Progress Report

Hydrologic Monitoring Program, Rifle Oil Shale Facility Site, Colorado

R. M. Ecker
W. H. Walters
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October 1979

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Richland, Washington 99352

SUMMARY

A hydrologic monitoring and assessment program is being developed to investigate the hydrologic characteristics of surface and ground waters in the region of the Anvil Points, Colorado, Rifle Oil Shale Facility. The objectives of the program are to:

- evaluate ground-water contributions to study streams
- assess contaminant transport capability of surface and ground waters
- determine peak discharge magnitude and frequency relationships for use in designing possible spent oil shale disposal works
- assess the impact of specified hypothetical problems, events, or scenarios.

To accomplish these objectives, seven major tasks have been identified:

1. Literature Review of Existing Studies Dealing With The Regional, Hydrological, Physiographical, Geological, and Climatological Characteristics
2. Ground-Water Characterization
3. Drainage Basin Characteristics and Channel Geometry
4. Streamflow and Sediment Transport
5. Stream Travel Times
6. Analysis of Spent Shale Disposal
7. Support of Water Quality Sample Collection

As part of the program, three field trips to the Rifle Oil Shale Facility site were taken to gather data. The initial trip, 17 through 22 June 1979, was a field reconnaissance to evaluate the site in terms of methods and procedures that could be used to monitor surface and ground waters. This field reconnaissance included a discussion and tour with personnel of Development Engineering, Inc. (operators of the Rifle Oil Shale Facility), inspection of existing ground-water observation wells, preliminary flow measurements in West Gulch

(small stream adjacent to the site), inspection of West Gulch from its headwaters to the Colorado River, and initiation of stream bed gradient and cross-section surveys of West Gulch.

The second field trip was taken 23 through 27 July 1979 for the purpose of completing the stream bed gradient survey, observing highwater marks produced by the May 1979 flood, investigating the diurnal flow fluctuations in West Gulch, and selecting flow gaging locations. A reconnaissance survey of Balzac Gulch was also made.

The third field trip, 10 through 14 September 1979, included further observations of highwater marks in addition to collecting and performing a seismic refraction profiling study to aid in selecting sites for additional ground-water observation wells.

CONTENTS

SUMMARY	iii
FIGURES	vii
INTRODUCTION	1
STRUCTURE OF HYDROLOGIC MONITORING AND ASSESSMENT PROGRAM	2
TASK 1: LITERATURE REVIEW OF EXISTING STUDIES DEALING WITH THE REGIONAL HYDROLOGICAL, PHYSIOGRAPHICAL, GEOLOGICAL AND CLIMATOLOGICAL CHARACTERISTICS	2
TASK 2: GROUND-WATER CHARACTERIZATION STUDIES	2
TASK 3: DRAINAGE BASIN CHARACTERISTICS AND CHANNEL GEOMETRY.	3
Subtask 3A	3
Subtask 3B	3
TASK 4: STREAMFLOW AND SEDIMENT TRANSPORT	3
TASK 5: STREAM TRAVEL TIMES	4
TASK 6: ANALYSIS OF SPENT SHALE DISPOSAL	4
TASK 7: SUPPORT OF WATER QUALITY SAMPLE COLLECTION	6
FINDINGS FROM FY-1979 FIELD INVESTIGATIONS AND LITERATURE REVIEW	7
PICEANCE CREEK BASIN	7
WEST GULCH	11
General Description	11
Fluvial System	18
Climate	23
Vegetation	25
Streamflow	26
Flooding	27
Sediment Transport Characteristics	30

Seismic Profiles	.	.	.	.	.	.	.	.	.	.	.	36
Balzac Gulch	.	.	.	.	.	.	.	.	.	.	.	38
REFERENCES	.	.	.	.	.	.	.	.	.	.	.	43
APPENDIX A - DETAILS OF MAY 1979 PEAK DISCHARGE ESTIMATE	.	.	.									A-1
APPENDIX B - CENTURY WEST ENGINEERING CORPORATION REPORT	.	.	.									B-1

FIGURES

1	Oil Shale Contaminant Mathematical Model Coupling and Interfaces	5
2	Drainage Area Map of West Gulch, Balzac Gulch, and The Roan Plateau	8
3	Centerline Profile of West Gulch	14
4	West Gulch Basin Cross Sections	16
5	West Gulch Bottom Profile	20
6	Undercutting of West Gulch Channel Walls	22
7	Estimated Frequency Curves, Unnamed Tributary to the Colorado River	28
8	Culvert Highwater Mudlines, Unnamed Tributary to the Colorado River	30
9	Example of Large Boulders in West Gulch	32
10	Results of Seismic Refraction Survey - Century West Engineering Corporation	37
11	Balzac Gulch Drainage Basin Profile	39

INTRODUCTION

The oil shale deposits of the Green River Formation in Colorado, Wyoming, and Utah represent the largest known oil resource in the world. However, potential environmental impacts from oil shale development in the Green River Formation region must be assessed before commercial production can begin. The scarce water resources of this region make water quality and quantity particular areas of concern. Furthermore, spent shale is highly alkaline and contains heavy metals and trace organics; therefore, nonpoint sources such as disposal areas for spent shale and retort water represent difficult problems to understand and control. At the request of the Department of Energy's Office of Health and Environmental Research (OHER), Pacific Northwest Laboratory (PNL) has begun an interdisciplinary research program to investigate these problems. The principal objectives of this program are to: 1) develop a basic knowledge of important processes influencing the form, mobility, chemical and microbiological stability, and plant availability and toxicity of trace metals and organic residuals in retort waters and retorted shales; 2) develop a rational basis for selection and subsequent planting of native or agricultural plant species to result in permanent, safe restoration of shale lands; and 3) model the chemical reactions and transport of these materials through retorted shale and soils to ground and surface waters.

This report describes the hydrologic monitoring and assessment program being developed at the Anvil Points, Colorado, Rifle Oil Shale Facility site by the Water and Land Resources Department, in cooperation with the Ecological Sciences Department, to accomplish objective (3) above. A discussion of initial field investigations made in FY-1979 is also included.

STRUCTURE OF HYDROLOGIC MONITORING AND ASSESSMENT PROGRAM

An evaluation of the mechanisms controlling the transport of oil shale contaminants to and in ground- and surface-water systems could be approached with an extensive sampling program designed to monitor each mechanism. However, such a program would be costly and require many years of effort to obtain useful information. A more efficient approach is to develop a system of mathematical models capable of simulating ground- and surface-water contaminant transport as a function of time and space.

PNL, in developing the hydrologic monitoring and assessment program, is using the second of the above approaches. The development of this program has been broken down into the following seven tasks.

TASK 1: LITERATURE REVIEW OF EXISTING STUDIES DEALING WITH THE REGIONAL HYDROLOGICAL, PHYSIOGRAPHICAL, GEOLOGICAL AND CLIMATOLOGICAL CHARACTERISTICS

Due to the extensive oil shale deposits in the Piceance Creek basin, geological, physiographical, hydrogeological and hydrological studies have been conducted on a regional scale. In addition, some site-specific studies of existing oil-shale lease tracts have been conducted or are ongoing. These studies will be reviewed with the purpose of including pertinent data and methodology into the program at West Gulch.

TASK 2: GROUND-WATER CHARACTERIZATION STUDIES

Preliminary chemical characterization studies of existing ground-water observation wells and seeps at the Rifle Oil Shale Facility site has indicated that ground water has been in contact with retorted shale, process water, and oil shale. Additional ground-water monitoring wells will be installed at strategic locations and equipped with multiple depth piezometers. These wells will provide more accurate water quality data and an estimate of the areal extent of possible ground-water contamination. The wells will also enable the determination of the direction and magnitude of ground-water movement and the time scale over which the contamination of ground water has occurred, along with possible mitigating measures that could be taken.

This task also includes seismic refraction profiling in the area of West Gulch upstream and downstream of the spent oil shale pile to aid in locating the observation wells. The seismic records provide the depths of alluvium overburden in West Gulch and can also be used to determine the foundation characteristics for the structural design of possible spent oil shale retention structures.

TASK 3: DRAINAGE BASIN CHARACTERISTICS AND CHANNEL GEOMETRY

This task will consist of two major subtasks both of which will be used to analyze and define the watershed geomorphology, hydraulics, sediment transport, and vegetation characteristics. The results will also be used to design the precipitation and stream gaging system described in Task 4.

