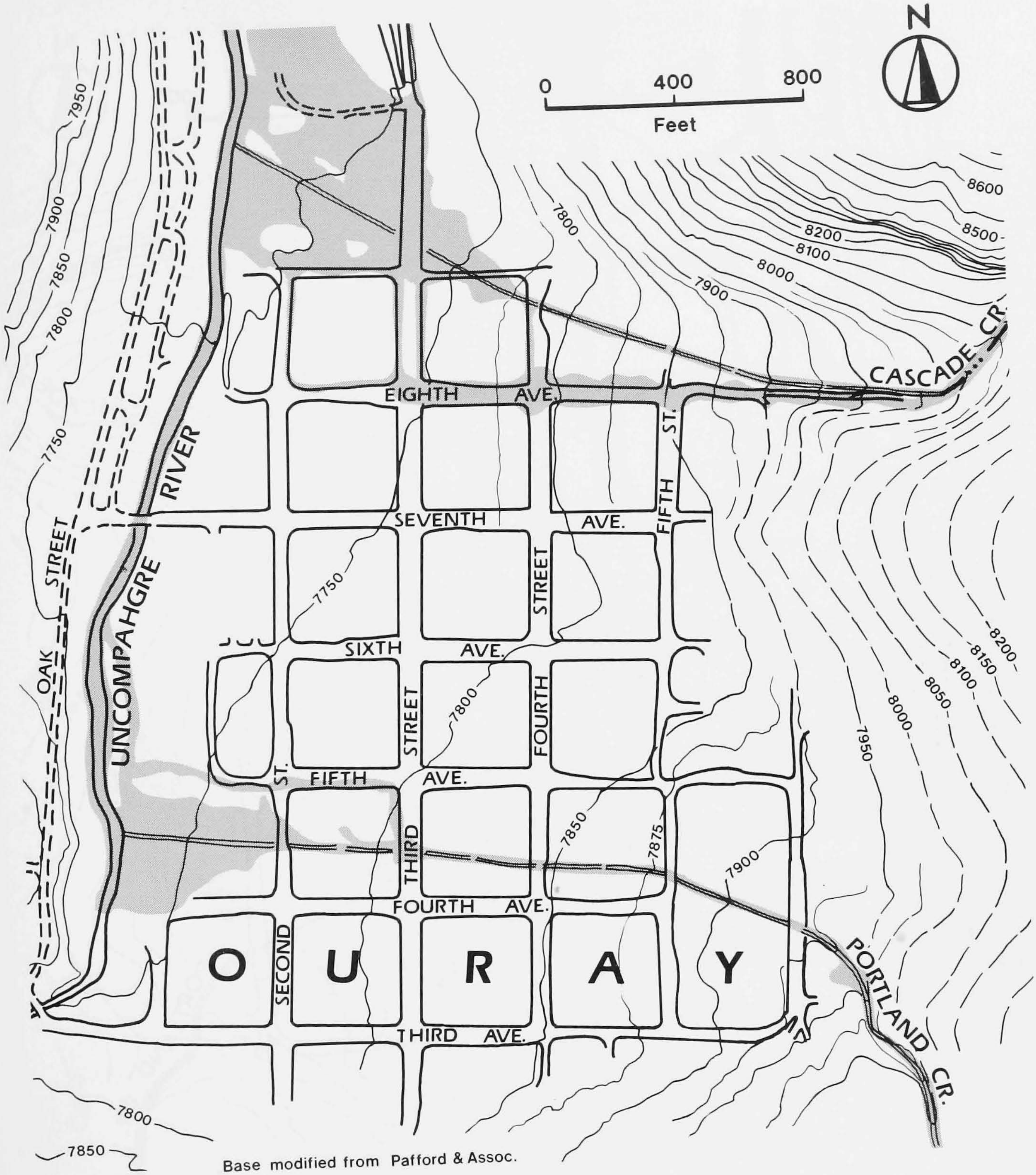
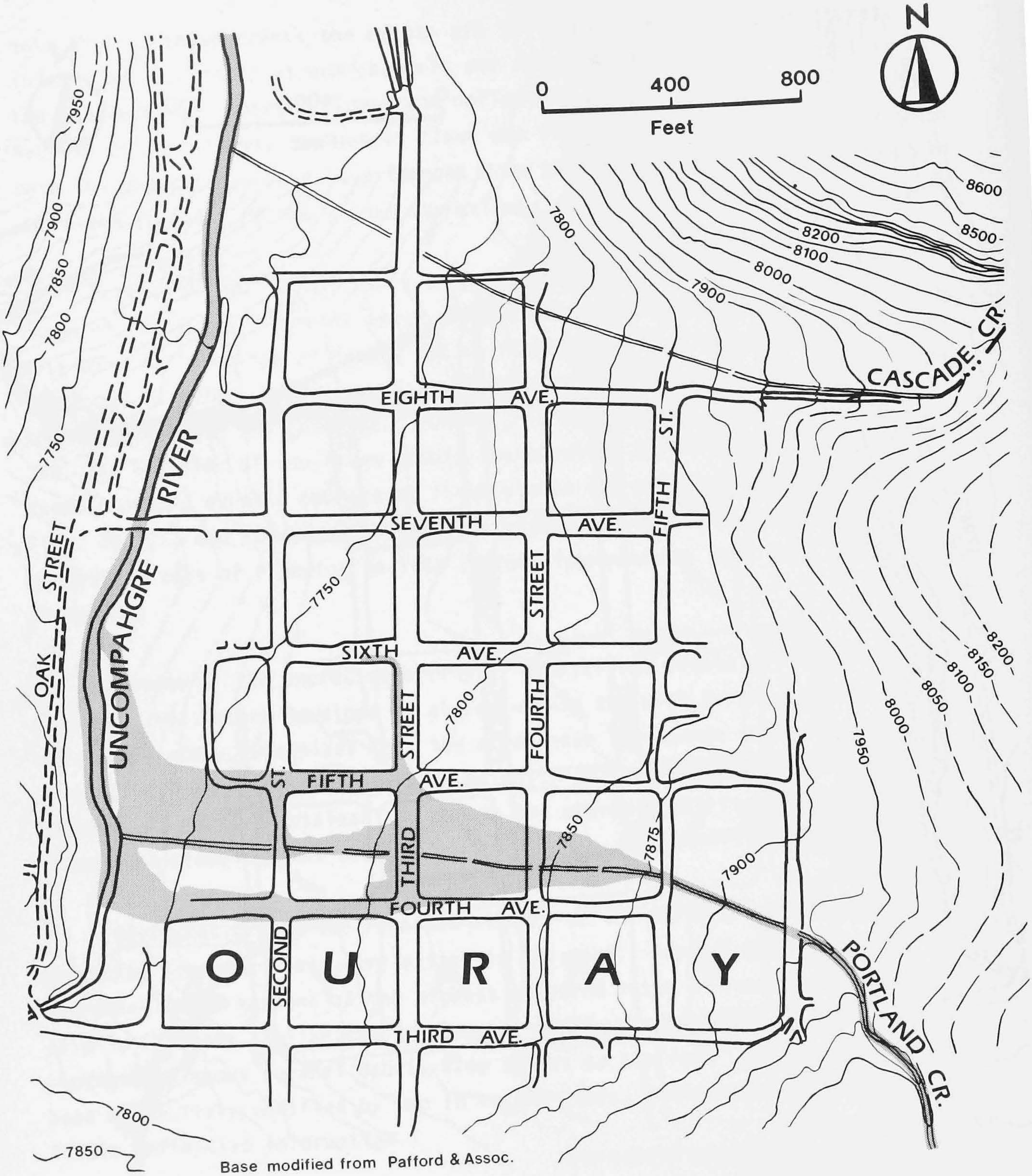
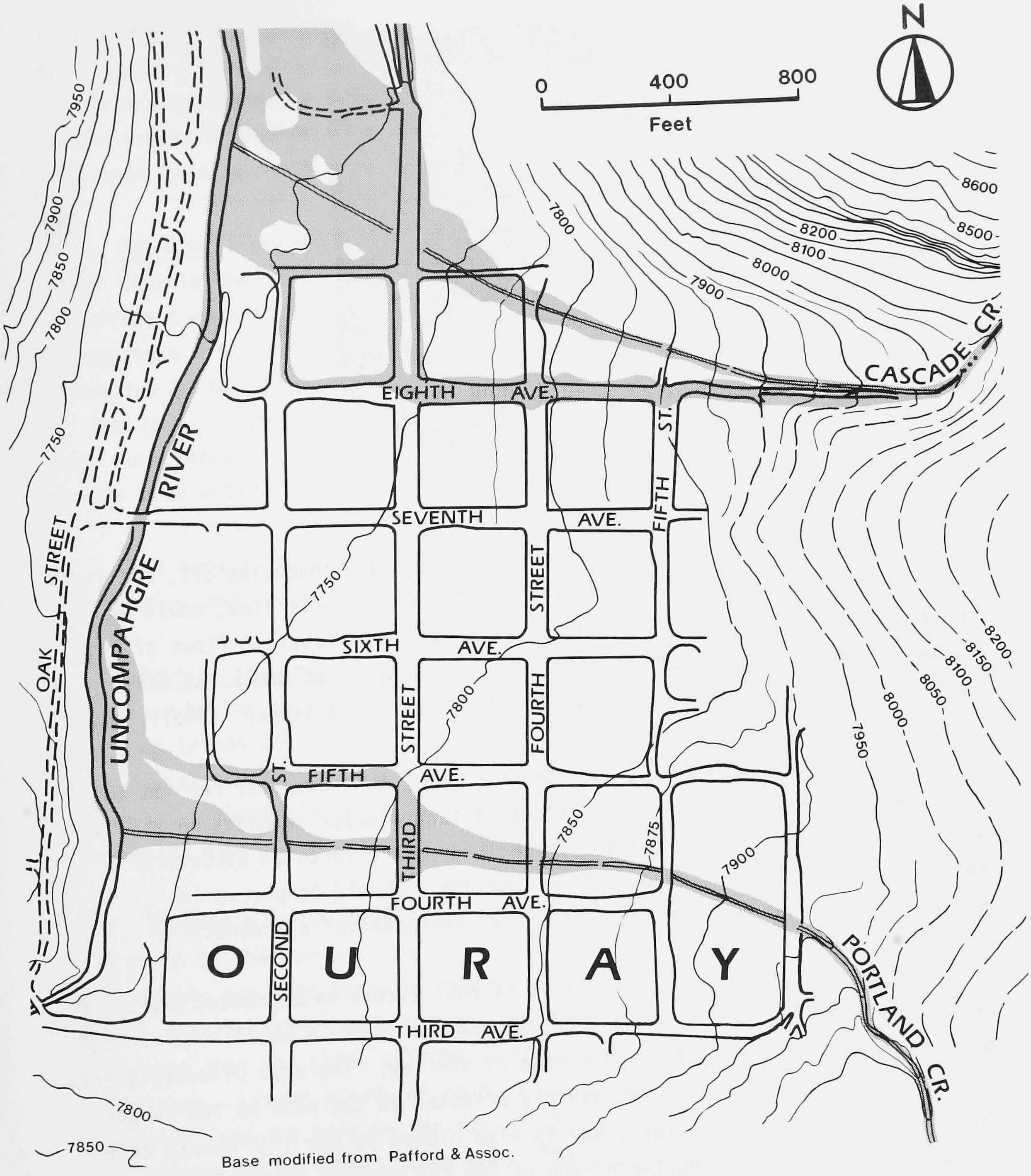


