PROJECT RIO BLANCO

ENVIRONMENTAL IMPACT EVALUATION

OCTOBER 12, 1971

CER GEONUCLEAR

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CONTENTS

Page

Page

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

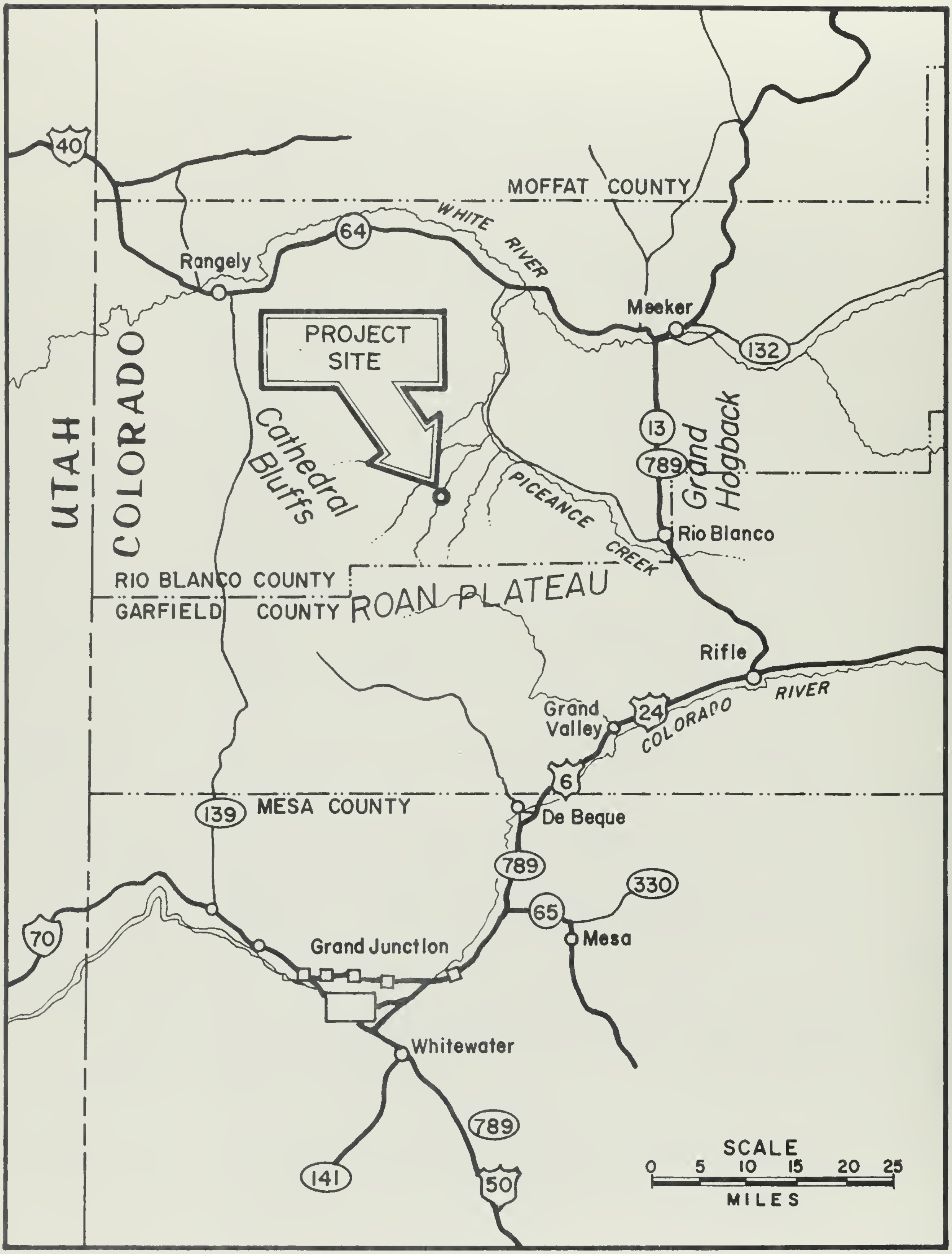


Figure IA-1. Map of general area.

ENVIRONMENTAL IMPACT EVALUATION

I. ENVIRONMENTAL SETTING

A. GEOGRAPHY

1. General Description

Project Rio Blanco takes its name from its location in Rio Blanco County in northwestern Colorado. The project site (Figure IA-1) lies within the Piceance Creek Basin in the central portion of the county. According to a native of the area, "piceance" (pé-ance) is derived from a Ute Indian word meaning "tall grass."

Piceance Creek Basin is a drainage tributary to the White River. The basin is bounded on the east by the Grand Hogback, running southward from the vicinity of Meeker toward Rio Blanco, and from there southeasterly into Garfield County. The Grand Hogback contains mountain peaks over 9,000 feet in elevation.

On the south, the boundary of the basin is formed by the Roan Plateau, the divide between the White River and the Colorado River drainages. This divide lies predominantly in Garfield County but closely parallels the county line at an elevation of approximately 8,000 feet.

The western boundary of the Piceance Creek Basin is formed by the Cathedral Bluffs, which separate the drainages of Yellow Creek and Douglas Creek. The general elevation of the Cathedral Bluffs is also in excess of 8,000 feet.

The Piceance Creek Basin slopes downward from the ridges that form its natural boundaries on the east, south, and west to an elevation of 5,700 feet at the confluence of the Piceance Creek with the White River.

The emplacement well (EW) location, NW/4 of NW/4, S14, T3S, R98W, is in the valley of Fawn Creek, one of the numerous tributaries of Piceance Creek (Figure IA-2).

2. Towns and Settlements

The two principal towns in Rio Blanco County are Meeker (the county seat), with a 1970 population of 1,535, and Rangely, with a

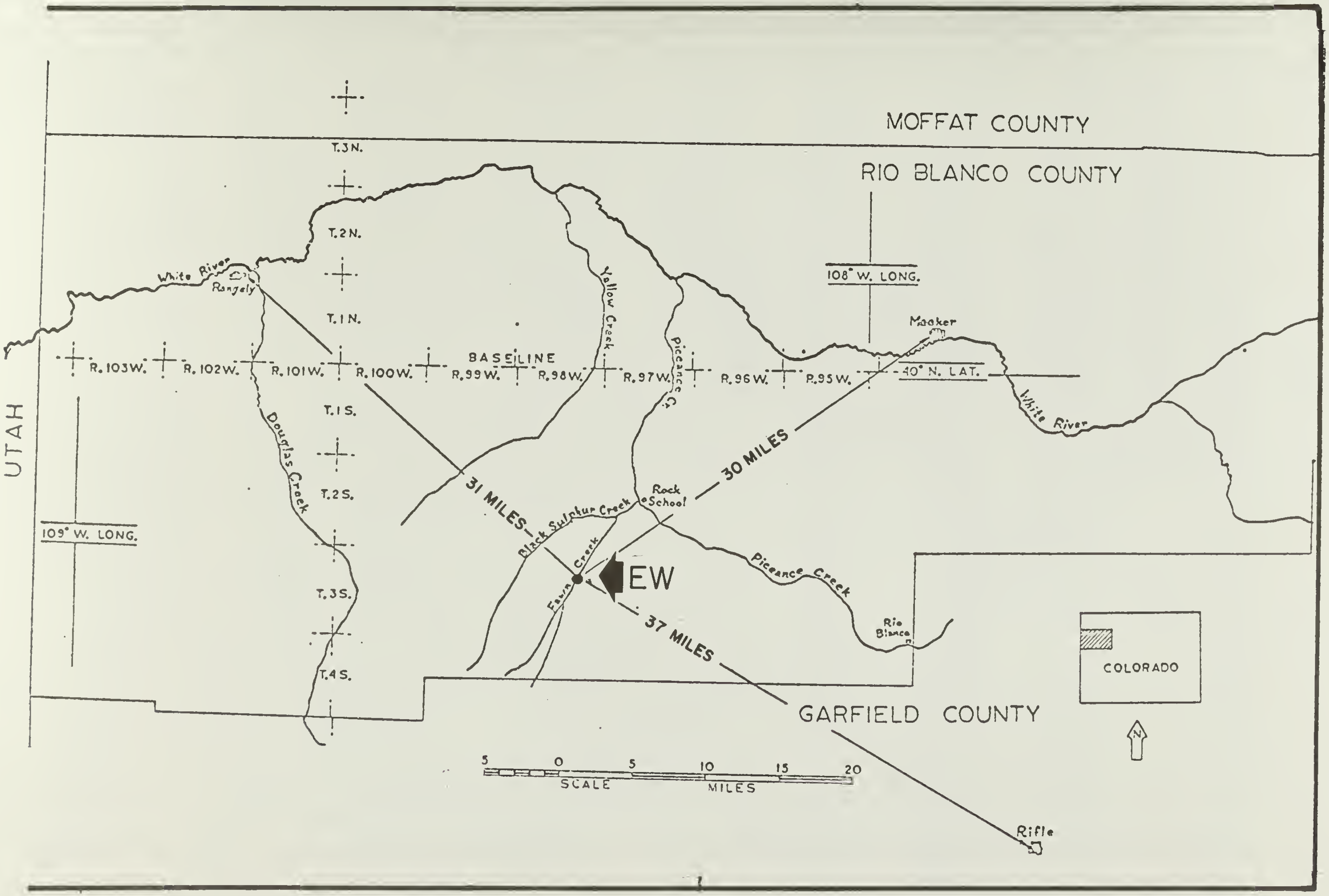


Figure IA-2. General map of the Project Rio Blanco area. Distances of the primary towns in the vicinity (from the EW location) are indicated.

population of 1,640. These towns are nearly equidistant from the EW, with Meeker lying 30 miles to the northeast and Rangely 31 miles to the northwest. Both these towns are bordered by the White River, flowing from east to west. The Rio Blanco Post Office (22 miles east of EW) is located near the intersection of the county line and the headwaters of Piceance Creek. The Utah state line forms the western boundary of the county. The total population of the county, as of 1970, was 4,761. In Garfield County, the city of Rifle (population about 2,200) lies about 37 miles to the southeast of EW, and the village of Grand Valley (population about 350) lies about 29 miles SSE of EW. De Beque, a village of 270, lies 33 miles south of the EW and services the ranchers that live on Roan Creek, north of De Beque and south of the Piceance Creek ranch area. Grand Junction, a city of approximately 22,000, lies about 52 miles to the south of the EW.

3. Population Distribution

The immediate project area is sparsely populated. Since cattle and sheep raising is the principal livelihood, most of the people live on scattered ranches. A few oil company personnel and their families live in semi-permanent homes in two separate areas. A population survey indicates that 63 persons live within a ten-mile radius of the EW and an additional 105 live within a 20-mile radius, giving an overall population density of about one person for every two square miles. On school days high school students are transported to Meeker, while about 30 grade school children are transported to the "Rock School," about seven miles northeast of the EW. The estimated distribution of population by sector is shown in Figure IA-3.

4. Topography

The landscape is highly dissected by the various streams or arroyos. Narrow, alluvial valleys along creeks are flanked by usually steep, rocky slopes that rise to higher uplands. Narrow bands of rolling upland, or mesas, form divides between upper reaches of the streams or arroyos. Figure IA-4, a view towards the southwest and up Hunter Creek from the plateau east of Piceance Creek, illustrates the topography and the vegetational cover.

The elevation of the valley floors ranges roughly from 6,000 to 6,700 feet above mean sea level (MSL), while the high country around the basin extends to elevations of 8,000 to 8,500 feet.

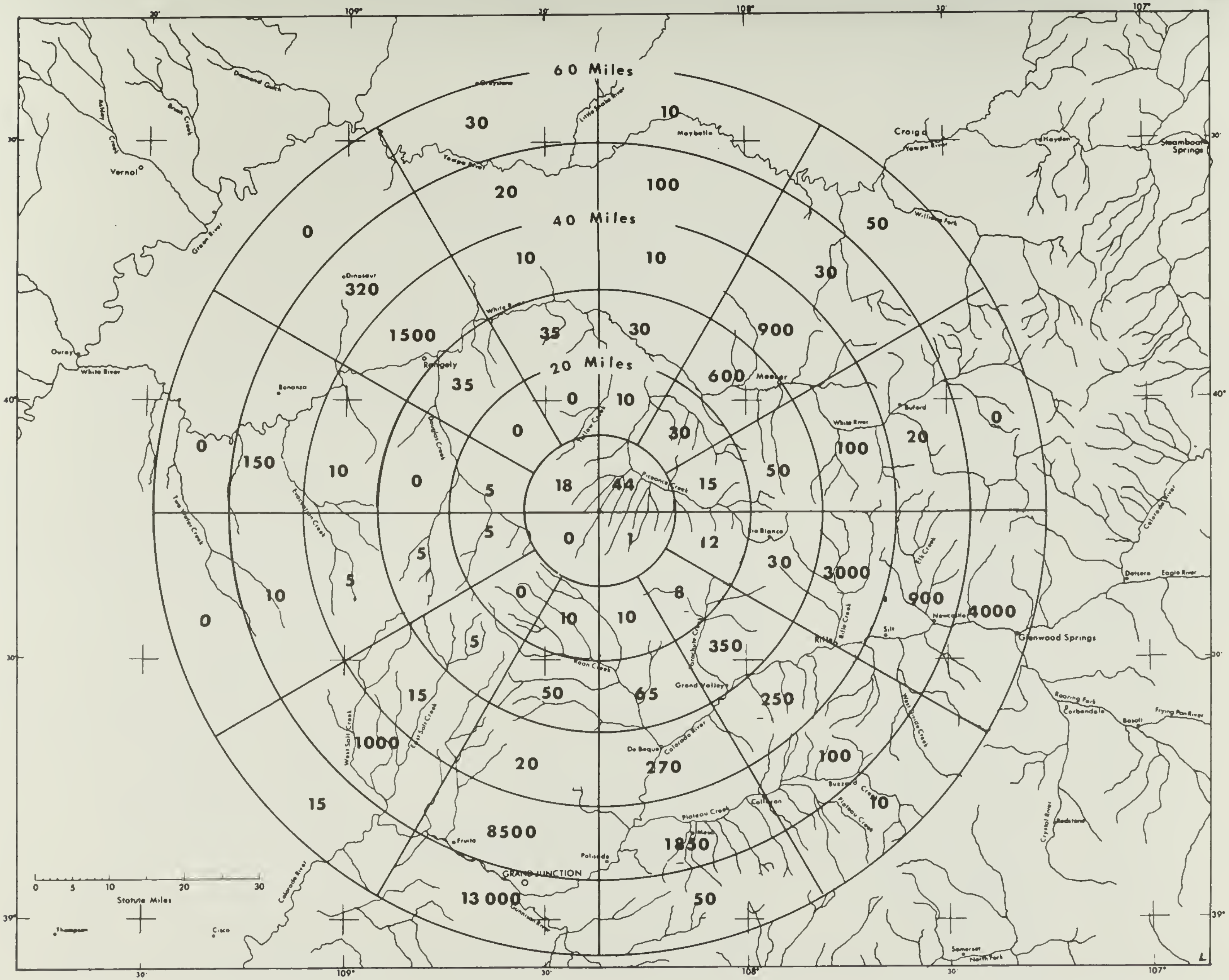


Figure IA-3. Estimated distribution of population to 60 miles from EW.

Figure IA-4. Typical view of the Piceance Creek Basin topography, showing Hunter Creek Valley with the Roan Plateau in the background.

5. Land

a. Surface Zoning or Land Use Classification

The entire Piceance Creek Basin area is zoned by the Rio Blanco County Planning Commission for agricultural use. Other zoning classifications are found only in and around the towns of Meeker, Rangely, and the Rio Blanco Post Office. The Rio Blanco Post Office is zoned for roadside business.

The agricultural zoning classification allows all agriculture farming, ranching, forest and recreation uses, including accessory uses. It also covers uses such as churches, schools, dairies, and country clubs, as well as vacation homes and cabins.

In the past, the Rio Blanco County Planning Commission has not exercised jurisdiction over the numerous oil and gas wells throughout the county.

b. Ownership

Land ownership within the Piceance Creek Basin is held by Federal and State agencies and private individuals and corporations. As shown in Figure IA-5, private ownership is generally limited to valley locations, though much of the land on the Roan Plateau is also privately held. The land areas administered by the Bureau of Land Management (BLM) and the Colorado Game, Fish and Parks Department (CGF&P) are also shown in Figure IA-5. The EW location is on BLM land. Within the boundary of the proposed unit, about 8% is privately owned; the BLM administers about 92% and the State less than 1%.

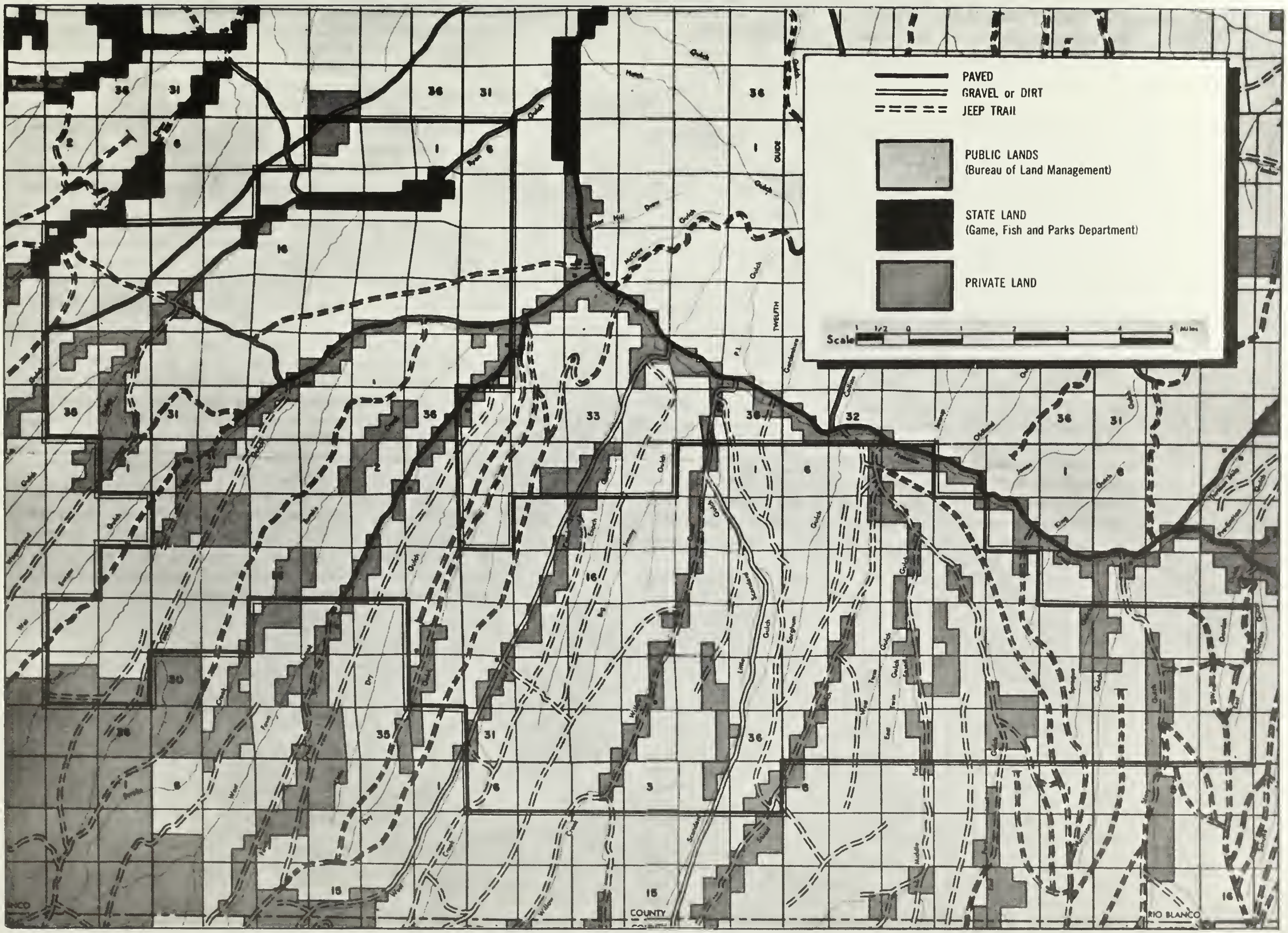


Figure IA-5. Distribution of land ownership in the Rio Blanco unit.

B. GEOLOGY

1. Structure, Faults, Joints, and Linear Features

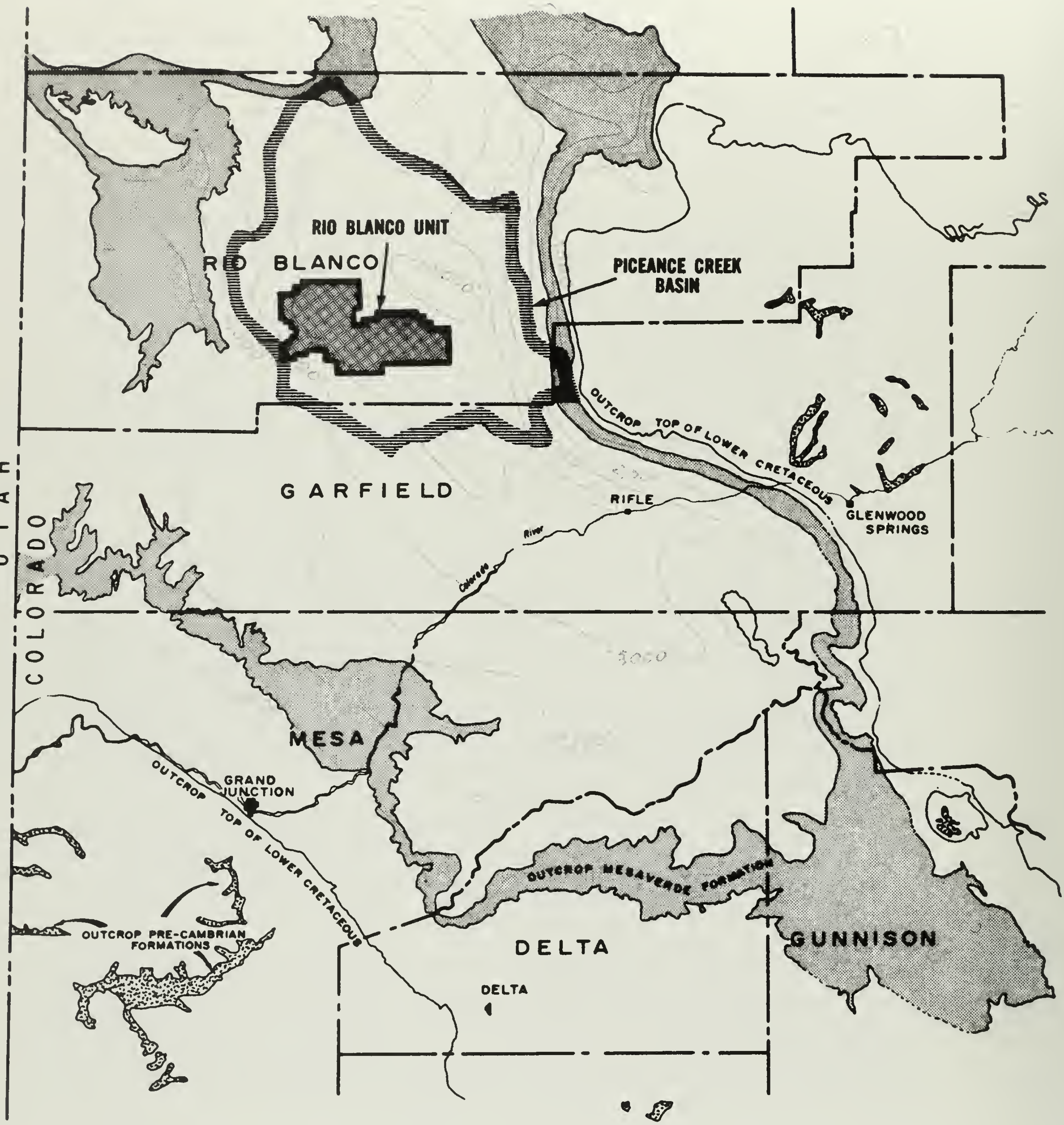
The Piceance Basin is a large structural downwarp. Its general configuration is shown in Figure IB-1. This figure outlines the Piceance Creek Dome with the closed -10,000-foot contour line. The Black Sulphur Creek Nose can be seen extending from the west into the area of interest as indicated by the flexure of the -7,500 and -5,000-foot contour lines. The Parachute Creek Nose is shown by the flexure of the -7,500-foot contour line southeast of the area of interest. The low dips of strata in the western basin limb and the steep dips of strata in the eastern basin limb are shown by the cross section in Figure IB-2. The amplitude of the folds is greater than on the surface (Ref. IB-1), and the fault density also increases with depth (Ref. IB-2).

The intermediate depth structural map, based on the Mesaverde II Formation (Figure IB-3), of the Rio Blanco project area shows a region of maximum fault density associated with the Black Sulphur Creek Nose and another fault zone trending toward the Parachute Creek Nose southeast of the area of interest. A shallower structural map contoured on the Wasatch G Marker shows a similar general pattern with fewer faults (Figure IB-4). A near-surface structural map of the area of interest shows faulting only on the Black Sulphur Creek Nose and Piceance Creek Dome (Figure IB-5). The faulting thus appears to be associated with the positive structural features of the basin.

The fault zones that are readily apparent on the surface are characterized by displacements in the sandstone ledges that crop out in the steep valley walls, as well as being discernible on aerial photos and topographic maps as linear depressions.

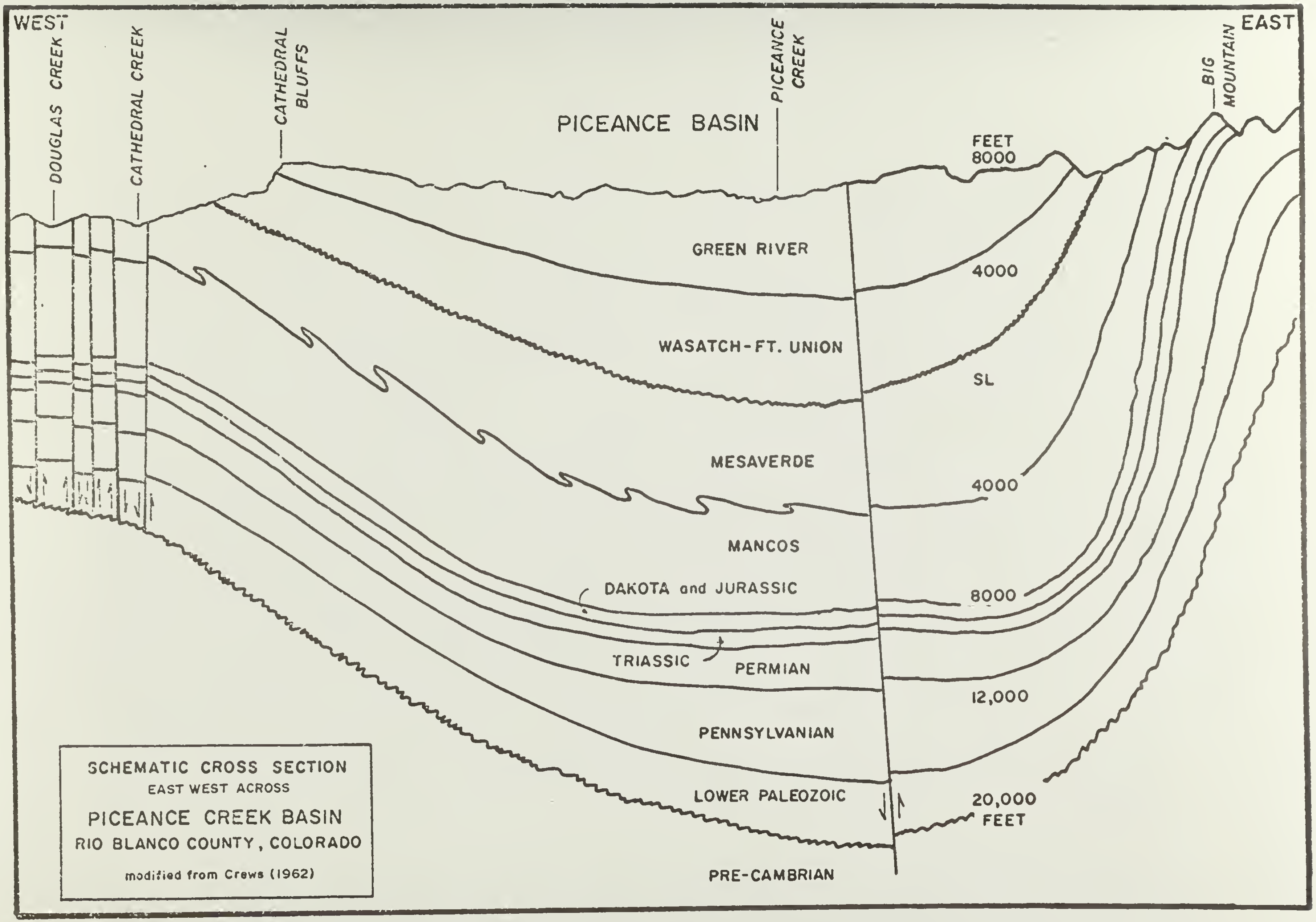
The surface rocks are jointed with the principal sets being oriented northeasterly and northwesterly. The jointing appears to be regional in nature and is reported everywhere in the Colorado Plateau and its marginal areas (Ref. IB-3). The surface jointing frequently has controlled the drainage patterns, and this has resulted in the subparallel drainage system that occurs in the Rio Blanco experiment area.

An analysis was made of linear features on aerial photos of the area around the proposed EW (Figure IB-6). Since no displacements were associated with these features, they appear to be only surface phenomena (Ref. IB-4).



REGIONAL MAP AND STRUCTURAL INTERPRETATION
CONTOURED ON TOP OF LOWER CRETACEOUS

Figure IB-1. The Piceance Creek Basin (Yellow Creek-Piceance Creek drainage basin) and the area of the Rio Blanco experiment shown superimposed on the regional structure map.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CATHEDRAL CREEK
CATHEDRAL BLUFFS
PICEANCE BASIN
PICEANCE CREEK
BIG MOUNTAIN
FEET 8000
4000
SL
4000
8000
12,000
20,000 FEET
GREEN RIVER
WASATCH-FT. UNION
MESAVERDE
MANCOS
DAKOTA and JURASSIC
TRIASSIC
PERMIAN
PENNSYLVANIAN
LOWER PALEOZOIC
PRE-CAMBRIAN
SCHEMATIC CROSS SECTION
EAST WEST ACROSS
PICEANCE CREEK BASIN
RIO BLANCO COUNTY, COLORADO
modified from Crews (1962)

Figure IB-2.

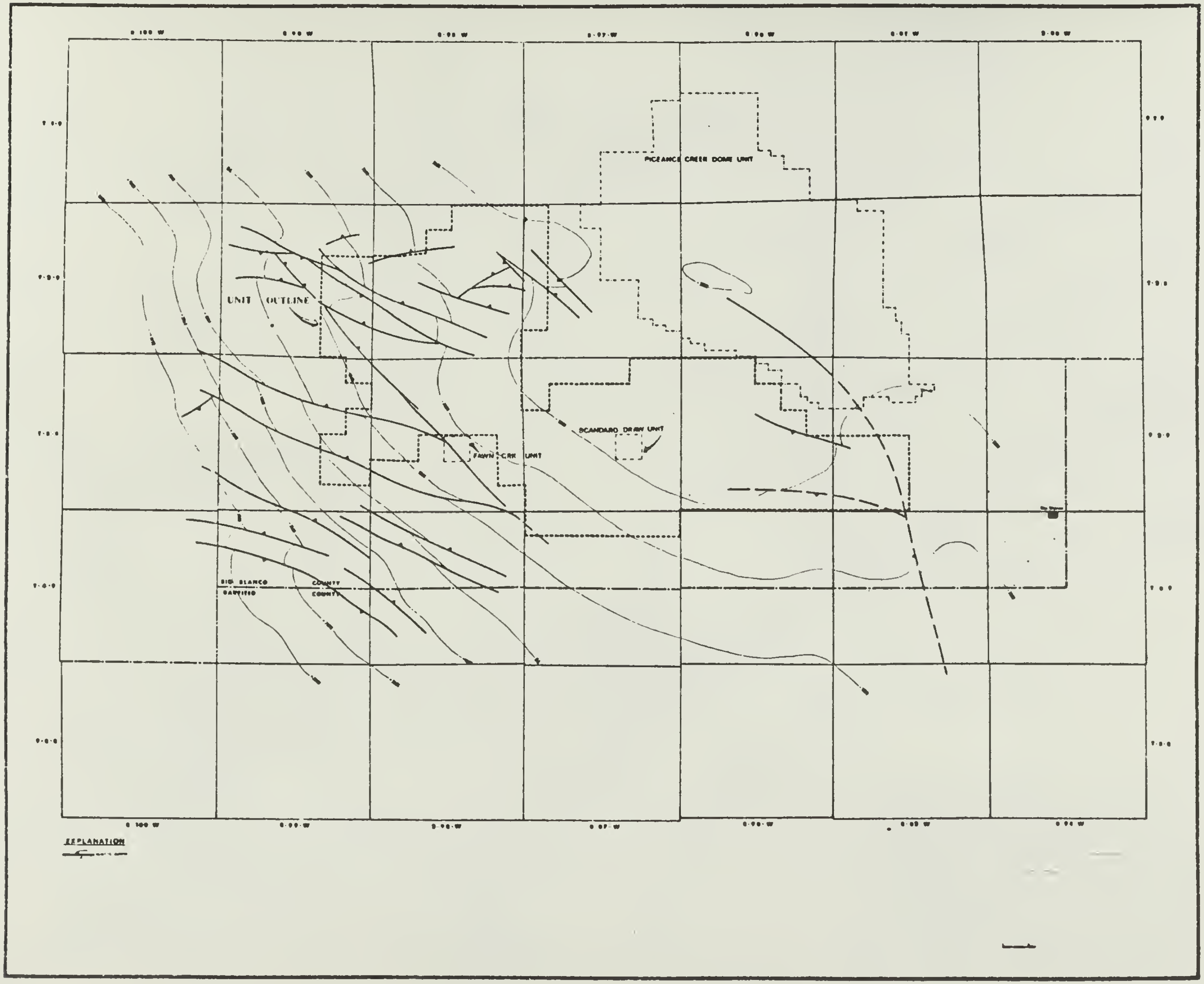


Figure IB-3. Mesaverde II structure map for Piceance-Sulphur Creek area.

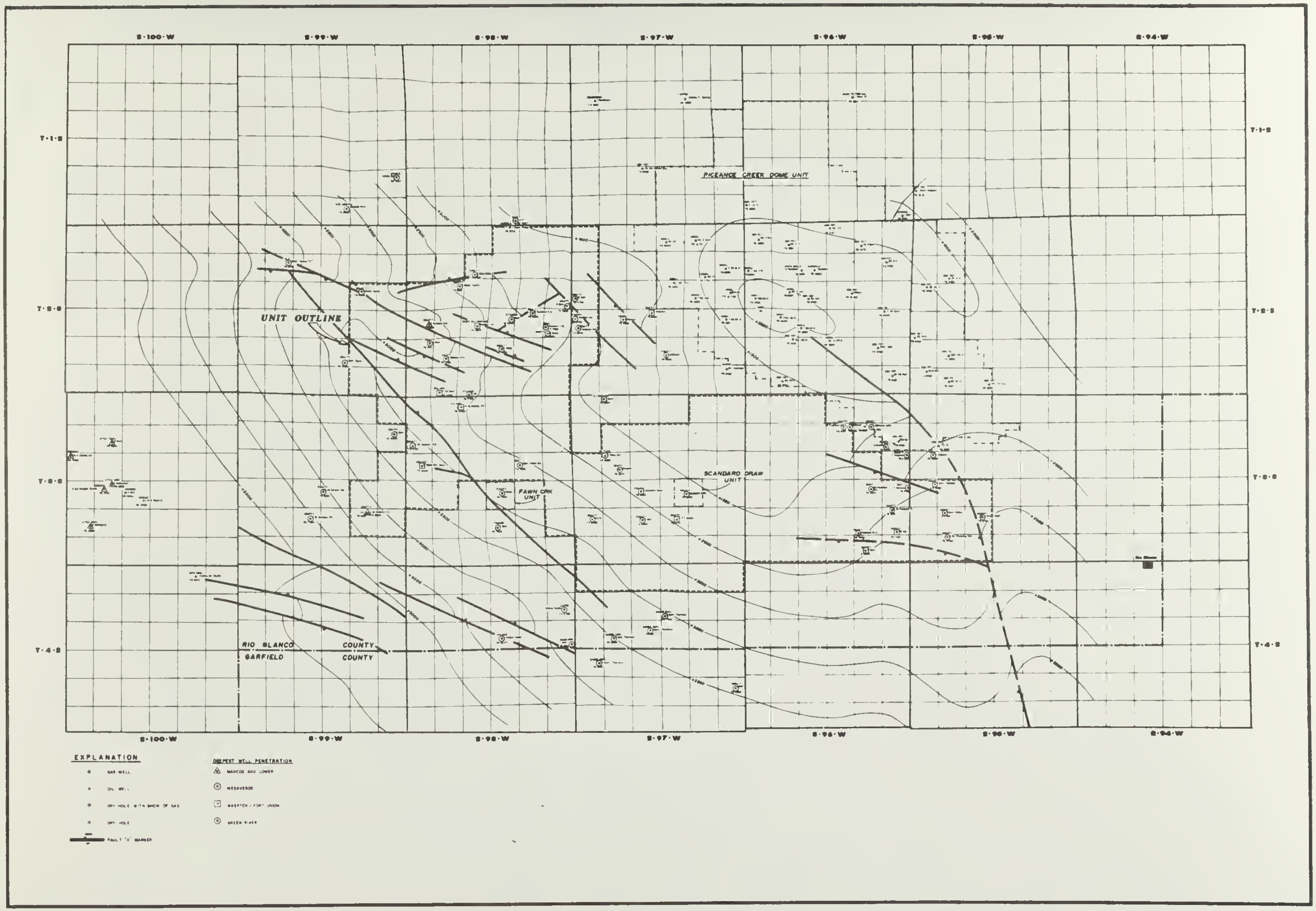


Figure IB-4. Wasatch "G" structure map, Piceance-Sulphur Creek area.

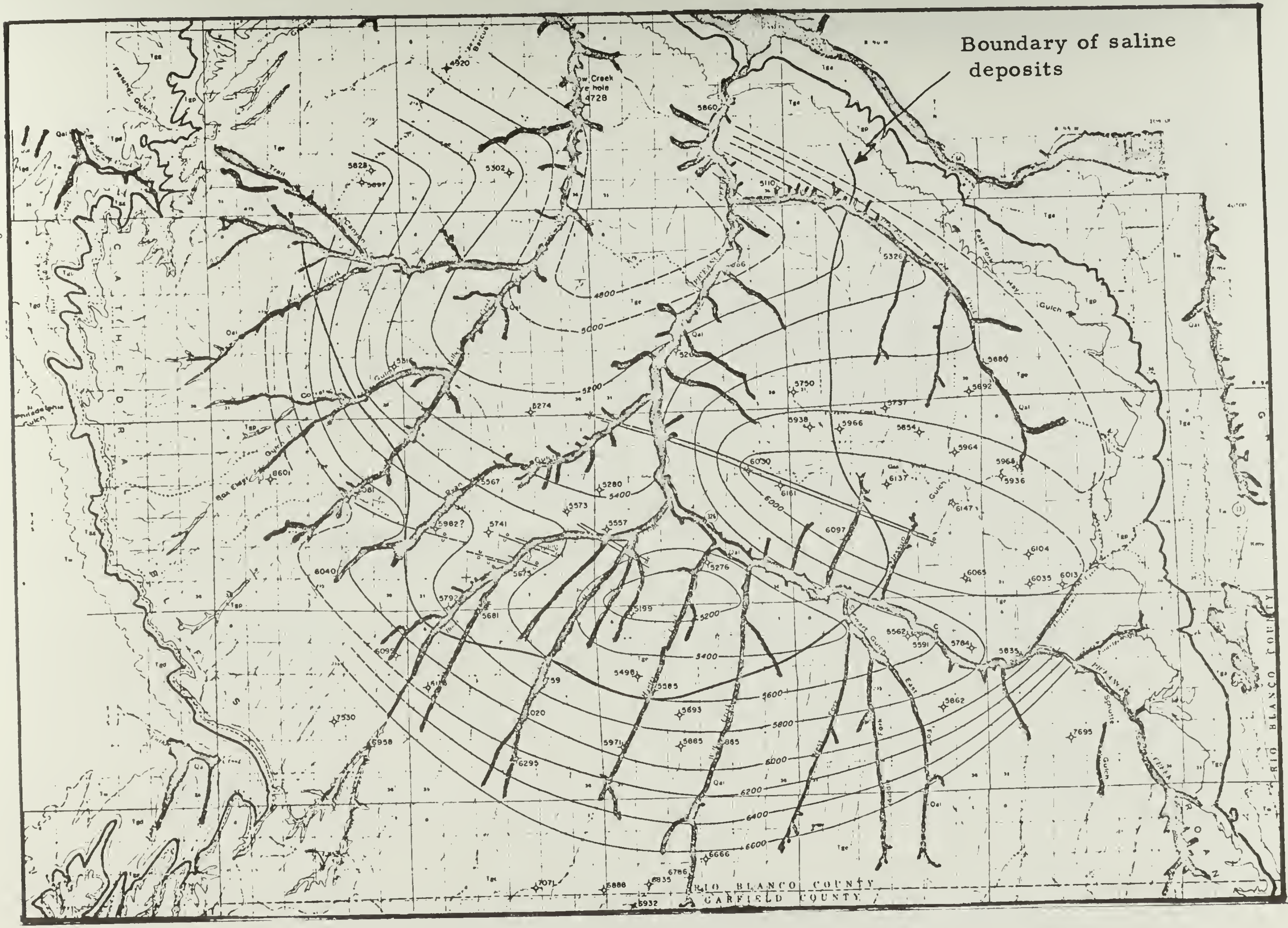


Figure IB-5. Structural map on Black Marker, Piceance Creek Basin, Rio Blanco County, Colorado.

Figure IB-6. Aerial photograph of EW area.

The absence of surface faulting in the area of the EW was also verified in the subsurface by a detailed geophysical study (Ref. IB-5). A seismic survey of the area shows no faults within two miles of the proposed EW site (Figure IB-7).

2. Stratigraphy and Sand Continuity

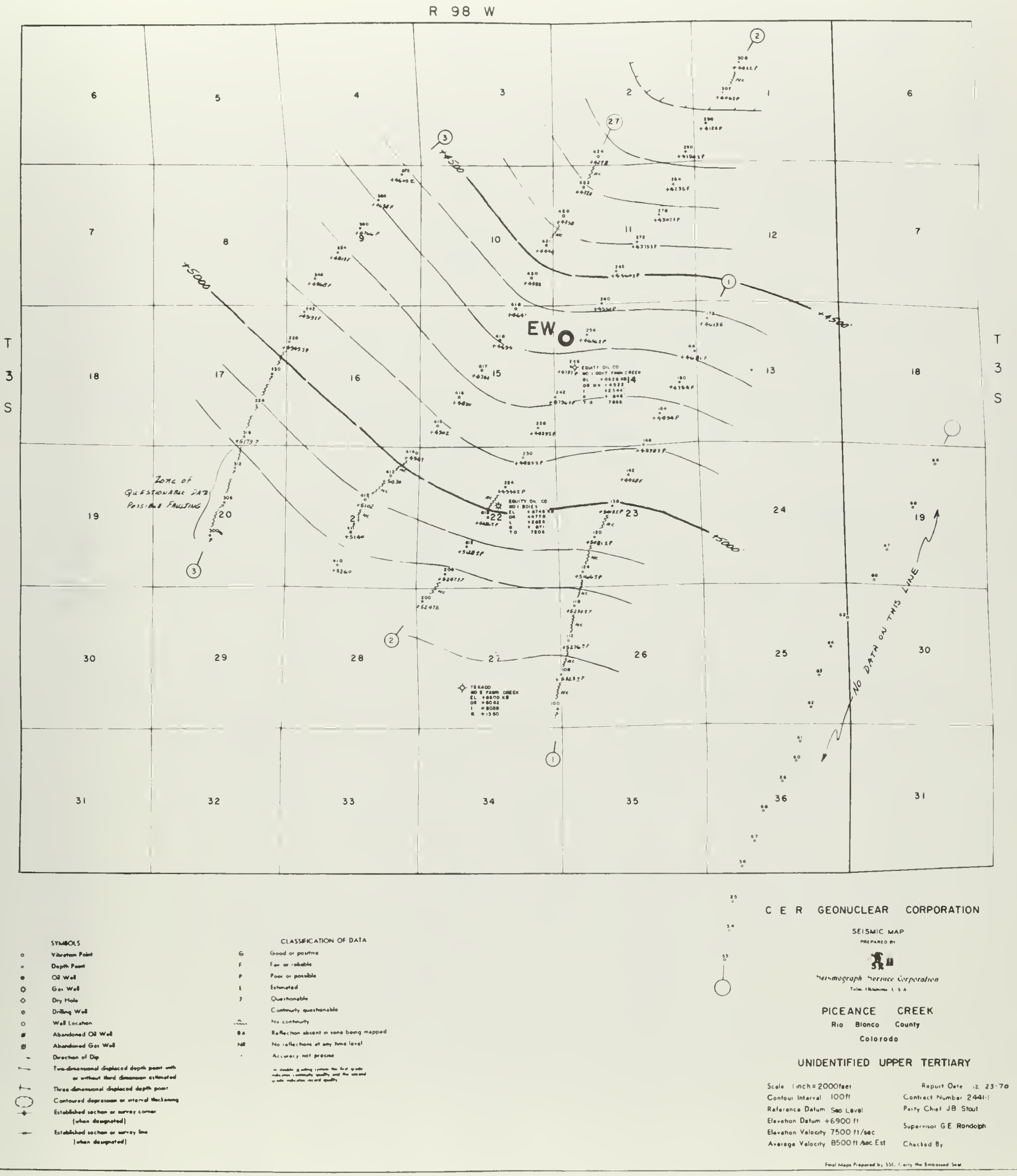
The surface bedrock in the Rio Blanco experiment area is the Evacuation Creek Member of the Green River Formation. This member is composed of brown sandstones, gray marlstones, and siltstones. The resistant sandstones form the horizontal ledges in the walls of the valleys.

The narrow valleys are floored with recent alluvium, usually less than 100 feet thick. Some Holocene and Pleistocene terrace and slide deposits are presently associated with the cliffs forming the basin margins.

The lower members of the Green River Formation crop out around the basin margin and form a classic example of layercake geology, with one exception. This is the Anvil Points Member which is a clastic wedge present only in the southeast portion of the basin. The relationship between the members of the Green River Formation, descriptions, and an indication of underlying rocks are summarized in Figure IB-8.

The Parachute Creek Member contains the bulk of the Green River oil shale. It also contains layers of saline minerals up to 100 feet thick near the center of the basin. A rich, continuous layer of oil shale has been identified throughout the basin. This layer, called the Mahogany zone, is about 150 feet thick in the area of interest and its oil yield averages approximately 35 gallons per ton.

The Wasatch is mapped in the field as a variegated, predominately shaly sequence that lies between the subdued grayish-greens, grays, and tans of the Green River Formation and the brown and yellowish-gray weathering Fort Union-Mesaverde rocks. A number of geological descriptions of the Wasatch Formation outcrops around the periphery of the Piceance Basin are available (Ref. IB-6 through 13). In general, the Wasatch thickens toward the southeast. It is less than 300 feet thick near Rangely, Colorado, and is more than 5,000 feet thick in the Rifle area.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+4500
ZONE OF QUESTIONABLE DATA POSSIBLE FAULTING
NO DATA ON THIS LINE
EQUITY OIL CO
TEXACO
SYMBOLS
Vibration Point
Depth Point
Oil Well
Gas Well
Dry Hole
Drilling Well
Well Location
Abandoned Oil Well
Abandoned Gas Well
Direction of Dip
Two-dimensional displaced depth point with or without third dimension estimated
Three-dimensional displaced depth point
Contoured depression or interval thickening
Established section or survey corner (when designated)
Established section or survey line (when designated)
CLASSIFICATION OF DATA
G Good or positive
F Fair or reliable
P Poor or possible
E Estimated
? Questionable
Continuity questionable
No continuity
Reflection absent in zone being mapped
NR No reflections at any time level
Accuracy not precise
C E R GEONUCLEAR CORPORATION
SEISMIC MAP
PREPARED BY
Seismograph Service Corporation
PICEANCE CREEK
Rio Blanco County
Colorado
UNIDENTIFIED UPPER TERTIARY
Scale 1 inch = 2000 feet
Contour Interval 100 ft
Reference Datum Sea Level
Elevation Datum +6900 ft
Elevation Velocity 7500 ft/sec
Average Velocity 8500 ft/sec Est
Report Date 12 23-70
Contract Number 2441-1
Party Chief JB Stout
Supervisor G E Randolph
Checked By

Figure IB-7.

Age	Piceance Creek-Yellow Creek Basin and Marginal Cliffs		
	Formation & Thickness	Member	Description
Holocene	"Alluvium" - 0-140 ft		Tan to brown boulder beds, sands and clays filling narrow valley bottoms
Pleistocene	"Landslide, Talus, and Terrace" 0-30 ft		Heterogeneous mixture of silt, sand, gravel, and blocks of sandstone and shale
Eocene	Green River 1,800-3,500 ft	Evacuation Creek	Light-brown and gray sandstone and siltstone, gray marlstone and siltstone
		*Parachute Creek	Black, brown, and gray marlstone (principal oil shale zone)
		Garden Gulch / Anvil Points	Gray marlstone, oolitic limestone / Brown sandstone gray shale and marlstone
		*Douglas Creek / Anvil Points	Buff and brown sandstone, gray shale / Brown sandstone gray shale and marlstone
	Wasatch 200-5,000 ft	*	Variegated shale and claystone with lenticular sandstone and thin limestones
Paleocene	Fort Union 500-1,500 ft	*	Brown and tan lenticular sandstones, somber-colored shales, thin coal seams, and a basal conglomerate
	Ohio Creek Cgl. 5-500 ft	*	
Upper Cretaceous	Mesaverde 5,500 ft ±	*	Resistant tan and white sandstone, brown to black shales and coal

* Indicates gas.

Figure IB-8. Stratigraphic section of surface rocks in the Piceance Creek-Yellow Creek Basin (after Ritzma, 1962).

The Paleocene rocks that underlie the Wasatch Formation have been referred to as the Fort Union Formation. The upper Fort Union varies in thickness from 1,500 feet along the eastern basin margin to a pinchout in the southwest. It is difficult to distinguish between the basal Wasatch and upper Fort Union on the logs from the center of the Piceance Basin; therefore, a log marker is used as the boundary. This marker may not correspond exactly with the outcrop pick, but it is in approximately the same stratigraphic position. The Fort Union rocks are of fluvial, coastal swamp, and lacustrine origins. The basal portion of the Fort Union is generally termed the Ohio Creek Member.

The basal Ohio Creek is a coarse or conglomeratic sandstone, 10 to 40 feet thick, that grades upward into an interbedded sandstone-shale sequence in the southern portion of the Piceance Basin (Ref. IB-12, 14). The interbedded shales are grayish-green and grade into the main Fort Union sequence of brownish-yellow sandstones and shales, containing Paleocene plant and animal fossils. The Ohio Creek Member of the Fort Union ranges from a few feet to 500 feet in thickness.

The Mesaverde Formation of Cretaceous age is a complex assemblage. The basal marine sandstone section is overlain by a coal-bearing, fluvial, coastal swamp sequence called the Neslen facies, which is in turn overlain by fluvial deposits termed the Farrer facies (Ref. IB-14, 15).

A marine transitional sand member called the Trout Creek sandstone is present in the Nelsen facies on the north and eastern margin of the basin (Ref. IB-14, 16) (Figure IB-9). This member cannot be traced in the subsurface at the center of the basin. The reddish, weathering middle-Mesaverde section occurs above the Trout Creek sand. The color is the result of the oxidation of the highly carbonaceous rock. This colored zone is present in the Grand Hogback and Douglas Creek area even when the Trout Creek is not present.

A second marine transition zone, termed the Fox Hills sandstone in the Axial Basin, is present in the Farrer facies in the northeastern portion of the basin (Ref. IB-16). The Fox Hills has a distribution that is more limited than the Trout Creek; hence it is not encountered except in outcrop in the northeast corner of the basin.

The Mancos Formation is a dark-colored Cretaceous marine shale sequence that underlies the Mesaverde. The Mancos is approximately 3,000 feet thick in the central portion of the basin.

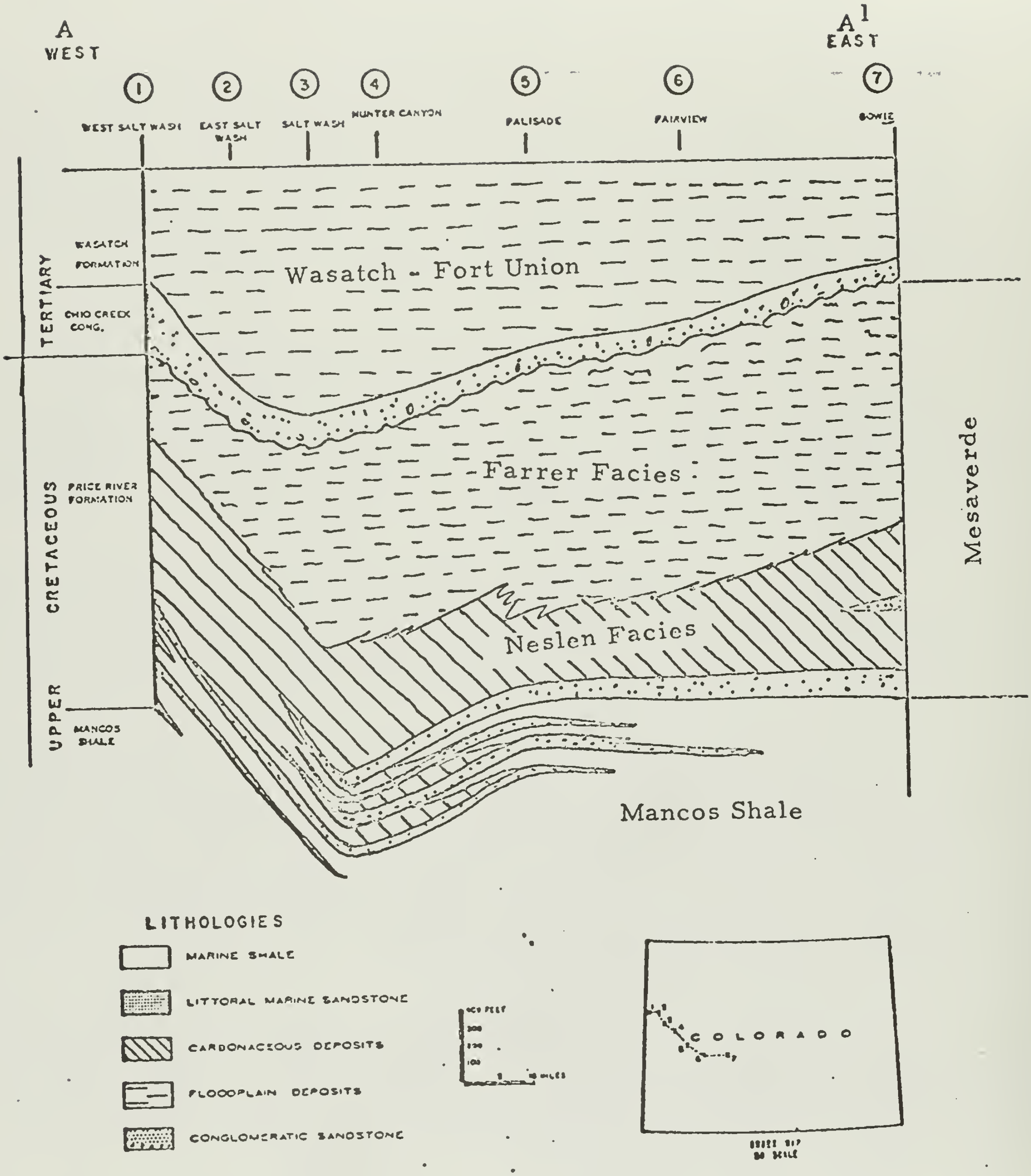


Figure IB-9. Paleocene, Eocene, and late Cretaceous deposits of Book Cliffs and Grand Mesa (after Quigley, 1968).

Regional studies of the Piceance Basin place the bulk of the Wasatch, Fort Union, and Mesaverde rock in the fluvial facies (Ref. IB-17). General geometric data on sand bodies deposited under fluviatile conditions can be combined with statistical studies of the geometries of sandstone bodies made on outcrops along the basin margin (Ref. IB-18, 19) to obtain a picture of expected sand continuity in the Rio Blanco experiment area.

The bulk of the sandstone appears to be of channel-fill origin. The expected widths of these bodies are in the order of 350 feet and lengths greater than 1,000 feet. (The calculated length/width/thickness ratio of a single bed from outcrop is 140/14/1.) Thus, for a 25-foot thick single bed cut by a wellbore, one would predict a sinuous lens form approximately 350 feet wide and 3,500 feet long (Ref. IB-19).

Point bar deposits are quite complex and not enough data are available from the Piceance Basin outcrops to construct regional geometries. However, from basic studies and a limited number of Piceance Basin observations (Ref. IB-19), the length/width ratio of 3,000/1,200 feet seems appropriate for expected point bar sands in the Rio Blanco experiment area.

3. Rock Properties

Geophysical logs provide the most voluminous set of records about rock properties in the Piceance Basin. A typical comprehensive suite of logs from the Green River Formation is displayed as Figure IB-10. The kerogen (hydrocarbon) content of the oil shale has a log response similar to normal hydrocarbon-filled pore space; hence, the oil shale yield is a direct function of the apparent porosity response for the sonic and density logs (Ref. IB-20, 21). The resistivity logs tend to saturate or read approximately zero conductivity in oil shale sections without fractures or secondary porosity. Hence, oil shale yields and estimates of extent of the fracturing can be derived from comprehensive logging suites through the oil shale. The non-oil shale Green River sandstones, siltstones, and shales respond to the logs in a normal manner.

The oil shale is quite anisotropic in its physical properties. The strength is a function of confining pressure and kerogen content (Ref. IB-22). This variation in strength and in the brittle/ductile transition point is illustrated in Figure IB-11 by the "granite-like" behavior of 18 gallons per ton shale and the "salt-like" behavior of 26 gallons per ton shale.

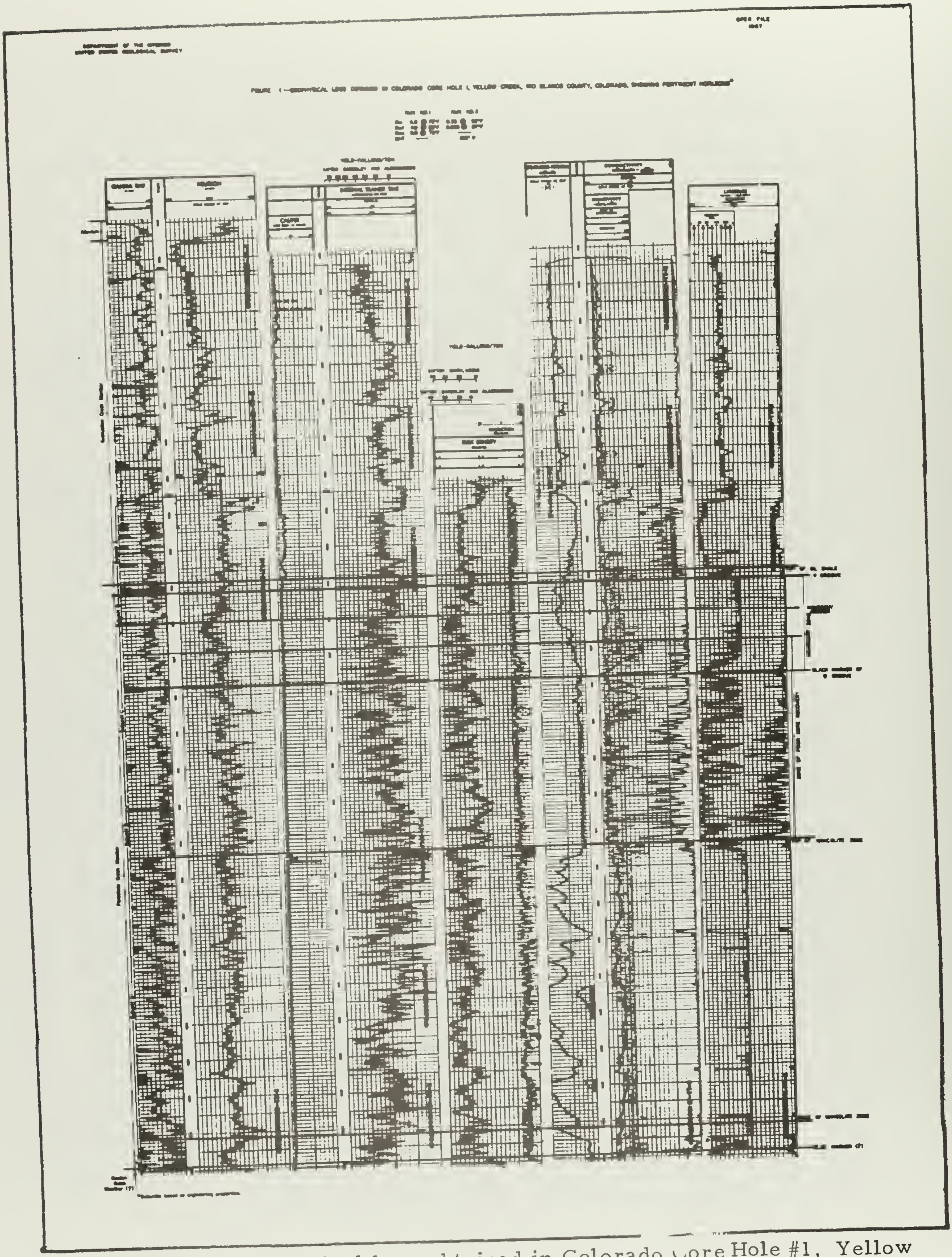


Figure IB-10. Geophysical logs obtained in Colorado Core Hole #1, Yellow Creek, Rio Blanco County, Colorado, showing pertinent horizons (subunits based on engineering properties).

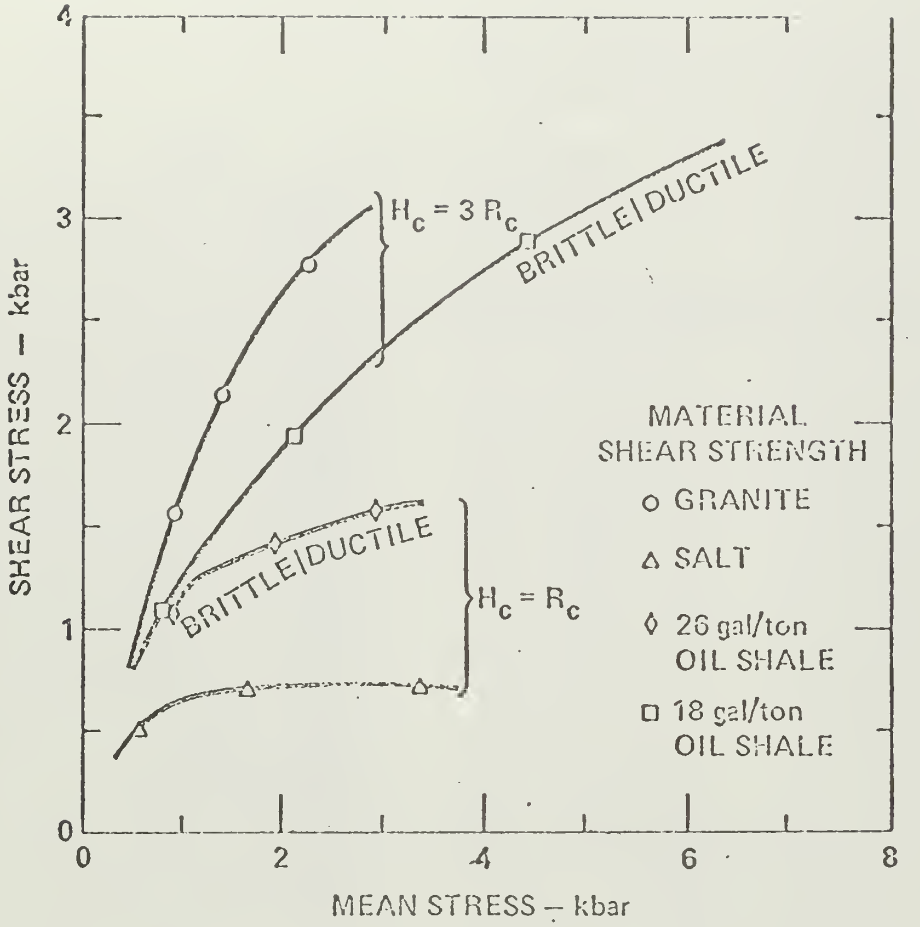


Figure IB-11. Comparison of brittle/ductile failure behavior of lean and intermediate grade oil shale and granite and salt (after Werth, 1971).

The Wasatch, Fort Union, and Mesaverde formations have similar physical characteristics. The variation in response is a function of the microvariation in the sand, silt-clay-carbonate content of rock. Figure IB-12, 13, and 14 presents a comprehensive logging suite for these formations. Shale or claystone and well-cemented sandstone can be considered end points for these rocks. The log response to these end points is presented in the following table:

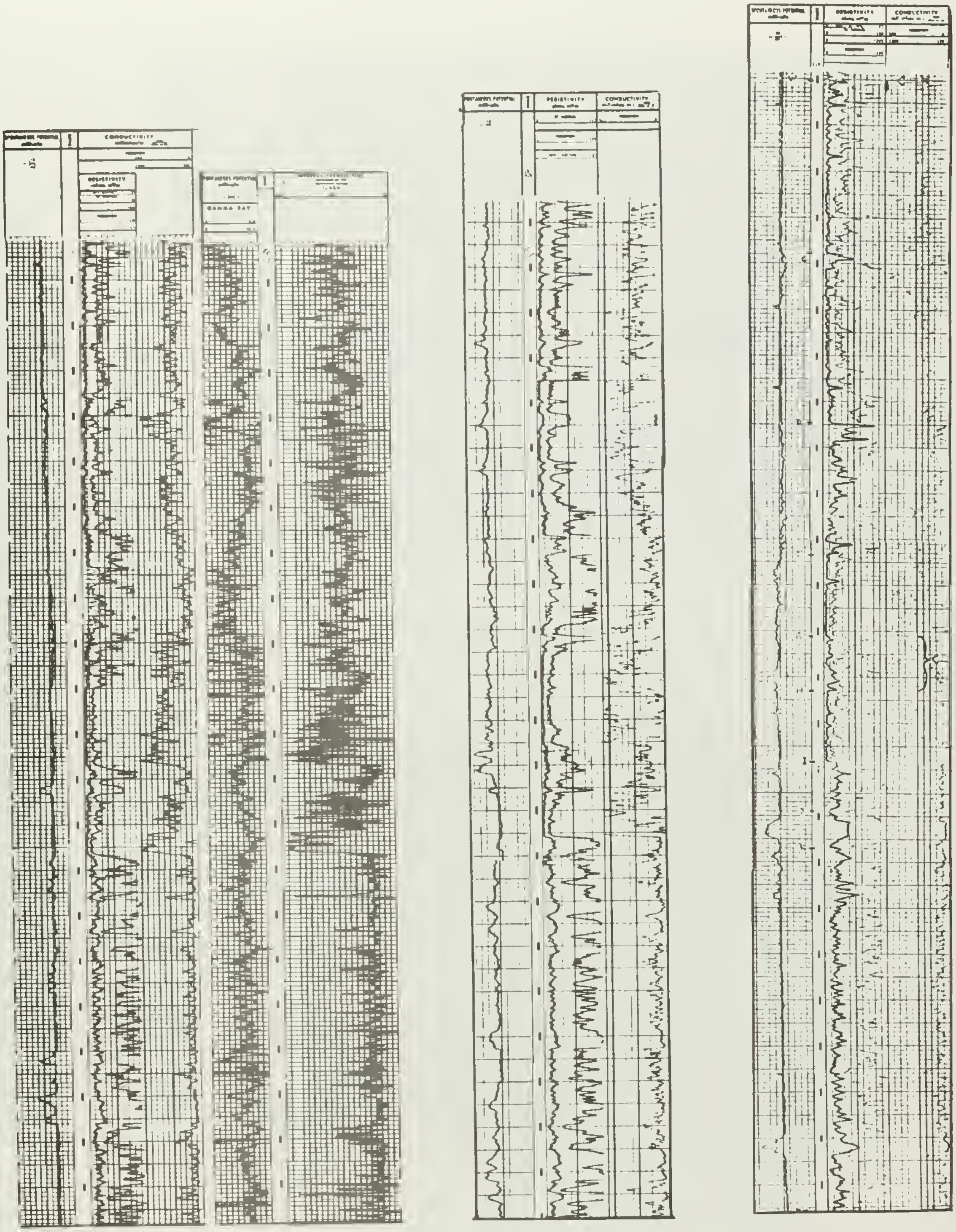
Table IB-I. Log response in Wasatch, Fort Union, and Mesaverde formations.

Log	Response		Units
	Shale/Claystone	Sandstone	
SP	0	-30	Millivolts
16 in. normal	5	65	Ohm m
Induction	5	90	Ohm m
Gamma	65	5	GR Units
Sonic	145	60	μ sec/ft
Density	2.20	2.68	g/cm^3

A number of porosity, fluid saturation, density, and permeability analyses have been made on cores from Piceance Creek Basin wells. Average values are presented in Table IB-II. These averages should apply to the Rio Blanco experiment area.

4. Rockfalls, Unstable Slopes, Landslides

The topography of the Piceance Creek area is characterized by high hills separated by open valleys. Although the water courses are fairly stable, the channels are deep with perpendicular sides and nearly all of them exhibit heavy sloughing during peak flows. Preventive action to stop the cutting of banks is taken only if structures or roadbeds are threatened. Rockfalls, and probably some slides, occur on the steep parts of the hill slopes, particularly during the spring thaw period in March and April. Some of these steep slopes border the main Piceance Road but, according to the County Road Department, no serious rockfall problems exist on this road and only minor clearing work is required (Ref. IB-23). There is no record of accidents as a result of rockfalls in the Piceance Creek area.



Fawn Creek Unit Government No. 3 Well

Boies No. 1

Fawn Creek Government No. 1 Well

Figure IB-12. Geophysical log cross section, Rio Blanco experiment area, Wasatch section.

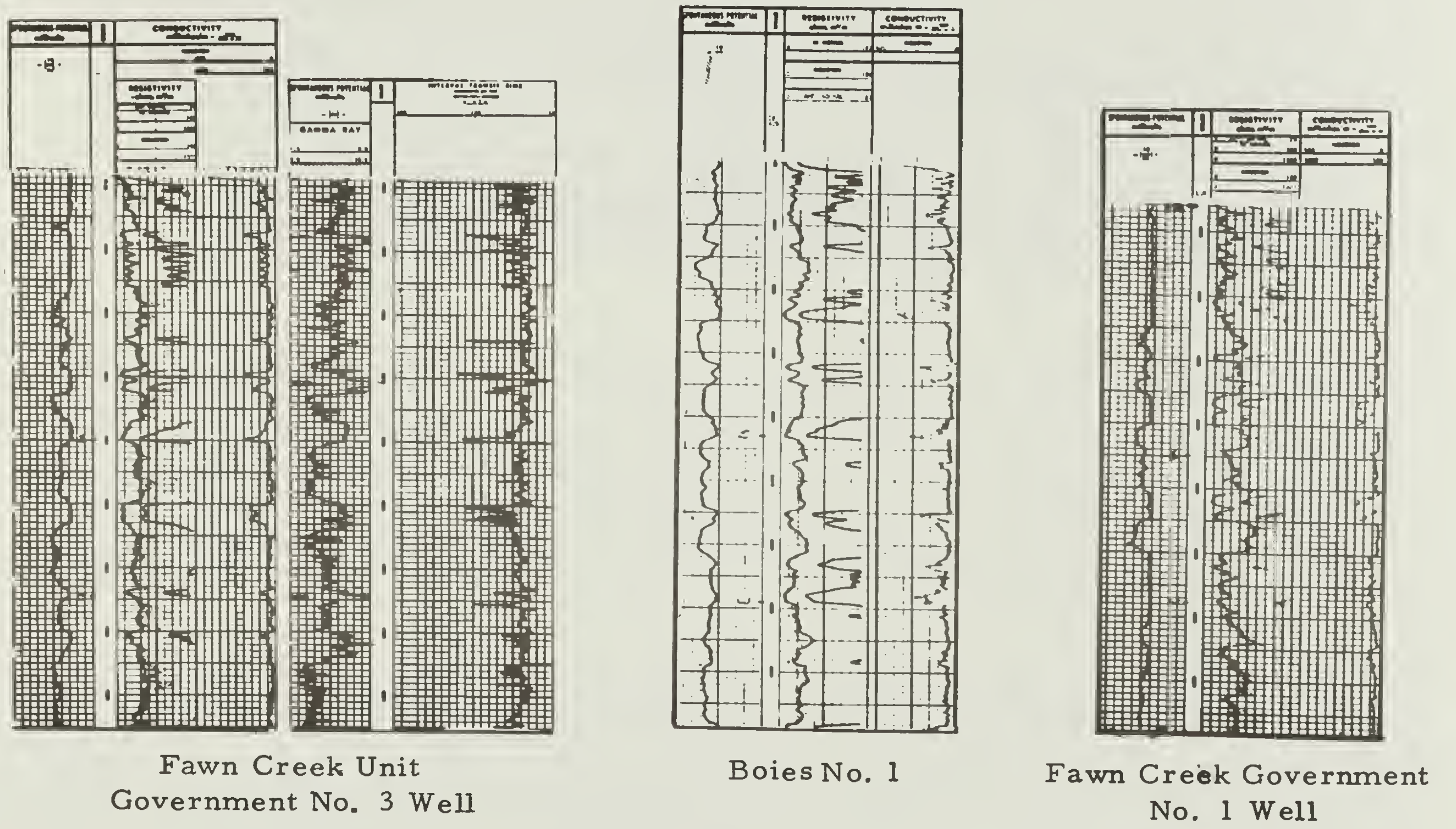


Figure IB-13. Geophysical log cross section, Rio Blanco experiment area, Fort Union section.

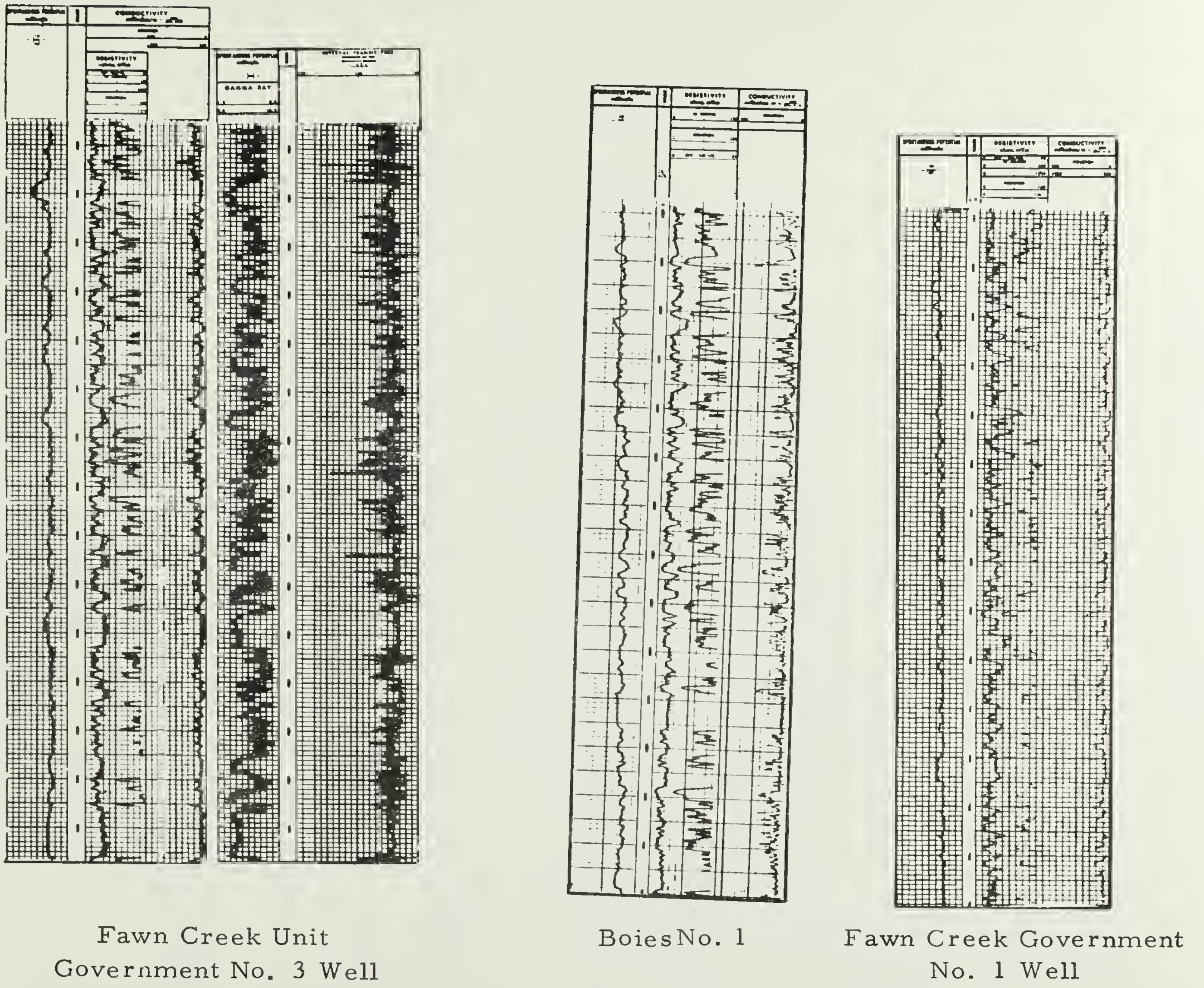


Figure IB-14. Geophysical log cross section, Rio Blanco experiment area, Mesaverde section.

Table IB-II. Average resevoir rock properties--Wasatch, Fort Union, and Mesaverde formations.

Formation	Porosity (%)	Water Saturation* (%)	Density: Bulk (g/cm^3)	Density: Grain (g/m^3)	Permeability (md)
Wasatch					
Range	8.5 - 16.7	-	-	-	.2 - 79
Median	11.5	-	2.41	2.7	1.0
Fort Union					
Range	5.3 - 17.7	27.0 - 70.0	-	2.65 - 2.70	.01 - 5.5
Median	9.8	47.0	-	2.68	.09
Mesaverde					
Range	5.0 - 18.0	30.0 - 70.0	-	2.66 - 2.69	.01 - 47
Median	12.0	56.0	-	2.68	.35

* Water saturations are for reservoir rock only; i.e., rock that contains less than 70% water saturation in pore space.

Farther away from the EW, slope-stability and rockfall problems exist in a number of locations, i.e., Douglas Pass, Glenwood Canyon, Parachute Creek Road, Rifle Gap Dam Road, and De Beque and Plateau Creek canyons. Major rockfalls in these locations are again limited to the early frost and spring thaw periods, although minor rock hazards exist throughout the year.

REFERENCES

IB-1. Dyni, J. R., "Structure of the Green River Formation Northern Part of the Piceance Creek Basin, Colorado," The Mountain Geologist, Vol. 6, No. 2, p. 65.

IB-2. CER Geonuclear Corporation, "Rio Blanco Feasibility Study" (April 16, 1970).

IB-3. Kelly, V. C. and N. S. Clinton, "Fracture Systems and Tectonic Elements of the Colorado Plateau," University of New Mexico, Geol., No. 6 (1960).

IB-4. Duncan, USGS, Washington, D. C., (personal communication).

IB-5. Seismic Survey, Piceance Creek Prospect, Seismograph Service Corporation (February 8, 1971).

IB-6. Cullins, H. L., "Geological Map of the Banty Point Quadrangle, Rio Blanco County, Colorado," USGS Map GQ-703 (1968).

IB-7. Cashion, W. B., "Geological Map of the Black Cabin Gulch Quadrangle," USGS Map GQ-812 (1969).

IB-8. Cullins, H. L., "Geological Map of the Mellen Hill Quadrangle, Rio Blanco and Moffat Counties, Colorado," USGS Map GQ-835 (1969).