Subtask 3A.

Stream bed gradients, cross-section shapes, highwater marks, and bed sediment characteristics of West Gulch will be determined as part of the surface-water characterization study. The data will be used to estimate maximum water discharges during extreme events, evaluate sediment yield volumes of the drainage basin, and provide the basis for future hydrodynamic and contaminant transport modeling.

Subtask 3B.

Aerial photography will be used to analyze the drainage networks, geologic structure, and vegetation of the study watersheds. Since no suitable vertical air photo coverage is available for interpretation purposes, overflights will be required to obtain the necessary coverage. The imagery will also be used to develop topographic maps of particular study areas.

TASK 4: STREAMFLOW AND SEDIMENT TRANSPORT

Preliminary studies of West Gulch indicate that extreme variations in streamflow and sediment load can occur. The intermittent flow can, within a given year, range from near zero or zero discharge during the summer and winter to out-of-bank flood flows in the spring and early summer. The corresponding suspended sediment is highly correlated to the discharge varying from very low

concentrations during low flow periods to near mudflow levels during intense thunderstorms. To fully understand the various mechanisms affecting stream-flow and sediment discharge in West Gulch, systematic records of suspended sediment concentrations commensurate with parallel records of water discharge are necessary. Since such records are currently nonexistent, continuous recording stream gages and suspended sediment samplers must be established within the surface water monitoring program. In addition, existing rainfall records for West Gulch and studies in nearby watersheds show that precipitation has extremely nonuniform temporal and spatial distributions within the basin. This nonuniformity dominates the precipitation runoff relationship for the basin and directly affects streamflow, sedimentation, evapotranspiration, etc., and ultimately, the transport of oil shale contaminants. Therefore, to fully characterize the precipitation in West Gulch a network of continuous recording rain and snow gages will be established.

To supplement these data collection activities, other data sources, including the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), and Colorado State University, will be consulted. Available information will be incorporated into the data base.

TASK 5: STREAM TRAVEL TIMES

The time of travel for a particle of water from the demonstration site to the Colorado River under differing discharge conditions is an important consideration in the assessment of possible oil spills or contaminant transport at the demonstration site. The length of time for water to travel from the site to the Colorado River will be determined for different discharges by means of fluorescent dye studies. Similar dye studies should also be conducted in Balzac Gulch because of the proposed location of the commercial oil shale retort in this drainage basin.

TASK 6: ANALYSIS OF SPENT SHALE DISPOSAL

The major concerns associated with surface disposal of retorted shale are: 1) the leaching of dissolved contaminants from the shale pile into the surface

or ground-water systems, 2) the transport of dissolved or particulate contaminants by overland and instream flow, and 3) the structural and hydrologic design of related structures such as retention dams, diversion systems, and holding ponds. In consideration of the above concerns, the objective of this task is to evaluate the potential risks and impacts of selected surface disposal strategies. The primary approach to these problems will be to couple mathematical hydraulic models which simulate the movement of water through surface channels and porous media with transport models which simulate chemical and/or biological reactions. Figure 1 shows the structure and interfaces of these models. The effort in this task will be, to a large part, supported by the other tasks in the program. For example, the data base in Task 4 is essential for model calibration and verification, and the results of the remaining tasks will provide invaluable insight to interpretation of model results.

FIGURE 1. Oil Shale Contaminant Mathematical Model Coupling and Interfaces

TASK 7: SUPPORT OF WATER QUALITY SAMPLE COLLECTION

Support will be given to the Ecological Sciences Department in their effort to collect water quality data of ground water and surface water by providing guidance on frequency of sampling as related to hydrologic conditions, location of samples as related to areas of sediment accumulation, and methods for collection of suspended and bed sediment samples, and measurement of streamflows.

FINDINGS FROM FY-1979 FIELD INVESTIGATIONS AND LITERATURE REVIEW

The Rifle Oil Shale Facility is located on the Naval Oil Shale Reserves 1 and 3 at Anvil Points, Colorado. The site is located in Garfield County, approximately 5 miles northwest of Rifle, Colorado and 55 miles northeast of Grand Junction, Colorado. The site is situated on the southeast margin of the Piceance Creek structural basin and is adjacent to the Colorado River.

Initial field and literature investigations have been concentrated in three watersheds: 1) the Piceance Creek Basin, 2) the small unnamed stream to the east of and adjacent to the Rifle Oil Shale Facility hereafter referred to as "West Gulch," and 3) Balzac Gulch, a stream about 1 mile west of West Gulch. The results of these investigations are presented in this section according to watershed.

PICEANCE CREEK BASIN

The Piceance Creek basin is a large structural basin coinciding with the original basin of deposition of the Late Cretaceous and early Tertiary sediments. The Piceance Creek basin is noted for its kerogen-rich marlstone deposits (oil shale) found in the upper units of the Green River Formation of middle Eocene age. The basin can be divided into two separate physiographic subbasins, a northern basin draining into the White River and a southern basin which drains into the Colorado River. The two drainages are separated by an east-west trending topographic rise located adjacent to and south of the Rio Blanco-Garfield County line. The northern basin is drained by Piceance and Yellow Creeks which flow northward into the White River. Roan and Parachute Creeks drain the southern basin and flow to the southwest into the Colorado River.

Land surface elevations range from 5,000 ft above sea level in the Colorado River Valley to 9,400 ft on the Roan Plateau and Cathedral Bluffs (Figure 2). The major physiographic feature of the basin is a large dissected plateau rising from 1,000 to 4,000 ft above the adjacent lowland. The

FIGURE 2. Drainage Area Map of West Gulch, Balzac Gulch, and the Roan Plateau

southern portion of the plateau is deeply dissected by tributary streams of the Roan and Parachute Creeks. This dissected plateau forms the Roan Cliffs. From the Roan Cliffs the plateau, known as the Roan Plateau, slopes gently downward to the north toward the center of the Piceance Creek Basin.

Since late in the Cretaceous Period, the Piceance Creek basin has been the site of considerable sediment deposition. During the Eocene Epoch (early Tertiary Period) crustal warping created an immense lake covering northwestern Colorado and northeastern Utah. The lacustrine deposits in the ancient lake range from nearshore sands to fine-grained clastic sediment and clay in the deeper portions of the former lake. When climatic conditions were right for plant and animal life to flourish, organic-rich layers of lake sediment developed. Younger deposits gradually buried these organic-rich sediments as the lake filled and the sedimentary deposits became more fluvial in nature. Consolidation of the deposits occurred from the weight of overburden and the highly organic layers formed the kerogen-rich marlstone beds known as oil shale.

The exposed rock outcroppings in the Piceance Creek basin are dated from the late Cretaceous Period to the Quaternary Period and are predominantly sandstone, shale, marlstone and kerogen-rich marlstone. The oldest rock outcroppings belong to the Mesaverde group and are exposed along the eastern margin of the basin, thinning toward the west. The Mesaverde group is an erosion-resistant, ridge forming, tan to brown sandstone. The group is interbedded with shale and coal beds.

Also exposed along the basin's east margin is the Ohio Creek conglomerate which overlies the Mesaverde group and is placed in the Paleocene Epoch. It consists of black and red chert and quartzite pebbles in a white sandstone matrix. The maximum thickness attained in this unit is 20 ft in the northeastern part of the Piceance Creek basin.

Overlying the Ohio Creek conglomerate is an unnamed rock unit (Paleocene Epoch) of brown ledge-forming sandstone. Interbeds of dark-colored shale and a few coal beds are present throughout its 500-ft maximum thickness. A continental deposition environment is indicated by plant and nonmarine mollusk fossils in the shale.

Lying conformably above the unnamed unit is the Wasatch Formation of the Eocene Period. It contains buff-colored lenticular sandstone and irregularly bedded, brightly colored shale. Minor amounts of limestone, conglomerate, coal, and black carbonaceous shale are also present in the Wasatch Formation. Outcrops of the formation along the basin margins form lowlands. The formation varies greatly in thickness with a maximum of about 5,500 ft in the eastern part of the basin. The many fossils in the Wasatch Formation indicate a fluviatile depositional environment.