Figure 20. Path of flooding on Portland and Cascade Creeks August 20, 1982 as mapped in the field by William P. Stanton of the CWCB.



Base modified from Pafford & Assoc.

Figure 21. Path of flooding on Portland and Cascade Creeks August 21, 1982 as mapped in the field by William P. Stanton of the CWCB.



Base modified from Pafford & Assoc.

Figure 22. Path of flooding on Portland and Cascade Creeks August 22, 1982 as mapped in the field by William P. Stanton of the CWCB.

Figure 23. Manmade berms on Skyrocket Creek fan.

events can probably be contained within the basin and channeled off, but it is questionable that a large event, such as a 100-year debris flow, could be controlled. Such structures should be engineered to withstand flows of high volume, velocity, and impact. The discharge of Skyrocket Creek has been measured at 2,300 cubic feet per second (Follansbee and Sawyer, 1948).

Evidence from old aerial photographs, maps, and newspaper reports shows that the creek has run in at least three different major channels on the fan in recent historic time. It also overwhelmed past efforts at structural control on several occasions. Little confidence should be placed in structures not designed and built to modern geotechnical standards.

Because of the frequency and size of past events on Skyrocket Creek, most of the fan is placed in the Very High Hazard Zone. A small band of high hazard has been placed at the outer edge of the fan. The area directly across the river from the fan has been severely affected in the past by the larger debris flows on Skyrocket Creek, and is also placed in the High Hazard Zone. The area surrounding the northern edge of the fan and the Radium Springs pool area are subject to mud and water flooding and minor debris flooding, and are placed in the Moderate to Low Hazard Zone.

Canyon Creek: Because of the large size of the Canyon Creek basin, debris flows at the mouth of the creek are rare. Although debris flows occur in the individual subbasins of the drainage, water floods are probably the most common events for the basin as a whole. The debris that does come down to the mouth of the creek is quickly eroded away by the combined waters of Canyon Creek, Oak Creek, and the Uncompahgre River. Therefore, at the mouth of Canyon Creek a small area of Moderate to Low Hazard is mapped.

Oak Creek: The Oak Creek fan appears not to be as active as most of the other fans in the study area. However, it has the potential to produce significant events as evidenced in 1971 when debris from Oak Creek dammed the Uncompahgre River forming a lake. The fan is very steep and is severely truncated by the river. A railroad bed has been benched into the outer part of the fan. If the profile of the fan is projected, it shows that the fan was once much larger. It has been eroded by the river, which has been pushed west by the more active Portland Creek fan.

The area of the fan closest to the creek is placed in the Very High Hazard Zone and the rest of the fan in the High Hazard Zone.