IB-9. Donnell, J. R., W. B. Cashion, and J. H. Brown, Jr., "Geology of the Cathedral Bluffs Oil Shale Area, Rio Blanco and Garfield Counties, Colorado," USGS Map QM-134 (1953).

IB-10. Duncan, D. C. and C. Belser, "Geology and Oil-Shale Resources of the Eastern Part of the Piceance Creek Basin, Rio Blanco and Garfield Counties, Colorado," USGS Map-1 OM-119 (1950).

IB-11. Waldron, F. R., J. R. Donnell, and J. C. Wright, "Geology of De Beque Oil-Shale Area, Garfield and Mesa Counties, Colorado," USGS Map OM-114 (1951).

IB-12. Donnell, J. R., "Tripartition of the Wasatch Formation near De Beque in N. W. Colorado," USGS Prof. Paper No. 424B, pp. B-145-147 (1962).

IB-13. Young, R. G., "Sedimentary Facies and Intertonging in the Upper Cretaceous of the Book Cliffs, Utah, Colorado," GSA Bull., Vol. 66, No. 2, pp. 177-201 (1955).

IB-14. Quigley, M. D., "Geologic History of Piceance Creek-Eagle Basins," AAPG Bull., Vol. 49, No. 11, pp. 1974-96 (1965).

IB-15. Warner, D. L., "Mancos-Mesaverde (Upper Cretaceous) Intertonging Relations Southeast Piceance Basin, Colorado," AAPG Bull., Vol. 48, No. 7, pp. 1091-1107 (1964).

IB-16. Haun, J. D. and R. J. Weimer, "Cretaceous Stratigraphy of Colorado," Guide to the Geology of Colorado, GSA-RMAG-CSS, pp. 58-65 (1960).

IB-17. Millison, C., "Gas Occurrence in Piceance Basin, Colorado," AAPG Memoir, No. 2, pp. 180-187 (1963).

IB-18. Knutson, C. F., et al., "Sand Continuity in the Mesaverde Formation, Rulison Field Area, N.W. Colorado, JPT, Vol. 23 (August, 1971).

IB-19. CER Geonuclear Corporation, "Project Rio Blanco Reservoir Report" (April 2, 1971).

IB-20. Bardsley, S. R. and S. T. Algermissen, "Evaluating Oil Shale by Log Analysis," JPT, Vol. 15, No. 1, pp. 81-84 (1963).

IB-21. Smith, John Ward, "Applicability of a Specific Gravity - Oil Yield Relationship to Green River Oil Shale," Chem. and Eng. Data Series, Vol. 3, No. 2, pp. 306-310 (1958).

IB-22. Werth, G. L., "Effect of a Nuclear Explosion on Oil Shale," Symposium on Oil Shale Retort and Project Utah, Laramie, Wyoming (February 17, 1971).

IB-23. Sullivan, Rio Blanco Road Department, Meeker, to L. van der Harst (personal communication, July 15, 1971).

C. SEISMIC ACTIVITY

1. Distribution of Earthquakes

The seismic risk map (Ref. IC-1) shows that all of the Piceance Creek Basin is a quiet seismic area and is classified as Zone 1. Structures in this zone with fundamental periods greater than 1.0 second can be expected to suffer no more than minor structural damage from large distant earthquakes.

The strain release map (Ref. IC-1) indicates very little probability of strain stored in the subsurface to cause earthquakes. This opinion of the seismic activity of the area is also held by Ruth Simon of the Colorado School of Mines (Ref. IC-2). Examination of the seismic activity of Colorado maps issued annually since 1966 (Figure IC-1) shows that the only earthquakes in Colorado within 50 miles of the Rio Blanco site (magnitude two or greater) were at the Harvey Gap Reservoir and at Rangely. That at the Harvey Gap is believed to have been due to the effect of the loading by the stored water (Ref. IC-2) on the geologic structure below. Those at Rangely have been postulated to result from the water flooding of the Rangely oil field (Ref. IC-3).

The Special Projects Party of the National Ocean Survey has made a search of the historical seismic data in an area within 50 miles and 100 miles of the Rio Blanco site. The results of this search are shown in Figure IC-2.

2. Observatories

a. U. S. Geological Survey

The USGS is operating a seismic array in the vicinity of the Rangely Oil field about 35 miles from the Rio Blanco site. The purpose of this array is to monitor any earthquakes resulting from the water flooding of the oil field. The data from this array would also indicate any change in seismic activity due to Project Rio Blanco.

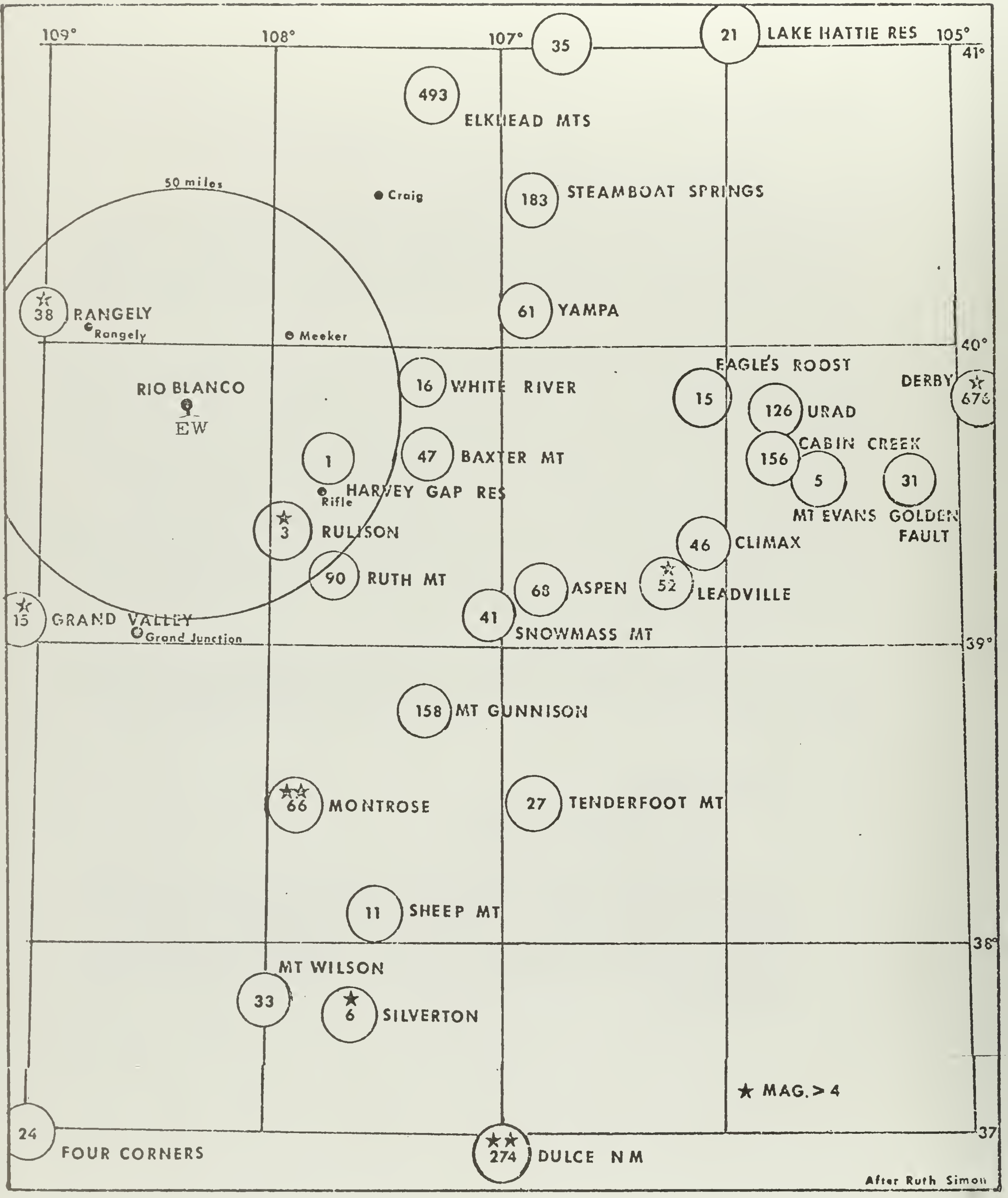


Figure IC-1. Seismic activity of western Colorado, 1966 - 1969.

(Numbers in circles indicate number of seismic events, magnitude 2 or greater, with epicenters in the area indicated. Each event with magnitude 4 or greater is indicated by ★. Events indicated at Rulison include nuclear explosion itself plus two local aftershocks.)

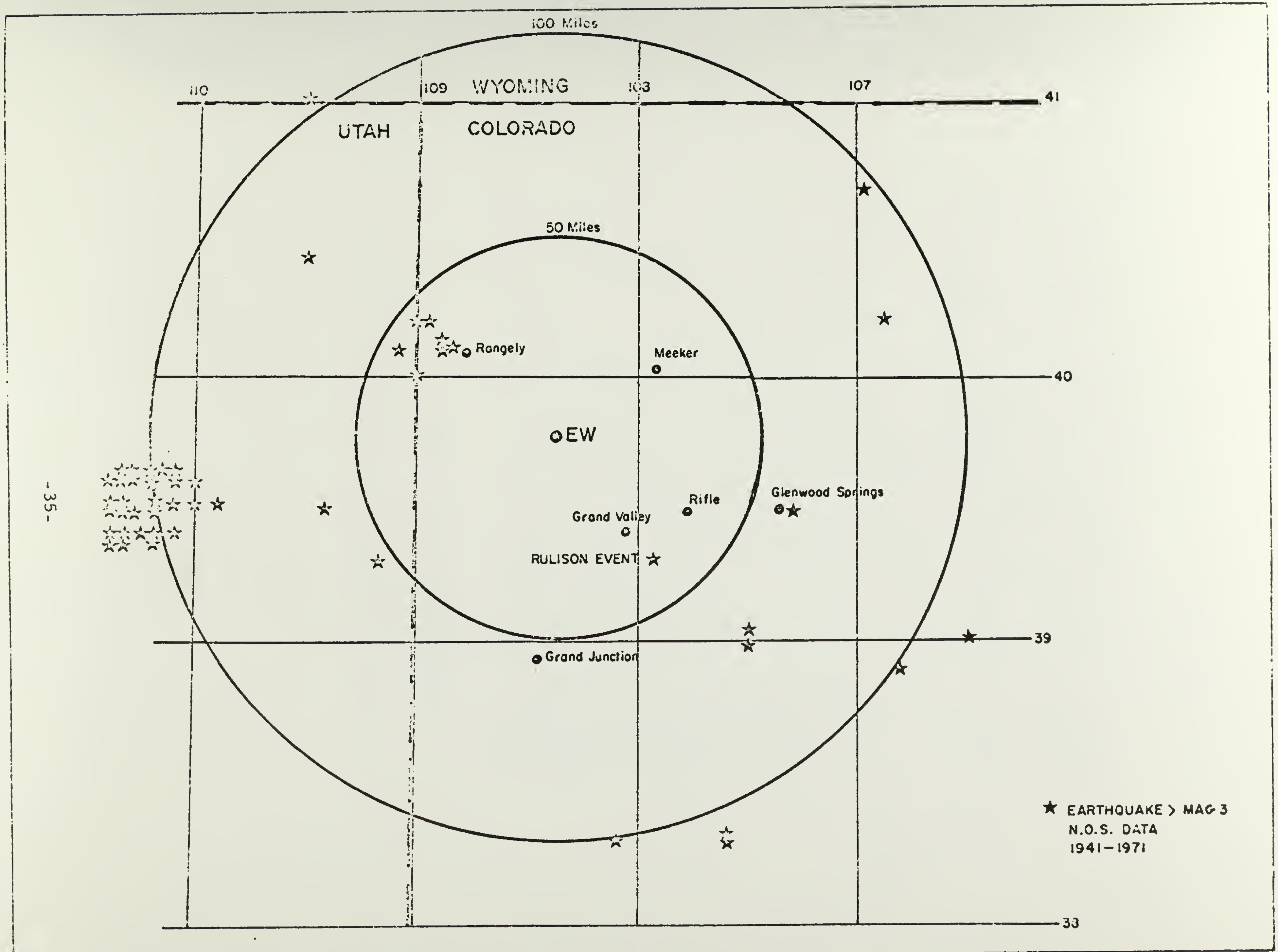


Figure IC-3. Seismic activity of general area

b. NOAA/CSM

The National Oceanography and Atmospheric Administration/Colorado School of Mines (NOAA/CSM) earthquake monitoring network, with nearby stations at Vernal, Craig, Eagle, and Grand Junction is expected to be available to document seismic activity in the area of the Rio Blanco EW for several months before and after the shot. This network should provide data on all earthquakes of magnitude two or greater in an area within 100 miles of the site and give their location within ± 3 kilometers.

c. CER Planned Observatory

A seismic station of one vertical component seismometer, recording on a drum recorder, will be established within one mile of the EW. This station will detect all earthquakes of magnitude zero or greater within a five-mile radius and will be in operation six months pre- and post detonation. From this instrumentation, a determination of the number, magnitude, and distance of the microearthquakes can be made. The direction of the microshocks from the recording site cannot be determined, but the data should be sufficient to establish the pre- and post detonation seismic activity of the area. The exact site for this station has not been selected but will have to be in a seismically quiet locale which has continual accessibility since the paper on the recorder will require changing daily. The station will be relocated for the detonation at a point several miles away from the EW and operated shortly after the detonation at that point until the EW area is reopened, when it will be returned to operation at its original location.

d. National Ocean Survey (NOS)

The worldwide seismic network of the NOS will locate all earthquakes of magnitude three or greater in the area.

REFERENCES

IC-1. Algermissen, S. T., "Seismic Risk Studies in the United States," Fourth World Conference on Earthquake Engineering, Santiago Chili (January, 1969). Reprint, NOS, U.S. Department of Commerce, Rockville, Maryland.

IC-2 Simon, Ruth B. "Seismicity of Colorado - Consistency of Recent Earthquakes with Those of Historical Record," Science, Vol. 165, pp. 897-899 (August, 1969).

IC-3. Healy, J., USGS, Menlo Park, California (personal communication).

D. HYDROLOGY

1. Surface Water

The Rio Blanco experiment area is in the Yellow Creek-Piceance Creek drainage basin, hereafter referred to as the Piceance Creek Basin, as shown by Figure ID-1. Surface drainage is to the north into the White River. The basin has an area of approximately 1,000 square miles and provides an average annual water yield of about 26,000 acre feet (Ref. ID-1).

The principal sources of water for the streams are the melting winter snowpacks and summer thunderstorm activity, augmented by groundwater discharge. Maximum stream flows occur from May to September of over 200 cubic feet per second (Ref. ID-2). Approximately 20% of the water in Piceance Creek is supplied by the Hunter's Creek-Black Sulphur Creek water shed. Fawn Creek is a tributary to Black Sulphur Creek and is included in this unit (Ref. ID-2).

Occasionally, low flow rates are encountered in Piceance Creek because of water diverted for irrigation. In April and May, 1966, rates as low as 0.8 cubic feet per second were measured in Piceance Creek below Ryan Gulch due to irrigation (Ref. ID-2).

Highest salinities in surface water occur in the lower reaches of Piceance Creek. This is the result of groundwater discharge from the Green River aquifer. The salinity is highest when surface runoff is lowest and the contribution from the long-term storage in the groundwater system represents the largest fraction of the stream flow. The increase in salinity in the groundwater discharge region of Piceance Creek is illustrated by Figure ID-2. When the measurements were made, little water was being diverted for irrigation and no precipitation had occurred for several weeks. Figure ID-2 illustrates the contributions of the longer-term storage factors. The general range of salinities in Piceance Creek is from approximately 400 mg/l in the upper reaches to approximately 6,000 mg/l in the lower reaches (Ref. ID-2).

There are six springs documented on Black Sulphur Creek and Fawn Creek in the vicinity of the proposed Rio Blanco EW (compiled from Ref. ID-4, 5). The location of springs in the experiment area is presented in Figure ID-3.

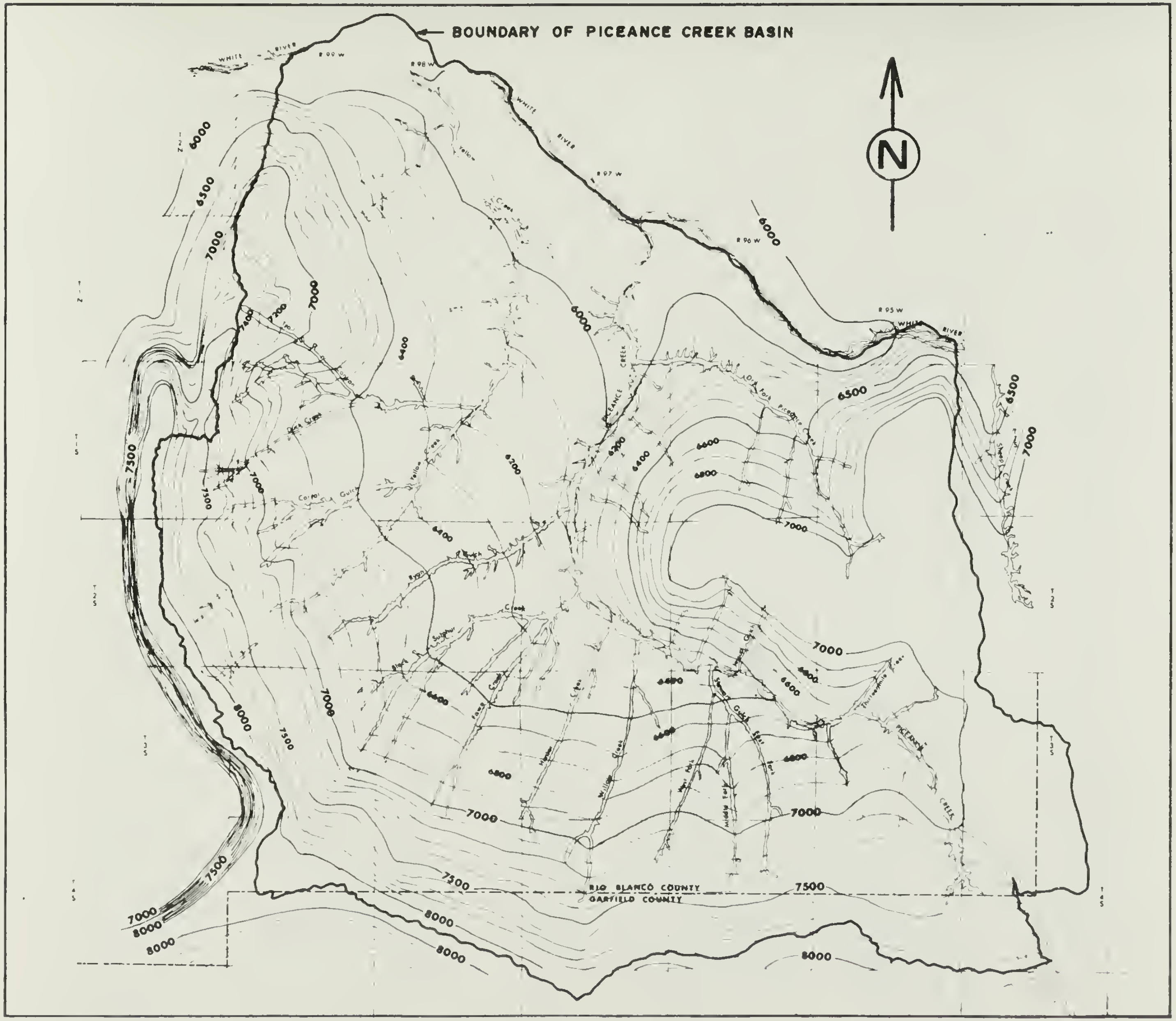
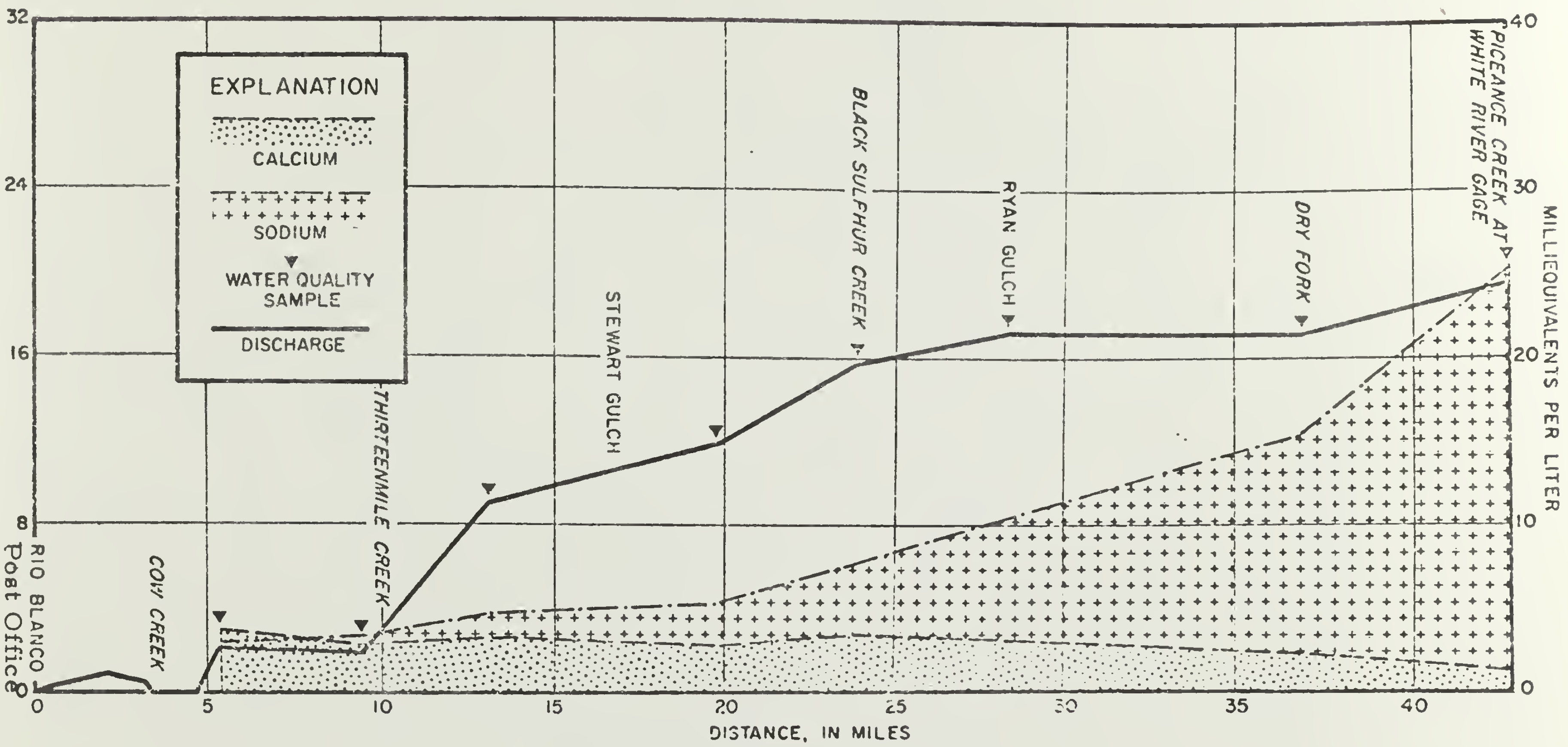


Figure ID-1. Drainage map of the Yellow Creek-Piceance Creek Basinwith stream level contours superimposed (After EGE, 1967; Ref. ID-3).



Discharge, in cubic feet per second

Post Office

Figure ID-2. Variations in rate and salinity of Piceance Creek, October 6, 1965 (after Coffin, 1969).

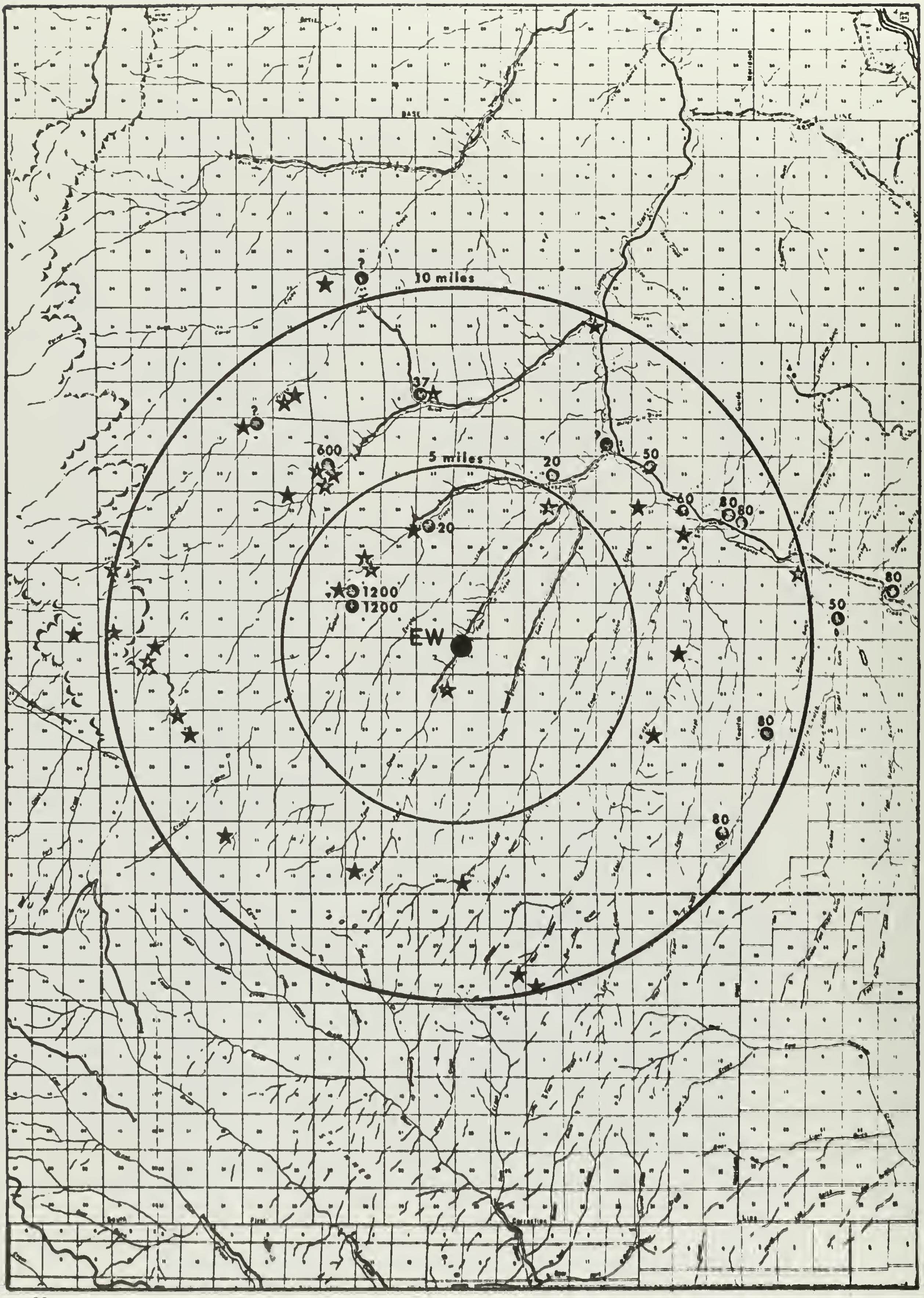


Figure ID-3. Documented springs and wells within 10 miles of EW.

2. Groundwater

Groundwater in the Piceance Basin occurs in the alluvium and in the Green River Formation. Water-filled porous zones also occur in the Wasatch, Fort Union, and Mesaverde formations, but these constitute saline interstitial water occurring in small sand lenses and do not represent a viable groundwater system.

The alluvium occurs as narrow bands and fills the bottoms of Piceance Creek, Yellow Creek, and their principal tributaries.

The thickness of the alluvium and its cross sectional area has been investigated by drilling at several sites on Piceance and Yellow Creeks (Ref. ID-4). The thickness varies from 0 to 140 feet with a saturated thickness of 100 feet or less. Alluvium aquifer pump test transmissibilities varied from about 20,000 to 100,000 GPD/ft and the calculated storage coefficient was approximately 0.20. Variations in transmissibility correlated with lithologies, with coarser and better-sorted sections exhibiting higher transmissibilities.

Water quality in the alluvium correlates with quality in the overlying surface water, having the same general ionic composition but slightly greater concentrations. The dissolved solids concentration varies from approximately 700 mg/l in the upper reaches of the stream valleys to more than 8,000 mg/l in the lower reaches.

There is one alluvium aquifer well within five miles and eight more within ten miles of the Rio Blanco experiment (Figure ID-3).

The alluvium water is recharged by precipitation, applied surface water, streams, and infiltration from the Green River groundwater system. The water discharges into the overlying streams and into the Green River groundwater system and is tapped by wells and phreatophytes which discharge water into the atmosphere by evapotranspiration.

The main Green River groundwater system and principal aquifer in the basin is a fracture network. The Evacuation Creek Member and the upper part of the Parachute Creek Member form a moderate transmissibility aquifer. The underlying Mahogany zone generally forms an aquitard. The middle and lower parts of the Parachute Creek Member form a high transmissibility aquifer where the fractures are open and leached. In the central part of the basin, any incipient fractures in the lower Parachute Creek are closed, and this "high- resistivity" zone forms an aquitard. The Garden Gulch Member also is basically an aquitard.

The Douglas Creek Member forms a separate subsystem, with water production occurring in low permeability sandstones.

The Anvil Points Member forms a separate subsystem but is not treated in this discussion, since it occurs only along the southeastern margin of the basin.

For this study, the fractured Green River aquifer subsystem above the Mahogany zone will be termed the "A" subsystem and that portion below the Mahogany zone will be termed the "B" subsystem.

A limited number of pumping tests from the "A" subsystem wells provide a transmissibility range of from 1,000 to 2,000 GPD/ft and calculated storage coefficients of 0.10.

The water quality varies from 250 mg/l dissolved solids along the southern margins of the basin to 18,000 mg/l in the discharge region near the basin center.

The Mahogany aquitard may be permeable where it is close to the surface, where it has been drilled and not cemented in oil, gas or core test wells, or where it is cut by fault zones. Throughout most of the basin, the permeability is low enough, compared to the adjacent subsystems, to provide marked separation between the "A" and the leached "B" subsystems.

The "B" subsystem is the principal "confined" groundwater zone in the Piceance Creek Basin.

The "B" aquifer is charged along the southern margin of the basin, where the fracture system provides limited communication through the Mahogany aquitard. The "B" subsystem exhibits intermittent hydraulic continuity with the "A" subsystem and discharges into it via faults in the north-central portion of the basin.

The variation in static water level in the wells which tested both zones indicates only a tenuous connection between the "A" and "B" zones. This difference is greatest in the areas intermediate in distance between the recharge area and the north-central part of the basin.

The "B" water quality is similar to that encountered in the "A" subsystem along the southern basin margins. As the water flows through the "B" subsystem, it dissolves soluble rock components. Hence, a salinity gradient is developed that increases toward the basin center. In all but the peripheral areas of the basin, a vertical-density gradient is also developed in the leached, high-resistivity transition zone. The specific conductance plot from USBM/AEC Colorado Core Hole Number 3 (Figure ID-4) illustrates this increase, as the "B" subsystem is penetrated in the interval 1,409 (430 m) to 1,889 (576 m) feet subsurface (Ref. ID-6).

The dissolved solids concentration in the "B" subsystem varies from 280 mg/l at the southern basin margin to 63,000 mg/l in the north-central portion of the basin.

The transmissibilities in the "B" subsystem vary from 3,000 GPD/ft at the basin margins to more than 20,000 GPD/ft at the basin center, where extensive suites of saline materials have been removed by solution. Figure ID-5 is a cross section showing the distribution of halite, nahcolite, and dawsonite in the high resistivity zone and thickness of the leached zone.

The artesian storage coefficient of the leached zone is approximately 10^{-5}, while the unconfined coefficient is approximately 10^{-1} (Ref. ID-4).

Because of the tenuous interconnection between the "A" and "B" subsystems, the general hydrologic gradient for the upper Green River fractured groundwater system should serve as a first order approximation of the "B" subsystem flow directions.

The Wasatch Formation is predominantly claystone, shale, and contains siltstone. It contains lenses of sandstone that are frequently gas bearing in the central basin. The sandstone members have relatively low permeability, contain saline water, and are of limited extent; hence they do not constitute aquifers or form a viable groundwater system.

The Fort Union and Mesaverde formations have a greater sandstone content than the Wasatch. However, the sands in general are similar to the Wasatch and do not appear to form viable groundwater systems under the Piceance Creek-Yellow Creek drainage basin.

The general groundwater picture for the basin is summarized in Table ID-I.

3. Hydrology of Rio Blanco Experiment Area

For hydrology, the area of interest for this experiment is considered to be enclosed by a five-mile radius circle with its center at EW.

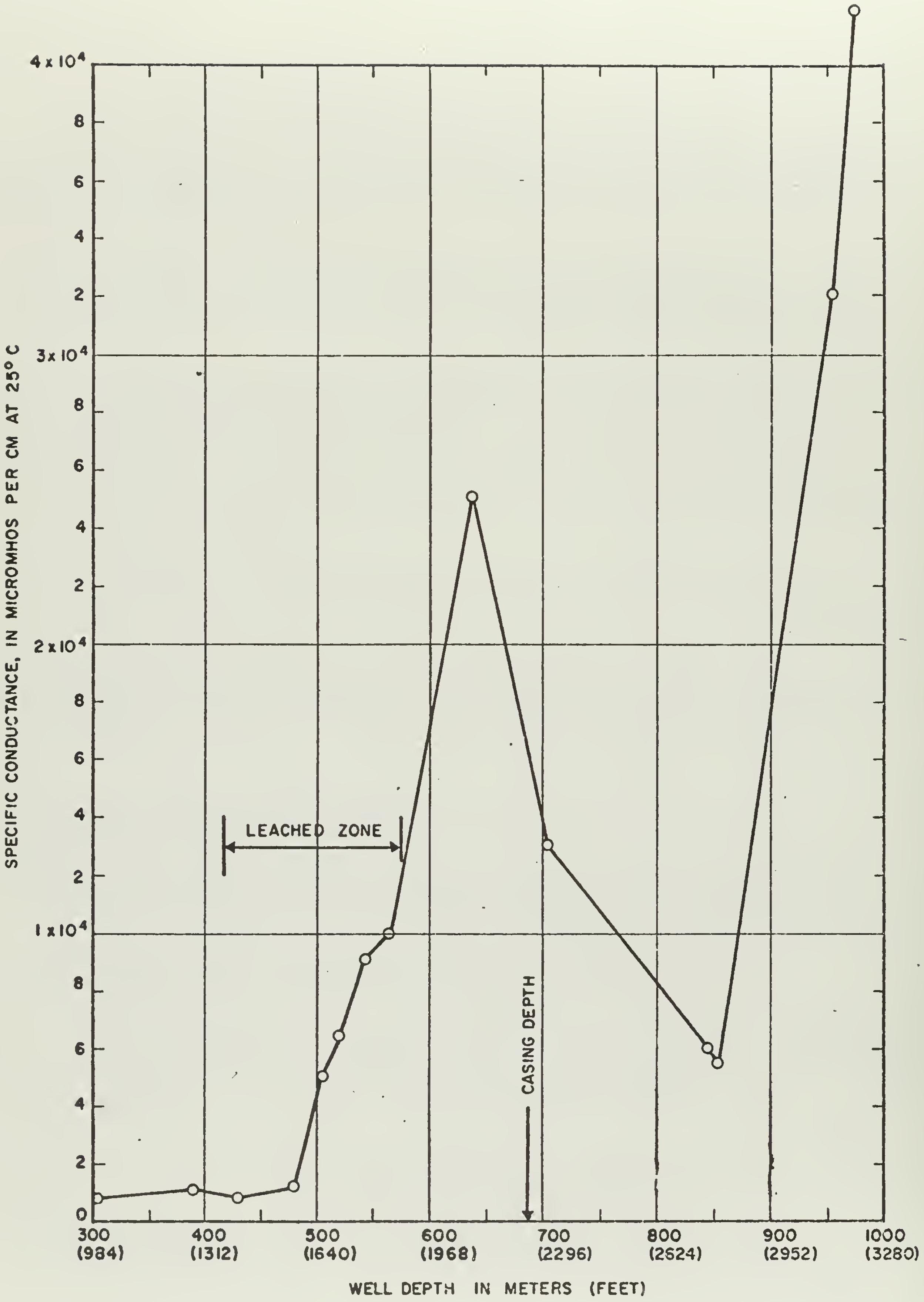


Figure ID-4. Specific conductance of fluid during drilling USBM/AEC Colorado Core Hole Number 3 (after Cordez, 1969).

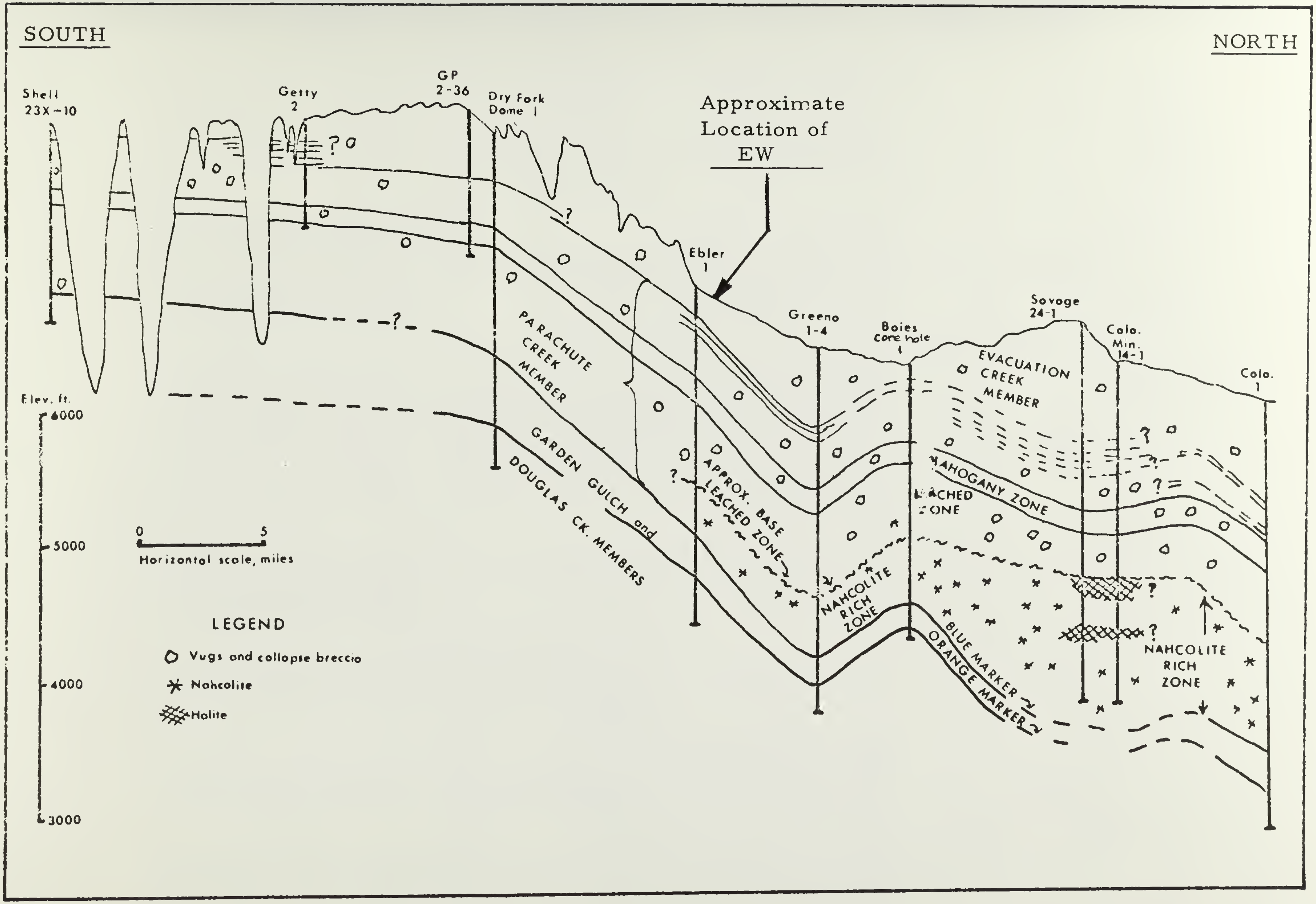


Figure ID-5. South-north cross section of central Piceance Creek Basin (after Trudell, 1970; Ref. ID-7).

Table ID-I. Summary of geologic units and their water-bearing characteristics (after Coffin, 1969)

System	Series	Geologic unit		Thickness (feet)	Physical charactar	Water quality	Hydrologic character
Quaternary	Holocene and Pleistocene(?)	Alluvium		0–140	Sand, greval, end cley pertly fill major vallays es much as 140 feat; ganarally less then half e mila wida. Beds of clay mey be es thick as 70 feet; ganerally thickest near the center of valleys. Sand and greval contein stringars of clay neer mouths of smell tributeries to mejor streems.	Naer tha headweters of the mejor streems, dissolvad-solids concentretions range from 250 to 700 mg/l. Dominent ions in tha weter ere genarelly calcium, megnesium, end bicerbonete. In most of tha eree, dissolved solids renge from 700 to es much as 25,000 mg/l. Above 3,000 mg/l tha dominent ions ere sodium end bicerboneta.	Weter is under artesian pressure where sand and grevel era overlain by beds of cley. Raported yialds as much as 1,500 gpm. Well yields will decreese with time because vallays ere nerrow end the velley walls act as raletively impermeeble bounderies. Transmissivity renges from 20,000 to 150,000 gpd per ft. The storege coefficient evereges 0.20.
Tertiary	Eocene	Green River Formation	Evecuation Creek Member	0–1,250	Intartonguing and gredetional beds of sendstone, siltstone, end merlstone; contains pyroclestic rocks and a few conglomerete lenses. Forms surfece rock over most of the araa; thins apореciebly westward.	Wetar ranges from 250 to 1,800 mg/l dissolvad solids.	Beds of sendstone ara predominently fine grained and heve low permeebility. Weter moves primerily through frectures. The pert of the member higher then velley floors is mostly dreined. Reportad to yield as much as 100 gpm where tested in tha north-central pert of the basin. Member has not baen thoroughly testad, and larger yields mey be possibla.
			Parachute Creek Member	500–1,800	Keroganaceous dolomitic marlstone (oil shale) end shela; conteins thin pyroclastic beds; fracturad to dapths of et least 1,800 feet. Abundant selina minerals in daeper part of tha basin. The member can ba divided into three zones—high rasistivity, low resistivity or leeched, end Mahogeny (oldest to youngest), which can be correleted throughout besin by use of geophysical logs.	Water rangas in dissolved-solids contant from 250 to about 63,000 mg/l. Below 500 mg/l, celcium is the dominent cetion; above 500 mg/l, sodium is generelly dominent. Bicarbonete is generelly tha dominent enion regerdless of concentretion. Fluoride ranges from 0.0 to 54 mg/l.	High resistivity zone and Mehogeny zone ere raletively impermaebla. Tha leached zona (middle unit) contains water in solution openings and is under sufficient artasien prassura to ceuse flowing wells. Transmissivity renges from lass than 3,000 gpd per ft in tha margins of tha basin to 20,000 gpd par ft in the centar of the basin. Estimeted yields es much as 1,000 gpm. Total wetar in storage in leached zone 2.5 million acre-feat, or more.
			Garden Gulch Mamber	0–900	Pepary end fleky merlstone end shele; contains some beds of oil shele end, locelly, thin bads of sendstona.	Ona weter enelysis indicates dissolved-solids concentration of 12,000 mg/l.	Relatively impermaeble and probebly contains few fractures. Prevents downwerd movement of weter. In the Perechute end Roan Creeks dreineges, springs ere found elong contact with overlying rocks. Not known to yield weter to wells.
			Douglas Creek Membar	0–800	Sendstone, shela, and limestone; contains oölites end ostrecods.	The faw enelyses avelleble indiceta thet dissolved-solids contant renges from 3,000 to 12,000 mg/l. Dominent ions ere sodium and bicerbonete, or sodium and chloride.	Raletively low parmeebility end probebly little fracturad. Meximum yiald is unknown, but probebly less than 50 gpm.
			Anvil Points Member	0–1,870	Shala, sendstone, end merlstone grede within e short distence westwerd into the Douglas Creek, Gerden Gulch, end lower part of the Perechute Creek Member. Beds of sendstone ere fina greined.	The principel ions in the wetar ara generelly magnasium end sulfete. Tha dissolved-solids content renges from ebout 1,200 to 1,800 mg/l.	Sandstone beds have low permeebility. A few wells tepping sendstone beds yield less then 10 gpm. Springs issuing from fractures yield es much es 100 gpm.
		Wesatch Formation		300–5,000	Cley, shela, lenticular sendstone; locelly, beds of conglomerete end limestone. Beds of clay end shele ere the mein constituents of the formetion. Conteins gypsum.	Gypsum contributes sulfete to both surfeca-weter and ground-weter supplies.	Beds of cley end shele ere reletively impermeeble. Bads of sendstona ere poorly parmeeble. Not known to yield water to wells.

This area is drained by Hunter Creek, Fawn Creek, and Black Sulphur Creek and appears to contribute approximately 20% of the flow in Piceance Creek. The alluvium-filled valley bottoms could conduct a maximum of 1,390,000 GPD into the Piceance Creek system. This maximum volume, calculated by using the maximum transmissibility measured in the entire Piceance Creek Basin, would result in a maximum calculated water velocity of 23.2 feet per day in the alluvium aquifer.

The base of the "A" subsystem exhibits a general northeasterly dip (Figure ID-6). This configuration is displayed in cross section in Figure ID-7.

The piezometric surface is presented as Figure ID-8 and the flow directions are displayed as Figure ID-9.

The directional permeability in fracture-type systems can be predicted from an analysis of surface jointing patterns (Ref. ID-8). Analyses made in the EW area show a maximum expected directional permeability parallel with the indicated flow direction.

The maximum calculated volume of flow in the "A" subsystem in the northeast experiment area is 2,000,000 GPD. This assumes a transmissibility of 10,000 GPD/ft, which is probably high since it represents a value of one-half of the maximum value obtained in pumping tests in the "B" subsystem and is about three times the maximum "A" subsystem value recorded in the basin.

The average water-flow velocities calculated, using the above maximum flow volume, are plotted in Figure ID-10. These values range from 0.35 feet per day in the northeast to 0.066 feet per day in the southwest. The values were based upon the gross cross-sectional area of the "A" subsystem, an average effective fractional porosity of 0.01, and no appreciable discharge into the "B" subsystem.

The gross and net thicknesses of the "B" subsystem were developed using logs, DST, and production test data (Figure ID-11). The gross values are reduced by the fraction of the section exhibiting gas shows to obtain nets, since it is believed that the zones showing trapped gas have little or no effective permeability to water flowing in response to the regional hydrologic gradient.

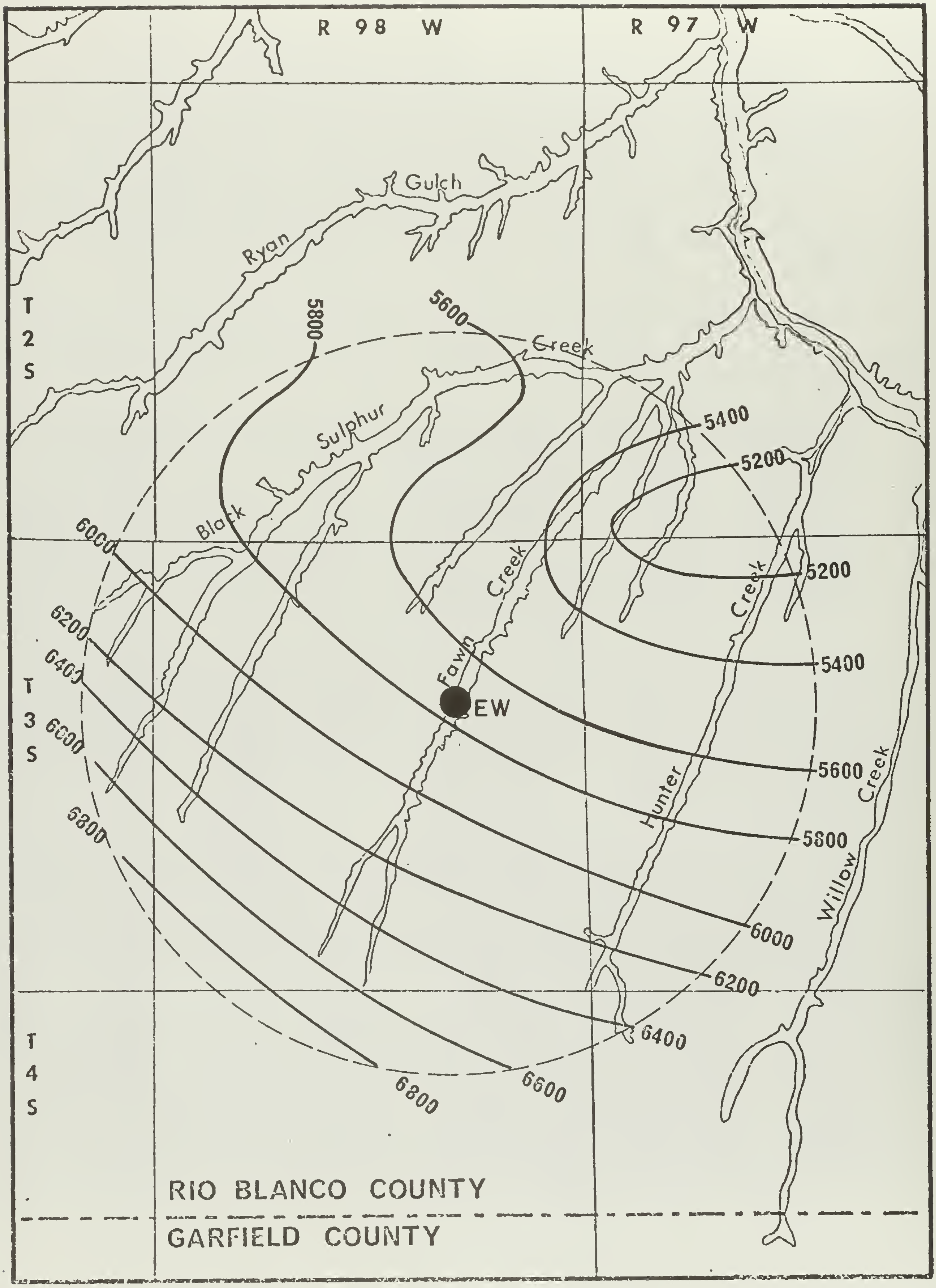


Figure ID-6. Structural map on base of Mahogany zone in Rio Blanco experiment area.

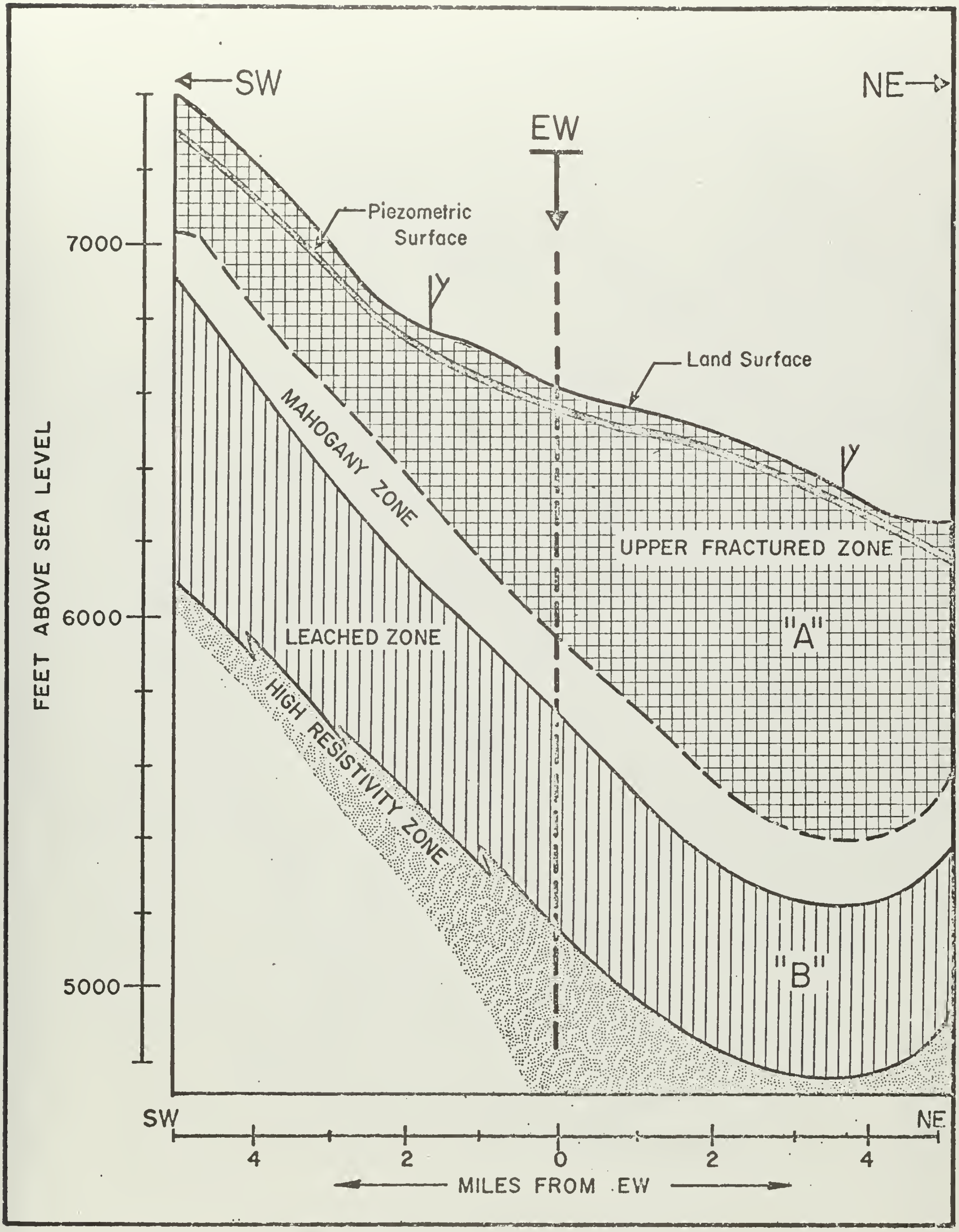


Figure ID-7. Cross section through the EW and parallel with groundwater flow direction, showing dip, gross aquifer thickness, and piezometric surface.

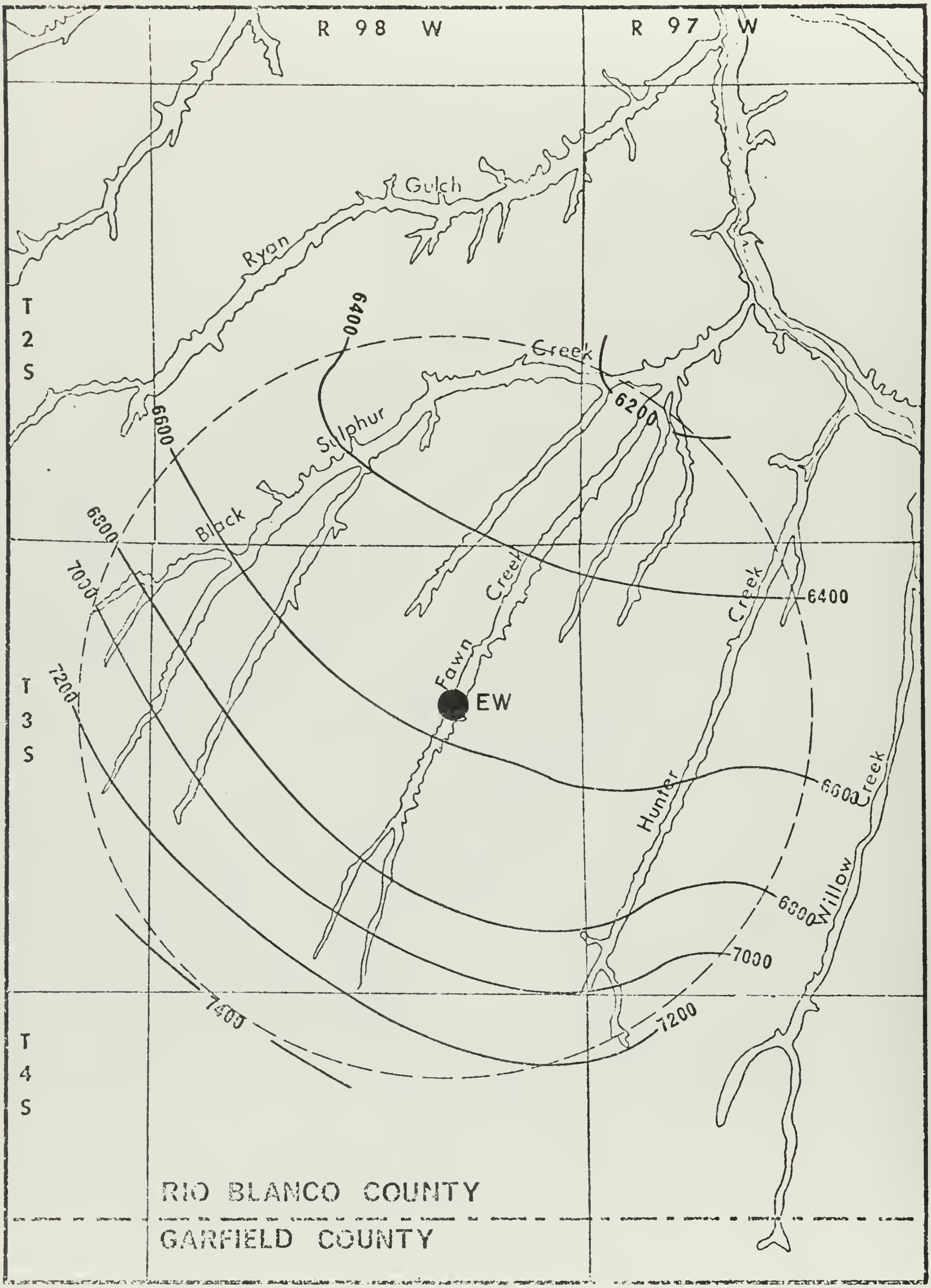


Figure ID-8. Green River fractured zone piezometric surface map in Rio Blanco experiment area.

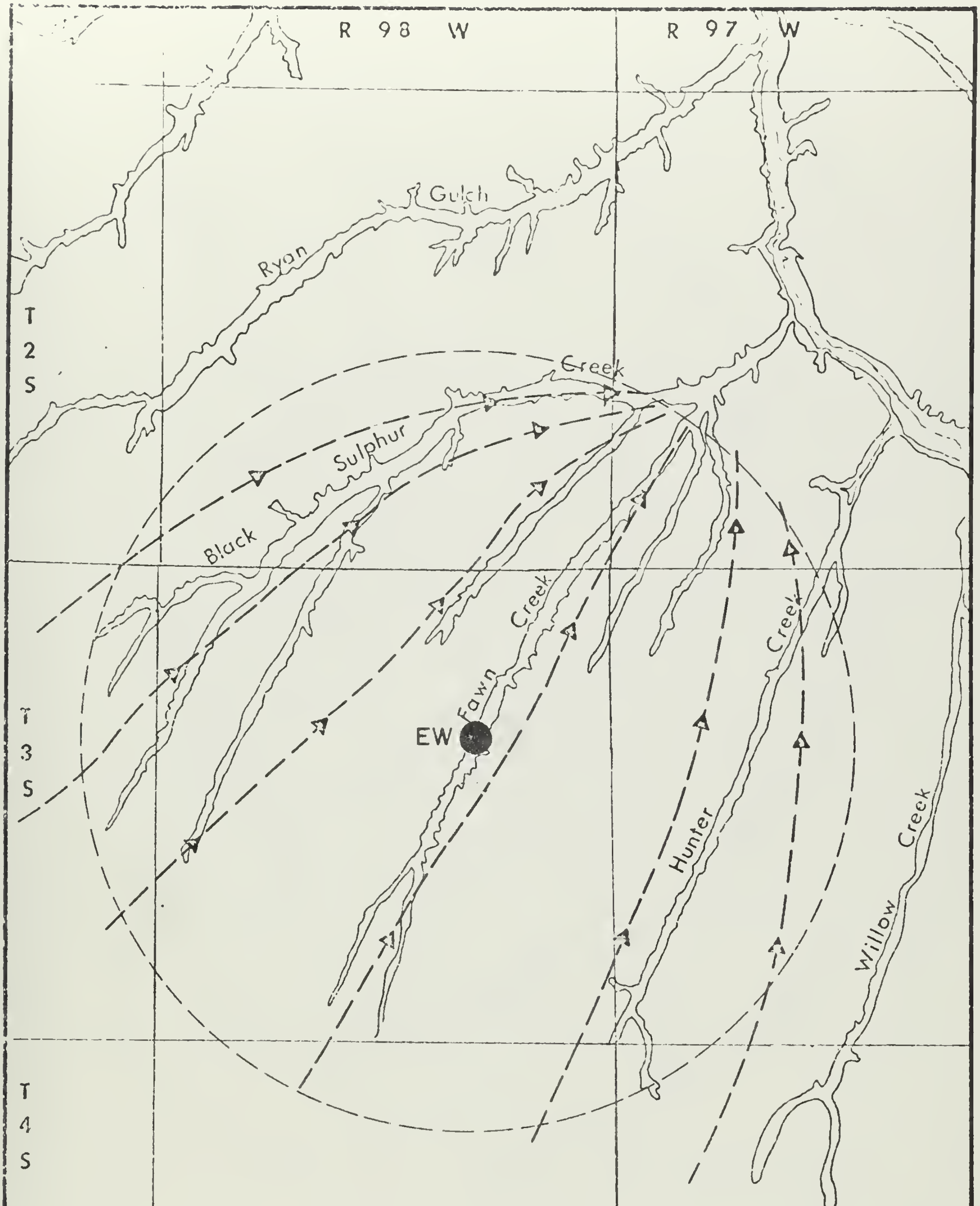


Figure ID-9. Flow directions in fractured Green River aquifer, Rio Blanco experiment area.

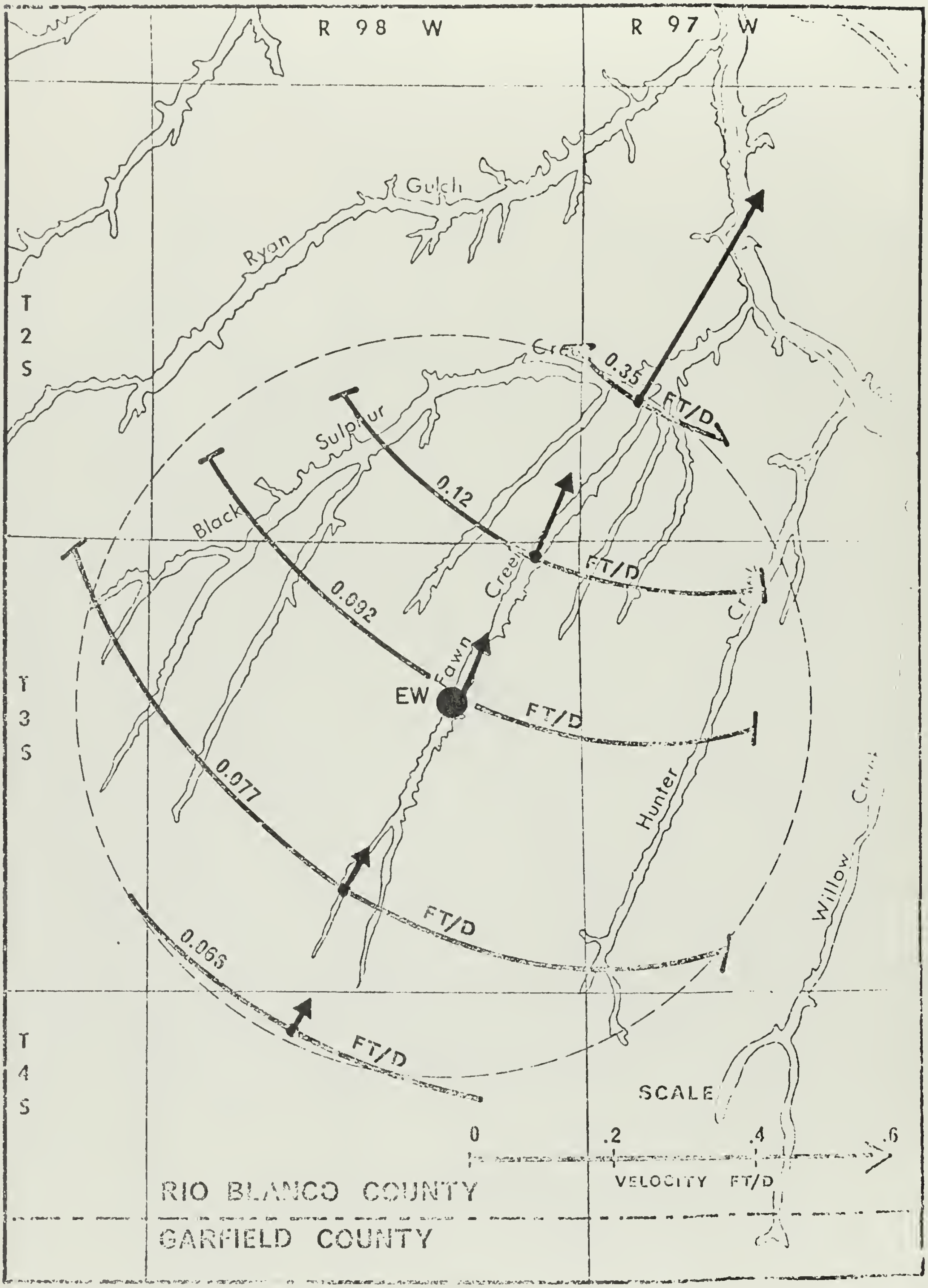


Figure ID-10 Maximum flow velocities in the upper Green River "A" fracture aquifer system. Rates based on a maximum transmissibility of 10,000 GPD/ft and an average porosity of 0.01.

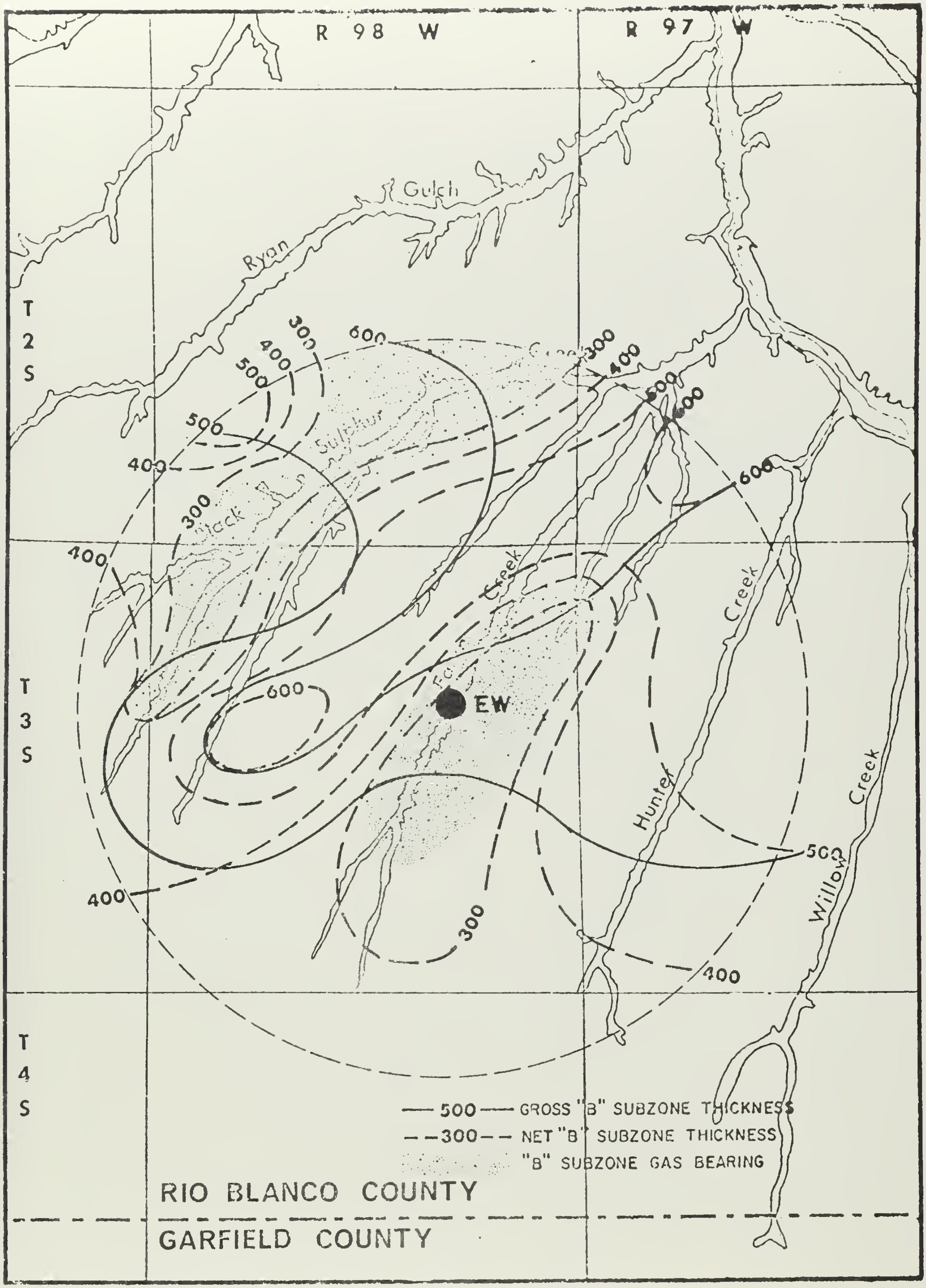


Figure ID-11. Gross and net isopachs of "B" subsystem.

The maximum volume of water flow in the "B" subsystem crossing the northeastern boundary of the five-mile radius circle enclosing the experiment area is 3,470,000 GPD, based upon a maximum transmissibility of 20,000 GPD/ft and the regional hydrologic gradient encountered in the upper Green River fractured zone.

The maximum velocities expected in the "B" subsystem range from 2.4 feet per day in the northeast to 0.72 feet per day in the southwest (Figure ID-12). These velocities were calculated assuming a maximum flow volume of 3,470,000 GPD, an effective fractional porosity of 0.025, and no appreciable recharge from, or discharge into, the "A" subsystem.

The lower Green River has little or no continuity in the experiment area and will not constitute a viable groundwater system. The Wasatch, Fort Union, and Mesaverde present a similar picture.

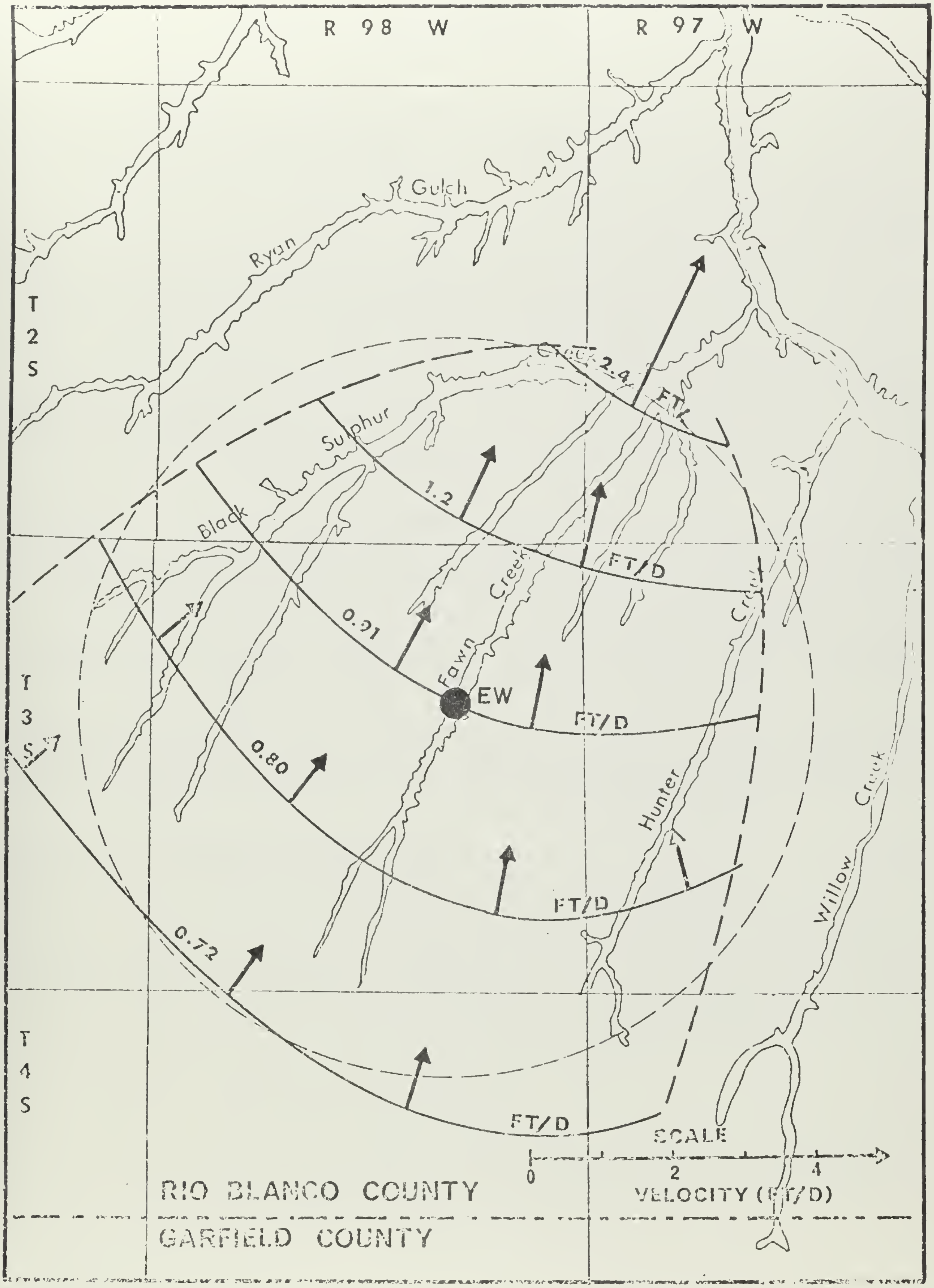


Figure ID-12. Maximum water velocities in "B" subsystem.

REFERENCES

ID-1. Mark, F. A. et al., "Water and Related Land Resources, White River Basin in Colorado," USDA, Economic Reservoir Serivce-Forest Service-Soil, Conservation Service, Denver, Colorado (1966).

ID-2. Coffin, D. L., F. A. Welder, R. K. Glanzman, "Geohydrology of the Piceance Creek Structural Basin between the White and Colorado Rivers, Northwestern Colorado," Colorado Water Conservation Board or USGS, Open File Report (April, 1969).

ID-3 Ege, J. R., R. D. Carroll, and F. A. Welder, "Preliminary Report on the Geology, Geophysics and Hydrology of USBM/AEC, Colorado Core Hole No. 2 Piceance Creek Basin, Rio Blanco County, Colorado," USGS TEI-970 (1967).

ID-4. Coffin, D. L., F. L. Welder, R. K. Glanzman, "Geohydrology Data from Piceance Creek Basin between the White and Colorado Rivers, Northwestern Colorado," Colorado Ground Water Circular 12 (1968).

ID-5. "Project Rio Blanco Structure Inventory," Kenneth Medearis & Associates, Fort Collins, Colorado (1971).

ID-6. Cordez, E. H. "Hydraulic Testing and Sampling of USBM/AEC Core Hole No. 3, Rio Blanco Co., Colorado," USGS Open File Report 289-3 (1969).

ID-7. Trudell, L. G., T. N. Beard, and J. W. Smith, "Green River Lithology and Oil Shale Correlations in the Piceance Creek Basin, Colorado," USBM RI 7357 (1970).

ID-8. Overby, W. K., R. L. Rough, "Prediction of Oil and Gas Bearing Rock Fractures from Surface Structural Features," USBM RI 7500 (April, 1971).

E. SURFACE RESOURCES

1. Soil

a. Introduction

The soil types of the Piceance Basin are in two zones. A zone of the shallow rocky and deep moderately dark upland soils occur in the basin center. It is surrounded by a zone of moderately deep and deep dark-colored upland soils (Ref. IE-1). The locations of these and the other minor types are shown in Figure IE-1. This map was constructed by outlining areas of generally similar soil types. Within these broad divisions, local variations occur that reflect small-scale variations in climate, ground moisture, and bedrock composition.

b. Soil Mapping Unit 3

This unit consists of the shallow rocky and deep moderately dark-colored soils of the uplands. The typical landscape in the Unit 3 area consists of low ridges highly dissected by creeks and their intermittent tributaries. The narrow creek valley floors are covered by alluvium, and the valley walls are steep to very steep rocky slopes. Narrow mesa-like ridges form the divides between the upper reaches of the creek tributaries.

The parent rock materials are limy sandstones and shales, together with reworked valley fill derived from sandstone and shale. Elevations range from 6,000 to 7,000 feet.

c. Soil Mapping Unit 5

This unit consists of the moderately deep to deep, dark-colored soils of the uplands. Most of the unit is at elevations of from 7,000 to 8,000 feet, and the annual rainfall ranges between 15 and 20 inches. The annual mean temperature is about 40° F, and approximately 47 frost-free days per year is typical. The parent rock types for this unit are similar to Unit 3.

d. Other Soil Mapping Units

Soil Units 7 and 8 are the dark-colored soils of the cold, forested mountain slopes, and shallow, dark-colored soils of mountain cliffs and ridges, respectively.

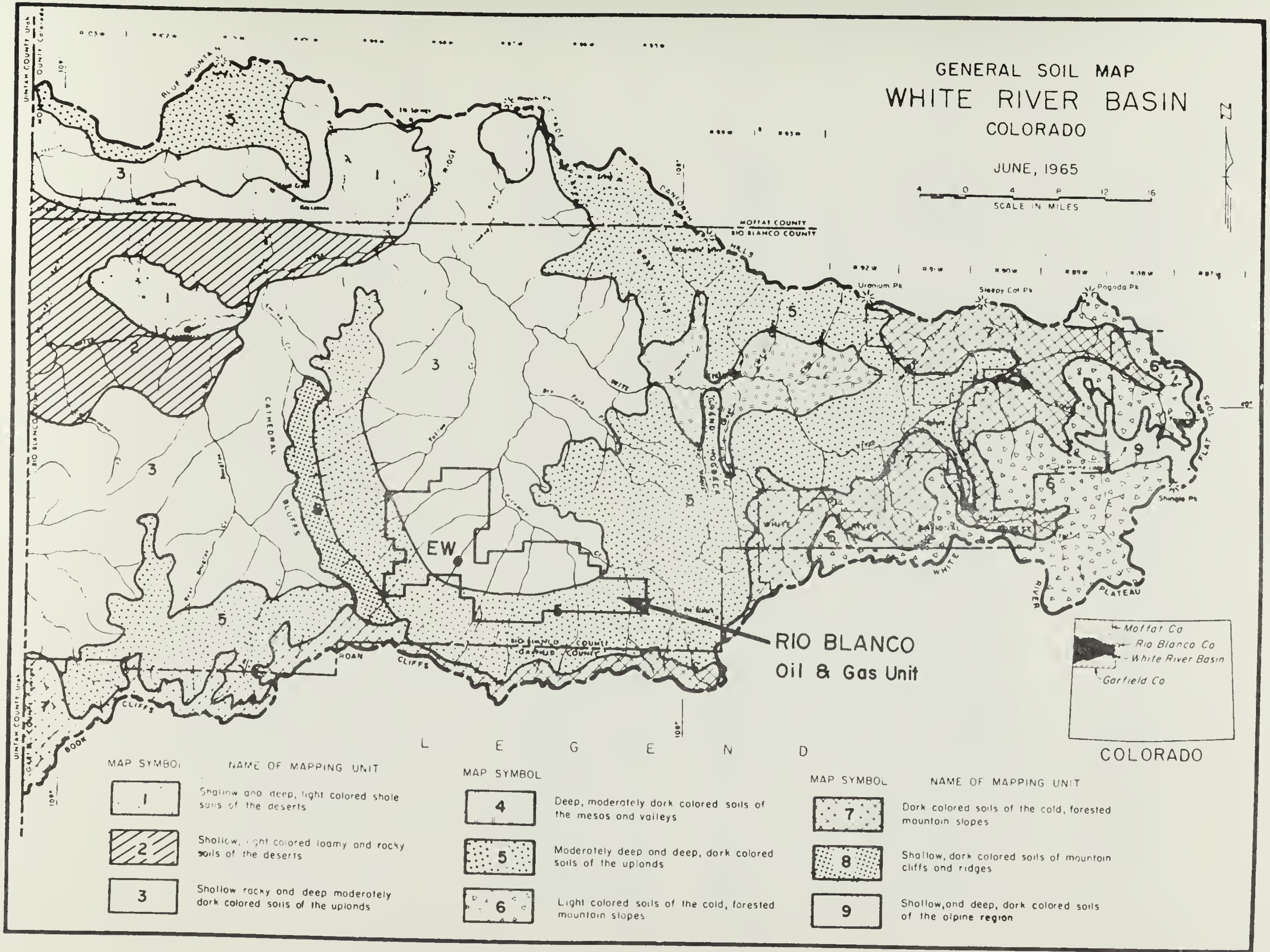


Figure IE-1. Soil map of White River and Piceance basins.