The Green River Formation of middle Eocene age lies conformably over the Wasatch Formation. It contains evidence of both fluviatile and lacustrine depositional environments. As it is now subdivided there are four members of the formation. The members in ascending order of occurrence are: Douglas Creek, Garden Gulch, Anvil Points, and Parachute Creek. Formerly, the Green River Formation contained a fifth member, the Evacuation Creek member [G. E. Maddox (Century West Engineering Corp.) and J. R. Raymond (PNL)]. This member has been abandoned and the rocks are now identified as being part of the lower Uinta Formation (Cashion and Donnell 1974).

The Douglas Creek member is predominantly a brown to buff-colored, erosion-resistant sandstone with minor amounts of limestone and shale. It outcrops along the southern and western margins of the basin, but is not exposed along the eastern and southeastern margins.

The Garden Gulch member consists of shale and kerogen-barren dolomitic marlstone. Thin beds of limestone and sandstone are also present. Its maximum thickness is about 900 ft and forms steep cliffs along all but the eastern margin of the basin.

The eastern equivalent to the Douglas Creek and Garden Gulch members of the Green River Formation is the Anvil Points member. It is a nearshore sequence of sandstone, interbedded shales and kerogen-barren marlstone. This member is erosion-resistant and forms cliffs with a maximum height of 1,870 ft in the southeastern part of the basin.

The Parachute Creek member overlies the other members of the Green River Formation and consists of white to gray varved dolomitic marlstone with

alternating dark kerogen-rich zones and sodium minerals. It is a cliff formation reaching a maximum thickness of 1,230 ft in the southeastern portion of the basin. A particularly kerogen-rich bed, the Mahogany zone, is found near the top of the Parachute Creek member.

The Unita Formation (late Eocene Epoch) overlies the Green River Formation and contains sandstone, siltstone, and generally kerogen-barren marlstone.

Alluvium belonging to the Quarternary Period occurs in the stream and river valleys. These unconsolidated deposits of gravel, sand, and clay have a maximum thickness of 200 ft (Golder and Associates, Inc. 1977).

WEST GULCH

Being on the southeastern margin of the Piceance Creek basin, the physiographic characteristics of the Rifle Oil Shale Facility site are similar to other areas within the basin (Figure 2). The site is comprised of vertical cliffs reaching an elevation of 9,000 ft above sea level. The cliffs are known as the Roan Cliffs. The Colorado River valley at the base of the Roan Cliffs is at an elevation of 5,200 ft above sea level. Promontories or points are present with steep sided, steep gradient gulches incised into the cliffs. At the base of the cliffs large talus piles are present comprised of rock sizes ranging from pebbles to boulders. The lowlands and gulch channels are filled with fine- to coarse-grained alluvium deposits. Intermittent streams can be found in most of the gulches. These intermittent streams, when flowing, discharge their water and sediment load out onto the lowlands and into the Colorado River.

General Description

The stratigraphic sequence of exposed rock outcroppings in the vicinity of Anvil Points, in ascending order of occurrence, includes the Wasatch Formation, Green River Formation, and overlying Quarternary alluvium. The Green River Formation, which is the cliff forming unit in the area, is comprised of the following members in ascending order: Anvil Points member (also known as the lower sandy member), Parachute Creek member and the Evacuation Creek member (now identified as the lower Unita Formation).

The West Gulch drainage basin is extremely small, as are most of the basins draining the southern margins of the Piceance Creek structural basin. The drainage area of the basin is 1.51 square miles and is oriented in a northwest-southeast direction. Most of the basin lies between the Roan Cliffs on the north and the Colorado River on the south. A small area of the basin, about 3,200 ft in length and 1,600 ft wide, extends northward of the Roan Cliffs escarpment. The greater portion of the basin extending southward from the cliffs is approximately 3.6 miles long and about 0.9 miles wide at its maximum. This portion of the basin forms part of the Colorado River flood plain. The local relief is about 3,800 ft with the elevation varying from 9,000 ft above sea level on top of the Roan Cliffs to about 5,200 ft at the Colorado River.

West Gulch is actually a tributary of the watershed adjoining the eastern boundary of the West Gulch. The confluence of West Gulch and the larger drainage system occurs about 2,000 ft upstream of the Colorado River. The larger watershed also begins above the Roan Cliffs, has a total drainage area of 5.46 square miles, and empties into the Colorado River.

West Gulch has extremely steep, V-shaped valley walls and steep in-channel gradients. The head of the gulch originates in the predominantly black, brown, and gray cliff forming marlstone and sandstone deposits of the Green River Formation, and in its passage to the Colorado River passes through the vari-colored sandy shale and lenticular sandstone of the Wasatch Formation. It appears that the head of the gulch is actively eroding into the East Fork Parachute Creek system and has captured a part of Second Anvil Creek. The Green River Formation, which is more resistant than the underlying Wasatch Formation, forms the vertical face of the Roan Cliffs, and delineates the maximum extent of headward erosion. The stream channel and much of the lower sidewalls are comprised of alluvium deposits originating from the Unita, Green River, and Wasatch Formations. The channel bed itself is incised into the alluvium and in many places passes over outcrop controls of sandstone and sandy shale that give the channel a stairstep character. The alluvium deposits are comprised of material sizes from clay to extremely large boulders. The finer sediments

are brown to reddish brown in color, whereas the larger boulders are predominantly gray to black varved marlstone with lesser amounts of sandstone boulders.

Vegetative cover in the West Gulch drainage basin is sparse to moderately thick. The high headwall of the Roan Cliffs and active talus pile at its base are sparsely vegetated. At the upper elevations the vegetation consists of upland sagebrush, mixed mountain shrub, pinyon-juniper woodland, and grassland. The grassland is confined to fairly narrow bands along the gulch channel and seeps originating in the alluvium above the channel bed. At the lower elevations the vegetation is comprised of bottomland sagebrush, desert shrub, grassland and limited stands of pinyon-juniper woodland.

West Gulch is a small intermittent stream. Its headwaters originate at the base of the Roan Cliffs, emerging from seeps in alluvium at about the 6,600-ft elevation. West Gulch is typical of those small streams where the primary source of streamflow is from snowmelt. In these small streams, along the margins of the Piceance Creek basin, precipitation is stored as snowpack at the higher elevations during the months of November through March. Water becomes available for recharge and runoff as the daily temperatures and solar radiation increase in the spring, causing the snowpack to melt. The snowmelt results in a period of high streamflows, starting in March or April. The duration of these high flows depends on the accumulation of snow, the size of the basin, and the rate of snowmelt. In the case of West Gulch with its extremely small drainage basin, the duration of the high streamflows from snowmelt is fairly short, lasting from 1 week to 1 month. Streamflow in these small basins will continue for an indefinite period beyond the snowmelt event as recharge water in the alluvium and talus deposits is discharged into the stream. High intensity spring and summer thunderstorms can also result in extremely high flows of short duration.

West Gulch drainage basin, as mentioned previously, has a fairly steep longitudinal gradient. Figure 3 is the centerline profile of the drainage basin from atop the Roan Cliffs to the Colorado River. The profile has been

FIGURE 3. Centerline Profile of West Gulch

drawn from the USGS Anvil Points, Colorado, 7.5 Minute Quadrangle map of 1952. The basin profile is concave downward with the steepest slopes near the headwaters, progressively decreasing toward the Colorado River. The basin can be divided into seven physiographic reaches shown in Figure 3 and described in the following paragraphs.

A small drainage area (Section A-A' in Figure 4) is present on top of the Roan Cliffs between the elevations of 8,600 ft and 9,000 ft. This small drainage area contributes significantly to the flow of West Gulch during the spring snowmelt, when water can be seen cascading over the edge of the Roan Cliffs, and during spring and summer thunderstorms.

The Roan Cliffs are exposed as a nearly vertical headwall with a relief of about 600 ft. The exposed rock of the headwall is gray, brown, and black varved marlstone belonging to the Parachute Creek member of the Green River Formation. The exposed headwall is concave inward with promontories delineating the lateral boundaries of the drainage basin.

At the base of the headwall is an extensive talus pile of large boulders originating from the Roan Cliffs. The coarse talus extends over about 1,200 ft of vertical relief and the angle of repose of the talus is approximately 34 degrees. A section across the basin in this reach is shown in Section B-B' of Figure 4.