Bridalveil Creek: The Bridalveil Creek fan is more active than would be suggested by the absence of published accounts. Inspection of the fan showed numerous levees and lobes of all sizes, several well-defined channels, and tree burial and scarring. Tree scarring was rarely noticed away from the main channels, although levees and lobes were noted all over the fan, giving it a corrugated appearance (Figs. 24, 25).

Airphotos taken in 1955 show a wide, fresh-looking debris-flow track to the north of the current channel. According to the 1955 field-checked USGS topographic map, the creek is running in that channel. It also appears on the photos that a channel had also existed where the channel now is. This indicates that the creek switched channels sometime prior to 1955 and again since then. Linear stands of young aspen twelve to fifteen feet high radiating from the apex of the fan to the south of both channels suggest an event about ten to twenty years ago. The quick-growing aspen are usually the first tree to revegetate a denuded area. The partial burial of trees less than five feet tall in the same area indicates another small event probably around 1981 or 1982.

Figure 24. Debris-flow levee on Bridalveil Creek fan.

Figure 25. Debris-flow levee on Bridalveil Creek fan.

The lack of reports of events on Bridalveil Creek is concluded to be the result of the low visibility of the fan, which is still heavily forested with large, old trees. In addition, there has been little development on the fan.

Scarring on trees near the present channel indicates that flows up to ten feet deep have come down Bridalveil Creek in the recent past.

Three hazard zones are identified for this fan. The flows appear to be more frequent at the apex and in the area from the northernmost major channel to the southernmost edge of the fan. Therefore, this area is placed in the Very High Hazard Zone. An area of High Hazard covers the lower portion of the fan. There is probably some mud- and water-flooding at the outer edge of the fan where a small band of Moderate to Low Hazard is mapped.

Corbett Creek: Several events have been reported on Corbett Creek in the recent past. The Corbett Creek fan differs from the other fans studied in that it has formed an elongate depositional lobe along the north side of the fan where the creek presently runs. This appears to be an area of intense activity. The channel has also become incised at the apex of the fan. It appears that the entrenchment of the stream at the fan head is preventing deposition on the upper fan and causing deposits to form on the middle and lower parts of the fan, thus creating the lobate area. Judging by the history of other debris fans, the creek will probably tend to build-up this area before spreading out onto the main part of the fan again. This could be accomplished by one or two large events.

Examination of the elongated active area showed large debris lobes, levees, and severe tree scarring and burial (Figs. 26, 27). Tree scars indicate that debris flows up to ten feet in depth have come down the channel (Figs. 28, 29). Boulders two feet in diameter were found lodged between trees.

Even though the last reported event on Corbett Creek was in 1971, evidence on the fan indicates that some debris flooding occurred around 1981 or 1982. Small maple trees, four to five feet in height, were found, with abraded trunks and partially buried.

It should be noted that the profile of the truncated edge of the fan indicates that a very large debris-flow event would probably cross the river and overrun the road. At present, the edge of the fan has been eroded by the Uncompaghre River, which abuts the cliffs on the opposite bank.

Based on the location of the debris lobes, levees, boulders, channels, and tree scarring, three zones were distinguished on the Corbett Creek fan. The apex of the fan, its northernmost portion, and most of the lobate area, were all placed in the Very High Hazard Zone. The lower portion of the fan

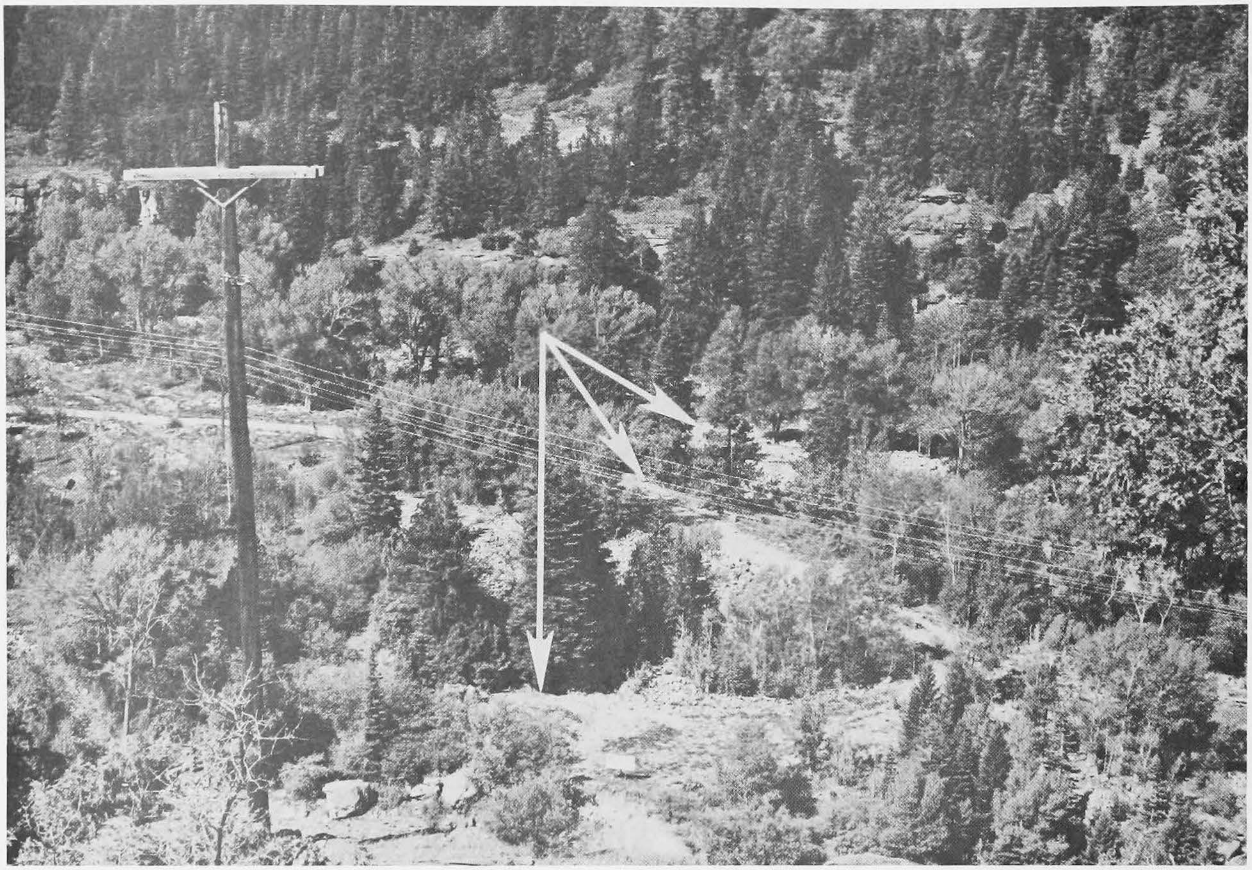


Figure 26. Debris-flow levees on Corbett Creek fan.

Figure 27. Debris-flow levee on Corbett Creek fan.

and the river and highway and part of the lobate area are placed in the High Hazard Zone. The fringes of the lobate area are placed in the Moderate to Low Hazard Zone.