2. Timber

The scattered stands of Douglas fir on the high ground about eight miles south of EW occupy fair to poor timber sites; therefore, these stands are primarily valuable for watershed, wildlife habitat, and recreation (Ref. IE-1). Pinyon pine and Utah juniper are prevalent in the area and are used for firewood and fence posts.

3. Vegetation Communities

The primary sources of existing information utilized for preparation of this section include unpublished data from the CGF&P, Colorado Department of Natural Resources (Ref IE-2), BLM (Ref. IE-3), and aerial photographs obtained from USGS (1967). Additional information concerning the existing vegetational inventory was gathered near the Project Rio Blanco site in March and April, 1971. This effort involved an assessment of the dominant vegetation within a three-mile radius of the EW. It included photographic documentation of vegetation, as well as other features of the natural environment.

Reference is made below to Game Management Unit 22, which encompasses the site and whose boundaries range from 8.5 to 29 lineal miles from the site. Unit 22 was a convenient region for many considerations because considerable information is summarized for the unit (Ref. IE-2). Reference is also made to BLM planning units W-01-09 (Yellow Creek) and W-01-11 (Piceance Basin) for total acreages by vegetation types (Ref. IE-3), and for other information (see Figure IE-2 for the relationship of these planning units to Game Management Unit 22).

a. Major Vegetation Types, Species, and Distributions

Six major vegetation types are described by the BLM for the Yellow Creek and Piceance Basin planning units, which together cover an area which roughly corresponds with Game Management Unit 22 (Ref. IE-3). These vegetation types, dominant plant species within types, and comparative acreages covered by each type are given in Table IE-I. Approximately 60% of the area is dominated by woody shrubs, 36% by pinyon and juniper trees, and less than 3% by broadleaf trees, including quaking aspen. The other types constitute less than 2% of the land area. Thus, over 95% of the land area is dominated by less than a dozen woody shrub species and by pinyon pines and junipers.

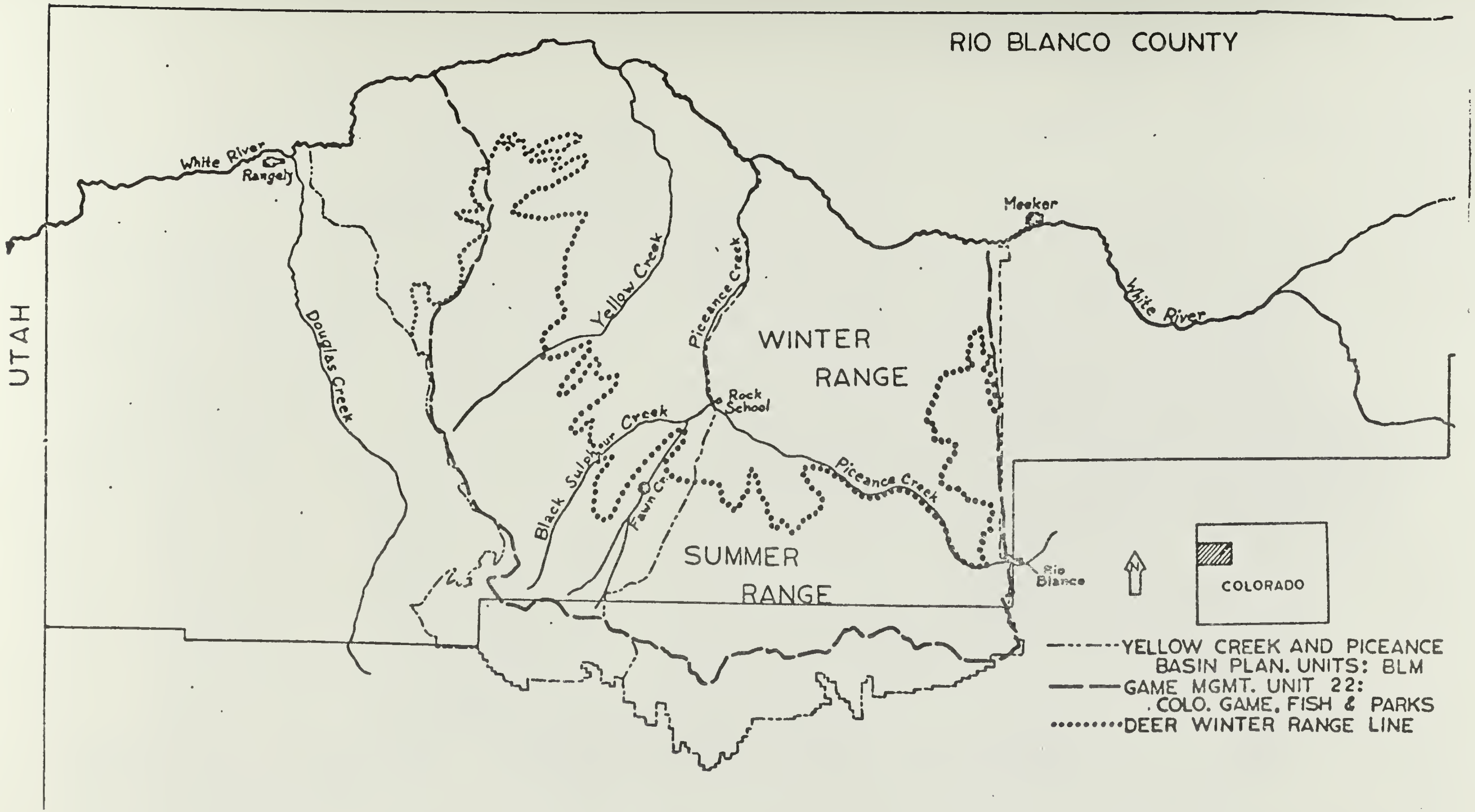


Figure IE-2. Map of the Piceance Creek Basin. Boundaries of the planning units established by the BLM are indicated by light-dashed lines; the Yellow Creek unit occupies the western portion of the basin and the Piceance Basin Unit contains the eastern portion. The boundary of Game Management Unit 22, as used by the CGF&P, is indicated by the heavy-dashed line.

Table IE-I. Vegetation types, major species, and acreages by types within the Yellow Creek and Piceance Basin planning units.*

Vegetation Type	Dominant Species	Acres	Percent of Total
Brush and Shrubs	*Artemisia tridentata* *Chrysothamnus sp.* *Cercocarpus montanus* *Amelanchier sp.* *Quercus gambellii* *Purshia tridentata* *Atriplex sp.* *Sarcobatus vermiculatus*	483,606	60.1
Pinyon-Juniper	*Pinus edulis* *Juniperus scopulorum* *Juniperus osteosperma*	288,040	35.8
Broadleaf Trees	*Populus tremuloides* *Prunus virginiana* *** *Quercus gambellii* *** *Symphoricarpos sp.* ***	21,632	2.7
Conifer	*Pseudotsuga menziesii*	5,407	0.7
Barren	Sparse grasses and forbs	3,596	0.4
Grassland **	*Koeleria cristata* *Agropyron sp.* *Oryzopsis hymenoides* *Stipa sp.*	2,738	0.3
Totals		805,019	100.0

* Area covered in these figures includes BLM planning units W-01-09 and W-01-11 (Ref. IE-3). These planning units cover about 25% more land area than Game Management Unit 22.

** This type includes cultivated and hay meadow land, which probably constitutes less than 5% of the acreage reported for this type.

*** These species are usually more shrub-like than tree-like. They also occur in the "Brush and Shrubs" type.

The distribution of vegetation community types within the Yellow Creek and Piceance Basin planning units is preimarily dependent upon elevation, slope exposure, and soil characteristics. Woody shrubs occur over most of the planning unit; however, the distributions of certain species are limited to certain environments. For example, salt brush (Atriplex sp.) and greasewood (Sarcobatus vermiculatus) are primarily restricted to bottomlands at lower elevations, whereas Gambel oak (Quercus gambellii) and serviceberry (Amelanchier sp.) are most predominant on sloping terrain at the higher elevations. Sagebrush (Artemisia tridentata) and rabbitbrush (Chrysothamnus sp.) together are predominant in bottomland at mid-higher elevations, but sagebrush also occurs rather extensively on slopes and ridges. Nearly pure stands of rabbitbrush frequently occur on abandoned bottomlands which were once cultivated or otherwise disturbed.

The pinyon (Pinus edulis)-juniper (Juniperus scopulorum; J. osteosperma) type occurs on ridges and slopes over most of the region but is more predominant at the lower mid-elevations. Juniper occurs more frequently than pinyon as elevation increases. Aspen (Populus tremuloides) and Douglas fir (Pseudotsuga menziesii) are primarily restricted to north-facing slopes at the higher elevations and cover only a small percentage of the Yellow Creek and Piceance Basin planning units.

Vegetation within a one-mile radius of the site is displayed by an aerial photograph (Figure IE-3). It is evident that the pinyon-juniper type is dominant on the ridges and slopes near the EW site, while the sagebrush-rabbitbrush type dominates the bottomland along Fawn Creek and the small ravines leading into it. Sagebrush stands, dotted with juniper, occupy several upland parks along the slopes and ridges. The steep, southeast-facing slopes and bluffs are dry, rocky, and semi-barren of vegetation.

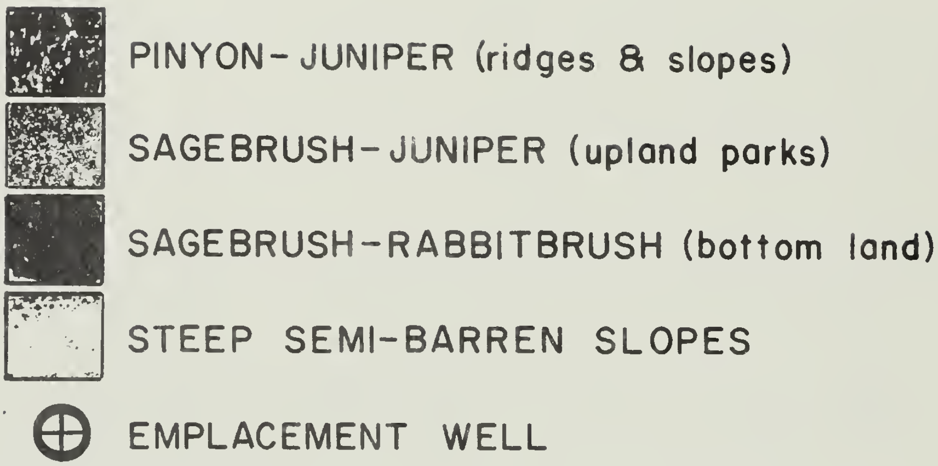
A partial check list of plant species which occur within Game Management Unit 22 near the Little Hills Experiment Station is given in Ref. IE-2. The check list shows four tree, 23 shrub, 86 forb, and 20 grass or sedge species listed, although most of the plant species which it lists are not particularly dominant. It is probable that nearly all of these species occur within a three-mile radius of the project site. Two species observed along Fawn Creek in moist habitats, which are not listed in Ref. IE-2, are willow (Salix sp.) and narrow-leaf cottonwood (Populus angustifolia). These species were observed both upstream and downstream from the site, but their occurrence in the general area is negligible, with the exception of water courses.

b. Ecological Aspects of the Native Vegetation

The natural vegetation in the environs of Project Rio Blanco forms the food base for all forms of terrestrial wildlife, and also to some extent for domestic cattle and sheep. In addition, the native vegetation provides shelter, modifies the micro-climate, and provides other benefits, both direct and indirect, for the wild animals of the region. The woody shrubs and herbaceous plants are particularly important as a source of food for the mule deer, which is the most important wildlife species in the region. The mature pinyon-juniper community provides less food for deer than do the shrub and herbaceous communities, but it provides necessary shelter from weather, hunters, and predators.

The native vegetation has been manipulated for many years in various locations for agricultural purposes. For example, several large stands of pinyon-juniper and some stands of sagebrush have been chained (i. e., uprooted by means of a heavy chain strung between two bulldozers) or sprayed in an effort to stimulate the growth of grasses and forbs which are preferred for livestock grazing (Ref. IE-3). These and other methods, such as burning and plowing, have been utilized in Unit 22, as well as elsewhere in the western states, to convert pinyon-juniper and shrub communities to grassland (Ref. IE-4). The general effect of these practices is to convert a mature plant community to an early successional stage. According to unpublished data provided by the CGF&P, 12,441 acres of pinyon-juniper and 628 acres of sagebrush have been chained within Unit 22. Approximately 1,480 acres of sagebrush and browse have been sprayed, burned, plowed, or harrowed within the unit.

Detailed data on plant succession in the major vegetation types of the study area were not found; however, discussions with persons who have observed successional changes following various kinds of disturbance in Game Management Unit 22, revealed some general patterns (Ref. IE-5). Major disturbance (e. g., clear-cutting, fire, chaining, spraying, etc.) to the pinyon-juniper or shrub communities can be expected to result in a cover consisting primarily of herbaceous forbs (weeds) and a few grass species the first few years following the disturbance. During the next few years, grasses begin to predominate with ricegrass



Legend for Figure IE-3. Aerial photograph (opposite page) showing the EW site for Project Rio Blanco and surrounding vegetation and physiographic patterns. Legend (above) indicates the vegetation community types. Photos by USGS (1967).

Figure IE-3.

(Oryzopsis hymenoides) being one of the dominant grasses which seeds naturally (Ref. IE-3). Wheatgrass (Agropyron sp.) is sometimes successfully seeded following chaining. Perhaps three to ten years following the disturbance, the appearance of woody shrubs can be expected (Ref. IE-6). Judging from once-cultivated pastures and abondoned homesteads along Fawn Creek, bottomland frequently tends to succeed to dominant stands of rabbitbrush after several years. There seems to be general agreement that restoration of pinyon-juniper woodland following a disturbance would take a very long time, perhaps from 50 to several hundred years. The specific pattern and timing of plant succession would undoubtedly vary, depending upon weather patterns, soil, original vegetative composition, grazing pressure (Ref. IE-5) and other factors.

4. Wildlife

The following description of wildlife resources is based largely upon information provided by the CGF&P (Ref. IE-2). Information from this source pertains to Game Management Unit 22, which encompasses nearly 1,000 square miles and covers much of the Piceance Creek Basin (Figure IE-2). Inasmuch as the EW site for Project Rio Blanco is located well within the boundaries of Unit 22, wildlife information from this unit is largely applicable to the site and environs. Additional information on wildlife resources, specific to the area within a three-mile radius of the project site, was gathered during March and April, 1971 and is included in this report.

This description of wildlife resources is restricted to mammals, birds, and fishes, and therefore excludes many other animal groups such as reptiles, amphibians, arthropods, annelids, and protozoa. Exclusion of these groups results primarily from a lack of information, not from any minimization of their importance in the ecosystems of the region. Some information on aquatic invertebrates, however, does exist (Ref. IE-7).

a. Big Game Animals

(1) Mule Deer

The Rocky Mountain mule deer (Odocoileus hemionus) is by far the most abundant big game animal in the region and is of prime importance from an economic as well as an ecological viewpoint. The mule deer of the Piceance Creek

Basin constitute the "Piceance Creek herd," which is believed to be one of the largest recognizable deer herds in North America.

A completely reliable census does not exist for the deer herd; however, an index to abundance is made each spring by CGF&P when animals enter meadows along the stream bottoms to feed on new pasture growth. The number of deer counted in a single evening along a 50-mile stretch of road ranged from a high of 9, 876 in 1947, to a low of 2, 153 in 1966, and up to 4, 626 in 1970 (Ref. IE-2). Although yearly fluctuations are significant and counts are subject to numerous variables, the data suggest a decline in numbers over the past 20 years. During April, 1971, deer were abundant along Fawn Creek, particularly from the project site downstream, and it was possible to see in excess of 150 animals between the EW site and Black Sulphur Creek (5. 5 miles) in evening or early morning. Aerial counts made on Yellow Creek during the winter of 1968 resulted in an estimate of 52 deer per square mile (Ref. IE-5). This estimate is probably applicable to the site environs during periods of maximum densities of deer.

The distribution of deer in Game Management Unit 22 is largely dependent upon seasonal and associated climatic conditions. In winter, the deer occupy the lower elevations of the unit, where snow accumulations are minimal and browse is available. In summer, some deer occupy the higher elevations in the south and west portions of the unit, while some migrate to the White River National Forest which covers higher elevations to the east of the unit. An approximate line dividing summer and winter ranges in the unit is shown in Figure IE-2; however, the winter line probably varies from year to year. The location of the project site is near the winter line, and it is possible for some deer to occupy the area during any month. However, maximum numbers of deer might be expected in spring, when animals are following the snow-line toward the higher elevations, and again in fall when animals are being forced toward lower elevations by accumulating snows. Deer are probably present, but scarce, in mid-summer and mid-winter at the site.

Most of the Piceance Creek Basin provides excellent deer habitat, particularly winter range, which is often a major factor regulating deer populations. Deer are dependent upon many features of the environment, including forage, water, cover, and certain relationships to other animals such as parasites, predators, and herbivorous competitors. Since deer are mostly browsing animals, shrub species are usually predominant in their diet during much of the year. Shrubs, such as mountain mahogany (Cercocarpus montanus), serviceberry (Amelanchier sp.), bitterbrush (Purshia tridentata), Gambel oak (Quercus gambellii), sagebrush (Artemisia tridentata), and several others, are probably of major importance for food within Unit 22. It is of considerable interest that deer utilize the hay meadows rather heavily for several weeks in April and May. It is not known whether these meadows are essential for the present herd or whether the meadows merely attract deer because they green up earlier than natural foraging areas.

The rather low, rounded ridges near the project site are primarily covered by a mixture of pinyon pine (Pinus edulis), Utah juniper (Juniperus osteosperma), and Rocky Mountain juniper (Juniperus scopulorum). Although mature stands of these trees preclude significant understory growth of grasses or shrubs, they provide, along with the many small ravines, excellent and probably necessary cover for deer. The topographic features of many small ridges, ravines and gulches in the region of the site result in a complex mosaic of vegetation types that provide both food and cover in close proximity. The numerous ridges also provide south-facing slopes that are warmer and therefore preferred during cold periods, and cooler north-facing slopes which are useful to deer during warm periods. Many of the gulches have permanent or intermittent creeks that provide water.

Predation and hunting are other factors which serve to regulate population densities of deer. Prior to heavy use of the region by humans, mountain lions (Felis concolor), bobcats (Lynx rufus), and coyotes (Canis latrans) were probably much more numerous than at present and served the beneficial function of maintaining deer herd vigor through selection and regulation of numbers. At present lions still roam the area, but their numbers are probably small. Coyotes are still considered enemies by ranching interests, and several methods are used to control these animals.

(2) Elk, Black Bear, and Lion

Elk (*Cervus canadensis*), black bear (*Ursus americanus*), and mountain lion (*Felis concolor*) occur in Unit 22; however, none of these species appear to be very abundant. These animals are seen only occasionally, and hunter harvest data further suggest sparse populations.

In winter, elk may be found throughout most of Unit 22, but highest densities apparently occur in the northeastern and northwestern sections. In summer, elk primarily occupy the higher portions of the Roan Plateau, which includes the southern boundary of Unit 22 and also the headwaters of east Fawn Creek.

Black bears appear most likely to occupy the higher elevations along the southern boundary of the unit, as well as Kendall, Segar, and Joe Bush mountains in the unit's northeast corner. This distribution is suspected to exist throughout the year.

Mountain lions are suspected to be most numerous in the north and west portions of Unit 22, although it is likely that they roam over the entire unit. It seems logical to assume that their seasonal distributions would correspond reasonably well with those of deer and domestic sheep.

Compared to mule deer, the economic value of elk, bear and lion in this unit is probably negligible. It is possible, however, that some hunters visit this unit as opposed to others on the chance of bagging one of these other game animals.

Since numbers of elk, bear, and lion are very low in Unit 22, these animals probably do not exert a major influence on the ecology of the area, except perhaps in isolated cases. Elk bands could have some impact on specific isolated stands of vegetation, and predation upon deer and livestock by lions has been documented. The present and anticipated use of this region by humans essentially precludes any major increases in the importance of elk, black bear, or lion.

b. Small Game Animals

(1) Mammals

Small mammals classified as "game" in Unit 22 include the cottontail rabbit (Sylvilagus audubonii and S. nuttallii), the snowshoe hare (Lepus americanus), and the pine squirrel (Tamiasciurus hudsonicus). Specific information on the abundance of these species is lacking for Unit 22, although it has been suggested that densities of 150-200 cottontail rabbits per square mile and 125 snowshoe hares per square mile should be applicable to areas of suitable habitat in the unit (Ref. IE-2).

Cottontail rabbits are probably distributed rather generally throughout Unit 22 where sufficient herbaceous vegetation and shrubs occur. Numerous cottontails were seen along Fawn Creek in April and May, 1971, and a few were seen within 0.5 miles of the project site. Snowshoe hares are probably most abundant at the higher elevations along the southern and western boundary of Unit 22. Pine squirrels are probably scattered throughout those portions of the unit that support stands of coniferous trees, particularly Douglas fir.

Food, predation, and disease are probably major factors determining numbers of these small game mammals.

(2) Upland Game Birds

Upland birds classified as "game" in Unit 22 include the blue grouse (Dendragapus obscurus obscurus), sage grouse (Centrocercus urophasianus urophasianus), ring-necked pheasant (Phasianus colchicus), chukar partridge (Alectoris graeca), band-tailed pigeon (Columba fasciata fasciata, and mourning dove (Zenaidura macroura marginella). Although each of these species is believed to occur in the unit, none are particularly abundant.

Relatively small populations of sage grouse occur on Cathedral Bluffs, on 84 Mesa on Yellow Creek, and in a few other locations. Blue grouse occur in the Douglas fir and aspen stands on the Roan Plateau, the Cathedral Bluffs, and on isolated, timbered, northfacing slopes elsewhere in Unit 22. Pheasants are believed to occur only along meadows adjacent to the White River near its confluence with Piceance Creek. Chukar partridge have been introduced at various sites in Unit 22 since 1955 (Ref. IE-2). However, the success of these plantings has not been carefully evaluated, and the present status of this bird is not known. Band-tailed pigeons occasionally traverse Unit 22, but it is not known whether they breed or winter in the area. Mourning doves apparently breed throughout most of the unit but do not winter there. The area within a three-mile radius of the project site does not appear to be important for any of these upland game birds at present.

(3) Migratory Waterfowl and Shorebirds

Twenty-seven species of migratory waterfowl and shorebirds are listed for Game Management Unit 22 (Ref. IE-2). Winter populations of about 300 ducks for the unit have been estimated; whereas spring, summer and fall populations may exceed 1,000 ducks (Ref. IE-2). Piceance Creek and its tributaries afford most of the waterfowl habitat in the unit, and one estimate suggests approximately 17 ducks per lineal mile of stream during maximum summertime densities.

During winter, the partially ice-free portions of Piceance Creek and tributaries provide habitat for mallards, green-winged teal, common golden-eye, and common merganser. Streams and ponds provide breeding territory for a resident flock of mallards and green-winged teal. Some migrants, including gadwalls, cinnamon teal, and blue-winged teal also breed in the unit. Rio Blanco Lake and White River also provide a breeding-resting area for these species--also for the American coot, pintail, and the Great Basin Canada goose.

During April, 1971, mallards were seen on Fawn Creek, and mallards, redheads, common golden-eyes, green-winged teal and cinnamon teal were observed along Piceance Creek and on the numerous small ponds and springs in the area. During May, 1970, common Canada geese were observed feeding in irrigated fields along Piceance Creek.

Resident waterfowl need protected, vegetated stream and pond banks for successful nesting; hence some breeding areas need protection from grazing. Availability and abundance of suitable surface waters no doubt affect the number of both resident and migratory flocks using the region.

c. Non-Game Animals

(1) Mammals

Many species of mammals occur in Unit 22, including representatives of the orders Insectivora (moles and shrews), Chiroptera (bats), Lagomorpha (hares and rabbits), Rodentia (rodents), Carnivora (carnivores), and Artiodactyla (even-toed hoofed mammals). A list of 26 species of fur-bearing and non-game mammals for the unit (Ref. IE-2) is mainly restricted to the larger animals and many obscure, but possibly abundant, species are not listed. A more complete listing of mammals that could occur in Unit 22 exists (Ref. IE-8). The only non-game mammals noticed during surveys in March and April, 1971, were the coyote (*Canis latrans*), the yellow-bellied marmot (*Marmota flaviventris*), and the muskrat (*Ondatra zibethicus*).

Essentially no information is available on the abundance, distribution, ecology, or economic importance of non-game mammals within the inventory area. Though inconspicuous to humans, small mammals may consume large quantities of natural and cultivated vegetation and, in turn, support significant numbers of predatory birds and mammals. Hawks and owls were particularly conspicuous during March and April, 1971, presumably indicating an abundance of small mammals.

It is interesting that wild horses roam over portions of Unit 22 in apparently small but increasing numbers. Wild horses are not protected by law in Colorado at present, but considerable controversy exists concerning their welfare. Unit 22 is one of the few areas of Colorado known to support wild horse populations. It is doubtful whether these animals are sufficiently numerous to have a significant ecological impact.

(2) Birds

A diverse array of non-game birds apparently occurs in Unit 22. The possible occurrence of 225 non-game avian species, including 24 Raptores, has been noted (Ref. IE-2).

Some of the common non-game birds sighted along Fawn Creek in March and April, 1971, included the black-billed magpie (*Pica pica hudsonia*), common raven (*Corvus corax sinuatus*), mountain bluebird (*Sialia currucoides*), killdeer (*Charadrius vociferus vociferus*), red-winged blackbird (*Agelaius phoeniceus fortis*), robin (*Turdus migratorius propinquus*), starling (*Sturnus vulgaris vulgaris*), red-tailed hawk (*Buteo jamaicensis calurus*), and great-horned owl (*Bubo virginianus*).

Specific information on the quantitative abundance, distribution and ecology of the non-game birds as might be pertinent for documentation prior to Project Rio Blanco was not found. The relatively large numbers of scavengers (magpies and ravens) and Raptores (hawks, and owls) seen in March and April, 1971, however, were impressive.

d. Game Fish

Sport fishing within Unit 22 is very limited (Ref. IE-2). The predominant fish species in Piceance Creek (and presumably its tributaries) are the mountain sucker (*Pantosteus platyrhynchus*) and the speckled dace (*Rhinichthys osculus*), neither of which are considered sport fishes (Ref. IE-7). Sport fishes occurring in Piceance Creek, primarily in the upper 4.8 kilometers of permanent water, include the rainbow trout (*Salmo gairdneri*) and brook trout (*Salvelinus fontinalis*). Another sport fish, the mountain whitefish (*Prosopium williamsoni*) also occurs occasionally in Piceance Creek, along with five other species (Ref. IE-7). The same species plus the brown trout (Salmo trutta), channel catfish (Ictalurus punctatus), and Colorado squaw fish (Ptychocheilus lucius) probably occur in the White River which borders the northern boundary of Unit 22.

Rainbow trout are stocked by the CGF&P in Stake Springs on Yellow Creek, Ryan Ponds, near the confluence of Ryan and Piceance Creeks, Foot Pond, near the confluence of Dry Fork and Piceance Creeks, and the Little Hills Pond at the Little Hills Experiment Station.

The upper reaches of several tributary streams of Piceance Creek may harbor trout, but no documentation of this was found, with the exception of Fawn Creek at the project site. On April 4, 1971, several small trout were observed in Fawn Creek in the immediate vicinity of the project site. One, caught by rod and reel, was a brook trout measuring eight inches in length.

It is possible, although not documented, that the native cutthroat trout (Salmo clarki pleuriticus) of the Colorado Green River Basin may exist within Unit 22, since Piceance Creek flows into the White River which, in turn, flows into the Green River (Ref. IE-9). This species is considered to be rare and endangered.

The most careful study located on the aquatic biology of Unit 22 was a thesis on the biota and chemistry of Piceance Creek (Ref. IE-7). This document contains considerable information on aquatic invertebrates and water quality.

REFERENCES

IE-1. Mark, F. A., et al., "Water and Related Land Resources, White River Basin in Colorado," Colorado Water Conservation Board and U. S. Dept. of Agriculture, Denver, Colorado (November, 1966).

IE-2. Bertram, B. D., W. T. McKean, H. M. Swope, S. Steinert, R. M. Bartman, C. W. Pieckert and C. Sealing, Fort Collins, Game Management Unit 22, Colorado Game, Fish and Parks Division, Dept. of Natural Resources (unpublished data). Printed as Appendix E, Vol. II, "Biological/Ecological Considerations for Project Rio Blanco," Colorado State Univ., Fort Collins, Colorado (June, 1971).

IE-3. Colby, Stanley G., Area Manager, BLM, "Resource analysis of the Yellow Creek Planning Unit W-01-09, and Resource analysis of the Piceance Basin Planning Unit W-01-11, White River Resource Area, Meeker, Colorado," (unpublished). Printed as Appendix A, Vol. II, "Biological/Ecological Considerations for Project Rio Blanco," Colorado State Univ., Fort Collins, Colorado (June, 1971).

IE-4. Aro, R. F., "Evaluation of Pinyon-Juniper Conversion to Grasslands," J. of Range Management, 24.3, pp. 188-197 (1971).

IE-5. McKean, W. T., B. D. Baker, and A. E. Anderson, Colorado Game, Fish, and Parks Division (personal communication).

IE-6. McCulloch, C. Y., "Some Effects of Wild Fire on Deer Habitat in Pinyon-Juniper Woodland," J. of Wildlife Management, 33, pp. 778-784 (1969).

IE-7. May, Bruce E., "Biota and Chemistry of Piceance Creek," (thesis), Colorado State University, Fort Collins, Colorado (May, 1970).

IE-8. Lechleitner, R. R., "Wild Mammals of Colorado," Pruett Publishing Company, Boulder, Colorado (1969).

IE-9. Behnke, R. J., "Progress Report: Cutthroat Trout of Rio Grande and Colorado River Basins," Cooperative Fishery Unit, Colorado State University, Fort Collins Colorado, (unpublished). "Rare and Endangered Species Report: The Native Cutthroat Trout of Colorado Green River Basin" (unpublished).

F. SUBSURFACE RESOURCES

1. Introduction

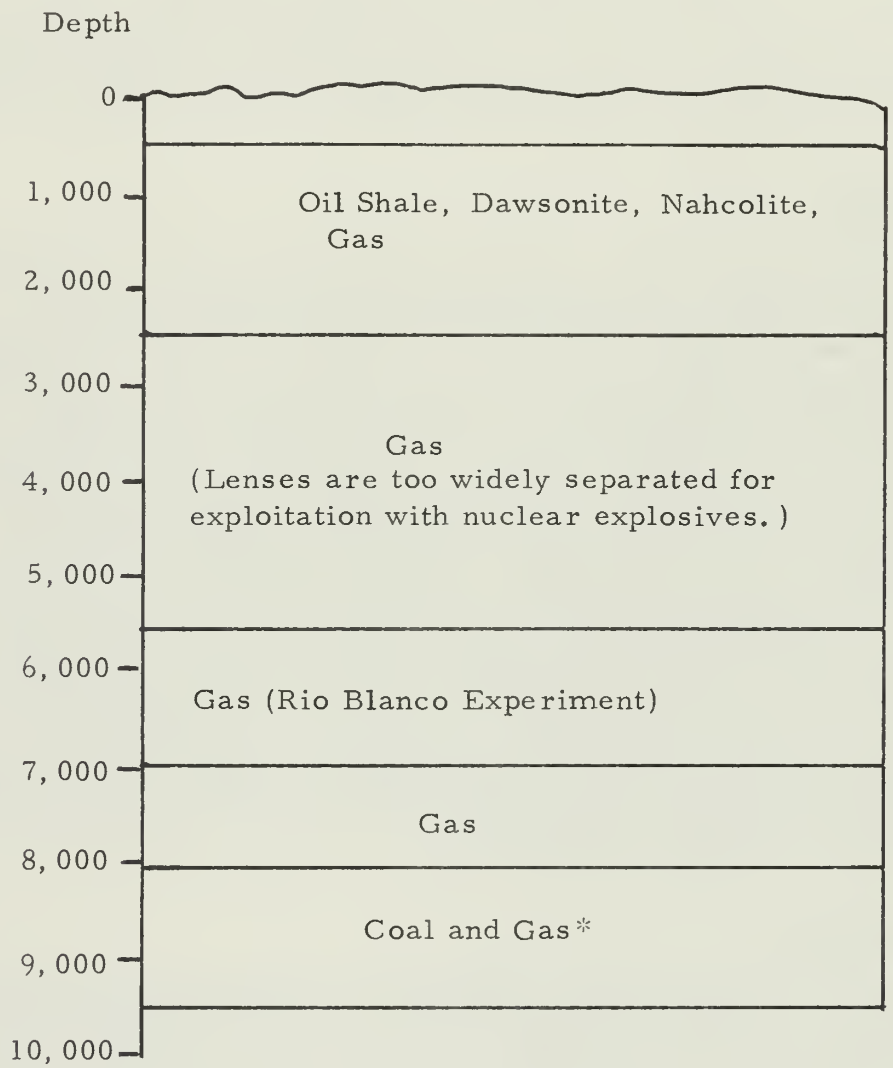
Substantial subsurface mineral resources are known to exist throughout the proposed unit area. These include oil shale, gas and oil, nahcolite and dawsonite, and coal. The approximate vertical distribution of these minerals, which are discussed below, is illustrated in Figure IF-1.

2. Oil Shale

Oil shale deposits occur throughout the proposed unit area in the Green River Formation. The distribution of the richest zone, as determined from a basin-wide study (Ref. IF-1), is shown in Figure IF-2. As indicated in this figure, the maximum thickness of continuous section, averaging 25 gallons of oil per ton, would be expected to be about 700 feet. Assays of the Fawn Creek Government Number 1 Well rotary cuttings (Ref. IF-1) indicate, however, that the continuous 24 gallons per ton oil shale is about 330 feet thick in this area. Based upon these measurements, it is expected that a relatively continuous oil shale section, with a minimum grade of ten gallons per ton, exists between the depths of approximately 550 and 1,730 feet. Below this section, discontinuous zones of oil shale greater than ten gallons per ton are expected to a depth of approximately 2,400 feet. From 2,400 feet to the base of the Green River Formation, oil yields are expected to be insignificant (generally less than three gallons per ton). The oil shales in the vicinity of the EW are estimated to contain more than 1.6 billion barrels of oil per section (Ref. IF-1).

3. Gas and Oil

In addition to that which is expected to be produced from the Fort Union and Mesaverde I formations as a result of this program, potentially commercial deposits of gas occur in sands of the Green River and Wasatch formations and the lower portion of the Mesaverde Formation. Noncommercial amounts of oil have been found to occur in the Green River, Wasatch, Fort Union, and Mesaverde formations within the proposed unit.



* Possibly exploitable with nuclear explosives.

Figure IF-1. Generalized subsurface distribution of resources.

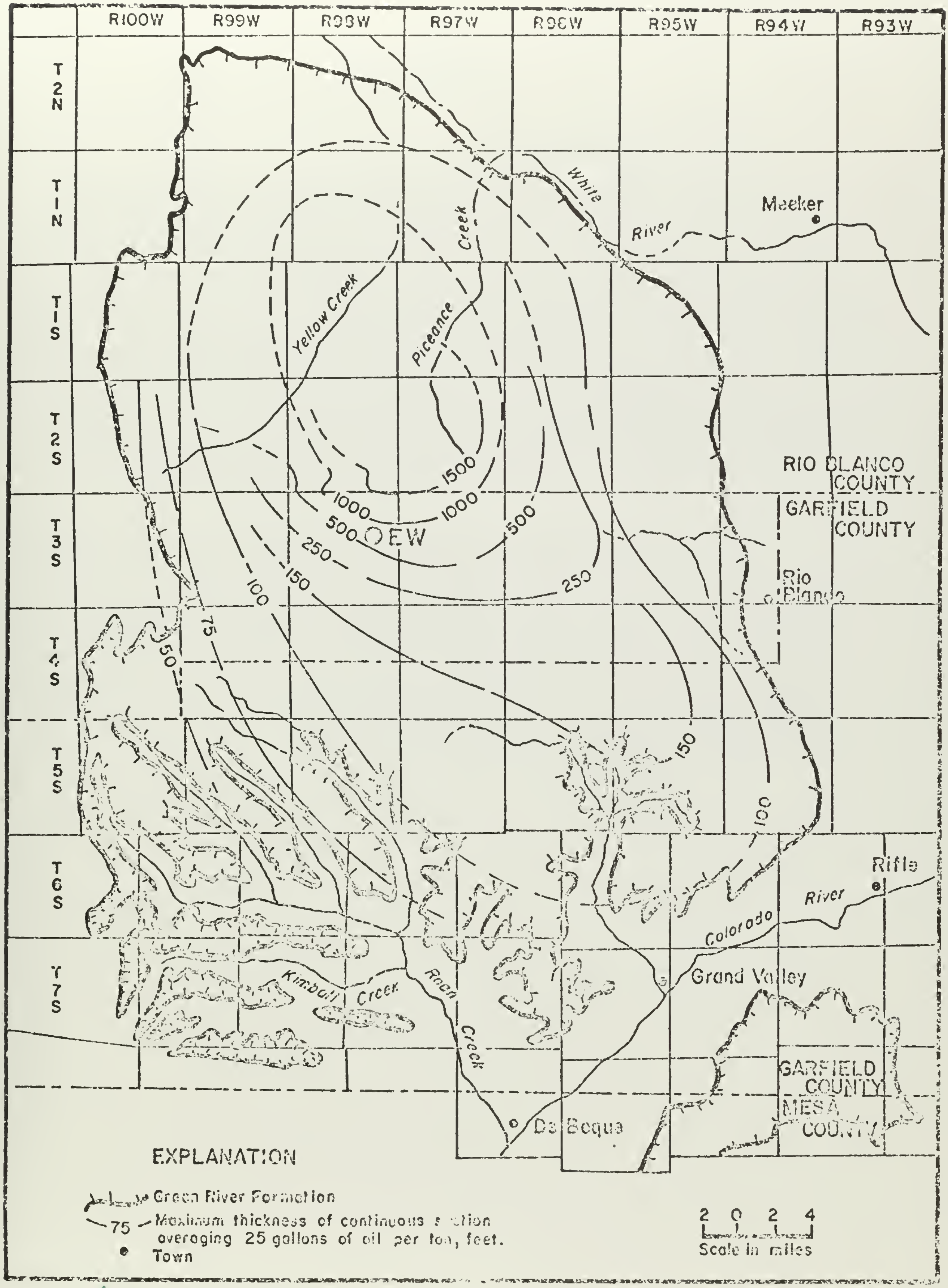


Figure IF-2. Isopachous map of 25-gallon-per-ton oil shale, Piceance Creek Basin, Colorado.

4. Nahcolite and Dawsonite

These minerals are potential raw materials for producing aluminum and soda ash. Nahcolite ($NaHCO_3$) occurs as irregularly radiating crystal aggregates, single crystals, and in thin beds in the lower portion of the Parachute Creek Member of the Green River Formation. Dawsonite ($NaAl(OH)_2CO_3$) occurs as very fine-grained crystals within, above, below, and alongside the nahcolite-rich zone (Ref. IF-2). Savage and Bailey (Ref. IF-3) estimated that the potential resources of each square mile in the central part of the basin are approximately 126 million tons of soda ash from dawsonite and nahcolite and 42 million tons of alumina from dawsonite.

5. Coal

Beds of coal (inches to several feet thick) are found predominately in the lower portions of the Mesaverde Formation; however, these coal seams also occur in the Fort Union and Ohio Creek formations. Based upon the description of the rock fragments recovered during drilling of Fawn Creek Government Number 1 Well, isolated zones of lignite may occur in the Mesaverde Formation at a depth of about 7,000 feet. (Refer to Figure IB-3, which identifies the appropriate depths of the Mesaverde Formation throughout the area of interest.)

REFERENCES

IF-1. Stanfield, K. E., J. W. Smith and L. G. Trudell, "Oil Yields of Sections of Green River Oil Shale in Colorado, 1957-63," USBM RI-7051 (December, 1967).

IF-2. Hite, R. J. and J. R. Dynl, "Potential Resources of Dawsonite and Nahcolite in the Piceance Creek Basin, Northwest Colorado," Col. School of Mines Quarterly Vol. 62, No. 3, pp. 25-38 (July, 1967).

IF-3. Savage, J. W. and D. Bailey, "Economic Potential of the New Sodium Minerals Found in the Green River Formation," Preprint, 27D, American Institute of Chemical Engineers (December, 1967).

G. LAND USE

1. Agriculture

a. Crops

Hay is by far the most important crop raised in Rio Blanco County. The total crop value in the county in 1968 is shown in Table IG-I. Approximately 33% of the hay is alfalfa produced on irrigated land and 67% is wild hay, also generally irrigated. There is normally one cutting a year and occasionally a second. Cutting starts near the end of June and is generally completed by the end of August. It is estimated that greater than 90% of the harvested hay is used for local cattle feeding (winter months) and less than 10% sold to other counties.

In the Piceance Creek Basin, native hay is the only crop grown and Table IG-II gives the major grass species. Grass is grown for hay only on private land, located along the principal drainage bottoms (Figure IA-5).

b. Domestic Livestock

The principal land use of the Piceance Creek Basin is grazing of livestock. The pinyon-juniper-native grass vegetational types have provided forage for livestock for at least 90 years. Settlement by cattlemen began around 1880, and by 1885 at least 23 settlers were in the cattle business along Piceance Creek. By 1920, substantial numbers of sheep were being grazed in the valley as well.

The livestock industry is the largest contributor to the agricultural economy of Rio Blanco County. Although in recent years the number of sheep raised in Rio Blanco County has slightly exceeded the number of cattle, cattle and calf operations provide the greatest single source of income to the county. Table IG-III shows numbers of livestock and their value for Rio Blanco County in 1968. The number of livestock remained constant from 1966 to 1969, but total market value has been increasing. These numbers are for the entire Rio Blanco County. The number of cattle grazing the two planning unit areas (Figure IE-2) is approximately 10,300 or 28% of the total, and for sheep, 9,300 or 17% of the total.

Table IG-I. Value of crops produced in Rio Blanco County. (Colorado Dept. of Agric., 1970)

Crop	Market Value (1968)
All hay	$1,001,000
All wheat	155,000
Barley	70,000
Corn grain and silage	12,000
Oats	10,000
Potatoes	2,000
Total	$1,250,000

Table IG-II. Grass species of major importance in the Piceance Creek Basin (Ref. IG-1).

Genus	Species	Common Name
Agropyron	smithii	Western Wheatgrass
Agropyron	dasystachyum	Thick Spike Wheatgrass
Agropyron	spicatum	Bluebunch Wheatgrass
Oryzopsis	hymenoides	Indian Ricegrass
Poa	secunda	Sandburg Bluegrass
Bromus spp.		Bromegrass

Table IG-III. Livestock numbers and market value in Rio Blanco County. (Colo. Dept. of Agric., 1970)

Livestock	Number	Market Value (1968)
Cattle and calves	37,300	$5,670,000
Cows and heifers (over two years old kept for milk)	300	69,000
Sheep	54,200	1,350,000
Hogs and pigs	330	8,950

Table IG-IV. Livestock numbers in Piceance Creek Basin (Ref. IG-2).

Livestock	Number (1970)
Cattle	10,247
Sheep	9,333
Horses (domestic)	193

Table IG-IV shows numbers of cattle, sheep, and domestic horses estimated in the Piceance Creek area.

Distribution of livestock within the Piceance Creek Basin varies drastically with the season,although the total number present in the basin remains relatively constant. From May through October, cattle are predominantly on Federal grazing allotments in the higher elevations. During the winter months, cattle are largely confined to the bottom lands, predominantly private, along the Piceance Creek and are fed locally harvested hay.

The boundaries of grazing allotments in the Yellow Creek and Piceance Basin planning units are shown in Figure IG-1 (Ref. IG-1). The allotments include areas of private land that have been leased back to BLM for grazing.

For purposes of impact analysis, the grazing allotments were grouped by sectors around the site of the EW for the project (Figure IG-2). Sector A includes the entire area within a five-mile radius and sectors B to E comprise the annulus between 5 and 15 miles from the site. Sector B is the quadrant containing the four compass points: NNE, NE, ENE, and E (11.25 to 101.25 degree). Sectors C, D, and E are the remaining quadrants, labeled clockwise.

The sectors were selected on the basis of seasonal livestock distributions, prevailing winds, and water drainage direction. Sector A lies almost wholly within allotment 16; the cattle that would be in the excluded portion of allotment 16 are compensated for by those that would be present in the included portions of allotments 14 and 18. There are essentially no cattle in sector A during the winter months.

Sector B includes the predominant cattle-wintering areas along Piceance Creek. It also encompasses the stream drainage area below the project site and lies in the prevailing downwind direction. Of the cattle grazing on Federal lands in the Piceance Basin during the summer months (Figure IG-3), at least two-thirds, or about 5,000, would be located within sector B during the winter. This would include cattle from allotments 18, 19, and 20 (Figure IG-4), as well as some from allotments 13 to 17 (Figure IG-5). The only cattle not likely to be in sector B during the winter would be

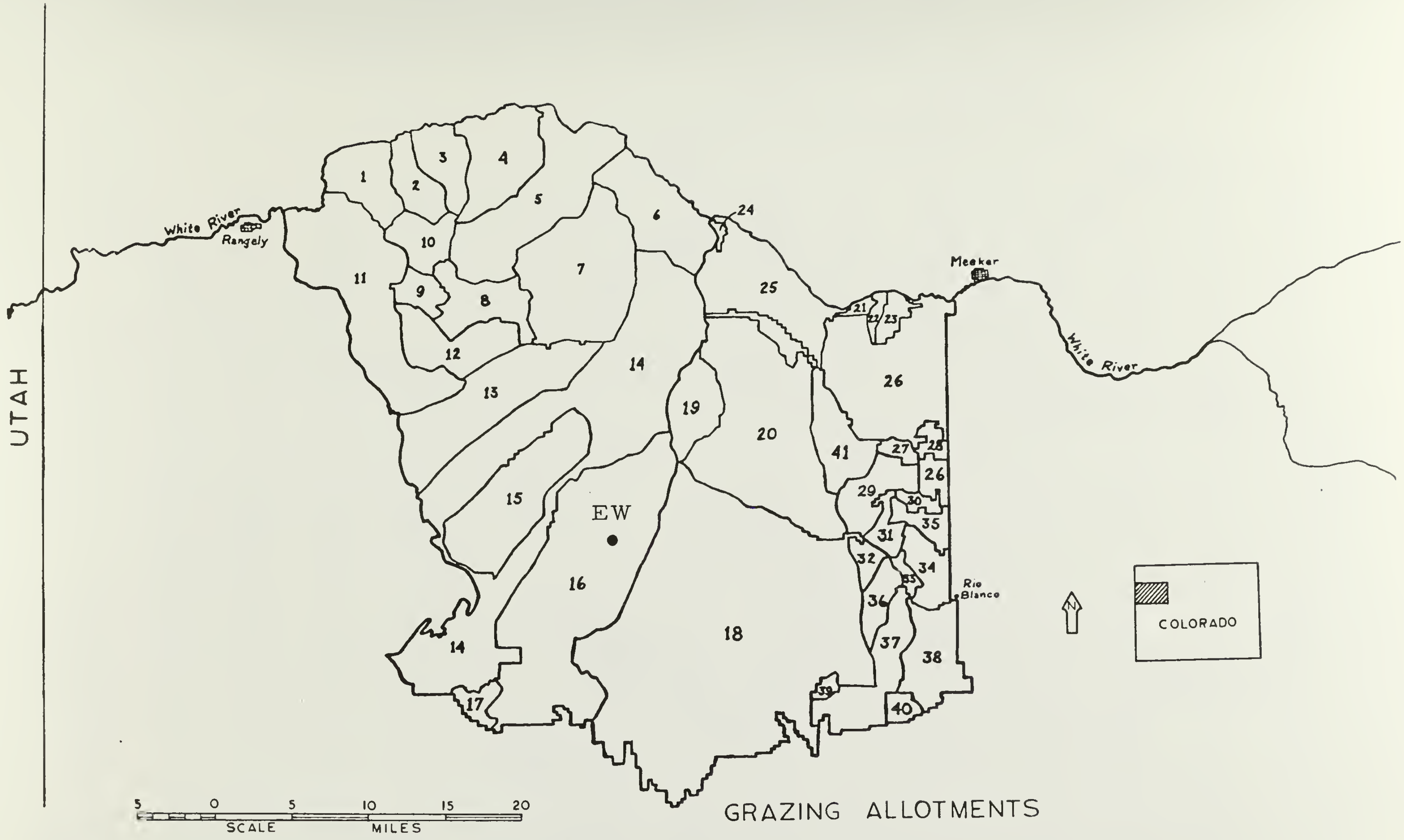


Figure IG-1. Federal (BLM) grazing allotments in the Yellow Creek and Piceance Basin planning units.

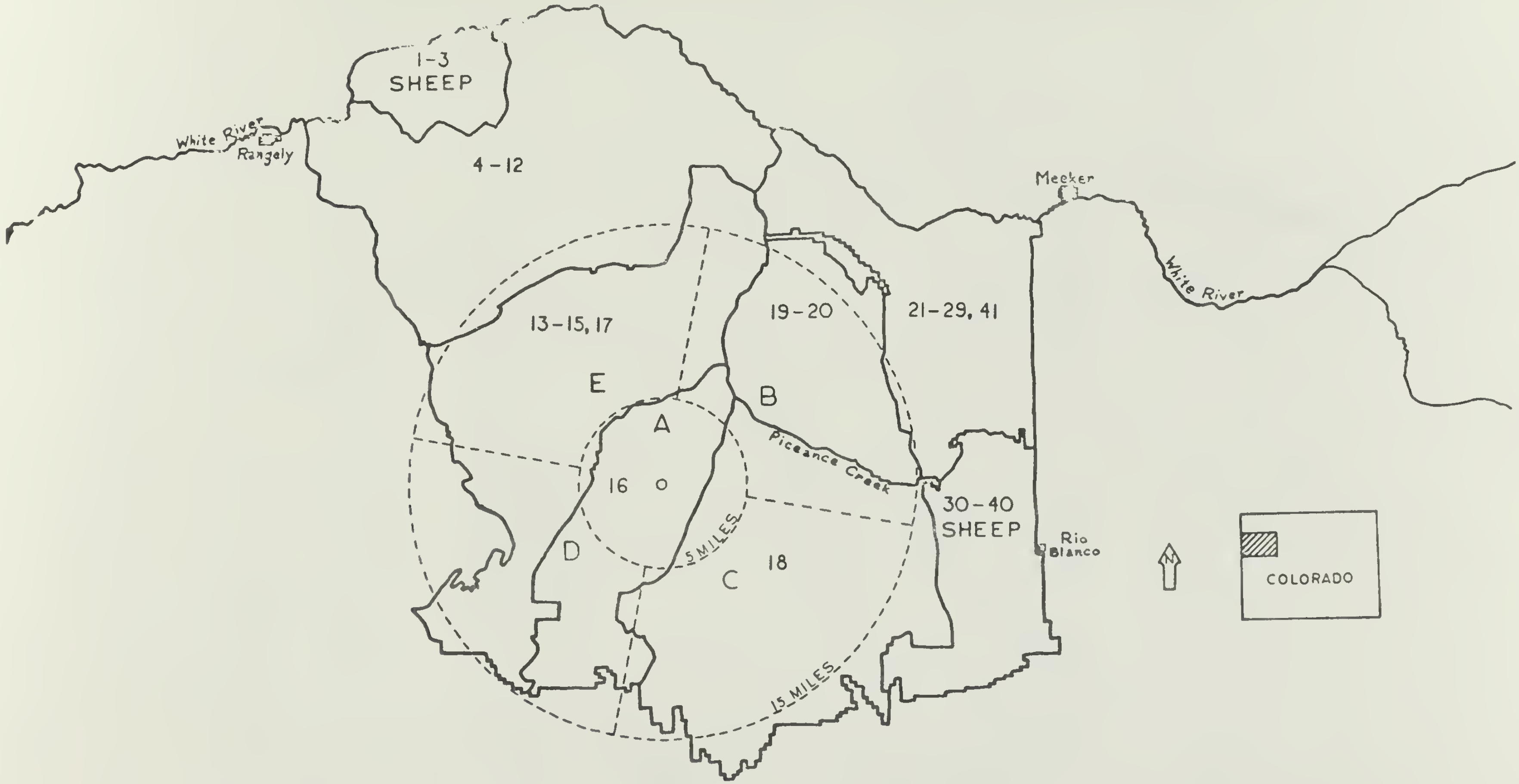


Figure IG-2. BLM grazing allotments grouped for impact analysis by sectors. Sector A comprises an area with a radius of 5 miles around the project Rio Blanco site. Sectors B, C, D, and E include the zone between 5 and 15 miles in radius.

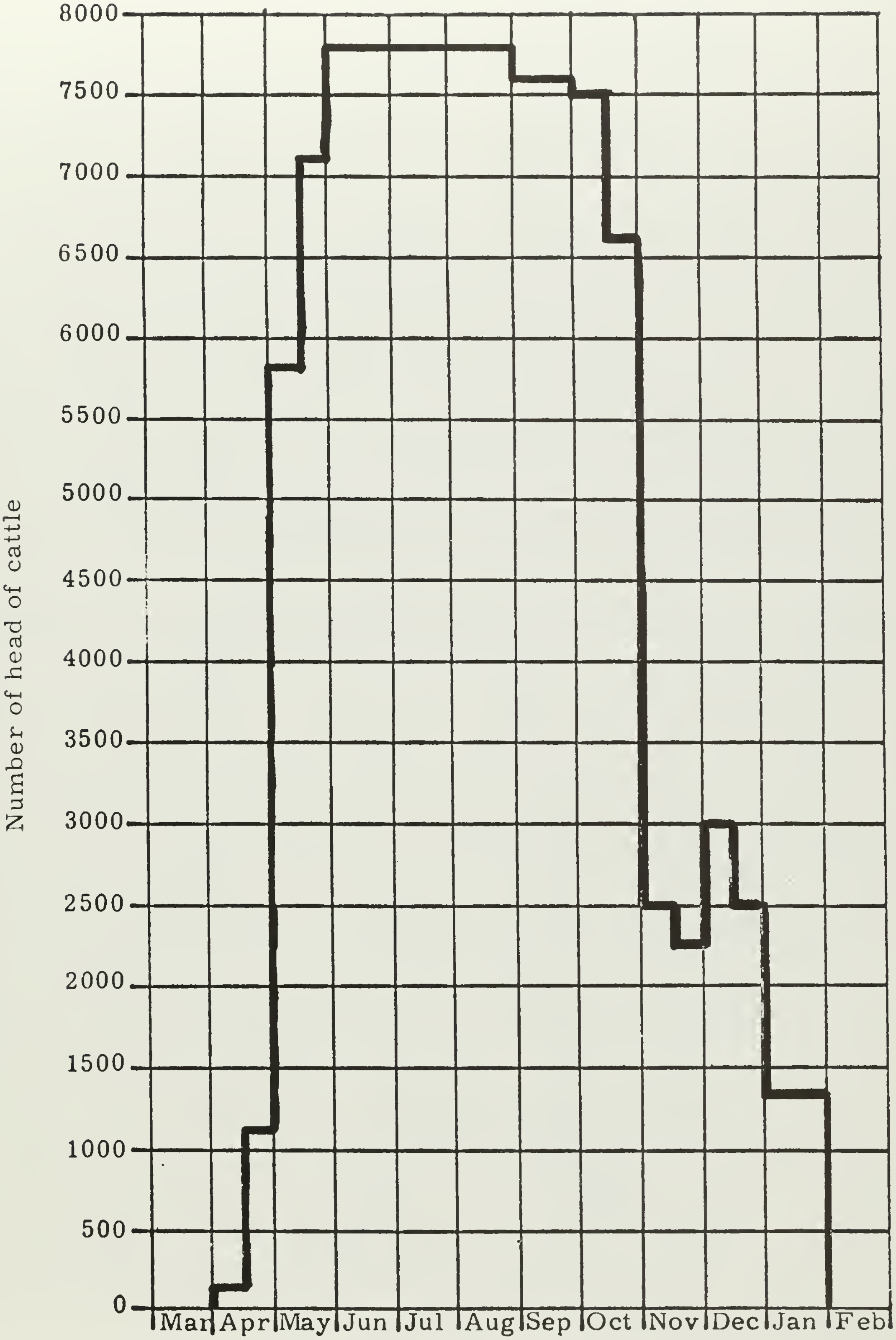


Figure IG-3. Total cattle on Federal land grazing allotments in the Yellow Creek and Piceance Basin planning units during 1970-71 season (Ref. IG-1).

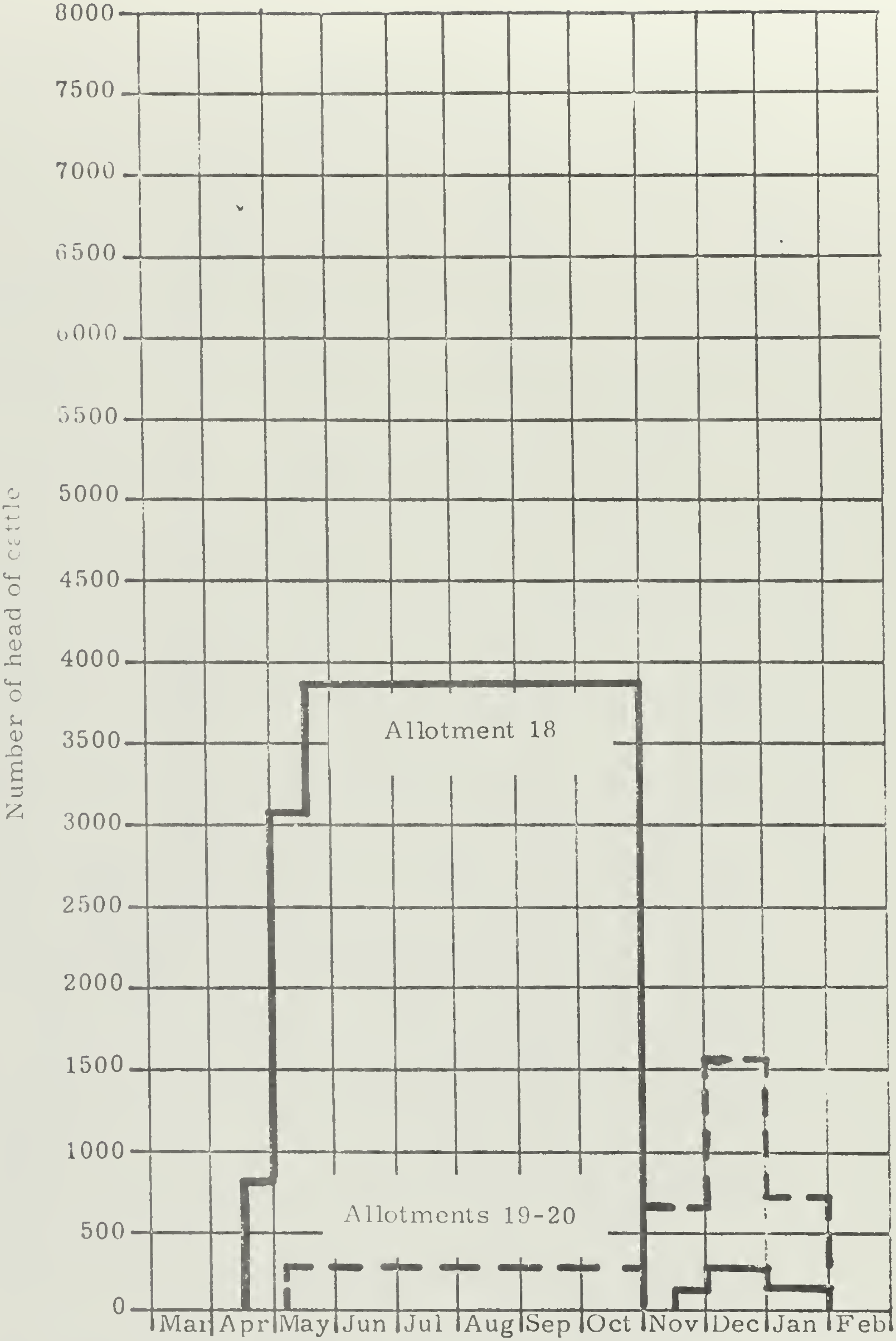


Figure IG-4. Cattle on Federal land grazing allotments 18 to 20 during 1970 (Ref. IG-1).

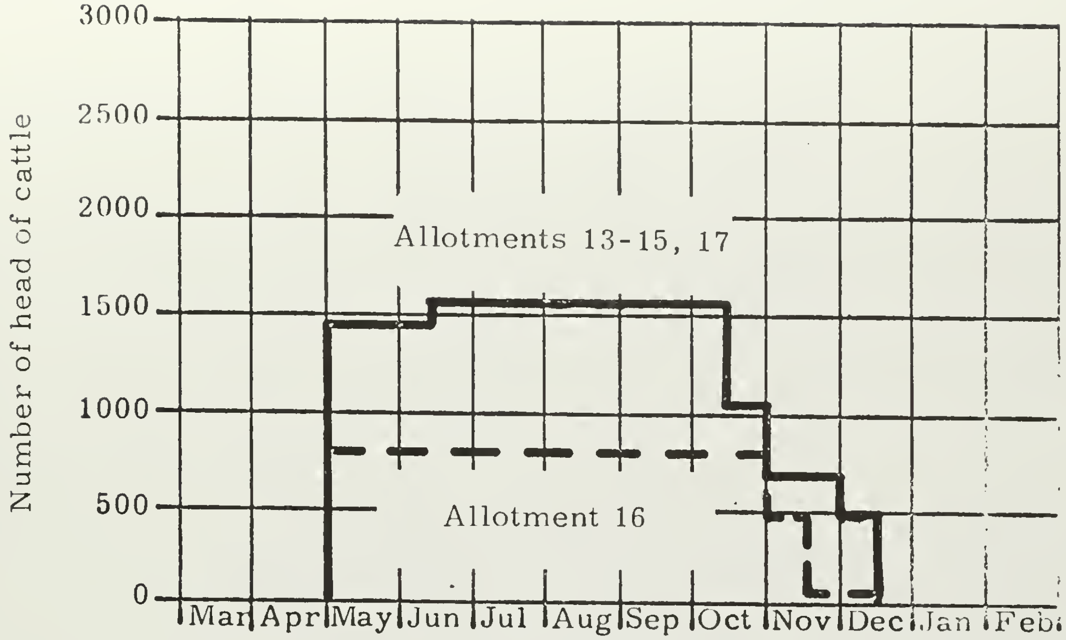


Figure IG-5. Cattle on Federal land grazing allotments 13 to 17 during 1970 (Ref. IG-1).

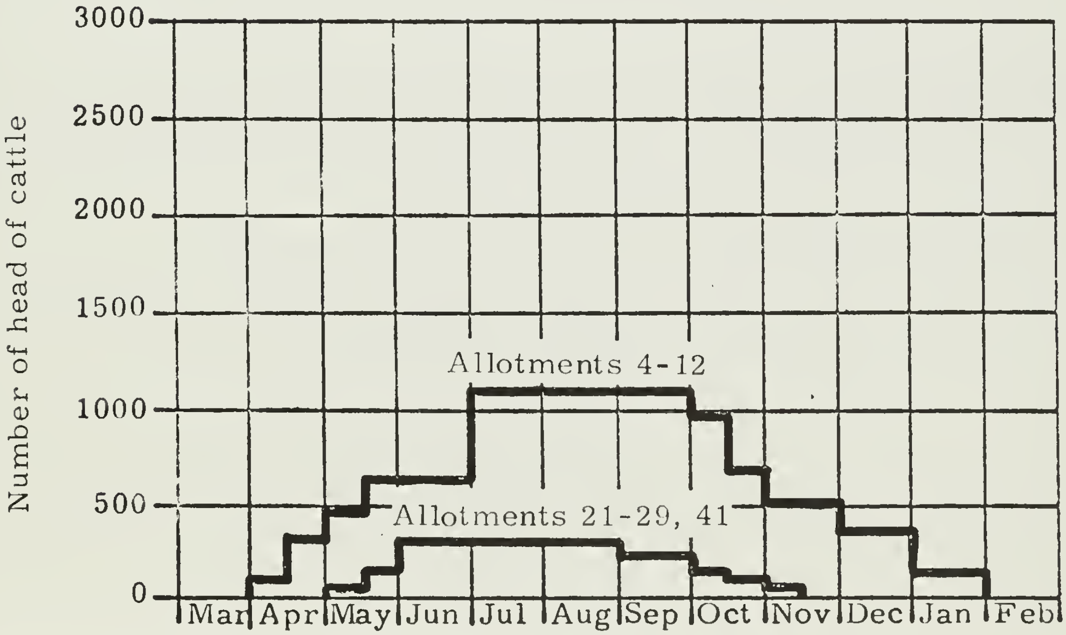


Figure IG-6. Cattle on Federal land grazing allotments 4 to 12, 21 to 29, and 41 during 1970 (Ref. IG-1).

those grazing on allotments 4 to 12 and 21 to 29 during the summer (Figure IG-6).

Sector C is represented by the summer grazing on allotment 18 (Figure IG-4). Sector D extends into high elevations of the Cathedral Bluffs area and includes portions of allotments 14 to 17, but it is not heavily grazed even during the summer. Sector E is also summer grazing range and its use can be approximated by combining allotments 13, 14, 15, and 17. The other grazing allotments within the Yellow Creek planning unit (1 to 12) lie almost wholly beyond the 15-mile radius northwest of the project site. In the Piceance Basin planning unit, allotments 21 to 41 are also largely beyond the 15-mile radius to the east.

The limited number of cattle grazing on allotments 4 to 12, 21 to 29, and 41 even during the summer (Figure IG-5) is indicative of the greater proportion of private land along the east edge of the Piceance Basin planning unit (Figure IIA-5) and of the relatively small number of cattle present in the northwest portion of the Yellow Creek unit at any time during the year.

The seasonal distribution and density of cattle in the Piceance Creek Basin may be summarized as follows:

(1) The total inventory area, comprising the Yellow Creek and Piceance Basin planning units, contains approximately 10,000 head of cattle throughout the year.

(2) Approximately one-fourth to one-third of the cattle are located more than 15 miles from the project site throughout the year.

(3) During May through October, approximately two-thirds to three-fourths of the cattle are rather uniformly distributed within 15 miles of the project site. The average density in this area during the summer is about 40 head per square mile, although the density may be as high as 80 to 100 head per square mile in allotment 18 to the east of the site, and as low as 10 to 20 head per square mile in allotments 13 to 17 southwest of the site.

(4) During the winter months, November through April, approximately two-thirds to three-fourths of the cattle in the area are to be found on the bottom lands along Piceance Creek, at distances of 5 to 15 miles and in a general northeasterly direction from the project site. These cattle are fed on locally grown hay during most of the winter and exclusively during February and March.

Allotments 1 to 3 and 20 to 38 are used almost exclusively for grazing of sheep, which is limited to fall and spring intervals. All of these allotments are more than 15 miles from the project site (Figure IG-2). Summer range for sheep is in the high country east of Meeker and Rio Blanco; the winter range lies west of Rangely. The use of grazing allotments for sheep in the study area occurs only during the transition periods between the summer and winter range. Figures IG-7 and IG-8 show the seasonal distribution of sheep on Federal grazing allotments for two consecutive years.

c. Dairy and Family Milk Cows

The number of dairy cattle in Rio Blanco County is approximately 300 (Ref. IG-2). The only grade-A dairy in the county is located five miles southeast of Meeker and has 72 Holstein and Brown Swiss cows. These cows are fed under dry-lot conditions. The remaining cows are located on individual ranches for family use. A reasonable upper-limit estimate would be an average of one cow per ranch family, or 25 to 30 lactating cows within 25 miles of the project site. These cows are fed principally on local hay and some grain.

d. Horses

Domestic horses in the Piceance Creek Basin number approximately 200. In addition, there are an estimated 250 wild horses in the basin and surrounding uplands (Ref. IG-3).

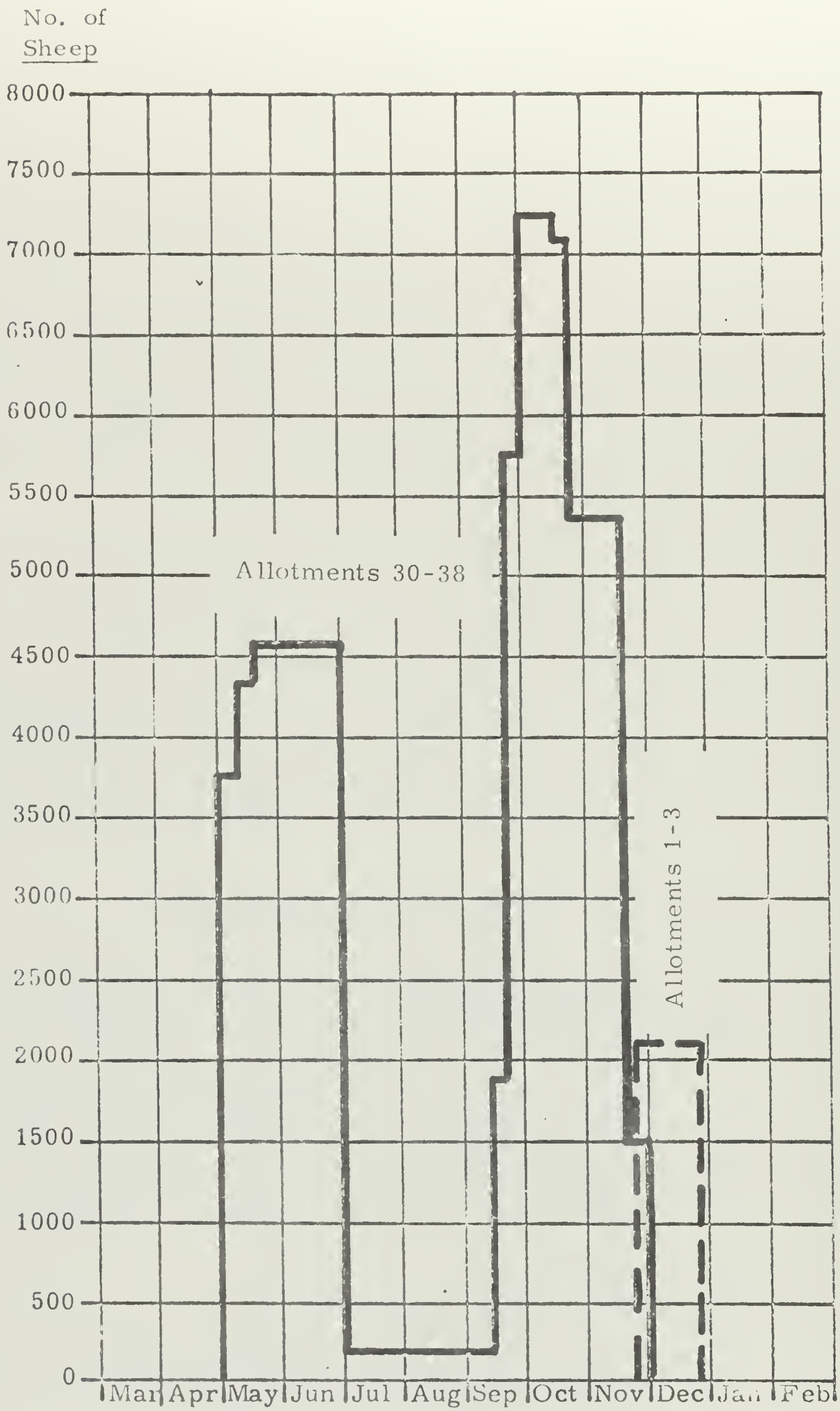


Figure IG-7. Sheep on Federal land grazing allotments during 1970-71 (Ref. IG-1).

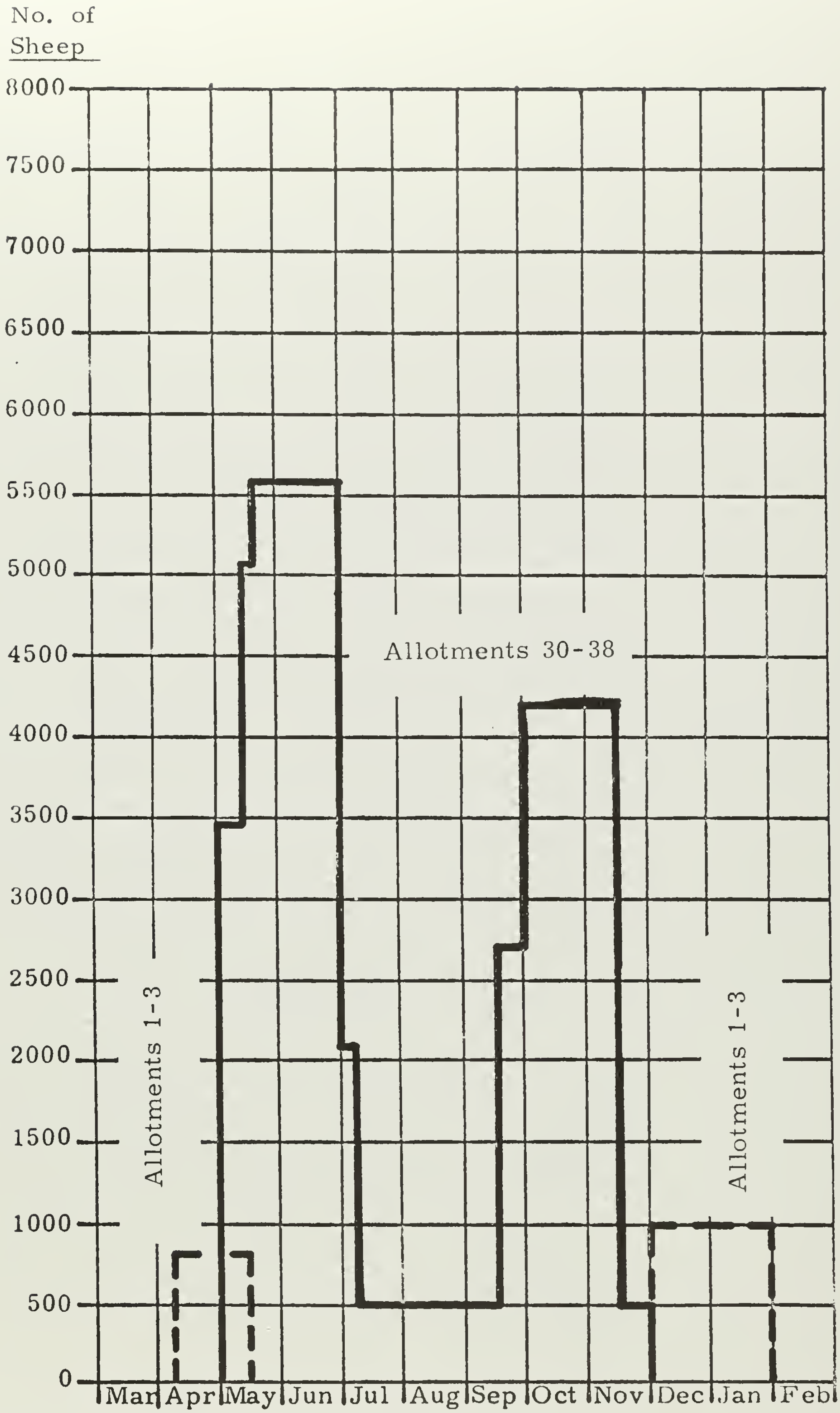


Figure IG-8. Sheep on Federal land grazing allotments authorized for 1971-72 (Ref. IG-1).

2. Industry

a. Mineral Resource Development

Within the proposed oil and gas unit area, attempts are being made by others to develop an economic in situ means of recovering oil from oil shale. While these facilities utilize only a small portion of land at present, should an economic in situ recovery method be developed, it is possible that an increased amount of land would be used for production facilities. Above-ground recovery methods are also being investigated outside the proposed unit. Should an economically and environmentally acceptable mining and surface retorting and waste disposal technique be developed, it is probable that an even larger amount of land would be used for oil shale development. Since dawsonite and nahcolite are associated with the oil shale, efforts to recover these minerals would not be expected to require significant additional land use above that necessary for oil shale development.

Development by mining of the Mesaverde coal beds within the proposed unit is not expected to proceed within the foreseeable future because of their relatively great depth (on the order of 8,000 feet). Should an economical in situ gasification process be perfected, it is conceivable that these deposits might be evaluated for possible development.

b. Gas and Oil Development

Although 44 wells have been drilled within the proposed unit, a commercial gas field has not been developed. Well distribution is shown in Figure IG-9. At present, there are no gas wells within the proposed unit area producing into a pipeline; however, an attempt to develop the gas from sands in the Wasatch Formation is expected soon.

Because the amount of oil in place is small, if it is produced at all, it would be in conjunction with natural gas or oil from the oil shale.

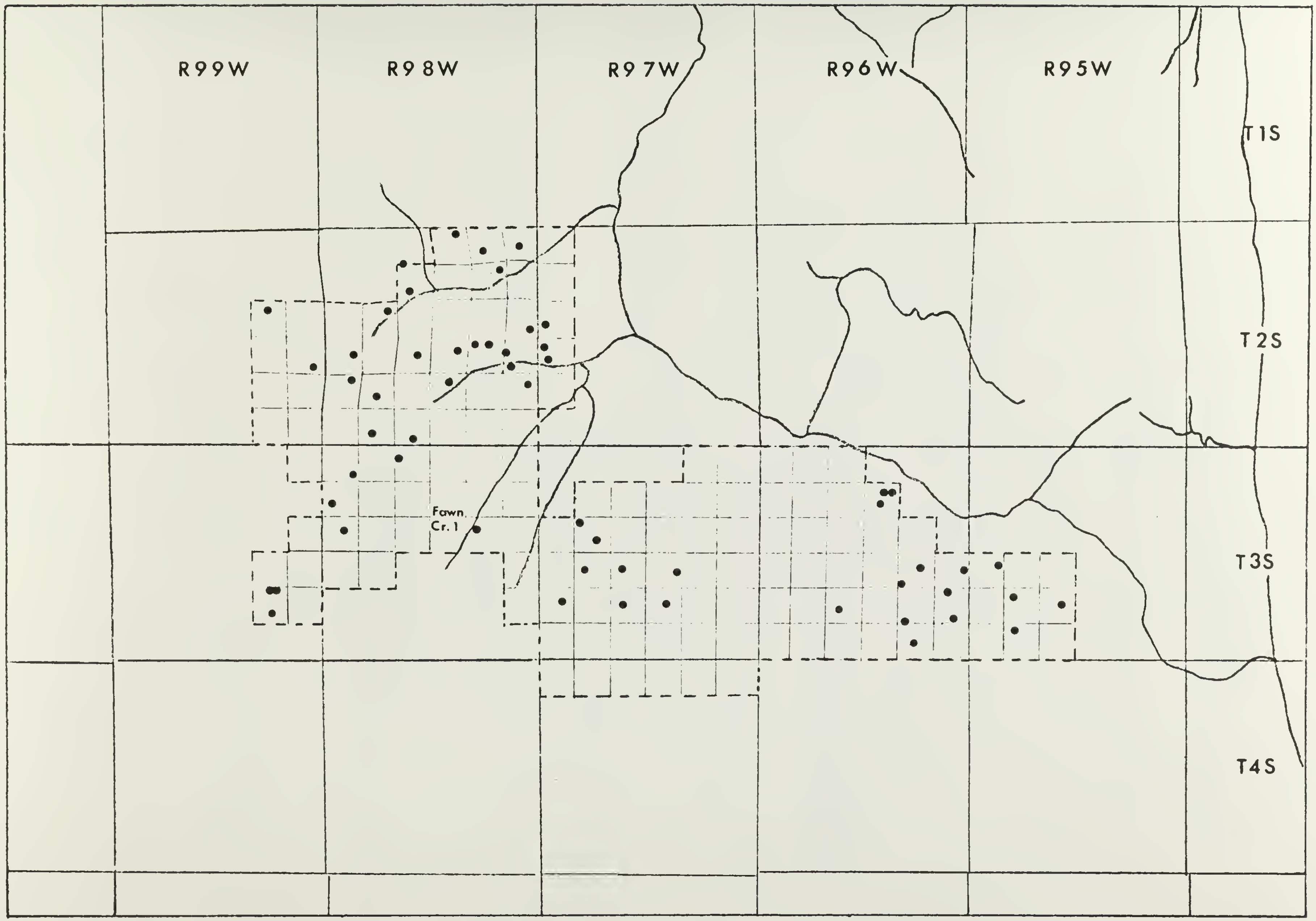


Figure IG-9. Hydrocarbon well locations in proposed unit.