Between the elevation of 6,400 and 6,800 ft the drainage basin gradient decreases to about 1,450 ft per mile or a slope of 16 degrees. Thick alluvium of fine unconsolidated sediments and large boulders make up the bottom of the drainage basin. It is in these deposits that West Gulch emerges from numerous seeps. A cross section through the basin in this reach is shown in Section C-C' of Figure 4. West Gulch becomes deeply incised into the unconsolidated alluvium and the steep sidewalls appear to be very unstable with much evidence of slumping during periods of heavy rainfall and snowmelt.

Between the elevations of 6,000 and 6,400 ft the basin gradient decreases to about 675 ft per mile (approximately a 7-degree slope) and the basin becomes wider. The alluvium is thinner and brown to buff-colored sandstone outcrops appear in the stream channel as controls and along the sidewalls of the basin.

FIGURE 4. West Gulch Basin Cross Sections (see Figure 2 for cross-section locations)

The basin sidewalls are steep, as shown in Section D-D' of Figure 4, but appear to be more stable than along the preceding reach. The West Gulch channel becomes better defined and more stable with a few large radius bends. The existing channel bed is often cut down through a relict channel with old channel terrace remnants along the side of the channel.

Between the elevations of 5,600 and 6,000 ft the basin gradient further decreases to about 400 ft per mile. The basin sidewalls are less steep and numerous small side gullies enter West Gulch (Section E-E' of Figure 4). The creek becomes very sinuous with many small and large radius bends. Reddish brown to purple-colored shale and buff to brown-colored outcrop controls are present in the channel. Seeps occur in the channel banks along a portion of the channel in this reach, but can be found only directly above the shale outcrops. In places the alluvium appears to be thicker, and, at some locations, West Gulch has cut down through as much as 20 to 30 ft of alluvium. The Rifle Oil Shale Facility is located on the east side of the basin in this reach at an elevation of about 5,800 ft. The spent shale pile and fines pile have been casted downslope and at one point infringe on the West Gulch channel.

The lowest reach of the West Gulch drainage basin has a gradient of about 240 ft per mile. A section across the basin in this reach is shown in Section F-F' of Figure 4. This area is part of a large alluvial fan running the length of the Roan Cliffs. West Gulch cuts through this fan as a narrow channel which is seldom deeper than 10 to 20 ft and no wider than 30 ft. No bedrock is exposed in this reach and the alluvium is comprised of fine- to coarse-grained sediment, and marlstone and sandstone boulders.

The Rifle Oil Shale Facility, operated by Development Engineering, Inc., is the only major development in the West Gulch area. The site presently consists of a small demonstration plant at an elevation of 5920 ft in a small watershed adjacent to West Gulch, raw shale and retorted shale piles near the West Gulch primary drainage channel, surface storage lagoons for water and oil down valley from the shale piles, and the oil shale mines at an elevation of 8,200 ft in Balzac Gulch to the west of West Gulch. Development plans by Development Engineering, Inc., call for the construction of a commercial-scale

retort along the existing mining road which runs along the west margin of Balzac Gulch. Disposal of solid waste from the commercial-scale plant will take place in Balzac Gulch.

Fluvial System

Schumm (1977) describes three zones in which a fluvial system can be divided, the major difference being each zone's relationship to erosion and deposition of sediment. The uppermost area (Zone 1) is called the watershed or sediment source where most of the water and sediment are derived. The intermediate area (Zone 2) is the transfer zone where long-term erosion or deposition is not occurring, and sediment inflow roughly approximates sediment outflow. The lowermost area of the system (Zone 3) is primarily an area of deposition. Schumm states that these three subdivisions may appear artificial because erosion, transport, and deposition occur in all three, but within each zone one process is dominant. Therefore, Zone 1 is considered to be the sediment producer; Zone 2 is mainly an area of transport; and Zone 3 is where sediment is deposited on alluvial fans, plains, or deltas. Although the West Gulch drainage basin is a tributary to a larger gulch, all three areas are present in the system. The three zones are shown in Figure 2.

Zone 1 - Sediment Production

Flow collected in the uppermost portion of the watershed cascades over the Roan Cliffs, joins flow from rills and gullies immediately below the cliffs, and enters the beginnings of a channel near the base of the talus pile. Below this point, flow is supplied by overland flow from larger rill systems and discontinuous gullies. As the channel becomes more well defined, tributary gullies become apparent.

Ephemeral rills are the smallest channels and mark the beginning of tributary systems. Their channels carry water and sediment during storms but most of the time are dry. Rills initially develop as parallel channels and eventually erode into each other by the process of cross-grading, which involves overtopping of rill divides by the flow. Cross-grading gradually obliterates

all original rill features and leads to development of well-defined gullies and tributaries. This is an erosional process and supplies sediment to the main channel primarily by overland flow.

As new gully systems begin to develop, certain characteristics become apparent. A series of headcuts become established along the future gully drainage path, characterized by a channel immediately below the headcut, which is often slightly deeper than it is wide and progressively decreases in depth downstream. Where the plane of the gully floor intersects the more steeply sloping valley floor, the gully walls have decreased to zero in height and a depositional fan occurs. The basin drainage pattern of Figure 2 was mapped from the USGS Anvil Points quadrangle map (1952) by connecting contour crenulations that indicate possible gully development.

Discontinuous gully channels appear to be the predominant drainage feature in Zone 1. This feature would imply that sediment is being temporarily stored where the gullies are discontinuous, although significant quantities would be transported during high runoff events. If the gullies have no well-defined junction with the main channel, the water and sediment mixture would have to travel as overland flow to reach the main channel, which seems to be the situation for most of the gullies mapped in Zone 1. Field reconnaissance revealed instances where concentrated water and sediment inflow had cascaded over the top bankline of West Gulch, causing some trenching and possibly bank material slumping. While discontinuous gully systems do temporarily store sediment, they are in the process of developing into continuous tributary systems by degradation, an erosional process.

Zone 2 - Sediment Transfer

Transition from an erosional zone to a transfer zone becomes noticeable in the vicinity of the oil shale development site. Beginning at about Well No. 1 (Figure 5) above the shale piles, tributary confluences become more apparent with small narrow V-shaped channels containing a considerable number of boulders. The tributary channel beds are at approximately the same level as the bed of West Gulch and their cross sections are very narrow. The main channel becomes much more sinuous in the Zone 2 segment, thus indicating a possible reworking of alluvium along the channel course.

FIGURE 5. West Gulch Bottom Profile

Lateral erosion of banklines by meandering streams contributes sediment to the flow, which usually deposits the material at bendway locations downstream. In West Gulch, the material remaining in Zone 2 is deposited almost continuously along the channel bed and there is no evidence to suggest there ever has been any significant lateral or trans-valley migration even though the meander geometry is well developed. The channel in this zone is incised into the alluvium as much as 25 ft in places, and has exposed erosion-resistant layers of clay and sandstone at numerous points along the channel. The channel gradient is partially controlled by these resistant layers, which take the form of a vertical drop or headcut of several feet. The material composing the channel sides is composed of shale and some sandstone fragments in a matrix of fine material with a high clay content. There is no apparent stratification which indicates deposition by mass movement phenomenon such as large mudflows or landslides.

The definite meandering channel pattern present along the Zone 2 segment has been restricted in its ability to migrate laterally across the valley for reasons not readily apparent. At several bendway locations the flow is undercutting the higher channel walls by a horizontal distance of several feet as shown in Figure 6. The fact that the channel walls can withstand this degree of undercutting is evidence of the erosion-resistant properties of the bank material. The restriction of lateral channel movement across the valley is probably due to three conditions: 1) a significant percentage of clay in the alluvium which establishes a more erosion-resistant bankline and greatly reduces the amount of lateral migration, 2) the ephemeral nature of the flow and the lack of frequent and lengthy high flows, and 3) the extremely high incoming sediment loads. If the bank material was mostly composed of easily erodible sandy material, the channel would be shallow and braided given the present valley slope. While high flows do obviously occur, they are probably too infrequent and heavily sediment-laden to produce rapid erosion and channel shifting. The degree of channel meandering can be characterized by its sinuosity which is the ratio of channel slope to valley slope. Based on field reconnaissance, the degree of channel sinuosity extending over long reaches of

FIGURE 6. Undercutting of West Gulch Channel Walls

sideways

West Gulch indicates that the sinuosity could be as high as 2.0; that is, valley slope could be about twice as steep as the channel along certain segments.