Dexter Creek: Although the Dexter Creek fan appears to be in a state of degradation, it has been active in the recent past. The fan is small and flat

Figure 28. Tree scarring on and boulder wedged between tree trunks adjacent to Corbett Creek, 1982.

Figure 29. Healed scars on trees bordering Corbett Creek.

and has no obvious debris levees or other indicators of debris flows. Before emerging onto the fan, the creek comes out of a deep, narrow gully in the sandstone cliffs. Accounts of past events and the shape of the fan suggest that past events on Dexter Creek may have been water-dominated. The low gradient of the fan may also be due to the periodic removal of the sediments by flooding of the Uncompahgre River.

Examination of the basin showed that there is an abundance of loose debris available for mobilization. The source of the debris is mass wasting in the volcanics, landslide material, and mine tailings (Figs. 30, 31).

Figure 30. Mine tailings near the Bachelor Mine in Dexter Creek basin.

Based on the history of the fan, and the fact that the narrow channel acts as a chute for debris-flow/mudflow events, the area of immediate impact is probably straight ahead of the gully. Therefore a triangular area leading from the gully is placed in the Very High Hazard Zone. The rest of the fan is placed in the High Hazard and Moderate to Low Hazard Zones.

Gullies and Small Basins: No specific hazard zones were mapped for these fans because of their small size. The gullies are simply denoted by an arrow and the fans are outlined. These areas should be subjected to a careful detailed geologic study of potential hazards before a land-use change is considered.

Figure 31. Debris available for mobilization in the Dexter Creek basin.

HAZARD MITIGATION

Past Attempts at Mitigation

After the 1878 event, the citizens of Ouray recognized the threat associated with Portland and Cascade Creeks. Even before the first serious debris flow in 1909, isolated stretches of wooden flume had been constructed on Portland Creek, presumably to protect property; although, the flume was also used as an open sewer (The Ouray County Herald, July 15, 1965). After the 1909 event, the city council decided to construct permanent concrete flumes on both Portland and Cascade Creeks.

The flumes were routed down the existing creek channels which were located on high parts of the fans. Therefore, when flooding occurs, there is no natural containment.

Over the years debris-laden floods have caused extensive damage to houses, businesses, and streets in the city. The flumes have also suffered extensive damage from the pounding of boulders and debris. Although buildings have been knocked from their foundations by the debris flows, most damage has been caused by debris, mud, and water getting into buildings and covering yards and streets. This has resulted in unorganized attempts to mitigate the damage of the flows by the construction of deflection walls around individual buildings (Figs. 32 A, B). This can be very effective in areas on the outer edges of a debris flow where it is only a few inches to a couple of feet thick

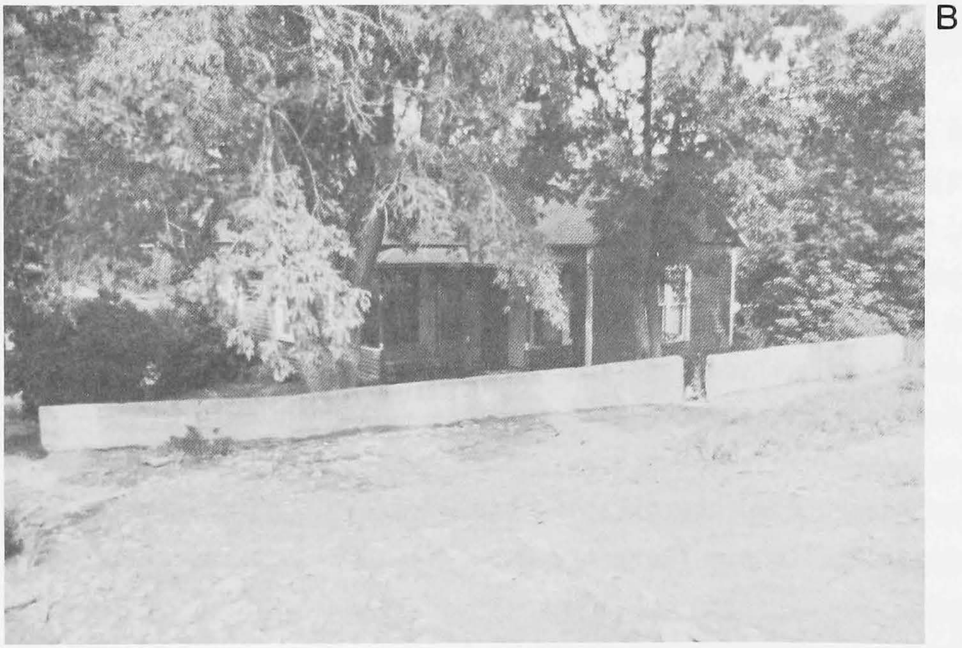


Figure 32. A, Deflection walls around houses near Portland Creek flume.
B, Deflection wall around house near Cascade Creek flume.

and may be mostly mud and water. However, unless constructed around all buildings, these walls tend to concentrate the flow and divert it and related damages onto adjacent property.

The cost of damage and cleanup has increased greatly through the years because of the increased value of the properties and the increased cost of materials and labor. Damage estimates for the 1981 and 1982 events were $196,000 and $360,000, respectively. Since the 1981 and 1982 storms are estimated to be only 10- to 25-year storms (Simons, Li & Associates, 1982), it is apparent that the cost of damages in the event of a 100-year storm probably would be many times higher.

Mitigation Options and Remedial Action Taken in 1983-1986

By studying past events it is possible to outline the general area subject to hazard from debris flows and water floods. By identifying the types and frequency of events that take place, it is possible to evaluate the possible designs and the probability of success for various mitigation measures that may be proposed.

Evidence indicates that the major threat to the city of Ouray is from debris flows. While the city is also subject to the hazard of water floods in the creeks and the Uncompahgre River, the damage from these events is not as severe and they are amenable to conventional storm-drainage approaches.

In areas subject to debris-flow hazard, the main methods of mitigation include: (1) avoidance, (2) basin stabilization, (3) channelization, (4) flow modification and catchment, (5) direct protection, and (6) floodproofing.

Avoidance: For the main part of the city of Ouray, avoidance for existing structures is not possible. The majority of the city is located on the coalescing debris fans of two creeks, Portland and Cascade. Even though the flumes exercise some control over the paths of debris flows, they will not, even in their present improved configurations, contain all the flows for large magnitude events or prevent their unintentional diversion to other areas on the fans.

Avoidance can still be used effectively in the areas subject to debris-flow hazard from Skyrocket, Bridalveil, Corbett, and Dexter Creeks, and the six small gullies since there is presently only minor development in these areas. Selected areas shown to be in the Moderate to Low Hazard Zone by detailed geologic and engineering studies could probably be developed if floodproofing and adequate direct-protection measures are included in the construction of buildings.

Avoidance is the preferable action for new development in areas subject to debris flows, since other mitigation measures may ultimately fail, causing great destruction and possible loss of life.