3. Recreation

a. Hunting

The entire proposed oil and gas unit lies within the boundaries of the GF&P Game Management Unit Number 22.

(1) Deer

During 1960 through 1969, an average of 6,000 deer were harvested annually from this key range, constituting up to 10% of the total Colorado deer harvest during these years. Since 1957, annual deer harvests in Unit 22 varied from a low of 2,400 in 1966 to a peak of nearly 24,000 in 1961. This variation, in large part, reflects the influence of management decisions designed to establish a favorable balance between deer populations and their habitat. Over a nine-year period, an average of 5,600 hunters (low 2,408, high 11,958) participated annually in Unit 22 deer harvests.

Archery hunting for the 1971 season opens August 21 and closes September 12, and the rifle hunting season opens October 30 and continues through November 11.

(2) Elk

There is one elk herd that migrates between Game Management Units 31, 32, and 22. During the 1970 hunting season, the harvest from this herd was 75 head.

There is no archery season for elk in Game Management Area 22. Regular elk season for 1971 is open October 16 through October 25. In 1971, there will be three early elk seasons in September, one in October, and four post-seasons in December in specified elk areas.

(3) Mountain Lion

Mountain lion season is March 1 through April 30.

(4) Non-Game Mammal (1970 Hunting Season)

(a) Marmot

April 1 to September 30.

(b) Prairie Dog

April 1 to December 31.

(c) Badger and Kit Fox

September 1 to February 28.

(d) Raccoon, Coyote, Gray Fox, Red Fox, Bobcat, Jackrabbit, Skunk, and Ground Squirrel

January 1 to December 31.

(e) Chipmunk and Lynx

All areas closed.

(f) Fisher, River Otter, Wolverine, and Black-footed Ferret

There is no open season on these furbearing species.

(5) Ducks, Geese, and Other Birds

The following hunting schedule is for the 1970 season, but it is expected that the 1971 season will be similar.

Ducks	October 10 to January 10
Geese	October 24 to December 20
Mourning Dove	September 1 to October 30
Blue Grouse	September 30 to October 3
Sage and Sharptail Grouse	September 12 to September 30
Wilson Snipe	October 10 to December 13

There was no season in the Piceance Basin area for turkey, chukar, ptarmigan, and little brown cranes.

b. Fishing

There is very little sport fishing in Game Management Unit 22. In 1966, Black Sulphur Creek was stocked with 3,000 one-inch rainbow trout. Each year, Stake Springs Pond (Yellow Creek), Ryan Pond, Foot Pond, and Little Hills Pond share about three 500-pound plants of creek-size rainbow trout. Brook trout have been caught in Fawn Creek, Piceance Creek, and Black Sulphur Creek.

At present, there are no known positive plans to develop additional fisheries in the area.

c. Camping

There is a small undeveloped campground at the confluence of Cow Creek and Piceance Creek, about 20 miles southeast of the EW. Camping facilities at Rio Blanco Lake, about 22-1/2 miles north, have been developed. Otherwise, the area has not been developed for camping. During the hunting season, however, thousands of deer and elk hunters camp out in undeveloped areas throughout Piceance Basin.

d. Winter Sports

Skiing is not a large recreational activity in the area. There is a rope tow on Nine-Mile Hill, north of Meeker, and the Meeker ski club plans to develop a ski slope east of Buford, or about 40 miles northeast of the EW. There is no commercial ice skating in the area. Occasionally, "ski-do" races are held on the snow-covered meadow across from the Rio Blanco Post Office on State Highway 13/789.

e. Estimates of Transient Population

The transient population occurs principally during the hunting season. Over a nine-year period, an average of 5,600 hunters participated annually in Unit 22 deer harvests. In addition, during the high-country grazing season, the cattle and sheep are accompanied by cowboys and sheepherders.

REFERENCES

IG-1. Colby, Stanley G., Area Manager, BLM, "Resource analysis of the Yellow Creek Planning Unit W-01-09, and Resource analysis of the Piceance Basin Planning Unit W-01-11, White River Resource Area, Meeker, Colorado," (unpublished). Printed as Appendix A, Vol. II, "Biological/Ecological Considerations for Project Rio Blanco," Colorado State Univ., Fort Collins, Colorado (June, 1971).

IG-2. Data supplied by Rio Blanco County Assessor's Office (personal communication).

IG-3. Steinert, Steven, Colorado Game, Fish, and Parks Division (personal communication).

H. CULTURAL FEATURES

1. Modern

a. Buildings

The environmental setting of the Rio Blanco project is essentially rural. Ranch houses and their associated outbuildings, and a few industrial installations are scattered throughout the area. The industrial plants involve the oil shale development projects of Colony Development, Equity Oil, and Shell Oil, as well as the Piceance Creek gas field with its associated facilities and pipelines. The closest towns or villages are Grand Valley at 29 miles, Meeker at 30 miles, Rangely at 31 miles, De Beque at 33 miles, and Rifle at 37 miles. The closest city is Grand Junction at 52 miles.

An extensive structural inventory, out to a distance of 30 miles from the EW, has been made by Kenneth Medearis & Associates of Fort Collins, Colorado. Based on this inventory, the distribution of structures out to 28 miles from the EW is shown in Figure IH-1.

The estimated value of all structures is $22.5 million, with $18.5 million valuation for 16 industrial locations and $4.0 million valuation for the remaining 336 locations. The fair market values of the taxable real property in the four closest towns are about $9.3 million for Meeker, $5.6 million for Rangely, $1.1 million for Grand Valley, and $0.5 million for De Beque. These values are based on 1971 reports of the Colorado State Property Tax Commission where the assessed valuations are at 30% of the market value.

b. Bridges

Bridges on the major roads, out to a radius of 30 miles, that cross the White River, Piceance Creek, and Roan Creek have been included in the structural inventory. The smaller bridges are in a supplemental inventory.

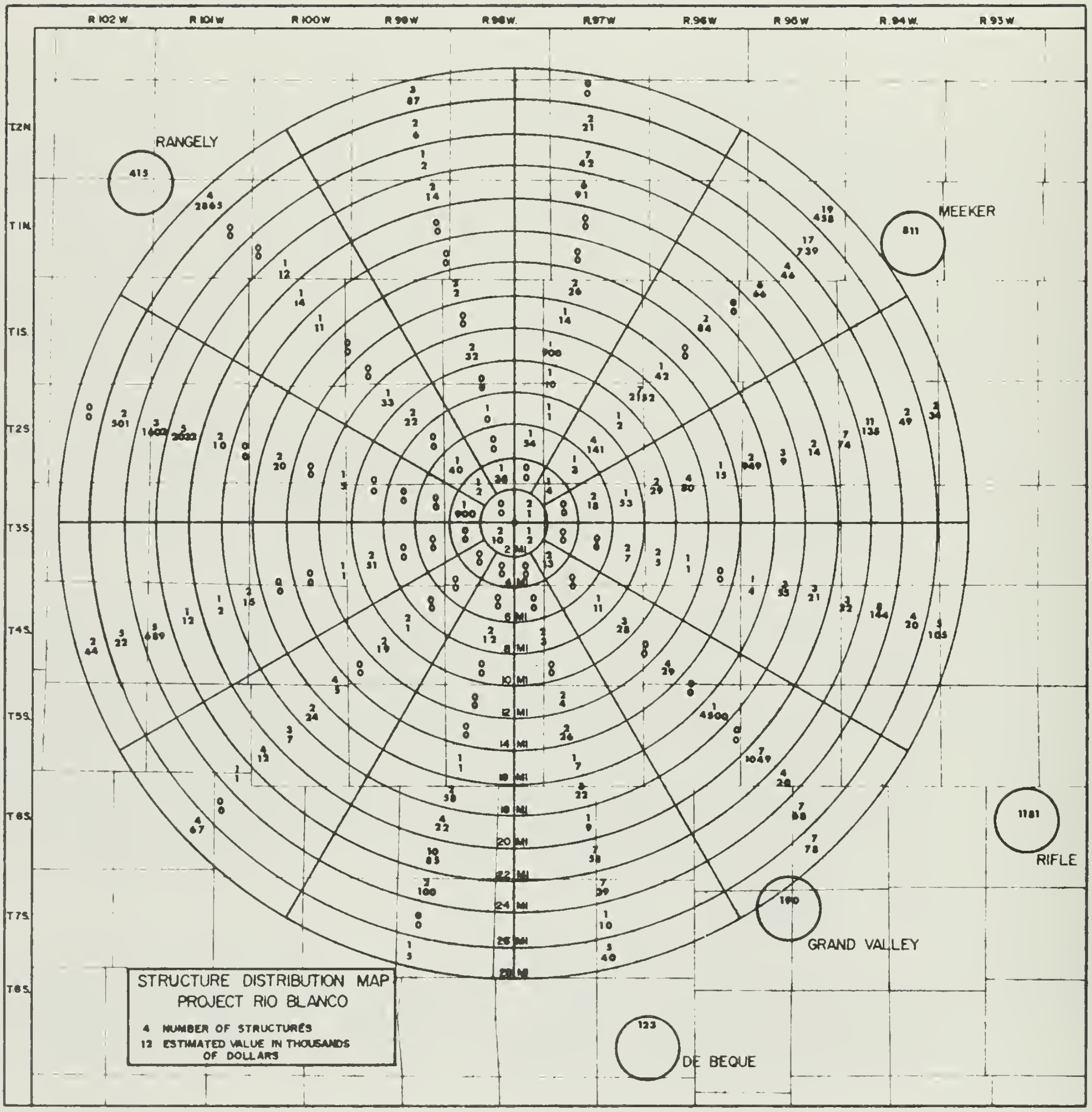


Figure IH-1. Distribution of structures around EW.

c. Tunnels

Four tunnels in the area, all located in De Beque Canyon, are about 40 miles from the EW. One is a railroad tunnel. The other three are tunnels for the Government Highline Canal.

d. Power

The electrical power system supplied by the White River Electric Association Inc. of Meeker, Colorado is shown in Figure IH-2.

e. Communications and Repeaters

The commercial telephone communication facilities are very meager. The system consists of two four-party lines along the Piceance Creek Road.

f. Hydrocarbon Wells

The locations of all recorded hydrocarbon wells within 10 miles of the EW are shown in Figure IH-3.

g. Mines and Quarries

The locations of mines and quarries in the vicinity of the Rio Blanco site are shown in Figure IH-4; a curve of 53-mile radius is superimposed; it outlines the area within which it is expected that all personnel will be evacuated from mines at time of Rio Blanco detonation. Table IH-Ia lists active mines that fall within or near this circle. Table IH-Ib lists inactive mines. A complete evaluation report on those mines has been made by W. W. Fertig (Ref. IH-1).

h. Gas Pipelines

There are three main gas pipelines in the area owned and operated by El Paso Natural Gas Company, Western Slope Gas Company, and Cascade Natural Gas Company. The locations of these lines are shown in Figure IH-5.

Figure IH-2. Existing power lines in Rio Blanco area with planned addition to EW.

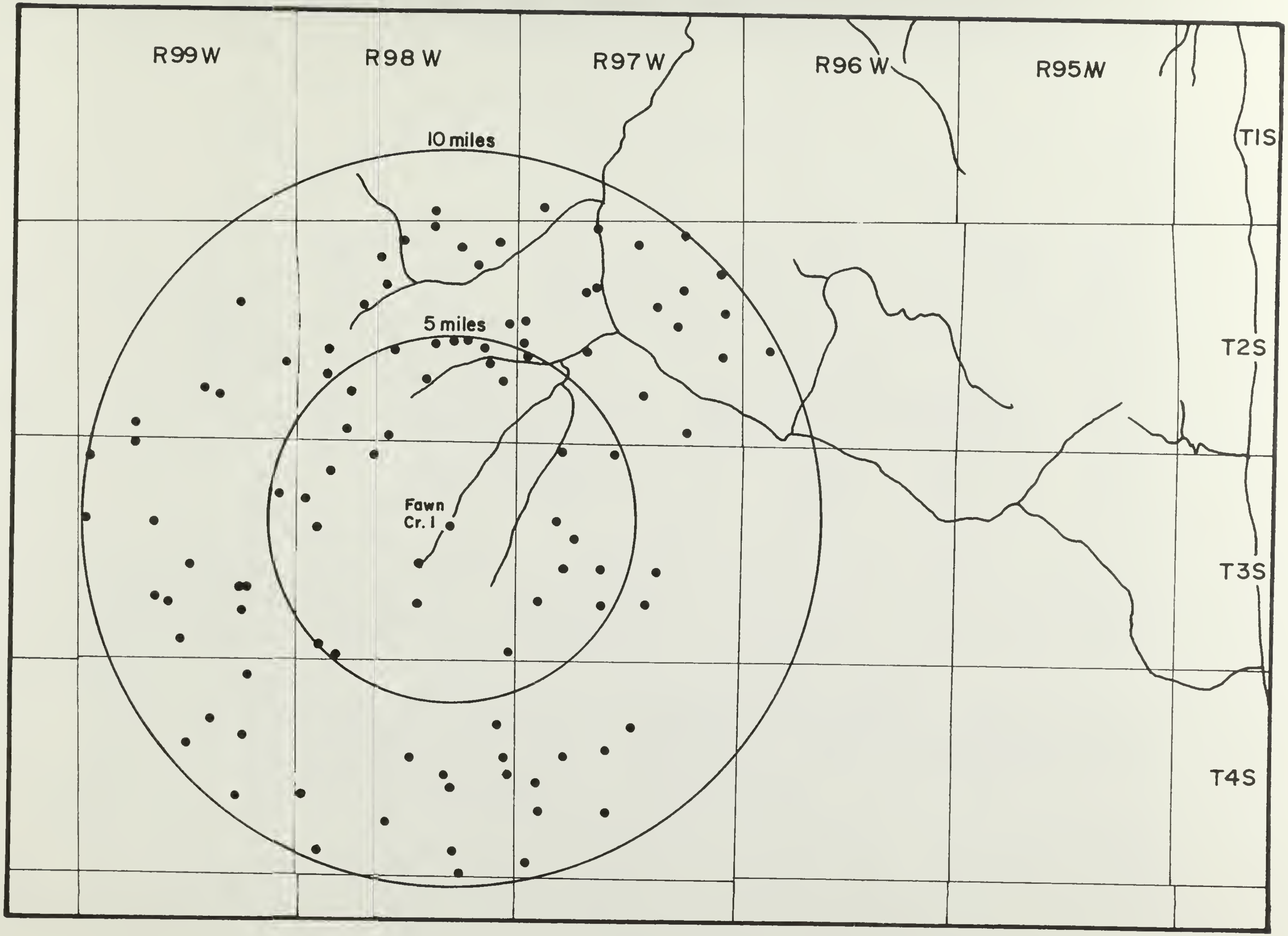


Figure IH-3 Hydrocarbon wells within 10 miles of the EW.

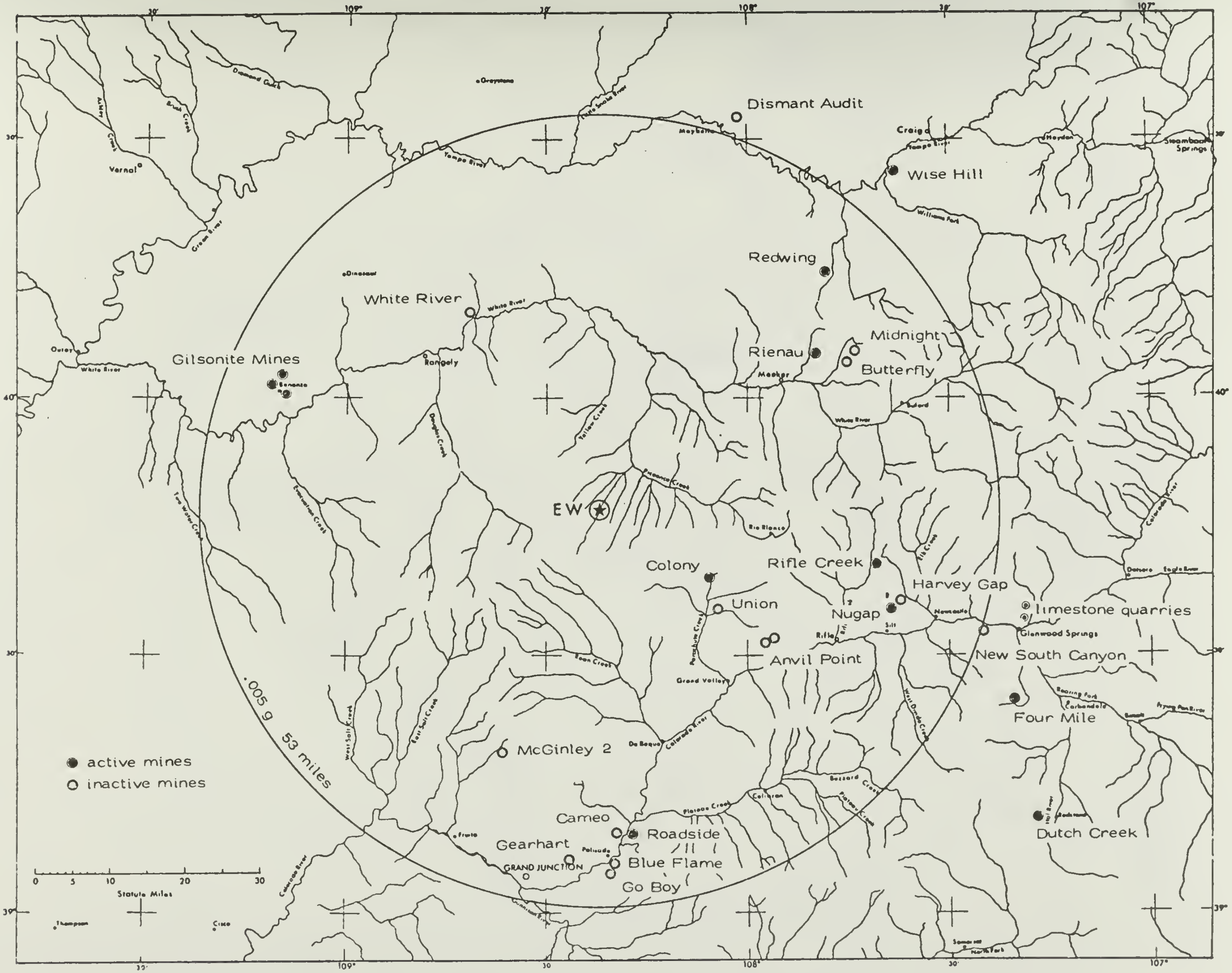


Figure IH-4. Location map of mines and quarries in Rio Blanco area.

Table IH-Ia. Active mines in Rio Blanco area.

Mine Name	Product	Miles to EW	Location and Description	Operstor	Contact	Operating Procedure	Production
Colony	oil shale	19	T5S, R95W, S7 on Parachute Creek on Middle Fork, Garfield County	Atlantic Richfield Corp. 300 Enterprise Bldg. Grand Junction, Colo. 303/243-5080	John Middleton Mgr., Shale Dev. Group (243-5080) Grand Junction, Colo.	One shift/day 5 days/week 4 to 5 men underground	1,000 ton/day
Rienau #2	coal	36	T2N, R93W, S29 6 miles north of Meeker, Rio Blanco County	Jenkins & Mathis Coal Corp., 560 Main Street Meeker, Colorado 303/878-5061	W. Jenkins, Jr. 303/878-4830	One shift/day 5 days/week 2 men undergr. 0800 to 1630 hrs	30 ton/day
Rifle Creek	vanadium	37.5	T4S, R92W, S34& 35 on Highway 325 north of Rifle-Garfield County	Union Carbide Corp. 1600 Ute Avenue Grand, Junction, Colo. 303/243-3700	Willmer Witt 625-2779 (mine) 625-1903 (home)	Two shifts/day 5 days/week 1st shift-20 men 2nd shift-3 men underground 0800 to 1600 hrs 1600 to 2400 hrs	200 ton/day
Nugap #3	coal	40.5	T5S, R92W, S24 south of Harvey Gap Dam, Garfield County	Henry Benedetti 1018 Colorado Avenue Glenwood Springs, Colo. 303/945-5797	Henry Benedetti 945-5797 (home)	One shift/day 5 days/week 2 men undergr. /shift	20 to 25 ton/ day
Redwing	coal	44	T3N, R93W, S2 18 miles north of Meeker near Axial on Highway 13	COLOWYO Coal Co. 1726 Champa Denver, Colo. 303/825-0231 Box 775, Craig, Colo. 303/824-5504	Jack White 824-6776 (mine)	Two shifts/day 5 days/week 24 men undergr. 0730 to 1530 hrs. 3 men undergr. 1600 to 2400 hrs. some winter mos. 6 days/week	750 ton/day
Roadside	coal	46	T10S, R98W, S34 on Highway 70 at Cameo, Colo.	Reliable Coal & Mining Company 79 West Monroe Street Chicago, Illinois	T. B. Richardson P. O. Box S Palisades, Colo. 303/464-7355 (mine)	One shift/day 5 days/week 5 men undergr.	80 ton/day
	gilsonite	47	T9S, R24E near Bonanza, Uintah County, Utah	American Gilsonite Co. 1150 Kennecott Bldg. Salt Lake City, Utah 801/328-0311 R. E. Nelson, Pres. Bonanza, Utah Phone #2	Paul Borden, Plant Manager Paul Wessenden, Mine Supt. 801/789-1921	Three shifts/day 7 days/week 15 men undergr. /shift 0800 to 1600 hrs. 1600 to 2400 hrs. 2400 to 0800 hrs.	33 ton/hour
	gilsonite	47	T9S, R24E near Bonanza, Uintah County, Utah	Arthur Boren, Sub-contractor to American Gilsonite Company 801/789-2728	Arthur or Cecil Boren	Two shifts/day 5 days/week 18 men undergr. /shift 0730 to 1530 hrs. 1530 to 2330 hrs.	
	gilsonite	47	T9S, R24E near Bonanza, Uintah County, Utah	Ziegler Chemical Co. Star Route Vernal, Utah 801/789-3593	Frank Godina Dale Gardner	@ Little Bonanza One shift/day 3 men undergr. @ Independent Two shifts/day 7 men undergr. /shift	100 ton/day
Wise Hill #4	coal	58	T5N, R91W, S5&6 T6N, R91W, S31& 32 6 mi south of Craig on Highway 13	Silengo Coal Company 835 Steel Craig, Colorado 303/824-3446	C. L. Silengo 824-6477 (mine)	Three shifts/day 5 days/week 9 men undergr. /shift 0700 to 1500 hrs. 1500 to 2300 hrs. 2300 to 0700 hrs.	1,500 ton/day
Basic Chemical Quarry	lime-stone	56	T5S, R88W, S31	Junction Tool & Bit Company	T. W. Holmes 303/945-6524	May 1 to Dec. 15 5 days/week 0715 to 1830 hrs.	

Table IH-Ib. Inactive mines in Rio Blanco area.

Mine Name	Product	Miles to EW	Location and Description	Operator	Contact
Parachute Creek	oil shale	22.5	T5S, R95W, S29 on East Fork Parachute Creek, Garfield County	Union Oil of Calif. Los Angeles, Calif. 213/482-7000	W. C. Flynn, Caretaker 303/285-7600
Anvil Point	oil shale	28	T6S, R95W, S12 Anvil Point, Garfield County	Mobil Oil Company and BuMines	Malcolm Smith 303/625-1134
White River	coal	31.5	T2N, R101W, S1&10 10 miles east of Rangely, Rio Blanco County	Staley Gordon Company Box 442 Rangley, Colorado	R. (Clem) Gordon 303/675-8726
McGinty #2	coal	36.5	T9S, R100W, S5 at end of Salt Creek Road	Eagle Head Coal Co.	Lawrence Downing 303/242-3636
Harvey Gap #3	coal	40.5	T5S, R91W, S19	Henri Benedetti 303/945-5797	Same
Midnight	uranium	42	T2N, R92W, S28	Harry Harp 303/878-5955	Same
Butterfly	uranium	42	T2N, R92W, S28	Lyle Francis Box 204 Moab, Utah	Same
Cameo Mine	coal	46	T10S, R98W, S27, 28, 33, 34	Juanita Coal Company	Robert Bowie Paonia, Colorado 303/527-4121
Gearhart Mine	coal	47.5	T11S, R98W, S5&6	Homer B. Phillips	
Blue Flame Mine	coal	47.5	T11S, R98W, S2	Willis S. Barstow	
Go Boy	coal	48	T11S, R98W, S2	Alta Fontanari	
New South Canyon	coal	53	T6S, R90W, S14	Henri Benedetti 303/945-5797	Same
Dismant Audit	uranium	55	T7N, R95W, S13 close to Maybell, Moffat County	Union Carbide Company	Mr. Martin Grand Jct., Colo. 303/243-3700
Glenwood Lime Quarry	limestone	56	T5S, R88W, S31	Holly Sugar Company	George Miles 303/471-0123

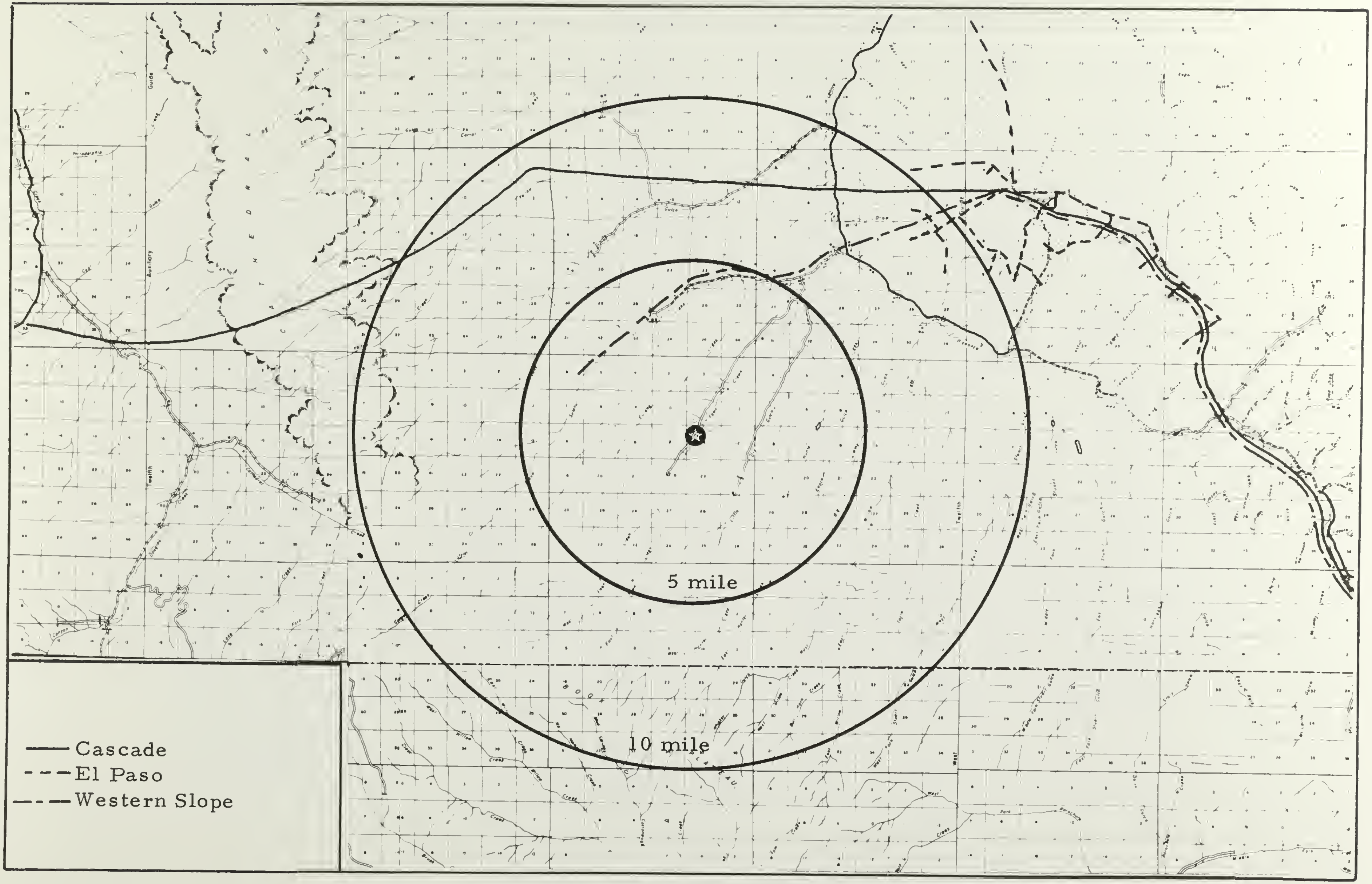


Figure IH-5. Gas pipelines.

i. Hydraulic Structures

The locations of these structures (dams, tunnels, ditches, reservoirs, etc.) are covered in a special supplement to the Medearis structural inventory. The only sizable dam within 30 miles of the EW is on Rio Blanco Lake, near the junction of White River and Piceance Creek.

There are numerous small irrigation ditches along Piceance Creek. In addition, there are 13 small dams within the proposed unit, most of which are on ranches and create ponds for storing water for ranch use.

j. Airports

The closest airport with commercial airline service is at Grand Junction. There are small airports at Rifle, Meeker, and Rangely. A small, unmaintained landing strip is located near the El Paso Compressor Station, S8, T2S, R96W.

k. Railroads

The only railroad in the area is the Denver and Rio Grande Western track along the Colorado River. The closest approach to the EW is at Grand Valley, 29 miles away.

l. Roads

The locations of the main roads are shown on the map of the general area, Figure IA-1. Numerous private roads and jeep trails within the Piceance Creek are shown in Figure IA-5.

2. Natural

There are no unique surface geological features. There is one known fossil site about 19 miles to the north. It has been tentatively identified as fossilized fly larva (Ref. IH-2). The Rocky Mountain National Park is the closest national part at about 135 air miles. Mesaverde National Park is about 170 miles south. Colorado National Monument is about 55 air miles southwest and Dinosaur National Monument is about 65 air miles northwest from EW.

3. Archeological

The closest known archeological site, located along the Douglas Pass Road, about 21 miles west of the EW, is a grouping of pictographs on the native rock (Figure IH-.6).

4. Historical

a. Monuments

The closest historical monument is the Meeker Massacre site, just north of the White River, 30 miles from the EW. The actual site is marked with a white concrete pylon. A rustic sign calling attention to it is located alongside the highway.

b. State, County, and Local Points of Interest

(1) Rock School

The Rock School House (Figure IH-7) is located on the east side of the Piceance Creek Road, near the point where Black Sulphur Creek flows into Piceance Creek (S16, T25, R97W). The single-room building has a simple, rectangular floorplan of about 40 by 30 feet and is constructed rather solidly of fieldstone and mortar. Dating from 1897 it is still in use as a school and is well maintained. An adjacent modern cement block building has been built recently to cope with the needs of about 30 school children. There is an adjacent residence for the husband/wife teacher family. The structures belong to School District Number 1 of Meeker, Colorado.

(2) Tack House

Tack House (Figure IH-8) is the name given to an old building constructed of rock and mortar, located on the corner of the Piceance Creek Road and the access road to the Little Hills Experimental Station (S2, T15, R97W). It is currently used for storage. It appears to have been built in the early 1900's by the same craftsmen who built the Rock School. It has not been maintained as well as Rock School; a large crack is visible in the north wall.

Figure IH-6. Portion of pictographs near Douglas Pass Road.

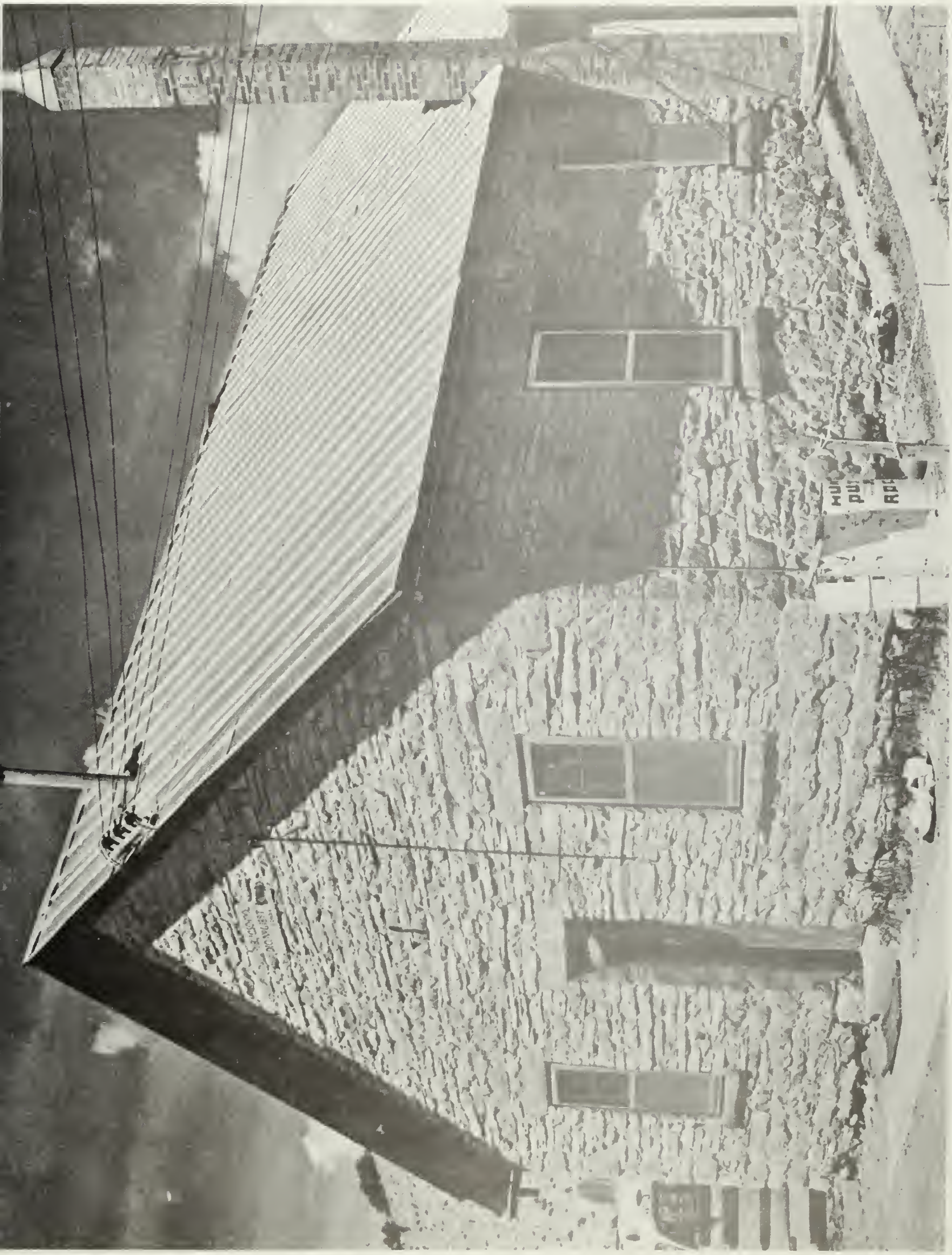


Figure IH-7. Rock School House.

Figure IH-8. Tack House.

(3) Ryan Gulch School

The Ryan Gulch School (Figure IH-9) is located about six miles up Ryan Gulch Road from Piceance Creek Road (S9, T2S, R98W). It is a small log cabin structure in rather poor condition. It is unused, the windows are out, and the walls and poorly constructed roof are badly deteriorated. Most of the caulking between the logs is gone.

(4) Miller Hill Cemetery

The Miller Hill Cemetery, about one mile north of the Rock School, is a local point of interest as many of the early settlers are buried there.

(5) Black Sulphur Creek Cemetery

Black Sulphur Creek Cemetery,near the confluence of Fawn Creek and Black Sulphur Creek, is of historical significance.

c. Protected Sites

There are no sites in the area which are protected under the Historic Sites Act of 1935, the Federal Antiquities Act of 1906, the National Historic Preservation Act (Public Law 89-665), the National Register of Historic Places, or the Colorado House Bill Number 1475, an act protecting historical, prehistorical, and archeological resources in the State.

Figure IH-9. Ryan Gulch School.

REFERENCES

IH-1. Fertig, W. W., "Rio Blanco Project, Preliminary Evaluation of Operating Mines Within 55 Miles from RB-E-01," (April, 1971).

IH-2. Colby, Stanley, BLM, Meeker, Colorado (personal communication).

I. CLIMATOLOGY AND METEOROLOGY

1. Upper Airflow

The EW location is about 45 miles NNE of the National Weather Service upper-air sounding station at Grand Junction. The Grand Junction observations provide a reasonable measure of the upper airflow over the Piceance Creek Basin. Figures I-I-1 and I-I-2 present the frequency of occurrence of flow in 22-1/2 degree sectors and velocity groupings for each of the four seasons for 700 millibars (10,000 feet) and 500 millibars (18,000 feet), respectively. The winds are plotted in the downwind direction in order to indicate the most probable transport sectors. The mean wind at 10,000 feet for winter is from 255 degrees at 10.6 knots, while for summer, it is from 243 degrees at 7.6 knots. Values for other seasons are similar. The most probable flow at 10,000 feet over the event area is from the WSW at eight to ten knots.

The mean maximum (afternoon heating) mixing depths (the thickness of the layer of vigorous vertical mixing due to convection arising from afternoon heating), determined from the Grand Junction upper-air sounding, are presented in Table I-I-I. The mean monthly maximum mixing depth computed from the Grand Junction station varies from a low of 340 meters in January to a high of 3,570 meters in June. Daily variation due to afternoon heating, snow cover, and cloud cover can cause wide variation in these mixing depths. The maximum likely afternoon mixing depth over the project area in May is 3,380 meters. However, variation in afternoon heating, due to ground snow cover and cloud cover, can cause wide variations in this value.

Tables I-I-II to I-I-VII inclusive, provide detailed analyses, by alternate months, of the frequency of occurrence of the Grand Junction 10,000-foot wind direction and speed categories. For April, the 10,000-foot flow is between 236.25 and 258.75 degrees 16.9% of the time and, within this direction category, at a velocity between 5 and 9 meters per second 49% of the time.

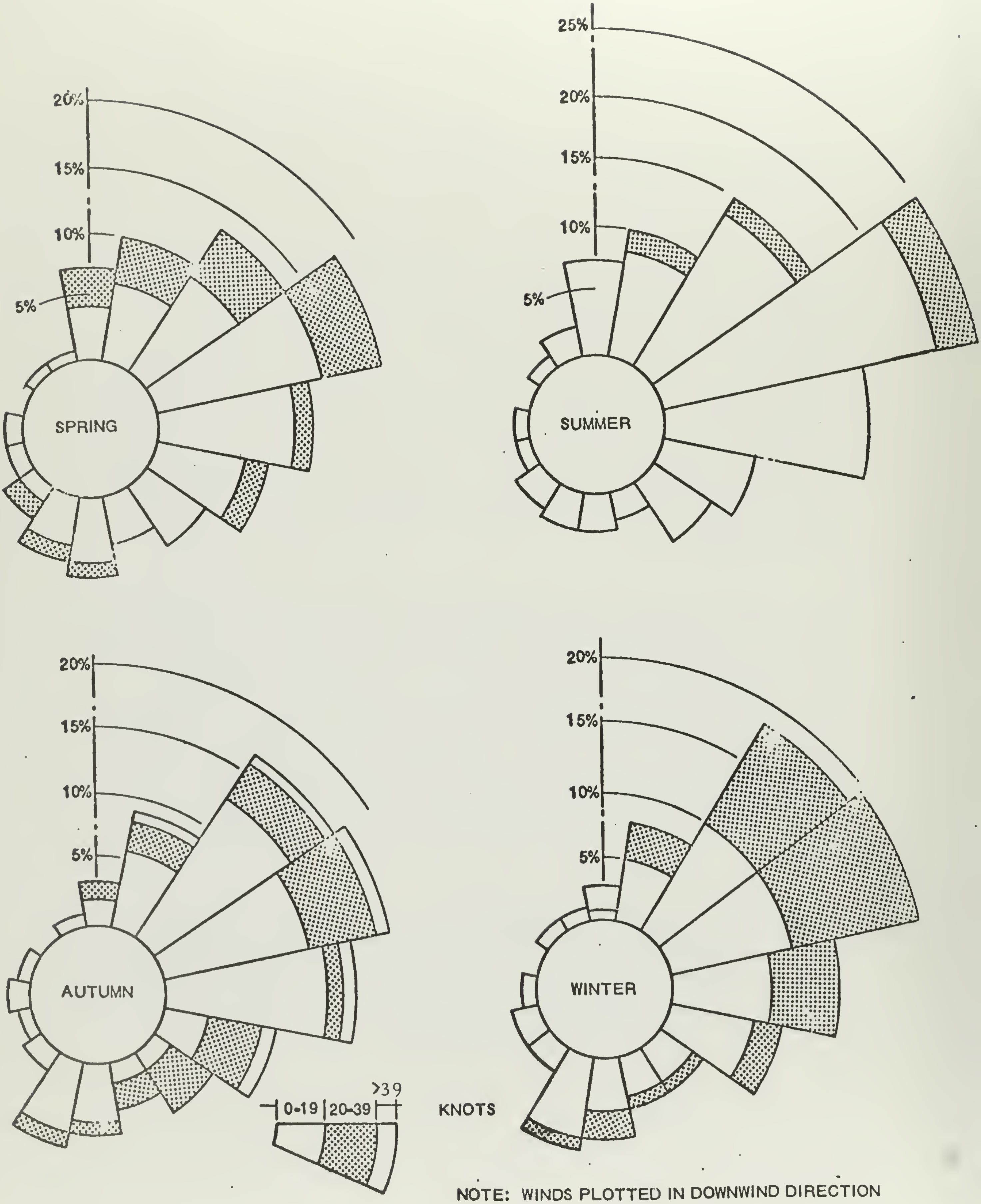


Figure I-I-1. Frequency of upper airflow for 700 mb.

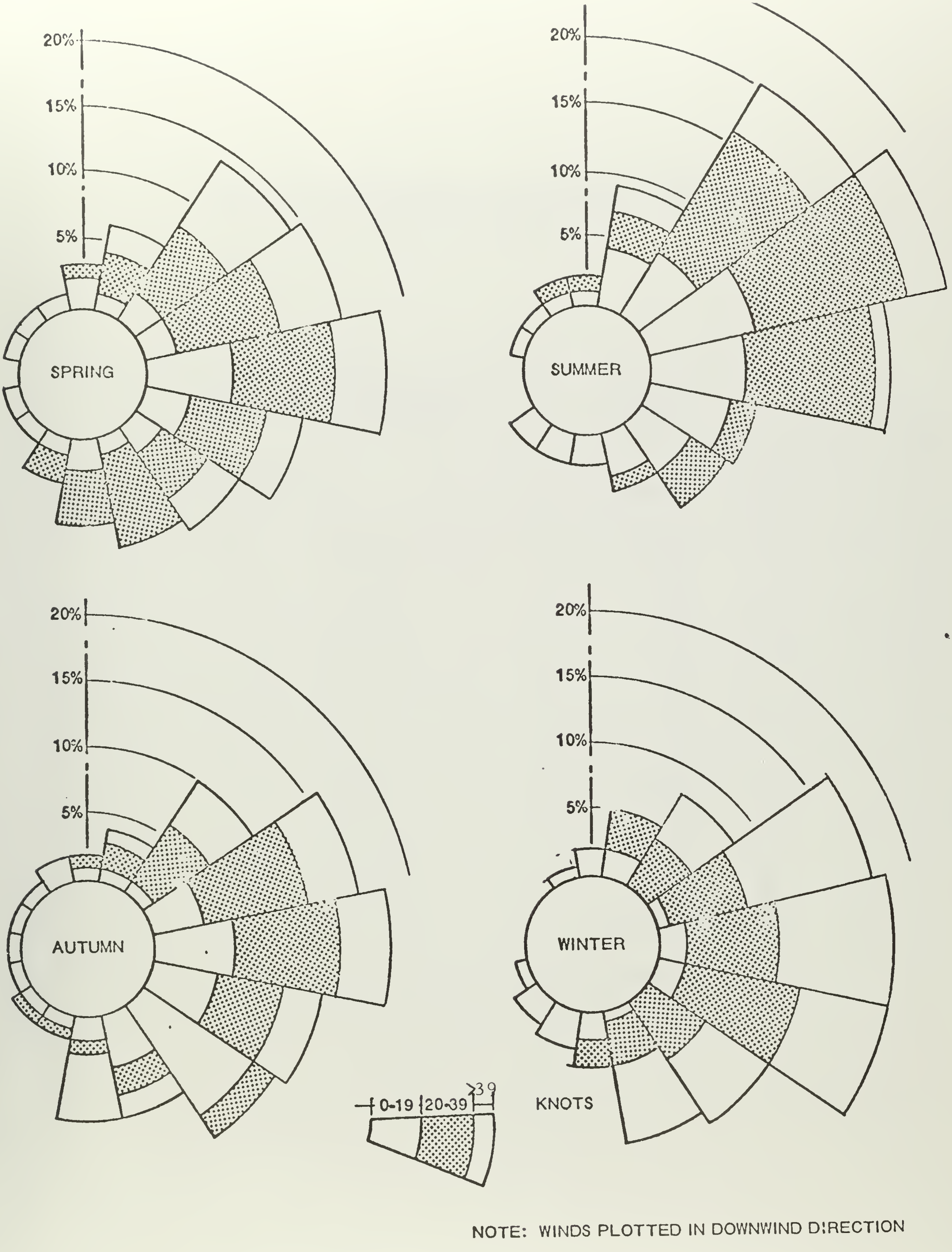


Figure I-I-2. Frequency of upper airflow for 500 mb.

Table I-I-I. Mean monthly maximum mixing depths, Grand Junction, Colorado (Ref. I-I-I).

Month	Meters Above the Surface
January	340
February	670
March	1,870
April	2,530
May	3,380
June	3,570
July	3,210
August	2,970
September	2,370
October	1,090
November	770
December	430

Table I-I-II. 700-millibar winds, Grand Junction, Colorado (February 1966 to 1970).

Direction	Direction Frequency (%)	Wind Speed				
			Frequency of Occurrence (%)			
		Mean	(m/sec) 0-4	5-9	10-14	≥15
360.0	5.8	7.1 (m/sec)	19	63	18	--
022.5	6.5	6.4	22	67	6	5
045.0	3.2	7.9	22	44	22	12
067.5	1.1	5.0	67	--	33	--
090.0	2.2	3.7	50	50	--	--
112.5	0.0	--	--	--	--	--
135.0	0.4	4.0	100	--	--	--
157.5	1.1	4.7	67	33	--	--
180.0	4.3	8.0	17	50	17	16
202.5	7.9	9.0	18	36	36	10
225.0	14.0	7.7	18	49	26	7
247.5	16.2	7.3	18	58	22	2
270.0	14.8	8.2	15	59	20	6
292.5	11.5	8.3	9	50	34	7
315.0	5.8	9.3	19	44	25	12
337.5	5.4	6.2	47	40	--	13

Table I-I-III. 700-millibar winds, Grand Junction, Colorado (April 1966 to 1970).

Direction	Direction Frequency (%)	Wind Speed					
		Mean	Frequency of Occurrence (%)				
			(m/sec)	0-4	5-9	10-14	≥15
360.0	4.0	7.3 (m/sec)		17	58	25	--
022.5	3.3	5.5		30	70	--	--
045.0	2.7	3.1		75	25	--	--
067.5	0.7	5.5		--	100	--	--
090.0	0.7	2.0		100	--	--	--
112.5	0.3	2.0		100	--	--	--
135.0	0.3	2.0		100	--	--	--
157.5	0.7	2.0		100	--	--	--
180.0	6.7	9.9		15	40	30	15
202.5	16.3	11.1		10	35	29	26
225.0	13.5	10.1		12	32	46	10
247.5	16.9	8.5		18	49	23	10
270.0	14.6	8.0		18	43	37	2
292.5	9.0	6.8		33	45	15	7
315.0	7.7	5.7		43	48	9	--
337.5	2.7	5.8		50	25	25	--

Table I-I-IV. 700-millibar winds, Grand Junction, Colorado (June 1966 to 1970).

Direction	Direction Frequency (%)	Wind Speed Mean	Frequency of Occurrence (%) (m/sec) 0-4	5-9	10-14	≥15
360.0	4	5.5 (m/sec)	33	58	9	0
022.5	2	4.0	57	43	0	0
045.0	3	6.0	34	33	33	-
067.5	1	6.5	50	0	50	
090.0	1	3.0	100	0	0	0
112.5	2	3.4	80	20	0	0
135.0	1	3.5	100	0	0	0
157.5	2	5.4	43	57	0	0
180.0	5	9.3	12	56	6	26
202.5	14	10.0	5	40	40	15
225.0	13	7.1	26	50	21	3
247.5	19	7.2	21	58	16	5
270.0	14	7.3	21	55	19	5
292.0	8	5.4	42	46	8	4
315.0	6	4.6	53	47	0	0
337.5	5	4.3	57	36	7	0

Table I-I-V. 700-millibar winds, Grand Junction, Colorado (August 1966 to 1970).

Direction	Direction Frequency (%)	Wind Speed				
		Mean (m/sec)	Frequency of Occurrence (%)			
			0-4	5-9	10-14	≥ 15
360.0	6	4.4 (m/sec)	42	58	0	0
022.5	5	3.6	80	20	0	0
045.0	4	2.5	91	9	0	0
067.5	1	3.0	33	67	0	0
090.0	1	2.0	100	0	0	0
112.5	2	2.4	100	0	0	0
135.0	1	2.5	100	0	0	0
157.5	2	3.5	67	33	0	0
180.0	3	5.6	78	11	0	11
202.5	6	6.9	35	35	25	5
225.0	8	5.8	48	32	20	0
247.5	15	6.7	26	57	13	4
270.0	17	5.9	30	62	6	2
292.0	16	4.6	60	33	7	0
315.0	6	4.3	44	56	0	0
337.5	7	3.9	78	22	0	0

Table I-I-VI. 700-millibar winds, Grand Junction, Colorado (October 1966 to 1970).

Direction	Direction Frequency (%)	Wind Speed				
			Frequency of Occurrence (%)			
		Mean	(m/sec) 0-4	5-9	10-14	≥15
360.0	12	6.3 (m/sec)	33	56	3	8
022.5	9	6.2	37	48	11	4
045.0	2	4.3	71	29	0	0
067.5	2	4.5	33	67	0	0
090.0	1	3.0	67	33	0	0
112.5	2	4.0	80	20	0	0
135.0	1	2.0	100	0	0	0
157.5	1	3.5	50	50	0	0
180.0	2	7.7	33	50	17	0
202.5	9	8.1	21	52	21	6
225.0	14	8.2	17	55	19	9
247.5	17	7.8	23	43	30	4
270.0	13	6.6	21	64	15	0
292.0	7	7.9	20	50	25	5
315.0	5	7.7	27	53	0	20
337.5	5	4.9	38	62	0	0

Table I-I-VII. 700-millibar winds, Grand Junction, Colorado (December 1966 to 1970).

Direction	Direction Frequency (%)	Wind Speed				
			Frequency of Occurrence (%)			
		Mean	(m/sec) 0-4	5-9	10-14	≥15
360.0	4.7	8.5 (m/sec)	29	29	42	--
022.5	3.7	7.5	--	82	18	--
045.0	4.7	6.8	14	72	14	--
067.5	1.0	4.0	67	33	--	--
90.0	0.3	5.0	--	100	--	--
112.5	1.0	5.3	33	67	--	--
135.0	2.0	8.2	33	--	67	--
157.5	1.3	3.8	75	25	--	--
180.0	5.0	6.3	33	47	20	--
202.5	6.0	9.9	17	33	22	28
225.0	21.3	9.8	9	39	39	13
247.5	20.0	9.0	6	52	30	12
270.0	12.7	9.3	11	42	37	10
292.5	5.0	10.1	7	33	47	13
315.0	8.0	8.6	9	58	29	4
337.5	3.3	7.1	30	30	40	--

2. Topography and Local Effects

Figure I-I-3 shows the major topographic features of the Rio Blanco area. The Flat Tops, a region more than 11,000 feet in elevation, lie to the east of this area and is the source of the White River. There is a large, high massif to the southeast of the Piceance Creek Basin area which drains into the Colorado River and tributaries of the Colorado. The locations of the four special recording weather stations, installed to collect data in advance of the project, are indicated as RB-1, RB-2, RB-3, and RB-4. The site of the planned EW is near RB-2. Figure I-I-4 details the drainages and topographic features in the immediate project area. The area is characterized by a series of shallow NNE draining valleys. Station RB-2 is on Fawn Creek, which drains through Black Sulphur Creek into the Piceance Creek near RB-3 and then into the White River near RB-4. Station RB-1 is on a ridge with the rather prominent Cathedral Bluffs and Cathedral Creek Canyon immediately to the north.

The local wind circulations and dynamic effects which will affect the transport and the diffusion characteristics in the Rio Blanco project area are strongly influenced by the topography. Two effects are primary: the mountain-valley local circulations, and the frictional effect induced by the mountains which causes the observed winds to blow to the left of the gradient wind vector.

a. Mountain and Valley Winds

The controls over air movement produced by local conditions are often more significant problems than the effects of the major synoptic scale forces. Diurnal tendencies are superimposed upon both the large- and small-scale patterns of wind. These diurnal tendencies are particularly responsible for local wind patterns. In general, there is a tendency for wind velocities to be lowest about dawn, when there is little vertical thermal mixing and the lower air does not couple into the velocity of the more freely moving upper air. Conversely, velocities of some local winds are greatest between 1300 and 1400 hours (local time) when the air exhibits its greatest tendency to move vertically due to terrestrial heating and couples with the faster moving air above.

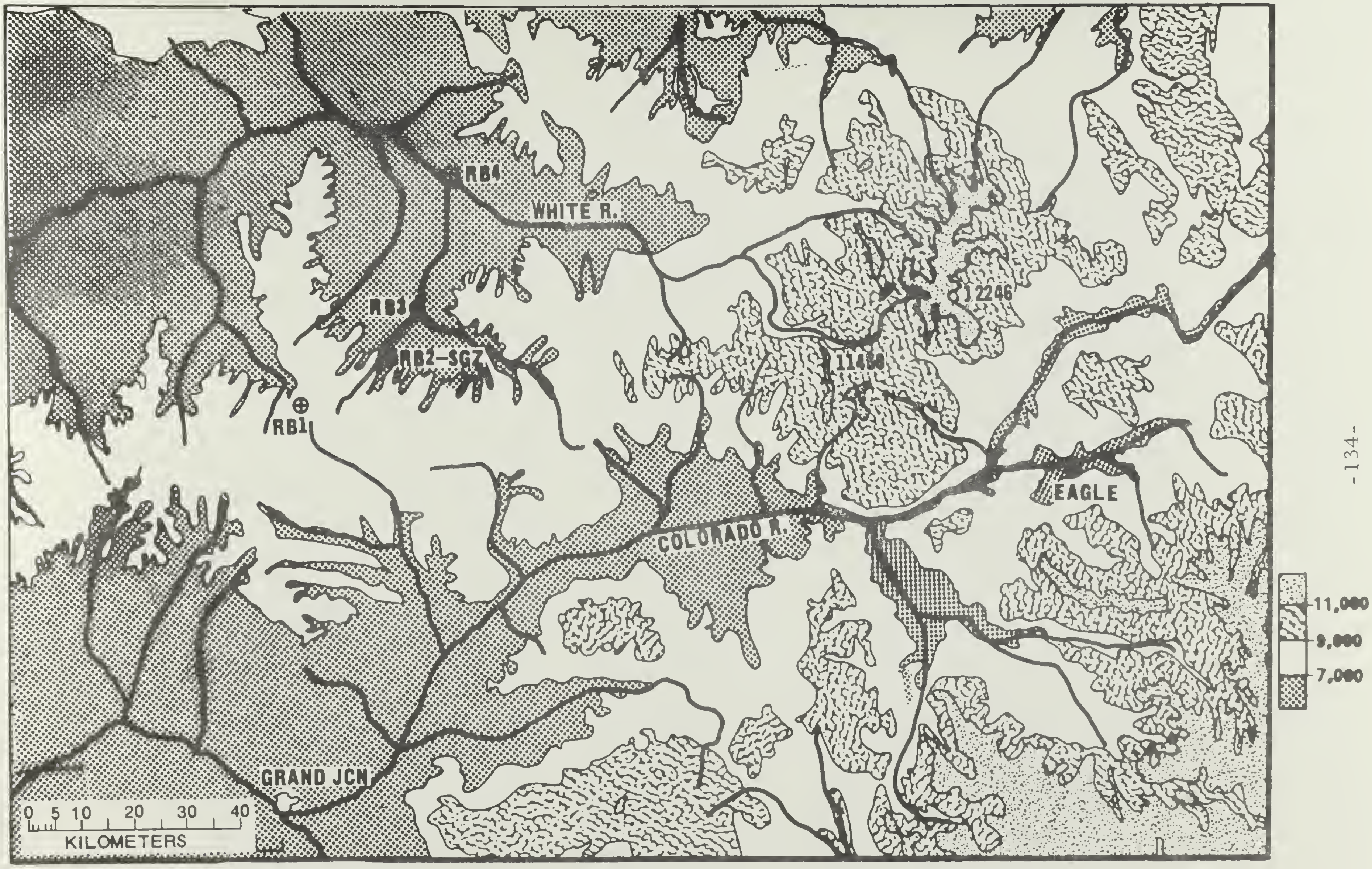


Figure I-I-3. Topography of the Rio Blanco area showing locations of weather stations.

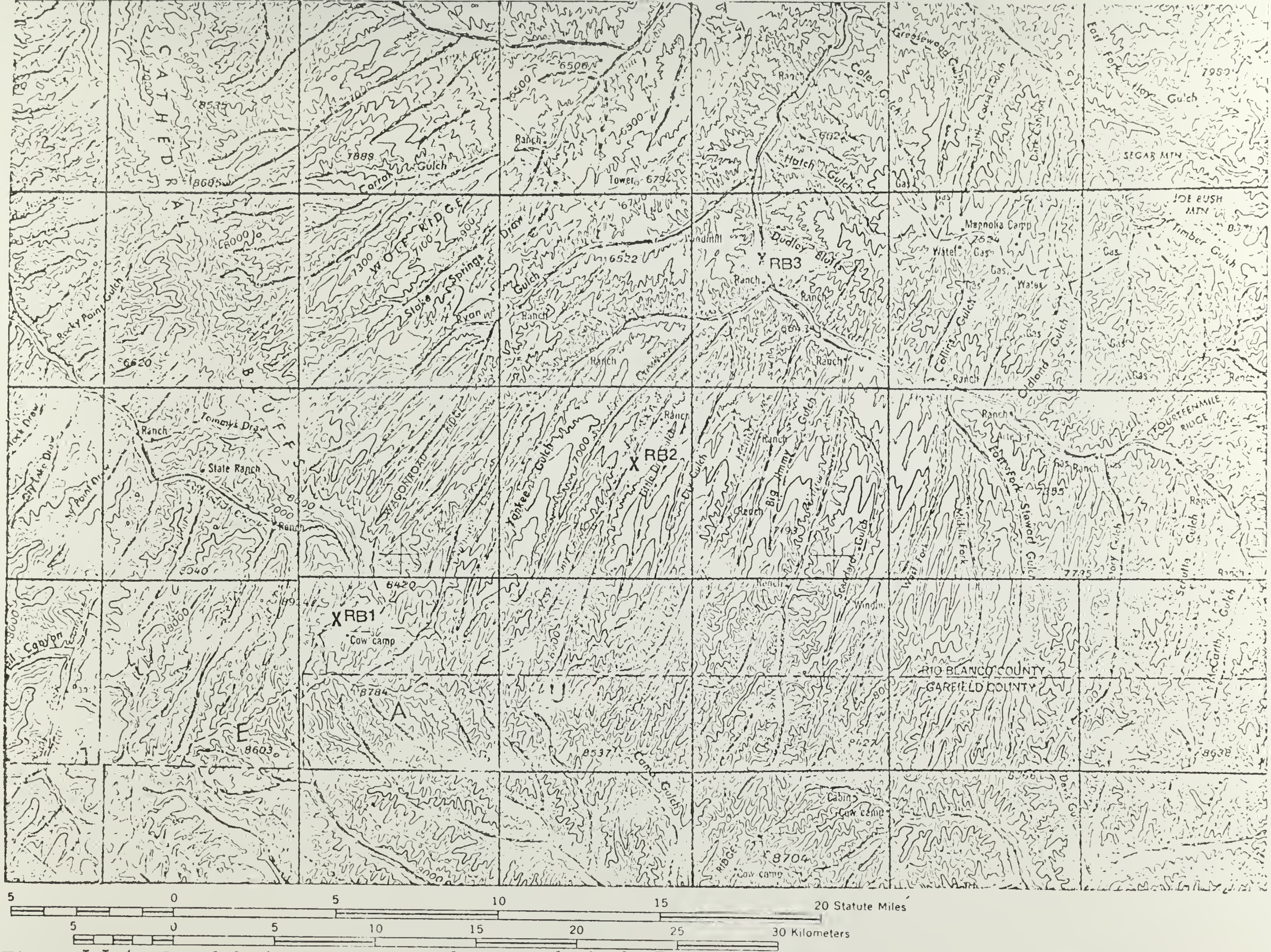


Figure I-I-4. Local drainage patterns and topography in the Piceance Basin showing locations of weather stations.

Terrain irregularities produce special meteorological conditions of their own. During warm afternoons, the laterally constricted but vertically expanding air tends to blow up the valley axis. Such winds, termed valley winds, are generally very light and require a weak regional pressure gradient in order to develop. This flow along the main valley develops simultaneously with anabatic (up-slope) winds which result from a greater heating of the valley sides compared with the valley floor. At night, there is a reverse process as the cold denser air at higher elevations drains into depressions and valleys; this is known as a katabatic wind. The greater loss of heat by radiation affecting the highest elevations, especially if they are snow-covered, cools the immediate surface air and this eventually sinks into the valley by its own weight. Downward movements of cold air motivated in this way set up katabatic winds which lead to an accumulation of cold, dense air in the valley bottom. Intense frost pockets can thus develop in mountainous, or even in moderately hilly areas. If the air drains downslope into an open valley, a mountain wind may develop along the axis of the valley towards the plain, where it replaces warmer, less dense, air. For this reason, the maximum velocities of the katabatic winds are found to occur usually at the times of maximum diurnal cooling (for example, between 0500 and 0600 hours in summer).

Sometimes anabatic and katabatic effects on one side of a pass are much greater than those produced on the other and, occasionally, the anabatic wind of one valley spills over into the upper reaches of the adjoining valley. This valley then experiences downslope flow both by night due to its own katabatic flow, and by day due to the abundant anabatic flow on the other side of the pass. (One of the locations where this anomalous valley wind is observed is the Maloja valley between Engadine and Bergell in Switzerland and, from this locality, the phenomenon has acquired the name Maloja wind or Maloja effect.)

b. Frictional Effects

The dynamic effect of mountains and rough terrain modifies the upper level free airflow considerably and must be considered in the determination of the transport and dispersion characteristics of an area such as the Rio Blanco project area. In some locations, lee waves must be considered, but the Piceance Basin is largely on the windward slopes of higher terrain to the east of the basin. The major effect of terrain roughness on the windward slopes of the Flat Tops is an increase in the frictional force on the wind flow. This retards the velocities and turns the winds in the frictional layer counter-clockwise from the gradient wind vector. For example, flow from the SWS in the area will tend to be turned in the lower layers so that it is more southerly.

3. Interaction of Local Effects and the Gradient Level Flow

In valleys with broad floors, or less-pronounced topography, and a gradient wind parallel to the valley, the local wind system is often obscured and cannot be distinguished from the gradient winds. At night, the local downslope circulation is uncoupled from the upper level gradient flow by a radiation inversion and is predominant in determining the valley wind direction. Transport through these inversions is essentially nonexistent. These inversions are usually broken during the day by surface heating, but under certain conditions may persist well into or through the daylight hours.

A major influence on the formation and persistence of these inversions is the amount and albedo of the snow cover in the winter season. If a snow cover mantles the ground, radiative cooling is greater, for not only is most of the incoming solar radiation during the short day reflected, but at night, the snow, which is an extremely good radiator in the infrared but a very poor conductor, allows little heat to come up from the ground below to replenish that lost by radiation. Thus, a snow cover greatly enhances the radiational cooling and the katabatic flow and, because of its high albedo, the snow reflects incoming radiation during the day and retards the development of the anabatic flow. The amount and character of snow cover is an important factor in the transport and dispersion characteristics of the area.

During the day, there is an interaction between the local circulations and the gradient level flow. The observed winds are reinforced where the directions are aligned, or retarded or replaced by the gradient wind where the directions are opposing.

4. Rio Blanco Area Winds Analysis

The data from the four special recording meteorological stations installed in the project area have been reduced for wind direction, wind speed, and temperature. To determine the most likely flow directions and establish the physical mechanisms that may be operative, plots have been made of wind direction frequency at the four recording stations for the period July, 1970 through April, 1971. The data were obtained in 30-degree sectors and in three-hour time segments. The wind direction frequencies for September, October, and November are indicated in Figures I-I-5 through I-I-8. Several pertinent flow features can be identified in these plots. The observations, based on local time, start at the upper left of the page and proceed through the day and the night and into the next morning.

The flow pattern for RB-2 (Figure I-I-6), the station near the planned EW site, is particularly well defined. For the first two daytime blocks, some up-valley (anabatic) flow can be seen to the SSW sector, but the predominant flow is to the NNE sector as driven by the upper level gradient wind. By the next time block (1700, 1800, 1900 MST), the flow to the NNE sector has increased due to the onset of the katabatic flow and by the 2000, 2100, 2200 hours MST time group, all other flow directions have nearly disappeared. Some up-valley flow started in the 0500, 0600, 0700 hours time group and is significant by the next time block. The predominant flow direction at RB-2 is to the NNE sector both day and night. Over 70% of the observations during the night were to the NNE sector.

Station RB-1 (Figure I-I-5) is evidently controlled almost completely by the upper-gradient level flow. No strong diurnal drainage or up-valley flow regimes are apparent. There is some evidence that drainage down Cathedral Creek results in flow to the NNE sector at night.

Station RB-3 (Figure I-I-7), which is in the main Piceance Creek drainage just down the valley from its intersection with Black Sulphur Creek, exhibits a very strong mountain-valley circulation. During the daylight time groups, there is a fairly prominent up-valley component to the SSE sector. Also during the day, there is flow down-valley to the NNE and NNW sectors driven by the gradient wind. By the 1700, 1800, 1900 MST time block, the down-valley circulation to the NNW has increased just slightly as some of the valley slopes become shaded and, from 2000 through probably 0600, the flow is nearly exclusively down-valley to the NW and NNW sectors. By 0800, the up-valley flow is again in evidence.

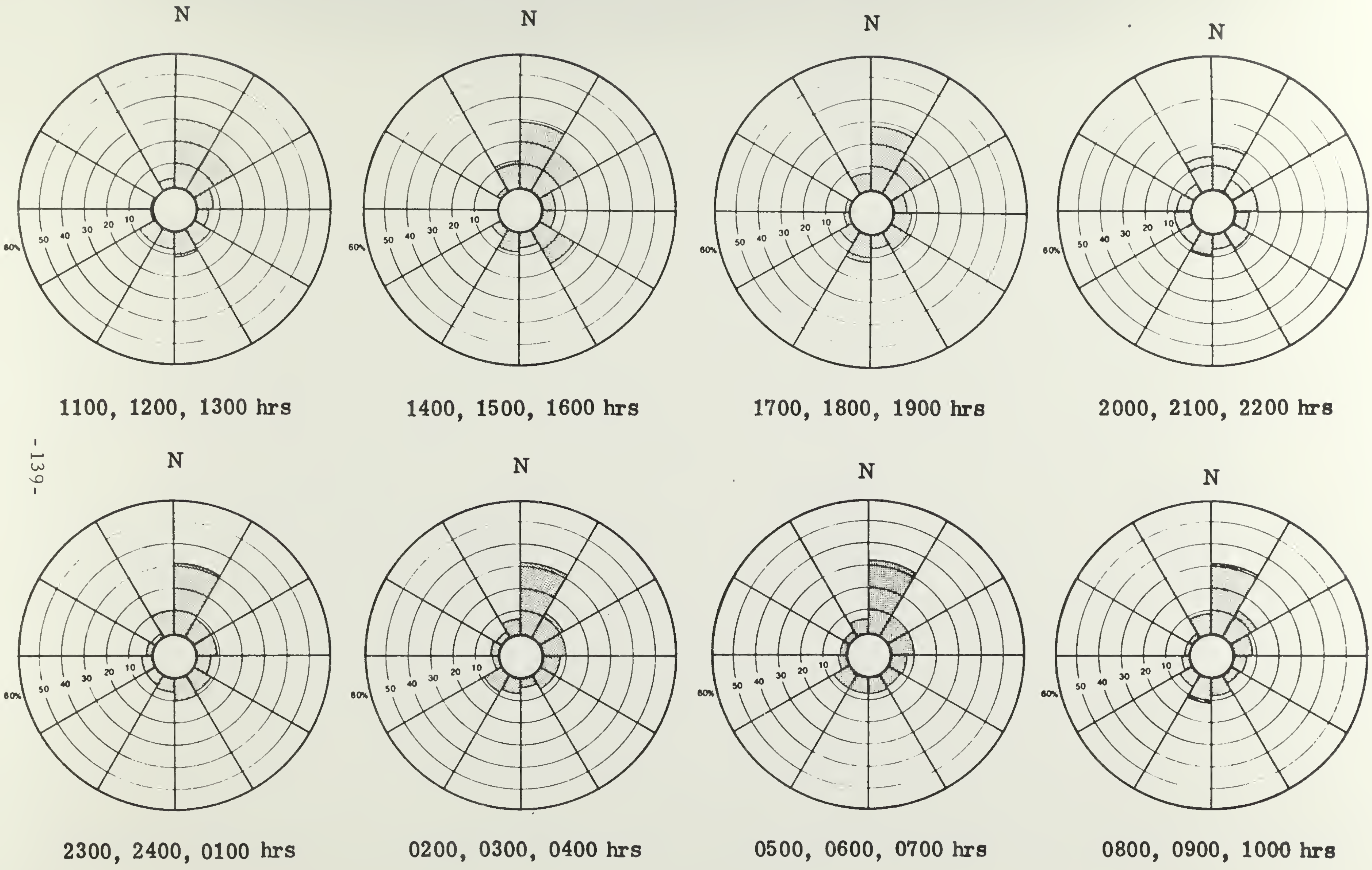


Figure I-I-5. Wind direction occurrences at RBI (September, October, November).

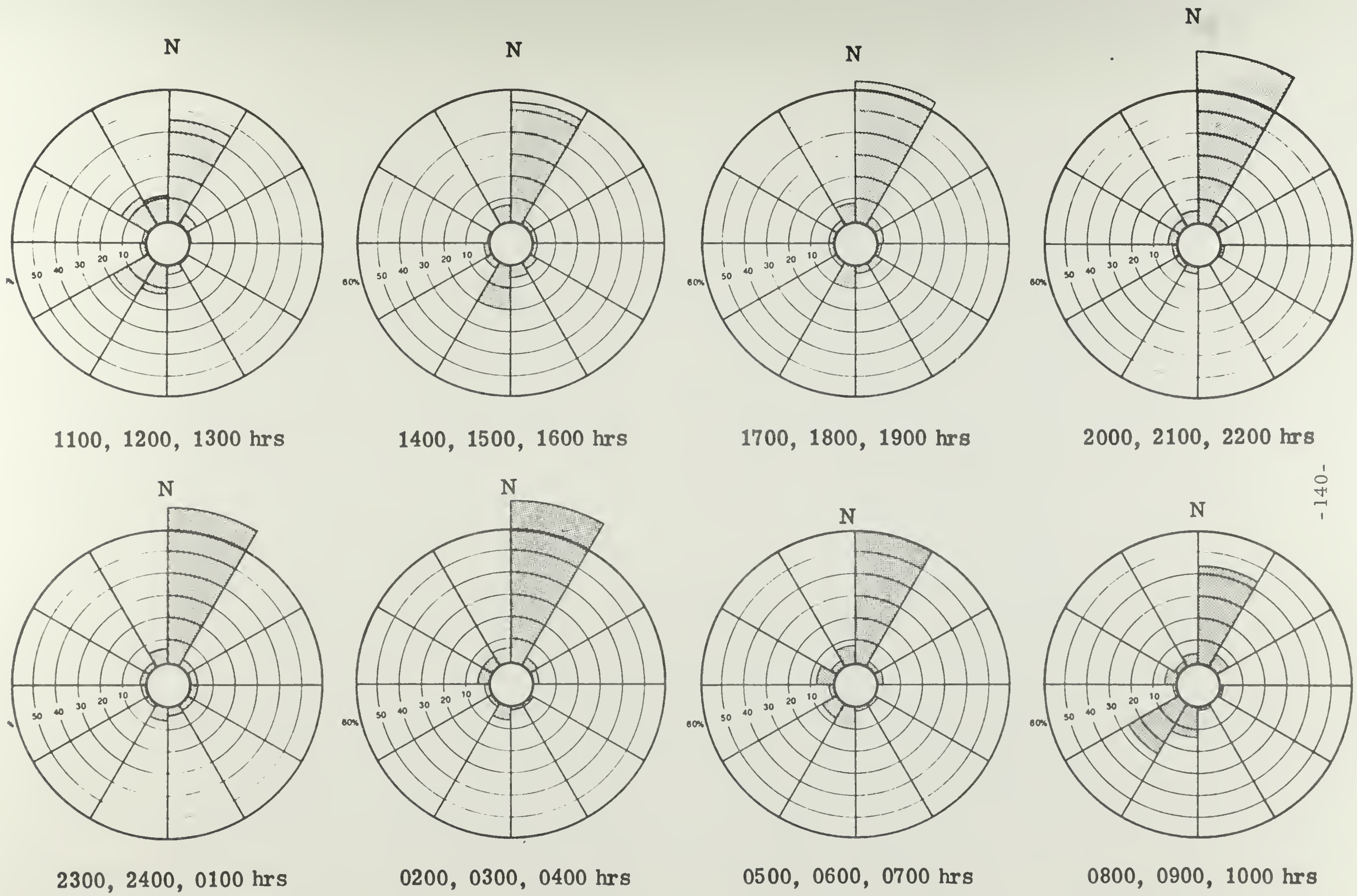


Figure I-I-6. Wind direction occurrences at RB2 (September, October, November).

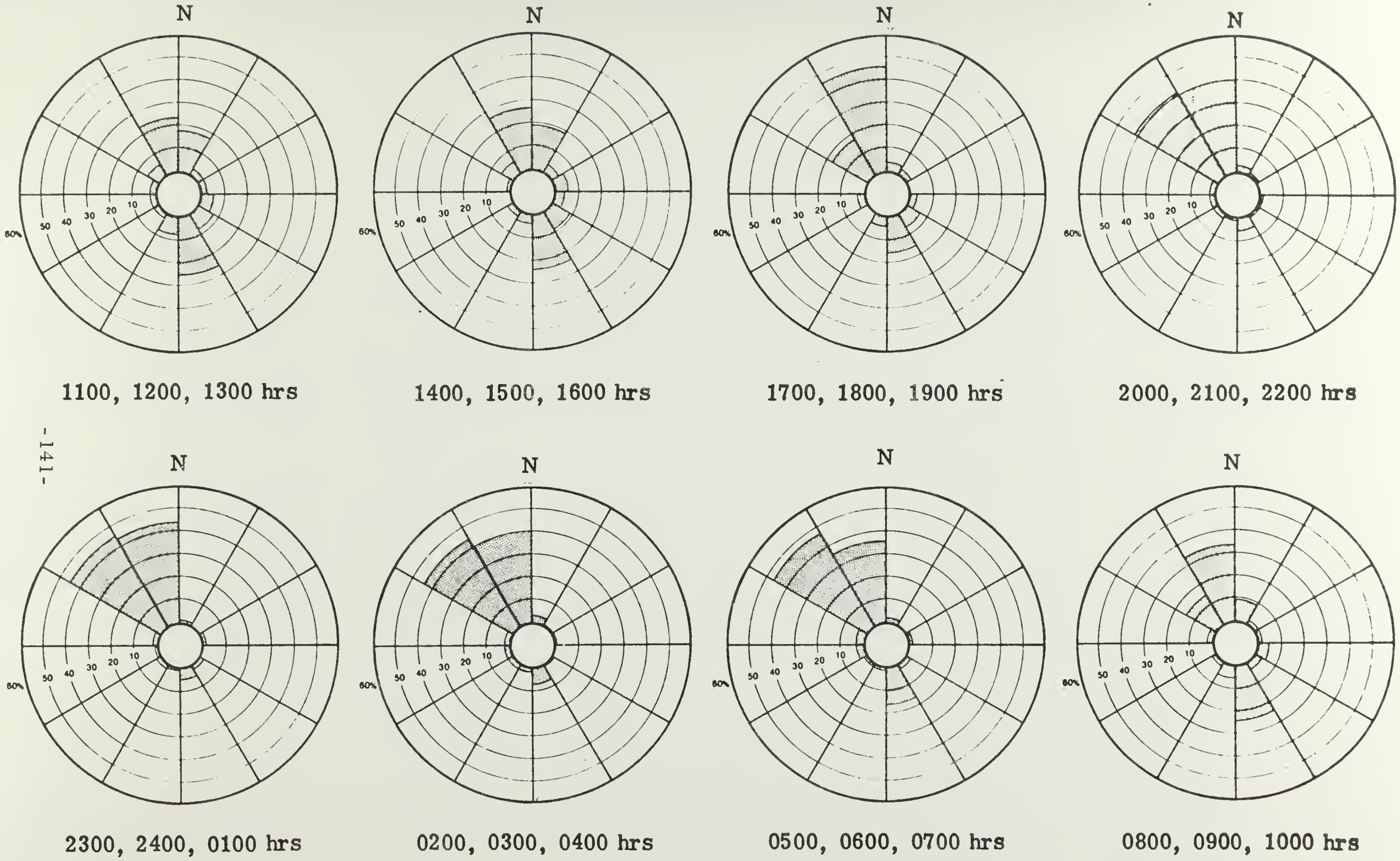


Figure I-I-7. Wind direction occurrences at RB-3 (September, October, November).