There is a terrace level found within the flood plain of West Gulch where the flood plain is defined as the area between the uppermost walls of the gulch. The terrace developed as a result of the present channel cutting vertically into and usually along one side of the narrow flood plain. Because the terrace tends to parallel the present channel slope, it could possibly be an old channel floor. Since the terrace is not continuous, it may be a remnant of a period when the gulch was discontinuous.

Zone 3 - Sediment Deposition

This area consists of alluvial fan deposits which have coalesced to form an alluvial plain. It is difficult to determine any drainage channels except the major gulches. West Gulch maintains an incised and meandering channel to its confluence with the main channel of its system. Numerous shallow drainage gullies are present between the major channels, but do not necessarily join them. The topographic map indicates that many of them are discontinuous and others find their own way to the Colorado River.

Climate

The general climate of the West Gulch watershed is semi-arid characterized by extreme temperatures and low annual precipitation. Maximum summer temperatures can exceed 100°F while winter minimums may drop as low as -40°F. The records at the Rifle, Colorado, weather station located about 5.0 miles to the east at elevation 5,320 ft show an average annual temperature of 47.2°F with monthly values ranging from 23.2°F in January to 70.7°F in July (NOAA 1978).

Long-term precipitation records in the region show considerable uniformity between monthly amounts. The station at Rifle has a 63-year average annual precipitation of 11.24 in. The monthly low is 0.76 in. in February and the high of 1.25 in. occurs in August (NOAA 1978). This uniformity does not preclude extreme variability, however, since months of little or no precipitation are possible.

The topography in and around the West Gulch drainage basin has a significant influence on the local climate and weather. The relief within the basin produces a decrease in temperature moving from the mouth to the headwaters. Wymore (1974) estimated this change to be as much as 3.2°F per 1,000 ft in the nearby Piceance Basin. It has also been noted that the number of frost-free days in the Piceance Basin decreases from around 120 days in the lower elevations to 50 days in the higher elevations (Weeks 1974). Precipitation has also been found to vary substantially with elevation. This trend can be seen in Table 1 which tabulates the weather stations in the region, their elevations, and 20-year average annual precipitation amounts.

Further evidence of orographic effects is seen in a U.S. weather map showing isohyets of 1931-1960 mean annual precipitation (USWB 1967). West Gulch is in a portion of the Colorado River Valley having isohyets of 12 in. to the east and west and 16 in. to the north and south. The isohyets of greater precipitation coincide with high elevation topographic features. To the north and northwest, the Roan Cliffs and Roan Plateau form a ridge with elevations up to 9,400 ft. To the south, beginning with Battlement Mesa, there is a mountainous barrier with elevations greater than 10,000 ft. Normally, winter storms in this area result from polar Pacific air entering from the west or northwest, while summer convective storms are usually derived from Gulf air moving in from the south and southeast (Patterson and Somers 1966). Before the moisture-laden air masses can reach West Gulch they must pass over the mountain barriers which produce a mechanical lifting effect. The result is two distinct precipitation patterns within West Gulch. The 0.20-square-mile subbasin above the Roan Cliffs varies in elevation from about 8,800 ft to almost 9,300 ft. Because of its high elevation, this area is near the crest of the lifting, receives substantial snowfall in the winter and is a center of thunderstorm activity in the spring and summer. The lower portion of the basin, however, is on the leeward side of the plateau at lower elevations and is essentially screened from a large number of the moist air masses. Hence, this area experiences less snowfall and thunderstorms. Conceivably, a thunderstorm could deposit several inches of precipitation on the upper basin with clear skies over the lower basin.

TABLE 1. Average Annual Precipitation in the Region of West Gulch(a)

<u>Station</u>	<u>Elevation (ft)</u>	<u>1951-1970 (average)</u>
Grand Junction	4849	8.18
Rangely	5216	9.03
Rifle 2ENE	5319	11.27
Attenbern	5690	15.83
Glenwood Springs	5823	15.84
Little Hills	6148	12.91
Meeker	6242	17.52
Marvine	7200	20.54

(a) Information in this table was taken from Wymore (1974).

Vegetation

The major factors determining vegetation type in this region are available moisture and soil characteristics. According to studies in the Piceance Basin, as much as 95% of the precipitation can be lost to evapotranspiration (Wymore 1974). The remainder normally runs off and discharges into the Colorado River with little, if any, deep percolation occurring.

The moisture for plant growth is mainly derived from the winter snowpack. During the spring snowmelt (March-May) when the evapotranspiration rate is low, moisture is stored in the soil. Since this period coincides with the beginning of the growing season, the moisture is available to the growing plants. Subsequent precipitation during the summer months (June-September) is absorbed by the surface layers of the soil and quickly evapotranspired due to a combination of high temperatures, intense insolation, and low humidity. This process limits the growing season for nonphreatic vegetation (vegetation that does not obtain moisture from ground water) to the period of time the snowmelt remains in the soil.

According to descriptions by Heil et al. (1977) the soils in the West Gulch region are from the unit Lithic Ustic Torriorthents. The soils are mostly formed in materials weathered from sandstone and shale. Elevations for the unit usually range from about 3,500 to 7,500 ft having slopes from 2% to 50%. Rock outcrops are common on the steeper breaks along the drainage ways. Generally, these soils are shallow, well drained, and highly erodible. In response to the low precipitation and high evapotranspiration rate in conjunction with the erodibility and low available water capacity of the soil, a semi-arid vegetation pattern has developed consisting of pinyon-juniper, grasses, and sagebrush.

Streamflow

A significant characteristic of the streamflow in West Gulch is its variability in both volume and frequency. The stream is ephemeral with little or no flow through the summer months and relatively high sustained flows in the spring. During the summer the predominant rainfall mechanism is convective thunderstorms. Most of the rainfall from these storms is absorbed by the soil and eventually evaporated, rarely producing runoff. For these events runoff is more dependent on intensity than volume. When rain falls with intensity greater than the infiltration rate, the lack of vegetation over much of the basin produces only minimal surface detention and overland flow occurs. Slope rills are formed which link into a network that rapidly conveys the runoff to the channels.

Winter precipitation falls mainly as snow. During the springmelt the melted snow that does not infiltrate or evaporate drains into the stream and discharges into the Colorado River. These flows are sustained as late as May, depending on the snowpack depth and the melt rate. This meltwater accounts for most of the runoff from West Gulch.

Additional discharges to West Gulch come from ground-water seeps in the channel sides. Spot measurements of these flows taken in the months of June through August 1979 indicate rates as high as 0.04 cfs. One characteristic of these flows is a marked diurnal fluctuation. Although this occurrence cannot be fully explained, it is probably due to transpiration by the phreatic

vegetation such as the pinyon-juniper. Generally, these seeps are from aquifers in the Wasatch Formation and could contribute as much as 10 to 15 acre-ft per year to the Colorado River.

Flooding

Several factors contribute to the flood potential in West Gulch. Normally, the maximum annual floods are produced by runoff from rapid snowmelt, intense thundershowers falling on saturated ground, or a combination of the two. When intense rainfall is a factor, there is little interception by the sparse vegetation and a high percentage of runoff from the rocky surfaces. The moderately high drainage density, plus the steep slopes, provides an efficient means of conveying the overland flow to the channel.

There are no observed streamflow records available for West Gulch. Therefore, peak discharge magnitude and frequency were obtained from information provided by two procedures applied at a point downstream from the mouth of West Gulch at the head of the first culvert (Figure 5), which had a drainage area of 5.46 square miles. Each procedure produced significantly different results.

The methodology presented by McCain and Jarrett (1976) consists of regression equations for each of four hydrologic regions within Colorado which relate peak discharges for the 10-, 50-, 100-, and 500-year floods to basin characteristics. Basically, the hydrologic regions represent areas of similar flood characteristics and runoff sources. The mountain, northern plateau, and southern plateau regions are areas where the maximum annual flood is normally produced by spring snowmelt. In the plains region, major floods are caused by April through September rainfall. Based on the map of hydrologic regions provided by the authors, West Gulch is located in the southern plateau region. The application of the appropriate set of regression equations to the selected location produced the frequency curve shown as Curve A in Figure 7. The applicability of this curve is questionable since maximum annual floods in West Gulch are apparently due to a combination of snowmelt runoff and rainfall. McCain and Jarrett suggest that the limited data for areas such as this have characteristics of mixed populations and do not fit into any of the hydrologic regions.