Basin Stabilization: Basin stabilization does not seem to be a viable method of control for the eight creeks studied in this report. The main method of stabilization in basins of this size would be by vegetation. But, the very characteristics that make debris so abundant in these basins also makes the establishment of permanent deep-rooted vegetation nearly impossible. The steep slopes, clay soils, high altitude, indurated sandstones, and severe winter climate are all hostile to the establishment of vegetation.

The use of structural methods of stabilization such as riprap, wire, and drop structures is probably economically and physically infeasible because of the steep and highly eroded state of the channels, and the excessive costs of construction.

Channelization: The third approach is the use of channelization. Although channelization is of limited effectiveness, it may be the only viable alternative for reducing losses to existing development. This method has been used in Ouray since 1909.

In 1982 Simons, Li & Associates, Inc., under contract to the Colorado Water Conservation Board (CWCB), prepared a debris and flood control plan for Portland and Cascade Creeks to evaluate the feasibility of improvements to the flume systems. They were aided in their recommendations by consultation with the city of Ouray, the Colorado Department of Highways, the CWCB, and suggestions from the Colorado Geological Survey.

In 1983, the city applied for and received partial funding from the Department of Local Affairs for project administration, right-of-way acquisition, utility relocation, and engineering design for both flumes.

The major channel improvements recommended for Portland and Cascade Creeks included enlarging the flumes; improving the entrances to the flumes; improving the conveyance capacity of the flumes by eliminating bends and irregular surfaces, and making the gradient more uniform; providing removable grates over the Highway 550 culverts; and adding a debris basin at the base of the Cascade Creek flume.

In 1984 1,160 feet of new flume were laid to replace and enlarge the dilapidated flume on the lower half of Portland Creek. The new flume is 10 feet wide, 7 to 8 feet deep, has a self-cleaning v-shaped bottom, and has an average slope of 8.0 percent. On Cascade Creek 1,002 feet of the lower flume were reconstructed. The improved reinforced concrete flume is 10 feet wide, varies from 5 to 10 feet deep, has a self-cleaning v-shaped bottom, and an average slope of 13.8 percent.

During 1985 and 1986, the remaining 1,079 feet of the upper half of the Cascade Creek flume were reconstructed. The average slope of the flume in this reach is 17.2 percent.

It is proposed to improve the remaining 1,345 feet of the upper half of the Portland Creek flume in the near future.

The flume entrances used to be a constant source of concern. Cascade Creek flows down a broad channel before turning and entering the flume. In past events, the flows have often jumped the flume at the entrance and headed down Eighth Avenue (Fig. 33). On Portland Creek, the flume entrance was heavily damaged (Fig. 34).

In 1984 the creek channel at the flume entrance on Cascade was deepened and widened and on Portland Creek, the height of the walls at the entrance to the flume was increased (Fig. 35).

It was also recommended that removable grates be installed over the Highway 550 culverts since it was there that the creeks usually blocked

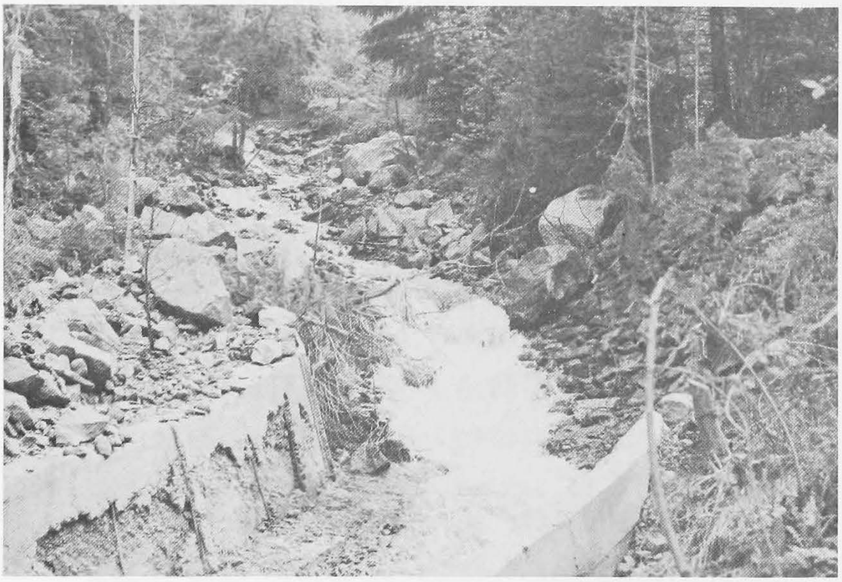


Figure 33. Cascade Creek flume entrance, 1982, before modification.

Figure 34. Portland Creek flume entrance, 1982. The flume shows damage from past events. The building on the right is spattered with mud from the 1982 event.

because of a decrease in slope and the constriction of the culverts. Debris often deposited below and jammed within the culverts. In the past, it was impossible to clear the blockage during a storm or even before a second storm arrived on the next day. In 1984 the Colorado Department of Highways, in a coordinated effort with the city, constructed enlarged concrete box culverts

Figure 35. Improved Portland Creek flume entrance. Construction in 1984 to increase flume wall height (photo courtesy of William P. Stanton, CWCB).

with a series of removable grates in each flume in order to provide maximum access to any blockage.

The total cost for project engineering through 1986, including the initial feasibility study, design, preparation of plans and specifications, and construction inspection amounted to approximately $177,060 for both flumes. Actual flume construction costs through 1986 amounted to approximately $618,040 on Portland Creek, including the highway box culvert; and approximately $1,306,005 on Cascade Creek, including a debris basin and the highway box culvert. In addition, approximately $223,875 were spent on right-of-way acquisition, legal fees, administration, and other project related costs.

Upon recommendation by Simons, Li & Associates, the city agreed that the Uncompahgre River should be periodically dredged below the mouth of the Portland Creek flume. This is to allow more room for the deposition of debris and help prevent the flume from backing-up at the mouth (Fig. 36). The catchment basins on Cascade Creek should eliminate the need for dredging at the mouth of that flume.

Figure 36. Debris accumulated at mouth of Portland Creek flume after 1982 event. (Photo courtesy William P. Stanton, CWCB)

Another recommendation would be that, if for some reason, a structure located next to a flume is destroyed by fire, deterioration, or flood damage, reconstruction would not be permitted. It is suggested that the property could be acquired by the city and used as a buffer zone.

There is not enough population on the fans of the other creeks in the study area to justify the construction of costly channelization structures.

Flow Modification and Catchment: It was suggested in the Simons, Li & Associates report, on the recommendation of the CWCB and the Colorado Geological Survey, that a catchment basin and debris fence could be placed at the base of Cascade Falls where there is already a small basin. This area is fairly accessible for purposes of cleaning out accumulations of debris. The basin would allow a portion of the larger material to be dropped out before it could move down the flume and cause plugging, while the debris fence would break up the viscous plug and dampen the surging effect associated with debris flows (Fig. 37). It would also allow the water and finer sediment to be controlled by conventional approaches.