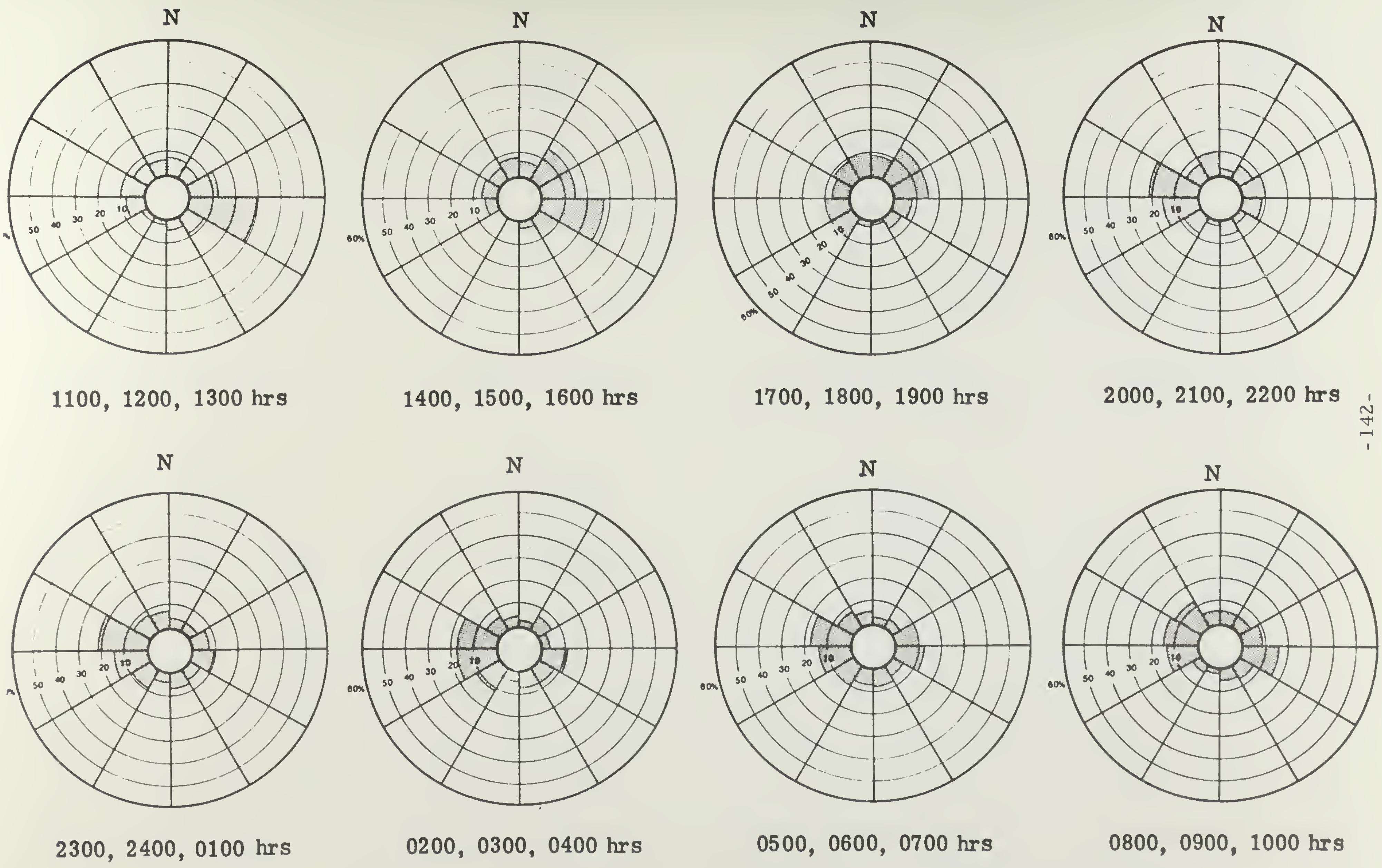


Figure I-I-8. Wind direction occurrences at RB4 (September, October, November).

At Station RB-4 (Figure I-I-8) in the main White River drainage, anabatic flow to the ESE is in evidence during the daylight hours; during darkness, a drainage to the west is in evidence. However, the relationships are much more complicated due to the interaction of a multiplicity of terrain features.

The same analyses for December, January, and February are presented in Figures I-I-9 through I-I-12. Almost all of the same comments apply. One significant factor is the absence of flow to the west at RB-1 (Figure I-I-9) indicating that at 8,500 feet, the station is above the main drainage inversion from flow off the Flat Tops to the east. This appears to be more anabatic nocturnal flow, particularly at Station RB-3 (Figure I-I-11); this may be a Maloja effect. The salient features are nearly identical to those of the fall season cases.

The spring season analyses containing data for March and April are plotted in Figures I-I-13 through I-I-16. Looking at the analysis for Station RB-1, it can be seen that the flow is evidently driven by the upper level flow and that there are no very strong diurnal local effects. There is some increase in flow to the SSE and SE quandrants during the daylight heating hours; this is up-valley flow from Cathedral Creek. There is a hint of a shift in flow to the NNW sectors as drainage flow is established in the early evening down Cathedral Creek. Also, there is a slight increase in components toward the west during the late nighttime blocks, 0200 to 0700, indicating some influence of a deeper drainage flow off the higher terrain to the east. This occurs less than 19% of the time.

Station RB-2 is characterized by over 70% occurrence in the NNE sector during the night. The typical daytime flow is also driven down-valley to the NNE sector by the upper level flow. Anabatic flow to the SSW sectors occurs 15 to 20% of the time during the day. There is a very slight increase in anabatic flow to the SSW during the 0200 to 0400 time block, possibly the result of the incidence of a deeper drainage flow off the Flat Tops.

Station RB-3 exhibits strong drainage flow directions to the NNW and NW sectors 70 to 80% of the time during the night. During the day, the predominant flow is also driven essentially down-valley to the NNE sector, with the occurrence of an anabatic wind to the SSE sector about 20% of the time. There is a small occurrence of 10% nocturnal flow to the SSE sector which is unexplained.

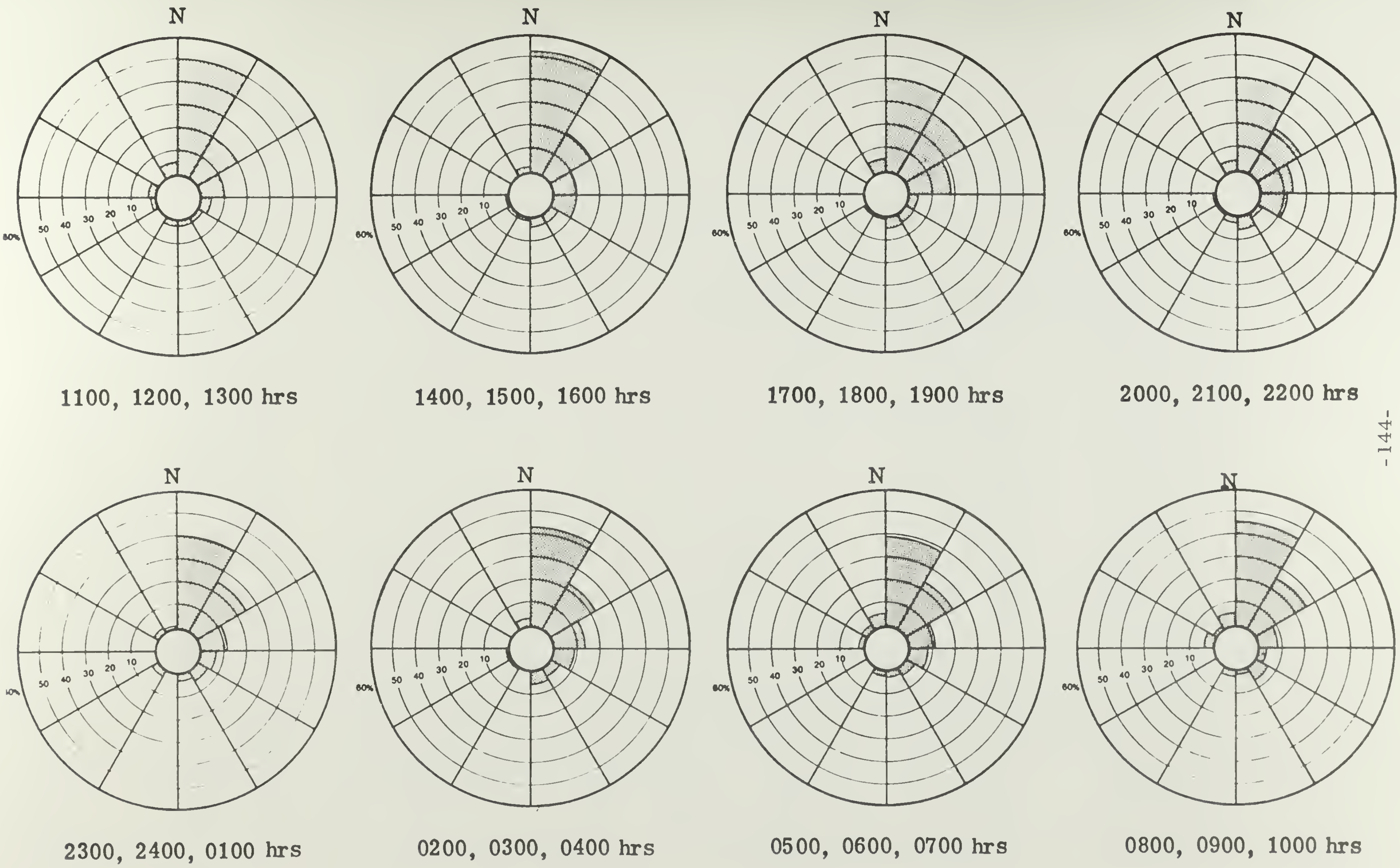


Figure I-I-9. Wind direction occurrences at RB1 (December, January, February).

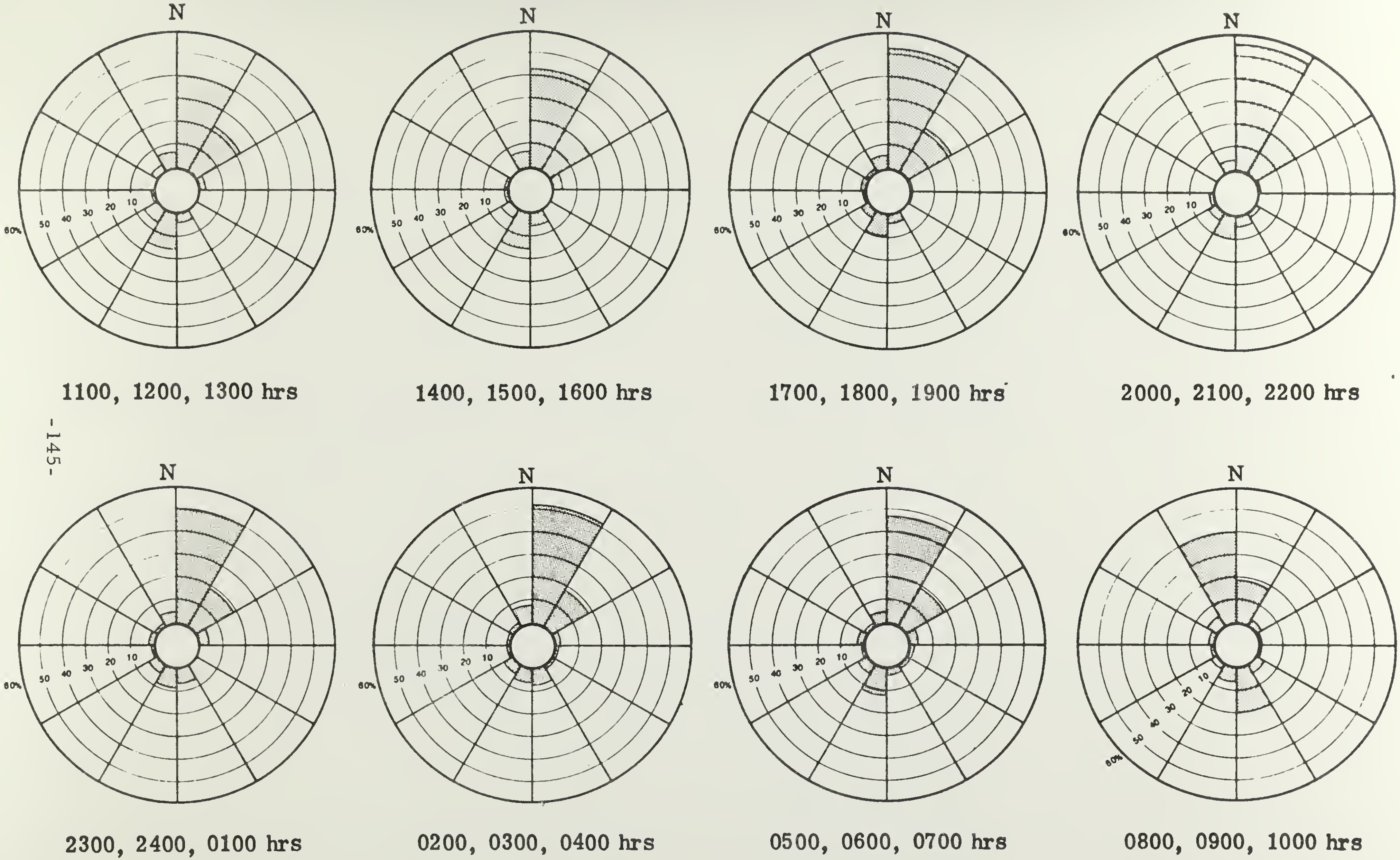


Figure I-I-10. Wind direction occurrences at RB2 (December, January, February).

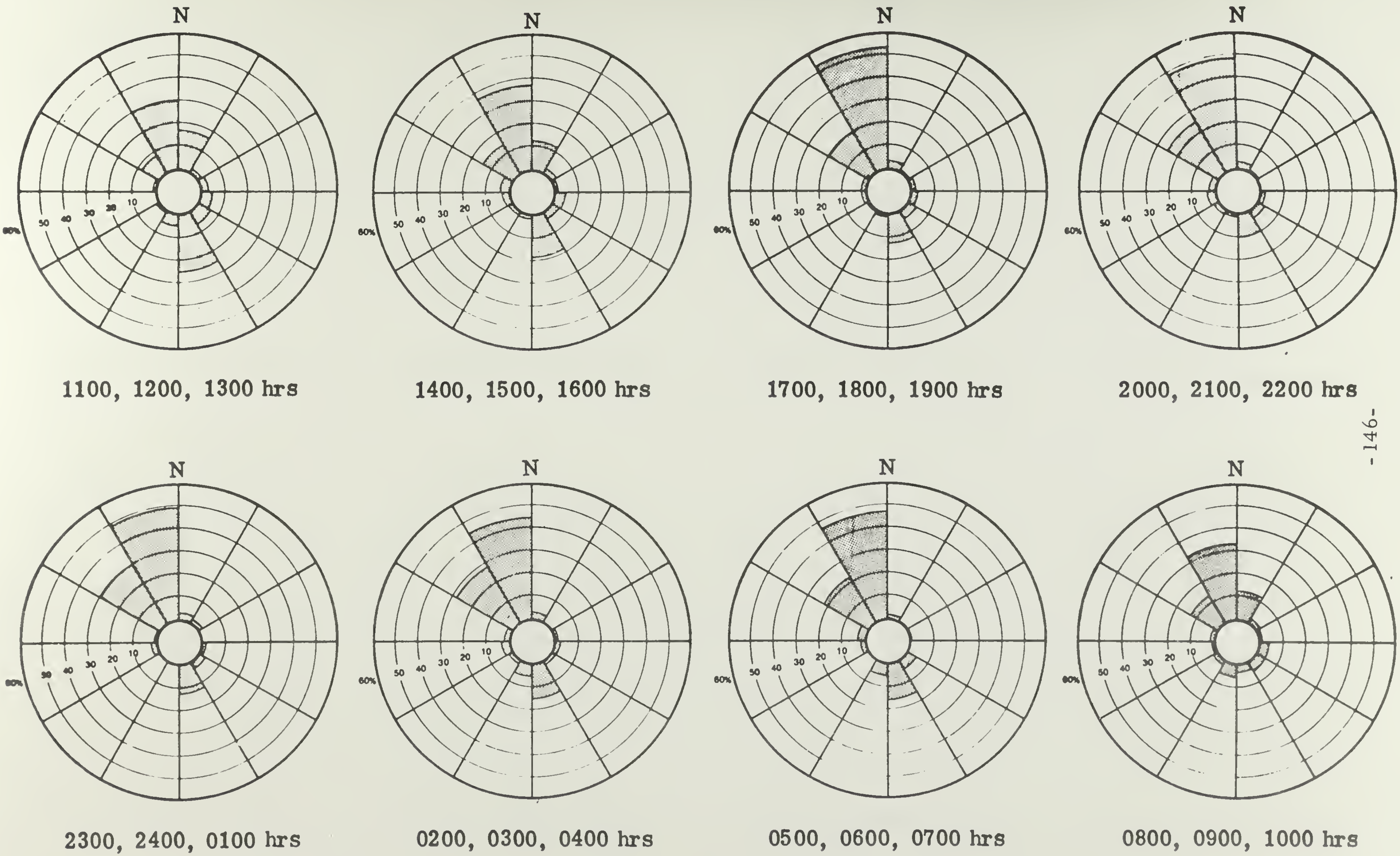


Figure I-I-11. Wind direction occurrences at RB3 (December, January, February).

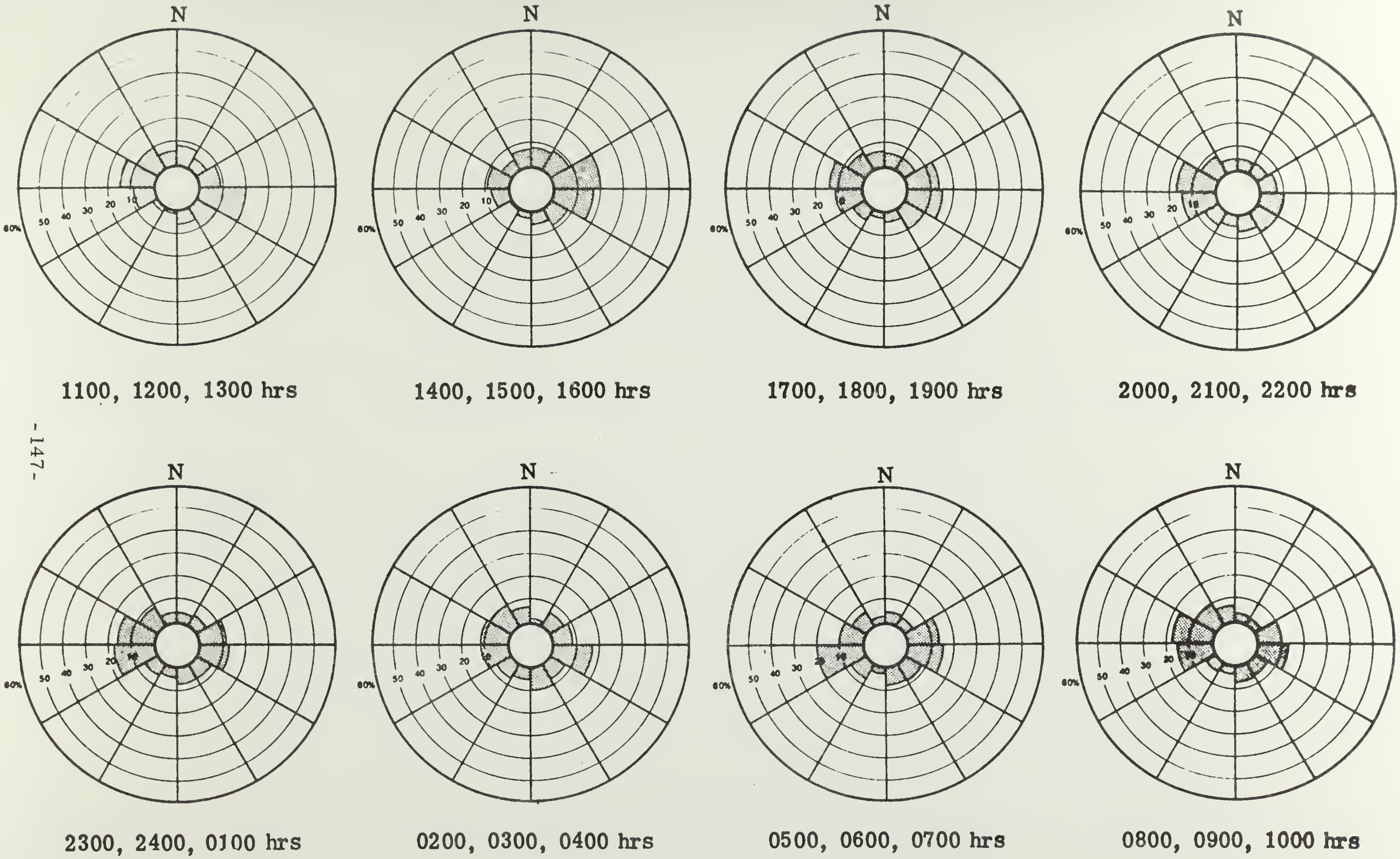


Figure I-I-12. Wind direction occurrences at RB4 (December, January, February).

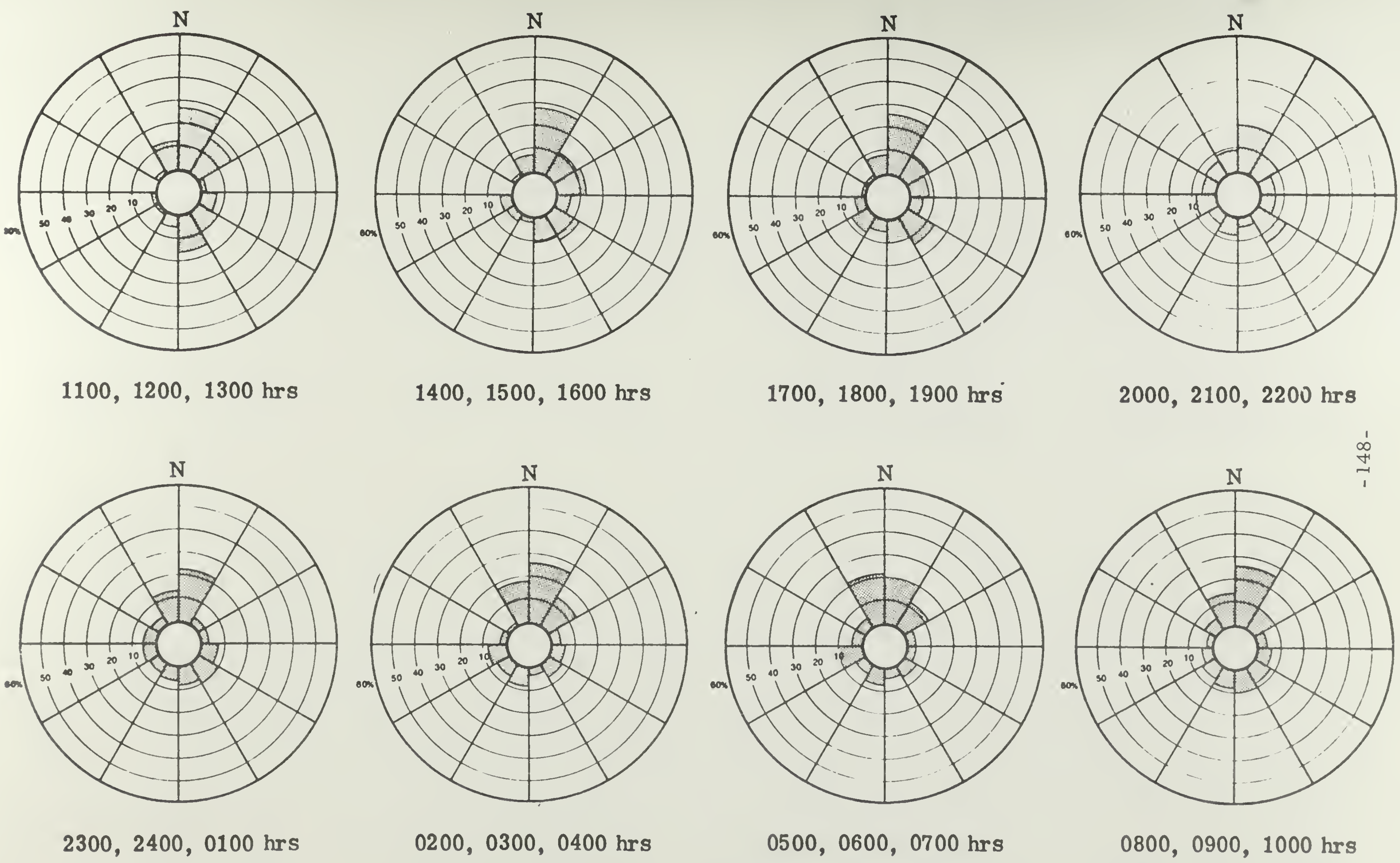


Figure I-I-13. Wind direction occurrences at RB1 (March, April 1971).

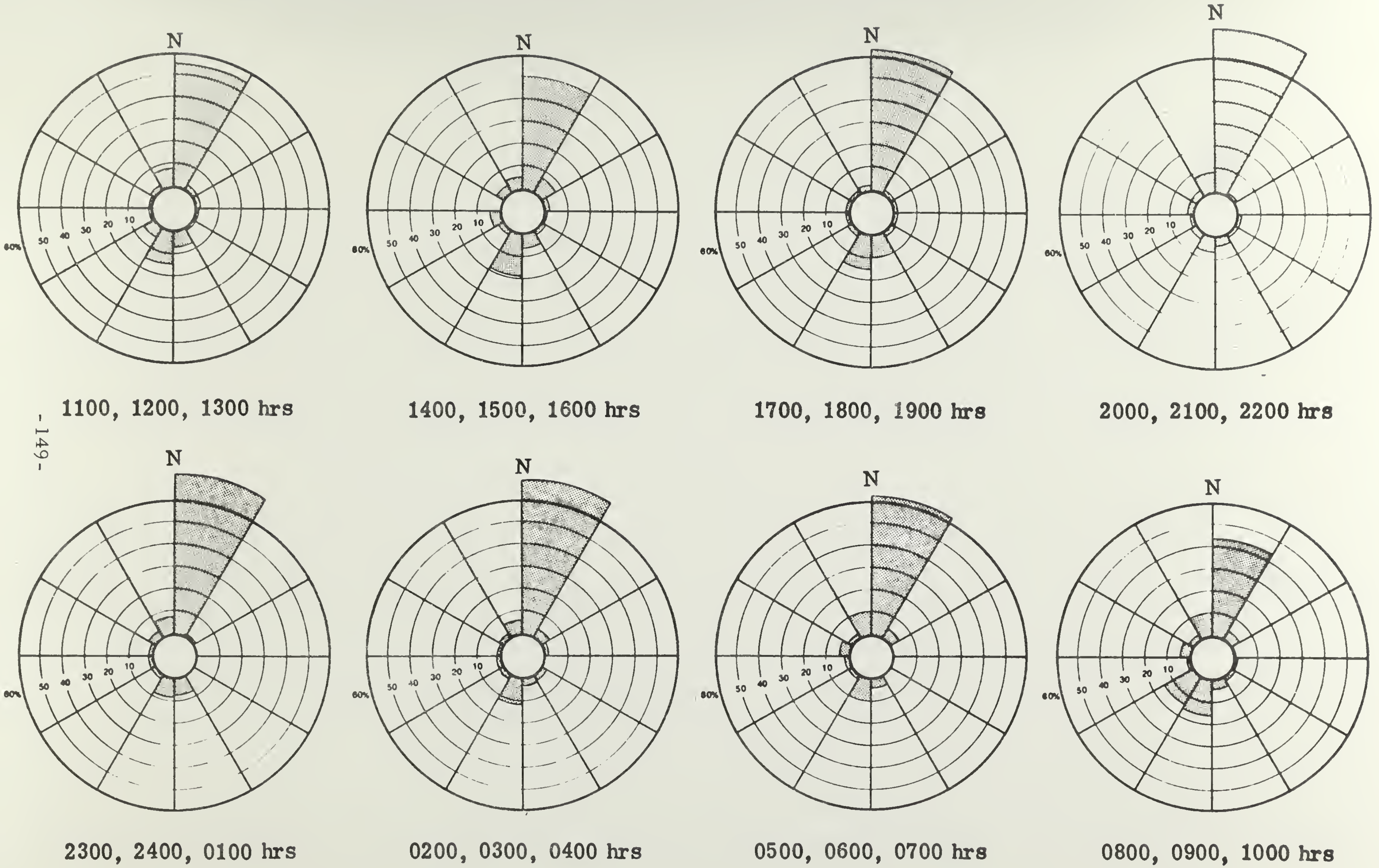


Figure I-I-14. Wind direction occurrences at RB2 (March, April 1971).

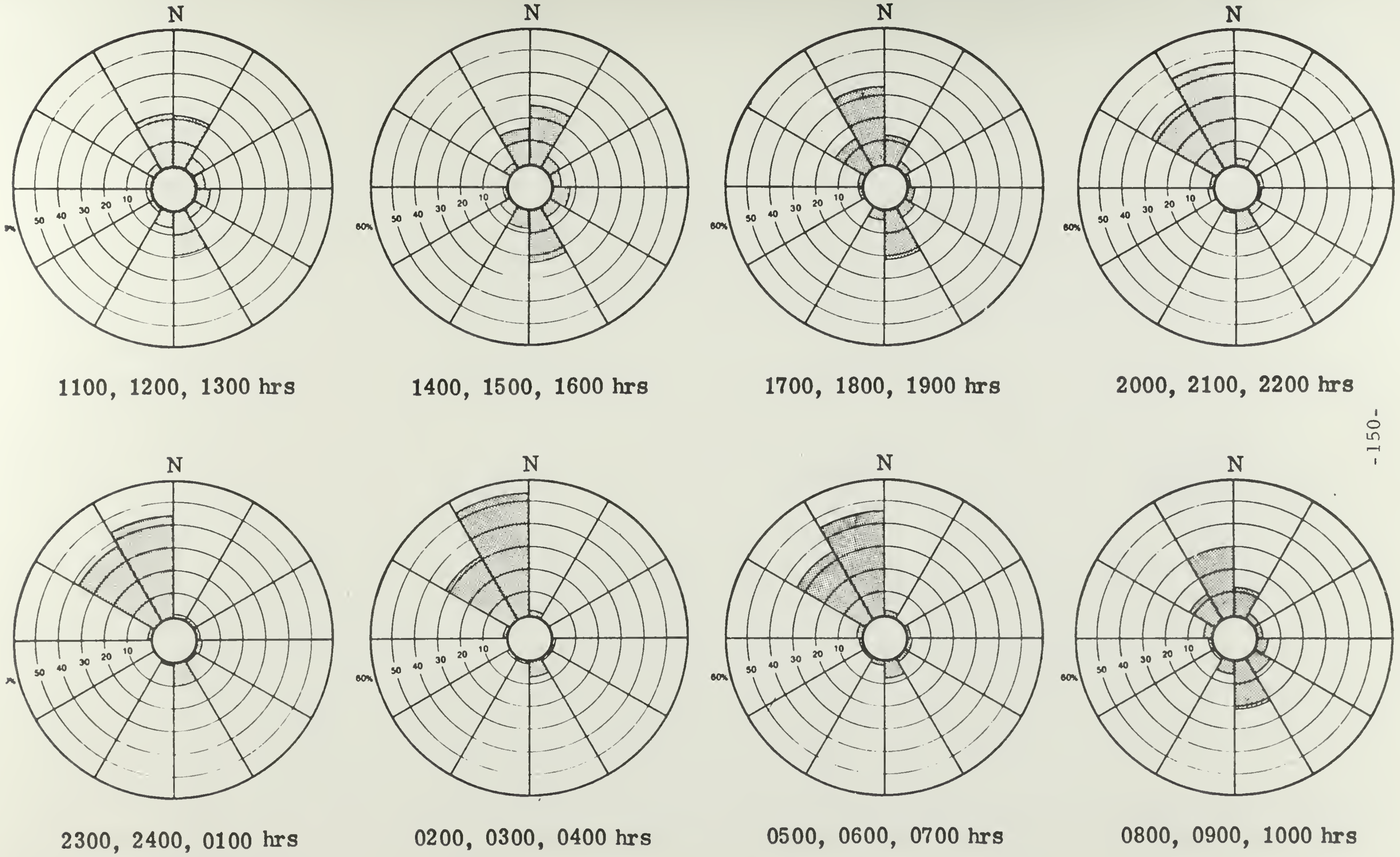


Figure I-I-15. Wind direction occurrences at RB3 (March, April 1971).

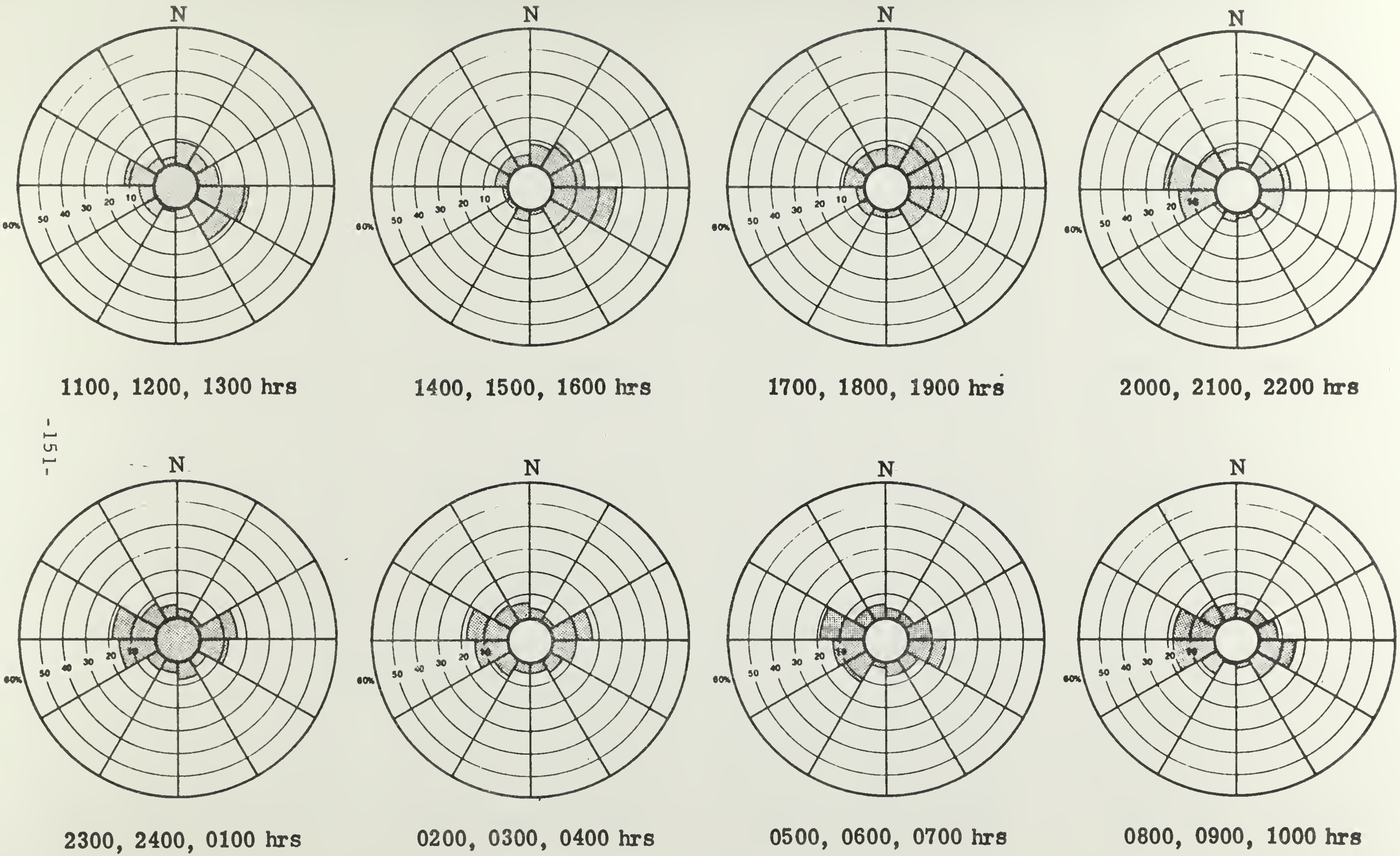


Figure I-I-16. Wind direction occurrences at RB4 (March, April 1971).

Station RB-4 exhibits a mixture of local effects and control by the gradient level winds. Some local diurnal effect is evidenced by an increase in flow to the ESE during the day and an increase in flow to the WNW sector during the night. The effects are not as well defined, or there is a complicated interaction of effects from a variety of terrain features.

The analyses for the summer season incorporating data for July and August are presented in Figures I-I-17 through I-I-20. Station RB-1 appears to be dominated by the gradient level flow. There is no strong increase in components to the west during the night, indicating that this station is above any drainage flows off the higher terrain to the east. Again, there is some small effect from Cathedral Creek evident, as was the case in other seasons also.

Station RB-2 exhibits almost exclusive flow (>75%) to the NNE during the night. The typical daytime flow is also driven down-valley to the NNE by the upper airflow. There is a 20 to 25% occurrence of up-valley to the NNE by daytime heating to the SW and SSW sectors. There is essentially no flow to the SSW during the night.

Station RB-3 exhibits a strong local effect with greater than 85% occurrence of flow to the NNW and NW sectors during the night. During the day the up-valley component does not appear as strongly as in the spring data. During the 0800 to 1000 time block the up-valley flow is strong (>40%) to the SSE sector but becomes weaker (20%) during the rest of the day, presumably as the upper level flow dominates.

Again, Station RB-4 is largely driven by the upper level winds. There is a strong down-valley component (35%) during the 2000 to 2200 early evening time group. During the day there is a moderate up-valley component to the ESE and SE sectors starting with the 1100 to 1300 time block.

In general, the stations with the exception of RB-1 exhibit varying degrees of control by the locally induced circulation of mountain-valley winds.

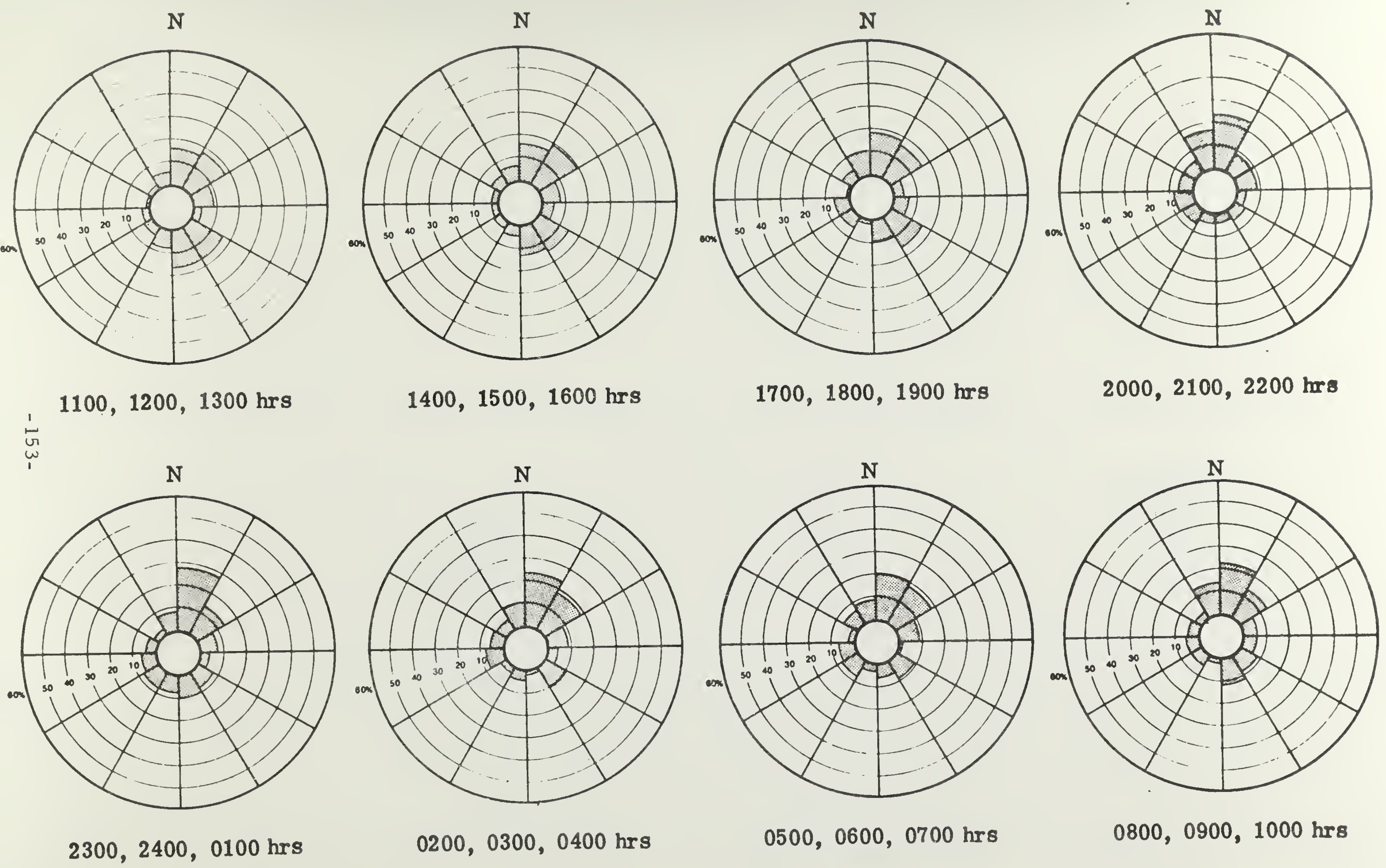


Figure I-I-17. Wind direction occurrences at RB1 (July, August 1970).

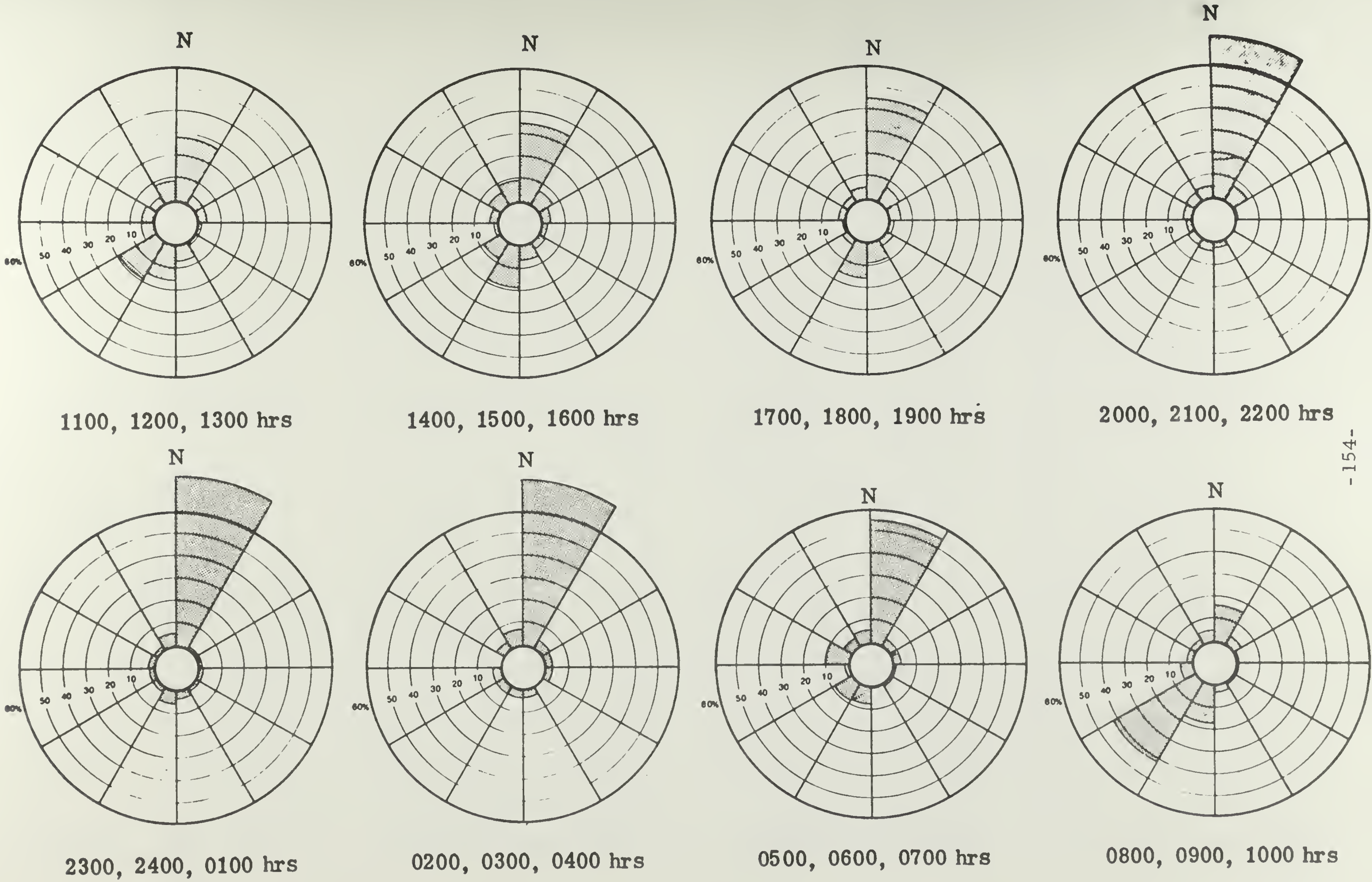


Figure I-I-18. Wind direction occurrences at RB2 (July, August 1970).

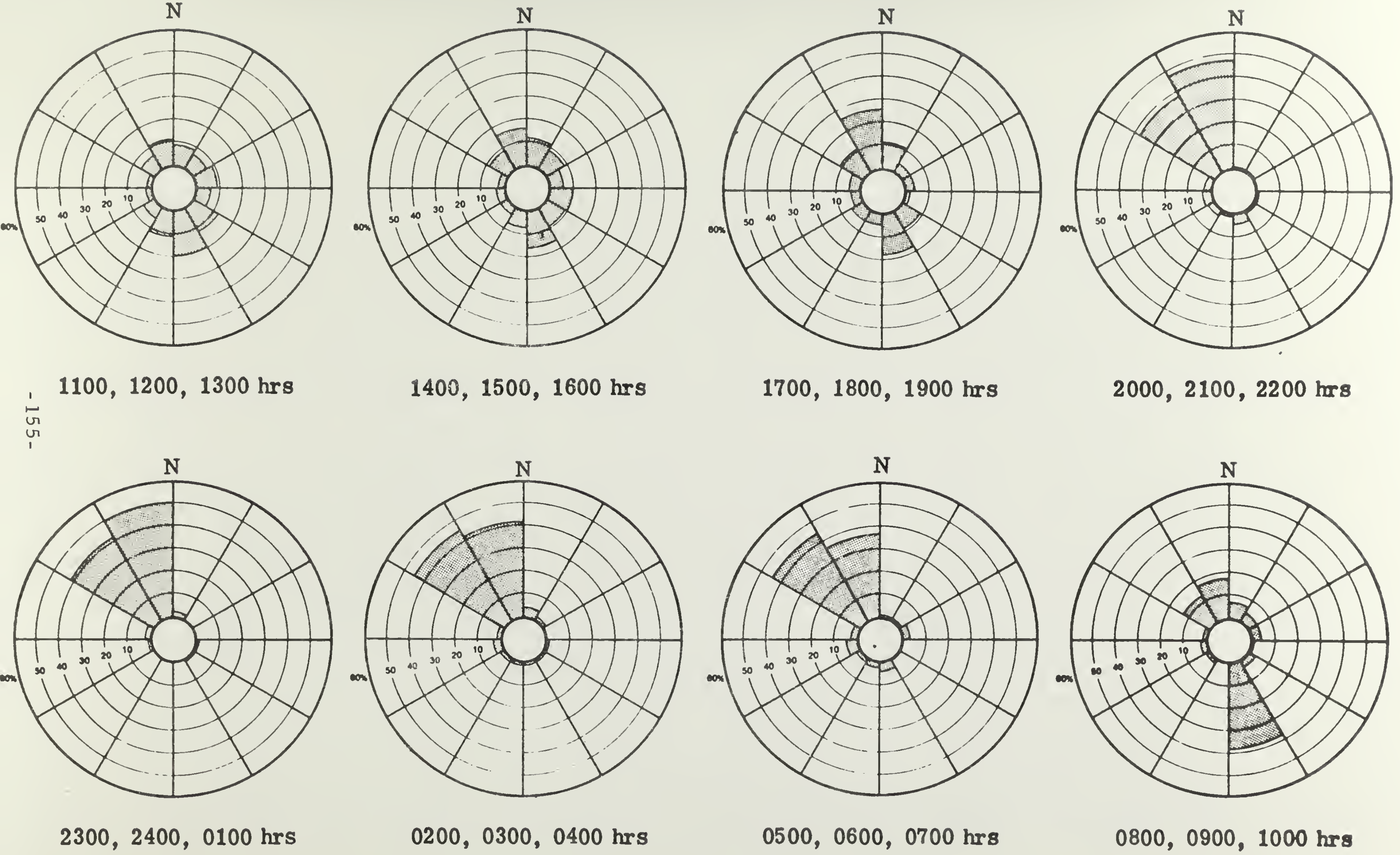


Figure I-I-19. Wind direction occurrences at RB3 (July, August 1970).

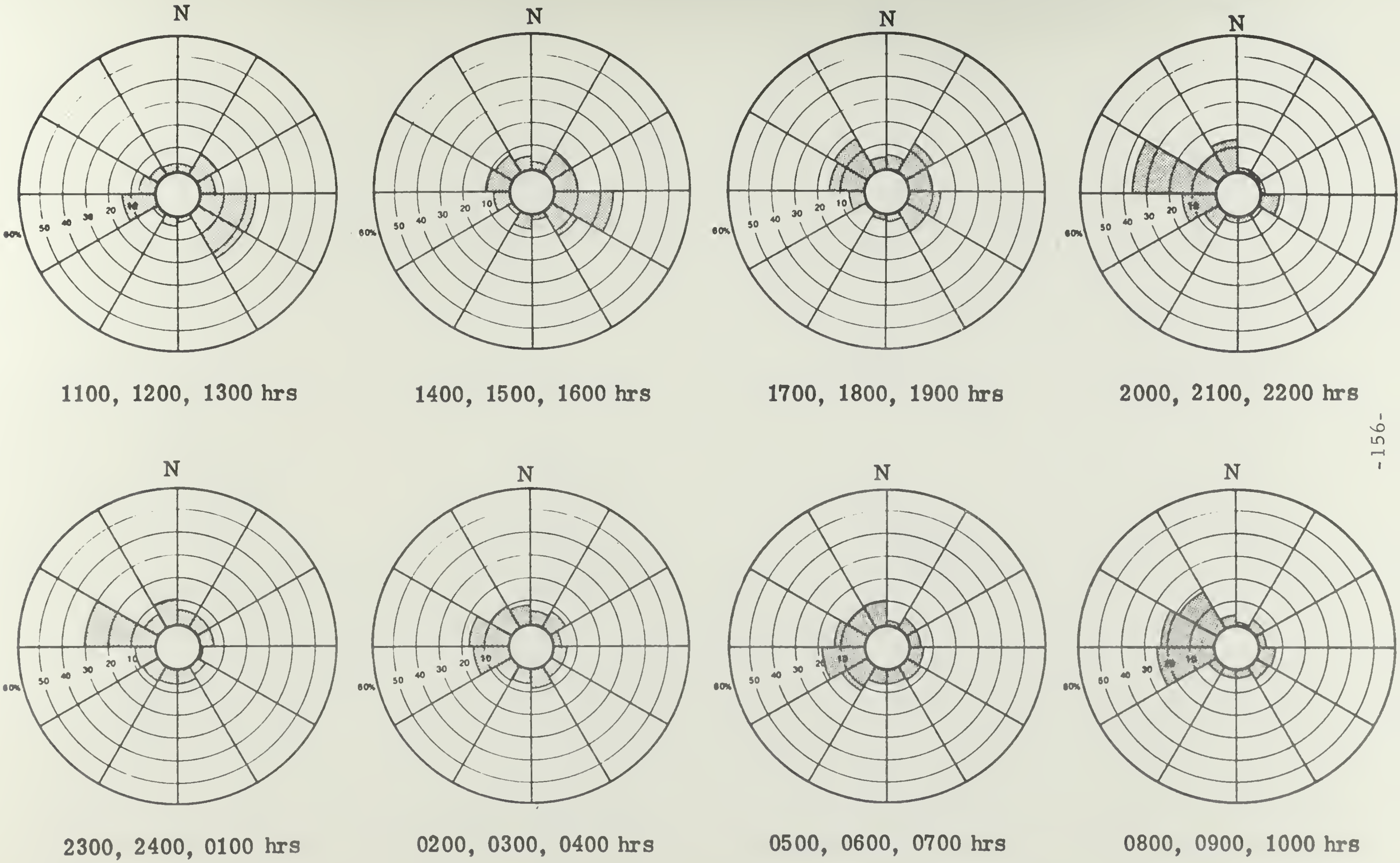


Figure I-I-20. Wind direction occurrences at RB4 (July, August 1970).

5. Analysis of RB-2 Surface Winds by Upper Airflow Categories

It is instructive to determine the direction of the surface flow under various upper airflow regimes and the interaction between the local topographic-controlled effects and the interaction with the upper airflow. To examine this effect, Station RB-2 surface data have been grouped according to the Grand Junction 700 millibars (10,000 feet) wind observations. The January and February period was used as indicative of the winter seasons. The distribution of the Grand Junction data samples by 700 millibars wind category is presented in Table I-I-VIII. The behavior of the observed winds at RB-2 only for those upper airflow categories for which adequate data exist is examined below.

a. Wind from NNE Sector

The valley in which RB-2 is located is aligned so that upper airflow from this sector should enhance up-valley flow to the SSW or SW sectors. During the day the predominant flow is indeed to the SSW sectors but there are still cases of down-valley flow event during the 1100 to 1600 time period. During the night there are a few cases of continued up-valley flow in alignment with the upper airflow, but by the 1700 to 1900 time block a drainage flow regime has started to establish, and flow to the NNE sectors is increasing. By the 0200 to 0400 time block this flow direction is predominant and in direct opposition to the 700 millibar flow direction.

b. Wind from NNW Sector

For upper airflow from the NNW sector, the surface flow behavior at Station RB-2 is similar to that of the flow from the NNE sector. During the daylight hours, 0800 to 1600, this upper airflow direction enhances up-valley flow to the SSW sectors. There is almost no flow to the NNE at all during the day under this upper air direction. The drainage flow sets up very quickly and there is almost no flow at all up-valley. It is all to the NNE sectors from 1700 to 2200. During the late night hours drainage flow to the NNE (2300 to 0700) is predominant, but some flow to the SSW develops. Flow from the NNW aloft over this area is typically characterized by clear skies after a new snowfall, and it is very likely that this late night flow is indeed driven by a deep drainage flow spilling out of the main White River Basin and filling the entire Piceance Basin.

Table I-I-VIII. January-February, 1971 data sample, 700-millibar wind direction distribution analysis.

Direction Category Upper Air Flow from Sector Shown	Pct. Occurrence < 12.5 Knots	Pct. Occurrence >12.5 Knots
NNE	6.0	6.0
ENE	0.9	0
ESE	0.9	0
SSE	3.5	0
SSW	4.3	13.8
WSW	8.6	19.0
WNW	3.4	19.8
NNW	5.2	8.6

c. Wind from WNW Sector (less than 12.5 knots)

The number of cases in this slow wind velocity group is limited, but it appears that the flow is down-valley to the NNE during the night and also during the day, with a few cases of flow to the SSW or up-valley during the day. It is surprising that the up-valley flow is not more dominant with the light WNW winds aloft. During the night drainage flow to the NNE is predominant.

d. Wind from WNW Sector (greater than 12.5 knots)

For upper airflow from the WNW, there are no surface flows at RB-2 in direct alignment with this direction. During the day the cases of down-valley flow driven by the wind are turned from a more northerly to a more easterly direction, particularly during the 1400 to 1600 time block. Also, during the day (0800 to 1600) there is a significant number of cases of up-valley flow to the SSW. The up-valley flow appears at speeds predominately greater than 12.5 knots. Drainage flow to the NNE is dominant during the night.

e. Wind from WSW Sector (less than 12.5 knots)

The RB-2 surface flow for upper air wind from the WSW sector with low velocities is predominately to the NNE sector. During the day the up-valley flow does not set up strongly in opposition to these light upper air winds. Drainage flow to the NNE is again dominant during the night and some erratic up-valley flow cases are also present during the night.

f. Wind from WSW Sector (greater than 12.5 knots)

Climatologically, this is the most likely upper air direction category, so it is particularly important to note the surface wind behavior in this category. During the daylight hours, and particularly from 1100 to 1600, surface flow is nearly in alignment with the upper air direction. Some up-valley flow builds in opposition to the upper level flow, but this is minor. During the night the flow is also to the NE; it appears that this is less of a pure drainage regime, being partly driven by the upper level winds, as indicated by the wider spread of direction values. This is important because it would indicate less stability and better dispersion if the nocturnal inversion tended to be broken by flow from this direction. Again, some largely unexplained nocturnal up-valley flow is indicated.

g. Wind from SSW Sector

The 700 millibar flow in this direction is nearly aligned with the down-valley direction. During the day the flow to the NNE sectors in alignment with the upper airflow direction is dominant. Some up-valley flow is able to establish in opposition to the upper airflow direction. During the early evening, it appears that a true local drainage flow to the NNE is setting up during the 2000 to 2200 time period. During the later night, 2300 to 0700, there is spreading across a wider sector and by the 0500 to 0700 time block, flow to the ENE sector is predominant and persists through the next time block.

6. Other Climatological Data

Table I-I-IX presents climatological temperature and precipitation data from the National Weather Service Station at Little Hills, about 19 miles northeast of the EW location. Table I-I-X presents a summary of Grand Junction flying weather categories as a function of wind directions. Table I-I-XI presents a 20-year record of thunderstorm climatology at Grand Junction.

Table I-I-IX. Surface climatological summary of temperature and precipitation (through 1960) at Little Hills Station (elevation 6, 148 feet) about 19 miles NE of EW.

	Temperature - °F.					Precipitation	
Month	Mean	Mean Max.	Mean Min.	Highest	Lowest	Mean (in.)	Days ≥ 0.1 in.
J	21.7	38.3	5.0	60	-35	.93	3
F	24.6	41.8	7.8	64	-32	.85	4
M	32.0	47.4	16.6	70	-25	1.20	4
A	41.9	59.1	24.5	80	7	1.28	3
M	50.5	68.8	32.3	87	13	1.01	4
J	58.7	79.5	37.9	97	20	0.92	2
J	65.3	86.3	44.4	98	30	1.09	3
A	63.4	83.4	43.7	98	28	1.71	4
S	56.0	77.8	34.2	95	12	0.88	4
O	44.4	65.0	23.7	91	-1	1.19	3
N	31.2	48.8	13.7	68	-27	0.93	4
D	24.4	41.2	7.7	69	-30	0.85	3
Annual	42.8	61.5	24.3	98	-35	12.84	41

Table I-I-X. Percentage frequency of occurrence of flying weather categories as a function of wind direction, Grand Junction, Colorado.

Wind Direction	Direction Frequency	Ceiling (ft) Visibility (mile) <1,000 ≦3	1,000-5,000 >3	>5,000 >3	Wind Speed (MPH) 1-12	13-38	>39
360.0	3.7	3	11	86	88	12	-
022.5	2.1	2	10	88	88	12	-
045.0	2.8	2	7	91	89	11	-
067.5	4.5	1	6	93	94	6	-
090.0	4.8	1	6	93	94	6	-
112.5	18.7	1	3	96	78	22	-
135.0	13.1	1	3	96	85	15	-
157.5	6.7	1	5	95	85	15	*
180.0	4.8	2	6	92	81	19	-
207.5	2.2	1	4	95	74	26	-
225.0	2.5	1	6	93	75	25	-
247.5	2.3	1	7	92	85	15	-
270.0	3.9	2	8	90	82	18	-
292.5	9.1	2	9	89	81	19	*
315.0	7.1	3	10	87	81	19	-
337.5	4.2	2	12	86	83	17	
Calm	7.6	4	7	89			

*Rare occurrence.

Table I-I-XI. Grand Junction, Colorado 20-year thunderstorm climatology.

	20-Year Total	Mean/ Season	Mean/ Month
Dec., Jan., Feb.	5	0.25	.08
Mar., Apr., May	169	8.5	2.7
June, July, Aug.	745	37.2	12.4
Sept., Oct., Nov.	206	10.3	3.4
Totals	1,125	56.3	18.6

REFERENCES

I-I-I. Holzworth, G. C., "Estimates of Mean Maximum Mixing Depths in Contiguous U. S.", Monthly Weather Review, 92, 5 (235) (1964).

J. AIR QUALITY

1. Airborne Particulate

The Colorado Department of Health operates an air sampling network of about 50 stations distributed throughout the State. None of these are in the Piceance Creek Basin.* The closest stations are distributed along the Colorado River between Rifle and Fruita. Because the data obtained at these stations are heavily dependent on local sources of airborne particulate matter, local topography, and meteorological conditions, they are not representative of conditions prevailing in the Piceance Creek Basin; hence quantitative data on air quality are not available for the basin. However, in the absence of known sources of airborne particulate matter in the basin other than occasional vehicular traffic at seasons when the roads are dusty, it is believed that the air quality in the basin is well within the air quality standard goals set for the State.

2. Radioactivity

Data on airborne radioactivity have been collected at several locations near the Piceance Creek Basin, including extensive measurements associated with Project Rulison. These are believed to represent baseline background values, except where indicated, which are representative of the Piceance Creek Basin.

The Western Environmental Research Laboratory (WERL), formerly the Southwestern Radiological Health Laboratory (SWRHL), under the U. S. Public Health Service but recently transferred to the newly established Environmental Protection Agency (EPA), with the cooperation of Continental Oil Company, maintained an air-sampling station during 1968 and 1969 at a point near Douglas Creek, about 25 air miles northwest of the Rio Blanco well location. Filter papers were counted for beta activity exceeding about 350 kev in energy. These data are summarized by quarter as follows:

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*In September, 1971, the Department expanded its network to include stations at Meeker, Rangely, and the Equity Oil Company camp near the EW. Filter samples will be analyzed for air particulate contaminants and gross alpha and beta radioactivity.

Summary of Radioactivity Observations at WERL Station #109
Rangely, Colorado (Located in S18, T1S, R101W)

Year and Quarter		Beta Activity (pCi/m^3)
1968	1st	0.21
	2nd	0.22
	3rd	0.13
	4th	2.8*
1969	1st	0.3
	2nd	0.8
	3rd	0.4
	4th	0.2

Comparable beta activity data were tabulated by WERL for five stations operated during Rulison operations, August to September, 1969 and April to October, 1970. These stations were operated at De Beque, Grand Valley, Rifle, Silt, and the community of Rulison, at distances ranging from 5 to 20 miles from the Rulison well location. All monthly averages for these five stations and the periods indicated were less than or equal to 1.0 pCi/m^3. The highest single daily average was 2.0 pCi/m^3 at the Grand Valley location.

The Colorado Department of Health (Ref. IJ-1) also operated eight air sampling stations throughout 1970 at populated locations along the Colorado River, from Glenwood Springs to Fruita and at Montrose. Annual mean beta activities vary from 0.49 to 0.63 pCi/m^3. The maximum monthly average observed was 1.81 pCi/m^3 at Rifle. The department investigated 374 filter papers by gamma spectroscopy. A typical spectrum includes peaks due to ^{141}Ce, ^{144}Ce, ^{103}Ru, ^{106}Ru, ^{7}Be, ^{95}Zr, and ^{95}Nb.

The department also reported on long-lived alpha activity at each of the eight stations. The annual average concentrations varied from .008 pCi/m^3 at Montrose and Glenwood Springs to 0.147 pCi/m^3 at Rifle. The higher activities were determined to be due to polonium-210, a decay product of uranium-238, a by-product of the vanadium plant at Rifle.

*Perturbation due to a few days of higher concentrations resulting from induced tungsten activity from the Schooner cratering experiment at the Nevada Test Site.

Air moisture samples were also collected in the Rulison area before reentry and during Rulison flaring operations. Of 49 samples assayed for tritium, 48 were in the background range of 5 to 10 pCi/m^3 of air. The assay for the other sample, collected just north of the Rulison site during the intermediate rate flaring, was about 28 pCi/m^3 of air, well below the uncontrolled area radioactivity concentration guide of 66,000 pCi/m^3 of air.

REFERENCES

IJ-1. Colorado Department of Health, Division of Occupational and Radiological Health "Project Rulison - 1970 Environment Surveillance, Summary Report."

II. PROBABLE IMPACT ON THE ENVIRONMENT

A. SITE CONSTRUCTION AND OPERATIONS

1. Emplacement Well Location

The EW location consists of the drill pad, adjacent mud pits, operational areas, which include space for office trailers, and the passive microwave repeater site located on the hill approximately 800 feet to the north. The total area described which will be cleared of the native growth and stabilized by compacting and grading the native materials amounts to less than four acres of land.

a. Drill Pad

The principal area of field operation for the experiment (EW drilling, nuclear stimulation, reentry, production testing, and flaring of the gas) is in the NW/4 of the NW/4, S14, T3S, R98W.

All surface facilities and equipment used during the experiment are portable or removable at the conclusion of the experiment with the exception of the required natural gas wellhead and the associated concrete cellar.

Anchors used to tie certain facilities to the ground during the detonation phase of the nuclear explosive package will be removed. Fencing will be erected around certain facilities to control access. The fencing materials will be removed when access control is no longer required.

b. Mud Pits

Two types of mud pits are required for use during the experiment, both steel tanks and those excavated in the ground. The steel tanks are portable while those excavated in the ground require treatment to the bottom and sides of the excavation to prevent leakage and erosion while in use. The size of the excavated mud pit is equal to three times the volume of the drilled hole or approximately 950 cubic yards or 192,600 gallons of storage volume. The excavated mud pit would be a minimum of 200 feet from Fawn Creek at the closest point.

The sides and the bottom of the mud pit will be sealed by mixing the native soil with bentonite. As water is added, the bentonite will swell and close the voids between the grains of soil to prevent leakage of water or drilling mud. At the conclusion of the experiment, the excavated mud pit will be backfilled.

c. Foundations

The items that require foundations are those that remain at the EW location during the actual detonation. In addition, the 90-foot flare stack used during the post detonation production testing and flaring of the well will require a foundation and guy wires to maintain it in a vertical position. All other items of equipment such as trailers, storage sheds, generators, drill rigs, etc., are portable. With the exception of the actual wellhead equipment and associated concrete cellar and anchor for the drilling rig, all foundations will be removed at the conclusion of the experiment.

2. Power Lines

No power lines exist in the Fawn Creek drainage at this time, except for minimal service which terminates in S30, T2S, R97W. Construction of a permanent power line is anticipated. This will include improvement of the existing power line from its beginning in the Black Sulphur Creek area and extension to the well location, a distance of approximately six miles.

Construction of the new power line adjacent to the existing access road will not require clearing and grading of additional right-of-way. It will probably be necessary to clear the sagebrush at locations where poles are erected. Also, it will not be necessary to cross land where local ranchers are raising forage crops for their livestock.

3. Gas Lines

Gas lines will be installed from the existing Fawn Creek Government Number 1 Well, approximately 1,350 feet north to the proposed EW and about 800 feet farther north to the location of the flare stack. The gas line will be laid on the surface and will not require clearing or grading. A road crossing will be provided by the installation of a culvert in the existing Fawn Creek access road through which the gas line will pass. Clearing and grading will be required for the 800 feet of line between the proposed well and the flare stack location. The clearing and grading involved are included in the four acres described in the EW location paragraph above. These gas lines will be removed at the conclusion of the experiment.

4. Roads

The existing access road in the Fawn Creek valley will be improved from its present BLM trail road classification to an all weather access road. Drainage structures will be provided at major arroyo crossings, and the existing road surface will be graded to provide an 18-foot wide compacted native material surface suitable for vehicle speed of 30 miles per hour. Additional right-of-way will not be required and those sections of the existing road that are fenced will remain fenced.

Present maintenance of the road is by the county on a very limited basis, but during the experiment, the road will be maintained. All other roads associated with the experiment are adequate in their present condition, although additional maintenance may be required for all weather operation.

5. Communications

It is planned to install telephones at the EW and Grand Junction Control Point (GJCP) locations. At this time, no telephone service is available at the EW.

A microwave system is being considered for communications between the EW and the GJCP location. It will utilize a system of repeaters located on selected sites determined by communications surveys.

6. Traffic

Principal access roads to the sites are the Piceance Creek, Black Sulphur and Fawn Creek roads which serve the EW area, and Collins Gulch road which serves the Firing Point Control Point (FPCP) area. Most of the ranchers in the area live adjacent to the Piceance Creek Road or the Black Sulphur Creek Road.

The types of heavy vehicles that will require access to the areas would be the drilling rig, rig-up trucks, cementing trucks, logging trucks, earth-moving equipment, material delivery trucks, and trucks delivering trailers, etc. This type of vehicle has been used in the area for prior and current drilling operations, and traffic will be limited to the access roads to the well area.

The types of light vehicles that will require access to the areas are sedans, station wagons, and pickups.

The total of these vehicles is not a significant increase over the present use by residents, hunters, fishermen, and oil and other gas operators.

CER's Industrial Safety Program will include specific agreements with contractors for safe driving.

7. Erosion Control

Erosion control will be established by a continuing maintenance program during the experiment. The working areas will be compacted to support vehicular traffic and drainage will be provided.

Where earth fill is required and a potentially unstable bank results, methods such as seeding will be employed to stabilize the bank and prevent erosion.

8. Water Requirements

Approximately 200,000 gallons of nonpotable water will be required to produce the drilling mud necessary to drill the EW and also to complete the redrilling during the reentry process. The water will be taken from Fawn Creek and will require installation of a portable water pump on the bank and a pipeline to the tankage area. The volume of water required will be removed over a period of several weeks. The effect on surface flow is considered negligible in view of the magnitude of surface flow in Fawn Creek, estimated to be 500,000 gallons per day.

Other requirements for nonpotable water would be for such items as dust control on the access road during the dry weather months, provided considerable operational activity was in progress. The entire access road to Fawn Creek can be watered to control dust utilizing 50,000 gallons of water per treatment.

A sourve of potable water will be be developed in the area at this time. Drinking water will be hauled to the experiment site from existing sources.

9. Unavoidable Adverse Effects

Unavoidable adverse effects will be limited to the clearing of four acres of land at the EW, plus a maximum of three acres elsewhere.

10. Site Restoration Plans

At the conclusion of the experiment the remaining equipment and facilities, including the foundations, will be removed from the EW. The native material will be reshaped to more natural grades to prevent erosion and then planted with a wheat-type grass (Agropyron (smithii) to replace the sagebrush.

The power line and improved road will remain as permanent installations for the use of others.

B. GROUND MOTION

1. Experience With Multiple Explosives

There have been several underground detonations in which more than one nuclear explosive was detonated nearly simultaneously at the Nevada Test Site (NTS). The aggregate energy of these tests ranged from the low to low-intermediate yields. In every case, the ground motion observed at localities in the vicinity of the test site, including Las Vegas, was the same or less than that observed by a single explosion with yield equal to the sum of the individual explosives in the multiple experiments. Since the specifics of these experiments are still classified by the Federal Government, it is not possible to present the data substantiating these statements. However, the experience from the NTS clearly indicates that the proper way to predict ground motion from multiple explosions is to use the motion one would obtain from summing the yields of the individual explosions and not by adding the motions one would expect from each individual detonations. As an example, for the case of three explosives of identical yield, using the total yield, one predicts surface velocities which are about 60% of those obtained by assuming that the motions from the individual motions are additive. There are some plausible physical reasons for this effect which also apply to the prediction of ground motion from multiple, simultaneous detonations such as Rio Blanco. The Rio Blanco plan envisions a vertical separation of about 450 feet between explosives. Subsurface measurements performed on Gasbuggy at a yield of 29 kt which is very close to that expected for the individual Rio Blanco explosives, indicate that within 1,500 feet the ground behaves inelastically. From the standpoint of ground motion generation, the Rio Blanco explosion would therefore consist of three overlapping sources which, when viewed from distances of a few miles, would appear as a source of seismic energy equal to the aggregate yield. Therefore, it is reasonable to predict Rio Blanco ground motion as if it were caused by a single explosive whose yield was equal to the total Rio Blanco yield (Ref. IIB-1).

2. Ground Motion Predictions

a. Phenomenology

The Rio Blanco explosive configuration, three 30 $\pm$ 3 kt explosives separated by 450 feet vertically in the same hole and fired simultaneously, has never been tried. Based on NTS experience, however, a more conservative estimate of the seismic effects can be made assuming a 100 kt explosive located at the midpoint of the explosive configuration at 6,350 feet. Scaling will be based on the Rulison data which were obtained in a similar geologic setting.

b. Prediction Equations

The Rulison regression equations as derived by CER are:

0 - 22 km

Vector Acceleration	=	$19.7R^{-1.64}$	$\sigma = 1.36$
Peak Horizontal Components Acceleration	=	$9.05R^{-1.49}$	$\sigma = 1.35$
Vector Velocity	=	$489R^{-1.72}$	$\sigma = 1.19$
Peak Horizontal Components Velocity	=	$196R^{-1.46}$	$\sigma = 1.31$
Vector Displacement	=	$14.3R^{-1.65}$	$\sigma = 1.21$
Peak Horizontal Components Displacement	=	$6.24R^{-1.43}$	$\sigma = 1.29$

22 km - 296 km

Vector Acceleration	=	$139R^{-2.31}$	$\sigma = 1.63$
Peak Horizontal Components Acceleration	=	$107R^{-2.30}$	$\sigma = 1.55$
Vector Velocity	=	$1564R^{-2.09}$	$\sigma = 1.61$
Peak Horizontal Components Velocity	=	$1888R^{-2.17}$	$\sigma = 1.60$
Vector Displacement	=	$17.2R^{-1.70}$	$\sigma = 1.42$
Peak Horizontal Components Displacement	=	$10.2R^{-1.63}$	$\sigma = 1.50$

Where a (acceleration) is in g's, v (velocity) in cm/sec, d (displacement) in cm, and R (radius) in km. σ is the antilogarithm of the standard error of estimate in the least squares fit of the logarithms of the data. The scaling equations as derived by CER are:

(1) $$a_1 = \left(\frac{W_1}{W_2}\right)^{.47} \left(\frac{h_1}{h_2}\right)^{.58} a_2$$ where yield (W) is in kt and h is depth of burial (DOB) in feet.

(2) $$v_1 = \left(\frac{W_1}{W_2}\right)^{.73} \left(\frac{h_1}{h_2}\right)^{.12} v_2$$

(3) $$d_1 = \left(\frac{W_1}{W_2}\right)^{.99} \left(\frac{h_1}{h_2}\right)^{-.33} d_2$$

The derivation of the above is briefly:

(1) The $\frac{h_1}{h_2}$ exponents for acceleration and displacement have been derived by Mueller (Ref. IIB-2) and are respectively 0.58 and -0.33.

(2) Simple harmonic motion is assumed to describe the ground motion in the elastic region. This implies, in general, that $v = (ad)^{\frac{1}{2}}$. Hence from above:

$$\frac{v_1}{v_2} = \left(\frac{a_1}{a_2}\,\frac{d_1}{d_2}\right)^{\frac{1}{2}}$$

$$= \left[\left(\frac{W_1}{W_2}\right)^{.47} \left(\frac{W_1}{W_2}\right)^{.99} \left(\frac{h_1}{h_2}\right)^{.58} \left(\frac{h_1}{h_2}\right)^{-.33}\right]^{\frac{1}{2}}$$

$$= \left(\frac{W_1}{W_2}\right)^{.73} \left(\frac{h_1}{h_2}\right)^{.12}$$, as given.

(3) The yield exponents derived from NTS experience are 0.66, 0.77, and 0.85 for acceleration, velocity, and displacement, respectively (Ref. IIB-3). The majority of these data come from detonations buried at a scaled DOB of 350 $W^{1/3}$. If one requires the equations to reduce to these exponents for depths of burial to the scaled depth, the exponents for $\frac{W_1}{W_2}$ become 0.47, 0.73, and 0.99 for acceleration, velocity, and displacement, respectively.

(4) In deriving the Rulison regression equations given, the data (Ref. IIB-4) have been edited as indicated in the following discussion.

Independent calculations of the recorded velocities were made by the NOS and Environmental Research Corporation (ERC) (Ref. IIB-4 and 5). Where the computed results differed by more than 10%, the data were considered doubtful and were eliminated. The data from stations where there were less than three components available for analysis were ignored. Data from Station R08, located inside the Mobil mine, were eliminated since its data were not comparable with surface recording locations.

Stations R26 and R27, located less than 1,000 feet apart in the town of Rifle, had significant variations in the data. R26 was selected as being the most representative of a hard rock station and data from R27 were eliminated. The same situation existed with stations R12 and R13 in the town of De Beque. R12 was selected as being the most representative of the hard rock situation and the data from R13 were eliminated. This editing of the data resulted in not using data from the following stations:

Station	Reason
R45	I
R08	II
R09	I
R27	III
R13	III
R14	IV
R37	I
R40	IV

I — ERC and NOS data differ by more than 10%

II — Data inside a mine which is not comparable with data taken on the surface.

III — Data not from a hard rock station (borne out by later Microtremor data).

IV — One horizontal component missing.

(5) By visual inspection of a plot of the data points, it appeared reasonable to fit the data by two straight lines in the logarithmic realm rather than by a single straight line. The data were divided into two parts, one from 0 to 22 km and the second from 22 to 296 km. A plausible explanation of this break in the data at approximately 20 km is that in a layered medium such as exists in the Piceance Creek Basin, there are numerous velocity contrasts (i.e. layers) available to refract seismic energy. Moving outward from the explosion point, refracted energy is picked up from deeper and deeper layers until finally some point is reached where there are no deeper layers to contribute refracted energy, i.e., the base of the sedimentary section. Beyond this point, the total

seismic energy arriving attenuates at a faster rate since there is no additional refracted energy available. A rough rule of thumb from seismic prospecting is that the depth of penetration of refracted energy is one-fourth the horizontal distance between source and receiver. In this case, the depth would be roughly 5 km which agrees fairly well with the geologists' estimate of the thickness of the sedimentary section in the Piceance Creek Basin.

Scaling the Rulison equations from 40 kt at 8,425 feet to the Rio Blanco conditions of 100 kt at 6,350 feet gives the following equations.

<u>0 to 22 km</u>

Vector Acceleration	=	$25.6R^{-1.64}$	$\sigma = 1.36$
Peak Horizontal Component Acceleration	=	$11.6R^{-1.49}$	$\sigma = 1.35$
Vector Velocity	=	$919R^{-1.72}$	$\sigma = 1.19$
Peak Horizontal Component of Velocity	=	$368R^{-1.46}$	$\sigma = 1.31$
Vector Displacement	=	$38.8R^{-1.65}$	$\sigma = 1.21$
Peak Horizontal Component of Displacement	=	$16.9R^{-1.43}$	$\sigma = 1.29$

<u>22 to 300 km</u>

Vector Acceleration	=	$180R^{-2.31}$	$\sigma = 1.63$
Peak Horizontal Component of Acceleration	=	$139R^{-2.30}$	$\sigma = 1.55$
Vector Velocity	=	$2940R^{-2.09}$	$\sigma = 1.61$

22 to 300 km (continued)

Peak Horizontal Component of Velocity	=	$3549R^{-2.17}$	σ = 1.60
Vector Displacement	=	$46.6R^{-1.70}$	σ = 1.42
Peak Horizontal Component of Displacement	=	$27.6R^{-1.63}$	σ = 1.50

Where acceleration is in g's, velocity is in cm/sec, displacement is in cm, and radius is in km.

There is an uncertainty in deriving the regression equations and in scaling them to a new yield and depth of burial. The current published data do not furnish information of the amount of this uncertainty. As a result, to be conservative, a safety factor of 3 to 1 over predicted values of acceleration has been assumed for the calculations involving safety of personnel or for damage to high value structures in the area. This assumption resulted from scaling the Gasbuggy data to the Rulison event and noting that all of the Rulison data fell within a 3 to 1 band.

The ground motion prediction technique used by CER differs from that published by ERC. The ERC regression equation for the Peak Horizontal Component of Acceleration based on the Rulison data is:

$$a = 17.5R^{-1.91} \qquad \sigma = 2.01 \quad \text{(Ref. IIB-4)}$$

It is likely that ERC would use the following scaling equation:

$$a_1 = \left(\frac{W_1}{W_2}\right)^{.64} \left(\frac{h_1}{h_2}\right)^{.58} a_2 \quad \text{(Ref. IIB-6)}$$

Using this technique the ERC prediction equation would become:

$$a = 26R^{-1.91} \qquad \sigma = 2.01$$

A comparison of the predictions is given in Figure IIB-1. For all practical purposes, the predicted results are reasonably close in the zone of interest, i.e., from EW to 28 miles.