FIGURE 7. Estimated Frequency Curves, Unnamed Tributary to the Colorado River

The second method simply relates the 2-, 50-, and 100-year discharges to drainage area (Steven Buchberger, Colorado State Department of Highways, 1979). These relationships were developed for sizing drainage structures along Interstate 70 from DeBeque to Rifle, Colorado, using a more localized data set than the above method. When this method was applied to the selected location, Curve B in Figure 7 resulted.

A fairly large flood occurred in West Gulch in May 1979. Although no discharge measurements were taken, the peak discharge was estimated using the highwater mudlines left at the culvert. Figure 8 is a sketch of these mudlines as determined in the field. Using methodologies presented by Henderson (1966) and Bodhaine (1969), total flows through the culvert were computed to be 1,500 cfs and 1,580 cfs, respectively. (Details of the computations using Henderson's method are presented in Appendix A.) These results show Curve A is an unreasonable estimate. Plotted on Curve B, however, the two peak discharges have a return period from 50 to 60 years. This estimate is supported by a report from a local resident that the flood was the largest he had seen in over 50 years.

Additional highwater marks were identified at a reach in West Gulch with a drainage area of about 0.75 square miles. Using the slope-area method (Chow 1959) the peak discharge was computed to be over 3,000 cfs. Based on results of the more reliable data at the culvert this discharge is too high and raises the question as to the source of the highwater marks. Based on discussions with hydrologists from the USGS in Denver, Colorado, mud and debris flows are common to this area. Apparently, as the peak of the hydrograph is approached, debris is sometimes pushed ahead of the floodwave and toward the channel sides at the water surface. It seems reasonable then that debris could have produced the upstream highwater marks and was then deposited upstream of the culvert.

The available precipitation records in the West Gulch area and eyewitness accounts indicate that the rainfall during the May flood was produced by localized thundershowers centered above the Roan Cliffs. Little, if any, rain fell below elevation 6000 ft. Even though the rain fell over a relatively small area (probably less than 0.5 square miles), it fell on ground saturated from recent snowmelt.

FIGURE 8. Culvert Highwater Mudlines, Unnamed Tributary to the Colorado River

Sediment Transport Characteristics

The May 1979 flow event left positive evidence that an extremely high sediment load accompanied the flow. The flow left a very definite and continuous mudline approximately 4 ft above the channel bed. Several feet above is another mudline much less well-defined. In many instances the traces of mud and small shale fractions extend over the terrace level, which indicates an almost complete filling of the channel up to its lowest top bankline. Because of two high flow marks several feet apart vertically, it would appear that two separate events occurred; however, only one event is described by personnel at the Anvil Points site. During visits to the site only baseflow conditions were observed which offered no clue to the hydraulics of highflows in the channel. The water of the baseflow is clear and transports no apparent suspended sediment, unless the bed sediments are disturbed artificially. The baseflow channel trace follows the pathway of a previous low flow that was several magnitudes larger and had winnowed out much of the finer material leaving only gravel and cobble-sized shale fractions on the channel bed.

The May flood event, considered to be unusually large for West Gulch, caused some bank erosion, but erosion appears to be no more than 2 or 3 ft

laterally at a few locations. This is only an estimate since pre-flood conditions are not known. Significant bankline slump failures most likely occurred following the high flow, or at some point in time during the spring season.

Large boulders are present in significant numbers along certain reaches of West Gulch and are resting on the channel bed, partially buried below the channel bed deposits, or jammed into narrow sections of channel creating impasses. In wide cross-sectional areas as many as 15 to 20 large-sized angular to rounded boulders can be found in one area as shown in Figure 9. In other instances large boulders are jammed into a narrow channel section and approach the height of the top bank. The vast majority of these boulders are shale. The steep walls of alluvium, which define the narrow flood channel of the gulch, contain many such boulders and other smaller fragments of shale and sandstone. Some of the boulders present in the channel are probably derived from this source. Two other sources would be from tributaries joining the channel and the talus pile at the base of the Roan Cliffs. It is not known whether the majority of these boulders are due to the May flood event or not; however, certain other physical evidence is present that remained from this event.

Evidence of a high flow event can be found in the channel as a result of the unusually high sediment load transported and the resulting deposition. At wide cross sections along the channel there are deposits of material from several inches up to about 2 ft thick. The deposits have hardened with mud-cracks on the surface about 3 in. deep, which indicates a large percentage of clay. During the field surveys, trenching into the hardened deposits revealed a heterogeneous mixture of shale and some sandstone fragments held in a matrix of mostly clay with some fine sand. Some of the fragments exceeded an average diameter of 6 in.; however, most appeared to be about 2 in. or less with many small flakes present. Furthermore, a lack of stratification indicated that the deposit occurred during one event.

A mud line along both banklines of the channel provides further evidence of a high flow. This mud glaze is about 1 to 1 1/2 in. thick, and persists from the farthest upstream station surveyed to downstream at the culvert near

FIGURE 9. Example of Large Boulders in West Gulch

sideways

the Colorado River. The veneer of mud completely covers the channel bed and banks, except where lower flows have washed it away. Many of the boulders, from 2 to 3 ft in diameter, are completely caked with the same mud veneer. The post-flood deposition patterns in the vicinity of the boulders indicate that as the flow decreased in magnitude it was forced to pass around the large boulders and finally come to rest as a single deposit of sediment. At this point the flow must have been highly viscous and traveling very slowly. The top edge of the mud veneer along both banks is straight (not wavy) and generally parallels the channel bed slope, except where superelevation of the water surface exists in bendways. Considering the steepness of the channel and the channel bed roughness, the turbulence must have been dampened considerably. This is in contrast to the higher water and mud line where irregularities are more apparent.

A possible explanation for these unusual flow characteristics can be found in the literature concerning sediment transport in small mountain watersheds located in semi-arid regions. A report by Scott and Williams (1978) on erosion and sediment yield in the mountain areas of California includes a description of mudflows as follows:

Witnesses described these flows as surges of what appeared to be mud covered with water backed up behind a moving boulder front. Highwater marks of the storm period were formed by the initial surge of mud in each channel.

The authors define a mudflow as having a concentration of fine sediment less than 0.0625 mm that exceeds 10% dry weight of the total load. The flows described in the report were caused by saturation of thick deposits of fine-grained alluvium near the end of a storm period and involved considerable quantities of mud. The main point of interest in the eyewitness account is that the flow of water traveled on top of the mudflow where the mudflow surface formed the channel bed for whatever amount of water was present.

Troxell and Peterson (1937) describe another extreme flood event in a steep 1.6-square-mile watershed near Los Angeles, where tremendous quantities

of sediment were transported with very little clay and silt (mud) involved. The flood occurred on January 1, 1934, and deposited large quantities of boulders, cobbles, gravel, and sand on the floor of La Canada Valley. The flood moved a very large sediment load, which had been temporarily stored in the channel, primarily during the flood peak. The sediment was described as moving a short distance very rapidly and only under the influence of the peak. Immediately following the peak the sediment was deposited, but the flow continued over the deposits. According to Troxell and Peterson, the highwater mark may not have been made at the time of maximum discharge, but instead was made at some time when the bed was higher and the discharge far less than the peak. This example also describes a separation of water and sediment flow which allowed the water to continue on after the mass of sediment had come to rest. The occurrence of the mass movement of sediment only around the flood peak may be due to the lack of clay and silt fractions.

Mears (1979) discusses a flood that occurred in an alpine drainage basin in the central Colorado mountains that exceeded the 100-year magnitude. The flood transported a very large volume of sediment and carried boulders toward the top of the flow. The deposits left by the flood consisted of everything from gravel to boulder-sized material in a matrix of silty sand. The matrix occupied only a small part of the volume. The author summarizes the action of the water and sediment complex as follows:

High-velocity floods with a large sediment load may become so heavily laden with coarse-grained sediment that parts of the bed load become decoupled from the flood wave and continue to advance even as the flood recedes.