In 1985 a large amount of accumulated debris was cleared out just below Cascade Falls at the upper end of the flume system, but the debris fence was

Figure 37. Debris fence. Example from Europe. (Photo courtesy Art Mears)

never built. Residents on Eighth Avenue opposed the construction of the debris fence calling it a "pickle fork" and insisted that it would act as a dam (The Ouray County Plaindealer, July 21, 1983). However, a berm was constructed about two hundred feet down from the flume entrance. This berm was designed by Simons, Li & Associates to recapture any water that might jump the flume as a result of blockage or surging associated with debris flows.

In 1909 the city engineer suggested that a catchment area could be constructed below where Main Street crosses the Cascade Creek flume because insufficient grade at that point prevents adequate passage of the debris. This was again suggested after the 1982 events.

In 1984, a 7.5 acre-foot debris basin was excavated below the Highway 550 culvert on Cascade Creek (Fig. 38).

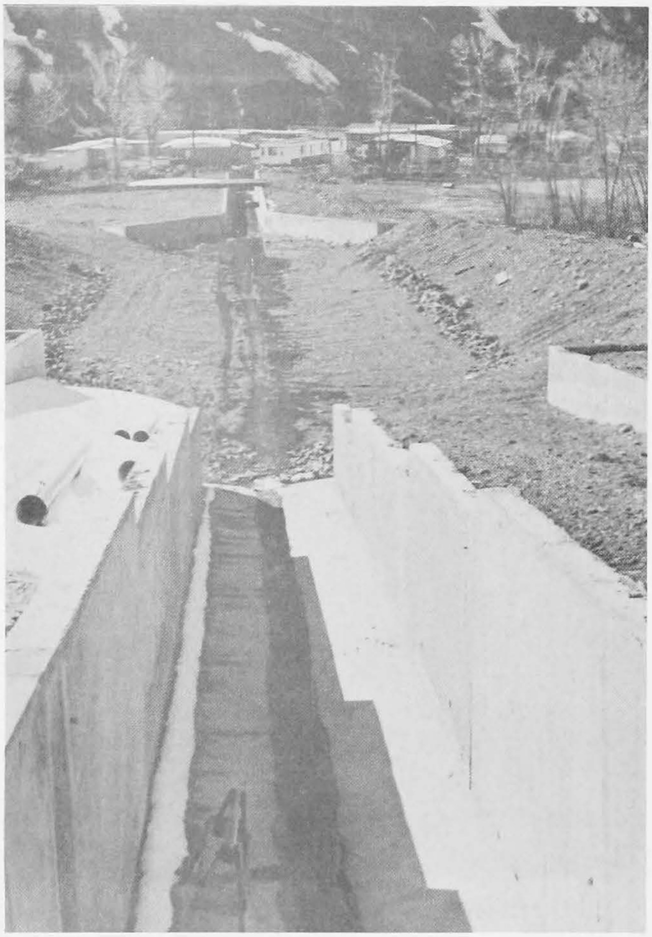


Figure 38. Debris-flow basin constructed on lower Cascade Creek, 1984. (Photo courtesy William P. Stanton, CWCB)

The catchment basin concept cannot be used on Portland Creek because there is no suitable area to locate one. However, a debris fence could possibly be located above Amphitheater Road.

Direct Protection: The construction of individual deflection walls has proved very effective in protecting property close to the flumes during minor events and property some distance from the flumes during most events. It is unlikely that they would be effective for property next to the flumes during large events.

Although there is not enough population on fans other than those of Portland and Cascade Creeks to justify the construction of elaborate deflection structures, residences located on such creeks as Bridalveil and Corbett might derive some benefit from the use of direct protection structures such as berms or a 'splitting wedge', which is a reinforced concrete wall in the shape of a "V' with the point facing uphill. These structures are used to divert small debris flows and floods. Plantings of lines or groves of trees and patches of scrub oak can also be used to break up the energy of a flow. The practicality of tree plantings is limited by the amount of time needed to establish a mature stand of trees. This may take twenty years or more.

Because of the steepness of Skyrocket Creek's fan, and the nature of its flows, it is unlikely that any deflection structure would be able to provide adequate protection. Development on this fan should be avoided. Development in the area near the outer edges of the fan should be protected against mud- and water-flooding.

Floodproofing: The sixth method, floodproofing, can be used on Portland and Cascade Creeks and in those Moderate to Low Hazard areas associated with Skyrocket, Oak, Bridalveil, Corbett, and Dexter Creeks .

Floodproofing consists mainly of (1) reinforcing foundations and uphill walls to withstand the pressure of debris flows and floods and (2) elimination of construction such as basements and crawl spaces, and uphill windows or doors where debris could enter a structure. A table of debris-flow impact pressures was prepared and presented in the Simons, Li & Associates report.

In conjunction with the structural improvements performed on Portland and Cascade Creeks, the city was required to adopt a comprehensive flood plain management ordinance. The ordinance addresses elevating first floors of new structures above the 100-year flood/debris elevations and protecting existing structures with flood/debris proofing measures. This ordinance was adopted by the city on April 18, 1983.

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APPENDIX A

(Adapted from Luedke and Burbank, 1962; 1981)

UNCOMPAHGRE FORMATION (Precambrian) - Thin to massive beds of white and gray quartzite alternating with thin to thick beds of laminated, dark greenish-brown and gray shale. About 3,000 feet thick.

ELBERT FORMATION (Upper Devonian) - Green, buff, and gray thin-bedded calcareous shale, limestone, fine- to coarse-grained sandstone and lenticular conglomerate. Thickness 30 to 50 feet.

OURAY LIMESTONE (Upper Devonian) - Thin to medium beds of gray, buff, and white locally dolomitic and fossiliferous dense limestone with thin shale partings. About 70 feet thick.

LEADVILLE LIMESTONE - (Lower Mississippian) - Thin to massive beds of brownish-gray and bluish-gray dense coarsely crystalline limestone. Locally fossiliferous or chert-bearing. Thickness 180 to 235 feet. Forms massive cliffs with some small step-like benches caused by interbedded shaley layers.

MOLAS FORMATION - (Middle and Lower Pennsylvanian) - Thin to thick beds of red, gray, and green calcareous shale, sandstone, and conglomerate. Thickness 40 to 50 feet.

HERMOSA FORMATION - (Upper and Middle Pennsylvanian) - Thin to massive beds of gray and red interbedded shale, siltstone, gritty sandstone, and limestone (dense and usually fossiliferous). Forms ledges and cliffs. Has a chert-pebble conglomerate at the base. About 1,450 feet thick.

CUTLER FORMATION - (Lower Permian) - Dominantly red and reddish-brown thin to massive lenticular beds. Lower part of the formation is calcareous, micaceous, and arkosic interbedded shale, siltstone, and fine- to coarse-grained sandstone; upper part mostly sandstone containing some shale, mudstone, and conglomerate layers. The conglomerates are derived from the older underlying rocks and contain well-rounded pebbles, cobbles, and boulders, averaging 4 inches. Formation forms benches and cliffs. Thickness 2,000 feet.

DOLORES FORMATION (Upper Triassic) - Reddish-brown, thin- to thick-bedded mudstone, siltstone, and sandstone with locally thin beds of limestone. Locally at the base is a white limestone-pebble conglomerate. Thickness ranges from 40 to 130 feet.