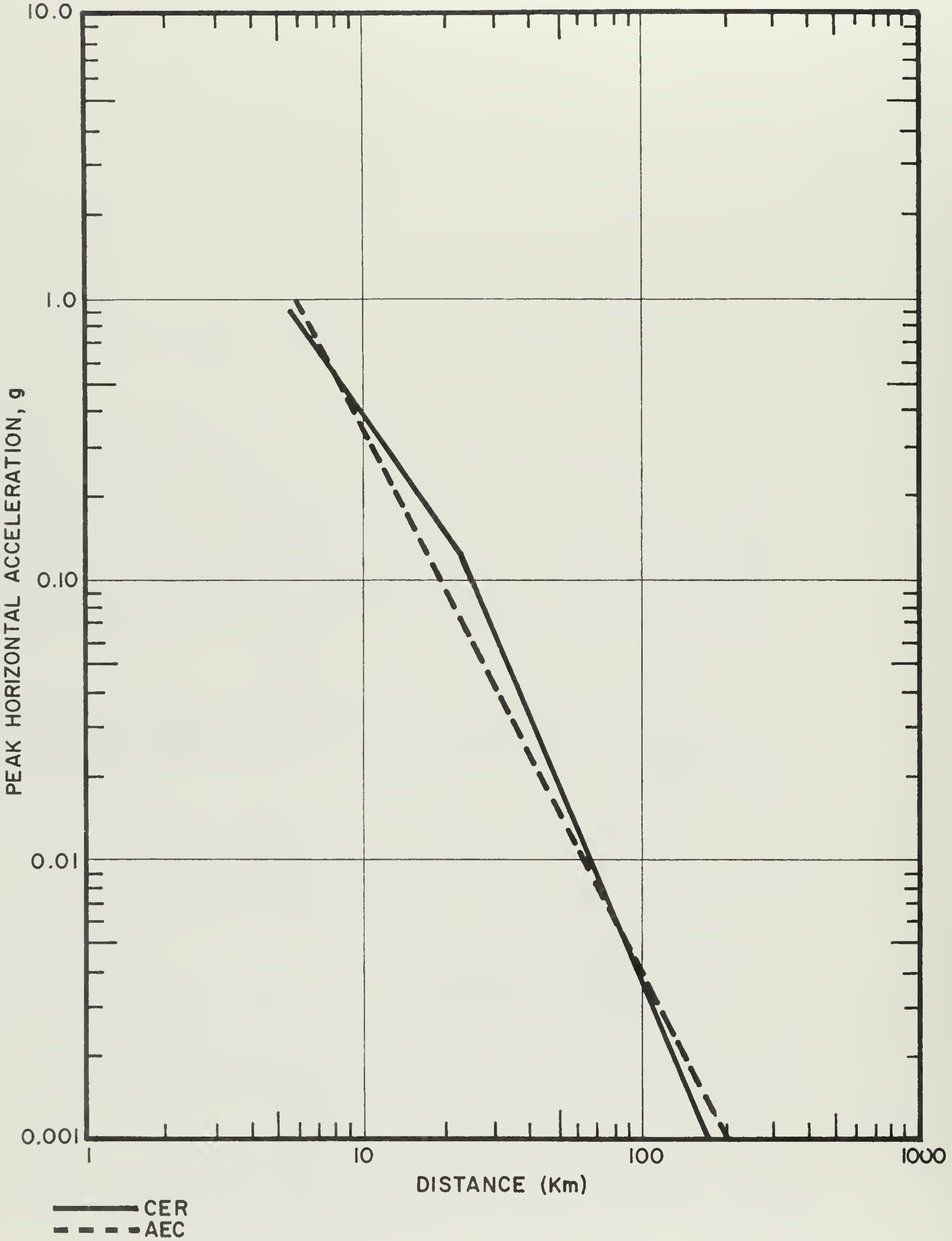

Figure IIB-1. Predicted peak horizontal component of acceleration versus distance.

c. Selected Distances

Using the CER equations, the following distances are computed for the selected values of Peak Horizontal Component Acceleration:

g's	=	Miles from EW	=	km
1.0	=	3.0	=	4.8
0.5	=	5.0	=	8.0
0.3	=	7.2	=	11.5
0.1	=	14.5	=	23.0
0.03	=	24.5	=	39.0
0.01	=	39.0	=	63.0
0.005	=	53.0	=	85.0
0.001*	=	107.0	=	170.0

(See Figure IIB-2)

d. Predictions for Selected Locations

Using the CER equations, the seismic predictions for selected locations are shown in Tables IIB-I, II and Figures IIB-2, 3.

e. Energy Travel Path Geology

The data from Rulison showed a small azimuthal effect. In general, this effect conformed as expected to the shape of the Piceance Creek Basin but was too small to materially affect the prediction equations. The same azimuthal variation is expected for Rio Blanco, and it is not anticipated that the effect

*Accepted limit of human perceptibility under most favorable conditions.

Table IIB-I. Predicted motion amplitudes at selected sites.

Name	Location	Az	Slant Distance (Miles)	Slant Distance (km)	A_1	A_2	V_1	V_2	D_1	D_2
Equity Plant	6-3S-98W	298°	3.9	6.2	1.28	0.77	39.8	25.6	1.90	1.24
Rock School	16-2S-97W	38°	7.1	11.2	0.48	0.32	14.0	10.8	0.72	0.53
Shell Plant	28-1S-97W	22°	10.8	17.3	0.24	0.17	6.9	5.7	0.35	0.29
El Paso Plant	5-2S-96W	51°	12.0	19.2	0.20	0.14	5.7	4.9	0.29	0.25
Cascade Plant	29-2S-95W	72°	15.8	25.3	0.10	0.082	3.4	3.2	0.19	0.14
Colony Plant	7-5S-95W	128°	18.0	28.8	0.077	0.061	2.6	2.4	0.16	0.12
Rio Blanco Lake	36-2N-97W	21°	22.5	36.0	0.046	0.037	1.6	1.5	0.11	0.080
Harris Res.	18-4S-93W	110°	27.0	43.0	0.030	0.024	1.1	1.0	0.077	0.060
Kirby Dams	28-4S-102W	252°	27.0	43.0	0.030	0.024	1.1	1.0	0.077	0.060
Meeker	23-1N-94W	55°	30.0	48.0	0.024	0.019	0.90	0.80	0.064	0.050
Rangely	11-1N-102W	311°	31.0	50.0	0.027	0.018	0.84	0.74	0.061	0.048
Rifle Gap Dam	7-5S-92W	110°	34.5	55.0	0.017	0.014	0.68	0.59	0.051	0.040
Rifle	16-6S-93W	120°	37.0	59.0	0.015	0.012	0.58	0.51	0.045	0.036
Harvey Gap Dam	13-5S-92W	108°	40.3	64.0	0.012	0.0097	0.49	0.43	0.040	0.031
Big Beaver Dam	18-1S-91W	71°	42.0	67.0	0.011	0.0088	0.45	0.39	0.037	0.029
Bonanza	25-9S-24E	295°	45.0	72.0	0.0092	0.0074	0.39	0.33	0.032	0.026
	Utah, PM									
Cameo	34-10S-98W	177°	45.2	72.0	0.0092	0.0074	0.39	0.33	0.032	0.026
Grand Junction	13-1S-1W	190°	52.0	83.0	0.0066	0.0054	0.29	0.24	0.025	0.021

A_1 = Peak Vector Acceleration (g's)
A_2 = Peak Horizontal Component of Acceleration (g's)
V_1 = Peak Vector Velocity (cm/sec)
V_2 = Peak Horizontal Component of Velocity (cm/sec)
D_1 = Peak Vector Displacement (cm)
D_2 = Peak Horizontal Component of Displacement (cm)

Table IIB-II. Peak resultant vector amplitudes at locations highly susceptible to rockfalls.

Name	Location	Slant Distance (km)	Vector Acceleration (g)	Vector Velocity (cm/sec)	Vector Displacement (cm)
Norell Ranch	19-2S-97W	8.3	0.79	24.0	1.18
13 Mile Creek	7-3S-95W	23.0	0.13	4.2	0.22
Parachute Creek	7-5S-95W	29.0	0.075	2.58	0.17
Rio Blanco	6-4S-94W	32.0	0.060	2.10	0.12
Douglas Pass	26-5S-102W	43.0	0.030	1.10	0.078
De Beque Canyon	19-9S-97W	61.0	0.013	0.55	0.042
Plateau Canyon	18-10S-97W	69.0	0.010	0.42	0.034
Glenwood Canyon	-6S-89W	96.0	0.0047	0.21	0.020

ACTIONS UNIQUE
TO
EACH PREDICTED ACCELERATION LEVEL

0.03g	Detailed inventory of all structures--sensitive structures beyond will be inventoried.
0.1g	All persons will be asked to be clear of overhead objects.
0.3g	All persons normally within this area will be temporarily relocated.

Notes regarding Figure IIB-2.

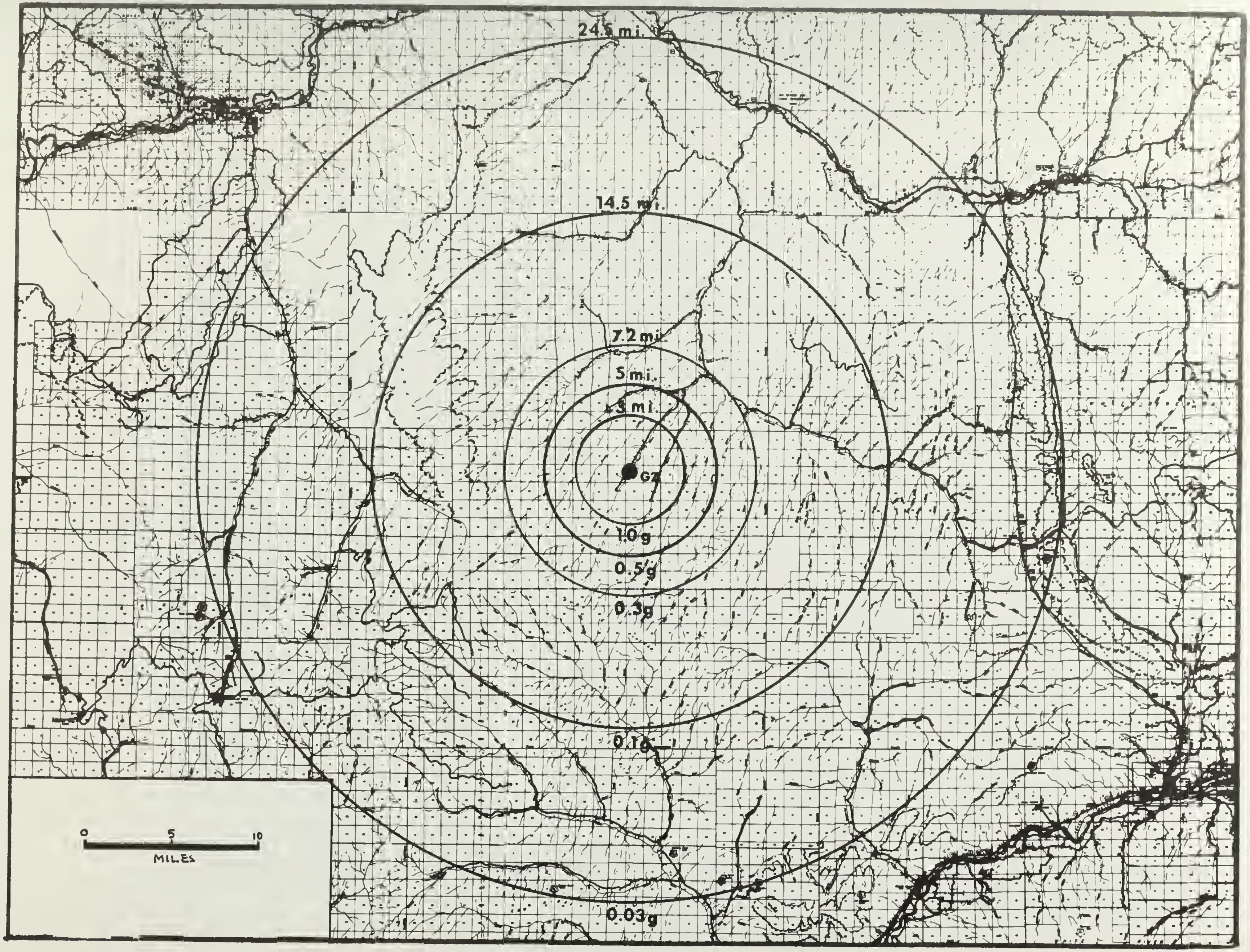

Figure IIB-2. Predicted distances for peak horizontal accelerations.

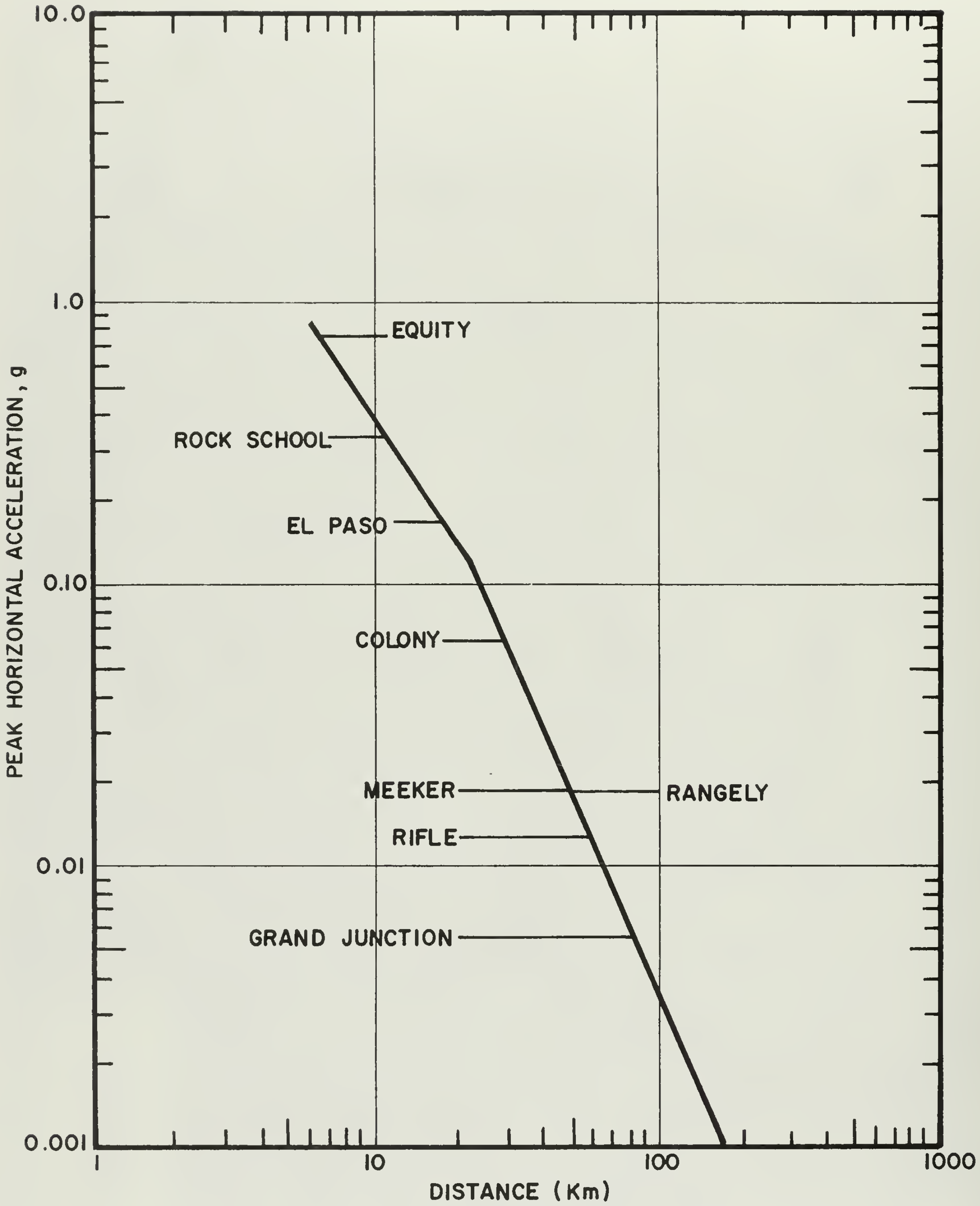

Figure IIB-3. Predicted peak horizontal component of acceleration versus distance.

will materially change the prediction equations. There will be a increase in motion in a NW, SE direction following the major axis of the basin and a small decrease in motion in a NE, SW direction parallel to the minor axis of the basin.

f. Structure Foundation Soil Investigations

To provide information on the foundation geology, Microtremor Surveys were made of the nearby towns and selected sites along the Piceance Creek.

In a Microtremor Survey, a recording is made of the ambient noise (cultural, traffic, wind, etc.) and the Power Spectral Density (PSD) is computed. It is assumed that the ambient noise is "white"; i.e., contains approximately the same amplitude at all frequencies of interest. Any peaking of the PSD is due to ground resonance, which is attributed to the shallow layer of low-velocity material, usually alluvium. Theory shows that the resonant frequency is dependent upon the thickness and velocity of the shallow layer. For layers of the same velocity, the thicker the layer, the lower the resonant frequency. Hence, the Microtremor Survey gives a qualitative assessment of the variation of seismic response over the area surveyed. Furthermore, if the fundamental frequencies of the typical structure are known, one can determine those parts of the area where the structure resonances and the ground resonances coincide - a condition which produces maximum structural response and damage, if any.

Experience with this technique is limited. However, a rough correlation of the damage pattern in Rifle for the Rulison event gives an empirical basis for applying the technique to areas in which most structures have a resonant frequency near 10 Hz, e.g., typical one- or two-story buildings. Empirical damage factors are assigned according to ground resonance frequency: above 12 Hz, unity; from 8 to 12 Hz, a larger value, probably 2; below 8 Hz, probably 1/2. For analysis of areas with respect to structures having other resonant frequencies, different damage factors should be used.

Surveys were run in De Beque, Grand Valley, Rifle, Meeker, and Rangely. A summary of the interpretation for each town follows.

(1) De Beque

Twenty stations were run showing a variation in resonant frequencies from 8 Hz to > 20 Hz. The NOS Rulison Station R12 in De Beque showed no peaking of the PSD which is interpreted as having > 20 Hz or hard rock. The NOS Rulison Station R13 showed a peak in the PSD at 11 Hz which would indicate a layer of alluvium and hence, a greater seismic response. The overall frequency contour map (Figure IIB-4) indicates that approximately one-half of De Beque is covered by alluvium while the rest has either very thin alluvium or none at all.

(2) Grand Valley

Twenty locations were surveyed showing a variation in resonant frequencies from 7 Hz to 16 Hz (Figure IIB-5). The NOS Station R25 for the Rulison event showed a resonant frequency of 15 Hz which would indicate very thin alluvium or hard rock. This would indicate weak seismic response at this location while other portions of town having lower resonant frequencies would have stronger seismic response.

(3) Rifle

Forty locations were surveyed showing a variation in resonant frequencies from 4 Hz to 16 Hz (Figure IIB-6). The NOS Station R26 for the Rulison event in the church had a resonant frequency of 15 Hz indicating very thin alluvium and weak seismic response. The NOS Station R27 to the east had a resonant frequency of 13 Hz indicating a slightly thicker alluvium and slightly greater seismic response. The station at the fairgrounds, where the refraction survey was made for Rulison, had a resonant frequency of 9 Hz as against 8 Hz derived from the refraction data. This survey would indicate that there were many parts of Rifle that saw more motion than recorded at the two NOS stations. The average structure in

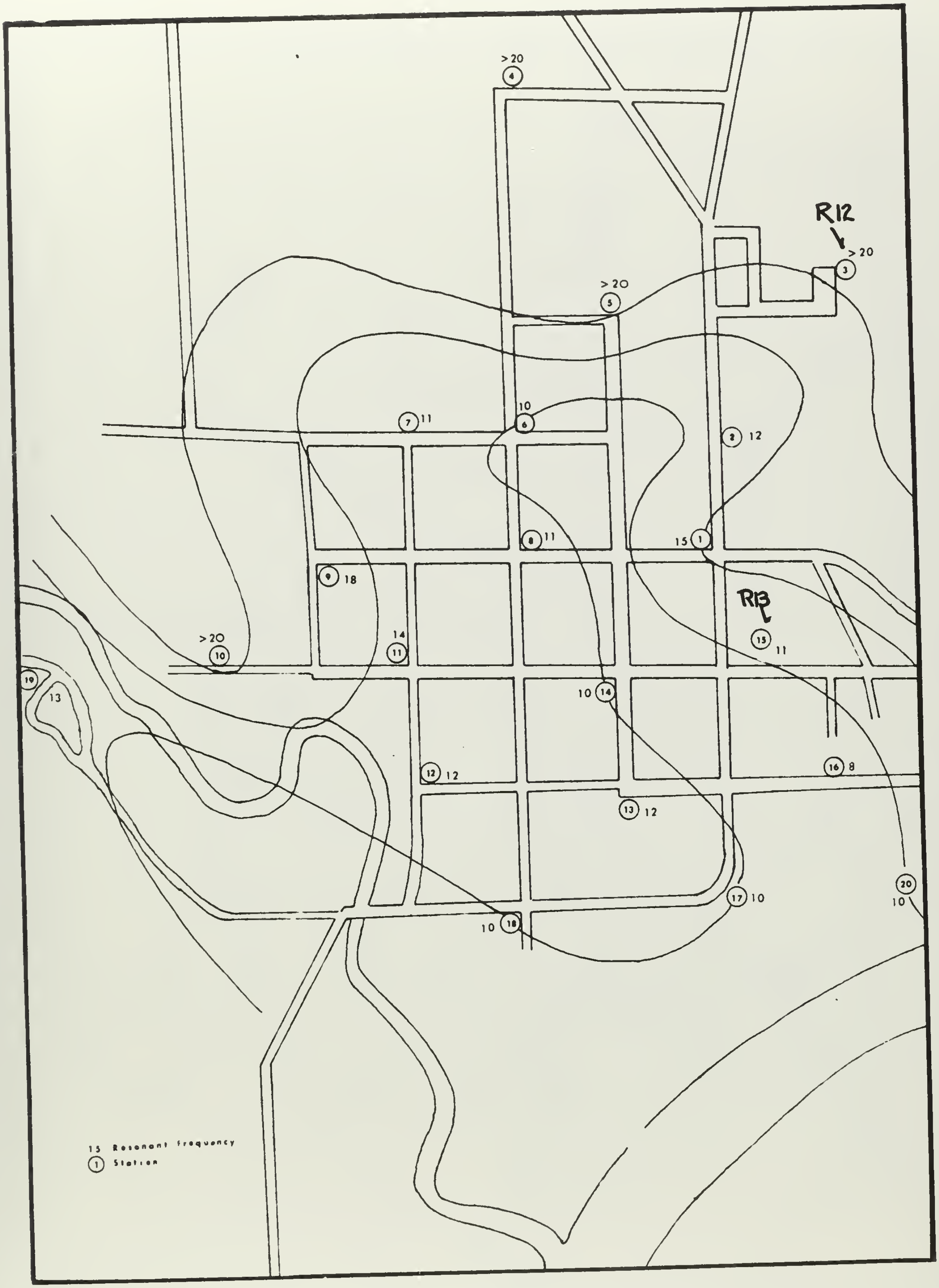

Figure IIB-4. De Beque Microtremor Survey.

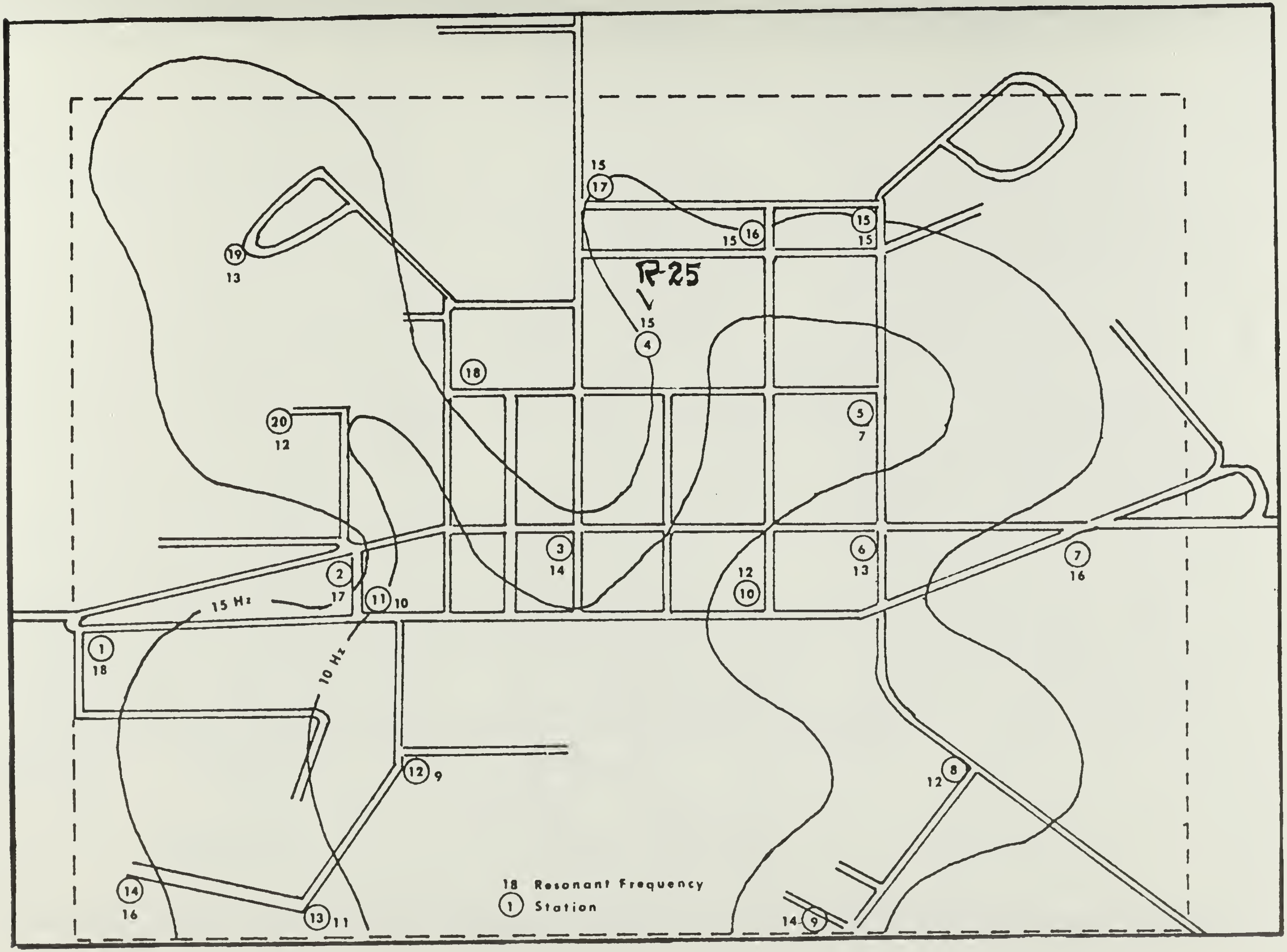

Figure IIB-5. Grand Valley Microtremor Survey.

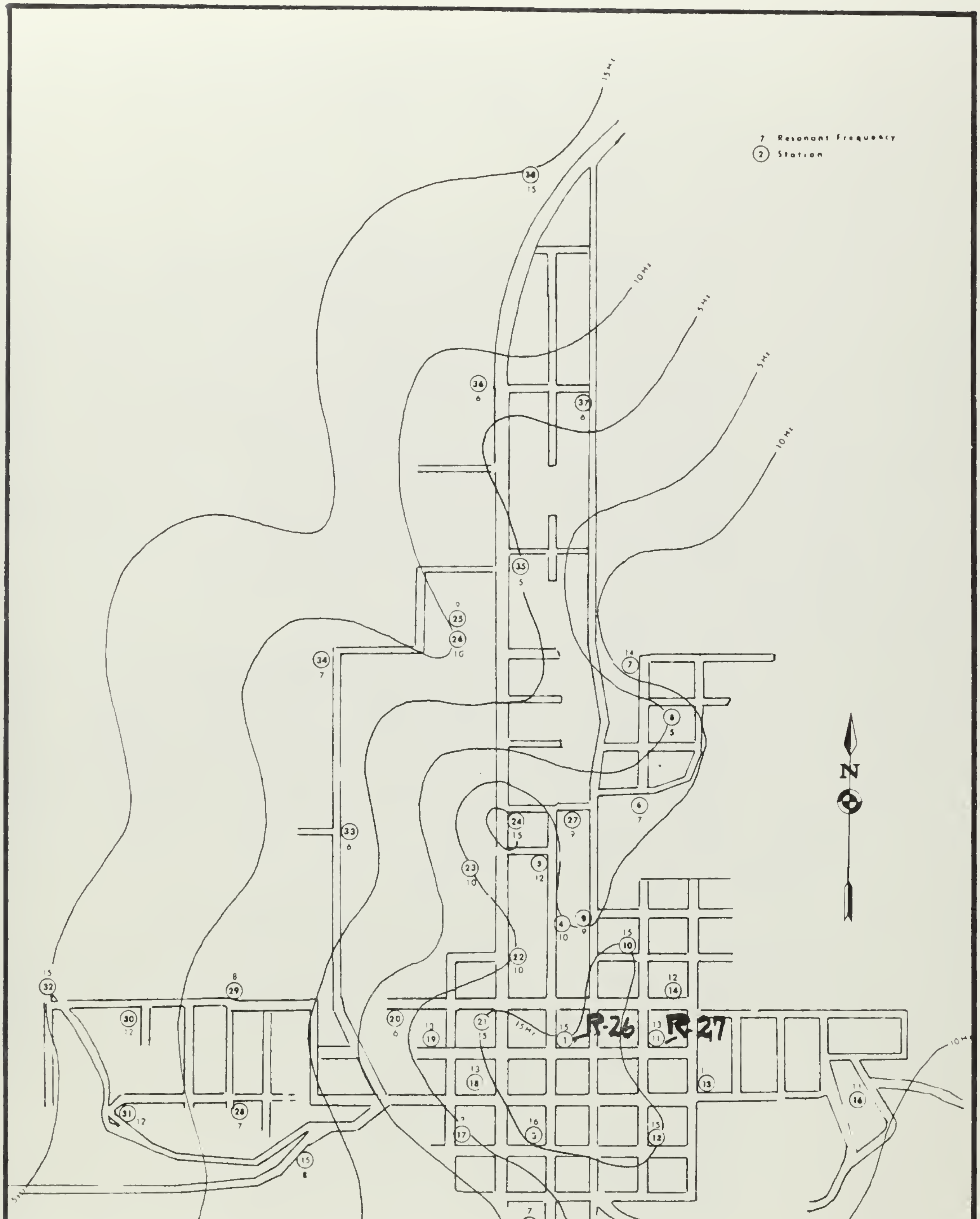

Figure IIB-6. Rifle Microtremor Survey.

Rifle would have a resonant frequency from 8 to 12 Hz. The damage pattern seems to indicate a greater concentration in those areas where the ground resonant frequency is from 8 to 12 Hz.

(4) Meeker

Forty locations were surveyed showing variations in resonant frequencies from 9 Hz to 18 Hz (Figure IIB-7). The NOS Station R29 for the Rulison event had a resonant frequency of 12 Hz. This would not be a hard rock location with weak seismic response, nor it is similar to the lowest resonant frequency location with the maximum seismic response. The structural characteristics of Meeker are similar to those in Rifle and the resonant structural frequencies would be from 8 to 12 Hz. The area where the ground resonances are from 8 to 12 Hz (where the structure and ground interaction is greatest) covers approximately 50% of the residential portion of Meeker.

(5) Rangely

Forty locations were surveyed showing variations in resonant frequencies from 6 to 19 Hz (Figure IIB-8). The NOS Station R35 for the Rulison event in the Rangely College had a resonant frequency of 8 Hz and the NOS Station R36 at the base of the ski lift had a resonant frequency of 10 Hz. Nearly 50% of Rangely is represented by resonant frequencies greater than 15 Hz.

(6) Piceance Creek and Black Sulphur Creek

Twenty-seven locations were surveyed at various locations along the Piceance Creek and Black Sulphur Creek. These locations were spread over a large area and cannot be contoured as was done in the town surveys. A summary of the results is shown in Table IIB-III. Many of the stations were uninterpretable due to pipeline noise in the area. A location was surveyed 50 feet from the Rock School showing a resonant frequency of 14 Hz. An ambient vibration survey of the school building showed resonant frequencies of 4 and 7 Hz. It would appear that there would

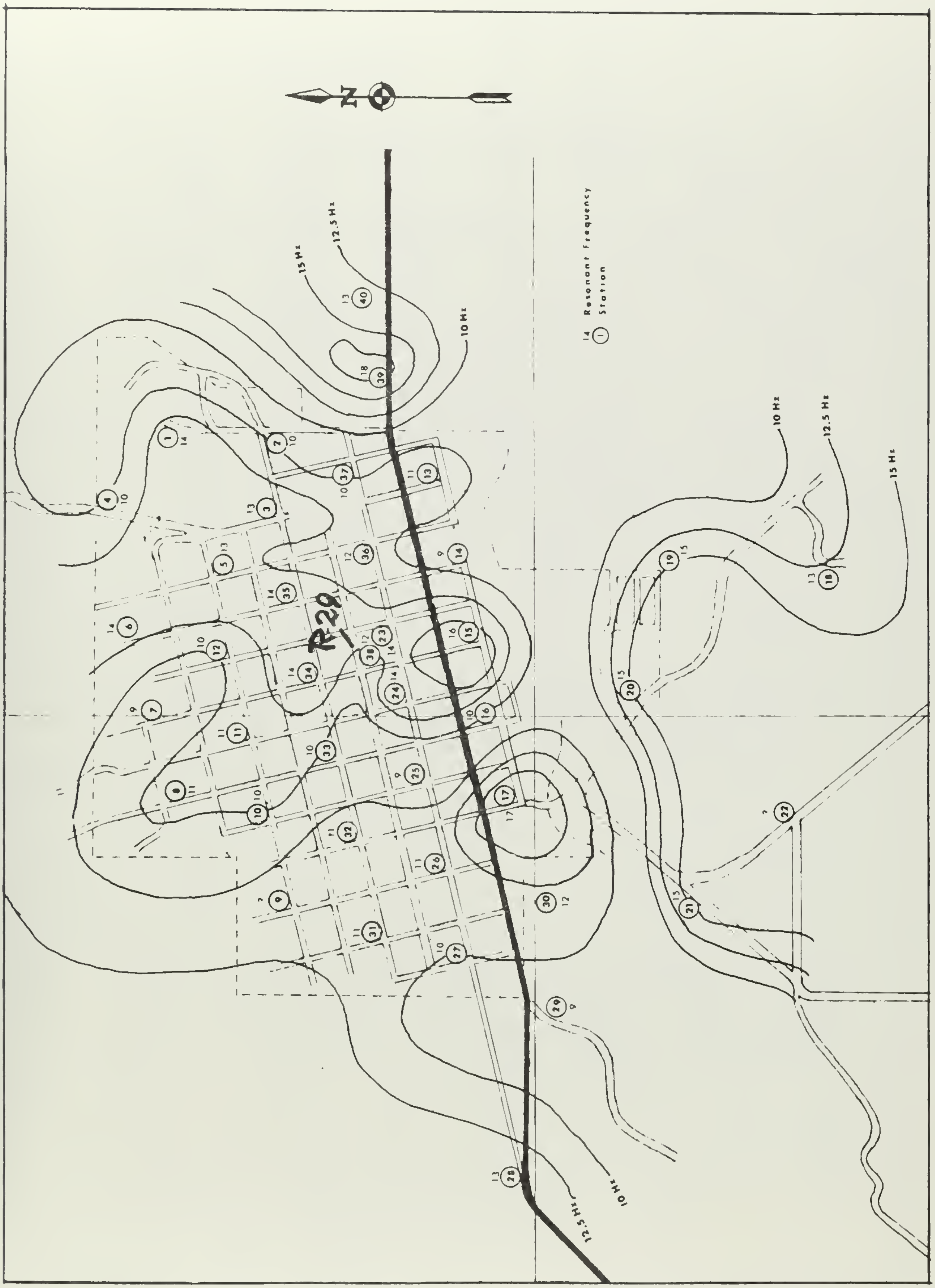

Figure IIB-7. Meeker Microtremor Survey.

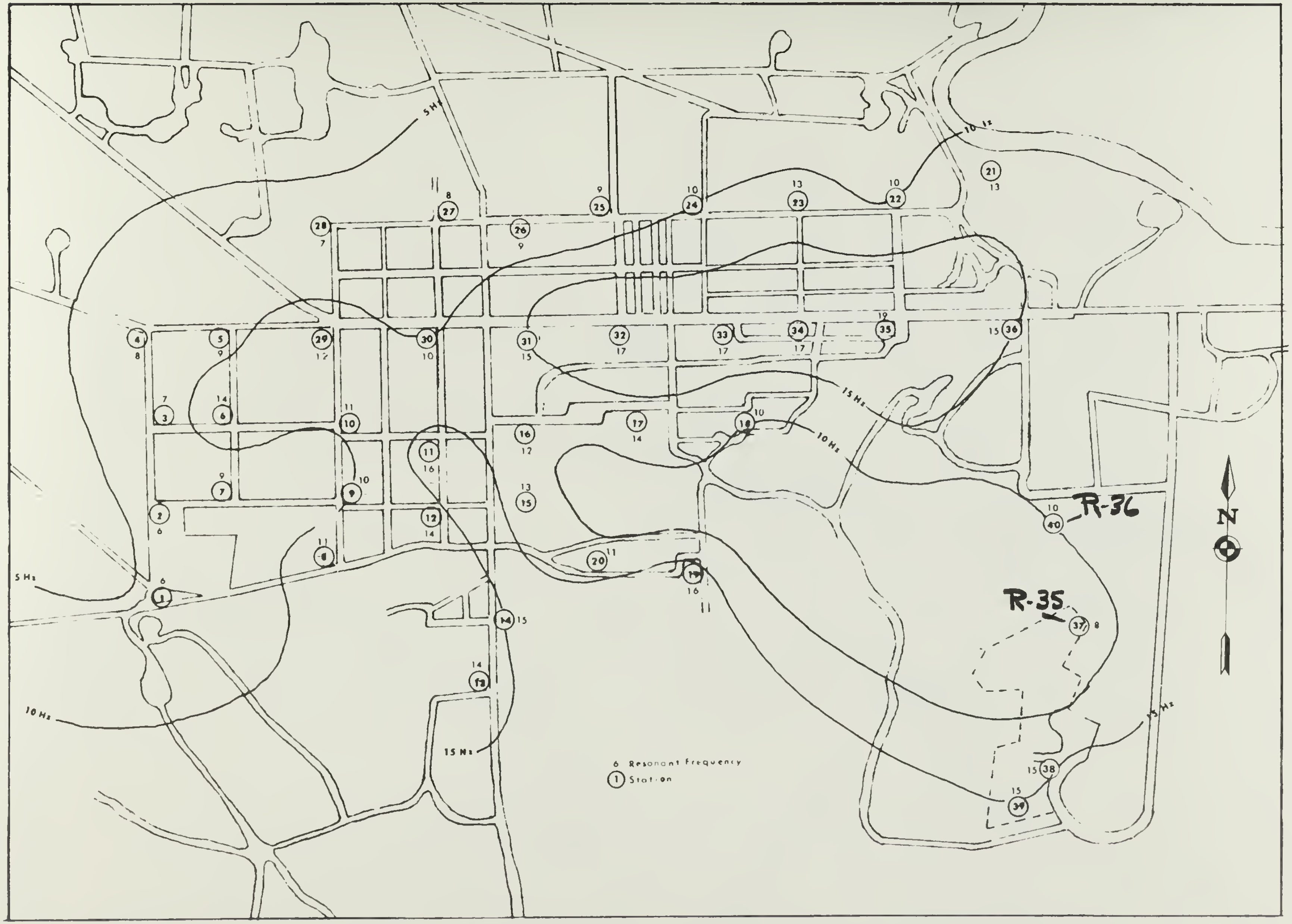

Figure IIB-8. Rangely Microtremor Survey.

Table IIB-III. Piceance Creek and Black Sulphur Creek Microtremor Survey

Station	Location	Resonant Frequency	Comments
1	1-1N-97W	10 Hz	Noisy due to tractor. South side of bridge over White River.
2, 3, 4	22-1N-97W	?	Too noisy from pipeline along line DD. *
5, 6, 7	32-1S-97W	?	Too noisy from pipeline along line EE. *
8,9, 10	32-1S-97W	?	Too noisy from pipeline along line FF. *
11	16-2S-97W	14 Hz	Rock School.
12	16-2S-97W	?	Too much noise from pipeline. Brennan Ranch.
13	19-2S-97W	5 Hz	Norell Ranch, pipeline noise.
14	27-2S-98W	15 Hz	Duckett Ranch.
15	6-3S-98W	15 Hz	Equity Oil Shale Plant.
16, 17, 18	25-2S-97W	9 Hz, 10 Hz, 11 Hz	Along line GG. *
19	5-2S-96W	?	Too much noise from pipeline. El Paso Plant.
20	9-2S-96W	20 Hz	Mobil Camp.
21	32-2S-96W	7.5 Hz	Walter Oldland Ranch.
22	3-3S-96W	11 Hz	Gerald Oldland Ranch.
23	12-3S-96W	?	Too noisy from compressor.
24	23-3S-95W	15 Hz	
25	36-3S-95W	10 Hz	
26	5-4S-94W	11 Hz	
27	4-4S-94W	12.5 Hz	Rio Blanco.

*See plate I, Ref. ID-4.

be very little interaction between the ground resonance and the building resonances. The higher frequency of the ground resonance would indicate a hard rock type or weak seismic response.

3. Effects

a. Structural Response

(1) Buildings

An extensive inventory has been made of structures out to a distance of 30 miles (Figure IH-1). The structures have been assessed for their susceptibility to seismic motion and in many cases have been subjected to a dynamic analysis. On the basis of this investigation, structural bracing and repair recommendations have been made which will be carried out prior to shot time.

(2) Bridges

An assessment was made of the seismic susceptibility of the bridges in the area out to a distance of 30 miles from the EW. Twelve bridges were found to be in poor condition, most of them built by or for ranchers on the access roads to their property. Although normal daily traffic on these bridges will probably impart more stress to them than the shot-induced ground motion, all ranchers involved will be advised not to allow traffic on the bridges at shot time.

In two cases, the bridges are part of the secondary road system and traffic across them will have to be stopped at shot time.

(3) Tunnels

The only tunnels in the area are in the vicinity of De Beque Canyon and are so distant that no damage is predicted.

(4) Power and Telephone Lines

The existing power and telephone lines have been designed and built to withstand far more motion from wind than they will be subjected to by the seismic motion from the shot. The installation to be made to the EW will also be designed to withstand the expected motion. No damage is predicted to any power or telephone facility.

(5) Communication Repeater and Transmitter Facilities

No damage is predicted to any of the commercial communication facilities.

(6) Wells - Gas and Oil

On the basis of past experience, all the gas and oil facilities in the area are outside the zone of predicted damage. The Fawn Creek Government Number 1 Well, 1,300 feet from the EW, is considered part of the project and will be handled separately.

(7) Pipelines - Gas, Oil, and Water

No damage is predicted to any pipelines in the area.

(8) Mines and Quarries

The mines closest to EW are located at a distance of about 18 miles, where a ground acceleration of about 0.06g is expected. These are the Atlantic-Richfield Colony Oil Shale Mine and the inactive Union Oil Parachute Creek Oil Shale Mine. All other mines are more than 30 miles from the EW and are expected to experience groundmotion accelerations of less than 0.015g. Explosives are widely used in underground mines to fragment the rock for removal, and all active mines are constructed to withstand the accelerations due to reasonable charge sizes. The Rio Blanco detonation is expected to submit the mines involved to lower acceleration value than those from mine blasting; consequently, no damage is expected in any of the mines as a result of the Rio Blanco shot.

(9) Hydraulic Features

All hydraulic structures such as dams, tunnels, irrigation ditches, reservoirs, etc., have been assessed for seismic hazard, seiche effect as well as ground motion. No damage is predicted to any dam, reservoir, or tunnel in the area. There are numerous small irrigation ditches in the project area that may suffer minor damage, such as bank caving, if the shot occurs when they are in use.

(10) Airports

No seismic damage is predicted for any of the airports or landing strips in the area.

(11) Railroads

There is no damage predicted for the railroads. However, since the slopes associated with some railroad cuts appear to be unstable, an inspection will be made pre-shot and agreed upon safety plans will be instituted.

(12) Roads

Although no damage is predicted to any of the roads in the area, travel will be restricted to avoid hazard to traffic in those zones where unstable slope conditions are suspected.

b. Water Wells and Springs

The only predicted effects of the shot on the water wells and springs in the area are a slight temporary increase in flow and a slight increase in turbidity due to a rise in the piezometric surface in the vicinity of the shot. These effects should not extend more than three miles from the shot and should dissipate in a few days, with conditions of flow and water quality returning to those existing pre-shot. There may be some increase in turbidity of the water in wells out to ten miles due to shaking of some of the wellbores but this should subside rapidly.

c. Landslides and Avalanches

An assessment of the slope stability in the area was made to a distance of 60 miles from the EW. Precautions to protect people in those areas where a hazard to life or property exists are detailed in Section 5, "Protective and Remedial Actions." If the shot occurs in the winter or early spring; e.g., before May, avalanche problems might exist in two areas (Douglas Pass and Grand Mesa). Precautions will be taken to eliminate any hazard to life.

d. Seismic Aftershocks

Previous underground nuclear explosion experience, such as Project Rulison, has shown that small aftershocks occur in the immediate vicinity for a short time. For an event in the yield range of Rio Blanco, it is expected that a few dozen aftershocks might occur with Richter magnitude values no greater than three. They will probably cease within a few hours after the explosion. The total energy released by the aftershocks will be substantially less than that of the Rio Blanco explosive itself, and the ground motion produced by them will probably not even be perceptible to an observer standing even in the immediate area of the Rio Blanco site. No hazard will be presented by the triggered aftershocks.

e. Ecological Systems

With respect to animal life, on at least one underground nuclear explosive test at NTS, cattle were positioned sufficiently close in that the shock lifted them off the ground, yet they survived with no known harm (Ref. IIB-7). It is not visualized that extensive and lasting harm from seismic shock to wild or domestic animals in the vicinity of the project area will result. Tunnels and dens of burrowing animals could conceivably suffer some damage, which appears reparable. Adverse effects of shock on soil invertebrates do not seem likely.

4. Unavoidable Adverse Effects

After an extensive structural inventory and hazard assessment, CER's structural response contractor, Kenneth Medearis & Associates of Fort Collins, Colorado, has estimated the probable damage to approximately 170 structures in the area to be \$51,000 $\pm$ \$13,000 (Ref. IIB-8). The structures in the area are generally described in Section III, H., 1., a.

Possibilities exist for damage costs which may not be identifiable by the method used in arriving at the above total. These might arise at a few identified locations or be due to unpredictable rockfalls. On the other hand, the planned extensive preventive actions consisting of pre-detonation structural bracing and repair would tend to reduce the total damage. In balance, it is believed that the actual damage will not exceed the upper limit indicated and may well be lower than the lower limit.

5. Protective and Remedial Actions

a. Population Safeguards

Precautionary measures will be taken to safeguard the occupants of all structures subjected to predicted ground motion accelerations of 0.1 g or more from the detonation. This involves everybody within a radius of 15 miles from EW and will affect less than 110 persons, provided the detonation falls outside the hunting season. All persons in the area will be requested to be outside of their dwellings or other structures and in open terrain at least two building heights away from the nearest structure at the time of the detonation. This will assume that no overhead object, jarred loose, will fall and injure anyone.

In addition, all persons within the area that is anticipated to be subject to ground motion accelerations of 0.5 g or more will be asked to move out of that area at the time of the detonation. This involves everybody within a radius of 5 miles from EW and will affect less than 25 persons, provided the detonation date falls outside the hunting season.

b. Roadblocks

Where steep cliffs border local highways and roads, the possibility that rockfalls might be caused by the shot-induced ground motion is not to be excluded. The chances that this may occur are far more acute during the spring thaw period, when steep slopes tend to be unstable due to their water content.

The precautionary measures will, therefore, depend to a certain degree on the slope conditions at the time of the shot. At all times, roadblocks are planned during shot time for road sections through the Douglas Pass, most of Parachute Creek, and the Rifle Gap Dam area.

Should the detonation date fall in March or April, roadblocks are proposed also for sections of the Glenwood, De Beque, and Plateau Creek canyons, although ground motion accelerations in these locations are expected to be insignificant (Ref. IIB-9). At all other steep cliff locations that border roads, traffic restrictions will be used to safeguard passing traffic at detonation. This usually will be done by detouring traffic onto the lanes farthest from the rock slope.

c. Railroad Inspection

The detonation time will be selected to allow road crews of the Denver and Rio Grande Western Railroad Company to inspect the track immediately post detonation.

d. Mine Evacuation

It appears prudent to evacuate all underground mines subjected to ground motion acceleration of 0.005 g and more (Ref. IIB-10). This entails an area within a radius of 53 miles from the EW. The mining operations involved are listed in Tables IH-Ia and IH-Ib and plotted on Figure IH-4.

e. Pre-Detonation Structural Bracing and Repair

Due to the prediction of minor damage (plaster cracks, fallen bricks, etc.), a preventive maintenance program will be conducted prior to the detonation. Experience on Project Rulison has shown that this type of action can substantially reduce damage.

f. Post Detonation Repair and Claim Adjustment

One of the more important considerations in the conduct of Project Rio Blanco is its effect upon the local residents. Great care is being taken to insure that no one is unduly inconvenienced or suffers financial loss as a result of the project.

CER will have workmen available immediately after the detonation to repair any damage which may occur in spite of the preventive maintenance program. In addition, claim adjusters will be available to make "on the spot" compensation if the residents desire.

REFERENCES

IIB-1. Holzer, A., LLL (personal communication).

IIB-2. Mueller, Richard A. and John R. Murphy, "Seismic Spectrum Scaling of Underground Detonations," ERC, NVO-1163-195 (March, 1970).

IIB-3. Weetman, B. G., R. H. Berry, L. L. Davis, P. O. deCaprariis, W. W. Hays, R. A. Mueller, J. R. Murphy, D. L. Orphal, and C. T. Spiker, "Predictions of Seismic Motion and Close-In Effects Rulison Event," ERC, NVO-1163-180, PNE-R-5 (August, 1969).

IIB-4. Anonymous, "Observed Seismic Data, Rulison Event," ERC, NVO-1163-197, PNE-R-16 (November 14, 1969).

IIB-5. Special Projects Party, Kenneth W. King, Chief of Party, NOS, "Rulison Seismic Effects," CGS-746-2, PNE-R-23 (February 16, 1970).

IIB-6. DiBona, B., NV-AEC (personal communication).

IIB-7. Campbell, E., NVOO (personal communication).

IIB-8. "Project Rio Blanco Structural Response Studies," Kenneth Medearis & Associates, Fort Collins, Colorado (July, 1971).

IIB-9. Bowman, J., Mesa County Highway Dept., and Colorado Highway Department Engineers (personal communication).

IIB-10. Anonymous, "Mine and Well Effects Evaluation for Project Rulison," BuMines-1002, PNE-R-39 (March, 1970).

C. PLANNED RADIOACTIVITY RELEASE

1. Production Testing

a. Test Plan

The production testing is experimentally necessary to allow determination of chimney and reservoir parameters from pressure drawdown and buildup data and chemical and radiochemical analysis. It has been designed to minimize the amount of gas released. Basically, the test program will consist of a flow period to measure the pressure depletion in the chimney to determine the effective chimney volume, followed by a long-term pressure buildup test to determine the extent of fracturing and the reservoir characteristics.

It is planned to delay reentry of the EW and, consequently, the production testing so potentially troublesome short-lived nuclides nuclides, principally rare gases and iodine, will have decayed to activity levels at which they are no longer a matter for concern.

All releases of radioactivity will be done in conformance with State and Federal regulations. As will be shown later, the upper limit calculated for the potential radiation exposure due to flaring is 0.8 mrem. The background level in the Rio Blanco area is 150 mrem/year.

(1) Flow Rates and Duration

For the flow test, it is planned to flow the gas at approximately 10 to 40 MMSCFD for an anticipated 10 to 40 day flow period. The actual length of the flow will be determined by the amount of pressure drop required to accurately determine chimney and reservoir parameters. Studies have indicated the 10 to 40 day flow period will be sufficient. Pressure and temperature will be monitored for six months to one year after shut-in.

(2) Equipment Layout

A schematic of the surface equipment for production testing is shown in Figure IIC-1. The gas flow will be up the seven-inch casing, through the wellhead wing valve, and then to the separator, where the free water and hydrocarbon

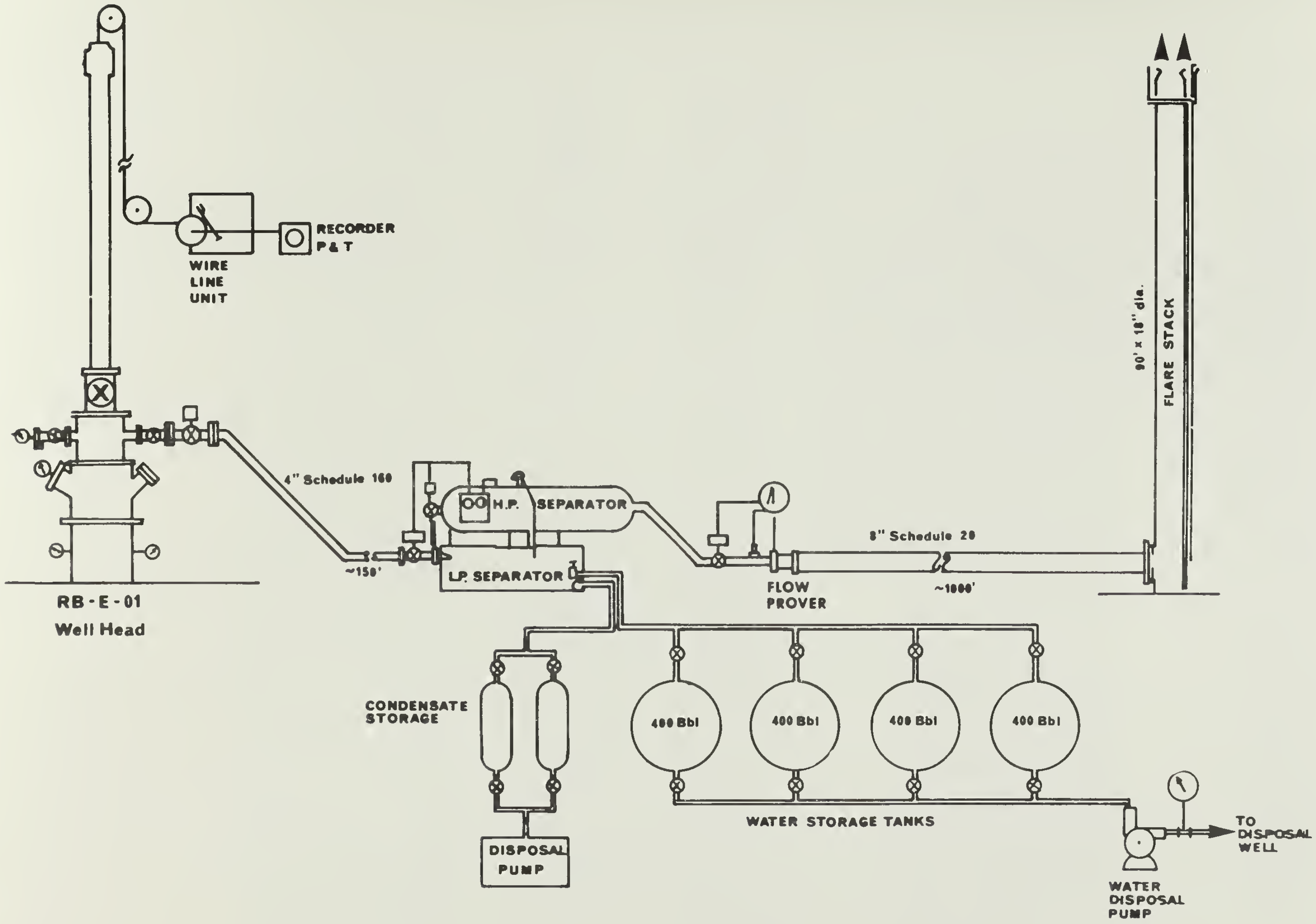

Figure IIC-1 Schematic of surface equipment for production testing liquids will be removed from the gas stream. The water will be metered and stored in water storage tanks, and the liquid hydrocarbon will be separated, metered, and stored in the low pressure condensate storage vessels. The gas from the separator will be measured through a critical flow prover and then flowed to the stack where it will be burned.

The hydrocarbon condensate will be burned along with the gas after radiochemical analysis. To limit release of the water to the biosphere, an attempt will be made to dispose of it by injection into one or more sand lenses of the Fort Union Formation (same formation that is being produced at EW) at the Fawn Creek Government Number 1 Well, rather than reinject it into the flare stack as at Rulison and Gasbuggy. Approval for this disposition will be sought from the Colorado Water Pollution Control Board.

(3) Monitoring System

A monitoring system will be provided to sample the gas stream upstream of the critical flow prover and to document its radioactivity. This will include assaying for activity in the gas, vapor, and solid phases, if any. Emphasis will be placed on continual assays of the gas phase for tritium and krypton-85 activity using the "TRY-KRY," a proportional counter system developed for the purpose by CER (Ref. IIC-1). This system will provide threshold sensitivities no greater than 1×10^{-2} pCi/ml for either tritium or krypton-85 in the presence of the other. Periodic whole gas samples will be taken and assayed in a laboratory for complete gaseous radioactivity. Water and hydrocarbon vapors in the sampled gas will be trapped and assayed for tritium. Whole gas sampling by particulate and activated charcoal filter techniques will be included in the monitoring system as necessary to identify any unexpected activities by gamma ray spectroscopy. Application of the monitoring techniques described here, together with those described below in conjunction with liquid disposal and measurement of gas and liquid flow rates and volumes, will provide the radioactivity effluent documentation to verify the source term for prediction of environmental effects, if any.

(4) Water and Condensate Disposal

The water and hydrocarbon condensates from the separator will be collected in separate tankage and subsequently disposed of by flaring or, preferably, by reinjecting into the Fawn Creek Government Number 1 Well (1,300 feet from the EW) into a sand lens at the depth of the chimney. Volumes and injection rates will be measured and recorded. After initial startup of the production test, production of hydrocarbon condensate is expected to be minimal. Adequate tankage will be provided so that accumulated liquids can be sampled for tritium activity prior to reinjection or flaring.

Duplicate samples of each batch of liquid will be taken and assayed for tritium specific activity prior to disposal.

b. Chimney Gas Parameters and Composition

(1) Chimney Void Volume, Gas Pressure and Temperature

For the calculations presented here, the chimney gas parameters have been deliberately chosen so as to determine a calculated concentration of radioactivity in the produced gas that is assured of being the upper limit. The parameters used are listed below:

Initial pressure (at reentry)	2,650 psi
Temperature	480°F
Chimney void volume	3.45×10^6 ft^3

(2) Chemical Composition

The primary constituents of the gas are expected to be methane, carbon dioxide, hydrogen, and steam. The amounts of carbon dioxide and hydrogen were estimated theoretically, whereas the amounts of steam and methane were estimated to conform with the foregoing pressure, volume, and temperature conditions. Ideal gas was assumed.

Specie	Chimney % by Volume	Volume at STP($ft^3 \times 10^6$)
Methane	26	89
Carbon Dioxide	34	117
Hydrogen	18	62
Steam	22	(not a gas at STP)

(3) Radioactivity Concentration Following Detonation

Five principal radionuclides are expected to be contained in the chimney gas at four to six months following the detonation: tritium, carbon-14, argon-37, argon-39, and krypton-85.

The half-lives and expected number of curies of radioactivity contributed by each of these radionuclides in the chimney at 120 and 180 days are presented as follows:

Radionuclide	Curies at 120 Days	Curies at 180 Days	Half-life
T	$<$ 3,000	$<$ 3,000	12.33 years
^{14}C	$<$ 22.5 *	$<$ 22.5 *	5,730 years
^{37}Ar	$<$ 8,720	$<$ 2,600	34.4 days
^{39}Ar	$<$ 20	$<$ 20	269 years
^{85}Kr	~ 2,000	~ 2,000	10.74 years

* Total in gas

Tritium is estimated to be distributed among CH_4, H_2, and H_2O in proportion to the mass of hydrogen in each specie. The mass of water is estimated to be 12×10^9 grams. On this basis, 675 curies of tritium are estimated to be in the methane, 235 curies in the hydrogen gas, and 2,090 curies in the water. Of the 2,090 curies in water, 285 would be in the steam. Thus, the total tritium in the gas would be 1,195 curies.

Finally, the resulting volume concentrations for all the radioactive gases would be as follows:

Radioactivity Concentration by Volume, Wet Chimney Gas, at 180 days

Nuclide	pCi/cc(STP)
Tritium	< 123
Krypton-85	205
Argon-37	< 267 *
Argon-39	< 2
Carbon-14	< 2.3

*Greater by a factor of almost 4 at 120 days.

2. Maximum Credible Dose Commitment

a. Assumptions

For the purpose of providing conservative predictions of potential radiation releases to the environment during the planned production testing, chimney parameters have been chosen which maximize the calculated concentrations of radioactivity in the produced gas and associated water. The parameters of interest are shown in Table IIC-I. Two cases of flaring operations are considered, a rate of 20×10^6 SCFD for up to 40 days, or at a rate of 40×10^6 SCFD for up to 20 days. In either case, the maximum volume of gas to be flared would be approximately 800×10^6 SCF, or about 2.3 times the volume of gas initially present in the cavity. Pertinent data for these conceptual high-rate flaring operations are listed in Table IIC-II. It is assumed for the purposes of these predictions that the preferred method of water disposal, reinjection into the Fawn Creek Government Number 1 Well, is not available and that it is necessary to dispose of all liquid water produced by injection into the gas being flared. The calculations are based on initiating flaring 180 days after the nuclear explosion. They would be essentially unchanged were flaring to commence at 120 days.

Table IIC-I. Predicted conditions* in the Rio Blanco cavity prior to reentry and flaring.

Minimum void volume:	3.45×10^6 ft^3
Minimum initial pressure:	2,650 psia
Maximum initial temperature:	480°F
Minimum gas volume in cavity (at 14.7 PSIA, 60°F)	344×10^6 ft^3
Minimum mass of free H_2O:	12,000 metric tons
Nominal mass of CH_4:	1,690 metric tons
Nominal mass of H_2:	150 metric tons
Nominal mass of CO_2:	6,200 metric tons
Minimum fraction of gaseous activity trapped in the melt zone:	Zero

*Conditions listed are either the minimum or maximum values, selected to maximize the predicted radioactivity concentrations in the gas.

Table IIC-II. Production flaring conditions assumed for Project Rio Blanco.

Flaring rate alternatives	20×10^6 SCF/day	40×10^6 SCF/day
Maximum flaring time	40 days	20 days
Maximum volume	800×10^6 SCF	800×10^6 SCF
Stack diameter	13 in.	18.5 in.
Gas exit velocity	250 ft/sec	250 ft/sec
Stack height	74 ft	104 ft
Flame height	130 ft	185 ft

For either flaring rate	Condition at start of flaring	Condition at end of flaring
Gas temperature in stack	200°F	--
Gas heating	720 BTU/ft^3	--
Flame temperature	3,000°F	--
Bottom hole pressure	2,650 psia	1,600 psia
Water production*	5.91 g/SCF	7.27 g/SCF

*Includes all water production, whether or not it enters the flare directly or is separated and then reinjected into the flare.

b. <u>Calculated Activity Release Rates</u>

The principal constituents of the gas predicted to be present in the cavity at the beginning of the flaring procedure are listed in Table IIC-III.

The last two columns in Table IIC-III list the maximum specific activities in the wet gas (referred to standard atmosphere) and the upper limits of total activities contained in the cavity at the start of the high rate flaring. During the flaring program, the cavity gases will be diluted by natural gas flowing into the cavity from the surrounding fracture zone. If the simplifying assumptions are made that all of the radioactive gases are initially present in the cavity and that all of the replacement gas from the surrounding rock is non-radioactive, the change in gas concentrations with flaring time may be readily calculated as an exponental decrease. The relative values for the two cases are shown in Figure IIC-2. It is noted that the concentrations of the gaseous nuclides would be expected to decrease by the end of the flaring to less than 10% of their initial value.

The actual situation during flaring will be somewhat different from that just described. The gas pressure in the cavity will decrease during flaring from an initial value of approximately 2,650 psia to about 1,600 psia at the end of flaring (Table IIC-II). Since the inflow rate of replacement gas depends upon the pressure gradient in the rock surrounding the cavity, an increase in the replacement rates would be expected as the flaring proceeds. However, since the maximum (initial) concentrations and the total activity released during flaring would be essentially the same, the simple exponential decrease will be assumed in the calculations.

The decrease in cavity pressure during flaring will also affect the rate at which water will vaporize in the cavity and be brought to the surface with the gas. The total water extraction rate is expected to increase by almost 25% during the period of production flaring. Although some dilution with water containing less tritium may occur, it will be assumed that the concentration of tritium in water remains constant. During the entire period of flaring, the amount of water released is expected to be 40 to 45% of the total water initially present in the cavity.

For all of the gases except water vapor, the initial activity release rates are calculated from the initial concentrations shown in Table IIC-III, and the final release rates are based on the expoential decrease shown in Figure IIC-2.

Table IIC-III. Principal constituents of the gas in the Rio Blanco cavity assumed at 180 days after the detonation.

Molecular species	Mass (Mg)	H Mass (Mg)	Partial pressure (psia)	Volumetric fractions		Nuclide	Max. conc. in wet gas at STP (pCi/ml)	Total activity (Ci)
				Wet gas	Dry gas			
H_2O	12,000	1,150 (Liq) 180 (Gas)	570	0.22	--	^{3}H	175,000 (Liq) 29 (Gas)	
H_2	150	150	480	0.18	0.23	^{3}H	24	
CH_4	1,690	430	690	0.26	0.33	^{3}H	70	<3,000
						^{14}C	0.5	
CO_2	6,200	--	910	0.34	0.44	^{14}C	1.8	< 22.5
Ar	--	--	--	--	--	^{37}Ar	267	<2,600
						^{39}Ar	2.0	<20
Kr	--	--	--	--	--	^{85}Kr	205	~2,000
Totals	--	1,910	2,650	1.00	1.00	--	--	--

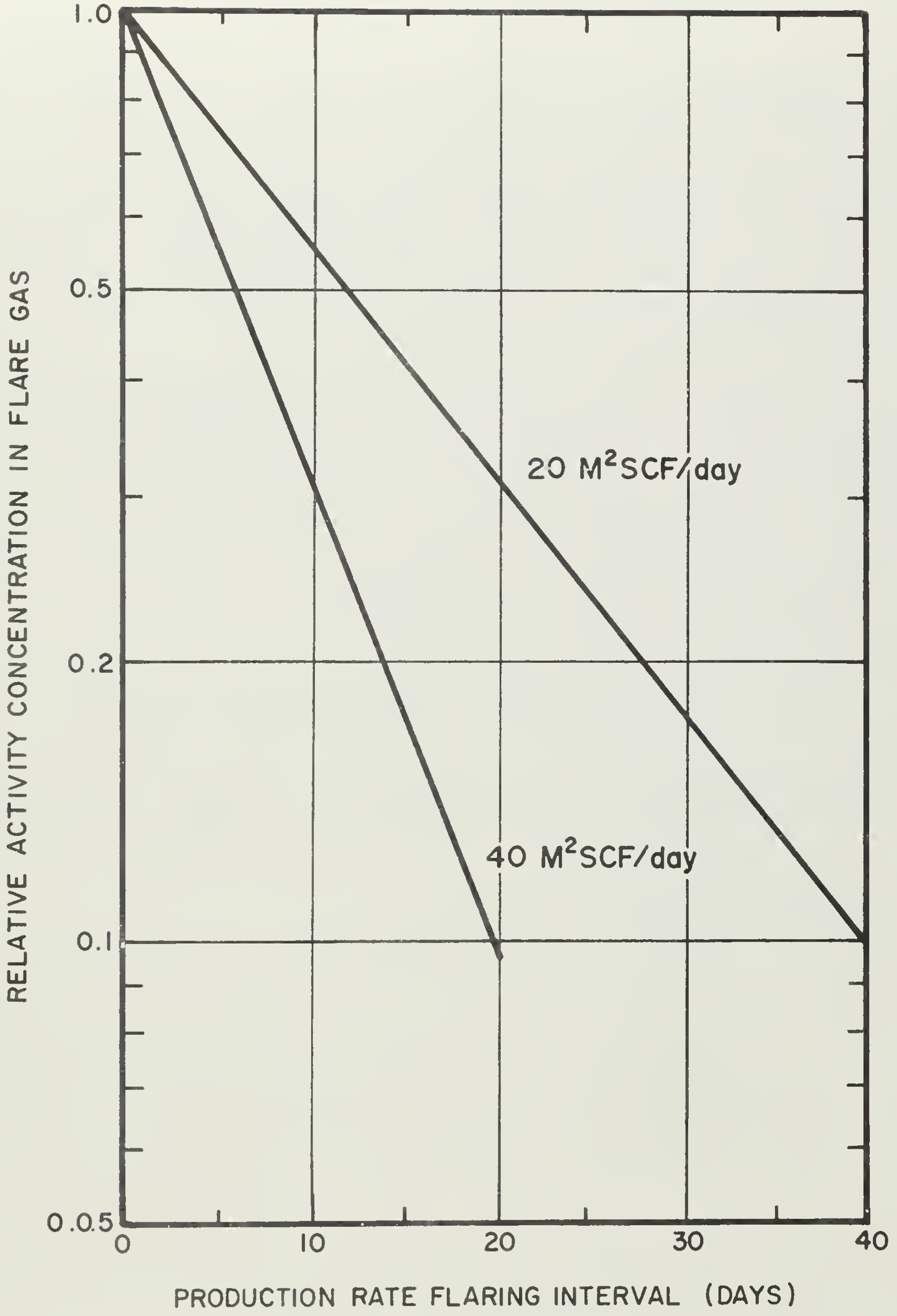

Figure IIC-2. Relative concentration of activity in flare gas, versus flaring time.

The final release rate of tritium extracted as water vapor is assumed to be 1.23 times its initial release rate. The calculated initial and final release rates are listed in Table IIC-IV.

c. Potential Radiation Dose from Flaring

From Figure IIC-2 and Table IIC-IV, it is noted that the concentrations of the gaseous radioactivity in the cavity will be reduced by a factor of 10 during the flaring program. In other words, 90% of the gaseous radioactivity will be released by the flaring of 8×10^8 SCF of gas, whether flared at 20 million SCFD for 40 days or at 40 million SCFD for 20 days. Thus, approximately 1,800 Ci of ^{85}Kr and a maximum 2,040 Ci of ^{37}Ar (at 50 million SCFD) will be released.

For liquid tritiated water, the release rate during flaring will actually increase, almost linearly. This component of tritium must be added to those in H_2 and CH_4, which will be depleted exponentially during flaring. The integral of the release rate for all tritium over the entire period of flaring was calculated to be 1,440 Ci. For making dose calculations, it is assumed that all of this tritium will be released to the atmosphere and that all of it will be oxidized to water vapor.

(1) Immersion Dose from ^3H, ^{37}Ar and ^{85}Kr

Calculated values of dose per day per unit concentration, together with the integrated releases shown above for ^3H, ^{37}Ar, and ^{85}Kr, are used to calculate the cumulative potential immersion dose per unit atmospheric dispersion values shown in Table IIC-V.

(2) Inhalation and Skin Absorption Dose from ^3H_2O.

Potential doses from inhalation and skin absorption of ^3H_2O have been calculated by assuming a total body (soft tissue) dose per unit activity uptake of 0.167 mrem/μCi (Ref. IIC-4) for an adult and 0.351 mrem/μCi for an infant. The adult is assumed to inhale 20 m^3 of air per day and the infant one-fifth as much. All of the inhaled ^3H_2O is assumed to be absorbed into the body (Ref. IIC-5) and, in addition, an equal quantity is assumed to be absorbed through the skin (Ref IIC-6). From these assumptions and the ^3H_2O activity release of 1,440 Ci, the cumulative total body doses per unit atmospheric dispersion are calculated to be: for an adult, 1.11×10^5 mrem - m^3/sec; for an infant, 4.67×10^4 mrem-m^3/sec.

Table IIC-IV. Calculated release rates for radioactive gases at the beginning (Q_{io}) and at the end (Q_{if}) of the production flaring.

Flaring rate:	20 million SCF/day		40 million SCF/day	
Nuclides	Q_{io} (Ci/sec)	Q_{if} (Ci/sec)	Q_{io} (Ci/sec)	Q_{if} (Ci/sec)
^3H in H_2O	1.90×10^{-4}	2.34×10^{-4}	3.80×10^{-4}	4.68×10^{-4}
^3H in H_2	1.58×10^{-4}	1.54×10^{-5}	3.15×10^{-4}	3.08×10^{-5}
^3H in CH_4	4.55×10^{-4}	4.46×10^{-5}	9.10×10^{-4}	8.90×10^{-5}
TOTAL ^3H	8.03×10^{-4}	2.94×10^{-4}	1.60×10^{-3}	5.88×10^{-4}
^{14}C in CH_4	3.28×10^{-6}	3.2×10^{-7}	6.55×10^{-6}	6.4×10^{-7}
^{14}C in CO_2	1.18×10^{-5}	1.16×10^{-6}	2.36×10^{-5}	2.31×10^{-6}
TOTAL ^{14}C	1.51×10^{-5}	1.48×10^{-6}	3.02×10^{-5}	2.95×10^{-6}
^{37}Ar *	1.75×10^{-3}	7.59×10^{-6}	3.51×10^{-3}	2.31×10^{-4}
^{39}Ar	1.25×10^{-5}	1.22×10^{-6}	2.5×10^{-5}	2.4×10^{-6}
^{85}Kr	1.34×10^{-3}	1.32×10^{-4}	2.69×10^{-3}	2.63×10^{-4}

*Owing to the relatively short half-life of ^{37}Ar (34.4 days), some decay will occur during the flaring period, resulting in the additional reduction of the final release rate, as indicated above.

Table IIC-V. Cumulative potential immersion dose per unit atmospheric dispersion for Rio Blanco production flaring.

Nuclide	$D/\overline{X}\,t$ (mrem-m^3/ μCi-day)	A_i (curies)	$D_i/(\overline{X}/\overline{Q})$ (mrem-m^3/sec)
^{3}H	0.263	1,440	4.374×10^3
^{37}Ar	0.068	2,040	1.606×10^3
^{85}Kr	6.31	1,800	1.314×10^5
Combined total			1.374×10^5

Note: Attention is called to the dominance of ^{85}Kr in the cumulative potential immersion dose and to the fact that ^{85}Kr has a half life of 10.74 years. Thus, this dose calculation is rather insensitive to time of cavity reentry after about 120 days.

(3) Ingestion Dose from ^3H_2O via the Pasture-Cow-Milk Pathway

With the foregoing assumptions and additional conservative assumptions on the parameters of deposition and uptake, the total body doses per unit atmospheric dispersion are calculated to be: for an adult, 4.29×10^7 mrem-m^3/sec; for an infant, 9.00×10^7 mrem-m^3/sec.

(4) Combined Doses for All Nuclides and Exposure Routes

Before proceeding to apply long-term atmospheric dispersion estimates to the foregoing dose calculations, it is informative to combine the values for the various nuclides and exposure routes, where appropriate, and to list all of the calculated values in one place. This has been done in Table IIC-VI. It is noted that the calculated skin dose is more than an order of magnitude smaller than the calculated total body dose. Since the ICRP (Ref IIC-5) considers the radiosensitivity of the skin to be only about one-sixth that of the total body, it is concluded that, for the production flaring situation, the skin dose is insignificant in comparison to the total body dose.

It is further noted that for the direct exposure routes, the calculated total body doses from ^{85}Kr and ^3H_2O are of the same order of magnitude for both adults and infants. Owing to the uncertainties in making the long-term average atmospheric dispersion estimates that must yet be applied to calculate total dose commitments, a rounded-off average of 2×10^5 mrem-m^3/sec is used for the direct exposures to both adults and infants. The errors resulting from this procedure (-17% for adults and +12% for infants) would be within the range of the uncertainties involved.

The third observation is that the potential dose by ingestion of tritium in milk is several hundred times larger than the potential dose by direct exposure routes. The calculations, of course, assume that all of the milk consumed comes from cows being fed exclusively on pasture exposed to the same tritium concentration in air as that to which the person is exposed. Although such a combination of circumstances is extremely unlikely to occur in the Rio Blanco area, the calculated value of 9.0×10^7 mrem-m^3/sec will be used in the subsequent calculations of total dose commitment.

Table IIC-VI. Cumulative dose per unit atmospheric dispersion for all nuclides and exposure routes of potential significance during flaring.

Nuclide and exposure route	Dose per unit atmospheric dispersion (mrem-m^3/sec)			
	To an adult		To an infant	
	Skin	Total body	Skin	Total body
^{3}H immersion	4.38×10^{3}	--	4.38×10^{3}	--
^{37}Ar immersion	1.61×10^{3}	--	1.61×10^{3}	--
^{85}Kr immersion	--	1.31×10^{5}	--	1.31×10^{5}
$^{3}H_2O$ inhalation and skin absorption	--	1.11×10^{5}	--	4.67×10^{4}
Sub-total, direct exposure routes:*	5.99×10^{3}	2.42×10^{5}	5.99×10^{3}	1.78×10^{5}
$^{3}H_2O$ milk ingestion **	--	4.29×10^{7}	--	9.00×10^{7}

*Since immersion, inhalation and skin absorption are necessarily concomitant exposure routes, these sub-totals may be used conveniently in subsequent dose calculations.

**Attention is called to the dominance of the dose due to the tritium in milk and to the fact that tritium has a half life of 12.33 years. Thus this dose calculation is rather insensitive to time of cavity reentry after about 120 days.

Since the calculated dose to an adult from ingestion of milk would be less than half that for an infant, and since the assumed values of 0.167 mrem per μCi intake and one liter of milk consumed per day were probably substantially overestimated, a separate calculation will not be made for the adult dose. If exposure by ingestion of tritium in milk should actually become a problem, the potential dose to infants would be the limiting case.

(5) Long-Term Atmospheric Dispersion Estimates for Production Flaring

Estimates of dispersion during production flaring require the additional consideration of effective plume height. On the basis of limited data from Project Rulison, the effective plume height at Rio Blanco flaring rates is expected to be at least 1,500 feet above the release elevation (about 6,850 feet MSL) at all times. The atmospheric dispersion estimates for the flaring case have been calculated by the methods of Ref. IIC-7, using a plume height of 500 m, and are shown in Table IIC-VII. The assumption of a plume height of 500 m is consistent with plume heights calculated by the methods recommended for a hot source by Ref. IIC-8.

From the 700 mb wind roses presented in Figure I-I-1, it is readily apparent that the prevailing upper-air winds would carry the radioactive materials released during flaring toward the NE or ENE. In the NE and ENE sectors, the nearest ranches are located along Piceance Creek at downwind distances of 10 km or more from the project site. The nearest location of concentrated population is the town of Meeker at 48 km downwind. One permanently occupied ranch is located NNE of the site at approximately 7 km downwind (at the confluence of Fawn Creek with Black Sulphur Creek). From Table IIC-VII, the maximum ground-level concentration would occur for stability category C at a downwind distance of 6 to 8 km. For stability category D the maximum occurs at 40 km downwind, and for category E the maximum would occur more than 100 km downwind. The long-term average atmospheric dispersion for distances of 8 and 40 km is calculated by the methods of Ref. IIC-9. The results are presented in Table IIC-VIII.

Table IIC-VII. Atmospheric dispersion estimates at ground level in the centerline of the plume for an effective plume height, H, of 500 m (e.g., production flaring) where upper level winds are controlling.

Downwind distance, x (km)	$X/Q = (Ci/m^3)/(Ci/sec) = sec/m^3$		
	Pasquill category C (unstable)	Pasquill category D (neutral)	Pasquill category E (stable)
	Wind speed, u = 7.3 m/sec	Wind speed, u = 7.3 m/sec	Wind speed, u = 2.5 m/sec
1	1.727×10^{-20}	--	--
2	0.175×10^{-9}	--	--
4	38.24 "	2.89×10^{-15}	3.02×10^{-27}
6	76.13 "	2.83×10^{-12}	2.02×10^{-20}
8	75.2 "	1.18 "	9.26×10^{-17}
10	64.8 "	0.624×10^{-9}	7.82×10^{-15}
15	40.34 "	4.84 "	2.88×10^{-12}
20	26.59 "	9.57 "	0.0487×10^{-9}
30	13.61 "	16.47 "	0.548 "
40	8.446 "	19.18 "	1.41 "
60	3.949 "	17.48 "	3.20 "
80	2.641 "	15.44 "	4.84 "
100	1.786 "	12.78 "	5.31 "
σ_y at 40 km	2.77 km	1.82 km	1.38 km

Table IIC-VIII. Long-term atmospheric dispersion estimates for 8 km (nearest ranch) and 40 km (Meeker and vicinity) downwind for production flaring release (H = 500m).