Beverage and Culbertson (1964) describe the extremely high sediment loads of small streams in the southwest as "hyperconcentrations" of suspended sediment, and define these as sediment loads exceeding 400,000 parts per million. Included in this load is a significant concentration of fine sediment (clay and silt) as opposed to an almost total predominance of coarse material in two

of the previous examples. Concentrations of clay and silt particles in the sediment increase the viscosity of the mixture and tend to dampen the turbulence of the flow. While turbulence may never be completely damped when hyperconcentrations occur, the authors reference others as stating that the stream can run with a smooth and oily movement instead of a choppy surface when fine sediment loads are exceptionally high.

The examples discussed above have some basic characteristics in common with each other: 1) they all involve small watersheds of no more than a few square miles, 2) the upper slopes are very steep providing a powerful driving force for the flows, 3) the sediment sizes available extend into the boulder range, and 4) a mass movement of sedimentary material trails the passage of the flood peak.

The decoupling of water discharge from the bed load is a plausible explanation for the two flow markings present in West Gulch as result of the May flood. Based on field evidence and the descriptions of floods in similar watersheds, the May flood peak in West Gulch appears to have moved downstream ahead of a mass movement of bed material load and probably pushed a collection of boulders ahead of it. Where the channel was extremely wide the velocity decreased enough to where some boulders were deposited. The trailing mass of sediment, including a large percentage of fine material, flowed as a highly viscous stream of mud and water leaving a mudline along the channel. This trailing flow possibly may have been the higher flow of the two since a moving boulder front would cause a ficticiously high water surface profile mark along the channel. By the time the peak reached the culverts most of the boulder front had deposited along the channel, although some of the smaller boulders must have passed through the culvert barrels since they are found downstream of the roadways. The primary source of the sediment was probably the deposits stored in the channel temporarily between extreme flood events. Secondary sources would be from tributaries, bank caving, and overland transport.

In summary, if the flood sequence occurred as depicted previously, an accurate peak flow value will be very difficult to determine from highwater

marks in the channel because the actual depth of flow cannot be reliably determined. The extent to which a boulder jam developed can only be assumed because field information is not available on pre-flood conditions in the channel.

The sediment load transported by West Gulch during flows similar to that which occurred during May can approach a mass movement type of phenomenon such as a mudflow. Any structure on West Gulch which would interfere with these flows will have to accommodate the sediment deposits that will inevitably occur. The best method would be to pass the heavily sediment-laden water through unrestricted to prevent storage of large volumes of sediment behind the structure.

Bank caving due to a meandering channel could be a minor problem because of the high and near vertical channel walls which have been undercut. If the decision is made to straighten the channel, downcutting degradation of the channel bed would be significant where no erosion-resistant bed-level controls exist. This would initiate bankline instability and increase sediment loads. The channel, if left alone after straightening, would attempt to reestablish the present meander geometry natural to the channels. Therefore, any artificial channel would require engineering maintenance and probably some type of lining such as concrete.

Seismic Profiles

A seismic refraction survey was conducted by Century West Engineering Corporation under contract to PNL. A complete copy of the Century West report can be found in Appendix B. Results of the survey (Figure 10) indicate the presence of a secondary, buried shale "bedrock" stream channel. According to Century West, the primary buried "bedrock" channel, which has a steeper gradient, captured the secondary "bedrock" stream channel. Due to the location of the secondary "bedrock" stream channel, leachate from the shale pile will probably follow the secondary buried channel and discharge into the primary "bedrock" stream channel downstream from the shale pile. Additionally, the flow path of ground water and leachate from the shale piles flowing through alluvial sediments in the secondary "bedrock" channel will pass under both the lined and

FIGURE 10. Results of Seismic Refraction Survey - Century West Engineering Corporation

unlined lagoons, where more leachate could enter ground water in the secondary "bedrock" channel. This ground-water flow would move southward until the flow is forced to enter the primary "bedrock" stream channel and the existing stream channel by the steep-sided and topographically high bedrock surface. Leachate from the oil shale could also enter the existing surface stream by lateral flow north of the "bedrock" ridge which separates the two buried "bedrock" stream channels. Gradient of the "bedrock" shale surface is generally to the south and probably forms an impermeable barrier to downward movement of ground water from the alluvium, thus effectively controlling and channelizing leachate from shale piles and lagoons.

BALZAC GULCH

A field reconnaissance of Balzac Gulch (Figure 2) was undertaken during July 1979 to determine seepage and surface flow conditions of the small watershed and for a preliminary assessment of its accessibility concerning the field data collection program. The upper portion of the Balzac Gulch watershed can easily be reached from the Anvil Points mine road. The trip began at this point and ended at the mouth of the gulch where it joins the Colorado River flood plain. A profile of the Balzac Gulch is shown in Figure 11.

The beginning of a primary drainage channel is located approximately 150 to 200 ft below the first switchback on the mine road. Although the channel is not well-defined it does appear to be the major collection point for the rill system above.

At about 400 ft below the mine road there is evidence of seepage as the ground surface is moist and soft with some salt deposits present. The channel gradually becomes more well-defined to where it measures about 3 ft wide by 2 ft deep with small boulders present at the 500-ft distance. The first active seep was found at 550 ft below the mine road. Water was seeping through the alluvium at the top of the right bankline at three separate locations. Another small seep was found near the 650 ft distance.

FIGURE 11. Balzac Gulch Drainage Basin Profile

At 700 ft the first major break in topography occurs. An outcrop of greenish-gray sandy shale or possibly sandstone establishes a geologic channel bed control with a series of three vertical breaks. The first is approximately an 8-ft vertical drop and the other two, a few feet downstream, are about 3 to 4 ft high. Some small seeps are also present at this location.

A water quality sample was taken at the 800 ft distance and the flow was measured to be less than 0.25 l/min. At this location vegetation becomes very dense and overhangs the channel. Scrub oak trees and numerous varieties of shrubs are present. Boulders up to several feet in diameter are present in and adjacent to the channel.

Surface flow disappears at the 1,000-ft distance; however, the alluvium of the channel bed is moist. The alluvium seems very soft at this location which may indicate an infiltration of flow below the surface of the channel bed and, therefore, may account for the lack of surface flow. Another possibility would be transpiration by the vegetation.

From about the 1,000 ft distance to 1,200 ft the channel becomes noticeably deeper. There are many sandstone boulders in the alluvium but very few shale boulders from the Green River Formation. At 1,150 ft surface flow reappears for a short segment of channel and intermittent terraces begin to appear. Another massive sandstone outcrop occurs at the 1,200 ft distance causing a vertical drop of about 15 to 20 ft. Surface flow is trickling over the rock ledge and infiltrating into the loosely packed material at the base of the rock outcrop as no surface flow occurs in the channel below this point.

Beginning in the vicinity of the sandstone outcrop at 1,200 ft and extending downstream to about the 2,000 ft distance, the soil becomes much deeper and the channel more incised. Pine trees and junipers are abundant adjacent to the channel. No surface flow was present during the reconnaissance.

Around the 3,500 ft distance, a tributary channel enters the gulch but was dry during the time of the survey. At that distance, the valley floor begins to widen and apparently enough moisture is available to support grasses on the adjacent alluvial terraces or benches.

Near the 5,000 ft distance, water reappears along the channel bed from seepage occurring along the right bankline. A recent slump failure occurred at the right bank where seepage is present. A small tree still rests on top of the failed material, an indication of an approximated 3- to 4-ft drop. Boulders are evident in the alluvium.

At the 6,000 ft distance, a tributary enters the gulch at the right bankline and is flowing about 3 l/min. The main channel upstream is dry. The tributary base flow channel is about 1 ft wide and from 6 in. to 1 ft deep.

A large seepage area is located at the 7000 ft distance. The bank material is alluvium and stands about 10 to 15 ft high. Bank material slump failures recently occurred at the seepage location partially filling the channel. The top of the seep is approximately 6 to 8 ft above the channel bed.

Beginning about the 8,000 ft distance is a steep walled canyon. The walls at the point are about 15 to 20 ft high. A sandstone outcrop extends to a high elevation along the left bank.

From the 8,000 ft downstream to about the 13,000 ft distance, the channel flows through a steep canyon with walls exceeding 25 to 30 ft in elevation in places. Most of the bank material seems to be representative of the Wasatch Formation because of its reddish color. Sandstone outcroppings appear intermittently and a small tributary enters along the right bankline. The tributary bed is elevated a few feet above the bed of Balzac Gulch at the confluence and was dry at the time of the reconnaissance.