ENTRADA SANDSTONE (Middle Jurassic) - White to buff friable fine-grained sandstone. Thick to massive bedding. Well-rounded, frosted quartz grains. Thickness 45 to 80 feet.

WANAKAH FORMATION (Middle Jurassic) - Consists of three units; Pony Express Limestone Member (lower), consists of thin-bedded, crumpled dark gray fetid limestone and shale, and a breccia of shale fragments; Bilk Creek Sandstone Member (middle) consists of buff fine-grained poorly cemented sandstone; and an unnamed marl-mudstone member (upper) consists of reddish-brown, thin-bedded calcareous mudstone and siltstone. Thickness is 85 to 125 feet.

MORRISON FORMATION - (Upper Jurassic)- Consists of two units. The lower Salt Wash Sandstone Member is yellowish-white and buff cross-bedded fine- to medium-grained sandstone interbedded with gray, green, and variegated mudstone and limestone. The upper Brushy Basin Shale Member consists of variegated, calcareous mudstones, sandstone, and limestone. Forms ledges, cliffs and steep slopes. Average 700 feet thick.

DAKOTA SANDSTONE (Upper and Lower Cretaceous) - Gray, yellowish-tan, white, and buff quartzose fine- to coarse-grained sandstone. Massive bedding. Forms cliffs. Thickness 40 to 175 feet.

MANCOS SHALE (Upper Cretaceous) - Gray to black, locally carbonaceous and calcareous fissile shale and platy mudstone, containing a few thin lenses of sandstone and limestone in the lower part. Thickness is 0 to 1,000 feet thick.

PORPHYRITIC GRANODIORITE (Paleocene and Upper Cretaceous) - Moderately porphyritic texture and predominantly sodic granodioritic composition with andesine, hornblende, biotite, and quartz phenocrysts in a light gray, fine- to medium-grained groundmass.

SAN JUAN FORMATION (Oligocene) - Mostly bedded volcanic conglomerates and mudflow breccias with minor flow breccias of predominantly rhyodacite. Forms steep, rounded slopes and cliffs.

GLACIAL DRIFT (Pleistocene) - Unconsolidated to semiconsolidated unsorted material, mostly till that ranges in size from clay to boulders; locally, some outwash gravels.

Colorado Geological Survey
Department of Natural Resources
John W. Rold, Director

Debris-Flow Hazard in the Immediate Vicinity of Ouray, Colorado

By
Candace L. Jochim

Special Publication 30
1986
Plate 1

Map A: Generalized Geologic Map Showing Debris-Flow Drainage Basins and Debris Sources

EXPLANATION

The geology of the drainage basins has been generalized to emphasize the potential sources of debris and clay minerals. Only units within the drainage basins have been mapped.

▭ QUATERNARY AGE DEPOSITS: These units are considered to be the major potential sources of loose debris and clay minerals.

Qal Alluvium
Qc Colluvium
Qac Alluvial cone deposits
Qd Glacial drift
Qs Landslide deposits
Qt Talus
Qr Rock glacier deposits
Qu Undifferentiated deposits

🟥 SEDIMENTARY ROCKS: This unit includes one or more of the following formations, ranging in age from Precambrian to Cretaceous (see appendix A for detailed descriptions.)

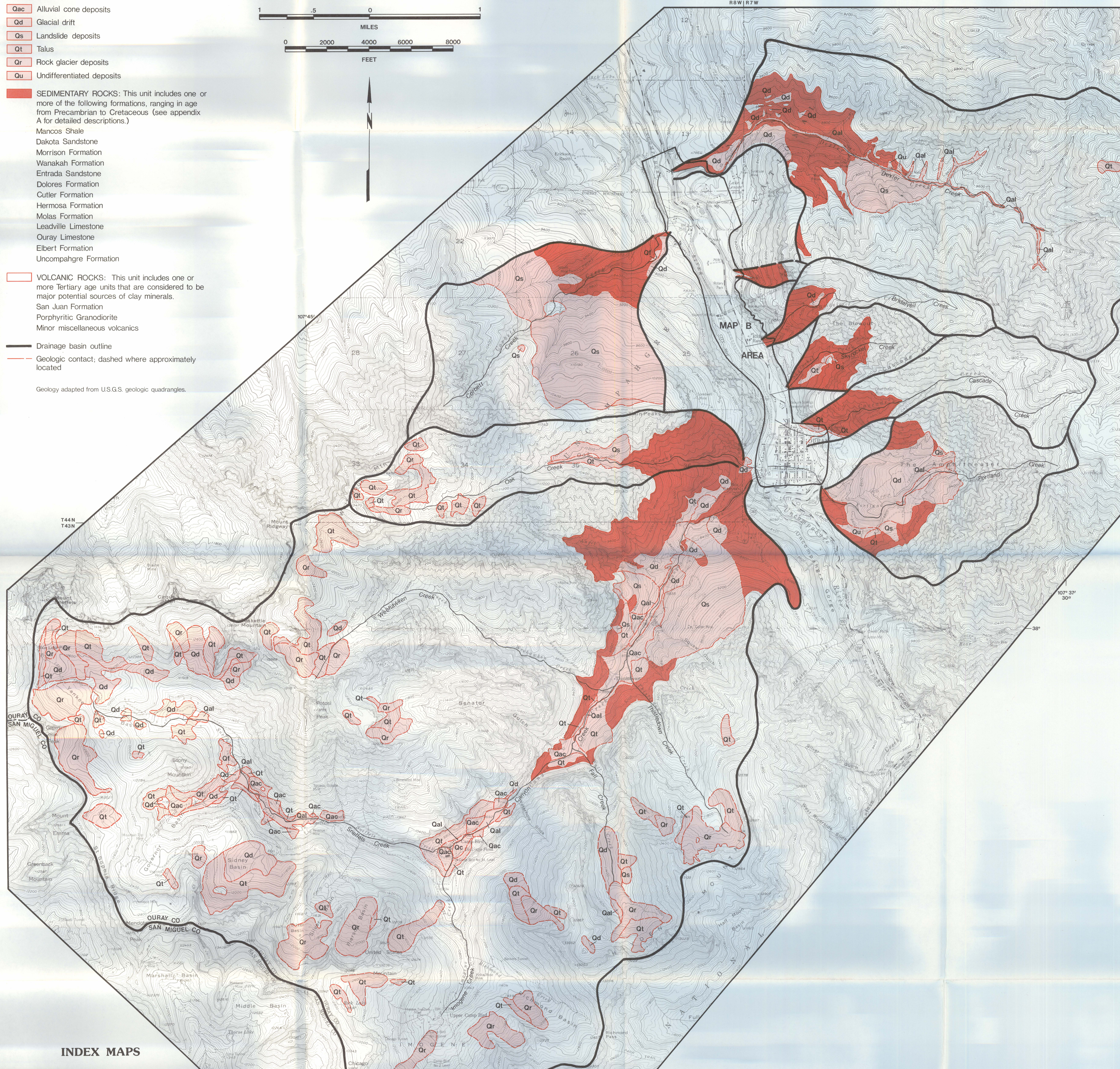
Mancos Shale
Dakota Sandstone
Morrison Formation
Wanakah Formation
Entrada Sandstone
Dolores Formation
Cutler Formation
Hermosa Formation
Molas Formation
Leadville Limestone
Ouray Limestone
Elbert Formation
Uncompahgre Formation

▭ VOLCANIC ROCKS: This unit includes one or more Tertiary age units that are considered to be major potential sources of clay minerals.