Downwind distance, x (km)	Pasquill(1) stability category	Wind speed, u (m/sec)	Short-term dispersion estimate,(2) X/Q (sec/m^3)	Lateral dispersion coefficient, σ_y (km) at x	Assumed frequency of occurrence, f	Long-term(3) dispersion estimate, $\overline{X}/\overline{Q}$ (sec/m^3)
8 km (Piceance Creek ranches)	C	7.3	7.52×10^{-8}	0.68	0.15	9.00×10^{-9}
	D	7.3	1.18×10^{-12}	0.46	0.50	2.16×10^{-13}
	E	2.5	9.26×10^{-17}	0.34	0.35	8.79×10^{-18}
			Combined average dispersion estimate:			9.00×10^{-9}
40 km (near edge of Meeker area)	C	7.3	8.45×10^{-9}	2.77	0.15	5.60×10^{-10}
	D	7.3	1.92×10^{-8}	1.82	0.50	2.79×10^{-9}
	E	2.5	1.41×10^{-9}	1.38	0.35	1.09×10^{-10}
			Combined average dispersion estimate:			3.46×10^{-9}

(1) It is estimated that stability categories A, B, and F occur not more than a total of 10% of the time. Accordingly, they are omitted from this analysis.

(2) From Table IIC-VII.

(3) These calculations assume no oscillatory up-and-down motions of the plume during unstable conditions, which it is estimated will occur about 10% of the time on an annual basis. This might cause somewhat higher dispersion estimates a portion of the time.

(6) Total Dose Commitment for Production Flaring

The maximum cumulative dose commitments for all nuclides and exposure routes combined, at the most critical locations with respect to the production flaring, are shown in Table IIC-IX. The calculated upper limit of the dose to humans (infants) is 0.8 mrem in an area where the dose per year due to background radiation is 150 mrem per year--so small that additional comment seems unnecessary.

3. Self-Imposed Restrictions on Production Testing

a. Delay of Reentry

It is planned to delay reentry of the EW and consequently the production testing so that potentially troublesome short-lived nuclides, principally rare gases and iodine, will have decayed to activity levels at which they are no longer a matter for concern. With this delay, radiological monitoring can be limited essentially to the radioactive nuclides listed above for the chimney gas composition and many potential operational problems become nonexistent.

An add-on experiment has been proposed which would allow sampling of the chimney gas at early times. Results from this experiment, if performed, could result in a more rapid reentry than currently indicated. Iodine-131 was not detected in the gas upon reentry into the Gasbuggy chimney 30 days after the detonation (Ref. IIC-2). An upper limit for the Iodine-131, extrapolated to the time of detonation, of 0.04 pCi/cc STP has been established (Ref. IIC-3). Because Rulison had an extensive delay prior to reentry, only iodine data related to the Gasbuggy experience are applicable. If the add-on experiment is performed and it confirms Gasbuggy results, reentry into the cavity can begin earlier than previously indicated.

b. Single Flow Test of Shortest Possible Duration

In order to conserve natural gas and limit the release of radioactivity, the production testing will be held to the minimum necessary for proper evaluation of the experiment. Only one production period is planned. It is estimated that the length of the production test will be between 10 to 40 days. The length of flow will be dependent on the amount of pressure drawdown obtained during the flow period.

Table IIC-IX. Total dose commitments for all nuclides and exposure routes at the critical locations for production flaring.[1]

	Piceance Creek ranches $(\overline{X}/\overline{Q} = 9.00 \times 10^{-9}$ sec/m$^3)$	Meeker and vicinity $(\overline{X}/\overline{Q} = 3.46 \times 10^{-9}$ sec/m$^3)$
Direct exposure routes $\left(D/(\overline{X}/\overline{Q}) = 2 \times 10^5 \text{ mrem-m}^3/\text{sec}\right)$ adult or infant	1.80×10^{-3} mrem	6.92×10^{-4} mrem
Milk ingestion route $\left(D/(X/Q) = 9.0 \times 10^7 \text{ mrem-m}^3/\text{sec}\right)$ infant	8.1×10^{-1} mrem	3.11×10^{-1} mrem

(1) These calculations assume no oscillatory up-and-down motions of the plume during unstable conditions, which it is estimated will occur about 10% of the time on an annual basis. This would result in calculating somewhat higher dose commitments than those shown.

c. Conformity with Radiological Regulations

Releases of radioactivity in flaring operations will be done in a manner consistent with the guidelines of AEC Manual 0524, Standards for Radiation Protection; Title 10, Code of Federal Regulations, Part 20; Standards for Protection Against Radiation, and Colorado Department of Health, Rules and Regulations Pertaining to Radiation Control.

4. Unavoidable Adverse Effects

The only identifiable adverse effect from the planned release of activity is the release to the environment of the quantities of gaseous (including water) radioactivities shown in Paragraph IIC-2c. As shown previously, the upper limit of the potential dose is about 0.8 mrem via the critical path of ingestion of tritiated milk by an infant. This is insignificant compared with the natural background radiation dose rate of 150 mrem per year. For comparison purposes, it is noted that a person receives an extra 0.8 mrem per year by living on a hill 50 feet high rather than at the bottom of the hill.

REFERENCES

IIC-1. Brundage, R. S., B. G. Motes, and P. Gant. "On-line Monitor of Natural Gas Lines for Hydrogen-3 and Krypton-85," Nuclear Technology, 11, No. 3, 400 (July, 1971).

IIC-2. Holzer, F., "Gasbuggy Preliminary Post Shot Summary Report," PNE-G-3 (January, 1968).

IIC-3. Smith, Charles F., Jr., "Project Gasbuggy Gas Quality Analysis and Evaluation Program Tabulation of Radiochemical and Chemical Analytical Results," UCRL-50635, PNE-G-44 (November, 1969).

IIC-4. ICRP Publication No. 10, "Report of Committee No. 4 on Evaluation of Radiation Doses to Body Tissues from Internal Contamination Due to Occupational Exposure," Pergamon Press, London.

IIC-5. ICRP Report of Committee No. 2 on "Permissible Dose from Internal Radiation," Health Physics, Vol. 3 (1960).

IIC-6. Pinson, E. A. and W. A. Langham, "Physiology and Toxicology of Tritium in Man," J. Applied Physiology, 10, p. 108 (1957).

IIC-7. Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," National Air Pollution Control Administration, U. S. Public Health Service Publ. 999-AT-26 (1969).

IIC-8. Briggs, G. A., "Plume Rise," USAEC, TID-25075 (1969).

IIC-9. Slade, D. H. (Editor), "Meteorology and Atomic Energy," USAEC, Div. of Technical Information, TID 24190 (July, 1968).

D. WASTE DISPOSAL PROTECTION

1. Radioactive Water

As previously described, it is planned that liquid water be separated by the separator to permit reliable measurements of gas flow rates at the critical flow prover. Some water in the vapor phase will remain in the gas stream and will be dispersed in the atmosphere with the combustion products of the flared gas. It is expected that the separated water will contain tritium with a specific activity on the order of 5×10^{-8} Ci/ml, a factor of about 15 in excess of the radioactivity concentration guide of 3×10^{-9} Ci/ml for an uncontrolled area. It will be necessary, therefore, to dispose of this water in such a way as to minimize exposure of the general population. The expected cumulative production of total water and separated liquid water with time is compared in Figure IID-1 with the cumulative production of gas with time. If the production testing is carried to the maximum anticipated to accomplish the objectives of the experiment, 5,000 to about 20,000 barrels of liquid water will be separated and sampled for radioactivity prior to disposal.

a. Disposal Method

If appropriate authorization is obtainable, reinjection of the tritiated water into one or more sand lenses of the Fort Union Formation in the Fawn Creek Government Number 1 Well will be attempted. It is believed from experience with this well that adequate flow rates can be achieved within anticipated pressure limitations. If this is the case, this method will be used and the tritiated water will simply be returned to a zone near the region from which it originated. The zone would be isolated from gas-producing zones in the same well. After injection, the tritiated water would be in a closed system, not free to migrate and unavailable for uncontrolled use. Within 50 years and without dilution, the concentration of tritium would be below the radioactivity concentration guide for drinking water. The volumes of water involved are less than 0.02% of those being used in a waterflood operation each year at the Rangely oil field. Hence, no effect on seismic activity is credible.

If it is not possible technically or for lack of authorization to reinject the separated water into the formation, it will be necessary to reinject it into the flowing gas at the flare stack. It has been shown in II-C that reinjection of the separated water into the flare would result in an insignificant potential exposure at nearby inhabited areas.

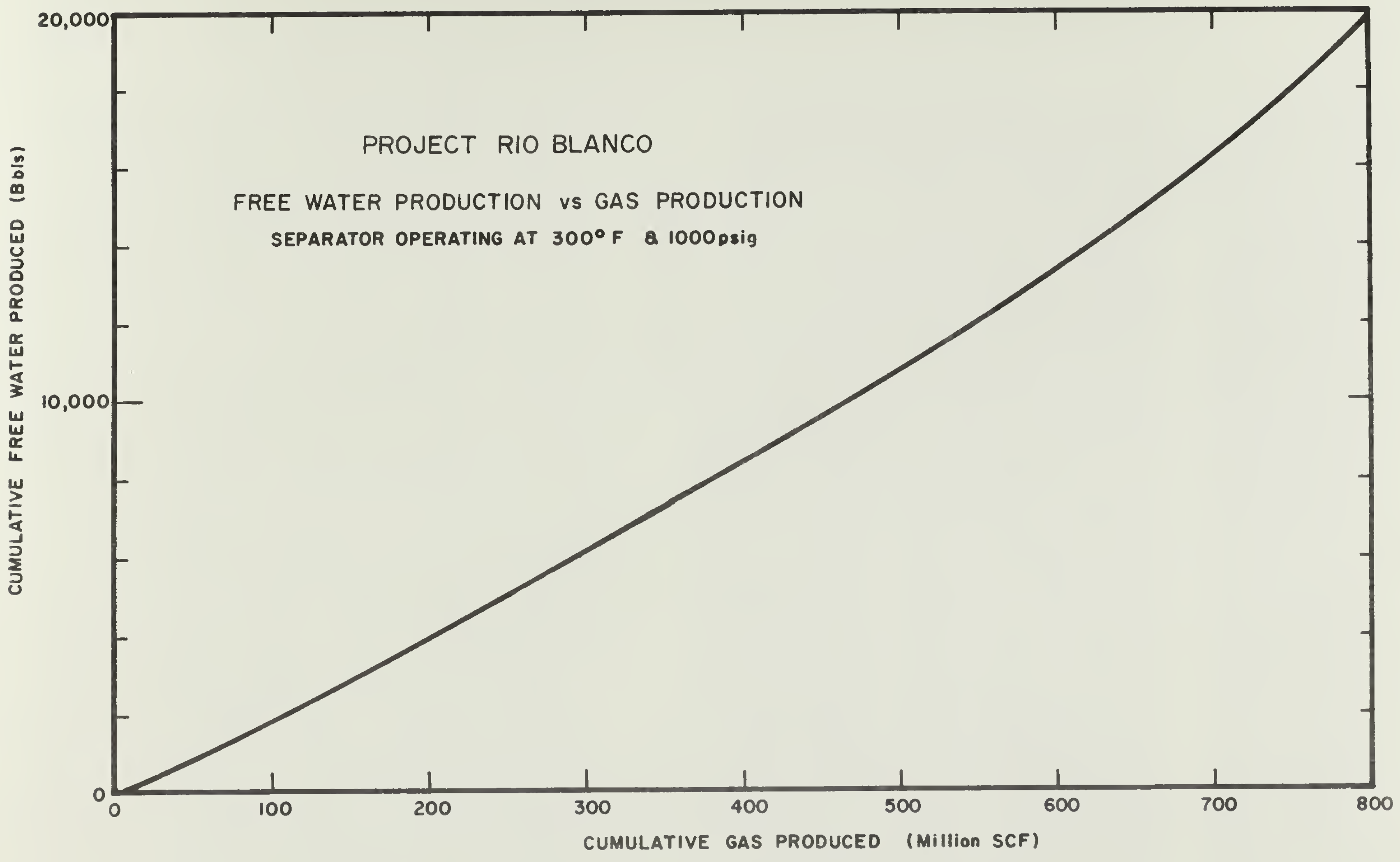
PROJECT RIO BLANCO
FREE WATER PRODUCTION vs GAS PRODUCTION
SEPARATOR OPERATING AT 300° F & 1000psig
CUMULATIVE FREE WATER PRODUCED (Bbls)
20,000
10,000
0
0
100
200
300
400
500
600
700
800
CUMULATIVE GAS PRODUCED (Million SCF)

Figure IID-1.

b. Alternatives for Disposal

Alternative methods for disposal of the separated water have been evaluated as follows:

(1) Reinjection into the Cavity

Reinjection into the cavity would require storing a maximum of 20,000 barrels of produced water until completion of the production testing program. This would require tank storage with provision for heating to prevent freezing and dike protection against tank leakage. In addition, when the well is subsequently connected to a pipeline, the injected water will have to be separated and handled a second time. Continued reinjection would gradually fill the cavity and would jeopardize the production life of the well. Thus, this method does not appear practical.

(2) Use of Evaporation Pond

Storage of the produced water in a bentonite and plastic-lined pond for evaporation would have the advantage of low cost. However, the same amount of tritium would ultimately be released into the atmosphere by evaporation as would be released by flaring. Plastic-lined pits are waterproof when intact, but are subject to damage, particularly from rodents. Thus, the possibility of water entering the groundwater system would exist. The pond would also provide an undesirable source of drinking water for wildlife. Excluding deer and ducks from the pond would be difficult, if not impossible. Thus, this method does not appear practical.

(3) Burial in Authorized Waste Disposal Area

The most uneconomical method would be burial in an authorized waste disposal area. This requires treatment of the water by gelling, barreling, shipping, and burial. At the estimated cost of $30 to $40 per barrel, the total cost of disposing of the 20,000 barrels of water would be $600,000 to $800,000. Thus, this method does not appear to be practical.

2. Other Contaminated Materials

a. Drilling Mud

If, as experience at Gasbuggy and Rulison indicates, reentry is accomplished by lost circulation of the drilling fluid, then no contaminated drilling mud will occur at the surface. To accommodate the remote possibility that contaminated mud does appear, the mud system for reentry will be maintained as two separate systems to minimize the amount that is contaminated. An active system of approximately 700 to 1,000 barrels in steel tanks will be used and could be subject to potential contamination. A reserve system of about 500 barrels will be set up as a backup for the active system and will not be subject to potential contamination unless transferred to the active system.

Any contaminated mud will be disposed of by reinjection into the wellbore after good communication has been established with the chimney and drilling operations have been discontinued. The cuttings which remain in the active system after disposal of the mud will be assessed for radioactivity and disposed of by burial either on-site or at an approved commercial radioactive waste disposal area, depending upon the quantity and levels of radioactivity encountered. Guidelines to be followed in disposal of radioactive drill mud residue are contained in the State of Colorado Rules and Regulations Pertaining to Radiation Control, effective July 15, 1970, in AEC Manual Chapter 0524, Standards for Radiation Protection, and in Title 10, Code of Federal Regulations, Parts 20 and 30.

b. Residual Contaminated Equipment and Material

It is expected that minimal additional contaminated equipment and material will be accumulated during the course of drill-back and production test operations. Examples of these are filter and swipe papers, desiccants, piping, valves, and tanks. Soils may be contaminated by accidental spills or leaks. The principal contaminating nuclide expected is tritium. Disposable, solid contaminated waste will be handled as described above for drill cuttings. Combustible solids may be handled by incineration either for direct disposal or for reduction in volume prior to burial, provided that the standards stated in the regulations cited above can be met.

Residual contaminated equipment will be decontaminated to activity levels below 1,000 dpm per 100 cm^2 of removable beta-gamma activity (removable by standard swipe tests) prior to release to unrestricted use. Pending decontamination, contaminated equipment will be retained under controlled conditions and not released to unrestricted use. Contaminated liquids resulting from the decontamination process will be disposed of in the same manner as described above for radioactive water. Small residual quantities of liquids not disposable in this manner will be disposed of in the same manner as described above for contaminated cuttings.

3. Industrial Waste (non-radioactive)

a. Drilling Mud

Approximately 5,000 barrels of drilling mud are required for drilling the EW and making the reentry to the nuclear chimney. During the drilling of the EW, the drilling mud will be maintained in the steel mixing tanks with the reserve mud maintained in a bentonite-sealed earth pit. Upon completion of the drilling activities, the drilling mud will be sprinkled on the access road to control dust. In the event that inclement weather would prohibit spreading of the drill mud on the local roads, a temporary holding pit will be constructed away from the EW site for storage of the mud until such time as the disposal can be accomplished. If the drilling mud is saved and used during reentry drilling, disposal will be the same, or injected into the chimney, at the conclusion of the experiment.

(1) Storage

The reserve pit for the drilling mud will be excavated out of native material. The sides and bottom will be mixed with bentonite so that when water is added, the bentonite will swell, sealing the pit. Lining mud pits with plastic liners has not been successful in the area, since muskrats burrow to the water through the banks and eat holes in the liners.

Drainage will be provided so that rainwater runoff will not add to the mud pit. The banks of the mud pit will be compacted to prevent erosion, and maintenance will be provided to control erosion.

(2) Disposal

The uncontaminated drill mud will be disposed of conventionally; for example, by spraying on gravel roads. To control erosion, the mud pit will be backfilled to approximately the original grade and planted with a wheat-type grass such as *Agropyron smithii*.

b. Sewage

Sewage will be collected in septic tanks and, as necessary, the tanks will be pumped into a tank truck and hauled to a local sewage treatment plant.

c. Other

Combustible waste and solid material will either be hauled to an approved disposal site or burned in accordance with the provisions of the air pollution laws of Colorado.

III. OTHER ENVIRONMENTAL CONSIDERATIONS

A. INTRODUCTION

The preceding section has emphasized aspects of the Rio Blanco experiment which have a clear, albeit limited, impact on the environment. Additional environmental considerations are discussed in this section which are known to be matters of interest to the public. These relate primarily to the improbable contingency of inadvertent transport of residual radioactivity into the biosphere. The integrity of other mineral resources in the project area, notably oil shale, is also discussed.

B. CONTAINMENT

1. Experience

The Rulison and Gasbuggy experiments provide the only U. S. nuclear explosion containment experience in natural gas-bearing formations. There is much additional experience in other geologic formations in the yield range of Rio Blanco from tests conducted at the NTS.

During underground nuclear testing through 1970, there have been 80 announced detonations in the low-intermediate range (20 to 200 kt) which have been buried in holes at an adequate depth for containment. None of these tests has resulted in a dynamic, prompt release of radioactivity to the atmosphere. There have been four detonations, in the 20 to 200 kt range, which seeped detectable amounts of radioactivity to the surface. In all cases, the seepage commenced hours after the detonation took place. In all four cases, the depths of burst were less than 2,000 feet, as contrasted to a depth of burst of over 5,000 feet for the shallowest explosion at Rio Blanco.

Therefore, because of this experience and the great depths of burst associated with stimulating natural gas production with nuclear explosives, only the seepage of gaseous radionuclides is considered as even a remote possibility in questions relating to containment. The long-lived gaseous radionuclides with the greatest biological impact produced by nuclear explosives are ^{85}Kr and ^{3}H. Other gaseous radionuclides produced in biologically significant quantities such as I, Xe, and other Kr isotopes have relatively short half-lives and decay more rapidly. The impact of seepage of gas from the chimney to the environment becomes less with each succeeding day, as both radioactive decay and dilution of the initial cavity gas with fresh natural gas from the formation take place. Within a few months, reentry to the chimney and production testing may generally be undertaken.

In the Gasbuggy experiment, the only radioactivity detected at the ground surface prior to reentering the chimney occurred several hours after the detonation in gas seeping through the permeable multiconductor timing and firing cable. Although this type of seepage is easily controlled, it is no longer expected as the firing cables now used are impermeable to gas flow.

In the Rulison experiment, there was no radioactivity above background recorded at the ground surface prior to production testing. The Rulison stemming material, unlike the cement used in Gasbuggy, was a permeable pea gravel and sand mixture with plugs of bentonite clay. An increase of pressure at the wellhead was observed starting about six days after the detonation, indicating either communication with the chimney or a gas-bearing formation above the top of the chimney. A radiation detector placed adjacent to the wellhead did not indicate any readings above normal background. Several months after the detonation, a small gas sample was withdrawn from the wellhead for radiochemical analysis. Gaseous radioactivity in this sample was determined to have originated from the nuclear explosion. Because the wellheads are designed to contain gases within the well at maximum reservoir pressures, with a suitable additional factor for safety, no uncontrolled release of gas occurred. The Rio Blanco stemming design eliminates the use of permeable materials like sand and gravel, thus further reducing any possibility of chimney gas seepage to the wellhead.

The primary factors important in containing nuclear explosions are very similar for the Gasbuggy, Rulison, and proposed Rio Blanco experiments. These factors include the explosive yields, depth of burst, and the physical-chemical properties of the rock formation. The pressure of the gases in the chimney formed by the explosion is the driving force for any postulated seepage.

The presence of natural gas (primarily CH_4) in the formation is not a major factor in the early pressure-time history of the cavity when containment is most important. The partial pressure of the formation gas within the initial cavity is only a small fraction of the total cavity pressure. Formation gas will not flow into the chimney until the chimney pressure falls below the formation pressure. Formation pressures are then not reached in the chimney for several weeks. Much of the containment experience gained from tests at the NTS is therefore applicable to gas stimulation experiments.

There is not expected to be a significant difference in the pressure-time histories of Gasbuggy, Rulison, and Rio Blanco. If there is a difference, the direction is likely to be toward a more rapid decay of pressures in the Rio Blanco test because of the effects expected from the simultaneous detonation of multiple explosives.

The spacing between explosives in Rio Blanco will be larger than the chimney developed by a single explosion. As a result, a larger volume of cold chimney rock may be available very rapidly to cool the cavity gases and to accelerate the decay of chimney pressures in the Rio Blanco experiment. The time at which the chimney forms is also important in predicting the pressure-time history, but since collapse of the cavity occurred very early (within less than one minute) for both Gasbuggy and Rulison, no significant difference is expected to be attributable to this factor for Rio Blanco.

2. Seepage Model

When a nuclear explosive is detonated at the great depths common to natural gas-bearing formations, it is hard to imagine the explosion not being contained. However, experience at NTS with explosions, at admittedly much shallower depths, showed not all nuclear detonations are contained, at least in the sense of zero release of radioactivity. Therefore, to be ultraconservative, it is prudent to construct a model which postulates an inadvertent release of radiation and to prepare operational plans that protect the public and the environment against the consequences of that unlikely event.

Natural gas occurs in reservoirs that are sealed naturally over geologic time against the escape of the gas by impervious strata of non-gas-bearing rock. The very fact that a gas reservoir exists is proof that there are no permeable or open paths that connect the reservoir to the surface or any acceptor strata at lower pressures. Thus, natural pre-shot leakage paths are out of the question. Natural zones of weakness, such as ancient faults or joints, may exist in the vicinity of gas reservoirs. For the reason stated above, they are not natural paths of communication. NTS experience generally shows that, while preferential surface cracking may occur over these zones of weakness, such cracks do not necessarily establish open paths to the detonation point media. In fact, if the detonation point is not located in the fault, joint, or other weakness, the loading is generally compressive at depth. Some possibility of opening a seepage path may exist if the overall tectonic structure is naturally in a tensile stress condition and the incremental loading produces a total stress in excess of the yield strength of the formation at its weakest points. The absence of faulting close to the EW and the presence of a natural gas accumulation at a high pressure, as evidenced by surveys and the discussion above, preclude these being factors in this case. It is concluded that the only credible pathway for communication between the Rio Blanco chimney and the surface would be through the man-made emplacement facility.

a. Credible Seepage Path

Containment within the casing is assumed because of the planned mud stemming and the systems of cement plugs. The seepage path used as the basis for the model is confined to the annular region between the walls of the drilled emplacement hole and the emplaced casing. The annular region is assumed to be completely cemented prior to emplacement, but changes are assumed to have occurred either before, or due to, the explosion. Possible mechanisms that might produce pathways through or around the cement include: shrinkage cracks (in spite of having used expanding cement), poor cure due to chemical action, gas entrainment, or loss of bonding to either the casing or the hole wall. Any resulting path may consist of a tortuous sytem of interconnected cracks and voids through or around the cement, or a permeable path past the cement, or a combination of the above. An equivalence exists between a crack path and a permeable path (Ref. IIIB-1). The effect of natural cement shrinkage due to curing has been investigated (Ref. IIIB-2). It was found that for cementing a 10-3/4-inch casing in a hole of nominal 15-inch diameter, cracks with a thickness of 10^{-2} to 10^{-3} cm can be expected. For Project Rio Blanco, the cementing plan includes the use of cement which expands rather than shrinks in curing. However, for the purpose of this model, the conservative assumption is made that a crack of 10^{-2} cm thickness develops between the annular cement and the casing at the time of the explosion. For the conditions in this project of a 10-3/4-inch outside diameter casing cemented in a 15-inch diameter hole, the equivalent permeability (by the methods of Ref. IIIB-1) is 1.3 darcies. If the cracking were to occur at the wall of the drilled well, the equivalent permeability would be somewhat larger, or about 1.7 darcies. To be conservative, an equivalent permeability of 4 darcies is assumed. The mechanism of seepage is taken to be Darcy flow through the annular cracked area.

b. Radionuclide Inventory

Materials expected to traverse the seepage path will consist only of the noble gases, tritiated water vapor, and the hydrocarbon host gases. It is conceptually possible that some extremely volatile compounds could be formed from the hydrocarbon and iodine families. None were observed in Project Gasbuggy during early reentry when iodine was observable, nevertheless they are treated in the model as described below.

The radionuclides of the noble gases and their daughters, which are of interest in this model, are listed in Table IIIB-I. Some months following the detonation, ^{85}Kr and ^{3}H will be of primary concern, but their relative concentrations are so low during the first few weeks that their contributions to the possible dose rates are negligible. For example, the ^{3}H concentrations expected in the gas from Project Rio Blanco will be a factor of a million lower than the total concentrations of the noble gas nuclides considered. Other noble gas nuclides not included have such short half-lives that they will not survive the passage to the surface. All radioactive daughters of the noble gas radionuclides are included, except ^{135}Cs, which has a half-life of 2×10^{6} years, or is essentially stable. The fission product decay curves for krypton and xenon are shown in Figures IIIB-I and IIIB-2, respectively (Ref. IIIB-3).*

Radioiodine detected in conjunction with seeps at the NTS has not been found in concentrations greater than 1% of the possible concentrations attributable to direct fission product production. Further, extrapolation of data back along decay curves indicates that ingrowth of radioiodine due to parent decay ceases at about five minutes following the detonation. Consequently, the fission product decay curves have maxima equal to the direct fission product values and decay from that point with their characteristic half-lives (Ref. IIIB-5). The mass numbers of the radioiodine nuclides considered here are 130 to 135, inclusive. The iodine fission product curves are shown in Figure IIIB-3.

c. Seepage Rate

The steady state seepage rate is calculated using the Darcy linear flow equation, which includes the cavity pressure as a parameter. The cavity pressure, P(t), depends on the vapor pressures of carbon dioxide, hydrogen, and water vapor after chimney collapse occurs and the quantities of formation gases which are initially in the cavity space or which flow into the cavity. A time history of the pressure is shown in Figure IIIB-4. The early peak

*The available curves are for ^{239}Pu fissionable material used in any explosion, which may be either ^{239}Pu or ^{235}U. Fission product inventory curves show that ^{235}U produces a slightly higher inventory of krypton isotopes than ^{239}Pu, but about the same inventory of xenon isotopes. Differences generally do not exceed a factor of 2.5.

Table IIIB-I. Noble gas radionuclides and daughters considered in seepage model.

Nuclide	Physical half-life	Decay constant, λ (min^{-1})	Immersion dose rate* ($mrem\text{-}cm^3/pCi\text{-}day$)
^{85m}Kr	4.4 hr	2.63×10^{-3}	15
^{87}Kr	76 min	9.12×10^{-3}	70
^{88}Kr	2.79 hr	4.14×10^{-3}	110 } combined
^{88}Rb	17.7 min	3.92×10^{-2}	
^{131m}Xe	11.96 day	4.02×10^{-5}	4
^{133m}Xe	2.26 day	2.13×10^{-4}	5
^{133}Xe	5.27	9.13×10^{-5}	5
^{135m}Xe	15.7 min	4.41×10^{-2}	1
^{135}Xe	9.16 hr	1.26×10^{-3}	15
^{138}Xe	14.2 min	4.88×10^{-2}	40 } combined
^{138}Cs	32.2 min	2.15×10^{-2}	

*Calculated by Gotchy, R. L., by methods of Reference IIIB-4.

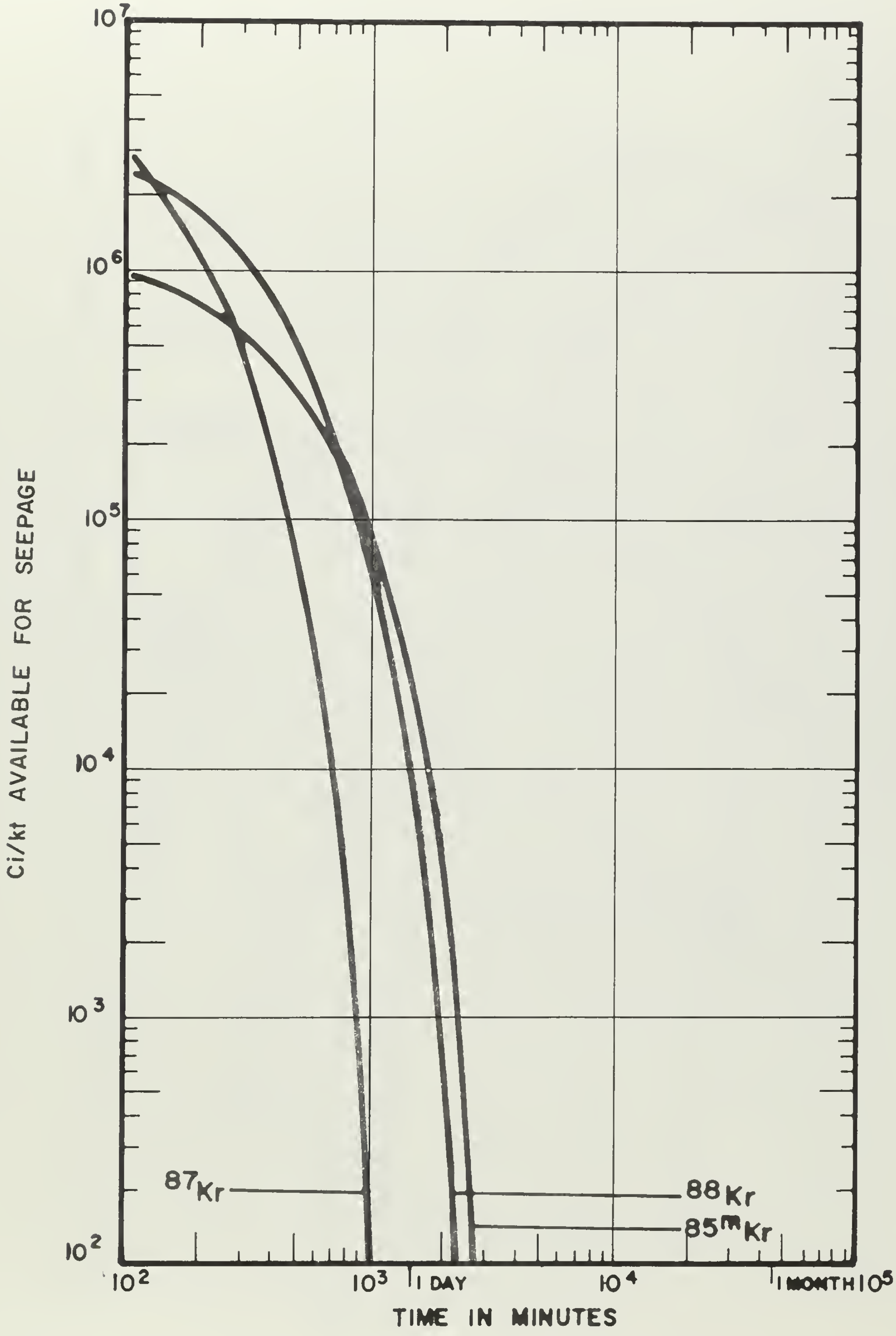

Figure IIIB-1. Fission product decay curves--krypton.

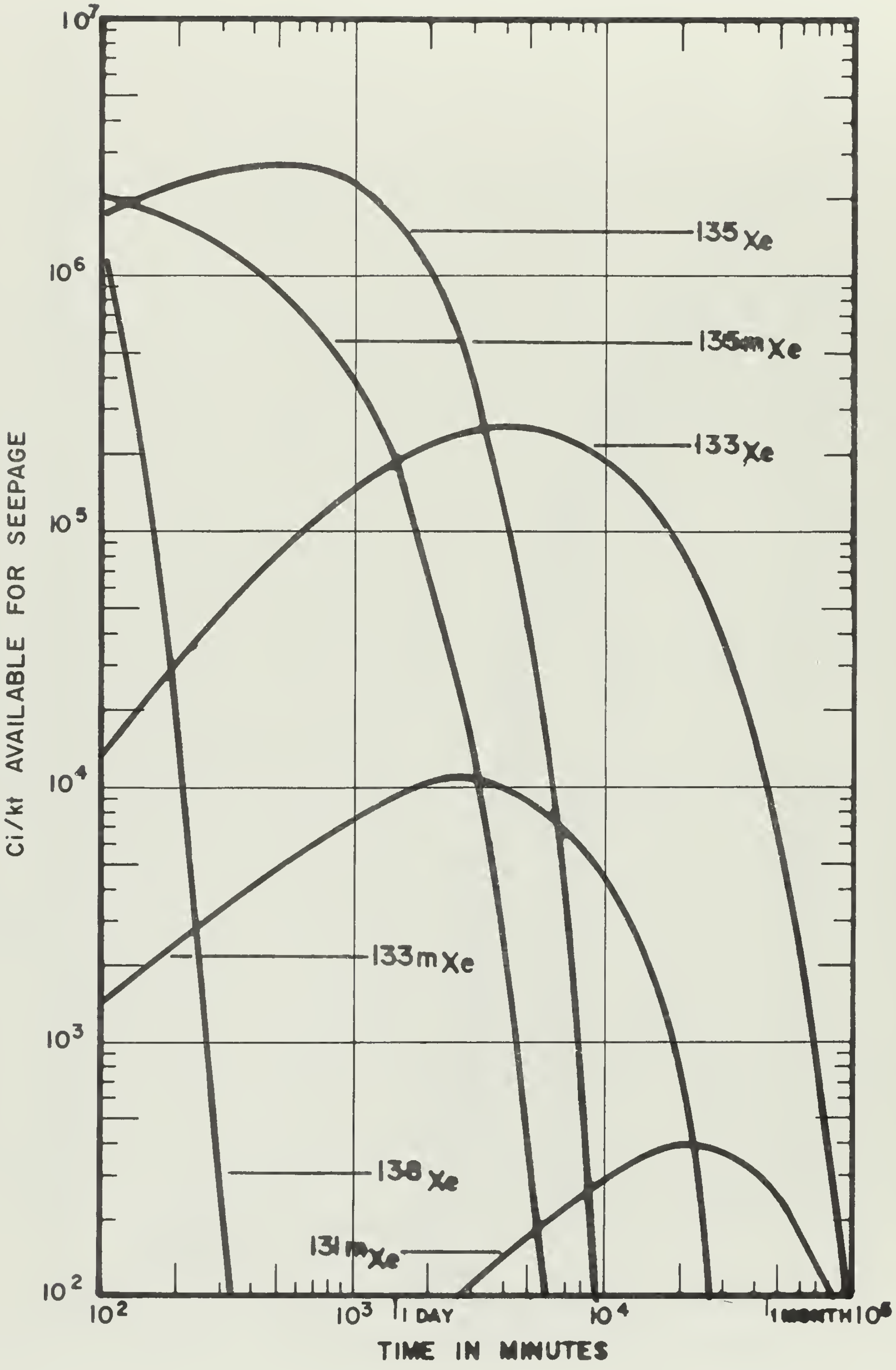

Figure IIIB-2. Fission product decay curves--xenon.

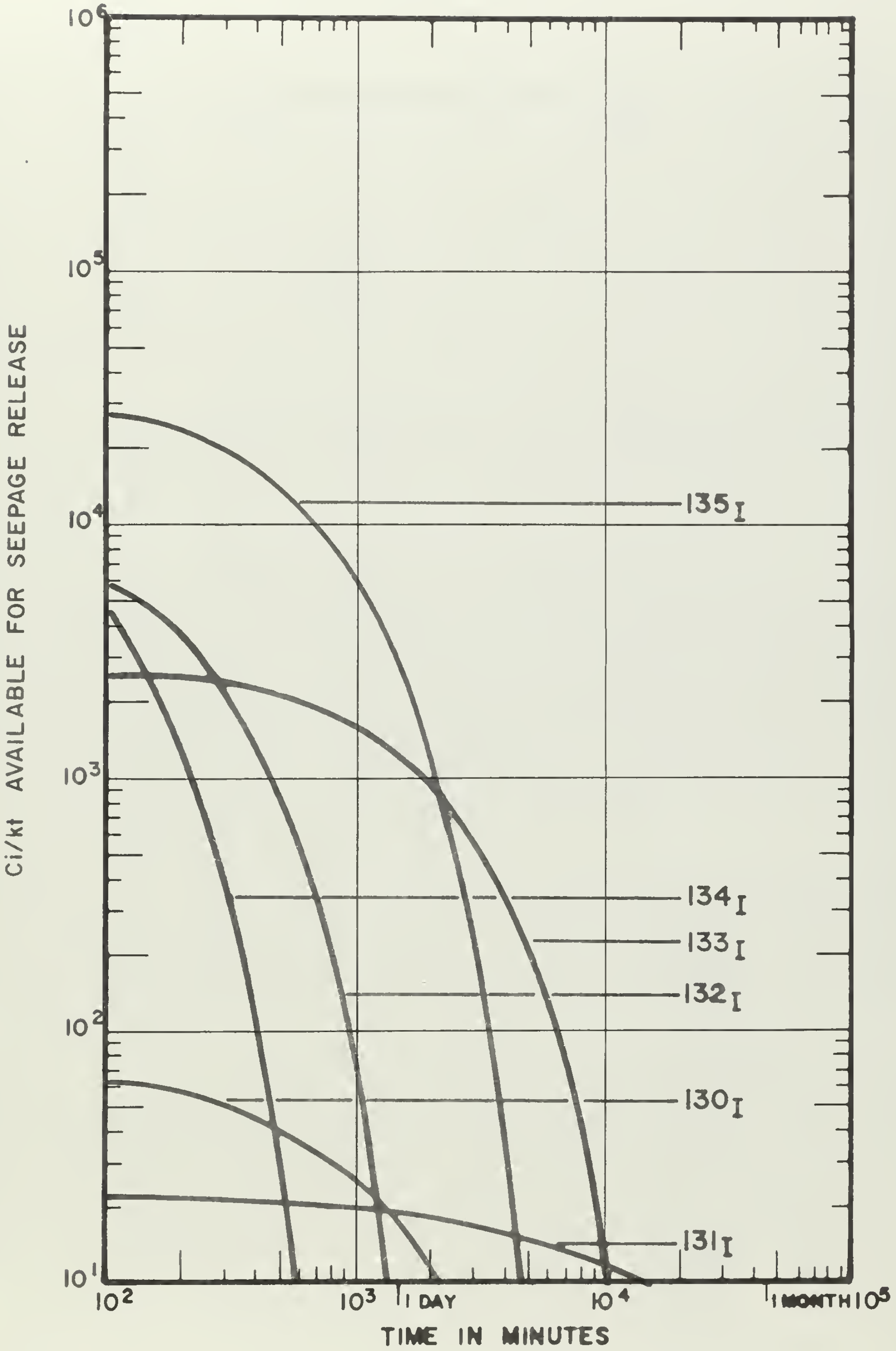

Figure IIIB-3. 1% fission product decay curves--iodine.

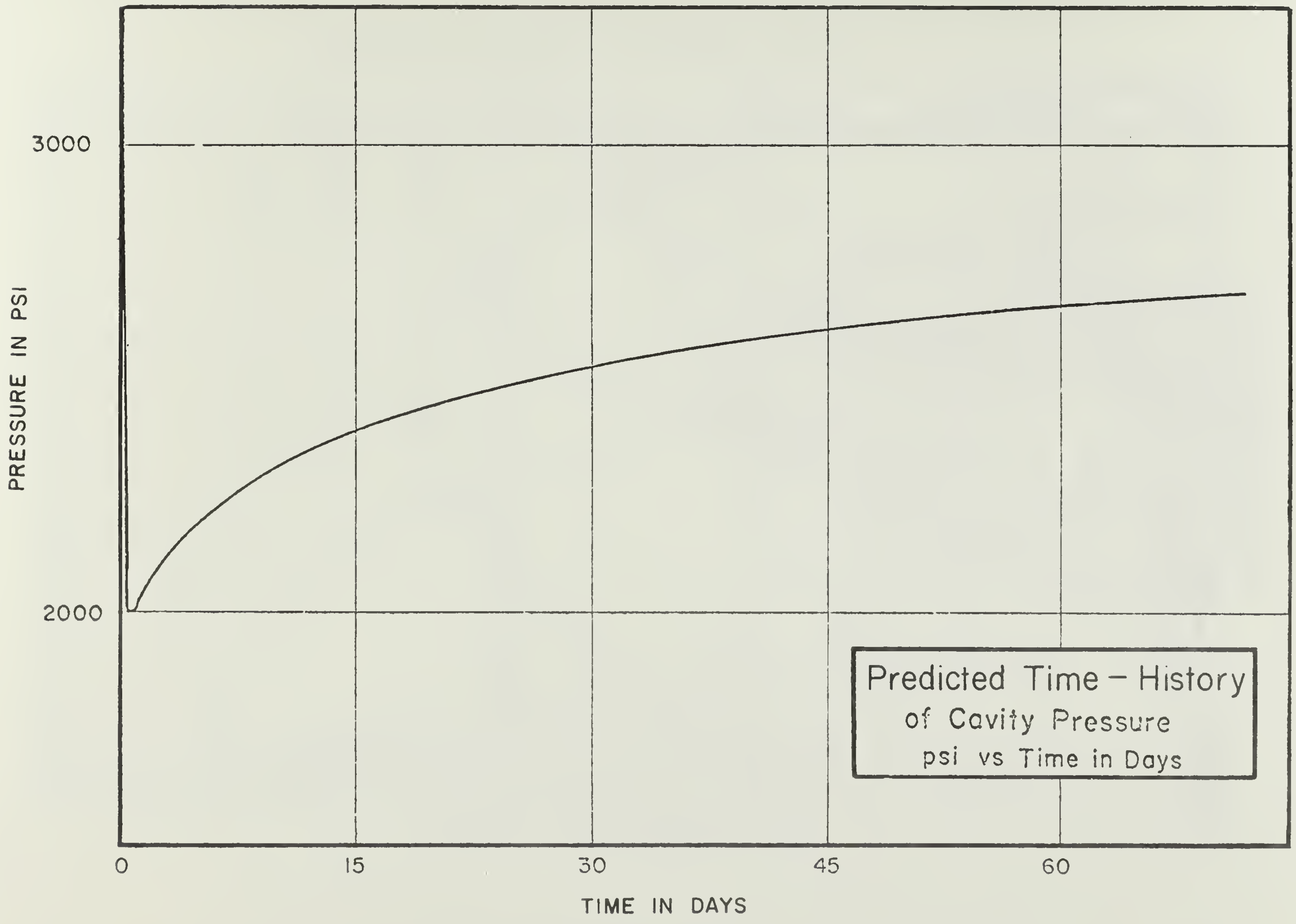

Figure IIIB-4. Predicted time history of cavity pressure.

is due to the heat from the explosion, but chimney collapse cools the cavity quickly and quenches the condensable gases. The duration of the early peak is so short in relation to the necessary transport time for seepage to the surface, that it may be neglected as an effective driving force for the seeping gases. It will be seen below that the pressure rises at a rate so slow that it is nearly constant at about 2,000 psi for the life of the nuclides of interest. Using, then, the value of 2,000 psi for the chimney pressure, the annular radii indicated above, an approximate path length of 5,000 feet, a permeability of four darcies, and a gas viscosity of 0.02 centipoise, the steady state flow is calculated to be about 22,000 ft^3/day.

Now, the rate of flow will not rise immediately to the steady state value but will increase to it in the manner illustrated in Figure IIIB-5. This curve is based on the methods described in Ref. IIIB-1.

d. Source Term for Calculation of Potential Dose Rates

The concentrations of the short-lived fission products that could conceivably leak to the surface and be released to the atmosphere within the first few weeks after the detonation can be calculated from the seepage model data and the chimney parameters. For conservatism, the chimney parameters used are, in general, chosen to maximize the concentrations of radioactivity in the assumed gas seepage. The parameters used are shown in Table IIC-I.

Using the graphical data shown in Figures IIIB-1 and IIIB-2 for the krypton and xenon nuclides, together with the fractional value of steady-state flow shown in Figure IIIB-5, the seepage source values have been calculated and plotted in Figure IIIB-6.

The radioiodine activities assumed to be in the cavity gas and available for seepage (plotted in Figure IIIB-3 as curies per kiloton yield versus time after detonation) have been used to calculate predicted release rates for the iodine isotopes in the same manner as was used for the noble gases. These are shown in Figure IIIB-7. It should be emphasized that the values plotted in Figure IIIB-7 are upper limits and, in all probability, no radioiodine will be released to the atmosphere.

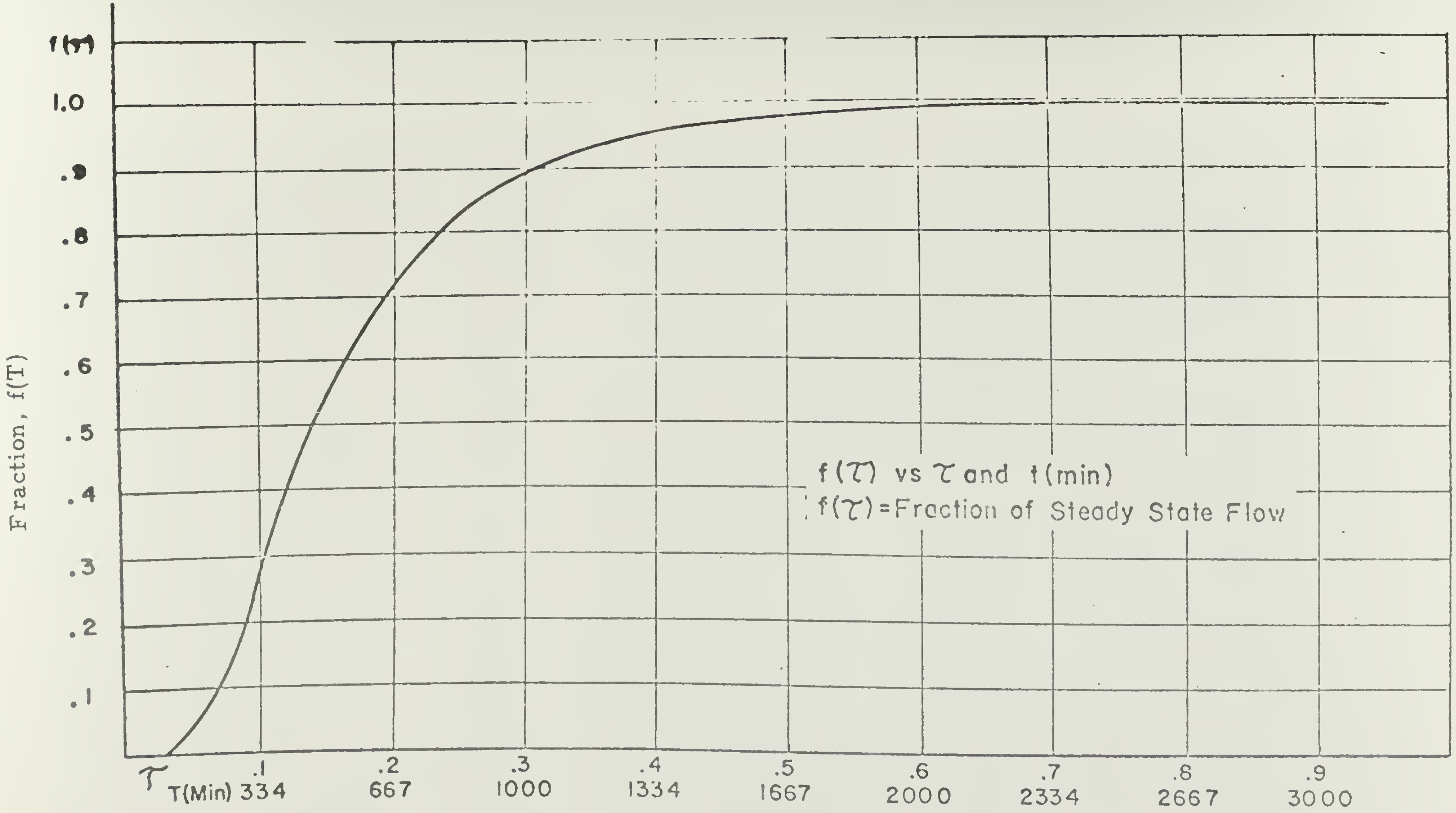

Figure IIIB-5. Fraction, f(t) of steady-state flow rate attained as a function of time, t (min).

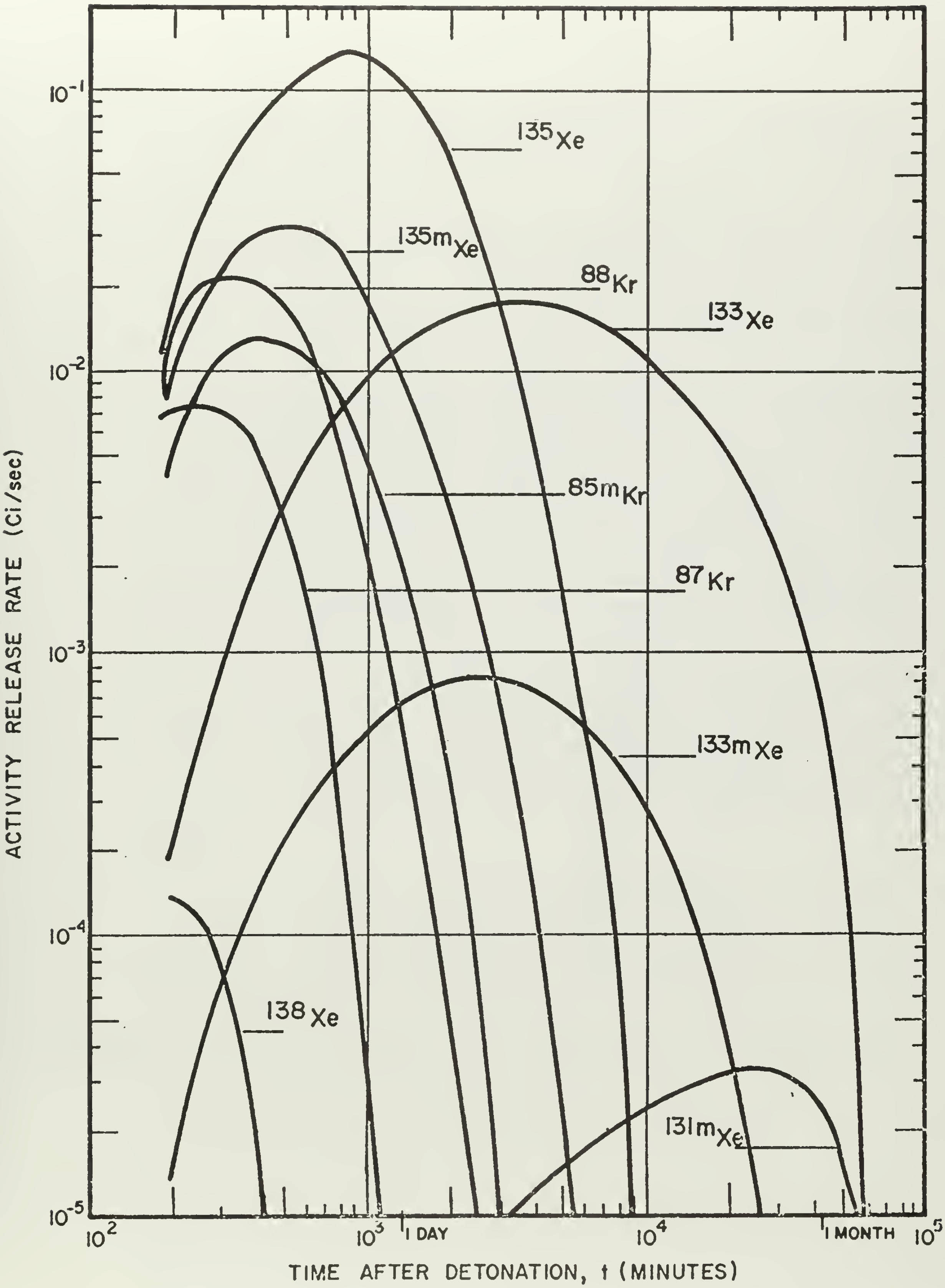

Figure IIIB-6. Activity release rate for noble gases versus time after detonation.

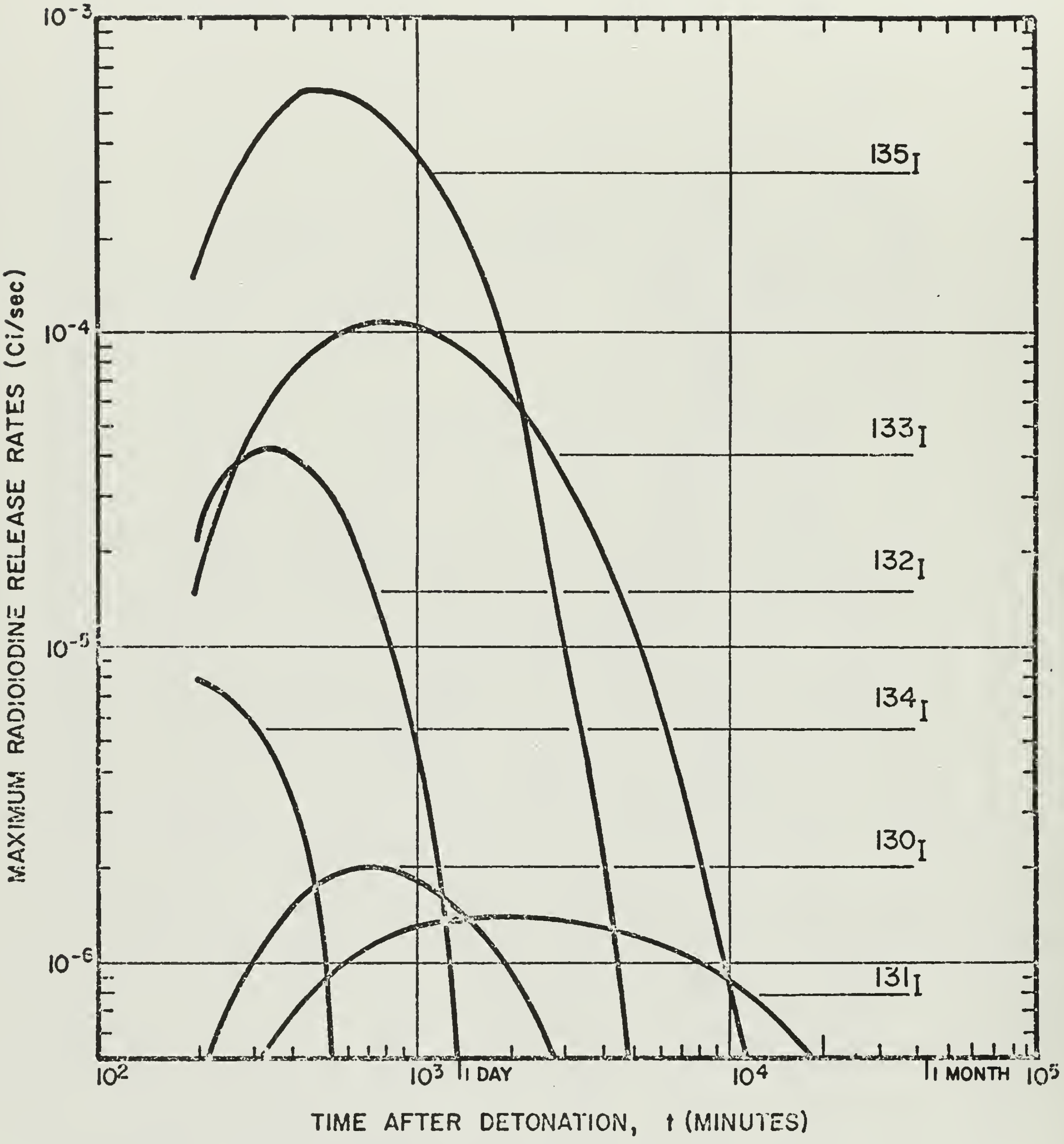

Figure IIIB-7. Maximum radioiodine release rates versus time after detonation.

e. Atmospheric Dispersion Estimates

The wind data summarized in section I-I indicates three predominant plume patterns of significance in dose calculations might be expected. These plume patterns, as well as the weather station locations, are indicated in Figure IIIB-8.

The typical nighttime drainage flow follows the creek drainages and is identified as plume A in the figure. The frequency of occurrence of this nighttime drainage pattern is so high that it will be assumed to occur every night for the dose calculations.

Plume B represents the typical plume expected during the predominant daytime wind conditions. For release at the earth's surface (seepage), the surface wind would carry the plume down the Fawn Creek drainage. By the time the plume has travelled several kilometers, the vertical dispersion would be sufficient to cause the plume to be primarily controlled by the upper winds. The plume would, therefore, tend to veer more to the east by the time it reached the lower end of Fawn Creek. Plume pattern B occurs, with only minor variations, approximately 75% of the time during the day throughout the entire year.

Plume pattern C is typical about one-fourth of the time during daytime hours. The dispersion characteristics of plume C would be similar to those for plume B; however, once the plume reaches the ridge to the south of the site, it would be caught by the upper level winds and may be turned nearly 180 degrees toward the ENE.

The estimates of atmospheric dispersion presented here are based upon the methods presented by Turner (Ref. IIIB-6), utilizing the Pasquill stability categories. Since long-term, or seasonal, dispersion isopleths are not available, a simplified frequency distribution of wind patterns was prepared for use in making dose calculations (Table IIIB-II). The frequency distributions presented are essentially the worst that can be construed from the available wind data. The atmospheric dispersion values calculated for seepage under nighttime drainage conditions (plume type A) are listed in Table IIIB-III. The dispersion values listed are simply the predicted ground level concentrations in the plume centerline, X (Ci/m^3), divided by the activity release rates, Q (Ci/sec), which can be obtained from Figures IIIB-6 and IIIB-7 for the noble gas and radioiodine nuclides,

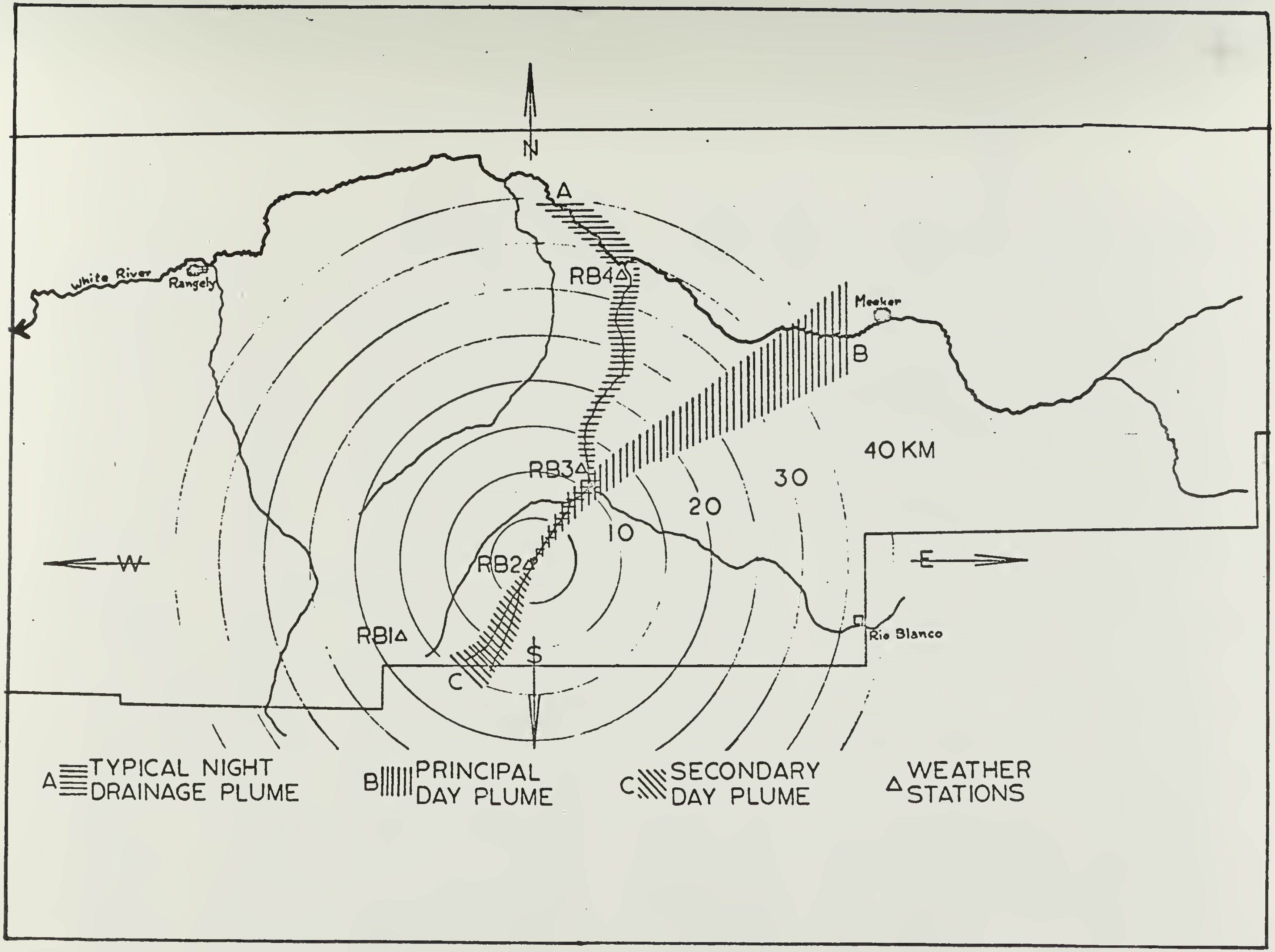

Figure IIIB-8. Predominant plume patterns predicted for Project Rio Blanco.

Table IIIB-II. Frequency distributions assumed for the three predominant plume types (as illustrated in Figure IIIB-8) and for the various meteorological conditions used in estimating atmospheric dispersion.

Pasquill stability categories:	C	D		E	F	
Wind speeds, u (m/sec):	7.3	7.3	4.5	2.5	2.5	Totals
Plume type A (100% of nighttime)	0	0	0	0.25	0.25	0.50
Plume type B (75% of daytime)	0.08	0.15	0.15	0	0	0.38
Plume type C (25% of daytime)	0.02	0.05	0.05	0	0	0.12
TOTALS	0.10	0.20	0.20	0.25	0.25	1.00

Table IIIB-III. Atomospheric dispersion estimates at the centerline of the plume for ground level release (e. g., seepage) under nighttime drainage flow (plume pattern A in Figure IIIB-8).

Downwind distance, x (km)	$X/Q = (Ci/m^3)/(Ci/sec) = sec/m^3$	
	Pasquill category E (stable)	Pasquill category F (very stable)
	Wind speed, u = 2.5 m/sec	Wind speed, u = 2.5 m/sec
1	121.4 $\times 10^{-6}$	267. $\times 10^{-6}$
2	40.2 "	90.6 "
4	14.16 "	34.2 "
6	8.03 "	20.0 "
8	5.35 "	13.7 "
10	3.93 "	10.18 "
15	2.25 "	6.05 "
20	1.523 "	4.24 "
30	0.907 "	2.60 "
40	0.645 "	1.87 "
σ_y at 40 km	1.38 km	0.92 km

respectively. The factor X/Q (Sec/m^3) need only be multiplied by the appropriate release rate to obtain the predicted concentrations.

Dispersion estimates for seepage releases under typical daytime conditions (plume types B and C) are given in Table IIIB-IV. The column for Pasquill stability category D and the lower wind speed (4.5 m/sec) represents the worst diffusion conditions expected during daytime. The few days of the year during which the nighttime inversion and drainage patterns persist throughout the day are considered to be included in the frequency distribution for plume type A.

f. Potential Radiation Dosage from Seepage*

(1) Noble Gases

The biological dose per day of exposure per unit atmospheric dispersion was calculated for each of the noble gas radionuclides listed in Table IIIB-I from the activity release data plotted in Figure IIIB-6 and the dose rates per unit concentration given in Table IIIB-I. The results are plotted in Figure IIIB-9. The ordinate scale is the dose in millirems a person would receive if exposed for one day at a location for which the actual atmospheric dispersion was 1 sec/m^3. Thus, the numerical values on the ordinate, when multiplied by the time-integrated atmospheric dispersion estimate, give the maximum predicted dose to the exposed person under the seepage assumptions. The units permit the summation of doses from all nine of the nuclides considered in the seepage model. (The calculated values for ^{131m}XE were more than an order of magnitude smaller than the smallest values shown in Figure IIIB-9.)

(2) Radioiodine Inhalation

The first step in calculating the potential doses from the iodine isotopes if they should seep from the cavity is to

*For all the nuclides considered here, a quality factor of one is appropriate, making dose (rads) and dose equivalent (rems) numerically equal. For simplicity, the term "dose" will be used throughout to mean "dose equivalent," with the units expressed as rems or mrems.

Table IIIB-IV. Atmospheric dispersion estimates at the centerline of the plume for ground level release (e.g. seepage) under typical daytime conditions (plume patterns B and C in Figure IIIB-8).

Downwind distance, x (km)	$X/Q = (Ci/m^3)/(Ci/sec) = sec/m^3$		
	Pasquill category D (neutral)	Pasquill category D (neutral)	Pasquill category C (unstable)
	Wind speed, u = 4.5 m/sec	Wind speed, u = 7.3 m/sec	Wind speed, u = 7.3 m/sec
1	31.9 $\times 10^{-6}$	19.7 $\times 10^{-6}$	6.88 $\times 10^{-6}$
2	10.88 "	6.71 "	1.89 "
4	3.75 "	4.32 "	0.551 "
6	2.04 "	1.26 "	0.269 "
8	1.29 "	0.797 "	0.1526 "
10	0.947 "	0.584 "	0.1067 "
15	0.527 "	0.325 "	0.0508 "
20	0.353 "	0.218 "	0.0306 "
30	0.197 "	0.122 "	0.01453 "
40	0.1317 "	0.0813 "	0.00878 "
σ_y at 40 km	1.82 km	1.82 km	2.78 km

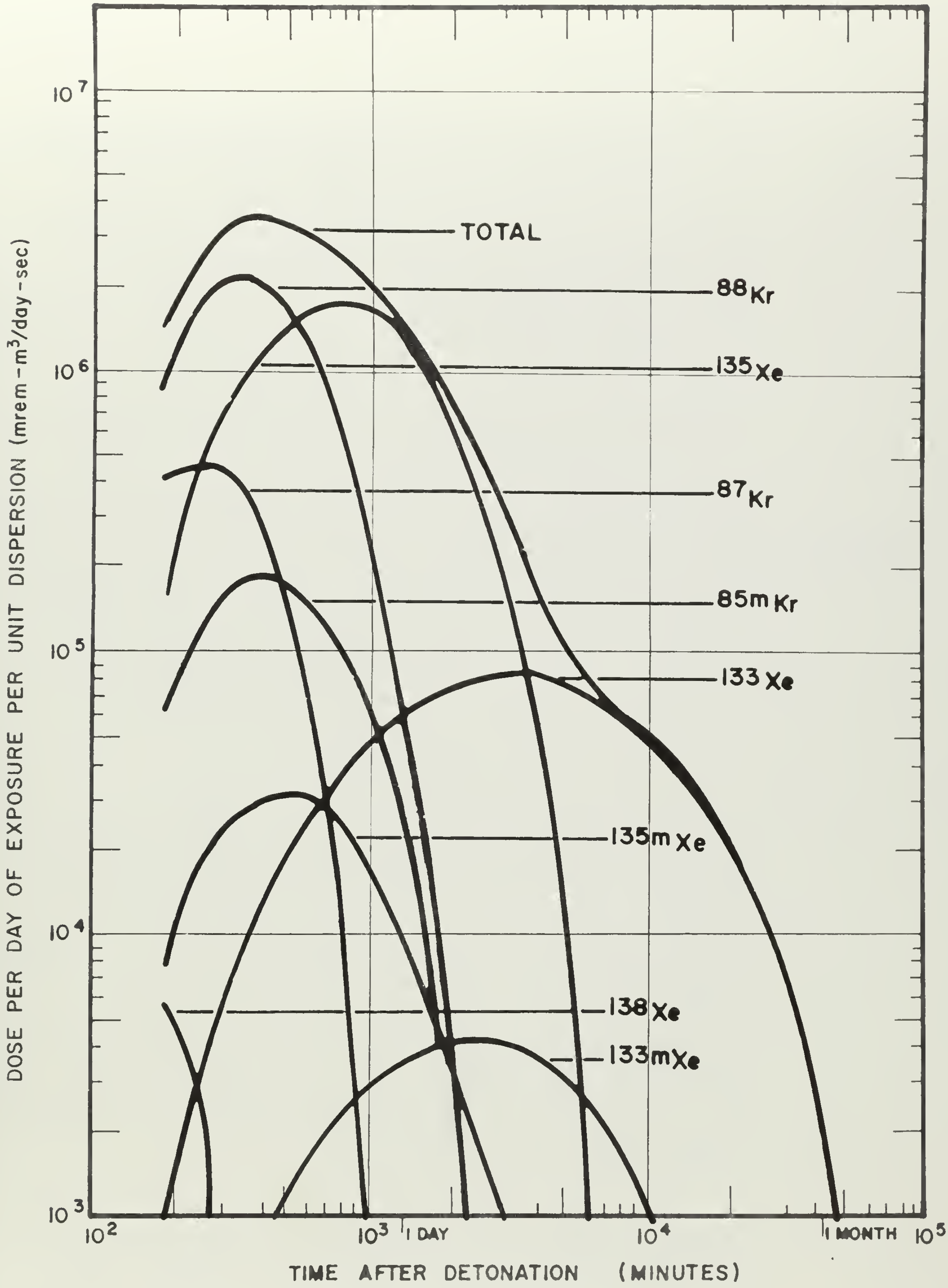

Figure IIIB-9. Total body immersion dose per day of exposure per unit atmospheric dispersion resulting from the assumed maximum seepage of noble gas radionuclides from the Project Rio Blanco cavity.

determine the thyroid dose per unit activity intake for each of the six nuclides of concern. The results of these calculations are summarized in Table IIIB-V. For an infant or small child, the estimated dose per unit activity is about a factor of ten higher than the value given in Table IIIB-V because of the much smaller mass of the infant thyroid. For inhalation exposures, however, the intake rate for an infant is about one-fifth that for an adult, so for equal exposures the cumulative dose for the infant would be only twice that for an adult. The inhalation dose per day of exposure per unit atmospheric dispersion was calculated for each of the radioiodine isotopes listed from the radioiodine release data plotted in Figure IIIB-7, the dose per unit intake shown in Table IIIB-V, and an inhalation intake rate of 20 m^3/day. The results are plotted in Figure IIIB-10 and show the thyroid dose in millirems a person would receive if exposed for one day at a location for which the atmospheric dispersion was 1 sec/m^3. The upper curve represents the total dose from all six iodine isotopes combined. (The calculated values for ^{134}I were all less than 10^2 mrem-m^3 / day-sec and, therefore, do not appear on the graph.)

(3) Radioiodine Ingestion Via Milk

For exposure by ingestion via the pasture--cow--milk pathway, a calculation was made only for ^{131}I. The short half-lives of the other iodine nuclides preclude significant transfer to milk owing to the delay times that occur in the pathway. Also, the dose per unit activity intake for these other isotopes is all much smaller than that for ^{131}I; the next largest is for ^{133}I, and it is only one-sixth of that for ^{131}I. Even though the activity release rate for ^{133}I could be an order of magnitude higher than for ^{131}I during the first day, it would decrease rapidly. After four days the release rate for ^{131}I would exceed the ^{133}I release rate. The cumulative dose, for the entire seepage time, would be very small for ^{133}I as compared to ^{131}I.

The thyroid dose rate via the milk pathway per day of pasture exposure per unit atmospheric dispersion was calculated from the release data shown in Figure IIIB-7, the dose per unit activity uptake in Table IIIB-V, and the following assumed values for other parameters (Ref. IIIB-7). The deposition velocity is taken to be 0.01 m/sec. The

Table IIIB-V. Calculated thyroid doses from selected radioiodine isotopes per unit activity intake.

Iodine Isotope	Maximum Dose to Adult 20-gram Thyroid Per Unit Intake in mrem/pCi
130	0.187
131	2.395
132	0.021
133	0.415
134	0.0005
135	0.091

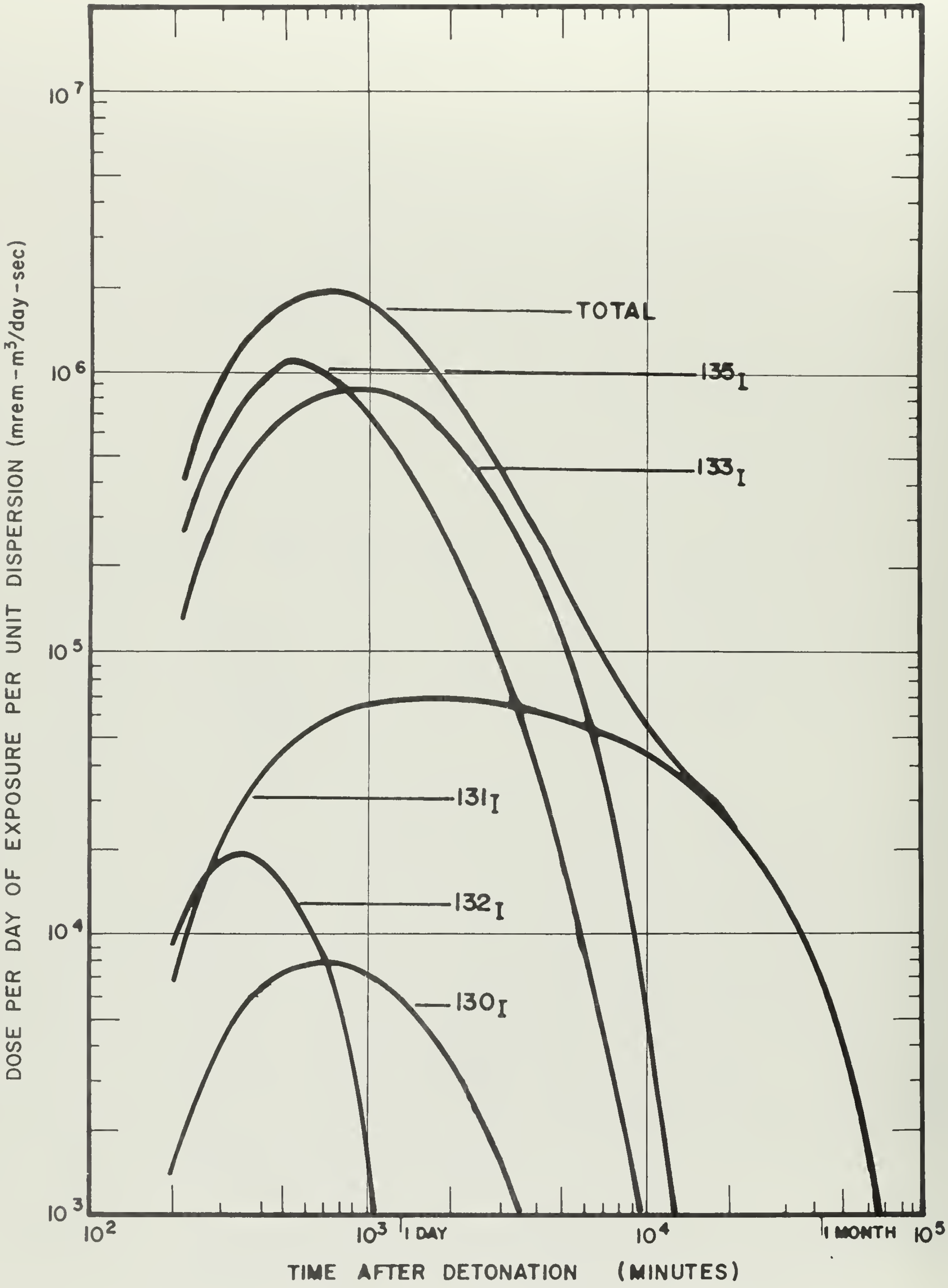

Figure IIIB-10. Adult thyroid dose per day of inhalation exposure per unit atmospheric dispersion resulting from the assumed maximum seepage of radioiodine from the Project Rio Blanco cavity.

effective removal rate from pasture is 14% per day. The transfer coefficient from pasture to milk is 0.09 m^2/liter, whereas the milk intake is assumed to be one liter per day. The results are plotted in Figure IIIB-11.

(4) Summary Dose Curves

The total dose rate per unit atmospheric dispersion data shown in Figures IIIB-9 and IIIB-10 are summarized in integral form in Figure IIIB-12.

g. Seepage Dose Estimate--Worst Case

A cursory inspection of the plume patterns presented in Figure IIIB-8 and the population distribution shown in section IA. are sufficient to indicate that the most critical locations for potential exposure from inadvertent seepage are at the confluences of Fawn Creek with Black Sulphur Creek and Black Sulphur with Piceance Creek. Consequently, the calculations of the worst exposure cases will be based upon the calculated concentrations at these locations, a downwind distance of 10 km for plume types A and B.

The very worst hypothetical single-day dose would be for a person continuously exposed in the centerline of a plume of type A (category F, u = 2.5 m/sec) for 12 hours, followed by plume type B (category D, u = 4.5 m/sec) for 12 hours. From the atmospheric dispersion data for 10 km in Tables IIIB-III and IIIB-IV and the data in Figure IIIB-8, one calculates the total body dose from noble gases to be 12.06 + 1.08 mrem = 13.14 mrem, where the first term represents the cumulative does from 0 to 12 hours and the second term represents the added dose from 12 to 24 hours post-detonation.

The first day thyroid dose under the same circumstances would be 5.26 + 0.74 mrem = 6.00 mrem by inhalation. As before, the two terms are the 0 to 12 and the 12 to 24 hour dose integrals.

If the maximum seepage and most adverse atmospheric dispersion conditions were to occur simultaneously, as assumed for these hypothetical calculations, countermeasures could be instigated to proscribe milk consumption from the affected area and, possibly, to eliminate or reduce the total exposure by temporary relocation of persons. Thus, the maximum first day dose from

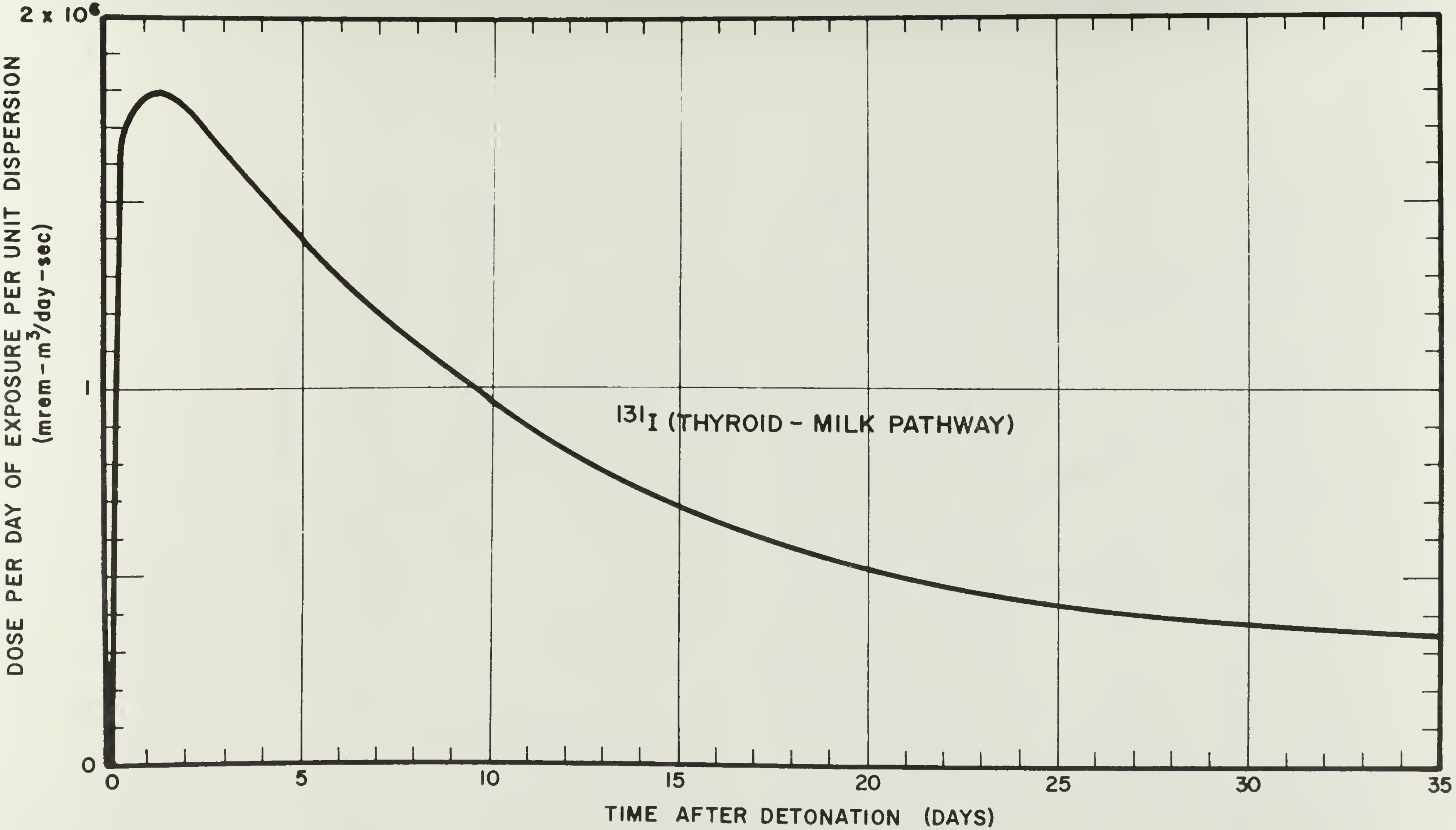

Figure IIIB-11. Adult thyroid dose via the milk pathway per day of pasture exposure per unit atmospheric dispersion from the assumed maximum seepage of ^{131}I from the Project Rio Blanco cavity.