As the mouth of the gulch is approached, the channel widens out considerably and assumes a near rectangular cross section about 10 to 12 ft wide and 4 to 5 ft deep. Boulders (approximately 1 to 2 ft in diameter) are present along the channel.

The drainage patterns of the Balzac Gulch watershed are mapped in Figure 2. The mapping shows that a very large percentage of the drainage area is located on the western side of the main channel. There are no fully developed tributary systems on the eastern side, while at least three are present on the western side. All the seepage and tributary flows documented during the field trip also entered from the west. This portion of the watershed includes a narrow strip of the Piceance Basin along its uppermost boundary above the Roan Cliffs. The strip parallels the head of the Balzac Gulch watershed for about 8,000 ft and extends about 1,000 ft at its maximum into the East Fork Parachute Creek watershed. The orientation of this drainage area would distribute precipitation runoff to several tributary and rill systems which would in turn

distribute the inflow to Balzac Gulch over a channel length of about 6000 ft. This distribution is quite different from the situation at West Gulch where runoff from the East Fork Parachute Creek watershed is concentrated at one point.

Based on the field reconnaissance, Balzac Gulch watershed appears to be able to support more vegetation than the West Gulch basin. Grasses and trees are more prevalent on the alluvial areas which would indicate a reliable source and a better distribution of water.

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APPENDIX A

DETAILS OF MAY 1979 PEAK DISCHARGE ESTIMATE

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An estimate of the May 1979 peak discharge through the culvert located at Sta 123+85 was made using the following equation presented by Henderson (1966):

$$Q = \frac{2}{3} C_B B H \sqrt{\frac{2}{3} g H} \quad (A-1)$$

where:

B = culvert width

H = upstream depth

C_B = coefficient expressing effect of width contraction in the flow.

Equation A-1 assumes the upstream head is less than 1.2 times the culvert height, the culvert has a steep slope, and is hydraulically short (does not flow full). It can be seen from Figure 8 that the entrance conditions for both barrels of the culvert were approximately the same. Therefore, Equation A-1 was applied to one barrel and the result was doubled to obtain the total discharge.

Inserting the appropriate parameter values into Equation A-1 resulted in:

$$Q_T = 2 \times \left(\frac{2}{3}\right) (0.9)(10)(9) \sqrt{\frac{2}{3}(32.3)(9)} = 1500 \text{ cfs} \quad (A-2)$$

The following checks insured the applicability of the equation:

1. $H/D = 9.0/10.0 = 0.9$, which is less than 1.2.
2. The highwater profiles in both barrels show they did not flow full.
3. The normal discharge Q_n computed from Manning's equation is 5300 cfs.

The critical discharge from Equation A-1 is 1500 cfs. Since $Q_n > Q_c$, the culvert slope is steep.

APPENDIX B

CENTURY WEST ENGINEERING CORPORATION REPORT:
EVALUATION OF SEISMIC REFRACTION SURVEY DATA AT THE RIFLE OIL SHALE
FACILITY SITE NEAR RIFLE, COLORADO

APPENDIX B

CENTURY WEST ENGINEERING CORPORATION REPORT: EVALUATION OF SEISMIC REFRACTION SURVEY DATA AT THE RIFLE OIL SHALE FACILITY SITE NEAR RIFLE, COLORADO

INTRODUCTION

This report is intended to set forth the findings, conclusions, and recommendations of this firm's seismic refraction survey to assess subsurface hydrogeologic conditions at the West Gulch facility near Anvil Points, Colorado, on September 10-14, 1979.

The objective of the seismic refraction survey is to provide information about subsurface rock conditions for use in predicting the direction of surface- and ground-water flow, and to facilitate selection of optimal locations for future ground-water observation wells.

Work involved in the seismic survey included:

1. conducting seismic refraction field surveys in sufficient detail to define the subsurface "bedrock" erosional surface
2. computing seismic refraction field data
3. constructing a plan view map showing the location of the seismic lines in relation to important topographic and cultural features such as West Gulch channel, lagoons, roads, etc., and to show structure contours of the shale "bedrock" erosional surface
4. preparing a report describing our findings and conclusions regarding the influence of subsurface "bedrock" topography on the movement of ground and surface water, thereby providing a partial definition of the hydrologic system at Anvil Points, and to recommend locations of future observation wells.

FINDINGS

Using horizontal and vertical survey control provided by PNL's staff, the elevation of the shale "bedrock" erosional surface was calculated for each end station of each seismic line. Using this information, the elevation was determined by interpolation for all middle stations along the surface trace of each seismic line. Contours describing the configuration of the shale "bedrock" erosional surface were then drawn using these calculated elevations. A total of 15 seismic lines (one of the lines was divided into two segments) were performed adjacent to West Gulch (Figure 10, main text). These "bedrock" contours show that downstream from north of existing observation Well No. 1, the alluvium ranges from a minimum of 7 ft in thickness to more than 28 ft in thickness near the oil shale pile. The shale "bedrock" channel of the small stream shown on the accompanying map slopes to the south of a gradient of 4% to a maximum of 12%, with stream channel walls included as steeply as 70%.

"Bedrock" contour information shown in Figure 10 shows there are two buried stream channels down gradient from the oil shale pile. This subsurface feature suggests that prior to deposition of the alluvium there were two "bedrock" streams. One buried channel, which we designate the secondary stream channel, is located under both the lined and unlined wastewater storage lagoons and, thereafter, its course turns to the east and rejoins the primary stream channel to the west of the unlined lagoons. Gradient of the primary buried "bedrock" stream channel, which closely parallels the surface stream channel, appears to be considerably steeper than the gradient of the secondary stream channel. Where the gradient of the "bedrock" channels or the side slopes of the shale "bedrock" stream valley steepen rapidly, "bedrock" is occasionally exposed at land surface in the existing stream-channel floor.

Detailed soil identification tests of the alluvium were not performed. However, field identification of alluvial material indicates that the silt, clay, shale gravel, and minor amounts of sand are derived from rock in the immediate locale. The permeability of the alluvium is believed to be very low.

CONCLUSIONS

Seismic data defining "bedrock" surface in the study area indicates the presence of a secondary buried shale "bedrock" stream channel. In our opinion, the primary buried "bedrock" channel, which has a steeper gradient, captured the secondary "bedrock" stream channel. Due to the location of the secondary "bedrock" stream channel, leachate from the shale pile will probably follow the secondary buried channel and discharge into the primary "bedrock" stream channel downstream from the shale pile. Additionally, the flow path of ground water and leachate from the shale piles flowing through alluvial sediments in the secondary "bedrock" channel will pass under both the lined and unlined lagoons, where more leachate could enter ground water in the secondary "bedrock" channel. This ground-water flow would move southward until the flow is forced to enter the primary "bedrock" stream channel and the existing stream channel by the steep-sided and topographically high bedrock surface. Leachate from the oil shale could also enter the existing surface stream by lateral flow north of the "bedrock" ridge which separates the two buried "bedrock" stream channels. Gradient of the "bedrock" shale surface is generally to the south and probably forms an impermeable barrier to downward movement of ground water from the alluvium, thus effectively controlling and channelizing leachate from shale piles and lagoons.

RECOMMENDATIONS

Continued ground-water studies in the West Gulch area, including selection of locations for additional observation wells, should include consideration of the buried "bedrock" surface presented herein. Specifically, the location of additional observation wells and ground-water sampling locations will require that ground water in both "bedrock" stream channels be sampled. It is recommended that one of the first boreholes for additional observation wells be drilled to verify the existence of the secondary buried shale "bedrock" stream channel and to measure the actual thickness of sediment in the buried stream channel. Site locations for the remaining observation wells should also be determined using "bedrock" information presented herein so that observation

wells are in close proximity to the lowest portion of the v-shaped, buried bed-rock channels. Wells so located will help to ensure the success of baseline water-quality sampling and determine the flow path of leachate from shale pits and lagoons. Construction of at least five observation wells should be initiated as soon as possible so that changes in ground-water level and quality can be monitored during periods of changing hydrologic conditions including freezing, thawing, and heavy storm-water runoff.

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