San Juan Formation
Porphyritic Granodiorite
Minor miscellaneous volcanics

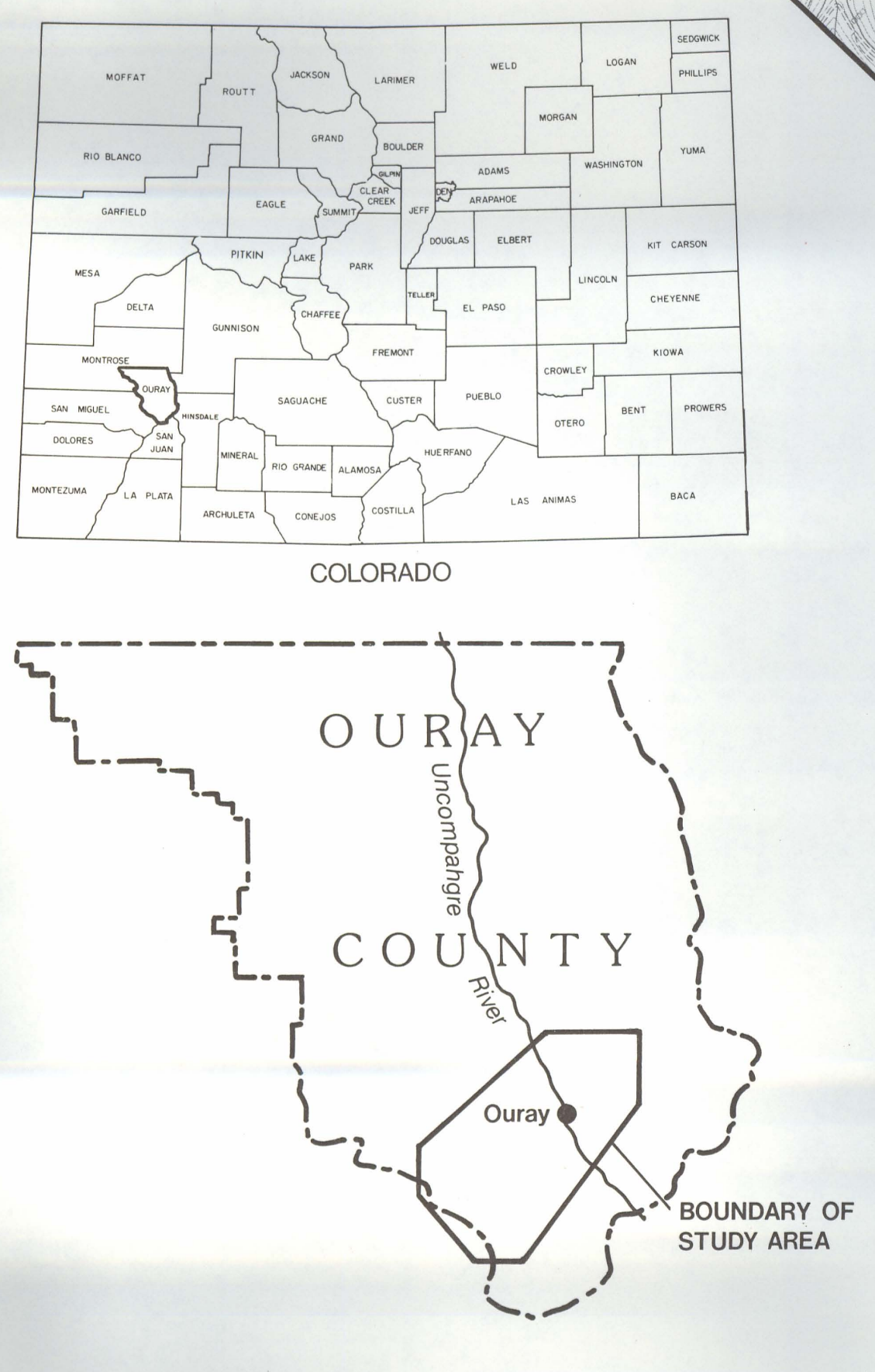
━ Drainage basin outline
— — Geologic contact; dashed where approximately located

Geology adapted from U.S.G.S. geologic quadrangles.



Base from U.S.G.S.

INDEX MAPS



Map B: Map Showing Generalized Hazard Zones for Debris Fans in Study Area

EXPLANATION

🟥 Very high hazard zone
🟥 High hazard zone
▭ Moderate to low hazard zone
⬜ 100-year floodplain of the Uncompahgre River

▨ 3 Fans associated with gullies and small basins. Arrow indicates location of gully. Fans are identified by number. No degree of hazard has been determined for these fans.

The boundaries of all hazard zones are estimates and should be used only as an approximation of the relative hazard at any particular location on or near a fan.

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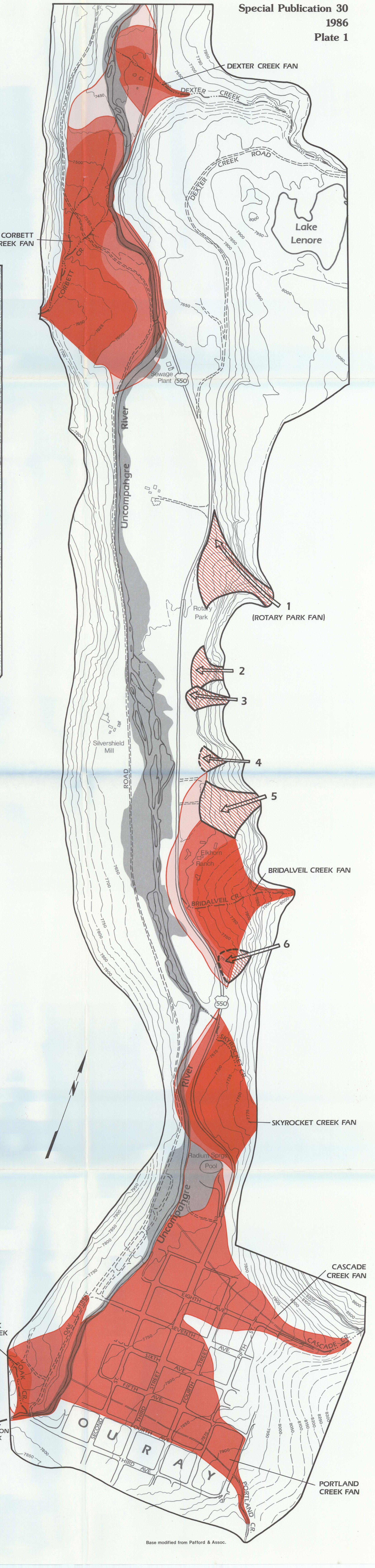

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