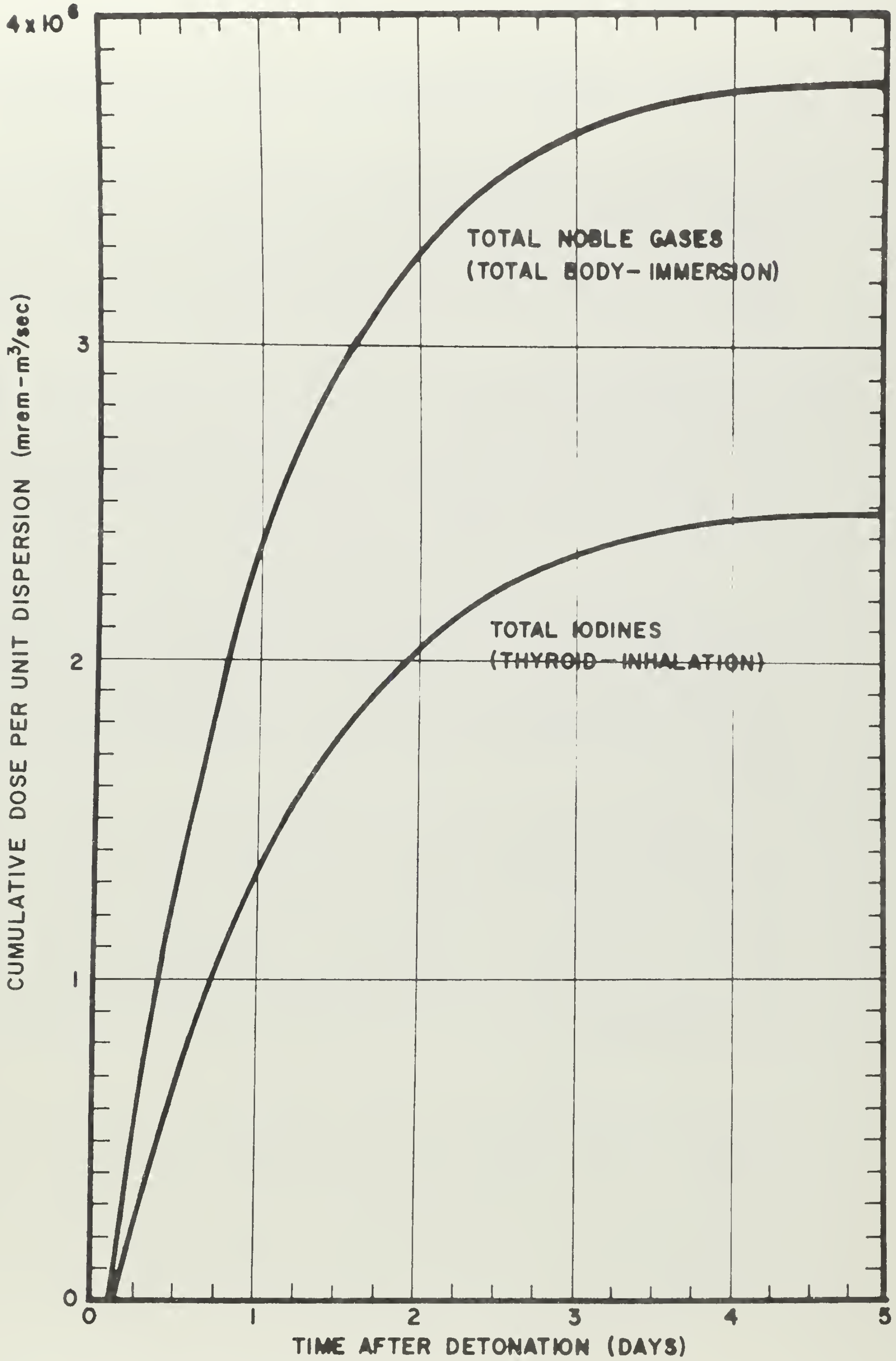

Figure IIIB-12. Cumulative dose per unit atmospheric dispersion from noble gases (total body) and radioiodines (thyroid) resulting from the assumed maximum seepage from the Project Rio Blanco cavity.

seepage would also be the maximum total dose for all practical purposes. The total adult thyroid dose for this hypothetical worst case, therefore, is estimated to be the sum, about 19 mrem.

For an infant the dose from noble gases would be the same as for an adult; the inhalation rate is assumed to be 20% of that of an adult but the dose per unit intake is 10 times that for an adult, making the net inhalation dose twice that of an adult. Based upon these adjustments, the total infant thyroid dose for this hypothetical worst case would be about 25 mrem.

Both the International Commission on Radiological Protection (Ref. IIIB-8) and the Federal Radiation Council (Ref. IIIB-9) have recommended 1,500 mrem as the annual thyroid dose limit for an individual under 16 years of age. The hypothetical worst case for Project Rio Blanco, as calculated above, is estimated to be no more than 1.7% of the recommended dose limit.

A more reasonable estimate of the dose commitment from seepage would be obtained by calculating the cumulative dose for longer time periods, using the assumed frequencies of atmospheric dispersion shown in Table IIIB-III. For these calculations, one must have a long-term atmospheric dispersion estimate rather than the plume centerline estimates given in Tables IIIB-IV and IIIB-V.

By the methods described in Ref. IIIB-10, and for the assumed frequency distribution of atmospheric dispersion estimates, the average long-term atmospheric dispersion of the Rock School location, 10 km distant, is estimated to be 1.22×10^{-7} sec/m^3. The maximum cumulative doses calculated for the Rock School location for the most adverse dispersion conditions that could be called typical for extended periods of time are given in Table IIIB-VI.

Thus, it would appear that the total dose commitment for seepage from Rio Blanco could be restricted to about 33.8 millirem, or about 22 thousandths of the recommended annual dose limit of 1,500 mrem for an individual under age 16. This restriction would depend primarily upon the existence of good atmospheric dispersion during the first 12 hours or more post-detonation, the period during which more than 90% of the immersion and inhalation exposures would be received under adverse conditions.

Table IIIB-VI. Maximum cumulative doses calculated for the Rock School location for the most adverse dispersion conditions that could be called typical for extended periods of time.

Category	Maximum Cumulative Dose in Millirem
Total body dose, immersion in noble gases, child or adult, 0-5 days.	0.46
Adult thyroid from all iodine inhalation, 0-5 days.	0.30
Adult thyroid dose from ^{131}I ingestion via the milk pathway, 0-35 days.	3.27
Total adult thyroid dose from all sources.	4.0
Infant thyroid dose from all iodine inhalation.	0.60
Infant thyroid dose from ^{131}I ingestion via the milk pathway.	32.7
Total infant thyroid dose from all sources.	33.8

REFERENCES

IIIB-1. Sherwood, A. E., "Venting Model for Gas Stimulation Experiments," UCID--15643 (April, 1970).

IIIB-2. Woodruff, W. P., LLL, Livermore, California (personal communication).

IIIB-3. King, W. C. and R. S. Coray, "Curves of Select Fission Products--Growth and Decay from Fission of ^{239}Pu by Fission Spectrum Neutrons," LLL (March, 1967).

IIIB-4. Blatz, H. (Ed.), Radiation Hygiene Handbook, McGraw-Hill (1959).

IIIB-5. Higgins, G. H., LLL, Livermore, California (personal communication).

IIIB-6. Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," National Air Pollution Control Administration, U. S. Public Health Service, Publ. 999-AT-26 (1969).

IIIB-7. Burnett, J. J., "Derivation of 'Factor of 700' for ^{131}I," Health Physics 18, pp. 73-75 (1970).

IIIB-8. ICRP Publ. No. 9, Recommendations of ICRP, Pergamon Press, London, England (1966).

IIIB-9. FRC Report No. 2, Background Material for Development of Radiation Protection Standards, Government Printing Office (1961).

IIIB-10. Slade, D. H., Editor, "Meteorology and Atomic Energy," USAEC, Div. of Technical Information, TID 24190 (July, 1968).

C. CONTINGENCY OF SEEPAGE INTO GROUNDWATER

1. Aquifers

No contamination of the groundwater around the EW is anticipated. However, as in the case of the preceding radiological safety analysis, "maximum credible" seepage calculations are presented to define the aquifer contamination limits if the unexpected were to occur. Depths from ground level to aquifers in the EW area are:

Aquifer	Depth (ft) From	To
Alluvium	Surface	100
"A" Subsystem	250	800
"B" Subsystem (gas shows expected from 1,230 feet to 1,500 feet)	950	1,500

In addition, significant porous zones are anticipated at the following levels between the aquifers and the gas reservoirs:

Porous Zone	Depth (ft) From	To	Expected Fluid Content
Douglas Creek Sand #1	2,400	2,450	Gas & Water
Wasatch "G" Sand	4,180	4,210	Gas & Water
Wasatch "J" Sand	4,500	4,540	Gas & Water
Wasatch "K" Sand	4,570	4,700	Gas & Water
Basal Wasatch Sand	5,190	5,220	Gas & Water

2. Models for Communication Between Chimney and Aquifers

A careful consideration of NTS and off-site experience, coupled with a study of gas reservoirs, leads to the conclusion that "...the only remaining credible pathway for communication between the nuclearly created chimney and the surface (or aquifers occurring between the chimney and the surface*) would be through the man-made emplacement

*Added for clarity in report.

facility" (Ref. IIIC-1). The seepage paths proposed for this model and their implications with respect to the transport of radioactivity in groundwater are:

a. Cracks occur in cement near or at contact with the outside of 10-3/4-inch OD casing and provide communication between the chimney and spall zone (Ref. IIIC-1).

   The EW is schematically presented in Figure IIIC-1. Thus, the first model would predict gas from the chimney traveling up the cement sheath and out a break in the 16-inch casing in the spall region, 0 to a maximum of 600 feet subsurface. This would cause a loss of water from the sealed annular space between the 10-3/4-inch and 16-inch pipes (plugged at the bottom by cement and at the top of the wellhead). When the gas from the chimney arrived, it could cause a pressure rise that would be detected by the pressure gauge installed post shot at the wellhead. Any sensible seepage rate would be detected, and the annular space and formation beyond the break in the 16-inch pipe could be filled with cement by perforating and squeeze cementing below the break. Thus, a seep by this model would be detected and stopped before any appreciable quantity of radioactive material had escaped. Hence, for the seep to release a significant amount of radiation, a second model must be considered.

b. The cement in the annular region between the 10-3/4-inch OD casing and the drilled hole becomes permeable. The seep paths are tortuous cracks through the cement, around the cement, or a combination of these. This seep path communicates with the formations forming the outside boundary of the annular space, and this path occurs:

   (1) Before the explosion as a result of shrinkage cracks, chemical action, gas entrainment, or

   (2) Post shot as a result of the explosion (Ref. IIIC-1).

   If the seep path has appreciable permeability (a necessary assumption; otherwise, no sensible seepage would occur), then under conditions of model b.(1), the path would be completely filled with water originating in the Green River "A" and "B" subsystems under a hydrostatic gradient at

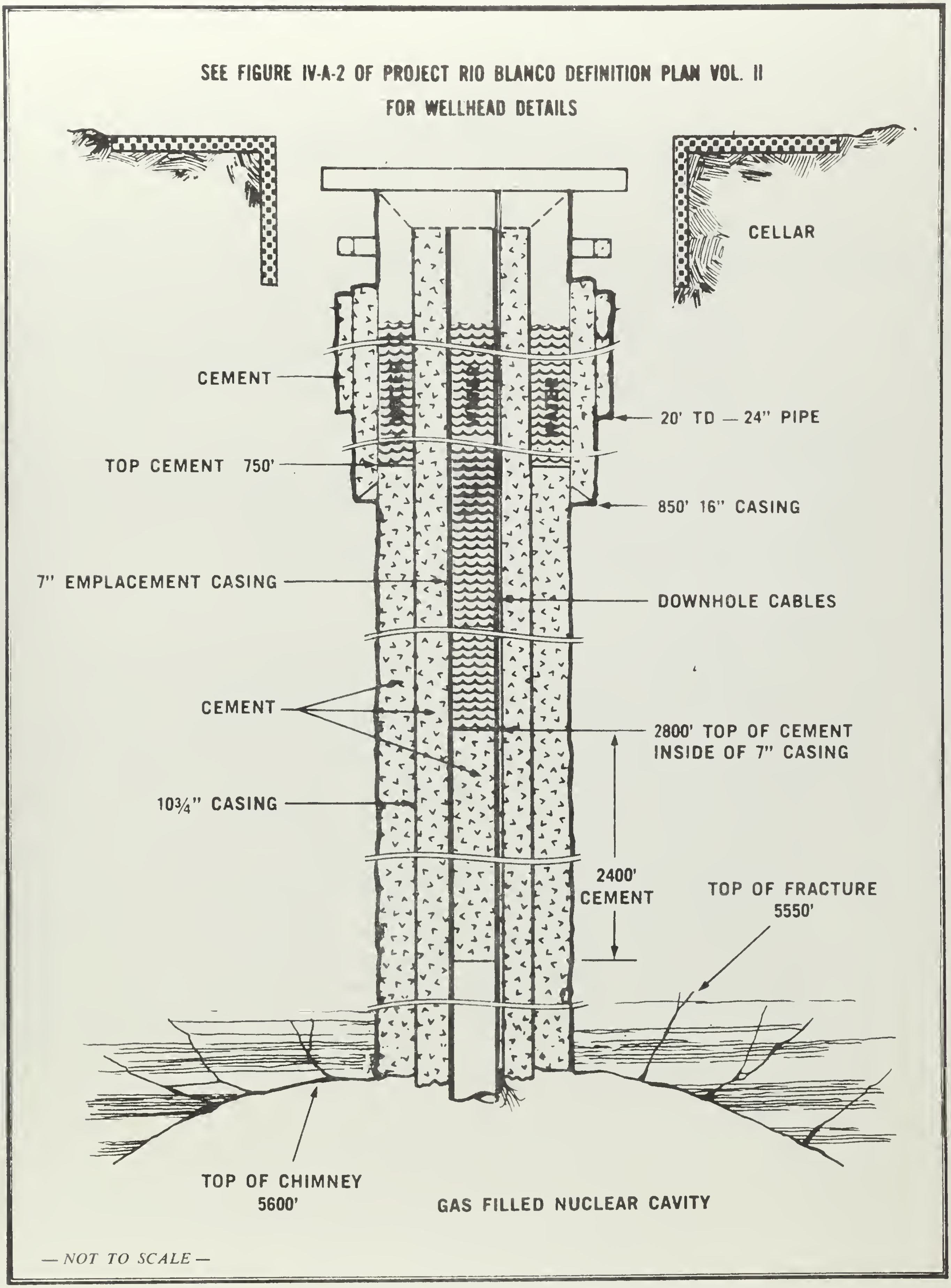

Figure IIIC-1. Rio Blanco EW schematic.

shot time. Thus, initially, the driving pressure would be toward the cavity instead of away and water would be flowing down into the cavity.

A two phase counter flow region would start post shot as the gas-filled, shot-induced fractures mesh with the seep path fracture system. Initially, the gas would move upward under a gravity differential drive, and an appreciable transient period would occur before the gas reached the "B" subsystem level. In addition, the volume of fluids flowing would be reduced by at least an order of magnitude because of phase interference (Ref. IIIC-2).

Under conditions of model b. (2), the gas would start to flow from the bottom, up the seep path, and water would start to flow from the top, down the seep path. Quasi-equilibrium would occur sooner under these conditions, and reduction in gas permeability would not be as great as for model b. (1).

3. Nuclides

The flow of the chimney gas up the seep path would result in the movement of the mixture of radioactive and host gases that are in "equilibrium" in the chimney at the time the incremental volume, Vi, starts its journey in the seep path. Some decay activity would occur because of the travel time in the path. Also, some reduction in volume would occur because of the condensation of the water vapor and from solution of the gas in the water moving down the seep path. Therefore, the nuclides of interest are those present approximately two days or more post shot. These nuclides are noble gases, tritiated water vapor, hydrogen and hydrocarbons, carbon dioxide, and possibly but not probably, iodine and/or volatile iodides. These nuclides will be mixed with the host gas. Table IIIC-I presents the amounts of these nuclides per unit yield expected at T + 2 days and their decay factors. It is apparent from the values in this table that the only nuclides existing in any significant quantities at T + 180 days would be T, Kr^{85}, Ar^{39}, Ar^{37}, and C^{14}. Since it will be shown that years would be required for any seeped gases to move in the aquifers to any use points, only these nuclides are considered.

Table IIIC-I. Gaseous radioactive nuclide inventory at T + 2 days and their decay factors (from PU-239 fission product tables).

Nuclide	Amount (Ci/kt)	Decay Constant (1/min)
^{14}C	2.5×10^{-1}	-
^{3}H	3.3×10	-
"Noble" Gases		
^{37}Ar	1.04×10^{3}	1.40×10^{-5}
^{39}Ar	-*	4.91×10^{-9}
^{85}Kr	2.07×10	1.24×10^{-7}
^{85m}Kr	1.0×10^{2}	2.63×10^{-3}
^{87}Kr	-*	8.88×10^{-3}
^{88}Kr	-*	4.12×10^{-3}
(^{88}Rb)	-*	3.89×10^{-2}
^{131m}Xe	-**	4.01×10^{-5}
^{133}Xe	2.4×10^{5}	9.13×10^{-5}
^{133m}Xe	1.1×10^{4}	2.09×10^{-4}
^{135m}Xe	1.1×10^{4}	4.53×10^{-2}
^{135}Xe	3.0×10^{5}	1.26×10^{-3}
^{138}Xe	-*	4.08×10^{-2}
(^{138}Cs)	-*	2.15×10^{-2}
Iodine Family (Assumes 1% of direct fission products available for seepage)		
^{130}I	-*	9.25×10^{-4}
^{131}I	1.7×10	6.08×10^{-5}
^{132}I	-*	4.95×10^{-3}
^{133}I	5.5×10^{2}	5.52×10^{-4}
^{134}I	-*	1.34×10^{-3}
^{135}I	2.0×10^{2}	1.72×10^{-4}

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* Indicates less than 1 Ci/kt

** Indicates peak of 4×10^{2} Ci/kt at approximately 20 days.

4. Concentrations

The noble gases will probably be rather uniformly distributed in the chimney gas, while the tritium will probably be partitioned in the chimney material, in the water, and in the chimney gas in a ratio of 4/5/1 (Ref. IIIC-3). Using this partition and the seepage model pressure versus time curve (Ref. IIIC-1) result in the following calculated radioactivity in the seeping gas at T + 180 days: (Tables IIIC-II and III).

The maximum volumes of gas that could seep to the various sinks, i.e., the "B" subsystem, the "A" subsystem, and the atmosphere, can be approximated using a pressure diagram (Figure IIIC-2). An inspection of this figure indicates no seep of gas from the fractured cement sheath would occur until the gas reaches the "B" subsystem. The maximum volume of gas that could reach the base of the "B" subsystem, under quasi-steady-state conditions, is 35 MCFD. This is based upon the following boundary conditions:

a. The pressure in the seep path has to be slightly higher than the pressure in the "B" subsystem for gas to flow up instead of water flowing down, i.e., $p_c \geq 575$ psia.

b. Other parameters of the linear flow equation area as presented in the seepage model (Ref. IIIC-1).

$$q_c = 6.33\ A\ k_{gc}\ \frac{p_o^2 - p_c^2}{\mu\, p_a\, L}$$

where:

A = cross sectional area of cement, ~0.597 feet^2

k_{gc} = relative permeability to gas in partially wet seep path, ~ 3d (relative permeability is less than the specific permeability derived in seepage model)

μ = gas viscosity, ~0.02 cp

p_a = reference pressure, ~ 15 psia

p_o = chimney pressure, ~2015 psia

p_c = pressure in seep path at base of "B" zone, ~ 575 psia

L = seep path, ~ 4,000 feet

Table IIIC-II. Relative chemical composition of chimney gas.

Component	Volume Percent T + 180D
Hydrocarbons	26
Carbon Dioxide	34
Hydrogen	18
Water Vapor	22

Table IIIC-III. Radioactivity concentrations in chimney gas.

Nuclide	Concentration pCi/cc
Tritium	< 123
Krypton 85	205
Argon 37	< 267
Argon 39	< 2
Carbon 14	< 2.3

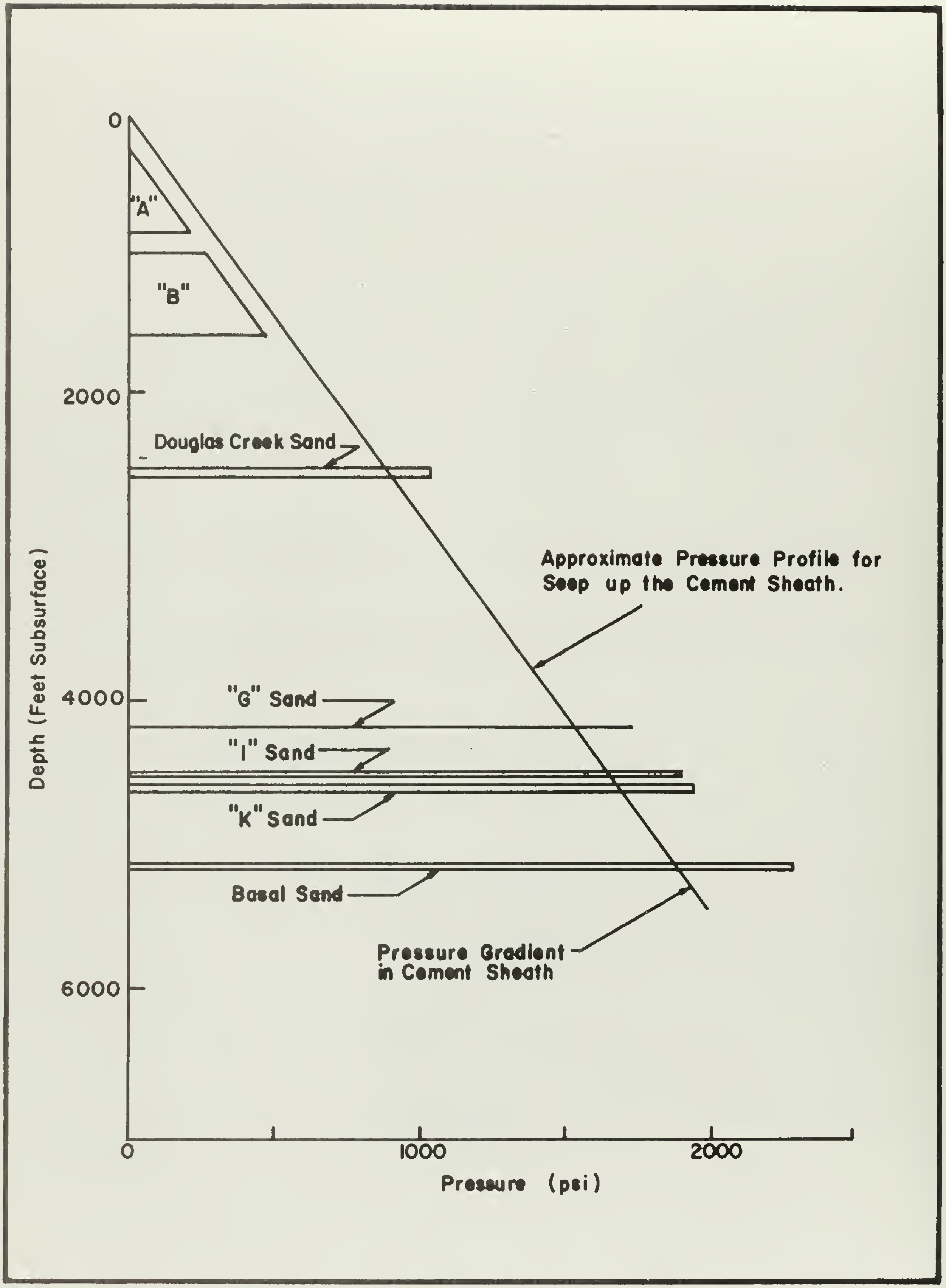

Figure IIIC-2. Rio Blanco experiment post detonation pressure condition seepage model.

$$q_c = \frac{6.33 \times 0.597 \times 3}{0.02 \times 15 \times 4000} (2,015^2 - 575^2)$$

$$= \frac{6.33 \times 5.97 \times 3 \times 10^{-1}}{2.0 \times 1.5 \times 4.0 \times 10^2} (2,015^2 - .575^2) \times 10^6$$

$$= 9.45 \times 10^{-3} (3.73 \times 10^6)$$

$$= 35 \text{ MCFD}$$

When the gas reaches the "B" subsystem, it can proceed up the seep path, or go into the "B" zone. The ratio of gas going to the "B" zone/gas going up the seep path can be evaluated by dividing q_b by q_{ca} and noting that $\frac{p_c^2 - p_c^2}{p_c^2 - p_{ca}^2}$ is approximately 1, since the larger squared term in both expressions is the same, and p_{ca} is not too different from p_b.

$$q_b = \frac{39.6\, h_b k_{gb} (p_c^2 - p_b^2)}{\mu\, p_a \ln \left(\frac{r_e}{r_w}\right)}$$

$$q_{ca} = \frac{6.33\, A\, k_{gc} (p_c^2 - p_{ca}^2)}{\mu\, p_a\, L}$$

where:

h_b = net "B" thickness, ~ 280 feet

k_{gb} = relative permeability of "B" zone to gas, ~ .05 d

μ = gas viscosity, ~ 0.02 cp

p_a = reference pressure, ~ 15 psia

$\left(\frac{r_e}{r_w}\right)$ = ratio of effective to well radius, ~ 600

A = cross sectional area, ~ 0.597 feet²

k_c = relative permeability of seep path to gas, ~ 3d

L = seep path length, ~ 700 feet

$$\frac{q_b}{q_{ca}} = \frac{\dfrac{39.6 \times 280 \times 0.05}{0.02 \times 15 \times \ln 600}}{\dfrac{6.33 \times 0.597 \times 3}{0.02 \times 15 \times 700}}$$

$$= \frac{\dfrac{3.96 \times 2.8 \times 5.0 \times 10^{1}}{2.0 \times 1.5 \times 6.4 \times 10^{-1}}}{\dfrac{6.33 \times 5.97 \times 3.0 \times 10^{-1}}{2.0 \times 1.5 \times 7.0 \times 10^{1}}}$$

$$= \frac{2.89 \times 10^{2}}{5.4 \times 10^{-2}}$$

$$= \frac{0.535 \times 10^{4}}{1}$$

$$= \frac{5350}{1}$$

Thus, much more than 99% of the gas reaching the "B" subsystem goes into the aquifer, and much less than 1% continues up the seep path.

The same general analysis can be made of the "A" subsystem. Again, the driving pressure would be the same; hence

$$\frac{p_{ca}^2 - p_a^2}{p_{ca}^2 - p_1^2} \quad \text{would approach 1.}$$

$$= \frac{\dfrac{39.6\, h\, k_{ga} (p_{ca}^2 - p_a^2)}{\mu\, p_a \ln\left(\dfrac{r_e}{r_w}\right)}}{\dfrac{6.33\, A_1\, k_{gc} (p_a^2 - p_1^2)}{\mu\, p_a\, L}}$$

where:

h_a	=	thickness of A zone, $\sim$ 500 feet
k_{ga}	=	relative permeability to gas A zone, $\sim$ .005 d
$\left(\frac{r_e}{r_w}\right)$	=	ratio of effective to well radii, $\sim$ 500
p_a	=	reference pressure, $\sim$ 15 psia
	=	gas viscosity, $\sim$ 0.02 cp
A_1	=	area of seep path, $\sim$ 0.785 $feet^2$
k_{g1}	=	relative permeability to gas of seep path, $\sim$ 3d
L	=	length of seep path, $\sim$ 500 feet

$$\frac{q_a}{q_1} = \frac{\dfrac{39.6 \times 500 \times 0.005}{0.02 \times 15 \times 6.21}}{\dfrac{6.33 \times 0.785 \times 3}{0.02 \times 15 \times 500}}$$

$$= \frac{\dfrac{3.96 \times 5 \times 5}{2 \times 1.5 \times 6.22 \times 10^{-1}}}{\dfrac{6.33 \times 7.85 \times 3 \times 10^{-1}}{2.0 \times 1.5 \times 5.0 \times 10^{1}}}$$

$$= \frac{53.14}{9.9 \times 10^{-2}}$$

$$= \frac{535}{1}$$

Hence, more than 99% of the very small amount of gas penetrating the Mahogany Zone would be dissipated in the "A" subsystem, and only a trivial amount would remain in the seep path.

The concentration of radioactivity in the Green River "A" and "B" groundwater subsystems would be:

("A" subsystem) The amount of gas that dissolved in the water and moves with the water in the aquifer (excess gas beyond that soluble in the water would be part of the gas that seeps to the atmosphere).

("B" subsystem) The amount of gas that dissolves in the water and moves with the water, plus the amount of gas that remains as a gas phase and forms a gas bubble against the base of the Mahogany Zone.

The critical gas saturation in a fracture system is less than 10%; hence, each cubic foot of gas would contact at least nine cubic feet of water prior to forming a bubble. Thus, the maximum concentration of radioactivity in the water would be that predicted by the solubility of the gases in the water. This value would decrease as the water moved along the aquifer and mixing occurred. These maximum concentrations in the water are presented in Table IIIC-IV.

The concentration of radioactive components in the gas phase would be that predicted by the initial concentrations and decay rates (Table IIIC-I).

5. Movement (direction and velocity)

A consideration of the radioactivity transport in the "B" subsystem would evaluate the bulk of the radioactivity released under the proposed maximum seepage model. The "A" subsystem velocities are lower, and the volume reaching the "A" subsystem is much less than 1% of that reaching the "B" subsystem.

The direction and velocity of transport of any dissolved gas released from the EW system into the "B" subsystem water would be to the NNW at about 1.2 feet per day.

The direction and velocity of a gas bubble is a more complicated function. The moving water pushes on the bubble in the direction of flow with a force proportional to the water velocity. The bubble is acted upon by gravity forces, and the resultant movement and velocity is the vector sum of the forces.

Table IIIC-IV. Maximum concentrations of radioactivity in groundwater*

Species	Concentration pCi/ml (@ 180 days)
T Total	< 43**
^{13}C	< 0.8
^{85}Kr	< 72
^{37}Ar Total	< 94
^{39}Ar	< 0.8

*Assumes a solubility equivalent to natural gas in fresh water at 100°F and 275 psia.

**The maximum possible tritium concentration 1.5% of the radioactivity concentration guide for an uncontrolled area. Note that this analysis does not consider the dilution that must occur as the water moves through the aquifer.

In the EW area, the gravity and flow forces are in opposition (see Figure IIIC-3), and the resultant is 2.4 feet per day at an azimuth of 206 degrees:

$$\frac{dz}{dx} = \frac{p_w}{p_w - p_g} \quad \frac{dh}{dx}$$

where:

$\frac{dz}{dx}$ = tilt of gas water interface

p_w = density of water, $\sim$ 1.0 gm/cc

p_g = density of gas, $\sim$ 0.025 gm/cc

$\frac{dh}{dx}$ = gradient of piezometric surface, $\sim$ 70/5280 feet/feet

$$\frac{dz}{dx} = \frac{1}{1 - 0.024} \times \frac{70}{5280}$$

$$= 1.39 \times 10^{-2}$$

$$\tan \phi = \frac{dz}{dx} = 1.39 \times 10^{-2}$$

$$\phi = 0^{\circ} \quad 48'$$

The velocity in the up-dip direction would be the ratio of the x components:

$$\frac{1.39}{1.2} = \frac{3.14}{x}$$

$$x = 2.7 \text{ feet per day}$$

Since the dip and piezometric gradient are in opposite directions, the azimuth will be the converse of the dip, or 206 degrees.

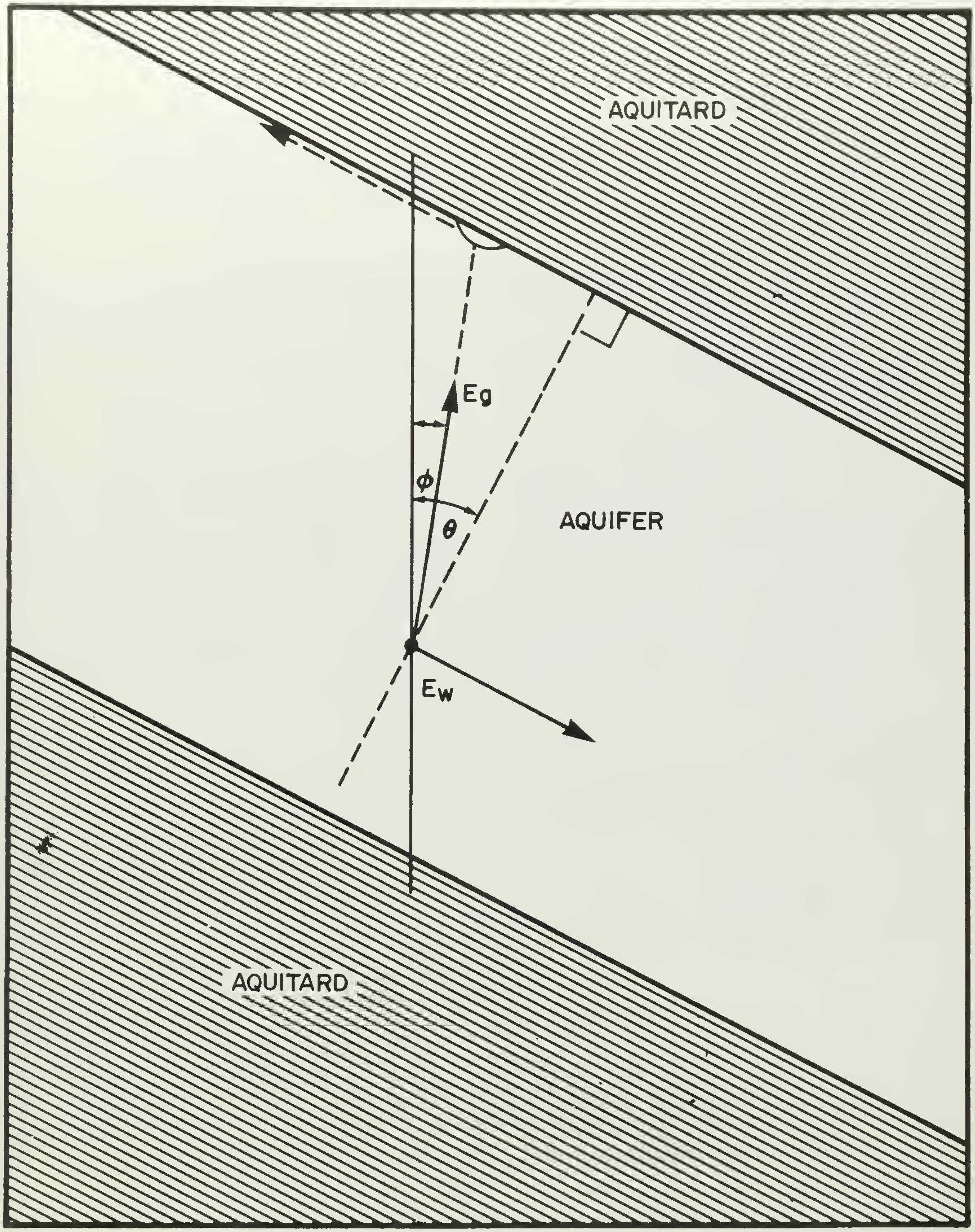

Figure IIIC-3. Migration of gas in flowing water. If angle ϕ ($dz/dx = \tan \phi$) is less than θ (dip of strata) then gas will migrate up-dip. If ϕ is greater than θ gas will be carried down-dip.

6. Retardation

Tritium and the noble gases will be assumed to have a retardation factor of one for this conservative evaluation;* hence, they are assumed to experience no retardation, only a decrease in concentration due to mixing.

The ^{14}C is present in such a low concentration that its retardation will have no appreciable affect upon the total radioactive concentration. Thus, to simplify calculations, no retardation will be assumed to apply to this component.

7. Residence Time

The down-gradient distance to the nearest potential "mixing" point is 4.8 to 8.6 miles. These are the Black Sulphur Creek and Piceance Creek fault zones. These are not the principal areas of discharge for the "B" subsystem (this is further to the north toward the White River), but they represent areas where "B" subzone water could enter the biosphere, although at a very reduced concentration. The distance to the up-dip recharge zone is about eight miles. Thus, the minimum residence time would be in the order of 58 years, although the most probable residence time would be in the order of several hundred years.

---

* $v = \frac{v}{K_f}$, v_1 = velocity of radiation transport, v - velocity of water

$$K_f = \left[\frac{(1 - \phi)}{(\phi)} \quad p K_d \right] + \quad \text{if} \quad K_d = 0, \; K_f = 1,$$

where:

ϕ = porosity
p = grain density
K_f = retardation factor
K_d = distribution coefficient

Applying a similar analysis to the "A" zone, the nearest discharge point is about 4.8 miles to the north. This would result in a residence time of about 500 years before radiation entrained in the "A" subsystem could become available to the biosphere.

8. Use Points

The wells tapping the "A" and "B" aquifer system down-gradient from the EW are plotted on Figure IIIC-4 and presented in Table IIIC-V.

The nearest well tapping the "A" subsystem is about 6.5 miles from the EW area in a direction almost perpendicular to the groundwater flow direction. If the flow direction were somehow to change, flow velocities would be lower than obtained in this analysis. However, if the current flow velocities are assumed to remain the same, the radioactive-contaminated water would take 738 years to reach the nearest "A" subsystem use point. In addition, it would have started out with a tritium concentration less than 2% of the maximum guidelines for drinking water, and it will have decayed by a factor of 4.37×10^{17} (all other radioactive components in the water are noble gases except ^{14}C, which originally was less than 1.0 pCi/ml); hence, radioactivity in the "A" subsystem from seepage would not constitute a problem.

The nearest use point in the "B" subsystem is 3.6 miles from the EW area in a direction almost perpendicular to the groundwater flow direction. If some of the water containing dissolved radioactive gas from the seepage model were to move in the direction of these use points, it would have a velocity less than the calculated maximum velocity in the normal flow direction. Hence, it would take more than 58 years to reach the use point, and the activity would have undergone a 32 fold decay. Since the maximum concentration in the water is initially less than 2% of the guideline for drinking water, this situation would not constitute a problem.

Any "gas bubble" in the "B" subsystem under gravity drive would be in an up-dip or southern direction. There are no use points within ten miles of the EW area in this direction; hence, the gas phase seepage would not constitute a problem under the current usage pattern.

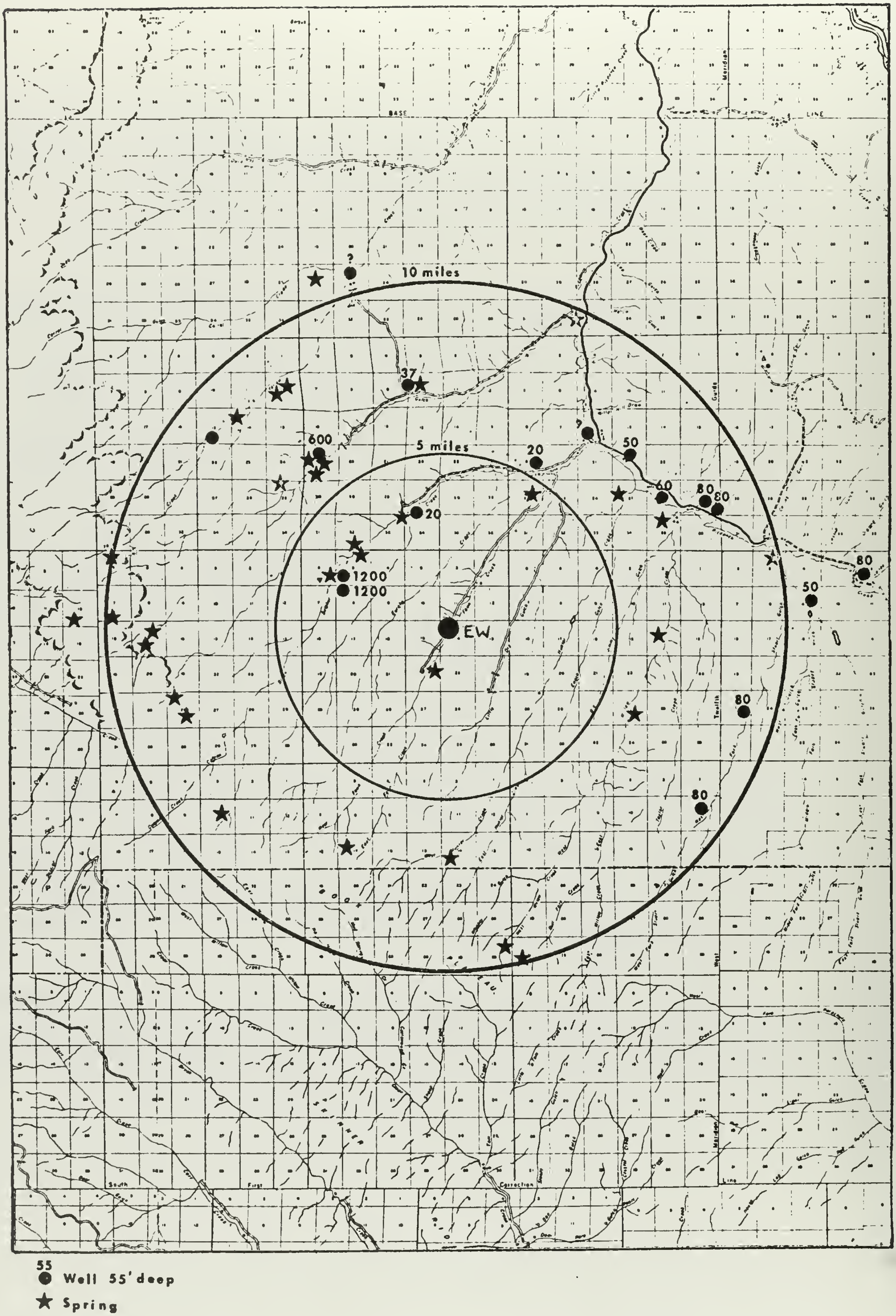

Figure IIIC-4. Springs and wells within ten miles of the EW (Ref. IIIC-4).

Table IIIC-V. Springs and wells within ten miles of Project Rio Blanco site

Distance Miles	Azimuth Degress	Location	Spring or Well	Well Depth	Casing Diameter	Bicarbo-nate	Dissolved Solids	Hard-ness	Non-Carbon-ate Hardness
1.5	203	C3-98-22db	Spring			460		578	201
3.25	311	C3-98-5abb	Spring						
3.75	311	C2-98-32cdd	Spring						
3.9	293	C3-98-6daa	Spring						
3.9	293	C3-98-6daa	Well	1200'	5-1/2"				
3.9	293	C3-98-6daa	Well	1200'	5-1/2"				
4.0	339	C2-98-28ddd	Spring			486	702	485	86
4.0	345	C2-98-27ccc	Well	20'	18"				
4.7	32	C2-97-30ad	Spring			526	1050	562	131
5.3	28	C2-97-19ad	Well	20'	40"				
6.0	322	C2-98-19ca	Spring			540		696	253
6.0	322	C2-98-19ca	Spring						
6.0	322	C2-98-19ca	Well	600'	6"				
6.0	116	C3-97-27cd	Spring			498		566	158
6.1	96	C3-97-14cb	Spring			542		578	133
6.2	55	C2-97-27c	Spring			556		734	278
6.6	311	C2-98-25ab	Spring						
6.8	180	C4-98-14cc	Spring			396		570	245
7.0	357	C2-98-10db	Spring			694		804	235
7.1	36	C2-97-16ac	Well						
7.1	63	C2-97-35ba	Spring						
7.1	350	C2-98-9da	Well	37'		682	1540	765	206
7.2	205	C4-98-17cb	Spring			350		352	22
7.2	46	C2-97-22ca	Well	50'	6"				
7.2	59	C2-97-26db	Well	60'	6"				
8.1	251	C3-99-28bd	Spring						
8.2	64	C2-97-25bd	Well	80'	6"				
8.2	64	C2-97-25bd	Well	80'	6"				
8.3	255	C3-99-28bb	Spring						
8.4	324	C2-99-12ca	Spring						

Table IIIC-V (continued)

Distance Miles	Azimuth Degrees	Location	Spring or Well	Well Depth	Casing Diameter	Bicarbo-nate	Dissolved Solids	Hard-ness	Non-Carbon-ate Hardness
8.4	327	C2-99-12ac	Spring			520		658	231
8.5	315	C2-99-14bb	Spring						
8.5	231	C4-99-10ac	Spring			374	419	294	0
8.6	310	C2-99-15dc	Well			414		512	98
8.8	267	C3-99-17ba	Spring						
8.9	270	C3-99-17ac	Spring						
8.9	105	C3-96-30ad	Well	80'	6"				
9.0	125	C4-97-12db	Well	80'		464	940	588	208
9.2	169	C4-98-36aa	Spring			388		382	64
9.6	168	C4-97-31bd	Spring			332		282	10
9.9	78	C3-96-5aa	Spring			500	928	555	145
9.9	272	C3-99-7dc	Spring						
9.9	24	C1-97-36c	Spring						
10.0	282	C3-99-6ab	Spring						

If the bubble moved in a non up-dip direction, it would have to be carried by the water and would have a velocity equal to or less than the water velocity. Thus, a non up-dip gas bubble movement would result in residence times the same as or greater than the radiation in the water.

REFERENCES

IIIC-1. Pastore, R. M., "A Seepage Model for Deeply Buried, Gas Stimulation Nuclear Detonations," AEC/NVOO (draft).

IIIC-2. Pirson, S. J., "Oil Reservoir Engineering," McGraw-Hill (1958).

IIIC-3. Toman, J., at Rio Blanco Technical Meeting (personal communication) (April 15, 1971).

IIIC-4. Hubbert, M.K., "Entrapment of Petroleum Under Hydrodynamic Conditions," AAPG Vol. 37, No. 8, pp. 1954-2026 (August, 1953).

D. MINERAL RESOURCES

1. Oil Shale

In assessing the impact of the Rio Blanco project upon the Green River oil shale, it has been concluded that the only effect would be the removal of an insignificant amount of the oil shale particles resulting from drilling the EW. The hole will be very carefully cemented, however, and the integrity of the oil shale formation should not be reduced as a result of the drilling of the EW.

Calculations have also been made to determine whether or not the oil shale would be affected by the explosions. Consideration has been given to (1) fracturing, (2) deposition of radionuclides, (3) rock vaporization, and (4) rock melting.

Fractures, which communicate with the chimney, are expected to extend about 320 feet above the upper shot point. The maximum upward extent of such fractures observed for contained explosions in competent rock; e. g., granite, sandstone, dolomite, rock salt, has not exceeded eight times the cavity radius. The maximum expected cavity radius for the uppermost explosion is 83 feet. Therefore, the maximum expected extent of chimney-connected fractures would be 8 x 83 feet or 664 feet, at a depth of about 5,200 feet. Since the base of the Green River is believed to be about 2,900 feet, there would be an unfractured buffer zone of approximately 2,300 feet between the maximum expected upward extent of fractures and the base of the Green Formation. Since the base of the oil shale is several hundred feet above the base of the Green River Formation, the total thickness of the buffer zone would exceed one-half mile.

Theoretical calculations have been made of the peak-free field stresses expected to be induced in the rock at the base of the Green River. These calculated stresses are about 100 bars or six percent of that required to break the rock. Other theoretical calculations indicate that spall may occur near the ground surface, to a depth of a few hundred feet, as a result of the reflection of the seismic wave at the air-ground interface.

Only about 70 metric tons of rock per kiloton yield will be vaporized, and possibly as much as 1,000 metric tons per kiloton yield will be melted. With 30 kt, the rock out to about 19 feet from shot point will be vaporized and rock out to as far as 46 feet could be melted. Since only this small amount of rock in the immediate vicinity of the shot point would be vaporized and melted, the oil shale would not be subject to these changes.

There are numerous gas-bearing sands within the buffer zone between the uppermost explosion point and the base of the oil shale. This demonstrates that there are no existing open channels between oil shale and the lowest of these gas-bearing sands. Fractures from the explosion will be limited to the Fort Union and Mesaverde formations; radioactivity cannot migrate into the oil shale.

2. Other

Because the nahcolite and dawsonite deposits are collocated with the oil shale in the Green River Formation, the discussion above on the effects on oil shale is relevant also to these deposits.

Since the object of this experiment is to fracture sufficient gas sands to enable economic recovery of natural gas, fracturing of any additional gas sands by the explosions would be beneficial.

IV. ALTERNATIVES

A. BACKGROUND

1. U. S. Gas Supply

In his special message to the Congress on June 4, 1971, regarding energy, the President made the following point regarding the supply of natural gas in this country:

> "For the past 25 years, natural gas has supplied much of the increase in the energy supply of the United States. Now this relatively clean form of energy is in even greater demand to help satisfy air quality standards. Our present supply of natural gas is limited, however, and we are beginning to face shortages which could intensify as we move to implement the air quality standards. Additional supplies of gas will therefore be one of our most urgent energy needs in the next few years," (Ref. IVA-1).

The National Petroleum Council in its recent report to the Secretary of the Interior states: "Gas markets, in recent years, have been characterized by rapidly increasing demand and lagging additions to supply," (Ref. IVA-2). This report further indicates that, assuming a seven-fold increase in imports, the total gas supply available in the United States in 1985 will be 6% less than 1970 (22.74 TSCF versus 21.49 TSCF); and yet, if one were to assume no gas supply limitations or changes in pricing structure, the demand could be expected to grow at 3.2% per year, resulting in a supply shortfall of 78% in 1985.

2. National Policy Regarding Nuclear Stimulation

In the previously referenced June 4 energy message, President Nixon said:

> "Federal efforts to augment the available supplies of natural gas include:
>
> ***
>
> "Progress in nuclear stimulation experiments which seek to produce natural gas from tight geologic formations which cannot presently be utilized in ways which are economically and environmentally acceptable.

"This administration is keenly aware of the need to take every reasonable action to enlarge the supply of clean gaseous fuels. We intend to take such action and we expect to get good results," (Ref. IVA-1).

Additional details were given June 15 when Dr. Glenn Seaborg, former Chairman, U. S. Atomic Energy Commission, testified before the Senate Interior and Insular Affairs Committee as follows:

"As the President stated in his Energy Message, 'additional supplies of gas will... be one of our most urgent needs in the next few years.' Recognizing this fact, the AEC has been concentrating in its Plowshare program on developing nuclear gas stimulation technology which would permit the Nation to tap the 317 trillion cubic feet of gas estimated by the Bureau of Mines to be potentially available from the tight gas formations of the Rocky Mountain area. This is an amount greater than the current reserves.

***

"Projects Gasbuggy and Rulison, the two nuclear gas stimulation experiments conducted to date, demonstrated that nuclear explosions can significantly stimulate the flow of natural gas not otherwise available. The 26 kiloton Gasbuggy nuclear detonation resulted in a five-to eight-fold increase in gas production over surrounding wells in the area. While results from Rulison, the second such experiment, are still being evaluated, preliminary analyses indicate that at least a five- to ten-fold increase in gas production was realized. Thus, we know that, technically, gas stimulation works.

***

"To summarize, we believe that within a few years, at a modest cost, Plowshare can make available significant quantities of competitively priced natural gas not otherwise available. This additional gas supply will buy time for development of other long-range means of meeting the Nation's energy needs," (Ref. IVA-3).

Speaking further to National policy relating to energy, following the President's message on June 4, was Interior Secretary Rogers Morton, in testimony before the Senate Interior and Insular Affairs Committee, June 15, 1971. Secretary Morton said:

> "...the facts suggest persuasively that we shall have an extremely difficult time meeting the demand projected for gaseous fuels, and that in all probability the full demand will not be met in the early part of the period, say the next five to ten years.
>
> ***
>
> "The Rocky Mountain area also holds a great potential for additional gas supply, provided the resource can be freed from the formations in which it is now so tightly bound that less than ten percent is recoverable. The Department estimates that a significant portion of 300 trillion cubic feet of natural gas might be recovered from these formations if stimulation through nuclear explosive fracturing proves to be technically feasible and economically practicable. The Department of the Interior, in cooperation with the Atomic Energy Commission and private industry, has sponsored a program aimed at increasing recovery through nuclear fracturing of the reservoir rock. The results of the two tests conducted so far, Gasbuggy and Rulison, are still being evaluated, and much additional information must be developed. The start of commercial development--assuming test results are favorable--is probably three or more years away, with gas from this source becoming significant in the latter half of the decade," (Ref. IVA-4).

The Congressional Joint Committee on Atomic Energy reaffirmed its support for nuclear gas stimulation during the authorization hearings, when it recommended the following:

> "The Joint Committee recommends authorization of $8,100,000, an increase of $3,100,000 over the amount requested by the Commission.
>
> ***

"In presenting the request for $5 million in operating funds for the next year to the committee, AEC witnesses set forth a program for research, development, testing and joint industry-Government ventures calculated to bring natural gas derived through nuclear stimulation to the consumer pipelines within five years at an anticipated Government cost of about $50 million. The committee strongly urges the adoption and implementation of this plan and recommends the addition of $2.6 million in fiscal 1972 to initiate it. Conservative estimates indicate the potential for this technology to make available a supply of natural gas which would more than double the current total proven reserves available in the 'lower 48' states. At the current rate of production to reserve growth, current proven reserves will suffice for only one-half of the estimated 1985 demand. Technological success of gas flow stimulation has been proven through projects Gasbuggy and Rulison. It remains to apply this technology on a field development basis which is industrially and ecologically sound.

"The next steps in the program will provide the device engineering which will produce clean commercial natural gas in an economic fashion. But to accomplish these steps will require both device development and testing as well as further joint efforts with the industrial experts in natural gas exploration and management. Two such joint ventures are well along in study and planning. Project Rio Blanco has been the subject of an industrial feasibility study and the project definition contract is being performed by industry and the AEC. A field development program has been proposed by the industrial sponsor. With satisfactory progress, this first multiple-chimney experiment can be performed during fiscal year 1972. A device development test scheduled for early in fiscal year 1972 should make a small diameter-low radioactivity device available in time for that project. Contemporaneous further development to adapt that device to sequential firing will permit timely execution of Project Wagon Wheel early in fiscal year 1973, also looking toward development of a full natural gas field, this one from deep thick low-permeability strata. Project definition activities are proceeding on this experiment also," (Ref. IVA-5).

REFERENCES

IVA-1. "Clean Energy," Message from the President of the United States transmitting a Program to Insure an Adequate Supply of Clean Energy in the Future (June 4, 1971).

IVA-2. "U. S. Energy Outlook--An Initial Appraisal, 1971-1985," An Interim Report of the National Petroleum Council, Vol. I (July, 1971).

IVA-3. Testimony by Dr. Glenn T. Seaborg, Hearings on the National Energy Policy, before the Committee on Interior and Insular Affairs, United State Senate (June 15, 1971).

IVA-4. Testimony by the Honorable Rogers C. B. Morton, Hearings on the National Energy Policy, before the Committee on Interior and Insular Affairs, United States Senate (June 15, 1971).

IVA-5. "Authorizing Appropriations for the Atomic Energy Commission for Fiscal Year 1972," Report by the Joint Committee on Atomic Energy (June 30, 1971).

B. ALTERNATIVES TO NUCLEAR STIMULATION FOR THE RIO BLANCO UNIT

1. Hydrofrac Completions

To date, 16 wells have been drilled through the Fort Union Formation; of these, 11 completely penetrated the Mesaverde I within the proposed unit. Production tests and permeability measurements in these wells have shown that insufficient gas can be produced to make them economical. Hydrofrac completions have been made in these intervals, but have not increased production appreciably. The lenticular nature of the gas-bearing sandstone intervals, the large gross interval over which they occur, and the extremely low permeability all contribute to the difficulty of making "more conventially" completed wells economic.

Even if conventional completions were economic, the number of wells required to drain the reservoir would be substantially greater than that for the proposed nuclear fracturing technique (Ref. IVB-1). This would, of course, entail the need for a larger number of drilling pad locations, roads, pipeline, etc., with the resulting greater environmental impact of such proliferate installations. Therefore, the probability that conventional hydrofrac completions provide an alternative to nuclear stimulation in this area is essentially zero.

2. High Explosives Completions

High explosives have been used in the past to stimulate gas and oil production, but a considerable loss of human lives was experienced in the process. With the advent of the hydrofrac process, interest in high explosive stimulations waned since hydrofracing was safe and more predictable and was sufficiently effective to successfully complete many wells in reservoirs undergoing development at that time.

More recently, as a result of the development of high explosives with a higher degree of safety in handling and the necessity for attempting exploitation of reservoirs with substantially lower permeability, some research has been carried out to determine whether or not these explosives will make possible the safe, economic recovery of gas and oil from tight reservoirs. To date, however, this research has not provided an adequate basis for predicting the effectiveness of high explosives stimulation in reservoirs with permeabilities as low and sand thicknesses as large as those of the Fort Union and Mesaverde I sections in the Rio Blanco field. Three of the most critical and unpredictable parameters of high explosive stimulation are the effective radial extent and the distribution of permeable fractures, as well as the magnitude of fracture permeability surrounding a wellbore. Three 30 kt of pelletized high explosives would require three spheres, 120 feet in diameter, at the bottom of the shaft. Because of these uncertainties and space disadvantages, high explosive completions are not regarded as a reasonable alternative to the proposed project.

REFERENCES

IVB-1. Howard, G. C. and C. R. Fast, "Hydraulic Fracturing," Society of Petroleum Engineers of AIME (1970).

C. OPERATIONAL ALTERNATIVES

As explained in Section III of this volume, prompt unplanned release or venting of the explosion gases is not credible; seepage to the atmosphere, or groundwater or damage to the oil shale one-half mile above the detonation is highly unlikely. As discussed in Section II of this volume, the only elements of the Rio Blanco project that will have an impact on the environment are: (1) construction damage through the clearing of about seven acres of land, (2) ground motion, and (3) some planned minimal radioactivity addition to the biosphere.

1. Construction

If the project supported by the foregoing National policy is to be executed, there appears to be no alternative to clearing about four acres of land for the drilling and subsequent production testing at EW, plus about three acres for operations, including the FPCP and microwave relay tower sites. As explained in Section IIA-10, the EW site will be restored after conclusions of the tests.

2. Ground Motion

This experiment has been designed to employ three 30 kt explosives to fracture effectively a section of rock about 1, 350 feet thick. The basis for this design can be explained by comparing the expected effects of one, two, and four explosive configurations with those of the selected one.

To fracture the 1, 350 feet of Fort Union and Mesaverde I sections effectively with only a single explosive, a yield of approximately 350 kt would be required. To fracture the entire 1, 350 feet of section with two explosives, single yields of 120 kt would be required, for a total yield of 240 kt. With four explosives, single yeilds of 14 kt or a total of 56 kt would be required.

Ground acceleration and krypton-85 production for the foregoing configuration are compared below with those for the three 30 kt explosive configuration. It is assumed that three 30 kt explosions cause ground accelerations equivalent to those of a single 90 kt explosion. Accelerations were scaled by the 0.47 power of the explosive yield.

No. of Explosives	Single Explosive Yield, kt	Total Yield, kt	Minimum Ratio of Ground Acceleration at any point to that for three 30 kt Configuration	Ratio of Krypton-85 Produced to that of three 30 kt Configuration
1	350	350	1.9	3.9
2	120	240	1.6	2.7
3	30	90	1	1
4	14	56	0.8	0.6

These ratios indicate that ground accelerations would be 40 to 90% greater for the one and two explosive configurations, and only 20% less for four explosives. Krypton-85 production would be approximately 100 to 200% greater for the one and two explosive configurations, and only 40% less for four explosives.

From a purely economic standpoint, and where damage claims are not included, the single-explosive configuration is the most desirable since explosive costs are not expected to vary significantly with yield, and since somewhat greater 20-year gas recoveries would result from the larger yield explosive.

The two-explosive configuration obviously would be a second choice from a purely economic standpoint (where damage costs are not included). However, in order to limit the extent of seismic effects and to keep the production of radioactive gases to as low a level as practical, these two configurations were rejected.

For the four 14 kt explosive configuration, the expected fracture radius would be about 25% less than that of Rulison. This configuration was rejected because the advantages did not outweigh the additional explosive's cost.

The Lawrence Livermore Laboratory is designing a nuclear explosive and firing system capable of sequential rather than simultaneous firing. They do not yet have the authorization or budget to build and test such a system. With a sequential system, the surface ground motion is a function of the yield of one device, not the sum of the yields as in simultaneous detonation. Thus, for a fixed ground motion limit, a greater underground thickness and area can be stimulated, or for a given cumulative underground effect, peak surface ground motion can be reduced. To delay Rio Blanco awaiting that uncertain development would simply delay the availability of this gas.

3. Alternatives to Planned Radioactivity Release

a. Separated, or Produced, Water Contaminated with Tritium

The alternatives for disposal of this water are discussed in Section IIC-1a and IID-1. Fawn Creek Government Well Number 1 is 1,300 feet from the EW and provides an ideal location wherein separated tritiated water can be injected and thereby isolated from the biosphere. Injection of the separated water into the well rather than flaring it only reduces the most probable dose from flaring by about 10% and, thus, is not of overriding importance on the first experiment. However, in the eventual field development, where the gas will be produced into a pipeline and little or none flared, produced water with tritium contamination must be separated and disposed. Successful injection on this experiment will prove up one method of disposal.

b. Flaring

In Section IIC-2e, the maximum credible dose from flaring is calculated. Under the assumption that the produced water referred to in "a" above is flared and released to the atmosphere, rather than reinjected, and under the assumption that 800 million SCF are flared rather than the more probable 300 million SCF, the maximum dose is calculated to be less than one millirem, or less than one one-hundredth of what a person in that area receives from background radiation every year. The following alternatives should be weighed against this upper limit dose estimate.

(1) Cooling of the Combustion Gases

One alternative would involve flaring and subsequent cooling of the combustion gases, and the condensing of the tritiated water vapors. Flaring at 40 million SCF/day produces a heat equivalent of approximately 500 megawatts. To provide this capacity by refrigeration would require the output of a major size electrical power plant not currently available in the State of Colorado. Alternatively, it would require cooling water in excess of that available in the local streams. The condensate would then need to be disposed, presumably by injection into Fawn Creek Government Well Number 1. Obviously, cooling the combustion products from the flared gases is not practical.

(2) Storage

The only other alternative to the previously described production test methods (disposal of produced gas by flaring) is storage of the natural gas taken from the cavity. Two methods of storage have been considered, one of which is in liquefied form and othe other in gaseous form.

(a) Storage in Liquefied Form

Liquefaction is a method to produce liquid natural gas (LNG), which condenses the gas by reducing its temperature to -258°F.

This method requires a large plant. A study of 27 such plants existing in the world was made in an attempt to determine the capital cost of construction. The Liquefied Natural Gas Committee of the Operating Section of the American Gas Association has prepared a book entitled "LNG Information Book II 1968," which is concerned with, among other things, construction costs of various sizes of liquefaction plants. The construction cost of a plant capable of handling only 10 million SCFD is $6.5 million, which is well in excess of the anticipated total cost of this project. This does not include the cost of operation or necessary storage capacity. Storage capacity for the LNG product from one billion SCF of gas would cost approximately an additional $3.3 million. Storage in LNG form does not appear economically practical.

(b) Storage in Gaseous Form

If the produced gas were stored above ground at atmospheric pressure, the cubic foot volume would be the same as the number of SCF produced during the testing procedure. The storage capacity needed for the testing would range from five million to one billion

SCF. Estimated costs of storing this amount of gas would be a minimum of $130 million, based upon the use of 100,000-barrel, 250 psi pressurized storage, cylindrical propane tanks. If the gas were stored at atmospheric pressure in 100,000-barrel tanks, the cost would be $267 to $534 million. These costs do not include costs of land, of compression, or operating costs.

At a lower pressure, however, the volume would necessarily be larger and the lower pressure storage would be more expensive than high pressure storage.

If the aim of storing is to prevent release to the atmosphere, then at the conclusion of the testing compressors would be required to take the gas out of storage and recompress it for injection into the chimney. The cost of a compressor to reinject the stored gas at a rate of five million SCFD would be about $600,000--exclusive of lines, storage tanks, and operating costs. These calculations are based on 400 brake horsepower to compress one million SCFD to 3,000 psi, using four stages with compression ratios of 4.5 per stage and installed costs of $300 per brake horsepower.

Storage in gaseous form does not appear to be economically practical.

c. <u>Other Radioactive Material</u>

As described in Section IID-2, the amount of other radioactive material is expected to be almost zero, especially if the drilling mud is lost into the cavity upon drilling into it. However, preparations will be made to handle all material that can possibly be contaminated as described in Section IID-2.

If it is National policy to attempt to stimulate natural gas-bearing formations with nuclear explosives, then there is no alternative to this very minimal contamination potential.

V. RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

A. GENERAL

Project Rio Blanco will, at the worst, lead to only minimal conflict with other short-term uses of the environment; but will, at its best, be a first step to significant enhancement of its long-term productivity. This first phase will interfere with the use of about seven acres of land for grazing and hunting; but, if the full unit is similarly developed, it has the potential of more than doubling Colorado's natural gas reserves from just the Rio Blanco unit, and of leading to the doubling of the present United States reserves. (BuMines estimates that 317 TSCF within the Rocky Mountain region are amenable to nuclear stimulation.)

B. GAS PRODUCTION POTENTIAL

1. Fort Union and Mesaverde Formations

Development of the Rio Blanco gas field with nuclear explosions would enhance gas production. Based upon log evaluations and reservoir performance computer runs, it is estimated that about four trillion SCF of natural gas could be recovered in 25 years from the Fort Union and Mesaverde I formations within the Rio Blanco unit. Possibly as much as an additional two trillion SCF could be recovered from lower sections of the Mesaverde Formation, for a total of six trillion SCF recoverable since predicted flow rates at the end of 25 years are sufficiently large to warrant further production.

2. Green River and Wasatch Formations

Development of gas production from the Wasatch and Green River formations should be enhanced, since more information about them will be obtained as the Rio Blanco development proceeds. This information would enable the developer of these shallow formations to program its production wells more advantageously.

The large amounts of gas reserves in this field are expected to support a major gas pipeline. This could possibly stimulate gas production activities in the regions through which the pipeline would be constructed, and particularly production from the Green River and Wasatch formations within the Rio Blanco field.

Based upon the results of Rulison, Gasbuggy, and Soviet tests, it is quite clear that wells can be spaced so that the nuclear explosion will not damage the producing wells.

3. Pre-Mesaverde Formations

Any possible future production from older formations would not be affected by the Rio Blanco development since the 1,000 plus feet of Mancos Shale, which underlies the Mesaverde, would serve as a buffer to protect the older sands.

C. AGRICULTURE AND RANCHING

Except for the improvement of roads, communications, and power facilities, it is expected that this project will not have any significant long-term effect upon agriculture and ranching.

D. OIL SHALE

The Piceance Creek Basin is known for its rich oil shale deposits. They are so plentiful that they will no doubt be developed over a long period of time--perhaps 50 to 100 years--with activity building up gradually. In contrast, it is to be expected that the gas field would be fully stimulated within the first quarter of that period, and then produced for 30 to 50 years thereafter.

Oil shale deposits would be affected only in that holes for emplacement of the explosives would be drilled through them. Casing and cementing programs would be designed to preclude communication for water transfer out of aquifers. This drilling should not interfere with any future development of oil shale, especially since only one or two gas wells per square mile are anticipated. If the oil shale deposits are mined, the gas wells could be programmed through joint planning so that they would be located within the mine pillars. If this resource is recovered by in situ retorting, again through joint planning, the development could be programmed so that the deposits immediately around the wellbores would be the last to be retorted. It might be necessary to shut the gas wells in, temporarily, and cool them as the retorting front moves through the rock immediately in the vicinity of the wellbore.

The development of the gas field could contribute to the development of the oil shale in several ways. First, the exploratory information from emplacement wells could be useful; and secondly, should the hot methane injection method of in situ retorting prove feasible, some of the stimulated gas could conceivably be used in any full-scale process. Roads and power brought in for the gas field development could also be used for future oil shale operations.

E. HUNTING AND FISHING

It is expected that detonation days will be chosen during periods outside of the hunting season. Consequently, the area's long-term hunting potential should not be adversely affected by either Rio Blanco I or any follow-on program.

Fishing will be affected on those days that detonation occurs, and then only for a few hours in the areas to be closed for reasons of ground motion safety.

F. TAX BENEFITS

If we assume that this project leads to the full unit development, what might that full development produce in taxes?

If we assume that four trillion cubic feet of gas is produced at a uniform rate from the full gas unit over 30 years at an average price of $0.30 per mcf, then the Federal Government will receive an average of $5 million per year in royalty payments. Under the above assumptions, the assessed valuation of the gas production for state and local tax purposes will be an average of $35 million per year. This compares with a total assessed valuation in Rio Blanco County in 1970 of $58 million, or a 60% increase.

VI. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Nuclear fuel required to produce 90 kt TNT equivalent energy will be expended irretrievably.

To evaluate the benefit from this expenditure, let it be assumed that 26 billion SCF of gas will be produced over 25 years from the Rio Blanco well when it is eventually produced into a pipeline. This is equivalent to 2.6×10^{13} BTU. The energy expended in the fissioning to produce 100 kt (90 $\pm$ 10 kt) yield is 4×10^{11}. This is a gain of 60 in energy available in the gas to energy expended in fissioning.

In order to evaluate the effectiveness of the nuclear stimulation treatment, it will be necessary to flare (irretrievably commit) 300 to 800 million SCF of gas.

VII. ENVIRONMENTAL EFFECTS OF CONTEMPLATED FUTURE ACTION

A. BACKGROUND

The future contemplated action is the full field development within the unit boundaries previously shown. This development, based on 640-acre spacings, could conceivably consist of about 140 well stimulations with the accompanying surface facilities and pipelines in the Piceance Basin. Increased activity related to stimulation might exist for seven or eight years, and field production activities for many more years beyond that, possibly for as long as 50 years. Future actions during the well stimulations would generally be a repeat of the actions described in this first project, with the notable exception that the long-term flaring of radioactive gas into the atmosphere for testing purposes would not be necessary. However, short-term testing may still be necessary.

The proposed field development schedule anticipates future oil shale development and provides for gas recovery and, therefore, effective multiple land use prior to any basin-wide oil shale production facilities.

B. RADIOACTIVITY

1. Groundwater

Groundwater content throughout the general area of interest for gas stimulation is similar to that described for Project Rio Blanco. Additional information would be gathered as more stimulations are completed; but for the purpose of gas stimulation in the area of interest, the basin hydrology is well known and no great deviations are expected. The water is not mobile within the vicinity of any anticipated stimulated gas zone and, therefore, undesirable migration of radionuclides will not be experienced. It has previously been shown that any unexpected seepage into the Green River aquifer will not constitute a safety hazard.

2. Period of Explosive Detonation

The depth of the gas formations of interest throughout the unit is such that the probabilities of releasing any radiation into the atmosphere at detonation time are negligible. Even so, extensive precautions have been planned on Project Rio Blanco in order to prevent even a slight accidental seepage of any radioactive gas to the atmosphere. Similar precautions would be taken for a demonstration program utilizing information gathered from prior stimulations.

Evaluation of containment techniques is continually being carried out at the NTS for weapons tests fired at significantly shallower depths than Rio Blanco. Greater assurances can be anticipated for the containment techniques of the future. However, emergency plans have been developed in the Project Rio Blanco Definition Plan, Volumes II and III, and similar plans will be developed for all future events. If an unforeseen seepage of radiation should occur, appropriate action would be taken. Monitoring techniques will be employed in Project Rio Blanco and on all future developments, primarily for negative documentation.

3. Production Testing

The current production testing techniques--extensive flaring of radioactive gases into the atmosphere through a flare stack located near a stimulated well--may not be needed on future experiments. If it is, however, it is probable that adequate testing to prove up the field and verify the experimental objectives could be accomplished with minimal flaring or production into a pipeline.

4. Gas Quality

It is anticipated that the chemical composition of the gas in each well stimulated would be similar to that predicted for Project Rio Blanco. The initially large CO_2 content in the chimney would be diluted with pipeline gas or separated by standard gas field practices before gas injection into the line. Unless it is shown that the most troublesome gaseous nuclides, such as iodine-131, are not present in the gas shortly after detonation, as Gasbuggy data imply, the standard policy would be to delay reentry into the wells for several months after the detonation. This will allow these short-lived nuclides to decay to levels at which they cease to present any health hazard.

The remaining gaseous isotopes, tritium and krypton-85, can be delivered at the point of actual consumption at concentrations that would provide exposure to the general population of less than one millirem per year. No insurmountable problem is anticipated in meeting future regulations or standards developed for the sale of the gas. ORNL has finished a study (Ref. VIIB-1) on one distribution scheme, using Gasbuggy data, and came to the following summary and conclusions:

> "The only radioactive species of consequence in natural gas from nuclearly stimulated wells are tritium and krypton-85. Of these, tritium is by far the most important from the standpoint of possible biological impact. Data from the first two tests, Gasbuggy and Rulison, show that a large fraction of the tritium produced by the nuclear detonations remained in the cavity. The tritium in the emerging gas appears to be distributed rather uniformly among the hydrocarbon species. There are many paths through which consumers of gas or others might be exposed to the radioactive contaminants. We have sought to define the more important paths and to assess the possible doses that might be received through use of gas or by-products manufactured from it. Home consumption of gas for nonvented heating or in unvented appliances appears to be the critical exposure pathway. All our investigations thus far show that with tritium levels in the natural gas which appear to be achievable in large-scale exploitation of gas fields, the potential annual doses calculated with very conservative assumptions are of the order of a few millirems, only a small fraction of the permissible level of 170 millirems per year recommended by the Federal Radiation Council for members of the general public. Mere compliance with standards should

not be used to imply safety, however, and it will be necessary to balance the benefits with the risks for this application of nuclear energy. While these results are very encouraging, it should be recognized that in this preliminary analysis we have considered mainly direct modes of exposure through inhalation, submersion, and absorption through the skin. Some effort has been devoted to possible pathways for ingestion, but more needs to be done in this field. We are looking forward to possible extension of Gasbuggy-type studies to other nuclearly stimulated gas wells such as Rulison."

Continuing studies such as this and the current one related to Rulison will significantly aid in the rapid development of regulatory oriented techniques and knowledge.

REFERENCES

VIIB-1. Barton, C. J., D. G. Jacobs, M. J. Kelly and E. G. Struxness, "Radiological Considerations in the Use of Natural Gas from Nuclearly Stimulated Wells," Nuclear Technology 11, p. 335, (July, 1971).

C. GROUND MOTION

The elastic ground motion resulting from use of any kind of explosive is clearly an undesirable but unavoidable effect. Enough energy must be imparted to the reservoir rock to create the fracture conditions needed for the recovery of the gas. The amount of gas recovered must, however, be balanced against the adverse effect of any disturbing levels of ground motion. Therefore, throughout the field development instrumentation will be used to monitor and refine ground motion predictions for the area of interest. In the first experiment, it is predicted that 100 kt of explosive energy can be utilized for stimulation with insignificant damage to any of the surrounding towns (Rangely, Meeker, De Beque, Grand Valley, Rifle, and Grand Junction). The maximum yield that can be used on any one detonation during field development will depend upon the actual detonation sites within the unit. Toward the northwest and east portions of the unit, it is possible that only 60 kt would be an acceptable yield; whereas, a site just a little more remote than the first experiment could possible use up to 200 kt and still not produce unacceptable damage. Measurements obtained on Project Rio Blanco will provide further information.

Because the effectiveness of the stimulation process is dependent upon the explosive energy, it is economically desirable to utilize as much energy as possible in keeping within acceptable seismic limits. It is hoped that a capability for the sequential detonation of multiple devices within a single wellbore can be developed by Lawrence Livermore Laboratory. If this capability were currently available, the Rio Blanco well stimulations could conceivably consist of three 90 kt explosives instead of three 30 kt without an increase in ground motion if there were a delay between detonations. This has obvious advantages when one considers the other portions of the unit for which smaller yields must be used because of potential ground motion related damages.

It would be annoying to the local residents and unacceptable to have local activities disrupted every few days because of detonations; therefore, particular care must be taken with scheduling. Consequently, a field development program has been developed on the concept of performing multiple detonations on a single day. These detonations would be spaced a few seconds or more apart and continue until the total had been completed. A typical day's activities might consist of 20 or more well stimulations, each consisting of two or more detonations. The time between each such series would be dependent upon drilling schedules, pipeline delivery schedules, etc., but such disruptions would occur no more than seven or eight days over several years.

As shown elsewhere, the shockwave will have no adverse affect on the oil shale. If a test lease were given and mining of oil shale were to begin in the immediate vicinity, the mutual programming of activities could eliminate any potential conflict. The actual mining could be designed to contain the gas wells in the pillars. If the maximum multiple use of resources from the land is to be established, the gas stimulation program must be coordinated with development of any large-scale oil shale activities. At present, the population and facility density is small. If it becomes large, the recovery of gas from the area of interest would be uneconomical and the resource lost for use. In order to have effective multiple land use and utilization of natural resources, the development schedule must be programmed to provide a minimum of interference and interaction. This has the added advantage of having natural gas locally available when oil shale lands are developed.

D. WASTE DISPOSAL

1. Radioactive Waste

It is anticipated that disposal of tritiated water can be accomplished by reinjecting the water in the earth in a formation which has been approved by all the appropriate authorities. Techniques for such disposal will be worked out, if possible, in the first experiment.

2. Industrial Waste

Methods for the disposal of industrial waste at future drill site locations would be similar to those described for Project Rio Blanco.

E. CONSTRUCTION

The full development of the field would be accompanied by some additional construction in the area. Each stimulated well would have construction similar to that occurring on Project Rio Blanco, but decreasing in complexity as the transition from experimental to commercial takes place. There would be roads and gathering pipelines to all of the locations. In addition, there will be, after detonation, the normal gas well completion equipment. Extension of power and telephone lines can be expected. Processing plants, warehousing, and office facilities would be constructed in the area.

F. IMPACT UPON THE CULTURAL CONDITIONS OF THE SURROUNDING AREA

The need for local services and materials will have relatively little effect for Project Rio Blanco, but as the Rio Blanco demonstration program advances the need will become greater. During the final series of the demonstration program and continuing until the field has been fully stimulated, a primary work force of 300 to 500 personnel can be expected. Following this, the residual work force of production and maintenance personnel would number less than 50. Currently available local sources of supplies and services would have to be substantially increased or supplemented. Since much of the work would be conducted year-around, there will undoubtedly be families moving to the area causing increased community needs such as schools and homes. Substantial revenue would be forthcoming to the county, as well as to the State and Federal governments. This could generate additional projects by the local authorities, which would add to the well-being of those in the area.

The extent of these effects cannot even be reasonably estimated until the Rio Blanco demonstration program advances beyond the first experiment.